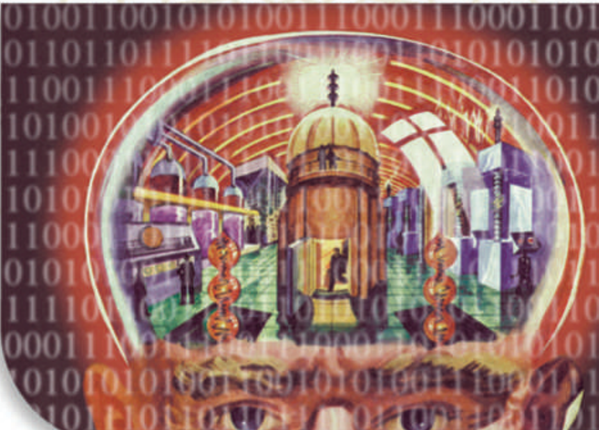
computer sciences

VOLUME 1

Foundations: Ideas and People



The Macmillan Science Library

computer sciences

computer sciences

VOLUME 1
Foundations: Ideas and People

Roger R. Flynn, Editor in Chief

MACMILLAN REFERENCE USA™

THOMSON GALE™

New York • Detroit • San Diego • San Francisco • Cleveland • New Haven, Conn. • Waterville, Maine • London • Munich

Macmillan Reference USA
300 Park Avenue South
New York, NY 10010

Gale Group
27500 Drake Rd.
Farmington Hills, MI 48331-3535

Library of Congress Cataloging-in-Publication Data
Computer sciences / Roger R. Flynn, editor in chief.
p. cm.
Includes bibiographical references and index.
ISBN 0-02-865566-4 (set: hardcover : alk. paper) —
ISBN 0-02-865567-2 (Volume 1: Foundations: Ideas and People : alk. paper) —
ISBN 0-02-865568-0 (Volume 2: Software and Hardware : alk. paper) —
ISBN 0-02-865569-9 (Volume 3: Social Applications : alk. paper) —
ISBN 0-02-865570-2 (Volume 4: Electronic Universe : alk. paper)
1. Computer science. I. Flynn, Roger R., 1939-
QA76 .C572 2002
004—dc21
2002000754

Printed in the United States of America
1 2 3 4 5 6 7 8 9 10

Preface

The science of computing has come a long way since the late 1930s, when John Vincent Atanasoff and Clifford Berry began work on the first electronic digital computer. One marvels to see how the science has advanced from the days of Charles Babbage, who developed the Difference Engine in the 1820s, and, later proposed the Analytical Engine. Computer science was and continues to be an intriguing field filled with interesting stories, colorful personalities, and incredible innovations.

Ever since their invention, computers have had a profound impact on society and the ways in which humans conduct business and financial matters, fight wars and maintain peace, provide goods and services, predict events (e.g., earthquakes, the weather, global warming), monitor security and safety, and a host of other applications too numerous to mention. Plus, the personal computer revolution, beginning in the 1980s, has brought computers into many homes and schools. This has helped students find new ways to prepare reports, conduct research, and study using computerized methods. In the new millennium, the role that computers play in society continues to grow.

The World of Computer Science

In preparing this encyclopedia, I came across references to the early work on the IBM System/360 series of computers, which featured capacities of 65,000 to 16 million bytes (4 byte-words) of main storage and disk storage of several million to tens or hundreds of million bytes. At the same time, I opened the Sunday paper in February of 2002 and scanned the ads for personal computers, announcing memories of several hundred million bytes and disk storage of gigabytes. The cost of the 360 series ranged from fifty to several hundred thousand dollars to more than a million. Prices for the computers advertised in my Sunday paper ranged from several hundred dollars to a few thousand. The IBM 360 series was released in 1964. If a similar breakthrough occurred in education or automobile manufacturing (a factor of 1000, on the conservative side), a year in college would cost $20, as would a good model car! This, of course, is not the case.

However, computer hardware is not the entire story. Machines all need software, operating systems, applications software, and the like. While a person was hard pressed to get a line drawing or a bar chart on the screen 25 years ago, someone today has a choice of presentation software (slides or projections of the computer screen), desktop publishing, spreadsheets, and the like, much of which comes bundled with the system.

In fact, today one can purchase, for a few thousand dollars, more equipment and software than the Department of Information Science and

Telecommunications at my school (the University of Pittsburgh) or, for that matter, the entire university, could buy, when I first arrived in 1974. This is, indeed, an extraordinary era to have been a part of and witnessed. However, this does not happen in a vacuum. In this encyclopedia we aim to detail the people, activities, products, and growth of knowledge that have helped computer science evolve into what it is today.

Volume Breakdown

The organization of this encyclopedia reflects the history and application of the field. Our first volume in this series is dedicated to the history of computing. Its subtitle is *Foundations: Ideas and People.* The second volume describes *Software and Hardware*, while the third addresses *Social Applications.* The fourth is appropriately subtitled the *Electronic Universe* as it looks at such developments and inventions as the Internet, ubiquitous computing (embedded computing), and miniaturization.

While the intent is to give an exhaustive view of the field, no encyclopedia of this size, or, for that matter, ten times its size, could provide a complete rendering of the developments, events, people, and technology involved. Hence, the four volumes provide a representative selection of the people, places, and events involved. The encyclopedia was developed from a U.S. point of view, but we trust that the articles herein are not intentionally biased and, hopefully, do justice to innovations and contributions from elsewhere in the world. A brief look at each volume of the encyclopedia follows.

Volume 1

Volume I discusses the foundations of computer science, including computing history and some important innovators. Among the people are American inventor Herman Hollerith (1860–1929), the designer of punched card and punched card equipment; English mathematician Charles Babbage (1791–1871), the inventor of the Difference Engine and the proposed Analytical Engine, a precursor of the stored program computer; English noblewoman Ada Byron King, the Countess of Lovelace (1815–1852), the first "computer programmer"; American executive Thomas J. Watson Sr. (1874–1956), early chief of the IBM Corporation; and American mathematician Grace Hopper (1906–1992), who helped in the development of COBOL (COmmon Business Oriented Language) and developed one of its predecessors, FLOW-MATIC, and is the person who allegedly coined the term "computer bug."

✶Explore further in Hollerith, Herman; Babbage, Charles; Lovelace, Ada Byron King, Countess of; Watson, Thomas J., Sr; and Hopper, Grace.

Within Volume 1, various groups and organizations are discussed. These include the Association for Computing Machinery (ACM), which brings together people from around the globe to exchange ideas and advance computer science; the Institute of Electrical and Electronic Engineers (IEEE), which serves as the world's largest technical professional association, with more than 350,000 members; and the IBM Corporation, Apple Computer Inc., and the Microsoft Corporation, which all contributed to the start of the personal computer (PC) revolution. Among the more general articles the reader will find those concerning topics such as early pioneers, featuring primarily American and European scientists and their work; language generations, focusing on the evolution of computer languages; and computer generations, discussing early machines such as the ENIAC (Electronic

✶Explore further in Association for Computing Machinery; Institute of Electrical and Electronic Engineers (IEEE); IBM Corporation; Apple Computer, Inc.; Microsoft Corporation; Early Pioneers; Generations, Languages; and Generations, Computers.

Numerical Integrator and Computer) and the EDVAC (Electronic Discrete Variable Automatic Computer).

Finally, other articles of general interest in Volume 1 concern the history and workings of supercomputers; the development of the mouse; the question of computer security; the beginnings of the Internet; and the basics of digital and analog computing. The government's role is explained in articles on the U.S. Census Bureau and funding research projects. In addition, mathematical tools such as the binary number system and the slide rule as well as innovations such as France's Minitel are also featured.

*Explore further in Supercomputers; Mouse; Security; Internet; Digital Computing; Analog Computing; Census Bureau; Government Funding, Research; Binary Number System; Slide Rule; Minitel.

Volume 2

Volume 2 describes software and hardware. Articles cover topics from system analysis and design, which is the cornerstone of building a system, to operating systems, compilers, and parallel processing, which discuss some of the technical aspects of computing. Telecommunication subjects range from network design to wireless technology to ATM transmission, while application-oriented articles include pattern recognition, personal digital assistants (PDAs), and computer music. Essays concerning software products include object-oriented languages, client/server technology, invasive programs, and programming.

*Explore further in System Analysis; Systems Design; Operating Systems; Compilers; Parallel Processing; Network Design; Wireless Technology; ATM Transmission; Pattern Recognition; Personal Digital Assistants; Music, Computer; Object-Oriented Languages; Client/Server Systems; Invasive Programs; and Programming.

Among the people featured in Volume 2 are John Bardeen (1908–1991), Walter H. Brattain (1902–1987), and William B. Shockley (1910–1989), inventors of the transistor; English mathematician George Boole (1815–1864), developer of Boolean logic; and Alexander Graham Bell (1847–1922), inventor of the telephone. Rounding out Volume 2 are the technical aspects of hardware-related topics, including coding techniques, digital logic design, and cellular technology.

*Explore further in Bardeen, John, Brattain, Walter H., and Shockley, William B.; Boole, George; Boolean Algebra; Bell, Alexander Graham; Coding Techniques; Codes; Digital Logic Design; and Cellular Technology.

Volume 3

In Volume 3, the emphasis is on social applications. From fashion design to meteorology, the use of computers impacts our everyday lives. For example, computer technology has greatly influenced the study of biology, molecular biology, physics, and mathematics, not to mention the large role it plays in air traffic management and aircraft flight control, ATM machines and magnetic stripe cards for shopping and business. Businesses, large and small, have significantly benefited from applications that track product growth, costs, and the way products are managed. Volume 3 essays also explore the computer's role in medical image analysis and legal systems, while our use of computers in everyday life and our means of interacting with them are addressed in subjects such as library applications and speech recognition.

*Explore further in Fashion Design; Weather Forecasting; Biology; Molecular Biology; Physics; Mathematics; Aircraft Traffic Management; Aircraft Flight Control; ATM Machines; Magnetic Stripe Cards; Project Management; Economic Modeling; Process Control; Productivity Software; Integrated Software; Image Analysis: Medicine; Legal Systems; Library Applications; Speech Recognition.

Volume 3 addresses our aesthetic and intellectual pursuits in areas such as composing music, playing chess, and designing buildings. Yet the advancements of computer sciences go much further as described in articles about agriculture, geographic information systems, and astronomy. Among the people featured in the volume are American inventor Al Gross (1918–2001), the "father of wireless"; Hungarian mathematician Rózsa Péter (1905–1977), promoter of the study of recursive functions; and American author Isaac Asimov (1920–1992), famed science fiction writer who wrote extensively about robots.

*Explore further in Music Composition; Chess Playing; Architecture; Agriculture; Geographic Information Systems; Astronomy; Gross, Alfred J.; Péter, Rózsa; Asimov, Isaac.

Volume 4

✶Explore further in Internet: History; Internet: Applications; Internet: Backbone; Molecular Computing; Artificial Life; Mobile Computing; Cryptography; E-banking; E-books; E-commerce; E-journals and E-publishing; Information Access; Information Overload; Ethics; Copyright; and Patents.

Volume 4 delves into our interconnected, networked society. The Internet is explored in detail, including its history, applications, and backbone. Molecular computing and artificial life are discussed, as are mobile computing and encryption technology. The reader will find articles on electronic banking, books, commerce, publishing, as well as information access and overload. Ethical matters pertaining to the electronic universe are also addressed.

✶Explore further in Photography; Art; Cybercafe; Social Impact; Data Mining; Data Warehousing; Java Applets; JavaScript; Agents; Visual Basic.

Volume 4 extends our aesthetic interest with articles on photography and the use of computers in art. Readers will learn more about how cybercafes keep friends and family connected as well as the type of social impact that computers have had on society. Data gathering, storage, and retrieval are investigated in topics such as data mining and data warehousing. Similarly, Java applets, JavaScript, agents, and Visual Basic are featured.

✶Explore further in Marconi, Guglielmo; Shannon, Claude E.; Glushkov, Victor M.

Among the people highlighted in Volume 4 are Italian physicist Guglielmo Marconi (1874–1937), inventor of wireless communications; American engineer Claude E. Shannon (1916–2001), a pioneer of information theory; and Soviet mathematician Victor M. Glushkov (1923–1982), who advanced the science of cybernetics.

The Many Facets of Computer Science

Computer science has many interesting stories, many of which are told in this volume. Among them are the battle between John Atanasoff and John Mauchley and J. Presper Eckert Jr. over the patent to the electronic digital computer and regenerative memory, symbolized and embodied in the lawsuits between Sperry-Rand (Mauchley-Eckert) and Honeywell (Atanasoff) and Sperry-Rand (Mauchley-Eckert) and CDC (Atanasoff). The lawsuits are not covered here, but the principal actors are. And there is Thomas J. Watson's prediction, possibly apocryphal, of the need ("demand") for 50 computers worldwide! Plus, Ada Byron King, Countess of Lovelace, became famous for a reason other than being British poet Lord George Gordon Byron's daughter. And German inventor Konrad Zuse (1910–1995) saw his computers destroyed by the Allies during World War II, while Soviet mathematician Victor M. Glushkov (1923–1982) had an institute named after him and his work.

✶Explore further in Zuse, Konrad.

✶Explore further in Data Processing; Nanocomputing; Mainframes; E-mail; Abacus.

Scientific visualization is now a topic of interest, while data processing is passé. Nanocomputing has become a possibility, while mainframes are still in use and e-mail is commonplace in many parts of the world. It has been a great half-century or so (60 some years) for a fledgling field that began, possibly, with the Abacus!

Organization of the Material

Computer Sciences contains 286 entries that were newly commissioned for this work. More than 125 people contributed to this set, some from academia, some from industry, some independent consultants. Many contributors are from the United States, but other countries are represented including Australia, Canada, Great Britain, and Germany. In many cases, our contributors have written extensively on their subjects before, either in books or journal articles. Some even maintain their own web sites providing further information on their research topics.

Most entries in this set contain illustrations, either photos, graphs, charts, or tables. Many feature sidebars that enhance the topic at hand or give a glimpse into a topic of related interest. The entries—geared to high school students and general readers—include glossary definitions of unfamiliar terms to help the reader understand complex topics. These words are highlighted in the text and defined in the margins. In addition, each entry includes a bibliography of sources of further information as well as a list of related entries in the encyclopedia.

Additional resources are available in the set's front and back matter. These include a timeline on significant events in computing history, a timeline on significant dates in the history of programming and markup and scripting languages, and a glossary. An index is included in each volume—Volume 4 contains a cumulative index covering the entire *Computer Sciences* encyclopedia.

Acknowledgments and Thanks

We would like to thank Elizabeth Des Chenes and Hélène Potter, who made the project possible; Cindy Clendenon; and, especially, Kathleen Edgar, without whose work this would not have been possible. Also thanks to Stephen Murray for compiling the glossary. And, I personally would like to thank the project's two other editors, Ida M. Flynn and Ann McIver McHoes, for their dedicated work in getting these volumes out. And finally, thanks to our many contributors. They provided "many voices," and we hope you enjoy listening to them.

Roger R. Flynn
Editor in Chief

Measurements

Data Unit	Abbreviation	Equivalent (Data Storage)	Power of Ten
Byte	B	8 bits	1 byte
Kilobyte	K, KB	2^{10} = 1,024 bytes	1,000 (one thousand) bytes
Megabyte	M, MB	2^{20} = 1,048,576 bytes	1,000,000 (one million) bytes
Gigabyte	GB	2^{30} = 1,073,741,824 bytes	1,000,000,000 (one billion) bytes
Terabyte	TB	2^{40} = 1,099,511,627,776 bytes	1,000,000,000,000 (one trillion) bytes
Petabyte	PB	2^{50} = 1,125,899,906,842,624 bytes	1,000,000,000,000,000 (one quadrillion) bytes

Time	Abbreviation	Equivalent	Additional Information
femtosecond	fs, fsec	10^{-15} seconds	1 quadrillionth of a second
picosecond	ps, psec	10^{-12} seconds	1 trillionth of a second
nanosecond	ns, nsec	10^{-9} seconds	1 billionth of a second
microsecond	µs, µsec	10^{-6} seconds	1 millionth of a second
millisecond	ms, msec	10^{-3} seconds	1 thousandth of a second
second	s, sec	1/60 of a minute; 1/3,600 of an hour	1 sixtieth of a minute; 1 thirty-six hundredths of an hour
minute	m, min	60 seconds; 1/60 of an hour	1 sixtieth of an hour
hour	h, hr	60 minutes; 3,600 seconds	
day	d	24 hours; 1,440 minutes; 86,400 seconds	
year	y, yr	365 days; 8,760 hours	
1,000 hours		1.3888... months (1.4 months)	1,000 ÷ (30 days × 24 hours)
8,760 hours		1 year	365 days × 24 hours
1 million hours		114.15525... years	1,000,000÷8,760
1 billion hours		~114,200... years	1,000 × 114.15525...
1 trillion hours		~114,200,000 years	1,000 × 114,200

Length	Abbreviation	Equivalent	Additional Information
nanometer	nm	10^{-9} meters (1 billionth of a meter)	~ 4/100,000,000 of an inch; ~ 1/25,000,000 of an inch
micrometer	µm	10^{-6} meter (1 millionth of a meter)	~ 4/100,000 of an inch; ~ 1/25,000 of an inch
millimeter	mm	10^{-3} meter (1 thousandth of a meter)	~ 4/100 of an inch; ~ 1/25 of an inch (2/5 × 1/10)
centimeter	cm	10^{-2} meter (1 hundredth of a meter); 1/2.54 of an inch	~ 2/5 of an inch (1 inch = 2.54 centimeters, exactly)
meter	m	100 centimeters; 3.2808 feet	~ 3 1/3 feet or 1.1 yards
kilometer	km	1,000 meters; 0.6214 miles	~ 3/5 of a mile
mile	mi	5,280 feet; 1.6093 kilometers	1.6 × 10^3 meters

Volume	Abbreviation	Equivalent	Additional Information
microliter	µl	1/1,000,000 liter	1 millionth of a liter
milliliter	ml	1/1,000 liter; 1 cubic centimeter	1 thousandth of a liter
centiliter	cl	1/100 liter	1 hundredth of a liter
liter	l	100 centiliters; 1,000 milliliters; 1,000,000 microliters; 1.0567 quarts (liquid)	~ 1.06 quarts (liquid)

Base 2 (Binary)	Decimal (Base 10) Equivalent	Approximations to Powers of Ten
2^0	1	
2^1	2	
2^2	4	
2^3	8	
2^4	16	
2^5	32	
2^6	64	
2^7	128	10^2; 100; one hundred; 1 followed by 2 zeros
2^8	256	
2^9	512	
2^{10}	1,024	10^3; 1,000; one thousand; 1 followed by 3 zeros
2^{11}	2,048	
2^{12}	4,096	
2^{13}	8,192	
2^{14}	16,384	
2^{15}	32,768	
2^{16}	65,536	
2^{17}	131,072	
2^{18}	262,144	
2^{19}	524,288	
2^{20}	1,048,576	10^6; 1,000,000; one million; 1 followed by 6 zeros
2^{21}	2,097,152	
2^{22}	4,194,304	
2^{23}	8,388,608	
2^{24}	16,777,216	
2^{25}	33,554,432	
2^{26}	67,108,864	
2^{27}	134,217,728	
2^{28}	268,435,456	
2^{29}	536,870,912	
2^{30}	1,073,741,824	10^9; 1,000,000,000; one billion; 1 followed by 9 zeros
2^{31}	2,147,483,648	
2^{32}	4,294,967,296	
2^{33}	8,589,934,592	
2^{34}	17,179,869,184	
2^{35}	34,359,738,368	
2^{36}	68,719,476,736	
2^{37}	137,438,953,472	
2^{38}	274,877,906,944	
2^{39}	549,755,813,888	
2^{40}	1,099,511,627,776	10^{12}; 1,000,000,000,000; one trillion; 1 followed by 12 zeros
2^{50}	1,125,899,906,842,624	10^{15}; 1,000,000,000,000,000; one quadrillion; 1 followed by 15 zeros
2^{100}	1,267,650,600,228,229,401,496,703,205,376	10^{30}; 1 followed by 30 zeros
2^{-1}	1/2	
2^{-2}	1/4	
2^{-3}	1/8	
2^{-4}	1/16	
2^{-5}	1/32	
2^{-6}	1/64	
2^{-7}	1/128	1/100; 10^{-2}; 0.01; 1 hundredth
2^{-8}	1/256	
2^{-9}	1/512	
2^{-10}	1/1,024	1 /1000; 10^{-3}; 0.001; 1 thousandth

Base 16 (Hexadecimal)	Binary (Base 2) Equivalent	Decimal (Base 10) Equivalent	Approximations to Powers of Ten
16^0	2^0	1	
16^1	2^4	16	
16^2	2^8	256	2×10^2; 2 hundred
16^3	2^{12}	4,096	4×10^3; 4 thousand
16^4	2^{16}	65,536	65×10^3; 65 thousand
16^5	2^{20}	1,048,576	1×10^6; 1 million
16^6	2^{24}	16,777,216	
16^7	2^{28}	268,435,456	
16^8	2^{32}	4,294,967,296	4×10^9; 4 billion
16^9	2^{36}	68,719,476,736	68×10^9; 68 billion
16^{10}	2^{40}	1,099,511,627,776	1×10^{12}; 1 trillion
16^{-1}	2^{-4}	1/16	
16^{-2}	2^{-8}	1/256	
16^{-3}	2^{-12}	1/4,096	$1/4 \times 10^{-3}$; 1/4-thousandth
16^{-4}	2^{-16}	1/65,536	
16^{-5}	2^{-20}	1/1,048,576	10^{-6}; 1 millionth
16^{-8}	2^{-32}	1/4,294,967,296	$1/4 \times 10^{-9}$; 1/4-billionth
16^{-10}	2^{-40}	1/1,099,511,627,776	10^{-12}; 1 trillionth

Base 10 (Decimal)	Equivalent	Verbal Equivalent
10^0	1	
10^1	10	
10^2	100	1 hundred
10^3	1,000	1 thousand
10^4	10,000	
10^5	100,000	
10^6	1,000,000	1 million
10^7	10,000,000	
10^8	100,000,000	
10^9	1,000,000,000	1 billion
10^{10}	10,000,000,000	
10^{11}	100,000,000,000	
10^{12}	1,000,000,000,000	1 trillion
10^{15}	1,000,000,000,000,000	1 quadrillion
10^{-1}	1/10	1 tenth
10^{-2}	1/100	1 hundredth
10^{-3}	1/1,000	1 thousandth
10^{-6}	1/1,000,000	1 millionth
10^{-9}	1/1,000,000,000	1 billionth
10^{-12}	1/1,000,000,000,000	1 trillionth
10^{-15}	1/1,000,000,000,000,000	1 quadrillionth

Sizes of and Distance to Objects	Equivalent	Additional Information
Diameter of Electron (classical)	5.6×10^{-13} centimeters	5.6×10^{-13} centimeters; roughly 10^{-12} centimeters
Mass of Electron	9.109×10^{-28} grams	roughly 10^{-27} grams (1 gram = 0.0353 ounce)
Diameter of Proton	10^{-15} meters	10^{-13} centimeters
Mass of Proton	1.67×10^{-24} grams	roughly 10^{-24} grams (about 1,836 times the mass of electron)
Diameter of Neutron	10^{-15} meters	10^{-13} centimeters
Mass of Neutron	1.673×10^{-24} grams	roughly 10^{-24} grams (about 1,838 times the mass of electron)
Diameter of Atom (Electron Cloud)	ranges from 1×10^{-10} to 5×10^{-10} meters;	$\sim 10^{-10}$ meters; $\sim 10^{-8}$ centimeters; $\sim 3.94 \times 10^{-9}$ inches (roughly 4 billionth of an inch across or 1/250 millionth of an inch across)
Diameter of Atomic Nucleus	10^{-14} meters	$\sim 10^{-12}$ centimeters (10,000 times smaller than an atom)
Atomic Mass (Atomic Mass Unit)	1.66×10^{-27} kilograms	One atomic mass unit (amu) is equal to 1.66×10^{-24} grams
Diameter of (standard) Pencil	6 millimeters (0.236 inches)	roughly 10^{-2} meters
Height (average) of Man and Woman	man: 1.75 meters (5 feet, 8 inches) woman: 1.63 meters (5 feet, 4 inches)	human height roughly 2×10^{0} meters; 1/804.66 miles; 10^{-3} miles
Height of Mount Everest	8,850 meters (29,035 feet)	$\sim$ 5.5 miles; roughly 10^{4} meters
Radius (mean equatorial) of Earth	6,378.1 kilometers (3,960.8 miles)	$\sim$ 6,400 kilometers (4,000 miles); roughly 6.4×10^{6} meters
Diameter (polar) of Earth	12,713.6 kilometers (7,895.1 miles)	$\sim$ 12,800 kilometers (8,000 miles); roughly 1.28×10^{7} meters (Earth's diameter is twice the Earth's radius)
Circumference (based on mean equatorial radius) of Earth	40,075 kilometers (24,887 miles)	$\sim$ 40,000 kilometers (25,000 miles) (about 8 times the width of the United States) (Circumference = $2 \times \pi \times$ Earth's radius)
Distance from Earth to Sun	149,600,000 kilometers (92,900,000 miles)	$\sim$ 93,000,000 miles; $\sim$ 8.3 light-minutes; roughly 10^{11} meters; roughly 10^{8} miles
Distance to Great Nebula in Andromeda Galaxy	2.7×10^{19} kilometers (1.7×10^{19} miles)	$\sim$ 2.9 million light-years; roughly 10^{22} meters; roughly 10^{19} miles

Timeline: Significant Events in the History of Computing

The history of computer sciences has been filled with many creative inventions and intriguing people. Here are some of the milestones and achievements in the field.

c300-500 BCE	The counting board, known as the ancient abacus, is used. (Babylonia)
CE 1200	The modern abacus is used. (China)
c1500	Leonardo da Vinci drafts a design for a calculator. (Italy)
1614	John Napier suggests the use of logarithms. (Scotland)
1617	John Napier produces calculating rods, called "Napier's Bones." (Scotland)
	Henry Briggs formulates the common logarithm, Base 10. (England)
1620	Edmund Gunter devises the "Line of Numbers," the precursor to slide rule. (England)
1623	Wilhelm Schickard conceives a design of a mechanical calculator. (Germany)
1632	William Oughtred originates the slide rule. (England)
1642	Blaise Pascal makes a mechanical calculator, which can add and subtract. (France)
1666	Sir Samuel Morland develops a multiplying calculator. (England)
1673	Gottfried von Leibniz proposes a general purpose calculating machine. (Germany)
1777	Charles Stanhope, 3rd Earl of Stanhope, Lord Mahon, invents a logic machine. (England)
1804	Joseph-Marie Jacquard mechanizes weaving with Jacquard's Loom, featuring punched cards. (France)
1820	Charles Xavier Thomas (Tomas de Colmar) creates a calculating machine, a prototype for the first commercially successful calculator. (France)
1822	Charles Babbage designs the Difference Engine. (England)
1834	Charles Babbage proposes the Analytical Engine. (England)
1838	Samuel Morse formulates the Morse Code. (United States)
1842	L. F. Menabrea publishes a description of Charles Babbage's Analytical Engine. (Published, Italy)

1843	Ada Byron King, Countess of Lovelace, writes a program for Babbage's Analytical Engine. (England)
1854	George Boole envisions the Laws of Thought. (Ireland)
1870	William Stanley Jevons produces a logic machine. (England)
1873	William Thomson, Lord Kelvin, devises the analog tide predictor. (Scotland)
	Christopher Sholes, Carlos Glidden, and Samuel W. Soule invent the Sholes and Glidden Typewriter; produced by E. Remington & Sons. (United States)
1875	Frank Stephen Baldwin constructs a pin wheel calculator. (United States)
1876	Alexander Graham Bell develops the telephone. (United States)
	Bell's rival, Elisha Gray, also produces the telephone. (United States)
1878	Swedish inventor Willgodt T. Odhner makes a pin wheel calculator. (Russia)
1884	Dorr Eugene Felt creates the key-driven calculator, the Comptometer. (United States)
	Paul Gottlieb Nipkow produces the Nipkow Disk, a mechanical television device. (Germany)
1886	Herman Hollerith develops his punched card machine, called the Tabulating Machine. (United States)
1892	William Seward Burroughs invents his Adding and Listing (printing) Machine. (United States)
1896	Herman Hollerith forms the Tabulating Machine Company. (United States)
1901	Guglielmo Marconi develops wireless telegraphy. (Italy)
1904	John Ambrose Fleming constructs the diode valve (vacuum tube). (England)
	Elmore Ambrose Sperry concocts the circular slide rule. (United States)
1906	Lee De Forest invents the triode vacuum tube (audion). (United States)
1908	Elmore Ambrose Sperry produces the gyrocompass. (United States)
1910	Sperry Gyroscope Company is established. (United States)
1912	Frank Baldwin and Jay Monroe found Monroe Calculating Machine Company. (United States)
1914	Leonardo Torres Quevado devises an electromechanical calculator, an electromechanical chess machine (End Move). (Spain)
	Thomas J. Watson Sr. joins the Computing-Tabulating-Recording Company (CTR) as General Manager. (United States)

1919 W. H. Eccles and F. W. Jordan develop the flip-flop (memory device). (England)

1922 Russian-born Vladimir Kosma Zworykin develops the iconoscope and kinescope (cathode ray tube), both used in electronic television for Westinghouse. (United States)

1924 The Computing-Tabulating-Recording Company (CTR), formed in 1911 by the merger of Herman Hollerith's Tabulating Machine Company with Computing Scale Company and the International Time Recording Company, becomes the IBM (International Business Machines) Corporation. (United States)

1927 The Remington Rand Corporation forms from the merger of Remington Typewriter Company, Rand Kardex Bureau, and others. (United States)

1929 Vladimir Kosma Zworykin develops color television for RCA. (United States)

1931 Vannevar Bush develops the Differential Analyzer (an analog machine). (United States)

1933 Wallace J. Eckert applies punched card machines to astronomical data. (United States)

1937 Alan M. Turing proposes a Theoretical Model of Computation. (England)

George R. Stibitz crafts the Binary Adder. (United States)

1939 John V. Atanasoff devises the prototype of an electronic digital computer. (United States)

William R. Hewlett and David Packard establish the Hewlett-Packard Company. (United States)

1940 Claude E. Shannon applies Boolean algebra to switching circuits. (United States)

George R. Stibitz uses the complex number calculator to perform Remote Job Entry (RJE), Dartmouth to New York. (United States)

1941 Konrad Zuse formulates a general-purpose, program-controlled computer. (Germany)

1942 John V. Atanasoff and Clifford Berry unveil the Atanasoff-Berry Computer (ABC). (United States)

1944 The Colossus, an English calculating machine, is put into use at Bletchley Park. (England)

Howard Aiken develops the Automatic Sequence Controlled Calculator (ASCC), the Harvard Mark I, which is the first American program-controlled computer. (United States)

Grace Hopper allegedly coins the term "computer bug" while working on the Mark I. (United States)

1946 J. Presper Eckert Jr. and John W. Mauchly construct the ENIAC (Electronic Numerical Integrator and Computer), the first American general-purpose electronic computer, at the Moore School, University of Pennsylvania. (United States)

J. Presper Eckert Jr. and John W. Mauchly form the Electronic Control Company, which later becomes the Eckert-Mauchly Computer Corporation. (United States)

1947 John Bardeen, Walter H. Brattain, and William B. Shockley invent the transistor at Bell Laboratories. (United States)

J. Presper Eckert Jr. and John W. Mauchly develop the EDVAC (Electronic Discrete Variable Automatic Computer), a stored-program computer. (United States)

1948 F. C. Williams, Tom Kilburn, and G. C. (Geoff) Tootill create a small scale, experimental, stored-program computer (nicknamed "Baby") at the University of Manchester; it serves as the prototype of Manchester Mark I. (England)

1949 F. C. Williams, Tom Kilburn, and G. C. (Geoff) Tootill design the Manchester Mark I at the University of Manchester. (England)

Maurice V. Wilkes develops the EDSAC (Electronic Delay Storage Automatic Calculator) at Cambridge University. (England)

Jay Wright Forrester invents three dimensional core memory at the Massachusetts Institute of Technology. (United States)

Jay Wright Forrester and Robert Everett construct the Whirlwind I, a digital, real-time computer at Massachusetts Institute of Technology. (United States)

1950 J. H. Wilkinson and Edward A. Newman design the Pilot ACE (Automatic Computing Engine) implementing the Turing proposal for a computing machine at the National Physical Laboratory (NPL). (England)

Remington Rand acquires the Eckert-Mauchly Computer Corporation. (United States)

1951 Engineering Research Associates develops the ERA 1101, an American commercial computer, for the U.S. Navy and National Security Agency (NSA). (United States)

The UNIVAC I (Universal Automatic Computer), an American commercial computer, is created by Remington Rand for the U.S. Census Bureau. (United States)

Ferranti Mark I, a British commercial computer, is unveiled. (England)

Lyons Tea Co. announces Lyons Electronic Office, a British commercial computer. (England)

1952 UNIVAC I predicts election results as Dwight D. Eisenhower sweeps the U.S. presidential race. (United States)

	Remington Rand Model 409, an American commercial computer, is originated by Remington Rand for the Internal Revenue Service. (United States)
	Remington Rand acquires Engineering Research Associates. (United States)
1953	The IBM 701, a scientific computer, is constructed. (United States)
1954	The IBM 650 EDPM, electronic data processing machine, a stored-program computer in a punched-card environment, is produced. (United States)
1955	Sperry Corp. and Remington Rand merge to form the Sperry Rand Corporation. (United States)
1957	Robert N. Noyce, Gordon E. Moore, and others found Fairchild Semiconductor Corporation. (United States)
	Seymour Cray, William Norris, and others establish Control Data Corporation. (United States)
	Kenneth Olsen and Harlan Anderson launch Digital Equipment Corporation (DEC). (United States)
1958	Jack Kilby at Texas Instruments invents the integrated circuit. (United States)
1959	Robert N. Noyce at Fairchild Semiconductor invents the integrated circuit. Distinct patents are awarded to both Texas Instruments and Fairchild Semiconductor, as both efforts are recognized. (United States)
1960	The first PDP-1 is sold by Digital Equipment Corporation, which uses some technology from the Whirlwind Project. (United States)
	The UNIVAC 1100 series of computers is announced by Sperry Rand Corporation. (United States)
1961	The Burroughs B5000 series dual-processor, with virtual memory, is unveiled. (United States)
1964	The IBM/360 family of computers begins production. (United States)
	The CDC 6600 is created by Control Data Corporation. (United States)
1965	The UNIVAC 1108 from Sperry Rand Corporation is constructed. (United States)
	The PDP-8, the first minicomputer, is released by Digital Equipment Corporation. (United States)
1968	Robert N. Noyce and Gordon E. Moore found Intel Corporation. (United States)
1969	The U.S. Department of Defense (DoD) launches ARPANET, the beginning of the Internet. (United States)
1970	The PDP-11 series of computers from Digital Equipment Corporation is put into use.(United States)

The Xerox Corporation's Palo Alto Research Center (PARC) begins to study the architecture of information. (United States)

1971 Ken Thompson devises the UNIX Operating System at Bell Laboratories. (United States)

Marcian E. (Ted) Hoff, Federico Faggin, and Stanley Mazor at Intel create the first microprocessor—a 4-bit processor, 4004. (United States)

1972 Seymour Cray founds Cray Research Inc. (United States)

Intel releases the 8008 microprocessor, an 8-bit processor. (United States)

1974 Intel announces the 8080 microprocessor, an 8-bit processor. (United States)

Motorola Inc. unveils the Motorola 6800, its 8-bit microprocessor. (United States)

Federico Faggin and Ralph Ungerman co-found Zilog, Inc., a manufacturer of microprocessors. (United States)

1975 Bill Gates and Paul Allen establish the Microsoft Corporation. (United States)

The kit-based Altair 8800 computer, using an 8080 microprocessor, is released by Ed Roberts with MITS (Model Instrumentation Telemetry Systems) in Albuquerque, New Mexico. (United States)

MITS purchases a version of the BASIC computer language from Microsoft. (United States)

The MOS 6502 microprocessor, an 8-bit microprocessor, is developed by MOS Technologies, Chuck Peddle, and others, who had left Motorola, (United States)

1976 Gary Kildall creates the CP/M (Control Program/Monitor or Control Program for Microprocessors) Operating System of Digital Research; this operating system for 8-bit microcomputers is the forerunner of DOS 1.0. (United States)

Steven Jobs and Stephen Wozniak found Apple Computer, Inc. and create the Apple I. (United States)

Seymour Cray devises the Cray-1 supercomputer. (United States)

Commodore Business Machines acquires MOS Technologies. (Canada)

1977 The Commodore PET (Personal Electronic Transactor) personal computer, developed by Jack Tramiel and Chuck Peddle for Commodore Business Machines, features the 6502 8-bit Microprocessor. (Canada)

The Apple II personal computer from Apple Computer, Inc., is released featuring a 6502 microprocessor. (United States)

The TRS-80 personal computer from Tandy Radio Shack, equipped with the Zilog Z80 8-bit microprocessor from Zilog, is unveiled. (United States)

1978 Intel announces the 8086 16-bit microprocessor. (United States)

Digital Equipment Corporation launches the VAX 11/780, a 4.3 billion byte computer with virtual memory. (United States)

1979 Intel presents the 8088 16-bit microprocessor. (United States)

Motorola Inc. crafts the MC 68000, Motorola 16-bit processor. (United States)

1980 Tim Patterson sells the rights to QDOS, an upgrade operating system of CP/M for 8088 and 8086 Intel microprocessors, 16-bit microprocessor, to Microsoft. (United States)

1981 The IBM Corporation announces the IBM Personal Computer featuring an 8088 microprocessor. (United States)

The Microsoft Operating System (MS-DOS) is put into use. (United States)

The Osborne I, developed by Adam Osborne and Lee Felsenstein with Osborne Computer Corporation, invent the first portable computer. (United States)

1982 Scott McNealy, Bill Joy, Andy Bechtolsheim, and Vinod Khosla found Sun Microsystems, Inc. (United States)

1984 The Macintosh PC from Apple Computer Inc., running with a Motorola 68000 microprocessor, revolutionizes the personal computer industry. (United States)

Richard Stallman begins the GNU Project, advocating the free use and distribution of software. (United States)

1985 The Free Software Foundation is formed to seek freedom of use and distribution of software. (United States)

Microsoft releases Windows 1.01. (United States)

1986 Sperry Rand and the Burroughs Corporation merge to form Unisys Corporation. (United States)

1989 SPARCstation I from Sun Microsystems is produced. (United States)

1991 Tim Berners-Lee begins the World Wide Web at CERN. (Switzerland)

Linus Torvalds builds the Linux Operating System. (Finland)

Paul Kunz develops the first web server outside of Europe, at the Stanford Linear Accelerator Center (SLAC). (United States)

1993 Marc Andreesen and Eric Bina create Mosaic, a web browser, at the National Center for Supercomputing Applications (NCSA), University of Illinois-Urbana Champaign. (United States)

1994 Marc Andreesen and James H. Clark form Mosaic Communications Corporation, later Netscape Communications Corporation. (United States)

Netscape Navigator is launched by Netscape Communications Corporation. (United States)

1995 Java technology is announced by Sun Microsystems. (United States)

1996 World chess champion Garry Kasparov of Russia defeats Deep Blue, an IBM computer, in a man vs. computer chess matchup, four to two. (United States)

1997 IBM's Deep Blue defeats world chess champion Garry Kasparov in a rematch, 3.5 to 2.5. (United States)

An injunction is filed against Microsoft to prohibit the company from requiring customers to accept Internet Explorer as their browser as a condition of using the Microsoft operating system Windows 95. (United States)

1998 America OnLine (AOL) acquires Netscape. (United States)

Compaq Computer Corporation, a major producer of IBM compatible personal computers, buys Digital Equipment Corporation. (United States)

America OnLine (AOL) and Sun form an alliance to produce Internet technology. (United States)

1999 Shawn Fanning writes code for Napster, a music file-sharing program. (United States)

The Recording Industry Association of America (RIAA) files a lawsuit against Napster for facilitating copyright infringement. (United States)

2000 Zhores I. Alferov, Herbert Kroemer, and Jack Kilby share the Nobel Prize in Physics for contributions to information technology. Alferov, a Russian, and Kroemer, a German-born American, are acknowledged for their contributions to technology used in satellite communications and cellular telephones. Kilby, an American, is recognized for his work on the integrated circuit. (Sweden)

Timeline: The History of Programming, Markup and Scripting Languages

The history of computer sciences has been filled with many creative inventions and intriguing people. Here are some of the milestones and achievements in the field of computer programming and languages.

CE c800	al-Khowarizmi, Mohammed ibn-Musa develops a treatise on algebra, his name allegedly giving rise to the term algorithm.
1843	Ada Byron King, Countess of Lovelace, programs Charles Babbage's design of the Analytical Engine.
1945	Plankalkul is developed by Konrad Zuse.
1953	Sort-Merge Generator is created by Betty Holberton.
1957	FORTRAN is devised for IBM by John Backus and team of programmers.
	FLOW-MATIC is crafted for Remington-Rand's UNIVAC by Grace Hopper.
1958	LISP is produced by John McCarthy at Massachusetts Institute of Technology.
1960	ALGOL is the result of work done by the ALGOL Committee in the ALGOL 60 Report.
	COBOL is formulated by the CODASYL Committee, initiated by the the U.S. Department of Defense (DoD)
1961	JOSS is originated by the RAND Corporation.
	GPSS (General Purpose Simulation System) is invented by Geoffrey Gordon with IBM.
	RPG (Report Program Generator) is unveiled by IBM.
	APL (A Programming Language) is designed by Kenneth Iverson with IBM.
1963	SNOBOL is developed by David Farber, Ralph Griswold, and Ivan Polonsky at Bell Laboratories.
1964	BASIC is originated by John G. Kemeny and Thomas E. Kurtz at Dartmouth.
	PL/I is announced by IBM.
	Simula I is produced by Kristen Nygaard and Ole-Johan Dahl at the Norwegian Computing Center.
1967	Simula 67 is created by Kristen Nygaard and Ole-Johan Dahl at the Norwegian Computing Center.

	LOGO is devised by Seymour Papert at the MIT Artificial Intelligence Laboratory.
1971	Pascal is constructed by Niklaus Wirth at the Swiss Federal Institute of Technology (ETH) in Zurich.
1973	C developed by Dennis Ritchie at Bell Laboratories.
	Smalltalk is invented by Alan Kay at Xerox's PARC (Palo Alto Research Center).
1980	Ada is developed for the U.S. Department of Defense (DoD).
1985	C++ is created by Bjarne Stroustrup at Bell Laboratories.
1986	SGML (Standard Generalized Markup Language) is developed by the International Organization for Standardization (ISO).
1987	Perl is constructed by Larry Wall.
1991	Visual Basic is launched by the Microsoft Corporation.
	HTML (HyperText Markup Language) is originated by Tim Berners-Lee at CERN (Organization Europeene pour la Recherche Nucleaire).
1993	Mosaic is created by Marc Andreesen and Eric Bina for the National Center for Computing Applications (NCCA) at the University of Illinois-Urbana Champaign.
1995	Java is crafted by James Gosling of Sun Microsystems.
	A written specification of VRML (Virtual Reality Markup Language) is drafted by Mark Pesce, Tony Parisi, and Gavin Bell.
1996	Javascript is developed by Brendan Eich at Netscape Communications co-announced by Netscape and Sun Microsystems.
1997	VRML (Virtual Reality Modeling Language), developed by the Web3D Consortium, becomes an international standard.
1998	XML (Extensible Markup Language) is originated by a working group of the World Wide Web Consortium (W3C).

Contributors

Tom Abel
Penn State University, University Park, PA
Martyn Amos
University of Liverpool, United Kingdom
Richard Archer
Pittsburgh, PA
Pamela Willwerth Aue
Royal Oak, MI
Nancy J. Becker
St. John's University, New York
Mark Bedau
Reed College, Portland, OR
Pierfrancesco Bellini
University of Florence, Italy
Gary H. Bernstein
University of Notre Dame, Notre Dame, IN
Anne Bissonnette
Kent State University Museum, Kent, OH
Kevin W. Bowyer
University of Notre Dame, Notre Dame, IN
Stefan Brass
University of Giessen, Germany
Barbara Britton
Windsor Public Library, Windsor, Ontario, Canada
Kimberly Mann Bruch
San Diego Supercomputer Center, University of California, San Diego
Ivan Bruno
University of Florence, Italy
Dennis R. Buckmaster
Pennsylvania State University, University Park, PA
Dan Burk
University of Minnesota, Minneapolis, MN
Guoray Cai
Pennsylvania State University, University Park, PA
Shirley Campbell
University of Pittsburgh, Pittsburgh, PA
Siddharth Chandra
University of Pittsburgh, Pittsburgh, PA
J. Alex Chediak
University of California, Berkeley, CA
Kara K. Choquette
Xerox Corporation
John Cosgrove
Cosgrove Communications, Pittsburgh, PA
Cheryl L. Cramer
Digimarc Corporation, Tualatin, OR
Anthony Debons
University of Pittsburgh, Pittsburgh, PA
Salvatore Domenick Desiano
NASA Ames Research Center (QSS Group, Inc.)
Ken Doerbecker
Perfection Services, Inc.; WeirNet LLC; and FreeAir Networks, Inc.
Judi Ellis
KPMG, LLP, Pittsburgh, PA
Karen E. Esch
Karen Esch Associates, Pittsburgh, PA
Ming Fan
University of Notre Dame, Notre Dame, IN
Jim Fike
Ohio University, Athens, OH
Ida M. Flynn
University of Pittsburgh, Pittsburgh, PA
Roger R. Flynn
University of Pittsburgh, Pittsburgh, PA
H. Bruce Franklin
Rutgers University, Newark, NJ
Thomas J. Froehlich
Kent State University, Kent, OH
Chuck Gaidica
WDIV-TV, Detroit, MI
G. Christopher Hall
PricewaterhouseCoopers
Gary Hanson
Kent State University, Kent, OH
Karen Hartman
James Monroe Center Library, Mary Washington College, Fredericksburg, VA
Melissa J. Harvey
Carnegie Mellon University, Pittsburgh, PA
Albert D. Helfrick
Embry-Riddle Aeronautical University, Daytona Beach, FL
Stephen Hughes
University of Pittsburgh, Pittsburgh, PA
Bruce Jacob
University of Maryland, College Park, MD
Radhika Jain
Georgia State University, Atlanta, GA
Wesley Jamison
University of Pittsburgh at Greensburg
Sid Karin
San Diego Supercomputer Center, University of California, San Diego
Declan P. Kelly
Philips Research, The Netherlands
Betty Kirke
New York, NY
Mikko Kovalainen
University of Jyväskylä, Finland
Paul R. Kraus
Pittsburgh, PA
Prashant Krishnamurthy
University of Pittsburgh, Pittsburgh, PA
Marina Krol
Mount Sinai School of Medicine, New York, NY
Susan Landau
Sun Microsystems Inc., Mountain View, CA
Nicholas C. Laudato
University of Pittsburgh, Pittsburgh, Pennsylvania

George Lawton
Eutopian Enterprises

Cynthia Tumilty Lazzaro
Pinnacle Training Corp., Stoneham, MA

Joseph J. Lazzaro
Massachusetts Commission for the Blind, Boston, MA

John Leaney
University of Technology, Sydney, Australia

Robert Lembersky
Ann Taylor, Inc., New York, NY

Terri L. Lenox
Westminster College, New Wilmington, PA

Joyce H-S Li
University of Pittsburgh, Pittsburgh, PA

Michael R. Macedonia
USA STRICOM, Orlando, FL

Dirk E. Mahling
University of Pittsburgh, Pittsburgh, PA

Cynthia J. Martincic
St. Vincent College, Latrobe, PA

Michael J. McCarthy
Carnegie Mellon University, Pittsburgh, PA

Ann McIver McHoes
Carlow College, Pittsburgh PA

Genevieve McHoes
University of Maryland, College Park, MD

John McHugh
CERT™ Coordination Center, Software Engineering Institute, Carnegie Mellon University, Pittsburgh, PA

Donald M. McIver
Northrop Grumman Corporation, Baltimore, MD

Maurice McIver
Integrated Databases, Inc., Honolulu, HI

William J. McIver, Jr.
University at Albany, State University of New York

Trevor T. Moores
University of Nevada, Las Vegas

Christopher Morgan
Association for Computing Machinery, New York, NY

Bertha Kugelman Morimoto
University of Pittsburgh, Pittsburgh, PA

Tracy Mullen
NEC Research Inc., Princeton, NJ

Paul Munro
University of Pittsburgh, Pittsburgh, PA

Stephen Murray
University of Technology, Sydney, Australia

Carey Nachenberg
Symantec Corporation

John Nau
Xceed Consulting, Inc., Pittsburgh, PA

Paolo Nesi
University of Florence, Italy

Kai A. Olsen
Molde College and University of Bergen, Norway

Ipek Özkaya
Carnegie Mellon University, Pittsburgh, PA

Bob Patterson
Perfection Services, Inc.

Robert R. Perkoski
University of Pittsburgh, Pittsburgh, PA

Thomas A. Pollack
Duquesne University, Pittsburgh, PA

Guylaine M. Pollock
IEEE Computer Society; Sandia National Laboratories, Albuquerque, NM

Wolfgang Porod
University of Notre Dame, Notre Dame, IN

Anwer H. Puthawala
Park Avenue Associates in Radiology, P.C., Binghamton, NY

Mary McIver Puthawala
Binghamton, NY

Sudha Ram
University of Arizona, Tucson, AZ

Edie M. Rasmussen
University of Pittsburgh, Pittsburgh, PA

Robert D. Regan
Consultant, Pittsburgh, PA

Allen Renear
University of Illinois, Urbana-Champaign

Sarah K. Rich
Pennsylvania State University, University Park, PA

Mike Robinson
Sageforce Ltd., Kingston on Thames, Surrey, United Kingdom

Elke A. Rudensteiner
Worcester Polytechnic Institute, Worcester, MA

Frank R. Rusch
University of Illinois at Urbana-Champaign

William Sherman
National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign

Marc Silverman
University of Pittsburgh, Pittsburgh, PA

Munindar P. Singh
North Carolina State University, Raleigh, NC

Cindy Smith
PricewaterhouseCoopers, Pittsburgh, PA

Barry Smyth
Smart Media Institute, University College, Dublin, Ireland

Amanda Spink
Pennsylvania State University, University Park, PA

Michael B. Spring
University of Pittsburgh, Pittsburgh, PA

Savitha Srinivasan
IBM Almaden Research Center, San Jose, CA

Igor Tarnopolsky
Westchester County Department of Laboratories and Research, Valhalla, NY

George A. Tarnow
Georgetown University, Washington, DC

Lucy A. Tedd
University of Wales, Aberystwyth, Wales, United Kingdom

Umesh Thakkar
National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign

Richard A. Thompson
University of Pittsburgh, Pittsburgh, PA

James E. Tomayko
Carnegie Mellon University, Pittsburgh, PA

Christinger Tomer
University of Pittsburgh, Pittsburgh, PA

Upkar Varshney
Georgia State University, Atlanta, GA

Jonathan Vos Post
Webmaster <http://magicdragon.com>

Tom Wall
Duke University, Durham, NC
Brett A. Warneke
University of California, Berkeley, CA
Patricia S. Wehman
University of Pittsburgh, Pittsburgh, PA
Isaac Weiss
University of Maryland, College Park, MD
Martin B. Weiss
University of Pittsburgh, Pittsburgh, PA
Jeffrey C. Wingard
Leesburg, VA
Victor L. Winter
University of Nebraska at Omaha
Charles R. Woratschek
Robert Morris University, Moon Township, PA
Peter Y. Wu
University of Pittsburgh, Pittsburgh, PA
William J. Yurcik
Illinois State University, Normal, IL
Gregg R. Zegarelli
Zegarelli Law Group, P.C.

Table of Contents

VOLUME 2

Abacus

The abacus, an ancient calculating device, probably originated in Babylon around 2400 B.C.E. as a "counting box." It was the world's first calculator, and contemporary versions are still in use today.

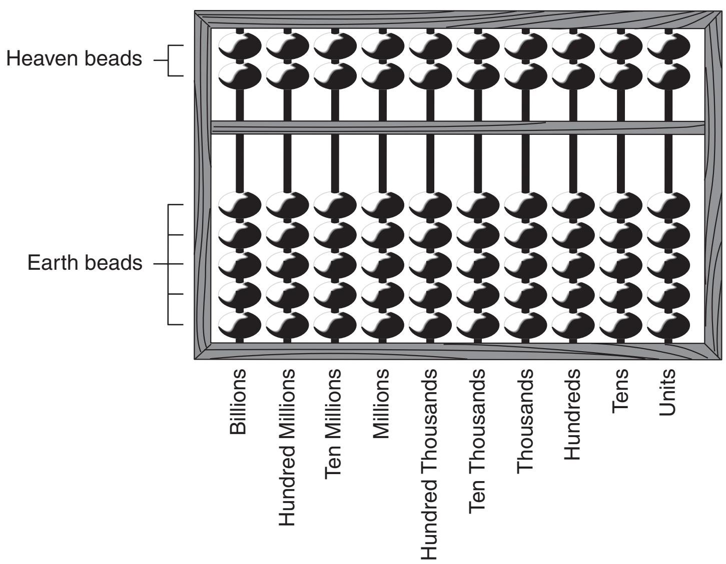
An abacus is a wooden or metal rectangular frame with vertical bars containing movable beads. Prior to the advent of the abacus, stones were used as computational tools. This had two major disadvantages: it was easy to lose track while figuring, and finding or transporting large numbers of stones was difficult. By contrast, the abacus was a highly portable, easy-to-use device that proved to be an excellent alternative to a bag of stones.

The abacus was used throughout the Middle East and as far eastward as Japan. The number of vertical bars and beads on each bar varied from culture to culture, but the basic function of the abacus—calculating the costs and quantities of goods—remained the same.

The Chinese abacus, which is the most familiar form today, divides the frame with a horizontal bar. The classic version, known as *suan-pan*, or the "2/5 abacus," is thought to have developed around C.E. 1200. The area above

AZTEC ABACUS

Archaeologists have discovered that the Aztec culture used a counting device similar to the Asian abacus. The Aztec abacus (c. C.E. 900–1000) consisted of a wooden frame on which were mounted strings threaded with kernels of maize (corn).



The Chinese abacus was an early calculator, which helped the user quickly determine sums.

the horizontal bar, heaven, contains two beads per vertical rod; each has a value of five. In the lower area, or earth, each vertical rod contains five beads, each with a value of one. Each vertical rod represents a unit of ten. Calculating is accomplished by moving beads toward or away from the horizontal divider. In the mid-1800s, the 2/5 abacus was replaced by the 1/5 abacus, and, by the 1930s, the most widely used form of abacus was the Japanese-made *soroban*, or 1/4 abacus.

Although pocket calculators and other devices have replaced the abacus in most parts of the world, many Asian shopkeepers and schoolchildren still use the abacus for basic arithmetic functions such as adding, subtracting, and multiplying. SEE ALSO Napier's Bones; Slide Rule.

Bertha Kugelman Morimoto

Bibliography

Menninger, Karl. *Number Words and Number Symbols.* Cambridge, MA: M.I.T. Press, 1969.

Internet Resources

Ryerson University, Department of Electrical and Computer Engineering, *The Abacus: The Art of Calculating with Beads.* <http://www.ee.ryerson.ca:8080/~elf/abacus/>.

Analog Computing

Humans have always desired mechanical aids to computations. There is evidence of "computing" devices such as the present-day abacus, from as early as the thirteenth century C.E. The first computing devices were accumulators only capable of adding or subtracting. Even "adding machines," which were made well into the twentieth century, could only perform that one function. Subtraction is nothing more than adding a negative number.

Nearly all modern computers are digital, which means that all the internal machine states are either on or off, a one or a zero, true or false, or other nomenclature. There is nothing between a zero and a one such as one-half or one-third etc. The number of **bits** used to define a quantity sets the number of different values that the quantity can have. As an example, a quantity represented by an 8-bit binary number can only be one of 256 values. The least significant bit of a binary number is the least amount by which two binary numbers can differ. If, in the example, the least significant bit were one, an eight-bit binary number would define integers from zero to 255.

Analog computing, on the other hand, uses physical characteristics to represent numerical values. For example, the **slide rule** uses distance to represent the **logarithms** of numbers, and an **oscilloscope** uses electric current to show the amplitude and frequency of waves. In an analog computer, the internal signals of the computer can assume any value. As an example, a voltage can vary from zero to one volt where there are an infinite number of values between the minimum of zero and a maximum of one volt. In a mechanical machine, voltage would be replaced with distance, or displacement such as the turning of a shaft. A pointer could be attached to the shaft, which will be a part of a mechanical dial to display an answer.

Many of the early computing devices are digital such as the previously mentioned abacus. Only one bead could be pushed along the wire. It was

bits the plural of bit, a single binary digit, 1 or 0—a contraction of Binary digIT; the smallest unit for storing data in a computer

slide rule invented by Scotsman John Napier (1550–1617), it permits the mechanical automation of calculations using logarithms

logarithms the power to which certain numbers called the base are to be raised to produce a particular number

oscilloscope measuring instrument for electrical circuitry; connected to circuits under test using probes on leads and having small screens that display the signal waveforms not possible to move a fraction of a bead to be used in calculations. These historic adding machines were well suited to accounting where the monetary system was inherently digital. If the least significant bit of an accounting machine were also the smallest unit of currency, the machine would be adequate for most calculations.

The Slide Rule

For accounting, addition, subtraction, multiplication, and division are usually the only mathematical operations required. Scientists and engineers routinely perform much more sophisticated mathematics such as trigonometric functions, logarithms, exponentiation, and many others. The **ubiquitous** tool of the engineer and scientist for calculations until the development of the hand-held scientific calculator in the early 1970s was the slide rule. The slide rule was invented in the 1600s and uses logarithms.

ubiquitous to be commonly available everywhere

The slide rule is an example of a mechanical analog computer while the adding machine is an example of a mechanical digital computer.

The slide rule could do any common mathematical function except add and subtract. The interesting characteristic of the slide rule was the device actually added and subtracted but it added and subtracted logarithms. When using logarithms to multiply, the logarithms are added. To determine the answer, the "anti" logarithm of the resulting sum is found. Division involved subtracting logarithms. Trigonometric functions were shown on the slide rule by simply transferring the "trig tables" found in a mathematics handbook to the slide rule.

The major problem of the slide rule was it was only accurate to about three decimal places, at best. When the hand-held scientific calculator appeared, the use of the slide rule disappeared, virtually overnight!

Early Calculators and Computers

The slide rule and the adding machine are "calculators." Fixed numbers are entered and fixed answers result. One requirement for engineers and scientists is to solve problems where the numbers are always in a state of change. Mathematician Isaac Newton (1642–1727) in his study of mechanical motion discovered the need for a math that would solve problems where the numbers were changing. Newton invented what he called "fluxions," which are called "derivatives" in modern calculus. Think of fluxions as describing something in the state of flux. Equations written using variables that are in a constant state of change are called "differential equations." Solving these equations can be very difficult particularly for a class of equations called "nonlinear." Solving these equations requires a nonlinear algebra and can be very complicated. The most effective way to solve this type of equation is to use a computer.

Some of the first true computers, meaning they were not calculators or accounting machines, were invented for the purpose of predicting tides. Later machines solved difficult differential equations. These machines used electric motors, gears, cams, and plotting devices to draw the solution of a differential equation. These early mechanical devices were called "differential analyzers." These machines were "programmed" by installing various

ANALOG THRIVES

Much of the world is analog and it would be no surprise that many early computers used analog techniques. Despite the development of extremely powerful digital microprocessors, analog computing still plays an important role in the modern world.

Aviation engineer Capt. Frank Whittle used a slide rule, an analog computational device, in his work with the British Royal Air Force.

gears, shafts, and cams on a large frame. These machines were actually used for solving equations up until the end of World War II.

Similar mechanical computers were used to control various machines such as naval guns. An analog computer would receive information relative to the ship's location, heading, speed, wind direction, and other parameters as well as operator-entered data concerning the type of projectile, the amount of explosive charge and, most important, the location of the target. The mechanical analog computer would then control the aiming of the gun. Perhaps the most well known analog computer was the computer used for controlling anti-aircraft guns from radar data during World War II.

Mechanical computers are very heavy and slow. After the war, engineers took advantage of the rapidly growing field of electronics to replace the mechanical components of the analog computer. Special amplifiers can add, subtract, and perform calculus operations such as differentiation and integration. The amplifiers were placed in what is called a "feedback" circuit where some of the output signal is fed back to the input. The nature of the feedback circuit would determine the mathematical operation performed by the amplifier. These amplifiers were called "operational amplifiers" because they perform mathematical operations. Feedback circuits can perform exponentiation, multiplication, and division, taking logarithmic and trigonometric functions. Replacing the bulky, massive mechanical components of the analog computer with electronic circuits resulted in a much faster analog computation. In the early days of the electronic computer, analog computers were faster than digital computers when solving complex differential equations.

Longevity of Analog Computers

Analog computation is still used long after digital computers achieved very high levels of performance. The physical world is mostly analog. Parameters such as distance, angles, speed, and so on are all analog quantities. If a simple calculation is required of an analog function where both the input and output are analog, it is often not worth the expense of a digital microprocessor to perform the task that an operational amplifier can provide. If the calculation is complicated, the advantages of the digital computer will justify the use of a microprocessor.

One of the more common modern applications of analog computers is in process control. As an example, a simple analog circuit using a few operational amplifiers may be used to control the temperature of an industrial process where the use of a digital computer is not warranted.

The stand-alone analog computer does not exist at the time of this writing. The stored-program digital computer has the distinct advantage that the computer is completely programmed by software and does not require any external feedback components. Very powerful software exists for solving differential equations and systems based on differential equations, both linear and nonlinear. Even though the "analog computer" no longer exists, operational amplifiers are standard electronic components and are used in a large number of applications still performing mathematical operations. SEE ALSO Abacus; Binary Number System; Digital Computing; Napier's Bones; Slide Rule.

Albert D. Helfrick

Bibliography

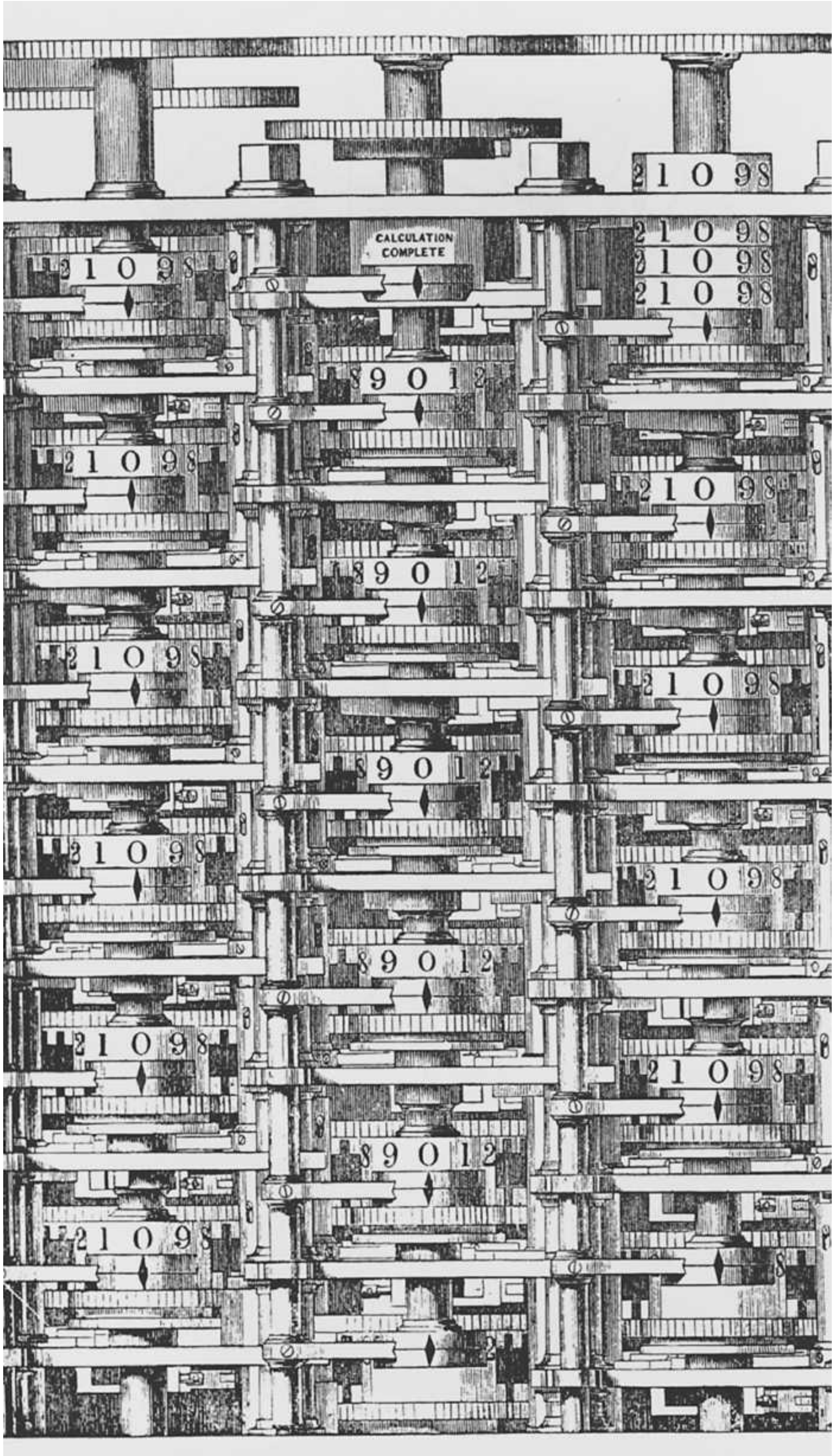
Aspray, William, ed. *Computing Before Computers.* Ames, IA: Iowa State University Press, 1990.

Cortada, James W. *The Computer in the United States: From Laboratory to Market, 1930 to 1960.* Armonk, NY: M. E. Sharpe, 1993.

Roy, Michael R. *A History of Computing Technology.* Los Alamitos, CA: IEEE Computer Society Press, 1997.

Analytical Engine

Inventions are often preceded by prototypes that introduce new concepts, serving as models in which development will occur. Sometimes these prototypical ideas arise before they can be carried out in any practical way. Such is the case of the Analytical Engine, which may be considered the great-grandfather of the modern computer. The Analytical Engine is widely



Charles Babbage's first machine was actually the Difference Engine (pictured here), which was begun in 1823. It was designed to calculate differences. Work on this precursor to the Analytical Engine continued over a period of years, but Babbage eventually abandoned it in 1842, when the British government stopped funding it. The Difference Engine was later kept in a museum in South Kensington, England.

recognized as the first conceptual device that incorporated principles found in contemporary computing.

What makes the Analytical Engine so truly extraordinary is that it was conceptualized well before electricity was in use. In the early 1800s, mathematician Charles Babbage (1791–1871) conceived of the idea of a computational device that would store numbers and process them with mathematical accuracy. The first actual computer built in the United States, known as the ENIAC (Electronic Numerical Integrator and Computer), was not in operation until the 1940s, some 120 years later. Still, Babbage's Analytical Engine set the blueprint for the modern computer.

The Analytical Engine was developed to meet the mathematical needs of the time, and it contained most of the features found in modern computers. There was a way to input data, a place for storing data, a place for processing data, a control unit to give directions, and a way to receive output. Babbage used **punched cards** for data input, which were also used for input into early electronic computers until the early 1970s. The punched card systems are actually derived from the textile industry; the Jacquard Loom of the early 1800s used punched cards to control color and pattern coordination in the weaving of textiles. Similarly, punched cards were employed in calculating machines of the nineteenth century, including the prototypical analytical engine.

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

Like modern computers, the Analytical Engine included programming capabilities. The first programmer was Ada Byron King, Countess of Lovelace, daughter of English poet Lord George Gordon Byron. Using punched cards, she entered data in **binary code** to automate mathematical processes. The binary code reduces all computed equations, images, etc. to a code using only zeros (0) and ones (1). Data are coded onto the punched cards and entered into the computing device. In this way the processes are automated. For Babbage's machine, the process was "automated" by a series of clicks that were the equivalent of counting. Many of these processes are still used today, and binary code remains the groundwork of all programming.

binary code a representation of information that permits only two states like 1 or 0

The Analytical Engine was never made operational, although much of Babbage's life work revolved around the design and construction of calculating machines. The Analytical Engine was, in fact, a theoretical construct that coincided with the onset of the industrial revolution. Western society as a whole was moving away from a farming-based economy to one in which the sources of capital depended less on working the land and more on the manipulation of raw materials with machinery. Events in the late nineteenth century would give rise to full-scale industrialization with steel mills, railroads, and other mechanized means of production and delivery of goods. The historical significance of the analytical engine lies in the fact that it was a product of the industrial revolution, but a forerunner to the foundation of the information age, namely, the computer.

Babbage created several other calculating machines in addition to the Analytical Engine. Most of his machines did not actually work; however, this is probably because they, like Babbage and Lovelace, were ahead of their time. Quite simply, the Analytical Engine contained all the theoretical components of the modern computer, but the technology was not yet available to make it operational. Still, as the first attempt at a digitally computational device, the analytical engine is considered the great-grandfather of the computer of today. SEE ALSO Babbage, Charles; Lovelace, Ada Byron King, Countess of.

Tom Wall

Bibliography

Babbage, Charles. *The Works of Charles Babbage: The Analytical Engine and Mechanical Notation, Vol. 3.* Edited by Martin Campbell-Kelly. New York: New York University Press, 1989.

Collier, Bruce. *The Little Engines that Could've: The Calculating Machines of Charles Babbage*. New York: Garland Publishing, 1990.

Jenkins, Richard A. *Supercomputers of Today and Tomorrow: The Parallel Processing Revolution*. Blue Ridge Summit, PA: Tab Books, 1986.

McCormack, Marie L. "What Sex Is the Internet?" *Futures* 30, no. 9 (1998): 923–933.

Animation

Animation is the art by which two-dimensional drawings or inanimate objects are turned into moving visual representations of three-dimensional (3-D) life. Computer animation uses computer hardware and software to make the animation process easier, faster, and executable by less skilled and fewer creators. Although there used to be clear divisions among cartoon and feature film animation, visual effects, gaming software, 3-D animation, and **GIF animation**, these related forms of animation now often overlap.

GIF animation a technique using Graphic Interchange Format where many images are overlaid on one another and cycled through a sequence to produce an animation

Animation can be described as the creation of the illusion of motion through a rapid sequence of still images. Although the quality of the original images is important, equally important is the quality of the sequence through which action, character, and story development are portrayed. There must be a coherent pattern to the action. A common story structure introduces characters, a source of conflict, the development of this conflict, a climax, and finally a resolution. But an animated story can also be more fluid, including the creation of forms or simple images, some interaction of them, and then a transformation or **transmutation**, such as a smiley face turning into a frown or dissolving into the background.

transmutation the act of converting one thing into another

Creating an Animated Story

Although the process of animation takes many forms depending on the medium used, the following is typical. A preview or rough overview of the story, called a pencil test, is created. This is a sample sequence of pencil drawings created on paper to present a rough overview of the story. In the early days of animation, these were then recorded on an animation stand, but now they are placed on film or videotape. Sometimes, after a story idea is conceived, a "treatment" is created instead of a pencil test; this is a brief narrative description of the proposed film or video. Both pencil tests and treatments are often used to solicit sponsors. The action of the story and its development are conveyed through the use of storyboards, which are used to compose, organize, and deploy the animation.

A storyboard is a series of visual sketches that the story creator uses when developing the narrative and depicting the action of the animation. This is done so that everyone involved in the animation project can literally sketch out what is happening, making sure that important details are not overlooked. The storyboard details the sequence of actions necessary to convey the story line, character development, and point of view. This would include the background, action, and camera movement of the scene, but also

In the movie *The Perfect Storm* (2000), animators used computer technology to recreate the treacherous weather and sea conditions which claimed the crew of the *Andrea Gail* commercial fishing vessel in 1991.

each change of scene, each change in perspective, the timing and length of each scene, sound requirements, and the timing of the whole work.

With the storyboard in place, the dialog or music for the animation is recorded, and the sound length is determined in terms of the number of frames that it can handle. This information is entered on a "dope sheet"—a document detailing the nature of the music clips, their times, and the number of frames per clip. A layout is drawn up for each scene and the director uses the layout and dope sheet to plan the action and its timing. Next a background is created and the movement is created by a sequence of drawn images, which is then also entered on the dope sheet.

The image drawings for movement are then tested; if there are discrepancies, corrections are made to the timing or the drawings. In traditional animation, hand-drawn or cel animation is the most common technique. The cleaned-up drawings are inked and colored by hand on acetate overlays called cels. The cels are placed on the background, which is then placed under the camera. The camera operator, using the dope sheet, assembles the background and movement cels, and shoots each frame, after which the film is sent for processing and printing. The printed scenes are then edited to integrate all the sound tracks, including music and dialogue.

The result of this integration is called a work or cut print. The lab makes a final print that can be projected to an audience or is transferred to film.

Computers are now used for many or all parts of this process. With current technology, the completed computer file is sent directly to digital tape, which will be transferred to film or broadcast on DVD or videotape.

Types of Animation

virtual reality (VR) the use of elaborate input/output devices to create the illusion that the user is in a different environment

animatronics the animation (movement) of something by the use of electronic motors, drives, and controls

Many types of animation exist but there is no common classification scheme to describe them. The *Encyclopedia of Animation Techniques* (1996) lists drawn animation and model animation, but there are also cutout animation, 3-D animation, **virtual reality (VR)** animation, and **animatronics**, to name a few other types. The hand-drawn or cel animation, mentioned earlier, is the most common traditional technique. Hundreds of examples of hand-drawn animation were generated by Walt Disney (1901–1966) and his studios, such as *Snow White and the Seven Dwarfs* and *Bambi*. Hand-drawn animation in pencil form and cels is no longer used much today. Drawings are often made with computer software, and foregrounds and backgrounds are now generated through the use of digital files.

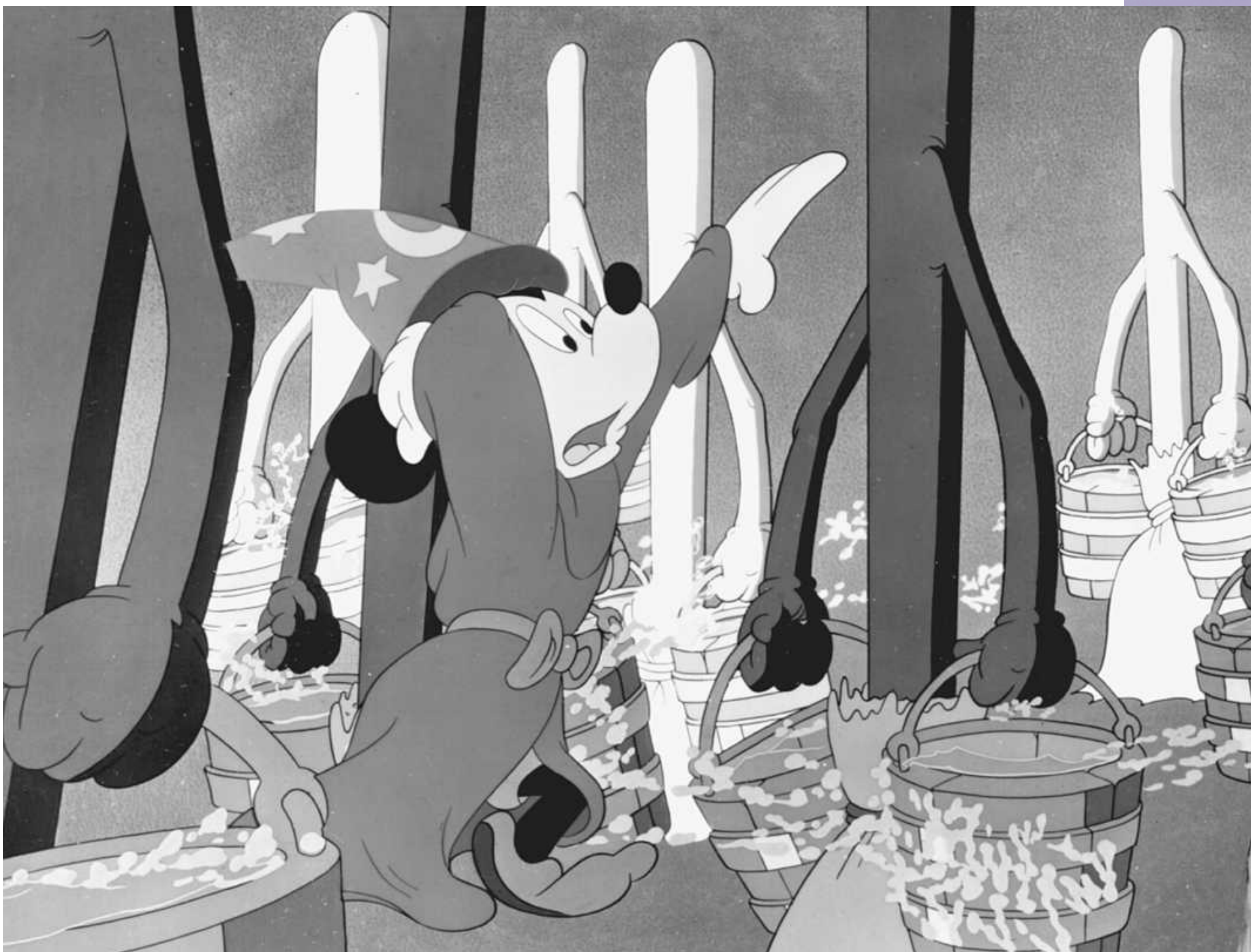
Model animation follows a process similar to hand-drawn animation, using models such as puppets (sometimes referred to as puppet animation) or clay figures (sometimes referred to as claymation). Set workers create movement by physically modifying the clay figures or changing the positions of the puppets. Each time this is done, a new scene is recorded on film or videotape. Because motion is captured through the position-by-position image of the models on single frames, model animation employs a technique known as stop-motion animation. The Christmas favorite *Rudolph the Red-Nosed Reindeer* is a classic example of stop-motion animation.

One of the well-known creators and directors of "claymation" was Nick Parks, who created the characters Wallace and Gromit in *A Grand Day Out* (1990), which won a British Academy Award. He also created *Creature Comforts* (1990), featuring interviews with inmates of a zoo, which won an Academy Award, as did two more adventures of Wallace and Gromit: *A Close Shave* (1995) and *The Wrong Trousers* (1998).

Cutout animation has been made notable by Terry Gilliam in *Monty Python's Flying Circus* and by Matt Stone and Trey Parker in *South Park*. To create cutout animation, an artist cuts actors and scenes out of paper, overlays them, and moves them, and captures their images frame by frame, again using stop-motion animation. In Gilliam's work, the animation was done frame by frame, but Stone and Parker quickly abandoned the physical work of generating the figures and turned instead to advanced computer workstations that create the same effect.

3-D animation is similar to hand-drawn animation, but it involves thinking in three-dimensional space and working with objects, lights, and cameras in a new way. 3-D animation requires the use of computers. The movie *Toy Story* is an example of 3-D computer animation.

Virtual reality animation is created through such technologies as VR and VRML (Virtual Reality Modeling Language). These make it possible to create 3-D environments, accessible through web sites, within which viewers can feel fully immersed in the animated surroundings. Quicktime VR



Numerous animators worked to produce Disney's *Fantasia* (1940), starring Mickey Mouse. The full-length film used animated cels, one of the earliest techniques for producing animated fims. Some of these cels now sell for thousands of dollars in today's collectibles market.

uses photographic images or pre-rendered art to create the inside of a virtual environment that is downloaded to the viewer's own computer. VRML uses 3-D models and real-time interaction that puts the viewer inside 3-D environments.

Animatronics entails the use of computer-controlled models that can be actuated in real-time. These models have electronic and mechanical parts including motion-enabling armatures covered with a synthetic skin. These models, often used in conjunction with live actors, form the foundation for animation sequences. Films featuring animatronics include *Jaws*, *Star Wars*, and *Jurassic Park*.

Animation Techniques

Two basic animation techniques are *keyframing* and *in-betweening*. Keyframing is derived from key moments of still frames in the animation sequence. A keyframe is defined by its particular moment in the animation sequence, its timeline, parameters, and characteristics. In traditional pencil drawings, these would be keyframe drawings; in claymation or puppet animation, these would be key poses. Once the keyframes are established, then the sequences of animations between these keyframes have to be done. This technique is called in-betweening; it involves creating the frames that fill the gaps between the key frames. In computer environments, the technique is called **interpolation** and there are several varieties. Keyframe interpolation provides the frames that are required, but how this is done depends on the kind of interpolation used, linear or curved. Linear interpolation provides frames equally spaced between the key frames, based on an averaging of the parameters of the key frames and employing a constant speed. Curved interpolation is more sophisticated and can accommodate changes in speed.

interpolation estimating data values between known points, but the values in between are not and are therefore estimated

History of Animation

Most basic animation principles and techniques were developed in the first twenty years of the twentieth century, and were perfected by the 1940s, particularly by Walt Disney, whose studios popularized the form through full-length feature films. Disney's impact on animation and the entertainment industry was profound. Ironically, his first attempt at an animated film production was a failure. In 1922, as a twenty-one-year-old commercial artist, he launched Laugh-O-Gram films in Kansas City. The company went bankrupt after a year. Fortunately, his creditors permitted him to retain one of his short features, which provided the basis for the launch of Disney Brother Studios in Hollywood. It produced the *Alice Comedies*, which featured a combination of animation and live action.

POPULAR ART FORM

Animation has been popular from the early 1930s in animated cartoons, especially by Walt Disney. With the use of computer technologies, however, it has become commonplace in such games as *Tomb Raider* and *Myst,* in such movies as *The Lion King* and *ANTZ,* and as visual effects in *Star Wars, Jurassic Park, The Mummy,* and *Harry Potter and the Sorcerer's Stone*.

Disney. In 1928 Walt Disney teamed with his brother, Roy O. Disney, and animator Ub Iwerks to produce *Steamboat Willie*, the first cartoon that was synchronized with sound. *Steamboat Willie* gave us Mickey Mouse, one of the long line of popular characters—such as Donald Duck, Goofy, Pluto, Cinderella, and Simba—that made Disney famous and on which the Disney empire is built. Then Disney made a series of animated short films set to classical music, called the "Silly Symphonies" (1929–1939), in which he introduced Technicolor into animation. Disney held the Technicolor patent for two years. Disney won an Oscar for the first cartoon and full-Technicolor feature called *Flowers and Trees* (1932).

In 1937 Disney released *Snow White and the Seven Dwarfs*, the first full-length animated feature film. In order to produce this film, Disney invented the multiplane animation camera. With this invention, for which he was inducted into the National Inventors Hall of Fame, he changed the animation industry. Disney's camera made it possible to have cartoon characters move through many layers of scenery.

Disney always pushed the limits in his use of new technologies: for example, he produced *Fantasia* (1940) in Fantasound, a forerunner of current movie sound systems; *Lady and the Tramp* (1955) in CinemaScope, an innovative movie viewing experience with a wide screen and stereophonic sound; and *101 Dalmations* (1961) using Xerox technology to make cels from animated drawings.

Following the success of *Snow White*, Disney produced a series of animated films, now regarded as classics, that secured his reputation. Among them are: *Fantasia* (1940), *Pinocchio* (1940), *Dumbo* (1941), *Bambi* (1942), *Song of the South* (1946), *Cinderella* (1950), *Alice in Wonderland* (1951), *Peter Pan* (1953), *Lady and the Tramp* (1955), and *Sleeping Beauty* (1959). Starting in 1961, Disney found additional success in the rapidly growing medium of television with what came to be known as *Walt Disney's Wonderful World of*

Color, which included many animated components or productions. During his lifetime, Walt Disney won thirty-two personal Academy Awards, and the Walt Disney Studios during the same time won an additional twenty-three Oscars in categories such as in animation (e.g., *Pigs Is Pigs* in 1953) and original musical compositions or songs (e.g., *Pinocchio* in 1941).

After the death of Walt Disney in 1966, his studios continued to garner awards and to produce commercial animation successes such as *The Little Mermaid* (1989), *Beauty and the Beast* (1991), *Aladdin* (1992), *The Lion King* (1994), *Pocahontas* (1995), *Mulan* (1998), and *Atlantis (2001)*. The company also produces many live-action films and television series. Disney's animations are also on display throughout the company's popular theme parks.

MGM. Metro-Goldwyn-Mayer (MGM) was an early promoter of animated films. Two of their in-house animators, William Hanna and Joseph Barbera, launched the *Tom and Jerry* films in 1940 that subsequently won five Academy Awards. They later created such familiar characters as the Jetsons, Scooby Doo, the Flintstones, and the Smurfs.

Trends. Major growth in animation productions started in the 1960s prompted by the growth of mass media, particularly with visual effects in films (e.g., *Mary Poppins*) and animated cartoon series on television (e.g., *The Flintstones*). In the 1970s, the growth of computer animation was facilitated by the invention of minicomputers, particularly by Digital Equipment Corporation's PDP and VAX computers. Because of cost and complexity, computer-assisted animation was still the domain of commercial companies. While personal computers (PCs), such as the Macintosh and the IBM-PC, were introduced in the mid-1980s, it was only in the 1990s that their power and available software were adequate for personal computer animation authorship. The diversity of developments and inventions and increasing use of technologies for computer animation are presented in a timeline (1960–1999) in Isaac Victor Kerlow's *The Art of 3-D Computer Animation and Imaging* (2000).

Principles of Animation

Around 1935, some animators at Walt Disney Productions wanted to develop lessons that would refine the basic animation techniques that had been in use from the earliest days of animation. These became the fundamental principles of traditional animation, though most can also be applied to Internet and 3-D graphics environments. John Lasseter, in "Principles of Traditional Animation Applied to 3D Computer Animation," provides a list:

1. *Squash and Stretch*, in which distortion is used in animated action to convey the physical properties of an object;
2. *Timing*, in which actions are spaced so that they help portray the personal or physical characteristics of characters or objects;
3. *Anticipation*, meaning that actions are foreshadowed or set up;
4. *Staging*, through which the animator conveys ideas clearly through background, foreground, and action;
5. *Follow-Through and Overlapping Action*, wherein the end of one action builds a bridge to the next action;

6. *Straight-Ahead and Pose-to-Pose Action*, which are two primary ways of creating action;
7. *Slow In and Out*, which refers to the animator's placement of the in-between frames to create various levels of sophistication in timing and motion;
8. *Arcs*, a visual representation of movement that appears natural;
9. *Exaggeration*, wherein an idea is emphatically represented through design and action that is not restricted to representing reality;
10. *Secondary Action*, which refers to the action of an animated object or character that is caused by the action of something or someone else;
11. *Appeal*, or audience-pleasing action, stories, and visuals.

Web Animation

Several software formats have been used for producing animation on the Internet. One of the first was Netscape Navigator 2's GIF89, which allowed a user to animate GIF (Graphic Interchange Format) images. It was not intended as a medium for full animation, however. Partly as a response to this, dHMTL (dynamic Hypertext Markup Language) was born. Dynamic HTML is a hybrid of JavaScript, HTML, and cascading stylesheets, but the disparity between Internet Explorer and Navigator platforms made it difficult to use.

When CD-ROMs (Compact Disk-Read Only Memory) became common, Macromedia distinguished itself with Director, a multimedia authoring system. In 1995 the company released the Shockwave Internet browser plug-in for Director, which allowed users to see online content created by Director. Macromedia later produced a plug-in designed specifically for web browsers, called Flash, which it continues to improve and support. However, realizing the value of dHTML, Macromedia created another product, called Dreamweaver, which avoids many browser platform disparities, by producing a dHTML page as an HTML page. Unfortunately, the standard HTML page was not conceived as a medium for animation, and its performance is not as great as plug-in formats, such as Flash, Director, or Quicktime, although the standards may evolve.

Game Animations

Games began to appear almost as soon as computers appeared. In the late 1960s, *Spacewar!* was created, partly as a way of experimenting with one of the earliest computers, the PDP-1, developed by Digital Electronic Corporation. A lot of two-dimensional games began to follow, including *Pac-Man*. In 1984 Atari's *I, Robot* appeared. Loosely based on Isaac Asimov's book by the same name, it foreshadowed the movement to three-dimensional games. At the same time, Nintendo was working on a video game console, Famicom, which later emerged as the Nintendo Entertainment System in the United States.

Part of the success of these systems was the structure of the computer they used: the computer had chips for the central processing unit (CPU), audio, and video which permitted better efficiency and looser control. This was the case with Commodore's Amiga and Atari's ST computer series. Before long, PC peripheral manufacturers started producing more powerful video cards (e.g., "graphics accelerator cards" with their own chips and memory, such as the ATI series), and sound cards (e.g., SoundBlaster). These eventually posed a challenge to the units designed specifically for games because they could handle the graphics and sound requirements necessary for games. Examples include Nintendo's GameCube, Sony's Playstation and Microsoft's X-Cube.

Animation in the early games was basic, relying on simple movement and graphics, but current games embrace sophisticated animation. There are many genres of games, including electronic versions of traditional games like *Monopoly*, *Solitaire*, *Hearts*, and *Jeopardy!* Early maze games, such as *Pac-Man*, and puzzle games, like *Tetris*, paved the way for more sophisticated action games like *Street Fighter* and *Killer Instinct* (fighting games); *Castle Wolfenstein* (a first-person shooter game); and third-person 3-D games, such as *Tomb Raider* and *Deathtrap Dungeon*. Animated computer games also include racing games such as *Destruction Derby* and 3-D vehicle-based games, such as *Dead Reckoning*; flight simulators, such as *Wing Commander*, and other popular simulations (e.g., *Sim City*, *Sim Ant*); role-playing games, such as *Dungeon Hack*; and adventure games, such as *The Hitchhiker's Guide to the Galaxy*. At the pinnacle are full-motion video games, like *Myst* and *Raven*. Software, including *The Games Factory* and *PIE 3D Game Creation*, has emerged to cope with the demands of creating animated games. SEE ALSO Games; Music; Music, Computer.

Thomas J. Froehlich

Bibliography

Finch, Christopher. *The Art of Disney: From Mickey Mouse to the Magic Kingdoms*. New York: Harry N. Abrams, 1995.

Kerlow, Isaac Victor. *The Art of 3-D Computer Animation and Imaging*, 2nd ed. New York: John Wiley and Sons, Inc., 2000.

Lasseter, John. "Principles of Traditional Animation Applied to 3D Computer Animation." *Computer Graphics* (ACM) 21, no. 4 (1987): 35–44.

Taylor, Richard. *Encyclopedia of Animation Techniques*. Philadelphia, PA: Running Press Book Publishers, 1996.

Wagstaff, Sean. *Animation on the Web*. Berkeley, CA: Peachpit Press, 1999.

White, Tony. *The Animator's Workbook*. New York: Billboard Publications, 1988.

Apple Computer, Inc.

Apple Computer, Inc. was founded by Steven Jobs and Stephen Wozniak in Jobs' garage in Los Altos, California, in 1975. Their goal was to change the world by developing an easy-to-use computer that everyone could own.

In November of 1975, Wozniak finished assembling the Apple I—a modest device that consisted of a **motherboard**, a keyboard, and a display. The advantages to the Apple I were simplicity, price, neatness, and reliability. The disadvantage was that it used the 6502 MOS Technologies microprocessor chip, a cheaper alternative to the popular Intel 8080 chip. This chip fundamentally set the Apple I apart from Intel-based machines. However, Jobs first proved his marketing skills with this computer when he found backers willing to supply the cash and personnel to incorporate the company.

motherboard the part of the computer that holds vital hardware, such as the processors, memory, expansion slots, and circuitry

Apple cofounder Steven Jobs helped begin the PC revolution by developing computer systems that the average person could operate and afford.

STEVEN JOBS

At the age of 21, Steven Jobs was persuaded by his friend Stephen Wozniak to help him create an "insanely great" personal computer that anyone could use. When the stock of their company went public five years later, Jobs made $256.4 million.

After ten years with Apple, Jobs left to start a new computer company, NeXT. He also bought Pixar, Inc., a small computer animation company, from George Lucas. Pixar produced *Toy Story,* the first feature-length computer animated film, using computers from SGI, Hewlett-Packard, and Sun. When Pixar's stock went public in January 1995, 30-year-old Jobs became a billionaire.

In 1997 Jobs returned to Apple and shortly thereafter assumed the role of CEO, a title he also holds at Pixar. Jobs is credited with the development of the very popular iMac computer.

For the Apple II, which was released in 1977, Wozniak switched to a Motorola microprocessor, then gave the personal computer a color display. In doing so, Wozniak redesigned the way the computer utilized the microprocessor. He engineered the software to allow the microprocessor to do multiple tasks at the same time, including driving the color display. This simplified the machine so much that personal computers became cooler in temperature, lighter, more durable, cheaper, and easier to assemble. As a result, computer hardware could be mass-marketed, resulting in an affordable product for the consumer and better profit for the manufacturer.

The Apple II computer was so successful that several versions of it remained on the market for ten years. During a time when the word "computer" evoked images of huge commercial, or mainframe, machines, Apple outsold all others in the budding personal computer market, dominating the competition from Atari, Zenith, Commodore, and Tandy.

In 1980 the Apple III was released. It proved unsuccessful. Shortly thereafter, IBM, the **mainframe computer** manufacturer and Apple's main competitor, introduced its PC in 1981. The IBM-PC used Microsoft's operating system and the Intel chip. This opened the door to a more competitive market for personal computers during the 1980s.

mainframe computer large computer used by businesses and government agencies to process massive amounts of data; generally faster and more powerful than desktop computers but usually requiring specialized software

In 1983, Apple's sophisticated Lisa failed to meet expectations. However the Macintosh, introduced in 1984 with a Motorola 68000 microprocessor chip, added a versatility that put the machine many years ahead of its competition. This also marked the division of the personal computer market into two primary segments: the Macintosh platform of hardware and software vs. the IBM or IBM-compatible PC platform.

In 1985 both Wozniak and Jobs left the company they had cofounded ten years earlier. Throughout the 1980s and 1990s, Apple declined to make the Macintosh operating system compatible with Intel-based PCs. With few exceptions, the company declined to license either its hardware or software, as well, making it difficult or impossible for other companies to create software and hardware peripherals that would be compatible with Macintosh systems.

Instead of continuing to dominate the industry it helped establish, Apple became the classic illustration of non-conformity and incompatibility in a marketplace that rewards compatibility. For example, a 60-watt light bulb of any brand is compatible with a lamp from any manufacturer. By the late 1980s, people had come to expect such compatibility between software and computers as well. Some industry experts believe that if Apple had agreed to license its products, the industry would have matched its peripheral hardware and software to Apple products. Instead, the establishment of computer industry standards fell to IBM, Intel, and Microsoft.

From its inception, Apple grew steadily into a multi-billion dollar company. However the dominant market share it once held shrank to less than four percent by 1997. Furthermore, it was not until the Internet was established that Apple made its products compatible with Intel-based computers. Before long, Apple Computer's decline appeared to be irreversible. Compatibility problems with PCs, low market share, persistent dismal sales, the frequent turnover of its top executives, the loss of talented personnel, and successive layoffs sent the value of the company stock to a record low of less than $13 per share in 1997, well short of its break-even point.

However, in 1997, then-CEO Gil Amelio recruited Jobs back to Apple. Jobs brokered an agreement between Apple and Microsoft. The contract provided Apple with a much-needed cash infusion, Microsoft software specific to the Macintosh, and new credibility. With the subsequent introduction of the iMac, PowerBook G3 laptop computer, and the PowerMac G4, Apple stock was revived. By December of 1999, the iMac was the best-selling personal computer brand in the retail market, and Apple's market share had increased to 11.3 percent. SEE ALSO Intel Corporation; Microcomputers; Microsoft Corporation.

Mary McIver Puthawala

STEPHEN WOSNIAK

Apple cofounder Stephen Wozniak was in his mid-20s, working for Hewlett Packard, when he and Steven Jobs began to build the first Apple computer. When their company went public in 1980, Wozniak made $135 million.

In February of 1981, Wozniak sustained serious injuries in a plane crash. After recovering, he intermittently worked at Apple, and briefly ran his own company making universal remote controls. He has become well known for his philanthropy and interest in lifelong learning. In 1990 Wozniak hired teachers to help him collaborate with the Los Gatos School District to teach computer science to middle school students in his own computer lab.

Bibliography

Carlton, Jim. *Apple: The Inside Story of Intrigue, Egomania, and Business Blunders.* New York: Times Books, 1997.

Levy, Steven. *Insanely Great: The Life and Times of the Macintosh, the Computer That Changed Everything.* New York: Penguin Books, 1994.

Malone, Michael S. *Infinite Loop: How Apple, the World's Most Insanely Great Computer Company Went Insane.* New York: Doubleday, 1999.

Rupley, Sebastian. "iMac Overhaul." *PC Magazine* 12, no. 1 (1999): 28.

Streisand, Betsy. "The Patience of Jobs: Apple's Cofounder Is Back on the Cutting Edge with Pixar." *U.S. News and World Report* 12, no. 11 (1995): 83.

Artificial Intelligence

Artificial Intelligence (AI) is a field of study based on the premise that intelligent thought can be regarded as a form of computation—one that can be formalized and ultimately mechanized. To achieve this, however, two major issues need to be addressed. The first issue is knowledge representation, and the second is knowledge manipulation. Within the intersection of these two issues lies mechanized intelligence.

History

The study of artificial intelligence has a long history, dating back to the work of British mathematician Charles Babbage (1791–1871) who developed a special-purpose "Difference Engine" for mechanically computing the values of certain **polynomial** functions. Similar work was also done by German mathematician Gottfried Wilhem von Leibniz (1646–1716), who introduced the first system of formal logic and constructed machines for automating calculation. George Boole, Ada Byron King, Countess of Lovelace, Gottlob Frege, and Alfred Tarski have all significantly contributed to the advancement of the field of artificial intelligence.

polynomial an expression with more than one term

Knowledge Representation

It has long been recognized that the language and models used to represent reality profoundly impact one's understanding of reality itself. When humans think about a particular system, they form a mental model of that system and then proceed to discover truths about the system. These truths lead to the ability to make predictions or general statements about the system. However, when a model does not sufficiently match the actual problem, the discovery of truths and the ability to make predictions becomes exceedingly difficult.

A classic example of this is the pre-Copernican model in which the Sun and planets revolved around the Earth. In such a model, it was prohibitively difficult to predict the position of planets. However, in the Copernican revolution this Earth-centric model was replaced with a model where the Earth and other planets revolved around the Sun. This new model dramatically increased the ability of astronomers to predict celestial events.

Arithmetic with Roman numerals provides a second example of how knowledge representation can severely limit the ability to manipulate that knowledge. Both of these examples stress the important relationship between knowledge representation and thought.

Through artificial intelligence, engineers and computer scientists are capable of creating machines that perform dangerous tasks in place of humans. Here, a police robot handles a live bomb.

In AI, a significant effort has gone into the development of languages that can be used to represent knowledge appropriately. Languages such as LISP, which is based on the **lambda calculus**, and Prolog, which is based on formal logic, are widely used for knowledge representation. Variations of **predicate calculus** are also common languages used by automated reasoning systems. These languages have well-defined semantics and provide a very general framework for representing and manipulating knowledge.

lambda calculus important in the development of programming languages, a specialized logic using substitutions that was developed by Alonzo Church (1903–1995)

predicate calculus the branch of logic that uses individuals and predicates, or elements and classes, and the existential and universal quantifiers, all and some, to represent statements

Knowledge Manipulation

Many problems that humans are confronted with are not fully understood. This partial understanding is reflected in the fact that a rigid algorithmic solution—a routine and predetermined number of computational steps—cannot be applied. Rather, the concept of search is used to solve such problems. When search is used to explore the entire solution space, it is said to be exhaustive. Exhaustive search is not typically a successful approach to problem solving because most interesting problems have search spaces that are simply too large to be dealt with in this manner, even by the fastest computers. Therefore, if one hopes to find a solution (or a reasonably good approximation of a solution) to such a problem, one must selectively explore the problem's search space.

The difficulty here is that if part of the search space is not explored, one runs the risk that the solution one seeks will be missed. Thus, in order to

heuristics procedures that serve to guide investigation but that have not been proven

ignore a portion of a search space, some guiding knowledge or insight must exist so that the solution will not be overlooked. **Heuristics** is a major area of AI that concerns itself with how to limit effectively the exploration of a search space. Chess is a classic example where humans routinely employ sophisticated heuristics in a search space. A chess player will typically search through a small number of possible moves before selecting a move to play. Not every possible move and countermove sequence is explored. Only reasonable sequences are examined. A large part of the intelligence of chess players resides in the heuristics they employ.

A heuristic-based search results from the application of domain or problem-specific knowledge to a universal search function. The success of heuristics has led to focusing the application of general AI techniques to specific problem domains. This has led to the development of expert systems capable of sophisticated reasoning in narrowly defined domains within fields such as medicine, mathematics, chemistry, robotics, and aviation.

Another area that is profoundly dependent on domain-specific knowledge is natural language processing. The ability to understand a natural language such as English is one of the most fundamental aspects of human intelligence, and presents one of the core challenges for the AI community. Small children routinely engage in natural language processing, yet it appears to be almost beyond the reach of mechanized computation. Over the years, significant progress has been made in the ability to parse text to discover its syntactic structure. However, much of the meaning in natural language is context-dependent as well as culture-dependent, and capturing such dependencies has proved highly resistant to automation.

ARTIFICIAL INTELLIGENCE: AI

As technology becomes more common in today's society, many questions are raised regarding its social and moral consequences. Often filmmakers tap into the high-tech market for ideas about family values and virtues. One such effort is Steven Spielberg's 2001 movie *Artificial Intelligence: AI.* The story revolves around David, a human-like robot, and his desire to experience real love and emotions, like other humans. The real question the film poses to its viewers is: Can humans love an artificial being?

The Turing Test

At what point does the behavior of a machine display intelligence? The answer to this question has raised considerable debate over the definition of intelligence itself. Is a computer capable of beating the world chess champion considered intelligent? Fifty years ago, the answer to this question would most likely have been yes. Today, it is disputed whether or not the behavior of such a machine is intelligent. One reason for this shift in the definition of intelligence is the massive increase in computational power that has occurred over the past fifty years, allowing the chess problem space to be searched in an almost exhaustive manner.

Two key ingredients are seen as essential to intelligent behavior: the ability to learn and thereby change one's behavior over time, and synergy, or the idea that the whole is somehow greater than the sum of its parts.

In 1950 British mathematician Alan Turing proposed a test for intelligence that has, to some extent, withstood the test of time and still serves as a litmus test for intelligent behavior. Turing proposed that the behavior of a machine could be considered intelligent if it was indistinguishable from the behavior of a human. In this imitation game, a human interrogator would hold a dialogue via a terminal with both a human and a computer. If, based solely on the content of the dialogue, the interrogator could not distinguish between the human and the computer, Turing argued that the behavior of the computer could be assumed to be intelligent.

Opponents of this definition of intelligence argue that the Turing Test defines intelligence solely in terms of human intelligence. For example, the ability to carry out complex numerical computation correctly and quickly is something that a computer can do easily but a human cannot. Given that, is it reasonable to use this ability to distinguish between the behavior of a human and a computer and conclude that the computer is not intelligent? SEE ALSO Assistive Computer Technology for Persons with Disabilities; LISP; Optical Character Recognition; Robotics; Robots.

Victor L. Winter

Bibliography

Luger, George F., and William A. Stubblefield. *Artificial Intelligence: Structures and Strategies for Complex Problem Solving*. Redwood City, CA: Benjamin/Cummings Publishing Company, 1993.

Mueller, Robert A., and Rex L. Page. *Symbolic Computing with LISP and Prolog*. New York: Wiley and Sons, 1988.

Russel, Stuart J., and Peter Norvig. *Artificial Intelligence: A Modern Approach*. Englewood Cliffs, NJ: Prentice Hall, 1994.

Association for Computing Machinery

The Association for Computing Machinery (ACM) is the world's oldest and largest educational and scientific computing society. It was founded in 1947 by a group of computer pioneers, including American physicist John Mauchly, co-inventor of the first electronic computer. The new professional society would foster the science and art of computing.

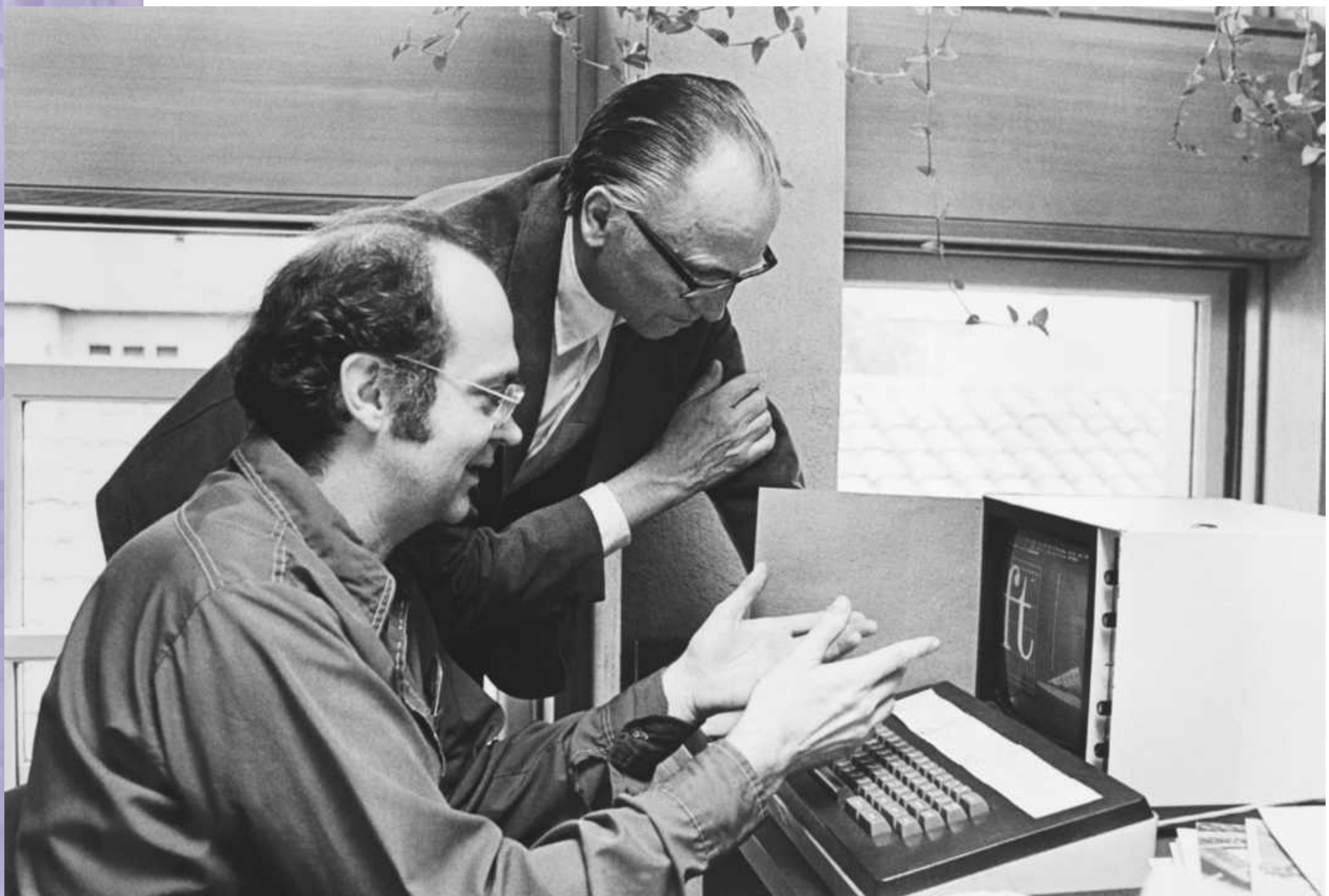
More than half a century later, the ACM is the nucleus for the ever-changing science of information technology. It plays a key role in leveraging the remarkable growth of the profession. Its membership comprises more than 80,000 computing and information technology (IT) professionals and students in more than 100 countries, working in all areas of industry, academia, and government. For its members, the ACM offers a vital forum for the exchange of information, ideas, and discoveries.

Since its inception, the ACM has chronicled the key developments in computer technology through its publications. Each year the ACM formally recognizes the accomplishments of the people responsible for these advances by awarding prizes such as the ACM Turing Award, named after British mathematician Alan Turing, who conceived of a theoretical computing machine in 1936 and thus set the stage for the development of computers in the twentieth century. The Turing Award is one of the leading honors in computing. Its famous recipients include Donald Knuth, author of *The Art of Computer Programming*; LISP creator John McCarthy; UNIX co-inventors Ken Thompson and Dennis Ritchie; mouse developer Doug Engelbart; graphics pioneer Ivan Sutherland; and **artificial intelligence (AI)** expert Raj Reddy. The ACM bestows many other awards for excellence, including the Grace Murray Hopper award, the Allen Newell award, and the Karl V. Karlstrom Outstanding Educator award.

artificial intelligence (AI) a branch of computer science dealing with creating computer hardware and software to mimic the way people think and perform practical tasks

Education and Curriculum Recommendations

A key mission of the ACM is the education of computer and information specialists. Volunteer committees under the Education Board develop and



ACM members Donald Knuth and Herman Zaph worked to design computer typefaces. The organization serves as an outlet to bring together top technological minds throughout the world.

recommend computer curricula for all educational levels and provide self-assessment procedures, home study courses, and professional development seminars for professionals already in the field. Through its participation in the Computer Sciences Accreditation Board, the ACM is instrumental in evaluating and accrediting computer science programs in colleges and universities.

The ACM has won worldwide recognition for its published curriculum recommendations, both for colleges and universities and for secondary schools that are increasingly concerned with preparing students for advanced education in the information sciences and technologies.

Member Products, Services, and Programs

The ACM provides many products and services to its membership. These include student activities, publications, special events, and a digital library, among others.

Student Activities. The ACM's vital electronic community offers high school and college students the opportunity to network with noted computer experts and access a wide range of activities and services, including free searching of its acclaimed Digital Library (located at www.acm.org), the world's largest online resource for information about computing. Students can also take advantage of the many services available at more than 500 ACM student chapters located in colleges, universities, and high schools throughout the United States and worldwide. These local chapters publish their own newsletters and meet regularly to hear lectures and conduct workshops and conferences. Other ACM services for students include networking at conferences, the International Programming contest, and the ACM's *Crossroads* magazine, published by and for students. The ACM has also established many ACM-W (women's) chapters.

ACM Publications. The ACM publishes, distributes, and archives original research and firsthand perspectives from the world's leading thinkers in computing and information technologies. ACM offers more than two dozen publications that help computing professionals negotiate the strategic challenges and operating problems of their work. The ACM Press Books program covers a broad spectrum of interests in computer science and engineering. The ACM also publishes many professional journals, including the *Communications of the ACM*, the *Journal of the Association for Computing Machinery*, *Computing Surveys*, and more than a dozen additional titles.

ACM Events and Services. The ACM is the driving force behind many key events in the computing world, including SIGGRAPH, the annual computer graphics show that attracts tens of thousands of people to see the latest developments in this fast-changing field. Over the years, the ACM has produced such high-profile events as the computer chess match between Garry Kasparov and the IBM Deep Blue computer, and the annual ACM International Collegiate Programming Contest, in which thousands of student teams compete worldwide. It also produces a special exposition and conference every four years dealing with the future of computing. The 1997 event attracted more than 20,000 attendees.

Special Activities. The ACM sponsors scores of special committees, boards, and forums dealing with a wide variety of special topics, including:

- The ACM's Committee on Women in Computing, dealing with all aspects of computing as it affects the lives and careers of women and girls;
- The online *Risks* forum, which deals with risks to the public associated with computers and related systems;
- The Membership Activities Board, which encourages the development of programs that enhance the value of membership in ACM.

The ACM Digital Library. The ACM's Digital Library is the world's most comprehensive online collection of information about the world of computing. It features an archive of journals, magazines, and conference proceedings online, as well as current issues of the ACM's magazines and journals. The ACM's online services included a lively IT-related opinion magazine and forum called *Ubiquity*, and the popular *Tech News* digest containing information about the latest events in the IT world.

Volunteerism and Special Interest Groups (SIGs). The ACM is built on a strong base of volunteerism. Volunteers serve on the ACM Council, boards, committees, task forces, and other subgroups that comprise ACM's governing structure. They are also at the heart of the ACM's 37 Special Interest Groups (SIGs), each covering a defined computing discipline. **SIGs** write their own newsletters and are governed by their own elected officers. SIGs come in many forms, including Electronic Forums, which promote

SIGs short for "Special Interest Groups," SIGs concentrate their energies on specific categories of computer science, such as programming languages or computer architecture the electronic exchange of ideas and information about one special interest area; Conference SIGs, which produce ongoing technical meetings and conferences; Newsletter SIGs, and so on.

ACM Fellows. The ACM Fellows Program was established by the ACM's Council in 1993 to recognize and honor outstanding ACM members for their achievements in computer science and information technology and for their significant contributions to the mission of the ACM. The ACM Fellows serve as distinguished colleagues to whom the ACM and its members look for guidance and leadership as the world of information technology evolves. More than 300 people have been recognized as ACM Fellows.

Code of Ethics

The ACM has developed a code of ethics for its members based on the following seven major tenets:

1. Contribute to society and human well-being.
2. Avoid harm to others.
3. Be honest and trustworthy.
4. Be fair and take action not to discriminate.
5. Honor property rights including copyrights and patent.
6. Give proper credit for intellectual property.
7. Respect the privacy of others.

SEE ALSO INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS (IEEE); TURING, ALAN M.

Christopher Morgan

Bibliography

Peterson, Tommy. "Connecting IT and Society." *Computerworld Magazine.* August 23, 2001. <http://www.computerworld.com>

Babbage, Charles

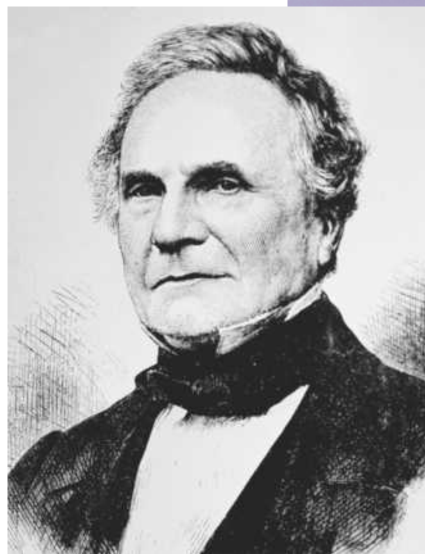
British Inventor and Mathematician
1791–1871

A mathematician, philosopher, and inventor, Charles Babbage is best remembered for his concept of the Analytical Engine—a calculating machine that was not actually built during his lifetime.

Being born into a wealthy family on December 26, 1791 allowed Babbage to pursue his interests free from financial worries through most of his life. The oldest child of a successful Devonshire banker, Babbage spent the greater part of his early childhood relieved of study due to poor health. Deprived of formal study, the young Babbage used experiments to find answers to his questions. For example, he would take toys apart to see what was inside. On another occasion, he tried, unsuccessfully, to summon the devil to confirm the creature's existence. His failure to do so led him to reason that devils and ghosts were not real.

Babbage's formal education began at a boarding school in London, England. Algebra interested him to such an extent that he and another student would wake at 3 A.M. to study for a few hours. In 1814 Babbage entered Cambridge University to study mathematics. As a result of his late-night algebra studies and knowledge of European mathematical advances, he knew more than his tutors. Babbage and his equally mathematically talented friends, John Herschel and George Peacock, formed the Analytical Society to promote European mathematics as a more advanced subject than the mathematics of English physicist Isaac Newton (1642–1727). On the lighter side, he joined friends to form the Ghost Club.

Upon completing a master of arts, Babbage continued to work for mathematical reform through the translation of a paper by Sylvestre François Lacroix. This and further works on calculus were recognized by Cambridge University in 1828 when Babbage was elected as Lucasian Professor of Mathematics. During his ten years as professor, Babbage gave no lectures; however he participated in the examination of students for the Smith prizes given for excellence in mathematics.



Charles Babbage.

A major outcome of his mathematical studies was the idea for a calculating machine—the Difference Engine—which would calculate and print numbers in a sequence based on the principle of differences. The sequences of the calculations can be described by a theorem or as a **polynomial** and the succeeding values are calculated by addition and subtraction rather than by multiplication. The Difference Engine produced tables of **logarithmic** and **trigonometric** functions to six decimal places. This machine would have a mechanical memory and the capability of producing printed tables. To get funding to build a large Difference Machine, Babbage used a small working model to demonstrate the machine's potential to the British government. The machine was designed to a second-order difference and six decimal places. All parts of the machine were hand tooled or cast. Babbage built a foundry and forge on his land to facilitate and oversee the creation of the components.

polynomial an expression with more than one term

logarithmic refers to the power to which a certain number called the base is to be raised to produce a particular number

trigonometric refers to functions that define the relationships between an angle and two sides of a triangle, e.g., sine, cosine, etc.

In 1824 Babbage was awarded a grant to build his machine. As work progressed on the machine, he was making changes on the design and eventually scrapped the original model for a more complex one, the Analytical Engine. He again petitioned the government for more funding but was denied. Despite the lack of funding, he continued to design and construct parts for the Analytical Engine using his own funds.

The Analytical Engine design incorporated the following functions. Variables and detailed instructions would be read into the machine from punched cards. These cards were based upon the card coding method used in Jacquard weaving. The variables would be placed in a 'store,' memory, as would intermediate calculations. The 'mill,' processor, would carry out the instructions thereby performing the calculations. Based on calculation results, the engine could determine which instruction should be used next. Babbage had developed a decision function. The results would be printed out. This design has all the characteristics of a computer.

Despite his accomplishments, Babbage could not get financial support for the Analytical Engine and did not have the resources to complete a working model. He did leave detailed drawings for the internal mechanism and notes for the design and construction.

In the early 1840s, Babbage came in contact with Ada Byron King, Countess of Lovelace, a female contemporary mathematician and theoretician. Lovelace had translated a summary of Babbage's achievements from an original Italian account. When she showed Babbage her translation, he suggested that she add her own notes, which turned out to be three times the length of the original article. Letters between Babbage and Lovelace raced back and forth. When Lovelace eventually published the article in 1843, it included her predictions that Babbage's machine might be used to compose complex music and to produce graphics, and it might be used for both practical and scientific use. She was correct. It was Lovelace who also suggested to Babbage the idea of writing a plan on how his engine might calculate **Bernoulli numbers**. This plan is now regarded as the first "computer language."

Bernoulli numbers the sums of powers of consecutive integers; named after Swiss mathematician Jacques Bernoulli (1654–1705)

When not completely involved with the calculating engines, Babbage turned his attention to other pursuits. He was avidly interested in all kinds of statistics, from the heartbeat of a pig, to the quantity of wood that a man could saw in a specific amount of time. Babbage would put himself into danger to learn more. Once he spent time in a large drying machine to test the human body's reaction to heat. On another occasion, he spent five to six minutes inside a 129°C (265°F) oven, noting his pulse and the quantity of his perspiration. Another venture was to explore the inside of an active volcano. Babbage descended into Italy's Mount Vesuvius to observe the occurrence of mini eruptions. Having determined that the time between eruptions was about ten minutes, Babbage proceeded to descend further and closer to the eruption site to see liquid lava and note its movement. He remained for six minutes allowing four minutes to retreat from his position before the next eruption.

THE COWCATCHER

In 1830 Babbage was a passenger on the opening run of the Manchester and Liverpool railroad line. His interest in rail travel led to the invention of the cowcatcher. This plow-shaped device was mounted on the front of the steam engine for the purpose of rapidly removing any obstruction on the rails, particularly cows.

In 1837 Babbage conducted experiments which determined that the Brunel wide gauge track (railway) was safer and more efficient than narrower gauge tracks. Plus, his calculations of mail delivery showed that the most costly aspect of the mailing process was the distance traveled, and not the time or labor involved. This analysis resulted in the introduction of uniform postal rates.

Babbage's book, *Economics of Manufactures and Machinery*, set out the mathematics for the manufacturing processes. The book became a basis for operations research. Babbage published numerous papers covering a wide range of topics, from science to religion. He founded the British Association's Statistical Society and the British Association for the Advancement of Science; was elected a fellow of the Royal Society; and was a member of the Astronomical Society. Babbage's *The Ninth Bridgewater Treatise* details his ideas that science could explain religion. Babbage died in London on October 18, 1871. SEE ALSO Analytical Engine; Lovelace, Ada Byron King, Countess of.

Bertha Kugelman Morimoto

Bibliography

Morrison, Philip, and Emily Morrison, eds. *Charles Babbage and his Calculating Engines.* New York: Dover Publishing Inc., 1961.

Internet Resources

Charles Babbage Institute. <http://www.cbi.umn.edu/exhibits/cb.html>

The Babbage Pages. <http://www.ex.ac.uk/BABBAGE/welcome.html>

Bell Labs

Bell Telephone Laboratories, Inc. was founded in 1925 as the research and development (R&D) branch of the Bell System. Until the early 1990s, Bell Labs was owned and supported by AT&T, the Bell System's parent company, and by the Western Electric Company (WECo), the Bell System's manufacturing branch, which was owned by AT&T. WECo paid the salaries of Bell Labs personnel who developed new products that WECo manufactured; AT&T paid the salaries of Bell Labs personnel who performed research and systems engineering (R&SE). The Bell System's customers provided R&SE revenue via their monthly telephone bills, and Bell Labs systems engineers ensured that the United States had the world's best telephone system.

transistor a contraction of TRANSfer resISTOR; semiconductor device, invented by John Bardeen, Walter Brattain, and William Shockley, which has three terminals; can be used for switching and amplifying electrical signals

automata theory the analytical (mathematical) treatment and study of automated systems

The research performed at Bell Labs was the world's best, especially between the 1940s and the 1970s. Over the years, many Bell Labs employees received prestigious awards in their fields, including a number of Nobel Prizes. During the three decades that followed the 1947 invention of the **transistor** at Bell Labs, scientists and engineers at Bell Labs contributed many other advances to the technologies that underlie digital communications and digital computing—electronics, magnetic and semiconductor memories, digital circuit design, and integrated circuits.

Although federal regulation precluded AT&T from participating in the commercial computer industry until the 1980s, Bell Labs personnel also contributed directly and significantly to computer architecture and software science—partly to find better ways to control telephone switching systems and partly through basic research. Bell Labs researchers contributed to digital design, **automata theory**, databases, operating systems, programming languages, coding, speech processing, and other fields of computer science.

Early Computing and Bell Labs

An early computer was built at Bell Labs in the late 1930s using electro-mechanical relays. This research project was a generalization of the special-purpose computers called markers that controlled telephone calls. Markers were used from the 1930s to the 1950s in the electro-mechanical telephone systems that were manufactured by WECo and operated by the Bell System's telephone companies. An even more significant contribution to computing came in the 1960s with a telephone switching system called the No. 1 Electronic Switching System (1E).

During the early 1960s, three significant commercial software systems were developed concurrently at different places in the United States: the first database (for airline reservations), the first operating system (for IBM's 7090 computer), and the first real-time process control software (at Bell Labs, for the 1E). Software similar to that found in the 1E thirty years ago still controls factories and operates automobile engines.

During the 1970s and 1980s, the Unix operating system was developed at Bell Labs. Even though AT&T could not sell computer products like operating systems, Unix became popular anyway because it was adopted at many universities.

BELL'S FAMED EMPLOYEES

Many famous scientists and engineers have been employed at Bell Labs. They have contributed to many branches of science: physics, chemistry, electronics, cognition, communications, computing, and even cosmology. Among the famous computer scientists who worked at Bell labs were Ed Moore, who contributed to automata theory, and Dick Hamming, who developed error-correcting codes. Unix was developed by a group of computer scientists including Brian Kernighan, Dennis Ritchie, and Ken Thompson. But perhaps the most remarkable scientist who ever worked at Bell Labs was Claude Shannon (1916–2001), who (besides his famous work on "Information Theory") proved that any digital function could be implemented using only two levels of elementary logic operations. Since this theory underlies modern digital design using electronic and-gates and or-gates, Shannon could be called the father of digital design.

Scientists at Bell Labs created an anechoic chamber in 1940 designed to eliminate echoes and reverberations. Here, they began testing advances in audio (sound) components and other technologies.

In the early 1980s, the Bell System was broken up, with a dramatic effect on Bell Labs. Since Bell Labs (and WECo) remained with AT&T, a new R&D company called Bell Communications Research (Bellcore) was created for the seven new "Baby Bells" (Ameritech, Bell Atlantic, Bell South, Nynex, PacTel, Southwest Bell, and US West). Many Bell Labs personnel were transferred to Bellcore before Bellcore split from Bell Labs in 1984.

Afterward, the phone companies' R&SE revenue went to Bellcore, and R&D at Bell Labs (now supported fully by WECo) gradually became more product-oriented. In the 1990s Bellcore's seven owners sold their R&D company, now called Telcordia, and AT&T split up again. WECo was divested as a separate company, called Lucent, and since Bell Labs went with Lucent, AT&T formed a new internal R&D division, called AT&T Labs. Some Bell Labs personnel were transferred to AT&T Labs before that split occurred.

Now the remnants of Bell Labs are spread across three different companies, one of which still uses the Bell Labs name. Although all three companies still perform outstanding R&D, the golden age of Bell Labs research is over. SEE ALSO Shannon, Claude E.; Telecommunications; Transistors.

Richard A. Thompson

Bibliography

Brooks, John. *Telephone: The First Hundred Years.* New York: Harper & Row, 1976.

Schindler, G. E. *A History of Engineering and Science in the Bell System.* New York: Bell Telephone Laboratories, 1982.

Thompson, Richard A. *Telephone Switching Systems.* Boston: Artech House, 2000.

Binary Number System

The binary number system, also called the **base-2** number system, is a method of representing numbers that counts by using combinations of only two numerals: zero (0) and one (1). Computers use the binary number system to manipulate and store all of their data including numbers, words, videos, graphics, and music.

The term bit, the smallest unit of digital technology, stands for "BInary digiT." A byte is a group of eight bits. A kilobyte is 1,024 bytes or 8,192 bits.

Using binary numbers, 1 + 1 = 10 because "2" does not exist in this system. A different number system, the commonly used decimal or **base-10** number system, counts by using 10 digits (0,1,2,3,4,5,6,7,8,9) so 1 + 1 = 2 and 7 + 7 = 14. Another number system used by computer programmers is the hexadecimal system, **base-16**, which uses 16 symbols (0,1,2,3,4,5,6,7,8,9,A,B,C,D,E,F), so 1 + 1 = 2 and 7 + 7 = E. Base-10 and base-16 number systems are more compact than the binary system. Programmers use the hexadecimal number system as a convenient, more compact way to represent binary numbers because it is very easy to convert from binary to hexadecimal and vice versa. It is more difficult to convert from binary to decimal and from decimal to binary.

The advantage of the binary system is its simplicity. A computing device can be created out of anything that has a series of switches, each of which can alternate between an "on" position and an "off" position. These switches can be electronic, biological, or mechanical, as long as they can be moved on command from one position to the other. Most computers have electronic switches.

When a switch is "on" it represents the value of one, and when the switch is "off" it represents the value of zero. Digital devices perform mathematical operations by turning binary switches on and off. The faster the computer can turn the switches on and off, the faster it can perform its calculations.

Positional Notation

Each numeral in a binary number takes a value that depends on its position in the number. This is called positional notation. It is a concept that also applies to decimal numbers.

For example, the decimal number 123 represents the decimal value 100 + 20 + 3. The number one represents hundreds, the number two represents tens, and the number three represents units. A mathematical formula for generating the number 123 can be created by multiplying the number in the hundreds column (1) by 100, or 10^2; multiplying the number in the

base-2 a number system in which each place represents a power of 2 larger than the place to its right (binary)

base-10 a number system in which each place represents a power of 10 larger than the place to its right (decimal)

base-16 a number system in which each place represents a power of 16 larger than the place to its right (hexadecimal)

Binary Number System	Decimal Number System	Hexadecimal Number System
0	0	0
1	1	1
10	2	2
11	3	3
100	4	4
101	5	5
110	6	6
111	7	7
1000	8	8
1001	9	9
1010	10	A
1011	11	B
1100	12	C
1101	13	D
1110	14	E
1111	15	F
10000	16	10

Each of these three number systems has a different way of representing numbers. The binary number system is simplest and fastest for computers.

> **YIN AND YANG**
>
> Some historians believe that the binary number system has its roots in the concept of *yin* and *yang*—the ancient Confucian belief in two forces of nature that are separate, yet equal, which when combined represent the whole of existence. In the Chinese language, *yang* is represented as a solid line, whereas *yin* is shown as a broken line. As with the binary numbers of "1" and "0," the symbols for *yin* and *yang* can be combined to make many more characters.

tens column (2) by 10, or 10^1; multiplying the number in the units column (3) by 1, or 10^0; and then adding the products together. The formula is: $1 \times 10^2 + 2 \times 10^1 + 3 \times 10^0 = 123$.

This shows that each value is multiplied by the base (10) raised to increasing powers. The value of the power starts at zero and is incremented by one at each new position in the formula.

This concept of positional notation also applies to binary numbers with the difference being that the base is 2. For example, to find the decimal value of the binary number 1101, the formula is $1 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 13$.

Binary Operations

Binary numbers can be manipulated with the same familiar operations used to calculate decimal numbers, but using only zeros and ones. To add two numbers, there are only four rules to remember:

$$0 + 0 = 0$$

$$0 + 1 = 1$$

$$1 + 0 = 1$$

$$1 + 1 = 10$$

Therefore, to solve the following addition problem, start in the rightmost column and add 1 + 1 = 10; write down the 0 and carry the 1. Working with each column to the left, continue adding until the problem is solved.

$$\begin{array}{r} 10101 \\ \underline{+\ 101} \\ 11010 \end{array}$$

To convert a binary number to a decimal number, each digit is multiplied by a power of two. The products are then added together. For example, to translate the binary number 11010 to decimal, the formula would be as follows:

Binary	1	+	1	+	0	+	1	+	0		
Formula	(1×2^4)	+	(1×2^3)	+	(0×2^2)	+	(1×2^1)	+	(0×2^0)	=	
Decimal	16	+	8	+	0	+	2	+	0	=	26

To convert a binary number to a hexadecimal number, separate the binary number into groups of four starting from the right and then translate each group into its hexadecimal equivalent. Zeros may be added to the left of the binary number to complete a group of four. For example, to translate the number 11010 to hexadecimal, the formula would be as follows:

Binary	0001	1010	
Formula	0001=1	1010=A	
Hexadecimal			= 1A

Digital Data

analog a quantity (often an electrical signal) that is continuous in time and amplitude

Bits are a fundamental element of digital computing. The term "digitize" means to turn an **analog** signal—a range of voltages—into a digital signal, or a series of numbers representing voltages. A piece of music can be digitized by taking very frequent samples of it, called sampling, and translating it into **discrete** numbers, which are then translated into zeros and ones. If the samples are taken very frequently, the music sounds like a continuous tone when it is played back.

discrete composed of distinct elements

A black and white photograph can be digitized by laying a fine grid over the image and calculating the amount of gray at each intersection of the grid, called a **pixel**. For example, using an 8-bit code, the part of the image that is purely white can be digitized as 11111111. Likewise, the part that is purely black can be digitized as 00000000. Each of the 254 numbers that fall between those two extremes (numbers from 00000001 to 11111110) represents a shade of gray. When it is time to reconstruct the photograph using its collection of binary digits, the computer decodes the image, assigns the correct shade of gray to each pixel, and the picture appears. To improve resolution, a finer grid can be used so the image can be expanded to larger sizes without losing detail.

pixel a single picture element on a video screen; one of the individual dots making up a picture on a video screen or digital image

A color photograph is digitized in a similar fashion but requires many more bits to store the color of the pixel. For example, an 8-bit system uses eight bits to define which of 256 colors is represented by each pixel (2^8 equals 256). Likewise, a 16-bit system uses sixteen bits to define each of 65,536 colors (2^{16} equals 65,536). Therefore, color images require much more storage space than those in black and white. SEE ALSO Early Computers; Memory.

Ann McIver McHoes

Bibliography

Blissmer, Robert H. *Introducing Computer Concepts, Systems, and Applications.* New York: John Wiley & Sons, Inc., 1989.

Dilligan, Robert J. *Computing in the Web Age: A Web-interactive Introduction.* New York: Plenum Press, 1998.

White, Ron. *How Computers Work: Millennium Edition.* Indianapolis: Que Corporation, 1999.

Census Bureau

The U.S. Census Bureau has a long history in the United States of America. The Census Bureau collects data about the people and economy of the United States every ten years. The first census was taken in 1790 by U.S. marshals who were told to visit every dwelling place and count the individuals living there. Taking about a year to complete the count, census clerks determined the population to be 3.9 million inhabitants.

As the country grew, an increasing need developed for statistics to help the government understand the current situation and to make plans for the future. The content of the census changed accordingly. In 1810 the first inquiry about manufacturing was included; questions about fisheries were added in 1840. In 1850 the census included questions about crime, taxation, churches, and other social issues. In 1870 the Census Bureau used a wooden machine invented by Col. Charles W. Seaton to help keep the columns of figures aligned. By 1880, the census undertaking was so complex that it took almost eight years to tabulate.

punched card a paper card with punched holes which give instructions to a computer in order to encode program instructions and data

American inventor Herman Hollerith (1860–1929) was employed by the U.S. Census Bureau to help tabulate the 1880 census. He left the Census Bureau for a succession of jobs and eventually he devised a **punched card** tabulating machine to track health statistics. After testing Hollerith's machine against two other inventions, the Census Bureau agreed to rent 56 Hollerith machines to speed up the tabulation of the 1890 census. Clerks used a hand punch to enter data into cards slightly larger than a dollar bill. The cards were then read and sorted by Hollerith's machine and summarized on numbered tabulating dials. The 1890 census took just two and a half years to complete and the Census Bureau saved more than $5 million.

Many researchers believe that the 1890 census was the first time that a large data collection and analysis problem was handled by machines. Because of the agency's need to process large amounts of data in a timely and cost-efficient fashion, the Census Bureau has been in the forefront of the data processing revolution.

The Census Bureau was instrumental in securing funding for John Mauchly and J. Presper Eckert, Jr., through the National Bureau of Standards, to develop a practical electronic digital computer. In 1951 the Census Bureau installed the Universal Automatic Computer (UNIVAC) I, which was developed by Mauchly and Eckert's company, Remington-Rand Corporation. It was the first commercially viable electronic digital computer.

Use of the UNIVAC I computer to tabulate the 1950 census did not yield great improvement over past tabulating methods, due to general inexperience with the computer and the awkwardness of this early computer technology. However, several surveys were tabulated using the UNIVAC I computer after the 1950 census. Improved performance on these surveys indicated to the bureau that increased use of electronic computing technology would continue to enhance survey productivity and expand the Census Bureau's ability to collect new types of data.

With the 1954 Economic Census, use of the electronic computer greatly reduced the bureau's reliance on the time-consuming and manually intensive punched card tabulating machines that had been in place since 1890. The new computer-based data processing system allowed the bureau to calculate sophisticated statistics that were previously impractical to use. The UNIVAC I computer also allowed the bureau to check for inconsistencies in the census data and correct them, thereby increasing accuracy. The electronic computer allowed longer records to be stored, sorted, and tabulated, which greatly increased the amount and types of data that could be analyzed. From this point, the Census Bureau focused much of its research and development efforts on auxiliary computer equipment to improve input and output operations and thus increase productivity.

The Census Bureau has developed a wide range of interactive tools to help people analyze and understand the statistics generated by the bureau. For example, the Data Extraction System (DES) is used to extract data from the current population survey and public use census data. DES is now available via the Internet, as are many other access and analysis tools. The TIGER system is another analysis and application tool; it integrates maps with information about highways, parks, railroads, streets, and population statistics. When a user enters a ZIP code, a map is displayed. The user can request various levels of detail, as desired. The CenStats system, also available to

U.S. Census Bureau workers compile information based on census results. The government uses the results to provide certain programs and services based on population patterns.

Internet users, makes a variety of applications available, including a street locator, business patterns for each county, surveys of manufacturers, international trade information, and more.

The U.S. Census Bureau is the only comprehensive, statistical source of social and economic data in the United States. The huge volume of data from the census is published and the statistics that are generated filter into almost every aspect of life in the United States.✶ Population statistics are used to help determine each state's number of seats in the House of Representatives, funding for school districts, and money for road and bridge repairs. Census numbers are used by the federal government to allocate more than $100 billion each year for education programs, housing and community development, health-care services for the elderly, and other programs and services. Businesses use the statistics to decide where to locate factories, shopping malls, movie theaters, banks, and offices.

✶The 1997 Current Population Survey by the Census Bureau indicates that in 1997, some 37.4 million households (36.6 percent of the American population) owned a computer.

Some people are concerned that the individual answers they provide in a census can be seen by others. However, by law, confidentiality in census information is rigorously enforced. Individual answers cannot be shared with anyone, including other government agencies.

Since the first census in 1790, the U.S. Census Bureau has been a source of data about who we are, where we live, and what we need to do to grow and prosper as a country. The bureau has been instrumental in developing new ways to collect, analyze, and distribute this data—first, through the use of mechanized tabulating machines, then through computer technology, and now through the Internet. SEE ALSO EARLY COMPUTERS; ECKERT, J. PRESPER, JR., AND MAUCHLY, JOHN W.; HOLLERITH, HERMAN; TABULATING MACHINES.

Terri L. Lenox

Bibliography

Shurkin, Joel. *Engines of the Mind: The Evolution of the Computer from Mainframes to Microprocessors.* New York: W. W. Norton & Company, 1996.

Internet Resources

The Census Bureau. <http://www.census.gov>

Computer Fraud and Abuse Act of 1986

Many years ago, no laws existed to regulate the speed of the revolutionary invention called the "automobile." Likewise, in the early days of computing, no laws existed to regulate the usage of computers. Laws are created to respond to social problems, but, at the early stages of those great inventions, there were no social problems regarding computers that required the creation of laws. In the 1970s and early 1980s, users of business computers were generally operating networked computers in a highly supervised and controlled employment setting. Computer hobbyists and home users were generally limited to computers that were neither as technologically advanced as business computers, nor as interactive or inter-connected with other computers.

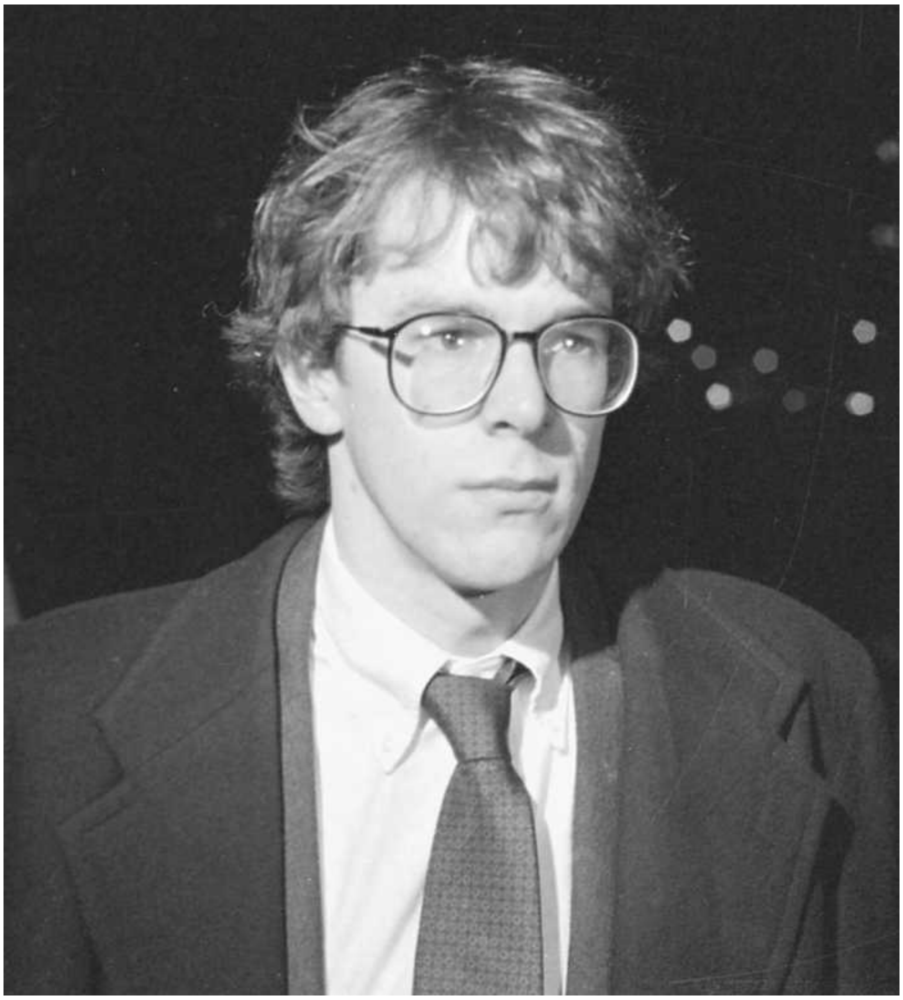
By the mid-1980s, however, technological advances brought personal computers into widespread use in homes, high schools, colleges, and businesses. **Interconnectivity** of computers via telephone lines and modems grew rapidly. Valuable, often confidential, information could now be stored on systems that were increasingly vulnerable to outside interference. The personal computer revolution had reached a stage similar to that achieved by automobiles earlier in the twentieth century: There were now scores of them, they were capable of going fast, and people were starting to speed. Society demanded the creation of rules for the electronic road.

Interconnectivity the ability of more than one physical computer to operate with one or more other physical computers; interconnectivity is usually accomplished by means of network wiring, cable, or telephone lines

Legislating Computer Activity

The United States Computer Fraud and Abuse Act of 1986 (referred to in this article as the "Act") was an amendment to the Counterfeit Access Device and Computer Fraud and Abuse Act of 1984 (the "1984 Act"). It was the first comprehensive legislation in the United States to identify and provide for the prosecution of crimes committed through and against computer systems.

The 1984 Act was limited in scope and provided for only three categories of computer-related crime: (1) unauthorized access to and use of certain federal data; (2) unauthorized access to or use of consumer credit-related information; and (3) unauthorized access to a computer used for, or on behalf of, the U.S. government. Thus, the 1984 Act only addressed crimes re-



The first person convicted under the Act was Robert Morris, a student at Cornell University. His Internet worm, though not malicious, crashed many computer systems.

lated to government computers, as well as government data and consumer credit data. Because of its limited scope, the 1984 Act was amended and superseded in 1986. The new Act was the first comprehensive federal legislation regarding computer crimes that affected non-government computers, as well.

Offenses and Penalties

The centerpiece of the Act was the creation of the concept of the "federal interest computer." Under the Commerce Clause of Article 8 of the U.S. Constitution, the government has the right to regulate commerce between or among the several states. The government exercised this power to make it a crime if an unauthorized act occurred with a "federal interest computer," the definition of which includes one of two or more computers not in the same state, even if the computers and data accessed were not owned by, or related to, the government. This means that, for the first time, unauthorized access to virtually any Internet connected computer could be a federal crime.

It became illegal if someone knowingly or intentionally, and without authorization, attempted to:

1. Obtain protected information relating to national defense or foreign relations;
2. Obtain financial information;
3. Access a government-related computer;
4. With the intent to defraud, access a federal interest computer and obtain anything of value;
5. Access a federal interest computer and alter, damage, or destroy information or prevent the authorized use of the computer or information, if the resulting loss is $1,000 or more or if the information relates to medical records;
6. Traffic in passwords with the intent to defraud.

Penalties for violation of the Act included fines as well as prison terms as long as ten years. Prison terms could more than double for subsequent convictions, which is the result of amendments to the Act as contained in the National Information Infrastructure Protection Act of 1996.

Necessity of the Act

To understand why the Act became necessary, one must study the then-current state of the computer industry. In 1965 Digital Equipment Corporation (DEC) introduced the PDP-8, the first commercially successful "mini-computer," which despite its name was large enough to require its own room and air conditioner. It was marketed to large enterprises, sparking a new era in business computing. In 1977 three mass-market personal computers opened up the consumer market: The Apple II, the Radio Shack TRS-80, and the Commodore PET. These computers were generally affordable but were purchased primarily by hobbyists for games and simple programming activities.

In 1981 IBM Corporation introduced its personal computer—the IBM-PC. Because of IBM's significant size and presence in the marketplace, it was uniquely able to mass-market and mass-produce personal computer hardware and software at a reasonable price. IBM had earned a reputation in the business community for traditional business machines, and other businesses became comfortable following IBM's lead in the new industry. From a technical perspective, and quite importantly, IBM allowed other companies to create products such as software, modems, and printers, that would work with IBM personal computers. This was sometimes called an "open architecture" and thus provided consistent and predictable standards required by the business community. Apple Computer, Inc., by comparison, did not have an open architecture for its computer hardware. By 1986, barely five years after the IBM-PC had been introduced, personal computers were being used for mainstream business purposes, and the computing power that had once been available to large businesses was now accessible to classrooms and homes, as well.

INTELLECTUAL PROPERTY

Intellectual property is something that the law recognizes as existing and capable of ownership, but which is not physical in its nature. The four common intellectual properties are patents, copyrights, trademarks, and trade secrets. Depending upon its purpose, function, and use, a computer software product can be or contain any combination of the four intellectual properties.

The Act Becomes Law

In the 1980s, because personal computers were so new, knowledge of computer programming techniques was primarily in the hands of people of high school and college age, who were the first to adopt and be formally trained in the new technology. As a result, for the first time, sophisticated computer systems containing sensitive economic, military, and other types of confidential information became uniquely vulnerable to the technological pranks, curiosities, and experiments of relatively young high school and college students. Existing laws were no longer adequate to address the trespassing and theft that could occur with the new technologies: Using a computer, a person could now perform a million crimes in a split-second, take something that is valuable even if it is not tangible, perform the act without actually being there physically or leaving any tangible evidence, and perform the act on any other computer anywhere in the world.

It was time for the U.S. Congress to begin debating the metes and bounds of what would become known as "intellectual property" in the vast new virtual territory called "cyberspace." The result was the U.S. Computer Fraud and Abuse Act of 1986, which continues to provide the foundation for prosecuting those whose actions breach the accepted standards of privacy and security in the world of electronic communication.

The Morris Worm

The first person convicted of violating the Federal Computer Fraud and Abuse Act of 1986 was Robert T. Morris, a Harvard graduate and grad student in Cornell University's computer science Ph.D. program. He was found guilty of distributing an Internet worm. Morris was working on a computer program to demonstrate security flaws on computer networks. On November 2, 1988, he anonymously released a self-replicating computer program, also known as a "worm," on to the Internet from a computer he was authorized to use at the Massachusetts Institute of Technology. The worm was not intended to interfere with normal computer operations. It consisted of two parts: a "probe" and a "corpus." The probe attempted to penetrate computers through flaws in network security systems, and if successful, compiled itself on the host computer and then sent for its corpus.

Despite the precautions Morris tried to build into the worm, which was not intended to cause malicious harm, as many as 6,000 computers (six percent of all computers on the Internet at the time) were infected within hours of the worm's release, causing widespread computer failure. When Morris discovered what was happening, he sent an anonymous message over the Internet instructing programmers how to kill the worm. But, the Internet routes were so clogged by his worm replication that the message did not get through in enough time to be meaningful.

Despite much debate to determine whether Morris intended to cause harm, it was ultimately decided that he intended unauthorized access, and that was enough for a conviction under the Act. Morris was sentenced to three years of probation, fined $10,000 plus the costs of probation, and ordered to perform 400 hours of community service. U.S. Attorney Frederick J. Scullin, Jr. commented: "Among other things, the *Morris* case should put the would-be hacker on notice that the Department of Justice will seek severe penalties against future computer criminals, whether or not they are motivated by a venal or malicious intent." SEE ALSO Association of Computing Machinery; Security.

Gregg R. Zegarelli

PROBE AND CORPUS

A probe is a computer program that operates on its own but is intended to operate with another (generally a larger and principal) computer program, and the purpose of which is to perform some preliminary inquisitive technical matter and report the result thereof to the other principal computer program with which it operates. The corpus is the principal portion of a computer program (or group of computer programs intended to operate together) that may or may not be capable of operating in a self-sufficient manner, but usually intended to operate in conjunction with a probe or other minor computer software product.

VIRUSES AND WORMS

The term "virus" is often used generically to identify any harmful migrating computer program. However, more strictly defined, a "worm" is a program that travels from one computer to another, usually over a network, but does not attach itself to the operating system of the computer it "infects." It replicates itself until the host computer runs out of memory or disk space. A "Trojan horse" is a piece of computer software that acts like it has a benign purpose, but is actually performing an ulterior malicious command, such as erasing files. A "virus" insidiously attaches itself to the operating system of any computer it enters and can infect any other computer that uses files from the infected computer.

Bibliography

Computer Basics. Understanding Computers Series. New York: Time-Life Books, 1989.

Computer Fraud and Abuse Act, P.L. 98–473, Title II, Section 2102, 98 Stat. 2190, October 12, 1984, as amended by P.L. 99–474, 100 Stat. 1213, October 16, 1986; 18 U.S.C. Chapter 47, Section 1030.

Gemignani, Michael C. *Computer Law.* Rochester, NY: Lawyers Co-operative Publishing, 1991.

Computer Scientists

The title "computer scientist" encompasses a variety of jobs in which people work to design computers and to discover new applications for them. Their work often involves using theory, research, and scientific concepts to solve problems. A strong background in computer science, mathematics, or a similar scientific area is necessary to work in the field.

Computer usage has expanded dramatically due to the development of the Internet, faster processors, cheaper prices, and better user interfaces. As a result, computers can be found in homes, companies, and educational institutions. They are used for business, scientific, and artistic applications. These applications have become increasingly complex, requiring sophisticated software and very fast processors. Computer scientists create the software and hardware products and concepts that fuel this technological progress.

Some computer scientists choose to work with hardware and explore new chip designs or design and build internal components that make computers work faster and more efficiently. Other computer scientists may specialize in creating new programming languages and writing software that expands the way people use computers. Because the process of creating software has become more complex, there is also a need for computer scientists to create better software development tools to assist programmers in writing error free computer code.

Today, computers are linked so that they can communicate with each other. These networks of computers may be small and occupy an office building, or they may be very large, as the Internet is. Computer scientists develop and test new methods for designing networks and improving the speed of transmitting data, voice, images, and video. Wireless networks similar to the ones used to provide cellular telephone communication have increased in popularity; their widespread use presents many technical challenges for computer scientists.

As computers become more powerful, computer scientists look for ways to help people interact with them more easily. Research is being done to increase the ability of computers to respond to voice commands as well as keyboard commands. This is a demanding task for computers and the effort requires computer scientists with specialized backgrounds in mathematics, software engineering, linguistics, and hardware design.

robotics the science and engineering of building electromechanical machines that aim to serve as replacements for human laborers

Robotics is another area in which computer scientists conduct research. Robots have a variety of uses in industrial, manufacturing, and medical areas. Robots present special challenges since they integrate computer tech-

The field of computer science offers scores of jobs for those interested in working with computers. This system management professional uses a variety of computers in his daily work.

nology with mechanical movement. Computer scientists specializing in robotics usually work in teams with professionals who have expertise in engineering and physics.

Knowledgeable professionals are also needed to help computer users learn to operate and work effectively with various hardware and software, and also to help workers solve problems that arise. In this consulting capacity, computer scientists play an important role.

There are many other areas, including database design, information retrieval, simulation, and modeling, in which computer scientists perform research and develop their ideas into product prototypes.

Education, Skills, and Job Outlook

Computer research scientists generally need to have a college degree and in most cases they also need an advanced degree due to the complexity of their work. They need to think logically and apply scientific theory to real world problems. Hardware and software designers who work on discovering new ways to use computers must be creative and possess an innovative style of thinking. Computer scientists often work as part of a team, so they need good communication skills. Because the field of computer science changes rapidly, computer scientists are always updating their skills and staying abreast of new developments. They read scientific

COMMON BOND

Computer scientists may work in different areas. However, they all work with scientific theory to solve complex computer problems with new and innovative techniques.

journals, attend conferences, and enroll in professional development classes.

A strong demand exists for computer scientists because computer usage is now so common at home, at work, and at school. Computer scientists can work at universities, companies, or research centers. They spend a large amount of time working with the computer and may work in an office or a laboratory. Because they need to stay current with changes in technology, they may find their jobs require some travel to attend conferences, trade shows, and training seminars. SEE ALSO Association of Computing Machinery; Institute of Electrical and Electronics Engineers (IEEE); National Aeronautics and Space Administration (NASA); Robotics.

Robert R. Perkoski

Bibliography

Bird, Drew, and Mike Harwood. *Information Technology Careers: The Hottest Jobs for the New Millennium.* Scottsdale, AZ: Coriolis Group Books, 2000.

Eberts, Marjorie, and Margaret Gisler. *Careers for Computer Buffs and Other Technological Types.* Lincolnwood, IL: VGM Career Horizons, 1998.

Goff, Leslie Jaye. *Get Your IT Career in Gear!: Practical Advice for Building a Career in Information Technology.* New York: McGraw-Hill, 2001.

Henderson, Harry. *Career Opportunities in Computers and Cyberspace.* New York: Facts on File, 1999.

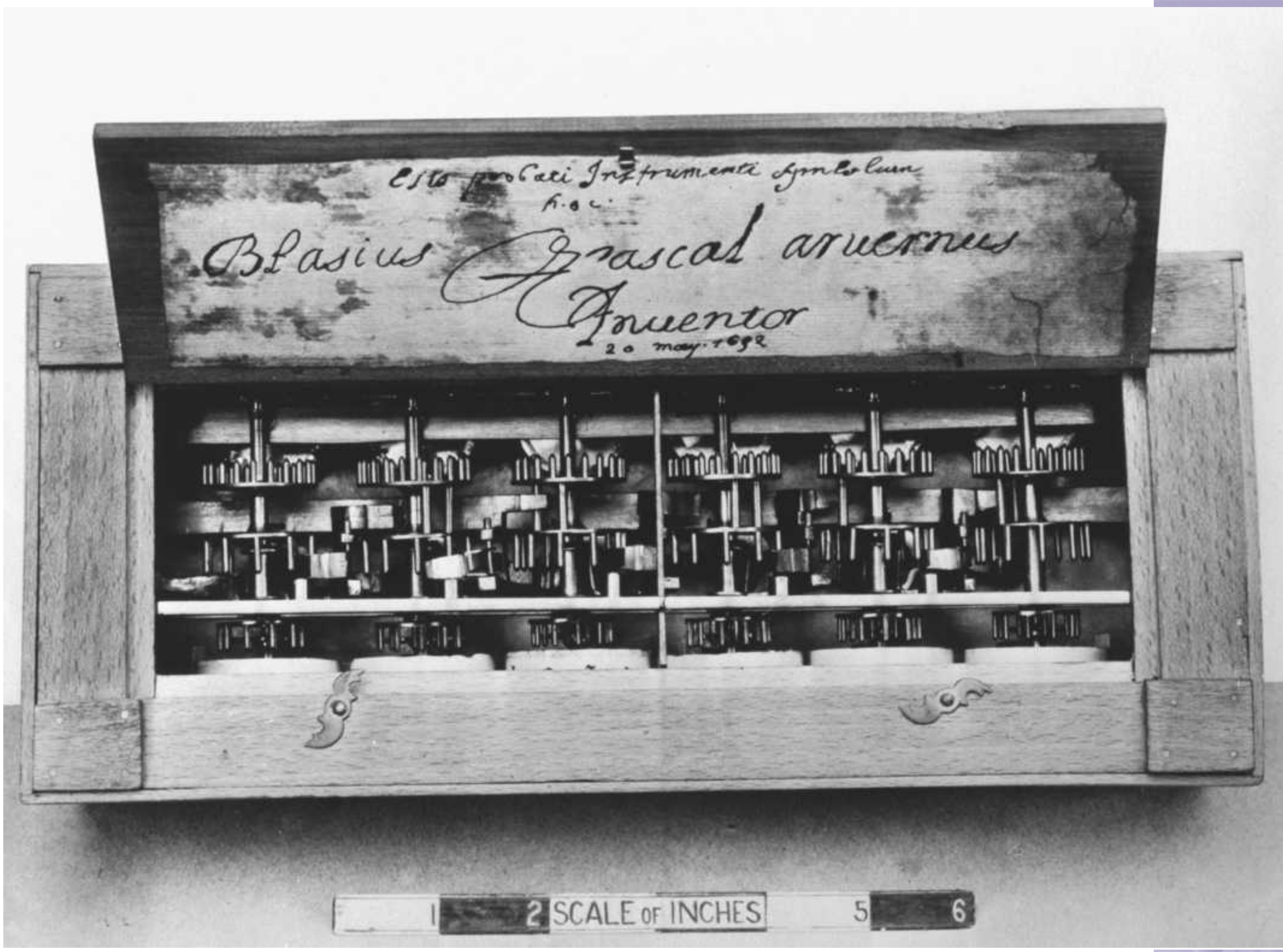
Digital Computing

There are two basic data transfer and communication systems in computing technology—digital and analog. Analog systems have continuous input and output of data, while digital systems manipulate information in discrete chunks. Although digital devices can use any numeric system to manipulate data, they currently only use the binary number system, consisting of ones and zeros. Information of all types, including characters and decimal numbers, are encoded in the binary number system before being processed by digital devices. In mixed systems, where sensors may deliver information to a digital computer in analog form, such as a voltage, the data have to be transformed from an analog to digital representation (usually binary also).

The chief difference between digital and analog devices is related to accuracy and speed. Since encoding is generally necessary for digital systems, it is not possible to exactly represent things like data from **sensors**, **oscilloscopes**, and other instruments. The information is numeric, but changes constantly. Therefore, what goes into a digital computer is an approximation. An example is the use of floating-point arithmetic to process large numbers in digital devices. Conversion from their complete form to floating-point representation (which is usually some power of ten) may result in some inaccuracy as a few figures of the least significant digits may be lost in trying to fit the mantissa (or fraction part) in the registers of a digital device. When floating-point numbers are used in calculations, the error compounds. As for speed, digital devices work on the coded representations of reality, rather than the analog model, which works from reality. This makes digital devices inherently slower due to the conversions and discrete nature of the calculations involved.

sensors devices that can record and transmit data regarding altitude, flight path, attitude, etc., so that they can enter into the system's calculations

oscilloscopes measuring instruments for electrical circuitry; connected to circuits under test using probes on leads and having small screens that display the signal waveforms



Blaise Pascal produced fifty of his mechanical calculating machines between 1642 and 1645. This invention was the first to mechanize addition and subtraction.

Analog devices can work on a continuous flow of input, whereas digital devices must explicitly sample the data coming in. Determination of this sample rate is an important decision affecting the accuracy and speed of real-time systems. One thing that digital computers do more easily is to include the evaluation of logical relationships. Digital computers use Boolean arithmetic and logic. The logical decisions of computers are probably as important as their numerical calculations.

The first instance of digital computing was the **abacus**. In fact, the word "digital" may originate from the "digits" of the hand that is used to manipulate the counters of the abacus, although the name may also have come from the tradition of finger counting that pre-dated it. The origins of the abacus are too ancient to have been recorded, but it made its appearance in China in C.E. 1200 and other parts of East Asia within a few hundred years. The abacus is not just a toy. Evidence of this was clearly presented when a Japanese arithmetic specialist, using an abacus, beat a U.S. Army soldier, who was using an electrical calculator, in a series of calculations in 1946. The abacus is digital, with five ones on one side of each post, and a five on the other side, the posts being the tens columns.

abacus an ancient counting device that probably originated in Babylon around 2400 B.C.E.

In 1642 French mathematician and philosopher Blaise Pascal (1623–1662) built a machine that was decimal in nature. Each dial of his calculator represented a power of ten. Each tooth of the gears represented a one. He also invented an ingenious carry mechanism, moving beyond the abacus, which required "carry overs" to be done mentally.

The first digital computer of the modern sort was the programmable calculator designed, but never built, by British mathematician Charles Babbage (1791–1871). This **Analytical Engine** used **base-10** numbers, with each digit a power of ten and represented by a gear tooth. The first electronic computers used both the common number systems, binary and decimal. The machine built by American physicist John Vincent Atanasoff (1903–1995) and his graduate student Clifford E. Berry (1918–1963) in the late 1930s could only solve a restricted class of problems, but it used digital circuits in **base-2**.

Analytical Engine Charles Babbage's vision of a programmable mechanical computer

base-10 a number system in which each place represents a power of 10 larger than the place to its right (decimal)

base-2 a number system in which each place represents a power of 2 larger than the place to its right (binary)

The Electronic Numerical Integrator and Computer (ENIAC), designed by American engineers J. Presper Eckert (1919–1995) and John W. Mauchly (1907–1980), is considered the first general purpose electronic digital machine. It used base ten, simplifying its interface. The first truly practical programmable digital computer, the Electronic Delay Storage Automatic Calculator (EDSAC), designed by Maurice V. Wilkes (1913–) in Cambridge, England, in 1949, used binary representation. Since then, all digital devices of any practicality have been binary at the machine level, and octal (base 8) or hexadecimal (base 16) at a higher level of abstraction.

Digital computers are forgiven their small inaccuracies because of their speed. For instance, the integral calculation is figuring out the area under a curve. The digital solution is to "draw" a large number of rectangles below the curve approximating its height. Each of these rectangles has tiny lines representing two sides—the larger the number of rectangles, the smaller the lines. These tiny lines approximate the curved line at many points, so if one adds up the areas of each rectangle, he obtains an estimate of the integral. The faster the machine, the more rectangles one can program it to create, and the more accurate the calculation.

There is also a time lag inherent in analog-to-digital conversion and vice versa. Many aircraft flight control systems have sensors that generate analog signals. For instance, one might transmit a voltage, the magnitude of which is important. This could be converted to a number in digital form, which can then be worked on by the flight computer, and the answer finally converted from digital form into a voltage again. These control systems are able to calculate new values fifty times a second.

SPEED OVER ACCURACY

Digital computers are actually less accurate than the older analog machines because they deal in larger numbers of approximations over the range of a problem while analog computers model reality continuously. However, digital machines are so fast, they have become preferable regardless.

These speed improvements in digital computers became common when the entire processor was integrated on one chip. Data transfers between the components on the chip are quite fast due to the small distances between them. Analog-to-digital and digital-to-analog converters can also be chip-based, avoiding the need for any speedup.

Digital computers are made of up to more than 1,000 of these processors working in parallel. This makes possible what has been the chief strength of digital computers all along: doing what is impossible for humans. At first, they performed calculations faster, if not better. Then they controlled other devices, some digital themselves, some analog, almost certainly better than people. Finally, the size and speed of digital computers make possible the modeling of wind flowing over a wing, the first microseconds of a thermonuclear explosion, or a supposedly unbreakable code. SEE ALSO ABACUS; ANALOG COMPUTING; BINARY NUMBER SYSTEM.

James E. Tomayko

Bibliography

Williams, Michael R. *A History of Computing Technology*, 2nd ed. Los Alamitos, CA: IEEE Computer Society Press, 1997.

E-commerce

E-commerce (sometimes called web-based commerce) is the term used to describe the activity of doing business on the Internet. It includes business-to-business, business-to-consumer, and even consumer-to-consumer transactions that involve the buying and selling of goods and services, the transfer of funds, and even the exchange of ideas. E-commerce includes functions such as marketing, manufacturing, finance, selling, and negotiations. The phrase can also refer to downloading software, accessing games, or downloading content such as journal articles and books.

Business-to-business transactions are commonly accomplished through Electronic Data Interchange (EDI). This **protocol** is now used by most Fortune 1,000 companies. EDI enables large organizations to transmit information over private networks; it has also found a role on corporate web sites (**intranet**).

protocol an agreed understanding for the sub-operations that make up a transaction; usually found in the specification of inter-computer communications

intranet an interconnected network of computers that operates in the same way as the Internet, but which is restricted in size to a company or organization

Business-to-consumer e-commerce can provide customers with convenience and access to a wide range of goods and services, while allowing businesses to reach large or unique markets. Components of business-to-consumer e-commerce include security measures, "shopping carts," payment options, and marketing.

Security

A business web site must be secure if it is going to handle financial transactions. A standard option is SSL (Secure Sockets Layer) using public key **encryption**, one of the strongest encryption methods available. SSL ensures that private information—such as passwords, credit card numbers, and customer profile data—is secure and encrypted as it is transmitted. Consumers will know they are using secure sites when they see closed padlock icons on the status bars of their web browsers. Another security protocol is called SET (Secure Electronic Transactions). SET encodes the credit card numbers on a business server. Created by Visa and MasterCard, SET is very popular in the banking community.

encryption also known as encoding; a mathematical process that disguises the content of messages transmitted

Shopping Carts

The electronic shopping cart is a popular feature that allows consumers simply to click on a button to select one or more products for purchase. When the customer has finished shopping, the cart system allows the consumer to "check out."

eBay, represented here by Meg Whitman (CEO) and Pierre Omidyar (founder), revolutionized the way auctions are conducted online. The service brings buyers and sellers of collectible goods together throughout the world.

Payments

Various payment options exist to facilitate business-to-consumer e-commerce. These include digital or electronic cash, electronic wallets, and micropayments.

Digital or Electronic Cash (E-cash). With digital cash, a consumer can pay for goods or services by transmitting a number. The numbers, similar to those on a dollar bill, are issued by a bank and represent specific sums of real money. Key features of digital cash are that it is anonymous and it can be reused, just like real cash. Various forms of e-cash have been around for awhile but consumers seem to prefer to use their credit cards. Federal laws provide credit card users the right to dispute any payments charged to their cards and limit theft losses to $50.

Electronic Wallets. These "wallets" store credit card numbers on personal computers in encrypted forms. Consumers can make purchases using their credit cards at web sites that support one of these wallets. A secure transaction is created by the electronic wallet company's server.

Micropayments. These transactions are in amounts up to $10, usually made in order to download or gain access to games or graphics. This method of paying for online content is not as widespread as others.

Marketing

Because e-commerce allows businesses to reach a worldwide market and to compete around the globe, creative marketing and promotion of a web site is crucial to the success of an Internet-based business. This must be balanced with sound business practices, however. Although many of the **dot.com** businesses that were heavily marketed to consumers during the late 1990s and into the new millenium managed to acquire good name recognition, a significant number were unable to stay in business, in part because they failed to provide the level of service consumers had been led to expect.

dot.com a common term used to describe an Internet-based commercial company or organization

E-Commerce vs. Traditional Commerce

The Internet has changed the nature and structure of competition. In the past, most businesses had to compete within a single industry (such as groceries) and often within a specific geographic area, but the Internet is blurring those boundaries. An example is Amazon.com. The company began as an online bookstore but quickly expanded into new products and markets such as music, videos, home improvement supplies, zShops (used music, books, etc.), and even the auction business. Through the Internet, customers can purchase products from virtually anywhere in the world.

A traditional business may have large **overhead** costs associated with maintaining a storefront. But a web-based business does not necessarily have that type of overhead, which may mean that continued growth becomes easier. With e-commerce, businesses can move more quickly and usually less expensively to reach a worldwide audience. For example, the cost of reaching a consumer in Minneapolis, Minnesota, is the same as reaching one in Clifton, Colorado.

An important difference between traditional business and e-commerce is the elimination of the middleman, known as **disintermediation**. Businesses and consumers can communicate directly to carry out transactions, which can help entrepreneurs market their products or services without the cost of salespeople or product representatives. Although e-commerce is still a developing part of the economy, some people believe that traditional stores and mail-order companies may eventually go out of business. Other observers believe that traditional and electronic commerce will find new ways to work together.

Despite some consumer wariness, due in part to reports of hackers breaking into allegedly secure web sites and downloading credit card information, businesses have found that financial transactions on the Internet can actually be more secure than in traditional retail environments. Much credit card fraud is caused by store employees who mishandle card numbers. Most consumers do not seem to realize their credit card numbers are vulnerable every time they hand their cards to waiters, place orders by phone, or toss out receipts. The encryption of card numbers for online transactions protects both the consumer and the business from credit card fraud.

Finally, the Internet is revolutionizing competition in the area of pricing. At any point, a business may choose to simply give away a service, free of charge, that others sell. One example was when Microsoft began to include a “free browser” with Windows software. Such businesses generate income through other means, such as by selling ads or products and

COMPETITIVE EDGE

One concern that consumers express about making their purchases online is the high cost of shipping and handling. As such, some online stores run “free shipping” campaigns, especially around the holidays, to entice customers to buy from them. E-sellers note that ordering online saves consumers from having to wait in long lines around the holidays.

overhead the expense or cost involved in carrying out a particular operation

disintermediation a change in business practice whereby consumers elect to cut out intermediary agencies and deal directly with a provider or vendor services related to the give-away item. Such strategies can help business attract customers. In addition, when "products" do not require manufacturing and packaging, as is the case with software downloaded via the Internet by a user, the reduction in business costs can be passed on to customers.

The Influence of the Internet

Research by Jupiter Media Metrix showed that 13.4 million households banked online from July 2000 to July 2001, a 77.6 percent increase in one year alone. In late 2001 Jupiter predicted online sales would reach $104 billion in 2005.

Statistics aside, the Internet has made strong inroads into the lives of people in virtually all demographic groups. Computer businesses, telephone companies, cable retailers, Internet providers, public libraries, and even coffeehouses have made Internet access available to almost anyone. School children are taught how to access the Internet, but so are patrons of libraries, community centers, and senior citizen centers. Readily available Internet access has opened the door wide for the world of e-commerce.

The Future of E-Commerce

Many analysts believe that e-commerce will reshape the business world. Some predict that the huge growth of virtual communities—people getting together in ad hoc interest groups online—promises to shift the balance of economic power from the manufacturer to the consumer, eroding the marketing and sales advantages of large companies. A small company with a higher quality product and better customer service can use these communities to challenge larger competitors—something it might not be able to do in the traditional world of commerce.

Non-business organizations are using lessons learned in the early years of e-commerce. An example of what the future may hold is "eduCommerce," a concept combining online course offerings with advertising content. Some experts believe that universities may eventually face stiff competition from organizations that offer their courses at no charge, counting on sales generated from ads to make their profits and draw new customers. Other forms of e-commerce will surely emerge as consumers explore the vast reaches of doing business via the Internet. SEE ALSO INTERNET; INTRANET; WORLD WIDE WEB.

Melissa J. Harvey

Bibliography

May, Paul. *Business of E-commerce*. Cambridge: Cambridge University Press, 2000.

Shapiro, Carl, and Hal Varian. *Information Rules: A Strategic Guide to the Network Economy*. Boston: Harvard Business School Press, 1999.

Shaw, Michael. *Handbook on Electronic Commerce*. Berlin: Springer, 2000.

Standing, Craig. *Internet Commerce Development*. Boston: Artech House, 2000.

Internet Resources

Varian, Hal. "Commerce." School of Information Management and Systems, University of California, Berkeley. <http://www.sims.berkeley.edu/resources/infoecon/Commerce.html>

Web Commerce Today. Wilson Internet. <http://www.wilsonweb.com/wct/>

E-mail

E-mail, which is short for electronic mail, offers virtually instant, one-way communication around the world via computer. It was one of the first methods of person-to-person communication made available through the information superhighway. In the early days of e-mail, simple text messages were sometimes difficult to manage, and adding pictures or documents was possible only if other software was available to make transmission from e-mail to computer possible. Current e-mail software generally provides easy-to-use options for attaching photos, sounds, video clips, complete documents, and **Hypertext Markup Language (HTML)** code.

Hypertext Markup Language (HTML) an encoding scheme for text data that uses special tags in the text to signify properties to the viewing program (browser) like links to other documents or document parts

Early e-mail access was typically provided by government agencies and universities to employees and special groups of people who needed to communicate with one another quickly and directly. Researchers and scientists were among the first consistent users of e-mail.

E-mail addresses are now available for a fee through commercial **Internet Service Providers (ISPs)** to anyone who has a home computer and a phone line or other means of Internet access. Users who do not care to contract with an ISP can acquire e-mail addresses through a variety of Internet web sites; well-known examples of free e-mail providers include Hotmail.com, Juno.com, and Yahoo.com. Although there is no direct cost to the user for these addresses, the services come with a non-monetary price. Sites providing such e-mail accounts usually are supported by advertising, and the e-mail accounts are often targets of that advertising.

Internet Service Providers (ISPs) commercial enterprises which offer paying subscribers access to the Internet (usually via modem) for a fee

E-mail vs. Snail Mail

E-mail provides a format for written communication that is different from the traditional postal service in number of ways. Messages can be delivered more rapidly through electronic means than on paper through what has been nicknamed “snail-mail.” E-mail is generally less formal than postal mail. Messages are often written quickly and respondents can weave their responses into the original message, replying point-by-point to the writer’s questions or comments.

Among the advantages of e-mail are speed and convenience. One advantage to using e-mail is the ability to send the same information to a number of recipients easily and simultaneously, complete with electronic attachments. Sending a copy of a message to interested parties at the same time as the intended recipient can save time by ensuring that everyone knows the details and has a chance to respond as needed.

Electronic mail offers new forms of communication that cross barriers of time and geography. Groups of people with similar interests can join together to share and discuss ideas via e-mail discussion groups. Each group can generate hundreds of messages from hundreds or thousands of users within a day. In some cases, discussion groups are moderated, with all incoming messages going to a single person to be screened before they are posted. This protects the entire list of message recipients from receiving messages that are not relevant to the group’s discussions. Other lists are not moderated, allowing any list member to send any message to the entire group.

E-mail retrieval centers are increasingly more available in public places such as bookstores and airports.

E-mail vs. Voice Communication

E-mail and telephone contact offer similar benefits in speed of contact. Answering machines and voice mail services provide options for asynchronous communication, similar to e-mail, where the recipient is able to receive messages on a time-delayed basis. With a sophisticated voice mail system, one message can be delivered simultaneously to a number of recipients on the same system, paralleling the ability of e-mail to communicate simultaneous messages and attachments to multiple recipients. This type of telephone delivery system is generally available only in business settings. One advantage of e-mail, however, is that it provides the option of communicating the same message to a number of people while also providing a text version of the message, instead of simply a voice message.

On the other hand, the voice message, whether live or recorded, offers certain advantages, as well. Listening to a voice message can give valuable information as to the emotional state of the speaker. Emotions conveyed through voice contact can clarify the meaning of a message that may be misinterpreted in e-mail format.

In an attempt to provide some emotional content to text-only messages, “emoticons” have been created; many are now widely recognizable. Emoticons consist of several keystrokes used together in a sequence to represent a facial expression. The most common are the use of a colon followed by a right or left parenthesis mark, representing a smiling face, or a frowning one, as in :) or :(respectively. Emoticons have become so popular that some word processing packages include smiling or frowning faces to replace typed in emoticons automatically.

Emoticons can be used to convey certain personal characteristics of a message’s author as well. Emoticons can portray glasses, using the numeral 8 followed by a parenthesis mark, or a beard and a wink, made up of a semicolon, a parenthesis mark, and a right-facing angle bracket mark, as in 8) or ;)> respectively.

E-mail for Business Use

E-mail has become quite popular for many business uses beyond communication within or between companies. As mentioned earlier, some Internet sites offer free e-mail accounts to attract users to the sites. Many of these are supported by advertising that is targeted toward specific consumer profiles. E-mail lists are also a valuable advertising commodity. They are used much like mailing lists for postal mail, or telephone lists for telemarketing.

For e-mail users who find advertiser-provided information valuable, or at least interesting, these e-mail marketing techniques are not a problem. There are some less scrupulous advertisers who send unsolicited and frequently unwanted messages to large numbers of e-mail accounts. This is a process known as “spamming.” E-mail spam is often sent to discussion groups’ e-mail lists, especially those that are not moderated. Various ISPs, such as Mindspring/Earthlink, offer their customers spam-filters such as the “Spaminator.”

Although e-mail has been fully adopted by business, government, industry, education, and the private sector, concerns about security and privacy still exist. E-mail software and ISPs offer varying levels of security in the e-mail packages they provide. While most providers offer a security level that most personal users find fairly reasonable, there are questions of security in business settings that must be addressed, not only to avoid spam, but to avoid unauthorized access to e-mail messages and accounts. People with significant computer skills can circumvent security systems and illegally access e-mail accounts. There are constant improvements made to security for all types of computer networks, including e-mail, but there will always be hackers who respond to every advance in security with new efforts to break through security measures.

E-mail privacy is not only at risk through illegal activity. In most business settings, there are regulations about who has legal access to e-mail sent or received via company-provided accounts. It may be true that e-mail sent with a company-provided account is not accessible to anyone from outside the company, but each e-mail message may be considered company property and can legally be accessed by the appropriate department within the

E-MAIL AND BIOTERRORISM

Although e-mail use has been increasing steadily with the growth of Internet access, it is expected to become even more popular in the wake of the appearance of anthrax-tainted postal mail during 2001. During a period of several weeks that year, large government and industry mailrooms were closed and traditional mail was undeliverable to elected officials and employees of numerous large media outlets. The volume of e-mail sent to these individuals and companies increased noticeably during these periods, because e-mail was the easiest and safest form of written communication that could be delivered to recipients working in affected buildings. However, on the downside, e-mail is often used to spread troublesome computer viruses and worms via infected attachments.

company. On occasion, corporate employees have been fired for using their company e-mail accounts in ways deemed inappropriate by their employers. Such objectionable use of company e-mail has included illegal betting, sending off-color jokes, forwarding chain letters, and sending pornographic photos.

E-mail accounts and messages may also be vulnerable to legal investigations. In the late 1990s and subsequent years, questions arose concerning e-mail contacts that U.S. President Bill Clinton made during ongoing legal investigations. Those e-mail messages were evaluated based on their content and their relevance to the investigations. Internet service providers were asked to provide information about account holders, who were then placed under investigation themselves.

E-mail provides a rapid and comprehensive method of communicating with others. Its low cost and widespread availability makes it a valuable tool for business and personal use. Advances in software and hardware are expected to help alleviate the privacy and security concerns that limit its use for highly confidential correspondence. SEE ALSO Internet; Intranet; World Wide Web.

Shirley Campbell

Internet Resources

Campbell, Todd. "The First E-Mail: Who Sent It and What It Said." *PreText Magazine.* <http://www.pretext.com/mar98/features/story2.htm>

"E-mail." *Webopedia.com.* <http://webopedia.com/TERM/e/e_mail.html>

Early Computers

To understand the development of the computer industry during the latter half of the twentieth century, one must look to the demand for computing power before and during World War II, when computing was a means to a very specific and urgent end. Between 1935 and 1945 there was a great need for **ballistics** computations and other statistical work in support of military efforts; this was time-consuming work carried out by people using rudimentary calculators. During this time, there was a rush to invent single purpose digital computing machines to speed up the calculation of the ballistics problems, firing tables, and code-breaking calculations. Several such machines were created by governmental organizations, industrial companies, and office machine companies in the United States, Great Britain, and Germany.

ballistics the science and engineering of the motion of projectiles of various types, including bullets, bombs, and rockets

Differential Analyzer

Although there were a number of calculators available for business use in the 1920s, they were not powerful enough to solve scientific computational problems. The first serious attempt at building a computer for scientists was made by Vannevar Bush (1890–1974), an engineer at Massachusetts Institute of Technology (MIT). In the 1930s, Bush and one of his students, Harold Locke Hazen, built an **analog** computer called the "differential analyzer." It was a collection of gears, shafts, and wires. It was better than the

analog a quantity (often an electrical signal) that is continuous in time and amplitude calculators of the time, but it was still slow and cumbersome, often needing two or three days of set-up time before it could solve a problem.

A faster and more accurate differential analyzer was built in 1935, but it, too, required adjustments with screwdrivers and hammers to prepare it for a run. It weighed 110 metric tons (200,000 pounds), had 2,000 **vacuum tubes** and several thousand relays, took up several hundred square feet (where one square meter equals about 10.8 square feet), and had about 150 motors and 322 kilometers (200 miles) of wires. Duplicates of the differential analyzer were set up at the U.S. Army's Ballistics Research Laboratory and at the Moore School of Electrical Engineering, at the University of Pennsylvania.

vacuum tubes electronic devices constructed of sealed glass tubes containing metal elements in a vacuum; used to control electrical signals

Bell Telephone Laboratories Model 1

Other computing devices were being built to serve purposes beyond what the differential analyzer was designed to do. The telephone company needed computing power to help set up telephone connections. At that time, when a rotary telephone was dialed, a number was transmitted to a machine that converted each digit to a four-pulse code. This was not fast enough for telephone switching demands, so Bell Telephone Laboratories engineers and scientists, including American engineer George R. Stibitz (1904–1995), began studying the **binary number system**. Stibitz felt that the binary system would be suited for the computation since a relay, called a flip-flop, had been developed. The relay could detect the presence or absence of a current (a binary system).

binary number system a number system in which each place represents a power of 2 larger than the place on its right (base-2)

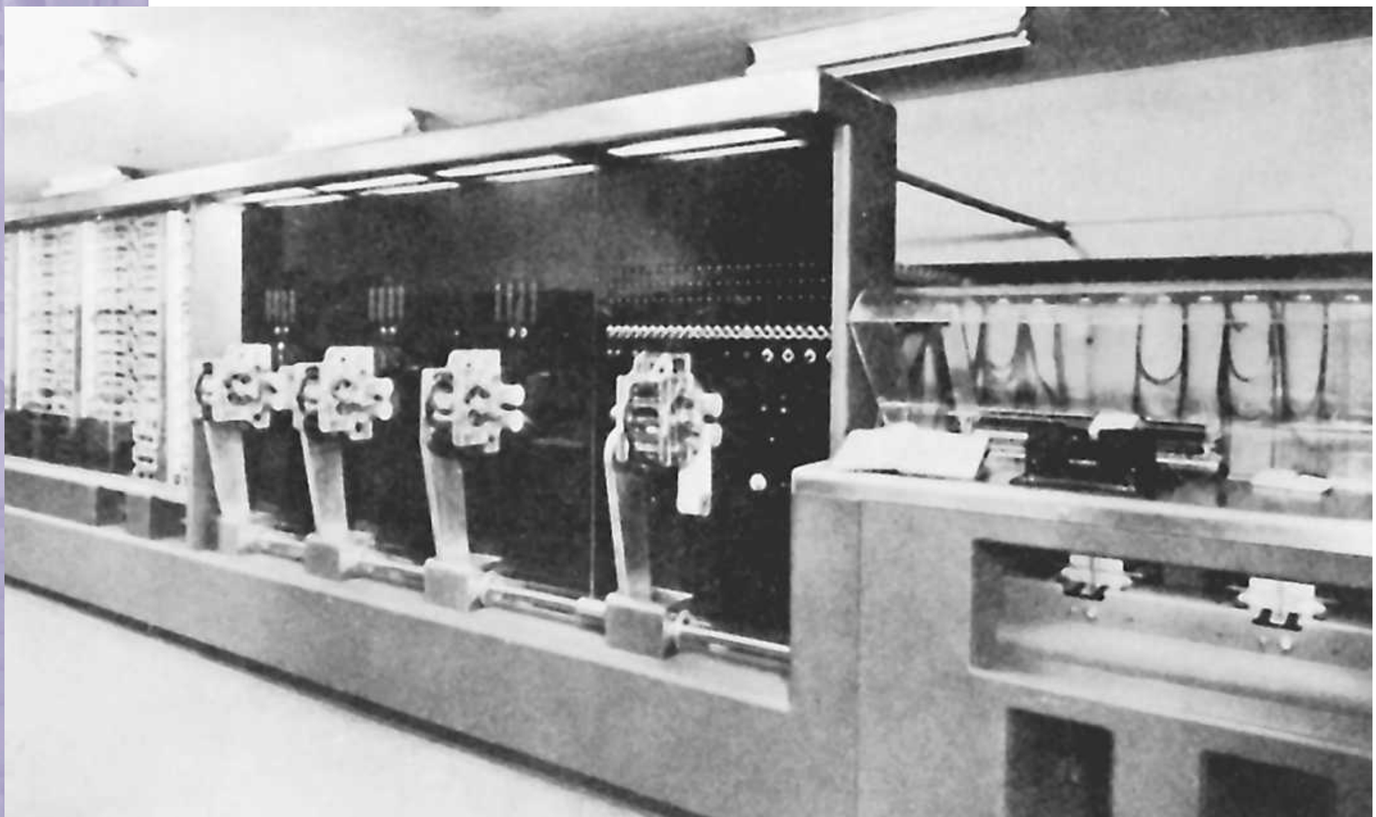
Stibitz built his "Complex Number Computer" in 1937. It converted decimal digits to binary, then converted them back to decimal for the answers. Push buttons were used to make it easier to operate, and in October 1939 it was sent to Bell Labs' New York office under the name of "Model 1."

The Model 1 may have been the world's first time-sharing computer, because several departments from Bell Labs accessed it remotely, with teletype machines. It may also have been the first remote job-entry computer. Mathematicians at Dartmouth College, in New Hampshire, accessed it through a teleprinter to submit problems to the computer in New York City. The answers came back on a telephone line hook-up in about one minute.

Harvard Mark I

In 1937 American mathematician Howard H. Aiken (1900–1973), then a Harvard graduate student, proposed building a machine based on the work of early computer researchers Charles Babbage and Herman Hollerith. He intended it to be an electromechanical Analytical Engine. The project was called the IBM Automatic Sequence Controlled Calculator (ASCC), or the Harvard Mark I. It was begun in 1939, and like the other computers of its day, it was huge. The Mark I was 15.2 meters (50 feet) long and 2.4 meters (8 feet) tall. Many of its 800,000 components were taken from IBM punched-card machines. It had 805 kilometers (500 miles) of wire, required an enormous amount of energy to run, and weighed about 5.5 metric tons (10,000 pounds). Every day, tons of ice were required to keep the machine cool.

The Mark I's memory had 72 adding registers made of 24 wheels each, and 60 special purpose registers using manual switches. The registers held



When Howard Aiken's Mark I computer was presented to Harvard University in 1945, computers were generally considered to be useful only to government offices and large businesses needing to process significant amounts of numerical data.

23-digit numbers plus the computational sign. Electric contacts were used to sense the number from the wheels. Clutches were used to transfer the number to another wheel for the calculation. Addition could be done in three-tenths of a second, multiplication in five seconds, and division in 11 seconds.

The machine input came from paper tape. Data was punched on three tapes and instructions on a fourth. It used two electric typewriters for output. There was no keyboard, and it was set up for a run by adjusting 1,400 switches. The Mark I computer was presented to Harvard in 1945. IBM had financed the research and construction costs of approximately half a million dollars. The Harvard Mark I was the first fully automatic computer to come into operation. It was already obsolete, however, as scientists and engineers would soon replace the electromechanical components with fully electronic models.

The Z1 in Germany

While Aiken was working on his computers at Harvard, a young engineering student in Germany was also thinking of computing machines that could perform long series of calculations. This person was German inventor Konrad Zuse (1910–1995), who decided on a design similar to Babbage's Analytical Engine, consisting of a storage unit, an arithmetic unit, and a control unit. The control unit would be directed by punched tape to deliver instructions to a selection mechanism, which connected the storage and arithmetic units.

Zuse decided to make it a binary device with a mechanical memory unit, using movable pins in slots to indicate zeroes and ones. This resulted in a compact memory that used only about 0.8 cubic meters (27 cubic feet), which was connected to a crude mechanical calculating unit. The machine was called the Z1 and was produced in 1938.

In 1941 Zuse completed the Z3. It had 2,000 relays and could multiply and divide, as well as extract square roots, in only three seconds. It was a compact machine that acted under program control. Push buttons were used on the control panel. One could push a button to convert decimal numbers into binary and then push again to convert them back. The Z3 was destroyed when an Allied bomb fell on Zuse's apartment building in 1944. Zuse's Z-machines were not too different from the microcomputers in use today.

DE-BUGGING THE SYSTEM

The Mark I's successor, Mark II, was run without air-conditioning in a room with open windows. One hot summer day in 1945, the Mark II stopped. Grace Hopper and her coworkers investigated and found that the source of the trouble was a moth that had been killed by a relay closing. The dead moth was removed and the incident was recorded in the logbook. Before long, Aiken came in to ask whether they were "making any numbers"—which was his phrase for computing. His team explained that they were "debugging" the Mark II. The word "bug" had been in existence for more than a century to describe mechanical system failures, appearing first in the writings of Thomas Edison, but this was allegedly the first use of "debugging" as a computing term.

Atanasoff-Berry Computer (ABC)

In 1939 John Vincent Atanasoff (1903–1995), a mathematician and physicist at Iowa State College (now Iowa State University), and a graduate student he recruited, Clifford Berry (1918–1963), began working on the machine that would be called the ABC (Atanasoff-Berry Computer). It used a binary number system and would use electronic technology. Numbers were stored on electric **capacitors** on two **Bakelite** drums and were read off as the drums rotated. Each drum could store 30 binary numbers of up to 50 binary digits.

Data were input through punched cards in decimal, five 15-digit numbers and a sign. This was converted to binary before doing the calculations. The computer was manually operated, with an operator pushing a button to show where the numbers should go, then putting a card in a holder and activating it by closing a contact. The card was read by rows of brushes, similar to the card readers developed later for computer use. To store intermediate results, Atanasoff designed a system to burn the cards with electric sparks. The burnt areas had less resistance than the rest of the card, so the numbers could be read by applying electric current to the card and reading the voltage.

capacitors fundamental electrical components used for storing electrical charges

Bakelite an insulating material used in synthetic goods, including plastics and resins

The memory was to be bigger than the 300 bits available on commercial machines, so they needed units that would be cheaper and smaller than vacuum tubes. Their choice was paper electrical condensers, which looked like miniature cigarettes. A memory built of condensers would have saved money but would have required recharging from time to time. Atanasoff developed a procedure for recharging that he called "jogging." The computer's memory would be regularly "jogged" by the computer by resetting the data as they were read out. This was similar to a person "jogging" his or her own memory by repeating some phrase or word. The concept of "jogging" influenced the design of later computers built after World War II.

The prototype of the ABC contained what Atanasoff called an "abacus," a plastic disc mounted on a shaft turned by an electric motor. Each side of the disc had 25 condensers arranged as spokes on a wheel, which gave it the capacity of 25 binary digits. It proved to Atanasoff and Berry that an electronic machine using binary numbers with a condenser memory was possible. It also showed that the "jogging" technique was feasible. However, Atanasoff and Berry were unable to complete the ABC as their work was interrupted by World War II.

Developments in Great Britain

As the Germans advanced across Europe, a team of scientists and engineers came together in a mansion north of London at the Government Code and

cryptographic pertaining to the science of understanding the application of codes and cyphers

algorithm a rule or procedure used to solve a mathematical problem—most often described as a sequence of steps

Cipher School. Their goal was to design machines that would break the codes generated by the Enigma, the **cryptographic** machine that the Germans used to encode and send messages.

The German Enigma used two typewriters. The original message was typed on one machine, a key was selected for encoding, and the coded message was automatically typed on the other electric machine. Every message could be sent with a different key, giving about a trillion possible code combinations. The key was changed three times a day, to make it more difficult to break the code.

British mathematician Alan Turing (1912–1954), one of the scientists on the project, developed an **algorithm** to sift through all the possible combinations and find the key. This was implemented on a special purpose computer called the Bombe. It was an electromechanical relay machine with wheels similar to those of the Enigma. Its goal was to work out the solution of the cipher as quickly and accurately as possible. It did not decode the messages, but found the key. The messages were then decoded by people. The Bombe, of which there were several individual machines, is credited with saving many lives during World War II.

When the Germans replaced the Enigma with a more sophisticated machine, known to the British as Fish, the British also attempted to build a better machine. The result was the Heath Robinson, an electronic machine using vacuum tubes. The Heath Robinson was named after a British cartoonist whose drawings of far-fetched machines were well known. For input, Heath Robinson used two synchronized photoelectric paper tape readers that could read 2,000 characters per second. This is the equivalent of a 300-page book being read in just over five minutes. Its output was a primitive printer that could print 15 characters per second. An adder carried out binary calculations used to break the codes of the German machine. It proved how fast and powerful electronic computing could be, but it still could not keep up with the demands being placed on it.

This led to the development of Colossus. The Colossus is considered to be an electronic computer, but it was a special purpose computer, unsuited for anything else other than deciphering codes. It was completed in December 1943. It had 1,800 vacuum tubes that counted and compared numbers and performed simple arithmetic calculations. It was fed information on paper tape at a rate of 5,000 characters per second, more than twice the rate of the Heath Robinson. It had no internal memory, but the users adjusted its operation as it came close to deciphering a message. The program was fed into it by an array of switches and phone jacks. Data were entered separately on tape.

Yet 5,000 characters per second was still not fast enough, so several machines were used in parallel, which today is called parallel processing. The parallel processing machine, of which there are different types, speeds up computing by performing tasks together, in parallel, instead of doing them sequentially.

Colossus had five different processors working in parallel. Each processor read a tape at 5,000 characters per second, so the total was 25,000 characters per second. This was made possible by the addition of shift registers, which allowed Colossus to read the tapes in parallel, and an internal clock that kept the parts of the machine working in synch. It was the best code breaker of its day.

ENIAC (Electronic Numerical Integrator and Computer)

John Mauchly (1907–1980), an American meteorologist interested in doing weather calculations, set out to build an inexpensive digital computer. He wanted to replace the calculators that were not fast enough for his needs. In 1941 he discussed his ideas with J. Presper Eckert (1919–1995), an American engineer, and in April 1943 the Moore School of Engineering received a contract from the Ballistics Research Laboratories to build a computer to calculate shell (munitions) trajectories. Mauchly and Eckert started work on the Electronic Numerical Integrator and Computer (ENIAC).

ENIAC had 18,000 vacuum tubes, 70,000 resistors, 10,000 capacitors, 6,000 switches, and 1,500 relays. It took up 162 square meters (1,800 square feet) and weighed 33 metric tons (60,000 pounds). It required 160 kilowatts of power and was 30.5 meters (100 feet) long, 3.1 meters (10 feet) high and 0.9 meters (3 feet) deep. It required two great 20-horsepower blowers to cool it. It generated 150 kilowatts of heat and its cost was more than $486,000.

ENIAC was 500 times faster than the Harvard Mark I and could perform 5,000 operations per second. It did an addition in two-tenths of a **millisecond**, a multiplication in 2.8 milliseconds, and a division in 24 milliseconds, which was extraordinary for that time.

millisecond a time measurement indicating one-thousandth (or 10^{-3}) of a second

ENIAC was a decimal machine working with numbers up to 20 digits long. The numbers were sent to the central processing unit by a transmitter made of relays connected to an IBM card reader. They were fed through the card reader at 125 cards per minute. Earlier machines, like the Harvard Mark I, were programmed with punched cards or paper tape so the program could be changed easily. This worked because their computational speed, being electromechanical, matched that of the paper tape readers and card readers. However, ENIAC's speed of 5,000 operations per second outstripped that of the card and tape readers. For that reason, Mauchly and Eckert decided to wire the machine specifically for each problem. This was similar to the plug boards used in electronic business machines or punched card equipment.

Each of ENIAC's problems was set up on a plug board similar to that used by punched card machines. If the program was complicated, it could take several days to set up. The later idea of creating a computer that could use a stored program came from this time-consuming effort. ENIAC became operational in November 1945, too late to help with the war effort, but it was a model for computers to come. It was highly regarded for its simplicity and carefully planning. The ENIAC was dismantled in October 1955.

> **DEMONSTRATIONS OF COMPUTING POWER**
>
> To make sure that the ENIAC gave the correct answers, two women were employed to work out a problem, using desk calculators, over a year's time. ENIAC solved the problem in an hour. At its dedication ceremony, it computed an artillery shell's trajectory in 20 seconds. It took the shell 30 seconds to reach the target in real life.

EDVAC (Electronic Discrete Variable Automatic Computer)

When Hungarian mathematician John von Neumann (1903–1957) was told of the work on the ENIAC, he arranged to become a consultant to the project. He played a key role in the design of the subsequent EDVAC, starting in 1944. This new machine was to remember its instructions in an internal memory. This would remove the need to plug and unplug and replug, as in the ENIAC. The instructions could be changed internally.

EDVAC was given delay-line storage instead of vacuum tubes. The delay lines used the binary number system. With 1,024 bits, which was their capacity, they could be used to store 32 32-bit words. It was estimated that the EDVAC would require between 2,000 and 8,000 words of storage, necessitating between 64 and 256 delay lines. This was a large amount of equipment, but it was still smaller than the ENIAC. When completed in 1951, the EDVAC had some 3,500 tubes, but its importance lies in the fact that it embodied the stored-program concept and the "von Neumann machine," two ideas that would greatly influence the design of computers. The stored-program computer is still in use today. A stored-program computer allows the instructions to be fed in with the data. Earlier computers, such as the Bell Labs Model 5 and Heath Robinson, had separate tapes for the data and the instructions.

PIONEERING COMPUTER SOFTWARE

On May 1949, before EDVAC was completed, a slim ribbon of paper containing the instructions to compute the squares of integers was fed into it. Thirty seconds later it began to print the numbers 1, 4, 9, 16, 25. . . . The first program in a stored-program computer had been born.

A von Neumann machine is the model on which most machines are built today. It executes the instructions sequentially, as opposed to a parallel processor, which supports multiple operations at the same time. EDVAC became operational at the end of 1951 and was active until 1962. Its separate components—memory, central control, arithmetic unit, and input and output—were introduced by von Neumann.

Manchester Mark I and EDSAC (Electronic Delay Storage Automatic Calculator)

After security was lifted from the ENIAC project, the dean of the Moore School organized a summer school to make sure that those outside of the project would know of its results. The lectures took place in July and August of 1946. They attracted many of the leading scientists of the day. Among them were British computer scientists, including Maurice V. Wilkes.

ENIAC was explained in detail during the lectures, but the EDVAC was not discussed since it was still a classified project. In retrospect, one can see the connection between these lectures and various projects carried out by the governments, universities, and industrial laboratories in Great Britain and the United States. Great Britain was the only European country not so devastated by the war that it could carry out a computer project.

British mathematician Max Newman (1897–1984), one of the researchers of the Colossus computer, launched the computer project at Manchester University in England. One of his university colleagues, British engineer Sir Frederic Williams (1911–1977), developed a memory system based on the **cathode ray tube (CRT)**. A primitive machine using this memory was developed in 1947, but it did not have input or output devices. The program was entered using push-buttons; the results were read from the tubes. Williams' project prevailed over Newman's original plans. The university's Manchester Mark I was completed in 1948, incorporating the stored-program concept. It proved that the idea was achievable. It stored 128 40-bit words on the tubes and had additional memory in the form of magnetic drums.

cathode ray tube (CRT) a glass enclosure that projects images by directing a beam of electrons onto the back of a screen

Inspired by the Moore School lectures, Cambridge University professor Maurice V. Wilkes (1913–) started work on a stored-program computer.

By February 1947 he had built a successful delay line storage that could store bit patterns for long periods of time. Encouraged by this, he went on to construct the full machine. Despite the short supply of electronic components in postwar Britain, the EDSAC (Electronic Delay Storage Automatic Calculator) began to take shape. Its control and arithmetic units were stored in three long racks, each 1.8 meters (six feet) tall. The vacuum tubes were exposed to keep them from overheating. Input was a tape reader, output was on a teleprinter, and the programs were punched on telegraph tape.

Although EDSAC was very large—it had 3,000 tubes and consumed 30 kilowatts of electric power—it was smaller than the ENIAC and had one-sixth the tube count. It could perform an addition in 1.4 milliseconds, and its users developed one of the first assembly languages, as well as a library of programming procedures called subroutines.

Whirlwind

In the early 1950s, the United States and the Soviet Union were engaged in the Cold War. MIT engineers were working on a computer to help the U.S. military with its computational needs. After considering an analog machine, it was finally decided that the machine would be digital, and would require a large memory to store the information needed to control an aircraft trainer, a "real-time" exercise. The requirements of the memory were beyond the capabilities of the CRTs and delay-lines of the day.

Jay Forrester (1918–), an engineer working on the project, thought of alternative designs. He eventually settled on a three-dimensional design, the "core memory." He also experimented with different media from which to construct the memory. He tried rolled-up bits of magnetic tape, then tried iron-bearing ceramics that were molded in the shape of tiny rings and mounted on grids. These became the magnetic "cores" of the powerful computer that would be named Whirlwind. The Whirlwind began working in 1951. It helped to coordinate New England military radar units in scanning the skies for Soviet planes during the Cold War.

Two decades after Whirlwind debuted, times had changed. At the time of Aiken and his colleagues, there were only a handful of computer designers and engineers, and most knew each other. By the 1960s and 1970s, the field was replete with practitioners, enough to populate a small city, and the pioneer computers seemed almost forgotten. SEE ALSO Babbage, Charles; Digital Computing; Early Pioneers; Memory; Vacuum Tubes.

Ida M. Flynn

Bibliography

Campbell-Kelly, Martin, and William Aspray. *Computer: A History of the Information Machine.* New York: Basic Books, 1996.

Moreau, Rene. *The Computer Comes of Age: The People, the Hardware, and the Software.* Cambridge, MA: MIT Press, 1984.

Ritchie, David. *The Computer Pioneers: The Making of the Modern Computer.* New York: Simon and Schuster, 1986.

Shurkin, Joel. *Engines of the Mind: The Evolution of Computers from Mainframes to Microprocessors.* New York: W. W. Norton & Co, 1996.

Early Pioneers

The evolution of computer technology between 1930 and 1950 was strongly influenced first by mathematical theoreticians and then by military needs during World War II. During this twenty-year span, the early pioneers of modern computer science found ways to create machines that harnessed the power of electronics, moving beyond strictly mechanical computational devices and laying the foundation for the transistor-based computers that would follow in the 1950s and 1960s.

Conceptual Foundations

In 1931 electrical engineer Vannevar Bush (1890–1974) designed a mechanical calculator that solved complex differential equations. Although its gears and other moving and stationary parts made the machine difficult to use, Bush's invention was considered significant in mathematical circles because mathematicians and scientists could use it to solve equations long thought to be virtually unsolvable. Bush's greater contribution to modern computer science came in 1945 with the publication of an article that described a conceptual device for linking and accessing information that he

Vannevar Bush described the memex device, an idea which is widely regarded as the ancestor to hypertext.

called a **memex**. His device was never built, but the ideas underlying his concept were later influential on the developers of what is now known as hypertext.

memex a device that can be used to store personal information, notes, and records that permits managed access at high speed; a hypothetical creation of Vannevar Bush

In the 1930s, British mathematician and cryptographer Alan Turing (1912–1954) developed the concept of a mechanical machine by which mathematical statements could be either proved or disproved. Although the Turing Machine was a concept, rather than a device, Turing's principles were part of the foundation upon which early mechanical computational devices were designed. In addition, his work toward speeding up the process of breaking German military codes during World War II was influential in the development of the Colossus (1943), a code-breaking computer that is the first known programmable logic calculator to use electronic valve technology. While the Colossus was significant in the Allied war effort, its influence on the development of computer science was negligible because it was not designed for general purposes and because its existence was considered classified military information until many years after the war had ended.

During the 1940s, the mathematical and theoretical work that would later be incorporated into modern computer technology was overshadowed by focused efforts to create machines designed for specific military purposes. Just as there was a wartime need to increase the code-breaking capabilities of the Allied military forces, there was an urgent need for the accurate creation of artillery firing charts. This was a repetitive task performed by large numbers of people using mechanical computing devices not specifically designed for the purpose. The need to compile these essential military tools more quickly led to government-funded efforts to invent machine solutions to the problem. Scientists in the United States and Great Britain, who had already been studying various means of creating electromechanical computing devices, then turned their energies specifically toward devising one-of-a-kind machines to meet this need.

From Concepts to Machines

The computing devices developed between 1941 and 1951 represent the first generation of modern computer technology, and their inventors are considered the true early pioneers of computer science. The physical implementation of a variety of concepts by men such as Howard H. Aiken, John V. Atanasoff, John Presper Eckert, John W. Mauchly, and German engineer Konrad Zuse set the stage for the business computers built during the 1950s and 1960s.

Howard H. Aiken. Working in partnership with IBM, Harvard engineer Howard H. Aiken (1900–1973) produced an electronic calculator for military use in 1944. The machine, which required 804 kilometers (500 miles) of internal wiring, was 15.2 meters (50 feet) tall and 2.44 meters (8 feet) high. It was used by the U.S. Navy to calculate and create ballistics firing charts. The electro-mechanical computer, known as the Harvard Mark I, was controlled by a punched tape paper roll. Its mechanical parts responded to electromagnetic signals. The five-ton machine was slow and time-consuming to program. Its components were vulnerable to damage from the heat generated by the unit. Despite its drawbacks, however, the Harvard Mark I represented a significant point of development in computing technology.

AN UNCLEAR VIEW OF THE FUTURE

The early computer pioneers may have been dedicated to their work, but perhaps they had little idea how their inventions would revolutionize the worlds of business and communication. In 1947 Harvard engineer Howard H. Aiken, who is credited with producing two of the first electronic computing machines in the mid-1940s, was quoted as saying he believed that "the computing needs of the entire United States"could be met with no more than "six electronic digital computers."

John V. Atanasoff

Aiken was a graduate student at Harvard in 1937 when he first conceptualized a machine that would combine and implement the ideas of Charles Babbage (1791–1871) and Herman Hollerith (1860–1929). The development of the machine that would be known as the Mark I began in 1939. This electronic relay computer was followed in 1947 by an electronic computer known as the Mark II. Aiken also opened the Harvard Computational Laboratory in 1947, creating the world's first computer science academic program. He later founded a company, Aiken Industries, and continued to influence the development of computer electronics through research and writing.

John V. Atanasoff. A mathematician at heart and an electrical engineer and theoretic physicist by education, John V. Atanasoff (1903–1995) began his career teaching mathematics and physics at Iowa State College in 1930. Fascinated by the prospect of finding ways to perform mathematical computations more quickly and accurately, Atanasoff studied the existing machines available for computation, and believed that they could be improved. Categorizing devices such as the Monroe calculator and the IBM tabulator as analog machines, Atanasoff envisioned an electronic, digital device based on **base-2** numbers (the **binary** system).

base-2 a number system in which each place represents a power of 2 larger than the place to its right (binary)

binary existing in only two states, such as "on" or "off," "one" or "zero"

During the 1930s, Atanasoff worked with graduate student Clifford E. Berry (1918–1963) to design and build an electronic digital computer that would be introduced in 1939 as the Atanasoff-Berry Computer (ABC). This is widely considered to be the world's first all-electronic digital computing device. Atanasoff filed patent applications for his invention, but the process was slow. Before he could be granted patent protection for his work, and thus historic credit as the creator of the first machine of its kind, patents would be released for the ENIAC as the first electronic digital computer. Atanasoff, who was one of the first computer scientists to understand the potential of digital computing, went on to receive patents for 32 other inventions. Eventually, credit for his best known innovation would revert to him, as well.

J. Presper Eckert, Jr. In November, 1945, another pivotal computing device was put into use, although its presence was not announced publicly until February 1946. The ENIAC (Electronic Numerical Integrator and Computer) was designed to perform mathematical calculations for military purposes. It began to take shape in 1943 at the Moore School of Electrical Engineering at the University of Pennsylvania, in response to the U.S. Army's need for new ways to produce trajectory tables used for precision targeting of large artillery. As the chief engineer on the ENIAC project, J. Presper Eckert, Jr. (1919–1995) shared credit for the computer's success with the ENIAC's architect, John W. Mauchly (1907–1980). Although it was finished too late to contribute to the war effort, the ENIAC was used to design hydrogen bombs, predict weather, and provide calculations related to military-sponsored studies of wind tunnels, **thermal ignition**, and other phenomena.

thermal ignition the combustion of a substance caused by heating it to the point that its particles have enough energy to commence burning without an externally applied flame

The ENIAC was 500 times faster than the Harvard Mark I computer. It cost a few hundred thousand dollars to develop, it weighed 33 metric tons (60,000 pounds), and its dimensions were gargantuan (3.0 meters (10 feet) tall, 0.9 meters (3 feet) deep, 30.5 meters (100 feet) long). Even as the ENIAC was being built, Eckert began working on the problem of creating a stored-program computer, in part because the ENIAC, which had to be rewired for each computational task, proved to be limited by the lack of stored-program capabilities. The result of this next project would be known as the EDVAC (Electronic Discrete Variable Automatic Computer), which was completed in 1951, without the continued involvement of Eckert, who resigned from the Moore School in 1946. Eckert took out patent applications for more than 80 more electronic devices between 1948 and 1966. His pioneering work on the ENIAC and later computer developments earned him many awards, including the U.S. National Medal of Science in 1969.

John W. Mauchly. The ENIAC computer, from which the modern electronic computer is said to have evolved, was conceived by John W. Mauchly (1907–1980), a physicist at the Moore School of Electrical Engineering, University of Pennsylvania. Mauchly and chief engineer John Presper Eckert gained notice for their creation of the first general-purpose computer that could perform 5,000 operations per second, a previously unimaginable speed.

During the early part of his career, Mauchly taught at Ursinis College near Philadelphia. After attending an electronics seminar at the Moore School, he ended up joining its staff. The U.S. Army's Ballistics Research Laboratory was familiar with earlier research Mauchly had performed involving the use of motors and vacuum tubes to design and build calculating equipment. In 1943 Mauchly was selected by the military to design a unit capable of writing programs to calculate the trajectories of artillery under multiple conditions. The result was the ENIAC computer, which was completed too late to be of use during World War II.

Although Mauchly and Eckert began collaborating on the EDVAC even as the ENIAC was still being built, they were both forced to resign from the Moore School before the EDVAC was operative due to their desire to be recognized in patent records as inventors of the ENIAC, which breached University of Pennsylvania protocol for patents. Mauchly continued to work with Eckert until 1959, during which time they established the first commercial computer company and built the UNIVAC (Universal Automatic Computer). Despite disputes over patent rights and the origin of certain computer design ideas, Mauchly can rightly be considered a major innovator in the development of practical computing machines designed for flexible use.

CREDIT WHERE CREDIT IS DUE

In 1940 John W. Mauchly met with John V. Atanasoff, who had recently introduced the Atanasoff-Berry Computer (ABC). Atanasoff demonstrated the ABC to Mauchly, who later implemented some of Atanasoff's ideas as he designed the ENIAC. Because Atanasoff's work had not yet been granted patent protection, the ENIAC received early recognition as the world's first electronic digital computer. Later on, Mauchly's reputation as a major contributor to the ENIAC's successor, EDVAC, would be undercut by the publication of a report by John von Neumann, who received credit for the design of the first stored-program computer.

British Computer Pioneers

During the years preceding and during World War II, American and British mathematicians and engineers joined forces to support their countries' military efforts, seeking ways to automate such tasks as the compilation of artillery firing tables and the deciphering of enemy coded communications. Much of this work led to the post-war development of electronic computing devices. Manchester University in Manchester, England, was the site of one of these developments, which was known as the Manchester Mark I.

Manchester Mark I. Following World War II, mathematician Maxwell Newman (1897–1984) joined Manchester University as professor of pure, rather than applied, mathematics. In 1946 he acquired funding and other resources to build a stored-program computer at the university specifically to investigate its use in the study of pure mathematics. His plan was similar to one being developed at Cambridge University by Maurice V. Wilkes.

cathode ray tubes (CRTs) glass enclosures that project images by directing a beam of electrons onto the back of a screen

At the same time, Freddie C. Williams (1911–1977), a professor in the electrical engineering department at Manchester University, was investigating the use of **cathode ray tubes (CRTs)** for program storage. As the work of the Williams team progressed, Newman's team at Manchester encountered difficulties. Ultimately, Newman decided to suspend work on his computer, pending the results of Williams' efforts. By October of 1949, the Williams group had successfully demonstrated an operational version of the Manchester Mark I, a computing machine with true stored program functionality.

EDSAC. At Cambridge University, meanwhile, Maurice V. Wilkes (1913–) was working on a project known as EDSAC (Electronic Delay Storage Automatic Calculator). In 1946 he studied electronic computer design at the Moore School of Electrical Engineering at the University of Pennsylvania, the home of ENIAC. Wilkes' research over the next few years resulted in the first operations stored-program computer; the EDSAC was introduced in May of 1949, barely five months before the Manchester Mark I was completed.

Konrad Zuse. Although American and British mathematicians, physicists, and engineers are credited with many of the innovations in early computer design and manufacturing, German engineer Konrad Zuse (1910–1995) is also considered one of the early pioneers of modern computer science. By 1941 Zuse had designed and built what became known as the Z3, the world's first electromechanical digital computer controlled by programming. Unlike the British and American efforts that were heavily funded by Allied money, Zuse's work was largely independent of government control or interest.

Between 1936 and 1938, Zuse used recycled parts and donations from friends and family members to assemble his first computer, which he called the Z1. This was the world's first binary computer. It is significant that Zuse's innovations took place outside the mainstream of computer development then going on in other parts of the world. Drafted for military service in 1939, Zuse tried in vain to persuade the Nazi/German Army military establishment of the value of his inventions. When he was reassigned from active duty to work as a structural aircraft engineer, Zuse resumed his computer-building activities, incorporating telephone relays in the construction of the Z2 and electromagnetic relays in the Z3.

Zuse's model Z4 was the only one of his original inventions to survive the bombing of Germany during World War II. By the end of the war, Zuse and his family were refugees in southern Germany. Between 1945 and 1950, Zuse continued his research when it was possible, and in 1947 he jointly founded the Zuse Engineering Company to design and build computers for scientific and business applications. Over the next several decades, Zuse and his company began interacting with computer-development interests worldwide, and his early innovations received the recognition they deserved. He received numerous awards and honors for his contributions to the field of modern computer technology.

Early Computer Programmers

In 1945 the U.S. Army hired eighty mathematicians whose high security, top-secret work no one had performed before. All of them were women. Their job was to program the ENIAC to calculate artillery firing trajectories, in order to increase the accuracy of military war efforts.

As the first wave of computer programmers, these women laid the foundation for all later computer programming. They had to become familiar with the mechanics of the ENIAC and then figure out how to give the computer directions to carry out specific actions. The women, many of whom had recently graduated from college as mathematics majors, were recruited because there was a scarcity of male mathematicians available.

In October of 1998, four of these pioneers—Jean Kathleen McNulty Mauchly Antonelli, Jennings Bartik, Frances Snyder Holberton, and Marlyn Wescoff Meltzer—were honored by Women in Technology International for their contributions to the computer industry. At the ceremony, Antonelli pointed out that the capabilities of the ENIAC were considered more remarkable during its decade of operation than were the achievements of the women who programmed the machine to perform as it did. Holberton, who compared their wartime work to that of construction engineers, would later be among the programmers who helped develop the programming languages known as COBOL and FORTRAN.

Computer Pioneers, 1930–1950

As the 1940s drew to a close, the early pioneers of modern computing continued to pursue new avenues of research in the growing field of computer science. Other engineers made new contributions. In 1947 came the invention of the transistor, which replaced vacuum tube technology in the design of computers and revolutionized the computer and electronic communications industries. The inventors of the transistor, John Bardeen (1908–1991), William Shockley (1910–1989), and Walter Brattain (1902–1987), would jointly share the 1956 Nobel Prize in physics. Their 1947 innovation rounded out two decades of pioneering work that took computing from mechanical calculating machines to the brink of the digital age. SEE ALSO COMPUTER SCIENTISTS; DIGITAL COMPUTING; EARLY COMPUTERS.

Pamela Willwerth Aue

Bibliography

Bellis, Mary. "Presper Eckert and John Mauchly—The ENIAC and UNIVAC Computers." *Inventors.* <http://www.inventors.about.com/science/inventors/library/inventors/bleniac.htm>

"The Birth of Electronic Computers." *Early Electronic Computers.* <http://www.netaccess.on.ca/~paulyoung/early.html>

Lee, J. A. N. "Konrad Zuse." Virginia Polytechnic Institute and State University. <http://ei.cs.vt.edu/~history/Zuse.html>

Lee, J. A. N. "Maurice Vincent Wilkes." Virginia Polytechnic Institute and State University. <http://ei.cs.vt.edu/~history/Wilkes.html>

Moreno, Raul. "The Advent of the Computer." <http://www.willamette.edu/~rmoreno/lab0.html>

Oldehoeft, Arthur. "The Atanasoff Berry Computer." Iowa State University Department of Computer Science. <http://www.cs.iastate.edu/jva/jva-archive.shtml>

Seminerio, Maria. "The Secret Mission of the First Computer Programmers." *ZD-Net News.* <http://www.zdnet.com/zdnn/stories/news/0,4586,2151971,00.html>

University of Manchester. "The University of Manchester Celebrates the Birth of the Modern Computer." <http://www.computer50.org>

"Wilkes, Maurice Vincent." *A Dictionary of Scientists.* <http://www.xrefer.com/entry/495367>

Ergonomics

Ergonomics is the science of designing machines and environments that are well suited to the people working with them. Ergonomics, or human factors, considers the design of machines, workspaces, jobs, health issues, and the human-machine interfaces. For example, an ergonomic design of an automobile's dashboard means that the controls can be reached easily and that all displays are visible for a range of drivers, whether they are 1.83 meter (6 foot) tall men or 1.52 meter (5 foot) tall women. Since the last decade of the twentieth century, ergonomics has become an important issue in the use of computer technology.

Before the start of World War II, emphasis was placed on conditioning people to fit the machines in their lives. Machines were created, then human beings were trained to operate them according to the machine's requirements; an example of this is training pilots to fly complex airplanes. However, during World War II, machine systems were inexplicably failing. Airplanes with well-trained pilots were flying into the ground with no apparent mechanical failures. Experimental psychologists were asked to analyze the human-machine interface to discover what was going wrong and to make recommendations. In many cases, they found that the machine systems were poorly designed and confusing, even for trained personnel. This led to the redesign of existing systems such as the altimeters on airplanes. Scientists also started looking at how best to distribute tasks, according to what people do best and what machines do best. Eventually, they realized that instead of changing systems after problems were found, they should use their knowledge about how humans process information to design more "people-friendly" systems from the start.

Many scientists have studied the problem of how to allocate separate pieces of a task to humans and to machines, respectively. Ernest J. McCormick, in *Human Factors in Engineering and Design* (1976), presented lists of what humans do well and what computers do well. In general, he wrote, humans can respond to perceptual changes in the environment. That is, humans can quickly sense low-level changes in sounds, images, smell, or touch. They can store large amounts of information over long periods of time and retrieve pertinent information. When it is necessary, humans can go beyond the information given to react to unlikely events and create entirely new solutions. Thus, human performance can be described as *flexible*. Although this flexibility is good, it can also cause problems since humans do not exhibit the same response to the same circumstances in every instance. People's responses can vary from one time to the next and can include errors.

By contrast, McCormick's list of machine strengths noted that such devices are good at sensing stimuli outside of the human's normal range of sensitivity (e.g., X-rays, ultraviolet light, and radar wavelengths). Machines can store and retrieve large amounts of information rapidly and respond consistently to signals. They perform repetitive actions reliably such as putting caps on bottles of soda pop and do not get tired or bored, as a human might under similar circumstances. McCormick believed that an understanding of the relative strengths and weaknesses of people and machines would help designers create more effective systems.

Ergonomics and Computers

For people who use computer systems, ergonomic design is crucial. Early computer systems of the 1950s and 1960s were extremely difficult to understand and operate. People had to devote much effort to learning how to manage the technology. In fact, operators of the early mainframe computers formed an elite group of men and women who were sometimes referred to as a "*priesthood* of computers."

As computer technology became more common, it was important to make the technology easier to use by a wide range of people. In the late 1970s, computers evolved to include microcomputers that could be operated by a single person. The first microcomputers were built by their users from components, and users had to write their own programs to make the computer do anything, even play a game. Once the business and education potential for microcomputers was recognized, ease of use became very important. Now, microcomputers are designed for use by store clerks, teachers, business people, students, and children, as well as by people with special needs. These diverse users may not have much training or computer background. This means that the human-computer interface must be carefully designed by user interface designers and ergonomic specialists.

Designers must ensure that the technology is designed with sensitivity to human capacities and needs and that the resulting work environment is safe and comfortable. Ergonomic design considers the physical, psychological, cognitive, and social aspects of the interaction between the human and the machine. Use of computer technology has been associated with several health issues including eye strain, migraine headaches, muscle and body pain (especially backs and shoulders), repetitive stress injuries (e.g., carpal tunnel syndrome) and stress. For example, repetitive stress injuries can be caused by awkward positioning of wrists and hands, extended periods of rapid repetitive motion, and staying in one position for a long time.

Following ergonomic workplace guidelines can help minimize injury. Suggestions by experts include:

- Positioning the screen at or below eye level to avoid muscle strain;
- Reducing glare with glare deflectors and careful positioning of the computer screen;
- Changing lighting to eliminate glare or eye strain;
- Positioning the keyboard low enough to avoid arm and wrist fatigue;
- Using an adjustable desk so that the user's feet are firmly on the floor;
- Positioning the seat back of the chair to support the lower back;
- Taking frequent breaks to stretch shoulders, neck, and wrists;

CARPAL TUNNEL SYNDROME

Ergonomic workstations are intended to relieve repetitive stress injuries that cause problems such as carpal tunnel syndrome (CTS), which causes pain, numbness, tingling, and loss of muscle control in the hands and wrists. Women are more likely to develop the problem than men, especially those who work as secretaries, keyboard users, or office assistants.

Ergonomically correct work stations help reduce eye strain and repetitive stress injuries.

- Training people to use and understand both hardware and software to reduce stress and fear.

The ergonomic principle of flexibility is important to the design of computer technology. People of different sizes, physical characteristics, and varying preferences need equipment that they can adjust. Taller people usually want their computer screens at a height that shorter people would find uncomfortable. Some people see best with desk lamps; others prefer natural light. Many organizations, including the Social Security Administration, microchip maker Intel, and retailer L. L. Bean, have implemented ergonomics programs. These programs include new equipment, workspace design changes, and training programs. Employees learn how to create healthy work environments by adjusting desks and chairs and taking frequent breaks. Companies implementing such programs find they can greatly reduce productivity losses due to work-related injuries. SEE ALSO KEYBOARD; MICROCOMPUTERS.

Terri L. Lenox

Bibliography

McCormick, Ernest J. *Human Factors in Engineering and Design.* New York: McGraw-Hill, 1976.

Shneiderman, Ben. *Designing the User Interface: Strategies for Effective Human-Computer Interaction.* Reading, MA: Addison-Wesley, 1998.

Wickens, Christopher D. *Engineering Psychology and Human Performance.* Glenview, IL: Scott, Foresman and Company, 1984.

Games

The video game entertainment industry is a multi-billion dollar international enterprise that has seen many technological advancements since its inception in the early 1960s. From primitive home entertainment systems wired by simple integrated circuitry to the digitally advanced games of the twenty-first century, the industry has been the proving grounds for some very influential scientific minds. The evolution of games technology has resulted in improvements in the quality of computer graphics for business and educational application as well, and aided design efforts in **virtual reality (VR)** software and the construction of **artificial intelligence (AI)** systems.

virtual reality (VR) the use of elaborate input/output devices to create the illusion that the user is in a different environment

artificial intelligence (AI) a branch of computer science dealing with creating computer hardware and software to mimic the way people think and perform practical tasks

Earliest Games

German-American inventor Ralph Baer (1922–), also known as the "Thomas Edison" of the video game, created the first video game console in 1966. While working for a company called Sanders Associates, he was commissioned to design a portable game for military training exercises based on strategy and reflex skills. Much of the early investment capital for projects at Sanders and in the collegiate think tanks came from the Pentagon. Baer believed the applications he was pursuing for the military would eventually have value in home entertainment.

Even earlier, MIT student Steve Russell brought widespread attention to the ability of computers to play games with his "SpaceWar," which was first played in the labs at Massachusetts Institute of Technology (MIT) on a **mainframe computer**. The 1960 game was a precursor to the much later "Asteroids" that captured the hearts and imaginations of many gaming enthusiasts. "SpaceWar" was later adapted from a mainframe computer game to a stand-alone console, under the name of "Computer Space," but the game met with little commercial success. Other MIT techies invented the first **joysticks** to replace the original games' simple control knobs.

mainframe computer large computer used by businesses and government agencies to process massive amounts of data; generally faster and more powerful than desktop computers but usually requiring specialized software

joysticks the main controlling levers of small aircraft; models of these can be connected to computers to facilitate playing interactive games

Video Games Go Public

The 1970s saw the most significant developments in bringing video games into the attention and the homes of the American public. Nolan Bushnell, a former employee of Ampeg of Sunnyvale, California, teamed up with design engineer Al Alcom to found the company Atari. Bushnell and Alcom designed the first "Pong" game, which was a form of computerized table

PONG ROCKS!

The staff at Andy Capp's bar thought the new Pong machine was defective and asked Atari to remove it. In reality, so many people had played the game, it was filled with quarters and had shorted out.

analog a quantity (often an electrical signal) that is continuous in time and amplitude

tennis, and introduced it to Andy Capp's bar in Sunnyvale. After the first night of public use, people lined up at ten the next morning to play this novel bar game. The video game craze was about to grip the public's attention.

Further popularizing the game craze in the eyes of Americans was the 1972 release of Magnavox's "Odyssey" that was introduced during a television broadcast hosted by the "Chairman of the Board," Frank Sinatra. These first games were quite simple compared to later technologies. Early games were based on **analog** systems using large-scale integrated (LSI) circuits. These game designs offered two-dimensional graphics with a restricted range of motion for participants and often-predictable responses from the computer.

The mid-1970s saw significant improvement in games and especially graphics technology with the introduction of customized microchips. Midway's 1975 game "Gunfight" was the first to utilize a microprocessor. Using an 8080 CPU (central processing unit), the game featured graphic and audio effects that had not been possible before. The simultaneous demand for higher resolution screens and increased depth of field was met by companies like Activision, using the new F8 microchips that were supplied by Fairchild Camera and Instrument.

Violence and Video Games

In 1976 Exidy's "Death Race" video game entered the market. Fashioned after a popular movie at the time, it was one of the games that first sparked public controversy aimed at violent video games. Considering the history of military involvement in early research funding, it is not unusual that the focus of video game design teams resulted in games with highly competitive strategies, a strong emphasis on physical conflict, and action and adventure settings. Many movies of the time period also reflected scenarios depicting violence and adventure: *Jaws* haunted the imaginations of beach-loving moviegoers, while *Star Wars* refreshed popular interest in the exploration and domination of outer space.

Video game violence has not been restricted by public moral outpourings. Games like "Mortal Kombat" continue to win audiences of all ages. Some observers argue that the ability to vent potentially violent aggressions in an electronic setting relieves the pressure to commit public demonstrations of violence. Other critics argue that these games provide a training ground for potentially violent youthful offenders. The 1999 Columbine School massacre in Littleton, Colorado, and other gun-related incidents in public schools throughout the United States are cited as occurrences where the perpetrators had demonstrated a history of fascination with violent games.

Many companies now offer Internet gaming services, which allow up to a few people to thousands of players to play a game simultaneously. Among the most popular applications for these multi-player games are interactive games in which a group of characters, activated by users who may be located geographically anywhere in the world, explore a virtual world to collaborate or kill one another. Regardless of the controversies, graphically sophisticated action video games of all kinds continue to be popular.

Japanese Contributions

No mention of video game technology would be complete without discussion of the Japanese market and its major contributions from the 1980s into the twenty-first century. The year 1980 saw the introduction of the "Pac-Man" game, which was invented by Toru Iwatami and associates for Namco, Ltd. Iwatami, who had tired of much of the violence depicted in video games, decided to develop a comical game that he felt everyone could enjoy.

"Pac-Man" became one of the largest selling arcade games ever, with more than 100,000 units sold in the United States alone, surpassing the then-monumental 70,000 unit record of "Asteroids" and the extremely popular "Space Invaders." Heavy use of the coin-operated "Pac-Man" was blamed for a severe coin shortage in the Japanese economy. The merchandising of "Pac-Man" T-shirts, posters, toys, and spin-off games ("Ms. Pac-Man" and others) would start another trend in home entertainment sales.

While "Pac-Man" and other arcade games grew in popularity during the early 1980s, there was a marked decrease in the sales of video games for home use. Most theories point to Atari's near dominance of the market with its 4-bit VCS console and what the public saw as limited graphical variation in game software available for home units. Nintendo's 1985 introduction of the 8-bit microprocessor dramatically changed the home video game market forever. The Japanese company became the dominant force in gaming technology with its proprietary console, the Nintendo Entertainment System (NES), and such popular games as "Donkey Kong" and "Mario Bros." The advent of 16-bit technology, most successfully marketed in Sega's "Genesis" console, allowed for a much more sophisticated graphics processing system with as many as 63 times more onscreen colors and the use of **anti-aliasing** and screen flipping techniques. This also brought competition to Nintendo's market dominance.

anti-aliasing introducing shades of gray or other intermediate shades around an image to make the edge appear to be smoother

Advanced systems design furthered the competition between Nintendo and Sega and improved the market for video game sales across the globe. The 1990s saw the advent of 32-bit systems and the Nintendo 64 with turbo 3-D graphics, as well as popular hand-held video game units like Nintendo's "GameBoy." Strong competition from Sega's continuing developments and the Sony PlayStation have chipped away at Nintendo's former market position as the leader of the home video game market, but the Japanese influence on the industry remains considerable.

From Video Games to Corporate Giants

The video game industry has nurtured designers and entrepreneurs who have gone on to make major contributions to the computer industry as a whole. Steven Jobs and Steve Wozniak were employees of Atari before leaving to start a small company that grew into a huge corporation—Apple Computer, Inc. While at Atari, Jobs and Wozniak created a game called "Blockbuster." Their game design knowledge and experience would prove influential in their personal computer designs.

Another major player in today's computer marketplace had its roots in video game technology. In 1979 a company called Control Video Corp. offered a service called "Gameline" via the telephone network. Consumers accessed their service using a **1200-baud** modem to receive features including

1200-baud a measure of data transmission; in this case the rate of 1200 symbols (usually bits) per second

The IBM Deep Blue, a two-tower RS/6000 SPS System, took on chess champion Garry Kasparov in 1997 and won.

COMPUTER CHESS

Video game technology has contributed to such monumental events as the Deep Blue Chess Competition. In 1997 IBM challenged then-current world chess champion Garry Kasparov to a match against the company's deep parallel supercomputer Deep Blue, to test the abilities of modern artificial intelligence. The entire match and a subsequent rematch were played online in real time.

Deep Blue won game six of the second match and defeated Kasparov before a hugely impressed global community. This pitting of man against a machine with a massive parallel search system matched a human being who makes perhaps two chess moves each second against an opponent who makes a quarter billion chess position decisions every second.

e-mail, news, banking, and financial management information. CVC became Quantum Computer Services in 1985 and in 1989, the company changed its name to America Online.

Simulation Game Technology

One of the most profoundly powerful gaming metaphors to emerge in the 1990s was the use of simulation technology that allows gamers to explore "what if" scenarios. The field was kicked off by Maxis with the game "SimCity," and was refined with various classics such as Microprose's "Transport Tycoon" and Art Dink's "A-Train."

This technology helps people understand and work within complex systems. Although many enjoy the products as entertainment, simulation games are used for education in schools and corporations. Maxis launched a spin-off to apply this technology to business systems. Chevron created "SimRefinery" to simulate the management of a large refinery operation. Another game called "SimHealth," which was commissioned by the Markle foundation, demonstrates some of the tradeoffs of different health care policies.

A number of war games have also been built around this kind of simulation technology. Some of the earliest hits have been "Warcraft" and "Command and Conquer," which both allow multiple players to create and control production facilities and armies of soldiers that can be directed in real time. These games introduce an element of non-linearity in which players must be able to focus on multiple things simultaneously.

Gaming technology such as this has deep implications for the way decisions are made in our modern society. We can expect to see electronic information systems monitoring the flow of goods and services in the global economy as well as potentially determining strategies that humans will adapt for their environment. SEE ALSO Artificial Intelligence; Game Controllers; Internet; Simulation; Telecommunications.

George Lawton

Bibliography

Burnham, Van. *Supercade: A Visual History of the Video Game Age, 1971–1984.* Cambridge, MA: MIT Press, 2001.

Kent, Steve L. *The Ultimate History of Video Games: From Pong to Pokemon and Beyond—The Story Behind the Craze That Touched Our Lives and Changed Our World.* Roseville, CA: Prima, 2001.

Internet Resources

"Classic Gaming." Game Spy Industries. <www.classicgaming.com>

"The History of Nintendo." Game Spot web site. <www.videogames.com/features/universal/hist_nintendo/>

Generations, Computers

Early modern computers are typically grouped into four "generations." Each generation is marked by improvements in basic technology. These improvements in technology have been extraordinary and each advance has resulted in computers of lower cost, higher speed, greater memory capacity, and smaller size.

This grouping into generations is not clear-cut nor is it without debate. Many of the inventions and discoveries that contributed to the modern computer era do not neatly fit into these strict categories. The reader should not interpret these dates as strict historical boundaries.

First Generation (1945–1959)

The **vacuum tube** was invented in 1906 by an electrical engineer named Lee De Forest (1873–1961). During the first half of the twentieth century, it was the fundamental technology that was used to construct radios, televisions, radar, X-ray machines, and a wide variety of other electronic devices. It is also the primary technology associated with the first generation of computing machines.

vacuum tube an electronic device constructed of a sealed glass tube containing metal elements in a vacuum; used to control electrical signals

The first operational electronic general-purpose computer, named the ENIAC (Electronic Numerical Integrator and Computer), was built in 1943 and used 18,000 vacuum tubes. It was constructed with government funding at the University of Pennsylvania's Moore School of Engineering, and its chief designers were J. Presper Eckert, Jr. (1919–1995) and John W. Mauchly (1907–1980). It was almost 30.5 meters (100 feet) long and had twenty 10-digit registers for temporary calculations. It used **punched cards** for input and output and was programmed with plug board wiring. The ENIAC was able to compute at the rate of 1,900 additions per second. It was used primarily for war-related computations such as the construction of **ballistic** firing tables and calculations to aid in the building of the atomic bomb.

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

ballistic pertaining to ballistics, which is the science and engineering of the motion of projectiles of various types, including bullets, bombs, and rockets

The Colossus was another machine that was built during these years to help fight World War II. A British machine, it was used to help decode secret enemy messages. Using 1,500 vacuum tubes, the machine, like the ENIAC, was programmed using plug board wiring.

These early machines were typically controlled by plug board wiring or by a series of directions encoded on paper tape. Certain computations would require one wiring while other computations would require another. So, while these machines were clearly programmable, their programs were not stored internally. This would change with the development of the stored program computer.

The team working on the ENIAC was probably the first to recognize the importance of the stored program concept. Some of the people involved in the early developments of this concept were J. Presper Eckert Jr. (1919–1955) and John W. Mauchly (1907–1980), and John von Neumann (1903–1957). During the summer of 1946, a seminar was held at the Moore School that focused great attention on the design of a stored program computer. About thirty scientists from both sides of the Atlantic Ocean attended these discussions and several stored programmed machines were soon built.

STEVENSON VS. EISENHOWER

Despite commentators's predictions that Adlai Stevenson would beat Dwight Eisenhower in the 1952 presidential election, the UNIVAC correctly determined that Eisenhower would win.

One of the attendees at the Moore School seminar, Maurice Wilkes (1913–), led a British team that built the EDSAC (Electronic Delay Storage Automatic Calculator) at Cambridge in 1949. On the American side, Richard Snyder led the team that completed the EDVAC (Electronic Discrete Variable Automatic Computer) at the Moore School. Von Neumann helped design the IAS (Institute for Advanced Study) machine that was built at Princeton University in 1952. These machines, while still using vacuum tubes, were all built so that their programs could be stored internally.

Another important stored program machine of this generation was the UNIVAC (UNIVersal Automatic Computer). It was the first successful commercially available machine. The UNIVAC was designed by Eckert and Mauchly. It used more than 5,000 vacuum tubes and employed **magnetic tape** for bulk storage. The machine was used for tasks such as accounting, actuarial table computation, and election prediction. Forty-six of these machines were eventually installed.

magnetic tape a way of storing programs and data from computers; tapes are generally slow and prone to deterioration over time but are inexpensive

The UNIVAC, which ran its first program in 1949, was able to execute ten times as many additions per second as the ENIAC. In modern dollars, the UNIVAC was priced at $4,996,000. Also, during this period, the first IBM computer was shipped. It was called the IBM 701 and nineteen of these machines were sold.

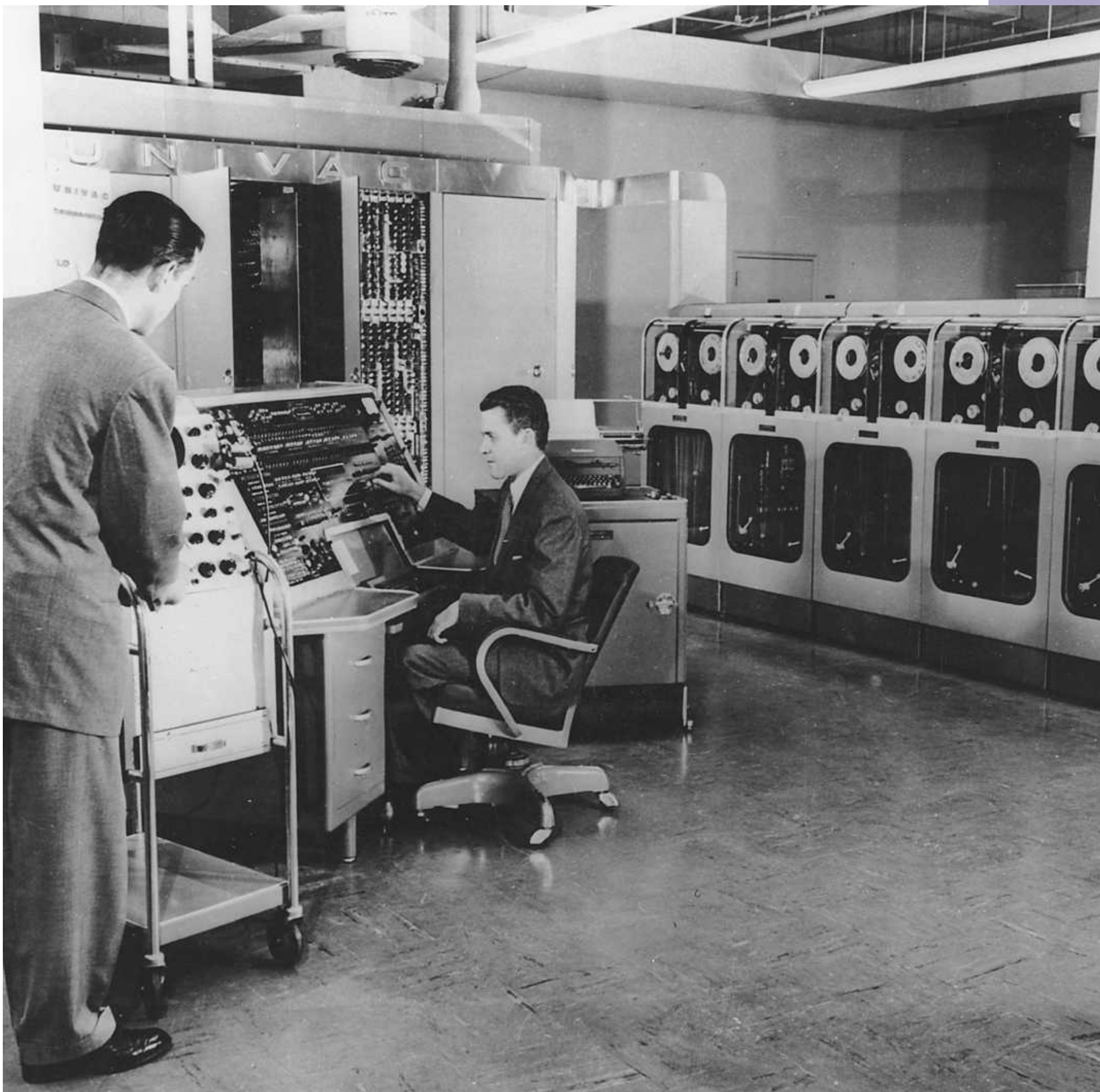
Second Generation (1960–1964)

As commercial interest in computer technology intensified during the late 1950s and 1960s, the second generation of computer technology was introduced—based not on vacuum tubes but on **transistors**.

transistors the plural of transistor, which is a contraction of TRANSfer resISTOR; semiconductor device, invented by John Bardeen, Walter Brattain, and William Shockley, which has three terminals; can be used for switching and amplifying electrical signals

John Bardeen (1908–1991), William B. Shockley (1910–1989), and Walter H. Brattain (1902–1987) invented the transistor at Bell Telephone Laboratories in the mid-1940s. By 1948 it was obvious to many that the transistor would probably replace the vacuum tube in devices such as radios, television sets, and computers.

One of the first computing machines based on the transistor was the Philco Corporation's Transac S-2000 in 1958. IBM soon followed with the transistor-based IBM 7090. These second generation machines were programmed in languages such as COBOL (Common Business Oriented Language) and FORTRAN (Formula Translator) and were used for a wide



variety of business and scientific tasks. Magnetic disks and tape were often used for data storage.

The creation of the UNIVAC, the first electronic computer built for commercial use, began the computer boom.

Third Generation (1964–1970)

The third generation of computer technology was based on **integrated circuit** technology and extended from approximately 1964 to 1970. Jack Kilby (1923–) of Texas Instruments and Robert Noyce (1927–1990) of Fairchild Semiconductor were the first to develop the idea of the integrated circuit in 1959. The integrated circuit is a single device that contains many transistors.

integrated circuit a circuit with the transistors, resistors, and other circuit elements etched into the surface of a single chip of semiconducting material

> **DID YOU KNOW. . . .**
>
> Jack Kilby and Robert Noyce were the founders of the integrated circuit. However, they worked independently of each other for different companies.

Arguably the most important machine built during this period was the IBM System/360. Some say that this machine single handedly introduced the third generation. It was not simply a new computer but a new approach to computer design. It introduced a single computer architecture over a range or family of devices. In other words, a program designed to run on one machine in the family could also run on all of the others. IBM spent approximately $5 billion to develop the System/360.

One member of the family, the IBM System/360 Model 50, was able to execute 500,000 additions per second at a price in today's dollars of $4,140,257. This computer was about 263 times as fast as the ENIAC.

During the third generation of computers, the central processor was constructed by using many integrated circuits. It was not until the fourth generation that an entire processor would be placed on a single **silicon** chip—smaller than a postage stamp.

silicon a chemical element with symbol Si; the most abundant element in the Earth's crust and the most commonly used semiconductor material

Fourth Generation (1970–?)

The fourth generation of computer technology is based on the microprocessor. Microprocessors employ Large Scale Integration (LSI) and Very Large Scale Integration (VLSI) techniques to pack thousands or millions of transistors on a single chip.

The Intel 4004 was the first processor to be built on a single silicon chip. It contained 2,300 transistors. Built in 1971, it marked the beginning of a generation of computers whose lineage would stretch to the current day.

In 1981 IBM selected the Intel Corporation as the builder of the microprocessor (the Intel 8086) for its new machine, the IBM-PC. This new computer was able to execute 240,000 additions per second. Although much slower than the computers in the IBM 360 family, this computer cost only $4,000 in today's dollars! This price/performance ratio caused a boom in the personal computer market.

In 1996, the Intel Corporation's Pentium Pro PC was able to execute 400,000,000 additions per second. This was about 210,000 times as fast as the ENIAC–the workhorse of World War II. The machine cost only $4,400 in inflation-adjusted dollars.

Microprocessor technology is now found in all modern computers. The chips themselves can be made inexpensively and in large quantities. Processor chips are used as central processors and memory chips are used for dynamic **random access memory (RAM)**. Both types of chips make use of the millions of transistors etched on their silicon surface. The future could bring chips that combine the processor and the memory on a single silicon die.

random access memory (RAM) a type of memory device that supports the nonpermanent storage of programs and data; so called because various locations can be accessed in any order (as if at random), rather than in a sequence (like a tape memory device)

During the late 1980s and into the 1990s cached, pipelined, and superscaler microprocessors became commonplace. Because many transistors could be concentrated in a very small space, scientists were able to design these single chip processors with on-board memory (called a **cache**) and were able to exploit instruction level parallelism by using instruction pipelines along with designs that permitted more than one instruction to be executed at a time (called superscaler). The Intel Pentium Pro PC was a cached, superscaler, pipelined microprocessor.

cache a small sample of a larger set of objects, stored in a way that makes them accessible

Also, during this period, an increase in the use of parallel processors has occurred. These machines combine many processors, linked in various ways, to compute results in parallel. They have been used for scientific computations and are now being used for database and file servers as well. They are not as **ubiquitous** as uniprocessors because, after many years of research, they are still very hard to program and many problems may not lend themselves to a parallel solution.

ubiquitous to be commonly available everywhere

The early developments in computer technology were based on revolutionary advances in technology. Inventions and new technology were the driving force. The more recent developments are probably best viewed as evolutionary rather than revolutionary.

It has been suggested that if the airline industry had improved at the same rate as the computer industry, one could travel from New York to San Franscisco in 5 seconds for 50 cents. In the late 1990s, microprocessors were improving in performance at the rate of 55 percent per year. If that trend continues, and it is not absolutely certain that it will, by the year 2020 a single microprocessor could possess all the computing power of all the computers in **Silicon Valley** at the dawn of the twenty-first century. SEE ALSO Apple Computer, Inc.; Bell Labs; Eckert, J. Presper, Jr. and Mauchly, John W.; Integrated Circuits; Intel Corporation; Microsoft Corporation; Xerox Corporation.

Silicon Valley an area in California near San Francisco, which has been the home location of many of the most significant information technology orientated companies and universities

Michael J. McCarthy

Bibliography

Hennessy, John, and David Patterson. *Computer Organization and Design*. San Francisco: Morgan Kaufmann Publishers, 1998.

Rockett, Frank H. "The Transistor." *Scientific American* 179, no. 3 (1948): 52.

Williams, Michael R. *A History of Computing Technology*. Los Alamitos, CA: IEEE Computer Society Press, 1997.

Generations, Languages

Programming languages are the primary tools for creating software. As of 2002, hundreds exist, some more used than others, and each claiming to be the best. In contrast, in the days when computers were being developed there was just one language—machine language.

The concept of language generations, sometimes called levels, is closely connected to the advances in technology that brought about computer generations. The four generations of languages are machine language, assembly language, high-level language, and very high-level language.

First Generation: Machine Language

Programming of the first stored-program computer systems was performed in machine language. This is the lowest level of programming language. All the commands and data values are given in ones and zeros, corresponding to the "on" and "off" electrical states in a computer.

In the 1950s each computer had its own native language, and programmers had primitive systems for combining numbers to represent

MACHINE LANGUAGE

This is an example of a machine language program that will add two numbers and find their average. It is in hexadecimal notation instead of binary notation because that is how the computer presented the code to the programmer. The program was run on a VAX/VMS computer, a product of the Digital Equipment Corporation.

					0000000A		0000
					0000000F		0008
					00000008		0008
							0008
							0058
							0080
FF55	CF	FF54	CF	FF53	CF	C1	00A9
	FF24	CF	FF27	CF	02	C7	00DC
							00E4
							010D
							013D

instructions such as *add* and *compare*. Similarities exist between different brands of machine language. For example, they all have instructions for the four basic arithmetic operations, for comparing pairs of numbers, and for repeating instructions. Different brands of machine language are different languages, however, and a computer cannot understand programs written in another machine language.

In machine language, all instructions, memory locations, numbers, and characters are represented in strings of zeros and ones. Although machine-language programs are typically displayed with the **binary** numbers translated into octal **(base-8)** or hexadecimal **(base-16),** these programs are not easy for humans to read, write, or debug.

binary existing in only two states, such as "on" or "off," "one" or "zero"

base-8 a number system in which each place represents a power of 8 larger than the place to its right (octal)

base-16 a number system in which each place represents a power of 16 larger than the place to its right (hexadecimal)

The programming process became easier with the development of assembly language, a language that is logically equivalent to machine language but is easier for people to read, write, and understand.

Second Generation: Assembly Language

Assembly languages are symbolic programming languages that use symbolic notation to represent machine-language instructions. Symbolic programming languages are strongly connected to machine language and the internal architecture of the computer system on which they are used. They are called low-level languages because they are so closely related to the machines. Nearly all computer systems have an assembly language available for use.

mnemonic a device or process that aids one's memory

Assembly language was developed in the mid-1950s and was considered a great leap forward because it uses **mnemonic** codes, or easy-to-remember abbreviations, rather than numbers. Examples of these codes include A for add, CMP for compare, MP for multiply, and STO for storing information into memory. Like programs written in other programming languages, assembly language programs consist of a series of individual statements or instructions that tell the computer what to do.

Normally an assembly language statement consists of a label, an operation code, and one or more **operands**. Labels are used to identify and reference instructions in the program. The operation code is a symbolic notation that specifies the particular operation to be performed, such as *move*, *add*, *subtract*, or *compare*. The operand represents the register or the location in main memory where the data to be processed is located. However, the format of the statement and the exact instructions available will vary from machine to machine because the language is directly related to the internal architecture of the computer and is not designed to be machine-independent. Machine dependence is a significant disadvantage of assembly language. A program coded in assembly language for one machine will not run on machines from a different or sometimes even the same manufacturer.

operands the elements on which a computer performs the instructions when it is executing a program

The principal advantage of assembly language is that programs can be very efficient in terms of execution time and main memory usage. Nearly every instruction is written on a one-for-one basis with machine language. Since all the instructions of a computer are available to the assembly language programmer, the programmer can readily manipulate individual records, fields within records, characters within fields, and even **bits** within **bytes**.

bits the plural of bit, a single binary digit, 1 or 0—a contraction of Binary digIT; the smallest unit for storing data in a computer

bytes groups of eight binary digits; each represents a single character of text

Programs written in assembly language require a translator to convert them into machine language. An assembly language instruction for multiply, *MP*, has no meaning to the computer because it only understands commands in the form of *11010110*. Therefore, a program called an assembler is needed to translate each assembly language instruction into a machine-language instruction.

Although assembly languages are an improvement over machine language, they still require that the programmer think on the machine's level. Because the level of detail required to write assembly programs is very high, it is easy to make mistakes. Although some programmers still use assembly language to write parts of applications where speed of execution is critical, such as video games, most programmers today think and write in very high-level or fourth-generation languages.

ASSEMBLY LANGUAGE

This is an example of an assembly language program that will add two numbers and will find their average.

The program was run on a VAX/VMS computer, a product of the Digital Equipment Corporation.

```
FIRST:  .LONG 10
SECND:.LONG 15
SUM:          .BLKL        0
AVG:          .BLKL        0
BEGIN PROG1B
              DUMPLONG            FIRST
              DUMPLONG            SECND
              ADDL3               FIRST, SECND, SUM
              DUMPLONG            SUM
              DIVL3               #2, SUM, AVG
              DUMPLONG            AVG
              EXIT
              .END         PROG1B
```

Third Generation: High-Level Language

Third-generation languages spurred the great increase in data processing that occurred in the 1960s and 1970s. During that time, the number of **mainframes** in use increased from hundreds to tens of thousands. The impact of third-generation languages on society has been huge.

mainframes large computers used by businesses and government agencies to process massive amounts of data; generally faster and more powerful than desktop computers but usually requiring specialized software

A programming language in which the program statements are not closely related to the internal characteristics of the computer is called a high-level language. As a general rule, one statement in a high-level programming language will expand into several machine language instructions. This is in contrast to assembly languages, where one statement normally generates one machine language instruction. High-level programming languages were developed to make programming easier and less error-prone.

High-level languages fall somewhere between natural languages and machine languages, and were developed to make the programming process more efficient. Languages like FORTRAN (FORmula TRANslator) and COBOL (COmmon Business Oriented Language) made it possible for scientists and business people to write programs using familiar terms instead of obscure machine instructions. Programmers can now pick from hundreds of high-level languages.

The first widespread use of high-level languages in the early 1960s changed programming into something quite different from what it had been. Programs were written in an English-like manner, making them more convenient to use and giving the programmer more time to address a client's problems.

Although high-level languages relieve the programmer of demanding details, they do not provide the flexibility available in low-level languages. A few high-level languages like C and FORTH combine some of the flexibility of assembly language with the power of high-level languages, but these languages are not well suited to the beginning programmer.

Some third-generation languages were created to serve a specific purpose, such as controlling industrial robots or creating graphics. Others are extraordinarily flexible and are considered to be general-purpose. In the past, the majority of programming applications were written in BASIC (Beginners' All-purpose Symbolic Instruction Code), FORTRAN, or COBOL—all considered to be general-purpose languages. Some other popular high-level languages today are Pascal, C, and their derivatives.

Again, a translator is needed to translate the symbolic statements of a high-level language into computer-executable machine language. The programs that translate high-level programs into machine language are called interpreters and compilers. Regardless of which translator is used, one high-level program statement changes into several machine-language statements. Each language has many compilers, and there is one for each type of computer. The machine language generated by one computer's COBOL compiler, for example, is not the same as the machine language of some other computer. Therefore, it is necessary to have a COBOL compiler for each type of computer on which COBOL programs are to be run.

Using a high-level language makes it easier to write and debug a program and gives the programmer more time to think about its overall logic.

In addition, high-level programs have the advantage of being portable between machines. For example, a program written in standard C can be compiled and run on any computer with a standard C compiler. Since C compilers are available for all types of computers, this program can run as written just about anywhere. However, porting a program to a new machine is not always easy, and many high-level programs need to be partially rewritten to adjust to differences between user interfaces, hardware, compilers, and operating systems.

Fourth Generation: Very High-Level Languages

With each generation, programming languages have become easier to use and more like natural languages. However, fourth-generation languages (4GLs) seem to sever connections with the prior generation because they are basically nonprocedural. Procedural languages tell the computer how a task is done: add this, compare that, do this if something is true, and so on, in a very specific step-by-step manner. In a nonprocedural language, users define only what they want the computer to do, without supplying all the details of how something is to be done.

Although there is no agreement on what really constitutes a fourth-generation language, several characteristics are usually mentioned:

- the instructions are written in English-like sentences;
- they are nonprocedural, so users can concentrate on the "what" instead of the "how";
- they increase productivity because programmers type fewer lines of code to get something done.

An example of a 4GL is the query language that allows a user to request information from a database with precisely worded English-like sentences. A query language is used as a database user interface and hides the specific details of the database from the user. For example, Structured Query Language (SQL) requires that the user learn a few rules of **syntax** and **logic**, but it is easier to learn than COBOL or C. It is believed that one can be ten times more productive in a fourth-generation language than in a third-generation language.

syntax a set of rules that a computing language incorporates regarding structure, punctuation, and formatting

logic a branch of philosophy and mathematics that uses provable rules to apply deductive reasoning

Consider a request to produce a report showing the total number of students enrolled in each class, by teacher, in each semester and year, and with a subtotal for each teacher. In addition, each new teacher must start on a new page. Using a 4GL, the request would look similar to this:

```
TABLE FILE ENROLLMENT
SUM STUDENTS BY SEMESTER BY TEACHER BY CLASS
ON TEACHER SUBTOTAL PAGE BREAK
END
```

Although some training is required to do even this much, one can see that it is fairly simple. Conversely, a third-generation language like COBOL would typically require a few hundred lines of code to fulfill the same request.

4GLs are still evolving, which makes it difficult to define or standardize them. A common perception of 4GLs is that they do not make efficient use of machine resources. The benefits of getting a program finished more quickly, however, can far outweigh the extra costs of running it.

Object-Oriented Languages

Smalltalk, developed in the 1970s by Alan Kay at Xerox's Palo Alto Research Center, was the first object-oriented programming language. In object-oriented programming, a program is no longer a series of instructions, but a collection of objects. These objects contain both data and instructions, are assigned to classes, and can perform specific tasks. With this approach, programmers can build programs from pre-existing objects and can use features from one program in another. This results in faster development time, reduced maintenance costs, and improved flexibility for future revisions. Some examples of object-oriented languages are: C++, Java, and Ada (the language developed by the U.S. Department of Defense).

What will be the next step in the development of programming languages? Future languages will probably have little in common with earlier ones. They will likely be much closer to natural languages. SEE ALSO Algol-60 Report; Algorithms.

Ida M. Flynn

THE DYNABOOK

Alan Kay designed the first object-oriented programming language in the 1970s. Called Smalltalk, the programs were the basis for what is now known as windows technology—the ability to open more than one program at a time on a personal computer. However, when he first developed the idea, personal computers were only a concept. In fact, the idea of personal computers and laptops also belongs to Kay. He envisioned the Dynabook—a notebook-sized computer, with a keyboard on the bottom and a high-resolution screen at the top.

Bibliography

Beekman, George. *Computer Currents. Navigating Tomorrow's Technology.* New York: Benjamin/Cummings Publishing Co., 1994.

Blissmer, Robert H. *Introducing Computers: Concepts, Systems and Applications*. New York: John Wiley & Sons, Inc., 1992.

Brightman, Richard W., and Jeffrey M. Dimsdale. *Using Computers in an Information Age*. Albany, NY: Delmar Publishers Inc., 1986.

Government Funding, Research

Government funding of scientific research has a long and fruitful history. The computer revolution was built by the combined efforts of industry, universities, and governments. One of history's first government research and development grants, excluding support for geographic exploration, was given to Charles Babbage (1791–1871), the father of modern computing, in England, in 1823. Babbage was granted an initial sum of 1,500 pounds by the British government to fund the development of his Difference Engine and later given additional monies.

Some ten years later, Babbage turned his attention to designing a new machine, which he called the Analytical Engine. The Analytical Engine had some innovative features including stored memory, **algorithms**, and the use of **punched cards**. Babbage had some help in describing the machine and in writing programs for it from Ada Byron King, the Countess of Lovelace (1815–1852). Many people consider her the first computer programmer. Although Babbage did not obtain additional funding from the British government to support his work on the Analytical Engine, and the machine itself was a conceptual design rather than a commercial product, the funding of developmental computer research by governmental agencies had begun.

algorithms rules or procedures used to solve mathematical problems—most often described as sequences of steps

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

Just before the start of World War II, Alan Turing (1912–1954) in Cambridge, England, defined the basic theoretical underpinnings of a universal computer. The British defense industry supported his efforts to construct **vacuum tube** computers able to break military codes from the Germans.

vacuum tube an electronic device constructed of a sealed glass tube containing metal elements in a vacuum; used to control electrical signals

After the war, much of what had been learned in government laboratories, industry, and universities was publicized and used by U.S. companies to build an industrial base for computing. New demands for data and data processing were created by the growing consumer economy. Technological advances made since the end of World War II, including many made possible through the financial support of national governments and military agencies, exponentially increased the power of computer technology between 1945 and 1995.

Since the mid-twentieth century, the United States has become a leader in computing and related communications technology. Tabulating machines, **graphical user interfaces (GUIs)**, real-time, online operating systems, the mouse, the ARPANET,* the Internet, and microprocessors have been developed through the interaction of government, universities, and industry. For example, the U.S. Census Bureau was one of the first organizations to use both Herman Hollerith's tabulating machines and punched cards and the first viable electronic computer (UNIVAC I).

graphical user interfaces (GUIs) technologies whereby graphical objects are placed on a computer screen for interaction with the user—examples are icons, menus, and buttons

***The ARPANET was an experimental network designed for the U.S. Department of Defense Advanced Research Projects Agency (ARPA) in 1969.**

Research is a vital part of new advances in computer technology. However, computer manufacturers spend an average of only twenty percent of their research and development budgets on research. Research activities carried out in industrial or university laboratories such as IBM's J. T. Watson Research Center, AT&T's Bell Laboratories, and the Xerox Palo Alto Research Center (PARC) are often funded jointly by industry and government resources.

A recent report by the National Research Council states that in 1996, $1.7 billion was invested in research by computer manufacturers, most of which was carried out in their own facilities. In contrast, federal expenditures for computer research reached almost $960 billion in 1995. Approximately $350 million supported university research; the remainder was distributed to industrial and government laboratories.

The U.S. government provides support for research funding, human resources, and physical facilities (e.g., computers, offices, and equipment). This support for the research infrastructure is intended to create a pool of resources that can benefit a variety of users in both the private and public sectors. For example, when universities receive government support, they can train students, conduct research, and build research facilities.

Federal funding is provided for both basic research and applied research. Federal funding comes from several sources, including the Department of Defense (DoD), which is the largest sponsor of computing and communications research with a particular military emphasis. The DoD's Defense Advanced Research Projects Agency (DARPA) provides more support for computer science research than all other federal agencies combined. By the 1970s, the National Science Foundation (NSF) was the second largest supporter of research in computers and communications. The NSF funds basic and university research, providing between forty and forty-five percent of all basic research funding in computer science.

Computers are often used in government-funded studies. For example, the C.E.S.A.R. body research study conducted in 1999 in Minneapolis, Minnesota, used lasers and other technology to take body measurements. The data were to be used by civilian and military entities in gauging clothing and seat sizes.

Many concepts developed by industry and designed into products received their initial funding from government-sponsored research and large-scale government development programs. Some examples include computer core memories, computer time-sharing, the mouse, network packet switching, computer graphics, **virtual reality (VR)**, **speech recognition** software, and relational databases. The federal government is the primary source of funding for university research in computer science and electrical engineering as well as for research equipment. It is also the primary support for graduate students who study and conduct research in these fields. This support complements industry's efforts to build the technological infrastructure needed to make the United States a leader in computer technology. SEE ALSO Babbage, Charles; Hollerith, Herman; Lovelace, Ada Byron King, Countess of; Tabulating Machines.

virtual reality (VR) the use of elaborate input/output devices to create the illusion that the user is in a different environment

speech recognition the science and engineering of decoding and interpreting audible speech, usually using a computer system

Terri L. Lenox

Bibliography

National Research Council. *Funding a Revolution: Government Support for Computing Research*. Washington, DC: National Academy Press, 1999.

Shurkin, Joel. *Engines of the Mind: The Evolution of the Computer from Mainframes to Microprocessors*. New York: W. W. Norton & Company, 1996.

Hollerith, Herman

American Inventor and Engineer
1860–1929

Born on February 29, 1860, in Buffalo, New York, Herman H. Hollerith was a prolific inventor and a pioneer in data processing. His punched-card tabulating machines, although primitive by modern standards, provided the first viable method of processing vast amounts of information in a timely and cost-effective way. When he died on November 17, 1929, he left behind a technology that, with continued improvement, would eventually lead to the development of the modern computer.

Herman Hollerith.

Hollerith was the son of German immigrants and one of five children. His father died in an accident when Hollerith was only seven, and to support the family, his mother kept a millinery shop, making one-of-a-kind hats for ladies of fashion. At barely nineteen, Hollerith graduated with distinction from Columbia University's School of Mines. One of his professors, who was also a consultant for the U.S. Bureau of the Census, introduced Hollerith to Dr. John Shaw Billings, head of Vital Statistics, who hired the young engineer to assist in the statistical analysis of the 1880 census. Over dinner one evening, Billings discussed the tabulating process and wondered whether it could be mechanized, a question that fired Hollerith's imagination and transformed his life.

Although Hollerith left Washington, D.C., in 1882 to become an instructor of mechanical engineering at Massachusetts Institute of Technology (MIT), he never abandoned the concept of automated tabulation. At MIT, he developed the basic ideas for his machine and the flair for invention that would ultimately result in thirty-one patents.

In 1883 Hollerith received an appointment as an assistant examiner in the U.S. Patent Office and returned to Washington, D.C. As an engineer and statistician, he knew little, if anything, about patent law, but as a fledgling inventor he understood its importance. Eager to learn, he used his three years at the Patent Office to develop a real expertise.

On September 23, 1884, Hollerith filed the first patent application for his tabulating machine. His initial design approach used rolls of perforated paper tape, but these were soon replaced by **punched cards**. Years before, he had watched a train conductor punch tickets that contained brief descriptions of each passenger, including hair and eye color. On the basis of this recollection, he adopted the punched card as a standardized unit for recording and processing information.

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

Punched cards had been introduced in the textile industry more than a century earlier by Joseph-Marie Jacquard (1752–1834), who had designed a mechanical loom. In Jacquard's loom, the hooks lifting the warp threads were controlled by cards perforated to the desired pattern. Hollerith's system used a similar approach but added a new ingredient—electricity. Information was recorded by punching holes on a card with twenty-four vertical columns and twelve punching places in each one. The cards were punched, sorted, and fed by hand into a machine, where electrical contacts were made through the holes as the cards passed through. Selected data were counted on electromechanical tabulators.

> **CENSUS 2000**
>
> In 2000 the U.S. Census Bureau reported the American population at 281,421,906. To calculate the population, the Census Bureau uses survey forms that are processed through tabulating machines. The Census Bureau first began using tabulation machines in 1890 that were designed by Herman Hollerith. At that time, the American population was nearly 63 million.

Hollerith's card processing system was first used in 1886 to tabulate census returns in Baltimore, Maryland, and subsequently in New Jersey and New York City. In 1889, when automated data tabulation systems were evaluated for the 1890 census, the Hollerith Electrical Tabulating Machine won the assignment. Consequently, the 1890 census was counted twice as fast as the previous one, and more than a billion holes were punched to record information from 63 million people.

For independent studies in developing Hollerith's tabulating system, the Columbia School of Mines waived its usual requirements and awarded Hollerith a doctor of philosophy degree in 1890. On September 15 of that year, he married Lucia Talcott, the daughter of a noted civil engineer. The couple had six children: Lucia; Herman, Jr.; Charles; Nan; Richard; and Virginia.

During the decades that followed, Hollerith continued to modify and improve his machines, which were used again in the 1900 census. By that time, they were used in Europe as well. To maximize commercial opportunities, he formed the Tabulating Machine Company in 1896 and successfully promoted his machines to insurance companies, department stores, and railroads.

In 1911 the Tabulating Machine Company became part of the Computing-Tabulating-Recording Company, a small conglomerate that was renamed the International Business Machines (IBM) Corporation in 1924. Hollerith continued as a consultant and director until 1914, when he retired to a farm in Virginia's Tidewater country. On November 17, 1929 he died of a heart attack at the age of sixty-nine, but his concept, although improved over the years, remained the basis of the information processing industry well into the 1940s. SEE ALSO Generations, Computers; IBM Corporation; Mainframes; Tabulating Machines; Watson, Thomas J., Sr.

Karen E. Esch

Bibliography

Austrian, Geoffrey D. *Herman Hollerith: Forgotten Giant of Information Processing.* New York: Columbia University Press, 1982.

Bernstein, Jeremy. *The Analytical Engine: Computers—Past, Present, and Future.* New York: Random House, 1963.

Goldstine, Herman H. *The Computer from Pascal to von Neumann.* Princeton, NJ: Princeton University Press, 1972.

Luebbert, William F. "Hollerith, Herman." In *Encyclopedia of Computer Science and Engineering*, ed. Anthony Ralston and Edwin D. Reilly, Jr. New York: Van Nostrand Reinhold, 1983.

Morison, Elting E. *From Know-How to Nowhere: The Development of American Technology.* New York: Basic Books, 1974.

Hopper, Grace

American Mathematician
1906–1992

A mathematician and computer programmer, Grace Murphy Hopper worked extensively with computers—including the Mark I, II, and III—

throughout her career. She joined the U.S. Naval Reserves, distinguishing herself by working with computer languages as well as by becoming one of the first female rear admirals in history. Remembered for her work with Common Business Oriented Language (COBOL), she is also credited with coining the term "computer bug."

Born in New York City on December 9, 1906, Hopper was the eldest of three children. Early in life, she expressed an interest in how devices work and began taking apart various alarm clocks. Hopper's parents believed that girls should be encouraged to learn and should have the same educational opportunities as boys, a unusual position to take in the early 1900s. Her father instilled the belief that Hopper could do anything she determined to do, regardless of her gender. This belief, coupled with her natural inquisitiveness, especially in how gadgets worked, and her innate determination, informed her approach to problem solving.

HONORARY TITLES

Grace Hopper was well respected for her contributions to computer sciences. In fact, she earned the nicknames "Grand Old Lady of Software" and "Amazing Grace."

When she was sixteen, Hopper applied to Vassar College but had to wait a year before she could attend as she had failed the Latin exam. She spent that year at Hartridge School in New Jersey. The following year, Vassar accepted her; four years later, in 1928, she graduated Phi Beta Kappa with a B.A. in mathematics and physics.

Upon graduation Hopper became a mathematics graduate student at Yale. After receiving her master's degree, Hopper returned to Vassar as an instructor while continuing her graduate studies. In 1934 she became the first woman to earn a doctorate in mathematics from Yale. Hopper remained at Vassar until 1943 when, during World War II, she took a leave of absence to join the U.S. Navy. Her age, gender, and low body weight all worked against her enlisting in the military. It took a waiver of the weight requirement and special government permission for Hopper to join the WAVES (Women Accepted for Volunteer Emergency Service) as part of the U.S. Naval Reserves.

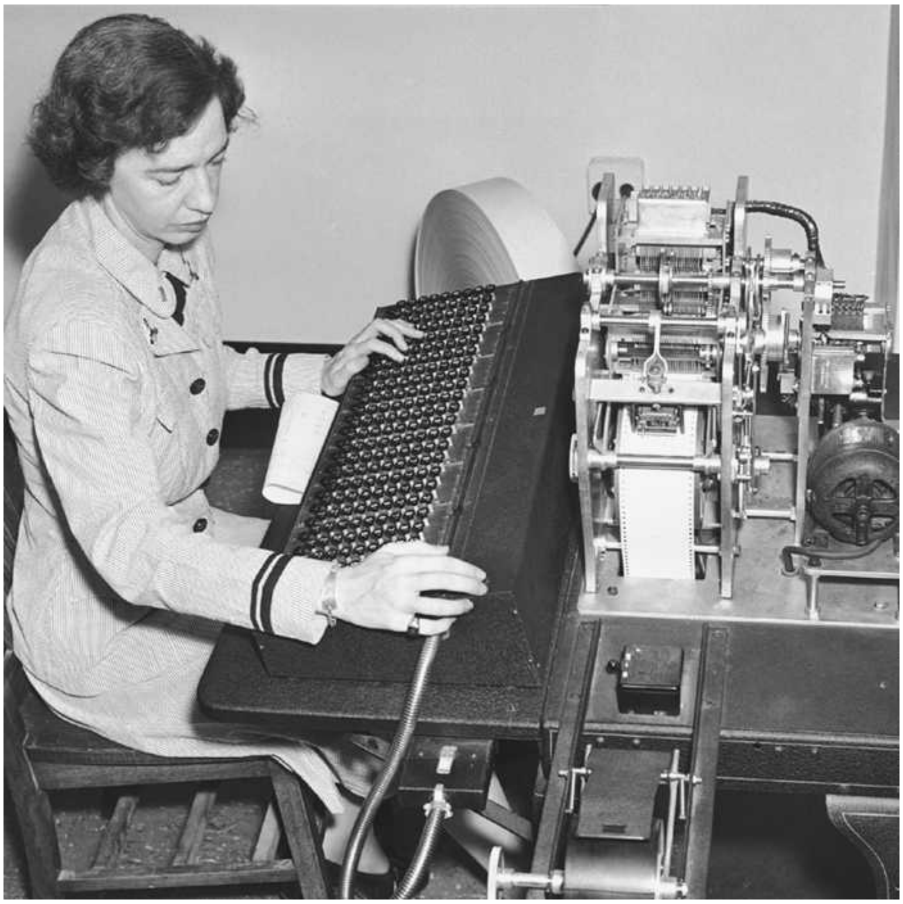
After graduating first in her class from the Midshipman's School for Women, Hopper was assigned to the Bureau of Ordnance Computation at Harvard University. Her first assignment was to program the Mark I computer to calculate the coefficients of the **arc tangent** series. The Mark I was another gadget for Hopper to explore and understand. Hopper put together a manual of operations that included an outline of the fundamental operating principles of computers.

arc tangent the circular trigonometric function that is the inverse of the tangent function; values range from $-\pi/2$ to $\pi/2$

At the end of the war in 1945, Hopper was working on the Mark II. It was during this time that she was credited for coining the term "bug." The story is that a moth flew in through a window and became trapped in the computer relays, causing a shutdown. The moth, after being extracted from the computer, was placed in the log book and labeled "computer bug."

In 1946 Hopper was released from active military duty. Rather than return to Vassar, she accepted an appointment at Harvard as a research fellow. The position allowed her to continue working on the Mark II and the Mark III until 1949. At that time she accepted a position as senior mathematician at Eckert-Mauchly Corporation, which introduced the BINAC (Binary Automatic Computer). This computer was programmed using C-10 code instead of the **punched cards** used by the Mark series of machines.

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data



Grace Hopper coined the term "computer bug" after a moth got into her computer and caused it to malfunction.

With the development of a new computer, UNIVAC (Universal Automatic Calculator) I, Hopper worked on developing a compiler, the A-0, for translating symbolic mathematical notations into binary, machine language. After two more generations of the compiler, Hopper proposed developing a compiler that would recognize English commands. Hopper succeeded by developing the B-0 compiler, which became known as Flow-Matic. Using Flow-Matic, the UNIVAC could be used for business applications such as payroll calculations and to automate billing functions. The Flow-Matic served as the foundation for COBOL, which debuted in 1959.

Hopper continued working on related problems such as setting standards for compilers and programming language. In 1966 she retired from the U.S. Navy with the rank of commander. About seven months into retirement, she was called back to help standardize high-level naval computer languages. The reappointment was initially for six months but was later extended indefinitely. In 1973 Hopper was promoted to captain and in 1977 became special adviser to the commander, Naval Data Automation Command (NAVDAC). Hopper remained in this position until she retired. She was promoted to the rank of commodore by presidential appointment and elevated to the rank of rear admiral. Hopper retired after forty-three years of service in 1986. She was eighty years old, the oldest active duty officer and one of the first women to achieve the rank of rear admiral. After retirement, Hopper served as a senior consultant to Digital Equipment Corporation (DEC).

While in the U.S. Navy, Hopper taught as a guest lecturer at various colleges and universities. She received many awards and honors. In 1969 Hopper was named the first computer science "Man of the Year" by the Data Processing Management Association, and in 1991, President George H. Bush awarded her the National Medal of Technology. Rear Admiral Grace Hopper died on January 1, 1992 and was buried with military honors in Arlington National Cemetery in Virginia. The U.S.S. Grace Hopper was named in her honor. SEE ALSO TELECOMMUNICATIONS.

Bertha Kugelman Morimoto

Internet Resources

U.S. Navy. <http://www.norfolk.navy.mil/chips/grace_hopper/>

Women's International Center. <http://www.wic.org/>

Hypertext

Hypertext is normally defined as accessing information in a non-linear fashion. Predating the emergence of computers by a few years, it was first suggested in 1945 by inventor, scientist, and teacher Vannevar Bush (1890–1974).

Bush was science adviser to President Franklin Delano Roosevelt during World War II—an era full of scientific advances, including nuclear capabilities. But he is best remembered for his idea to create an interactive, cross-referenced system of scientific research, and is considered by some as the grandfather of hypertext. Bush developed plans to build a system, called Memory Extender (Memex), because he was worried about the sudden increase of scientific information, which made it difficult for specialists to follow developments in their disciplines. Bush explored different ways to allow people to find information faster and easier.

Memex was supposed to be a machine that would hold thousands of volumes in a very small space and would allow users to retrieve any requested information just by touching a few buttons. Although the Memex was never implemented, computer scientists like Douglas Engelbart and Theodor (Ted) Nelson were inspired by Bush's ideas and became pioneers in the development of interactive systems.

The hypertext field remained dormant until Engelbart started work in 1962 on one of the first major projects related to office automation and text processing. This project was conducted at the Stanford Research Institute (SRI) and was demonstrated in 1968 at a special session of the Fall Joint Computer Conference. This first public presentation of many of the basic ideas in interactive computing was risky, but it changed the way people thought about computers.

Many miles from the conference site, Engelbart and a co-worker controlled a stream of computer graphics and text and video images that were displayed on a large screen. This system, called Augment, was years ahead of its time because it introduced the mouse and video display editing. It allowed mixing text and graphics, and implemented windows. It also demonstrated video conferencing and hypermedia. Engelbart introduced what is now known as an interactive multimedia workstation.

DOUGLAS ENGELBART

Douglas Engelbart is known as one of the creators of hypertext linking. But that is not all he is known for doing. Engelbart is reputed to be the inventor of the pointing cursor, shared-screen teleconferencing, e-mail, and the mouse. For his lifelong achievements in the field of technology, he was awarded the U.S. National Medal of Technology in 2000.

Nelson coined the word "hypertext" in 1965 while working on a computer system, Xanadu, that was to serve as storage for everything that anybody had ever written. Plans allowed access to those documents from anywhere in the world. Because it demanded a certain degree of computing power, storage, graphics, user interface, and networking sophistication, hypertext did not gain widespread public attention until Apple Computer, Inc. introduced HyperCard in 1987.

Hypertext was important because it presented two fundamental changes in the storage and retrieval of data. The first was the capability to move rapidly from one part of a document to another by means of an associative link. The sequential pattern of reading so familiar from the print world was replaced by a truly interactive format. The second change was the capability of sharing information across different machines and systems. Hypertext built upon the advances made in networking to provide transparent access to data regardless of where it was located. In short, hypertext is about connectivity within and across databases. SEE ALSO Apple Computer, Inc.; Hypermedia and Multimedia; World Wide Web.

Ida M. Flynn

Bibliography

Beekman, George, and Eugene Rathswohl. *Computer Confluence*, 2nd ed. Reading, MA: Addison-Wesley, 1999.

Nielsen, Jakob. *Hypertext and Hypermedia*. San Diego, CA: Academic Press, Inc., 1990.

Shneiderman, Ben, and Greg Kearsley. *Hypertext Hands-On!* Reading, MA: Addison-Wesley, 1989.

IBM Corporation

Although IBM holds many patents in computer-related technology, it did not invent the computer. IBM did, however, play a significant role in the development of commercial applications for emerging computer technology.

IBM's Beginnings

The history of the IBM Corporation can be traced to the year 1890, when a new process to record census information was developed by German immigrant Herman Hollerith (1860–1929). He developed a code that could be punched into holes in cardboard cards to represent data. These holes could then be sensed electrically by his punched card tabulating machine to sort or total the data represented by the **punched cards**. Hollerith's code was adopted by the U.S. Census Bureau and was still widely used into the 1960s. In 1896 Hollerith created the Tabulating Machine Company to market his product.

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

Hollerith's company merged with the Computing Scale Company of America and the International Time Recording Company in 1911 to form the Computing-Tabulating-Recording Company or C-T-R. In addition to Hollerith's tabulating machine, the new company also made time clocks, meat and cheese slicers, and a unique new calculating scale.

The Early Watson Years

In 1914 Thomas J. Watson was hired from the National Cash Register (NCR) Company as the firm's general manager. Watson was an effective leader—stern but compassionate, motivated yet ethical. He dramatically grew the company's revenues, consolidated its products, and expanded its operations internationally. In 1924 he formally changed C-T-R's name to International Business Machines Corporation (IBM). Watson's success was based on two key beliefs: that employees are truly a valuable asset and should be treated as such, and that his customers' success would be his number one goal.

Due to the high initial costs of his product, Watson leased his equipment to customers. This enabled IBM to enjoy a regular stream of income throughout the economic pitfalls of the Great Depression of the 1930s. While other companies were laying off employees and declaring bankruptcy, Watson was building a large inventory of data processing equipment based on Hollerith's system. This helped IBM land the massive data processing contract for the new Social Security Administration in 1935. Continuing production through the Depression was a big gamble, but it worked.

In 1937 Watson hired his son Thomas J. Watson Jr. as a salesman, and the next leader of IBM began his training. He would eventually become chief executive officer in 1956, the year his father died.

Early in his career, T. J. Jr. became enamored with the idea of electronic calculation as opposed to the mechanical approach. His dreams became reality in 1944 with the Mark I, a large-scale electronic calculating "computer" developed at Harvard with IBM support. This was followed by the 701 in 1952 and the RAMAC 305 in 1956. These early machines were experimental, rather than commercially viable units. They were built using vacuum tubes and relays, and were so expensive that only a few of the largest companies and the federal government could afford them.

THINK ABOUT IT

"THINK" became the daily directive for IBM and was printed on signs throughout the company. IBM's focus was on quality and customer service. "IBMers" made sure their equipment worked to the benefit of the customer. In the complex and precarious world of data processing, the statement "No one ever got fired for buying IBM" became an industry adage.

Creating an Industry Standard

In the 1960s the computer industry centered on the development of the mainframe computer. IBM was the best-known name in the commercialization of the mainframe computer for business use, but it was not the only company developing computer technology. Other players in the mainframe computer industry in the early 1960s included RCA, Sperry Rand, Burroughs, and NCR.

No standardization existed for computer design and programming, so computers from each of these companies were incompatible with each other in both hardware and software. Often, even new computers released by a given manufacturer were not compatible with their predecessors. In this atmosphere of industry fragmentation, T. J. Jr. took a gamble as significant as the one his father made during the Great Depression. Betting on a technological evolution generically called the **microchip**, IBM developed Solid Logic Technology (SLT) and designed a bold, new commercial computer system, the System/360, around it.

microchip a common term for a semiconductor integrated circuit device

transistor a contraction of TRANSfer resISTOR; a semiconductor device, invented by John Bardeen, Walter Brattain, and William Shockley, which has three terminals; can be used for switching and amplifying electrical signals

Computers of the early 1960s were based on the **transistor**, which had been invented by Bell Labs. While the transistor was a major improvement over the vacuum tube, it still was a discrete component. Only a limited number of discrete components could be connected together to make a bigger computer that would still be reliable and as fast as its predecessors. In comparison, SLT chips could hold hundreds of transistors on a single

0.64-centimeter (0.25-inch) square silicone wafer, thus breaking through the discrete component limitation.

Although SLT was a significant hardware advance, the software was even bigger. OS/360 was developed as the standard operating system. It would remain constant through the evolution of the 360, 370, and 390 and would always be compatible with the versions before it.

The enormity of the 360 project taxed IBM to the breaking point. At times, the junior Watson's dream took on nightmarish proportions. He had literally bet the company on the success of the 360. Eventually, his staunch belief in his father's business approach prevailed over the technical problems. The IBM System/360 was announced in 1964 and IBM became the predominant—and, at times the only—mainframe computer manufacturer.

Eventually, the S/360 evolved into the S/390. The standard of the mainframe industry, S/390 has turned out to be one of IBM's most enduring and valuable products. There are only two major competitors, Hitachi and Fujitsu, both of which make clone computers which emulate the instructions of the S/390. These machines use the IBM OS/390 operating system, which provides IBM with a large amount of ongoing revenue.

IBM's strategies proved so powerful that its competition gradually disappeared. As IBM grew in size and became the dominant force in the industry, it achieved monopoly status and the government took action to rein in the giant. Three separate and enormously draining anti-trust suits were filed between 1932 and the 1980s. The U.S. Justice Department finally prevailed in undoing IBM's dominance. Although the final suit was settled as being without merit, IBM had become a victim of its own success.

Starting in 1914, the Watsons had built a vast, highly respected, and profitable company known for its ethics and honest concern for customers and employees. T. J. Jr.'s retirement in 1971 marked the start of a succession of CEOs and, some say, a general decline at IBM.

Birth of the IBM-PC

By the late 1970s, it was possible to make a functional computer that would fit on an individual's desktop. Great debates took place at IBM over the development of such a unit. The main detractors were the executives in charge of the mainframe program, who considered the development of individual computers a threat to the demand for mainframe computers.

In 1981 John R. Opel was named CEO. He ordered the creation of the personal computer. Internal opposition to this decision was so strong that Opel set up a separate lab in Boca Raton, Florida, to create and manufacture the device. This was geographically as far away from the mainframe and storage advocates as he could place it. Phil Estridge, the leader of the PC project, was given a great deal of autonomy to make decisions necessary to carry out his mission.

While IBM had a huge internal staff of programmers and processor designers, they were all too busy and their departments were too bureaucratic to help with the PC project. Estridge turned instead to two new startup companies for help: Intel and Microsoft. Intel would design and manufacture the microprocessors and Microsoft would develop the operating system based on DOS (Disk Operating System).

IBM continues to investigate and experiment with new technologies. An e-newspaper reader, under development at IBM, allows users to download articles via wireless access to news sources and display the articles on flexible panels for easy reading.

In an attempt to foster acceptance of the IBM-PC, Estridge decided the architecture would be "open," thus fostering the development of complementary attachments. This was in stark contrast to the strategy of competitors Apple and PET. The result was that the IBM-PC was the most successful architecture of all the PC approaches.

Unfortunately for IBM, the company does not own any of it. Estridge failed to obtain the ongoing rights to the intellectual property IBM was paying Microsoft and supporting Intel to develop.

In 1992, during the John Akers administration, IBM finally crashed. It had amassed many more employees than it really needed. Facing losses for the first time in decades, IBM divested itself of more than 100,000 employees, mostly through generous early retirement programs.

Akers left IBM in 1993 as the stock price hit an all-time low. The board hired Louis V. Gerstner Jr., the former CEO of RJR Nabisco, Inc. and American Express. He immediately started to attack the entrenched bureaucracy and redefine the company. Gerstner inherited many problems stemming from decisions made by his predecessors; for example, in 1998, IBM's PC division lost more than $900 million dollars. However, Gerstner has worked to resolve the profitability problem and restore the stock price. Under his leadership, IBM may be expected to pursue growth in the professional, outsourcing, and Internet services businesses. SEE ALSO HOLLERITH, HERMAN; INTEL CORPORATION; MAINFRAMES; WATSON, THOMAS J., SR.

Ken Doerbecker

Bibliography

Austrian, Geoffrey D. *Herman Hollerith*. New York: Columbia University Press, 1982.

Foy, Nancy. *The Sun Never Sets on IBM*. New York: Morrow, 1975.

Rodgers, William. *Think: A Biography of the Watsons and IBM*. New York: Stein and Day, 1969.

Watson, Thomas J. *A Business and Its Beliefs*. New York: McGraw-Hill, 1963.

Internet Resources

IBM Corporation. "The Story of IBM." <http://www.ibm.com/ibm/history/>

Information Retrieval

Information retrieval, commonly referred to as IR, is the process by which a collection of information is represented, stored, and searched in order to extract items that match the specific parameters of a user's request—or query—for information. Though information retrieval can be a manual process, as in using an index to find certain information within a book, the term is usually applied when the collection of information is in electronic form, and the process of matching query and document is carried out by computer. The collection usually consists of text documents (either bibliographic information such as title, citation and abstract, or the complete text of documents such as journal articles, magazines, newspapers, or encyclopedias). Collections of multimedia documents such as images, videoclips, music, and sound are also becoming common, and information retrieval methods are being developed to search these types of collections as well.

The information retrieval process begins with an information need—someone (referred to as the user) requires certain information to answer a question or carry out a task. To retrieve the information, the user develops a query, which is the expression of the information need in concrete terms ("I need information on whitewater rafting in the Grand Canyon").

The query is then translated into the specific search strategy best suited to the document collection and search engine to be searched (for example, "whitewater ADJ rafting AND grand ADJ canyon" where ADJ means "adjacent" and AND means "and"). The search engine matches the terms of the search query against terms in documents in the collection, and it retrieves the items that match the user's request, based on the matching criteria used by that search engine. The retrieved documents can be viewed by the user, who decides whether they are relevant; that is, whether they meet the original information need.

Information retrieval is a complex process because there is no infallible way to provide a direct connection between a user's query for information and documents that contain the desired information. Information retrieval is based on a match between the words used to formulate the query and the words used to express concepts or ideas in a document. A search may fail because the user does not correctly guess the words that a useful document would contain, so important material is missed. Or, the user's search terms may appear in retrieved documents that pertain to a subject other than the one intended by the user, so material is retrieved which is not useful. Research in information retrieval has aimed at developing systems which minimize these two types of failures.

History of Information Retrieval

Almost as soon as computers were developed, information scientists suggested that the new machines had the potential to perform text processing as well as arithmetical operations. By representing text as **ASCII** characters, queries formulated as character strings could be matched against the character strings in documents. The first computer-based IR systems, which appeared in the 1950s, were based on **punched cards**. These were followed in the 1960s by systems based on storage of the database on **magnetic tape**.

These first systems were hampered by the limited processing power of early computers, and the limited capacity for and high cost of storage. They operated **offline**, in a **batch processing** mode. It was not until the 1970s that IR systems made it possible for users to submit their queries and obtain an immediate response, allowing them to view the results and modify their queries as needed. The development of magnetic disk storage and improvements in telecommunications networks at this time made it possible to provide access to IR systems nationwide.

At first very little textual information was available in electronic form, though printed indexing and abstracting services for manual searching had been available for many years. Over time, however, a significant back file of a number of databases was created, making it realistic to do a retrospective search for literature on a given topic.

One of the best known commercial information systems is DIALOG, which currently has hundreds of databases containing many types of information—newspapers, encyclopedias, statistical profiles, directories, and full-text and bibliographic databases in the sciences, humanities, and business. Another well-known commercial system is LEXIS-NEXIS, which is widely used for its full-text collection in business and particularly law, since it provides computer searching of statutes and case law.

Much early work in information retrieval was conducted at U.S. government institutions such as the National Aeronautics and Space Administration (NASA) and the National Library of Medicine (NLM), and included the forerunners of today's systems. Versions of the DIALOG system were first operated by NASA and the Atomic Energy Commission; it later became a commercial system. The MEDLINE system operated by NLM today originated in an experimental system for searching their medical database, MEDLARS.

Boolean Information Retrieval

For many years, the standard method of retrieval from commercially available databases was Boolean retrieval. In Boolean retrieval, queries are constructed by combining search terms with the Boolean operators *AND*, *OR*,

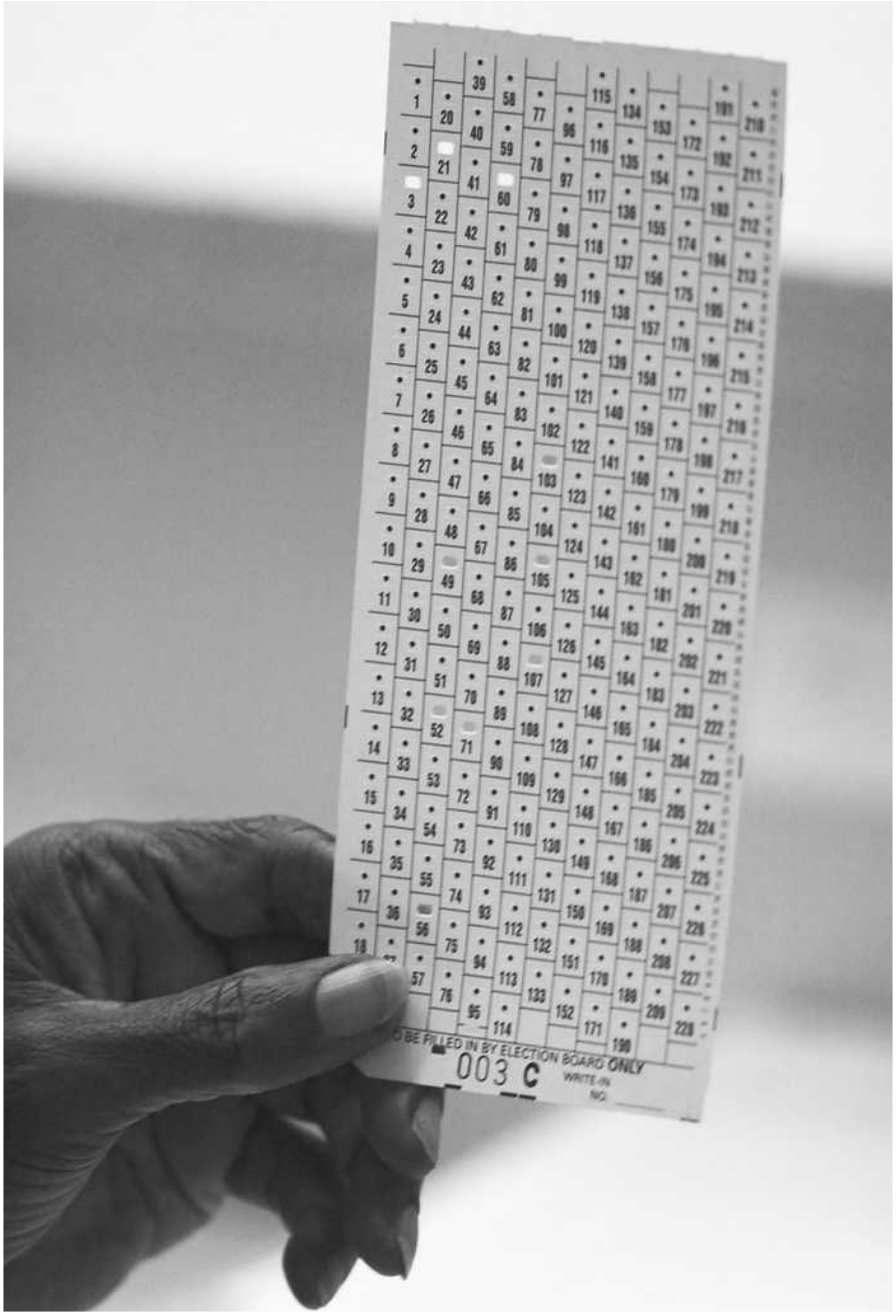
ASCII an acronym that stands for American Standard Code for Information Interchange; assigns a unique 8-bit binary number to every letter of the alphabet, the digits, and most keyboard symbols

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

magnetic tape a way of storing programs and data from computers; tapes are generally slow and prone to deterioration over time but are inexpensive

offline the mode of operation of a computer that applies when it is completely disconnected from other computers and peripherals (like printers)

batch processing an approach to computer utilization that queues non-interactive programs and runs them one after another



Punched cards were used for information retrieval in the 1950s. They are still in use today for various applications, including voting in U.S. elections.

and *NOT*. The system returns those documents which exactly match the search terms and the logical constraints.

In addition to the basic AND, OR, NOT operators, most operational Boolean systems offer proximity operators so that searchers can specify that terms must be adjacent or within a fixed distance of one another. This allows the specification of a phrase as a search term, for example "grand ADJ canyon," meaning "grand" must be adjacent to "canyon" in retrieved documents. Many other functions are commonly available, such as the ability to search specific parts of a document, to search many databases simultaneously, or to remove duplicates. However the basic functionality in commercial systems remains the standard Boolean search.

Problems with Boolean Retrieval

Boolean searching has been criticized because it requires searchers to understand and apply basic Boolean logic in constructing their search strategies, rather than posing their queries in natural language. Another criticism is that Boolean searching requires that terms in the retrieved document exactly match the query terms, so potentially useful information may be missed because a document does not contain the specific term the searcher thought to use. A Boolean search essentially divides a database into two parts: documents that match and those that do not match the query. The number of documents retrieved may be zero, if the query was very specific, or it could be tens of thousands if very common terms were used. All documents retrieved are treated equally so the system cannot make recommendations about the order in which they should be viewed. Because of its complexity, Boolean searching has often been carried out by information professionals such as librarians who act as research intermediaries for their patrons.

Boolean retrieval has also been criticized on the basis of performance. The standard measures of performance for IR systems are precision and recall. Precision is a measure of the ability of a system to retrieve *only* relevant documents (those which match the subject of the user's query). Recall is a measure of the ability of the system to retrieve *all* the relevant documents in the system. Using these measures, the performance of Boolean systems has been criticized as inadequate, leading to the continuing search for other ways to retrieve information electronically.

A BOOLEAN SEARCH EXAMPLE

A Boolean search for "winter AND Yosemite AND camping" would only retrieve documents which contained all three words "winter," "Yosemite," and "camping" since the AND operator requires that a term be present. The OR operator allows one of the terms to be present, and the NOT operator rejects documents if a term is present. A more complex search, "winter AND (Yosemite OR Yellowstone) AND skiing NOT downhill" would retrieve all documents which referred to skiing in either Yosemite or Yellowstone in winter, unless there was a specific reference to downhill. Of course, the documents would have to match the search terms exactly, so a document discussing skiing in Yosemite in January would not be retrieved unless it specifically mentioned the word *winter*.

Alternatives to Boolean Retrieval

Since the 1960s and 1970s, IR researchers explored ways to improve the performance of information retrieval systems. Gerard Salton (1927–1995), a professor at Cornell University, was a key figure in this research. For more than thirty years, he and his students worked on the *Smart* system, a research environment that allowed them to explore the impact of varying parameters in the retrieval system. Using measures such as precision and recall, he and other researchers found that performance improvements can be made by implementing systems with features such as term weighting, ranked output based on the calculation of query-document similarity, and relevance feedback.

In these systems, documents are represented by the terms they contain. The list of terms is often referred to as a document vector and is used to position the document in N-dimensional space (where N is the number of unique terms in the entire collection of documents). This approach to IR is referred to as the "vector space model."

For each term, a weight is calculated using the statistics of term frequency, which represents the importance of the term in the document. A common method is to calculate the *tfxidf* value (term frequency x inverse document frequency). In this model the weight of a term in a document is proportional to the frequency of occurrence of the term in the document, and inversely proportional to the frequency with which the term occurs in the entire document collection. In other words, a good index term is one that occurs frequently in a particular document but infrequently in the database as a whole.

The query is also considered as a vector in N-dimensional space, and the distance between a document and a query is an indication of the similarity, or degree of match, between them. This distance is quantified by using a distance measure, commonly a similarity function such as the **cosine** measure. The results are sorted by similarity value and displayed in order, best match first.

cosine a trigonometric function of an angle, defined as the ratio of the length of the adjacent side of a right-angled triangle divided by the length of its hypotenuse

The relevance feedback feature allows the user to examine documents and make some judgments about their relevance. This information is used to recalculate the weights and rerank the documents, improving the usefulness of the document display.

These systems allow the user to state an information need in natural language, rather than constructing a formal query as required by Boolean systems. The ranked output also imposes an order on the documents retrieved, so that the first documents to be viewed are most likely to be relevant. The search is modified automatically based on the user's feedback to the system.

More recently, information retrieval systems have been developed to search the World Wide Web. These search engines use software programs called crawlers that locate pages on the web which are indexed on a centralized server. The index is used to answer queries submitted to the web search engine. The matching **algorithms** used to match queries with web pages are based on the Boolean or vector space model.

algorithms rules or procedures used to solve mathematical problems—most often described as sequences of steps

Individual search engines vary in terms of the information on the web page that they index, the factors used in assigning term weights, and the ranking algorithm used. Some search engines index information extracted from **hyperlinks** as well as from the text itself. Because information on the search engine is usually **proprietary**, details of the algorithms are not readily available. Comparisons of retrieval performance are also difficult because the systems index different parts of the web and because they undergo constant change. Recall is impossible to measure because the potential number of pages relevant to a query is so large.

hyperlinks connections between electronic documents that permit automatic browsing transfer at the point of the link

proprietary a process or technology developed and owned by an individual or company, and not published openly

The Future of Information Retrieval

Researchers continue to improve the performance of information retrieval systems. An ongoing series of experiments called TREC (Text Retrieval Evaluation Conference) is conducted annually by the National Institute of Standards and Technology to encourage research in information retrieval and its use in real-world systems.

One long-term goal is to develop systems that do more than simply identify useful documents. By considering a database as a knowledge base rather than simply a collection of documents, it may be possible to design retrieval systems that can interpret documents and use the knowledge they contain to answer questions. This will require developments in **artificial intelligence (AI)**, natural language processing, **expert systems**, and related fields. Research so far has concentrated primarily on relatively narrow subject areas, but the goal is to create systems that can understand and respond to questions in broad subject areas. SEE ALSO Boolean Algebra; E-commerce; Search Engines; World Wide Web.

artificial intelligence (AI) a branch of computer science dealing with creating computer hardware and software to mimic the way people think and perform practical tasks

expert systems computer systems that use a collection of rules to exhibit behavior which mimics the behavior of a human expert in some area

Edie M. Rasmussen

Bibliography

Bourne, Charles P. "On-line Systems: History, Technology and Economics." *Journal of the American Society for Information Science* 31 (1980): 155–160.

Hahn, Trudi Bellardo. "Pioneers of the Online Age." *Information Processing and Management* 32 (1996): 33–48.

Korfhage, Robert R. *Information Storage and Retrieval*. New York, NY: John Wiley and Sons, 1997.

Lancaster, F. Wilfred, and Amy J. Warner. *Information Retrieval Today*. Arlington, VA: Information Resources Press, 1993.

Meadow, Charles T. *Text Information Retrieval Systems*. San Diego, CA: Academic Press, 1992.

Salton, Gerard. *Automatic Text Processing: The Transformation, Analysis, and Retrieval of Information by Computer*. Reading, MA: Addison-Wesley Publishing Company, 1989.

Information Technology Standards

Standards are quantifiable metrics to which parties adhere for purposes of allowing some common ground for interchange. Some view monetary systems developed for the exchange of goods as the earliest standards. A language is a standard for communication. The alphabet is a base standard for the exchange of information. For example, all English speakers agree that the letters "d," "o," and "g" in this order stand for the word "dog," which in turn stands for a four-legged furry animal that can be trained to fetch a ball or newspaper. What most people think of as the classic standards include a variety of different measurement standards—the rod, cubit, pint, quart, foot, yard, and the meter, liter, and gram. The U.S. Congress, in accord with Section 8 of the U.S. Constitution, has the power to "coin money, regulate the value thereof, and of foreign coin, and fix the standard of weights and measures." Most national governments assign similar responsibilities to provide standards to promote commerce.

Standards may be broken down into a variety of categories. One simple classification breaks them down into three groups: measurement, minimum attribute, and compatibility. A measurement standard is the one that most people associate with the word "standard." Examples would include: an inch, a volt, a kilogram. A minimum attribute standard provides a measurement in context—the quality of certain grades of motor oil (SAE 10-30), or the voltage that may safely be carried by a given gauge of wire, for example. Finally, compatibility standards, which constitute the majority of the standards in the realm of information technology, specify the nature of the agreement that will allow two things to interact. For example, your phone connects with an RJ-11 jack that has a certain number of wires carrying specified signals and voltages, and the audio CD (compact disk) in your CD player has a certain track design on which bits of information are encoded so that any CD player can read them and turn them into music.

For thousands of years, standards were primarily a matter of currency and standard weights and measures. An explosion in standards came about with the industrial revolution. The growth in standardization in the manufacturing arena was caused by both mass production and the development of railroads as a means of transportation. Railroads themselves required stan-

German-born American inventor Emil Berliner literally stands at the receiving end of a phone call in the late 1800s. As telephone technology advanced, inventors and designers realized the need to set equipment standards, which helped people communicate more quickly, cheaply, and at greater distances.

dardization on many fronts, from track gauge to time. The current system of standardized time zones is an outgrowth of the need to be able to publish schedules for train stops. Through the 1830s, the time was set in each geographic area by a local observatory. When it was 9 P.M. in Washington, D.C., it might be 9:12 P.M. in Philadelphia. By 1850 the Harvard Observatory was telegraphing a form of standard time to various railroad hubs. In 1879 the United States had about seventy-five standard times! The lack of standard time created problems for railroads. How could they tell someone when a train would arrive or depart if everyone's watches used a different time? After a series of negotiations, it was agreed in 1885 that there would be four basic time zones in the United States. Interestingly, it was not until 1918 that the general population agreed to use these four standard time zones.

The railroads had the capability to move mass-produced goods great distances creating a need for standardized parts that could be obtained from local sources. A stove manufactured in New Haven, Connecticut, could be repaired in Denver, Colorado, if the parts used in manufacture were standardized. From guns to watches to washing machines, the growth of mass production and the growth of catalog sales by companies such as Sears created a need for manufacturing standards and standard parts. The development of new methods of heating homes and buildings involved the development of boilers as heat exchangers. Boiler explosions led to a call for standards for testing boilers and the development of modern safety standards.

One of the key events in the development of standards in the United States occurred as a result of a major fire in Baltimore. Many of the fire companies from other cities that responded to the call for help could not connect their hoses and pumpers to the Baltimore fire hydrants because of different pipe diameters and thread sizes. This led the U.S. Congress, with its constitutional mandate to set standards, to establish the National Bureau of Standards (now the National Institute for Standards and Technology). To this day, one of the nine standards laboratories is concerned with standards for fire fighting and fire prevention.

Among the first information technology standards were those in the telecommunications arena. Standards have played an important role in telecommunications. With the minor exception of touch tone versus pulse dialing phones, any phone manufactured for use in the United States can be connected to any phone outlet. Thousands of manufacturers and network owners have agreed to the same power and signaling conventions. Telecommunications providers have also given us the ability to uniquely identify each phone in the world with a number and to connect virtually any two of those devices automatically. From a technological perspective, the phone system is far and away the largest and most complex device ever conceived, designed, and built.

More recently, manufacturers of information processing equipment, particularly telecommunications equipment, have developed standards for hardware and software to cover areas such as data packet construction, power specifications, and connection types. The number of standards for software design and information formatting is growing.

Standards Organizations

Standards originate from a variety of sources and processes. Industries set shared standards to allow them to interoperate. These range from standard parts such as bolts and pipe sizes to standards for Electronic Data Interchange (EDI). **De facto** standards emerge from the adoption of a common way of doing something. VHS became the de facto standard for videotape, and the PC became the de facto standard for computing. **De jure** standards emerge from the legislative and judicial branches of government. These include standards set by the Occupational Health and Safety Administration (OSHA) and environmental standards set by the Environmental Protection Agency (EPA).

de facto as is

de jure strictly according to the law

Standards are also set by organizations that seek to achieve a voluntary consensus as to what the standard should be. Three main organizations operate internationally to assist in the development of voluntary standards—the International Organization for Standardization (ISO), the International ElectroMechanical Commission (IEC), and the Consultative Committee for International Telegraphy and Telephony (CCITT). The CCITT is a

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

The International Organization for Standardization was founded in 1947 to promote the exchange of goods and services throughout the world. Comprised of member organizations from 140 nations, the international group sets standards for everything, from the size of credit cards, to the representation of country names. The organization is also known as the ISO, which is a play on words. It is not the acronym for the group; it is based on the Greek word *isos,* meaning "equal."

multilateral treaty organization concerned with all aspects of international telephony. The United States is represented in the CCITT by the State Department, which relies on representatives of the various U.S. organizations concerned with telephone service. A trade organization, the Alliance for Telecommunications Industry Solutions (ATIS), serves as the host for the U.S. standards committee, T1.

The IEC has a number of technical committees concerned with electrical, electromechanical, and electronic standards. ISO is the largest of the international standards organizations and has technical committees covering all aspects of standards from fasteners to pressure vessels to wood products. All three of these organizations have committees to develop information technology standards. The most notable of these is ISO Joint Technical Committee 1, which serves as the liaison to the other organizations.

Input to these international standards committees comes from national-level standards organizations. These include the British Standards Institute (BSI) , the Deutsch Institute fur Normung (DIN), and the Association Francais de Normalization (AFNOR). In the United States, the American National Standards Institute (ANSI) serves as the conduit for contributions from a federation of more than 100 American standards organizations, including the Society of Automotive Engineers, the American Petroleum Institute, and the American Bankers Association. Multinational standards organizations include such organizations as the European Computer Manufacturers Association (ECMA) and the Council on European Normalization (CEN).

In the information technology arena, several organizations based in the United States contribute time and expertise through individual and corporate contributions. These organizations include the National Committee for Information Technology Standards (NCITS), the Engineering Industries Association (EIA), the National Information Standards Organization (NISO), the Institute of Electrical and Electronics Engineers (IEEE), the Internet Engineering Task Force (IETF), and the World Wide Web Consortium (W3C). Their work is coordinated through the American National Standards Institute (ANSI).

Information Technology Standards

As the use and importance of computers and computer networks have grown, standards in this area have become increasingly important. Individual and organizational consumers of information processing equipment and software have begun to demand that the services and equipment they purchase comply with selected standards. Beginning in the late 1990s, standardization efforts in the information technology arena have produced more pages of standards than all other standardization efforts combined.

Information technology standards include both hardware and software standards. Software and information formatting standards are increasingly important. Standards exist for operating systems, programming languages, communications protocols, and human computer interaction. For example, the global exchange of electronic mail messages requires standards for addressing, formatting, and transmission.

For one word processor to be able to read another word processor's output requires standards for organization of the information within the file. From an information encoding point of view, the most basic standard is how to represent a character. Because computers exchange information as numbers, there must be agreement as to what the numbers mean. For the last thirty years this standard was the American Standard Code for Information Interchange (ASCII). It was agreed that computers would exchange information as sequences of bytes—packages of numbers represented as a sequence of ones and zeros. A byte is defined as eight binary digits—for example, the binary number 00000001 is the same as the decimal number one and the binary number 10000000 is equivalent to the decimal number 128. It is possible to represent 256 different decimal numbers using eight binary digits.

ASCII defines the association between these numbers and characters. The number 65 is A and the number 66 is B, for example. At the end of the 1990s, ASCII began to be replaced by a more comprehensive standard that uses sixteen bits that can represent more than 65,000 different characters. This standard, known as UNICODE, has made it possible to exchange information not only in English but also in Arabic, Chinese, Japanese, and other languages. Information formatting and processing standards are growing to include more and more kinds of information in increasingly complex aggregate forms. There are now standards for images (TIFF and JPEG), audio files (WAV, AU), and movies (MPEG).

A growing array of standards allows the World Wide Web to operate, including the standards for the basic protocol, the hypertext transfer protocol (HTTP), the standard for the messages (HTML), and a whole series of new standards to describe more general documents (the eXtended Markup Language or XML), links (the XML Linking Language or XLL), and appearance (XML Stylesheet Language or XSL).

Standards Issues

A large effort is underway to develop and disseminate standards for information technology. It should be noted in closing that with the reduction of the tariff barriers to free trade, standards have come to play an increasingly prominent role in the restriction or promotion of trade. In very simple terms, a standard may be used by a nation to constrain the products that may be sold within its boundaries. Similarly, getting a nation to adopt a standard can cause a whole new market to be opened to business. Thus, engineers and scientists who have historically engaged in standardization as a technical process now find themselves engaged in the process with an eye to how it impacts an organization's ability to promote and market its products. SEE ALSO Association of Computing Machinery; Government Funding, Research; Institute of Electrical and Electronics Engineers (IEEE).

Michael B. Spring

Bibliography

Cargill, Carl F. *Open Systems Standardization: A Business Approach.* Upper Saddle River, NJ: Prentice Hall, 1996.

Libicki, Martin. *Information Technology Standards: The Quest for the Common Byte.* Bedford, MA: Digital Press, 1995.

Spring, Michael B. "Information Technology Standards." *Annual Review of Information Science and Technology* 26 (1991): 78–110.

Institute of Electrical and Electronics Engineers (IEEE)

The Institute of Electrical and Electronics Engineers, Inc. (IEEE) is the world's largest technical professional association with more than 350,000 members in 150 countries. It is a non-profit organization that is dedicated to advancing the theory and application of electrical and electronics engineering and computer science. Through its members, the IEEE is a leading authority on areas ranging from aerospace, computers, and telecommunications to biomedicine, electric power, and consumer electronics.

The IEEE has served electrical and electronics engineers and scientists since 1884, when a group of inventors and entrepreneurs including Thomas Edison and Alexander Graham Bell founded the American Institute of Electrical Engineers (AIEE). In 1912 radio technology practitioners formed a separate international society, the Institute of Radio Engineers (IRE). In 1963 the AIEE and IRE merged to form the IEEE.

Today, the IEEE produces nearly 30 percent of the world's literature in the electrical, electronics, and computer engineering fields, and sponsors or cosponsors more than 300 technical conferences each year.✶ It also has produced 900 active industry standards, more than one third of which influence the information technology and computer industries.

✶Nearly 700,000 pages of IEEE publications published since 1988, and all current IEEE standards are available to members and others via the Institute's web site at <www.ieee.org>

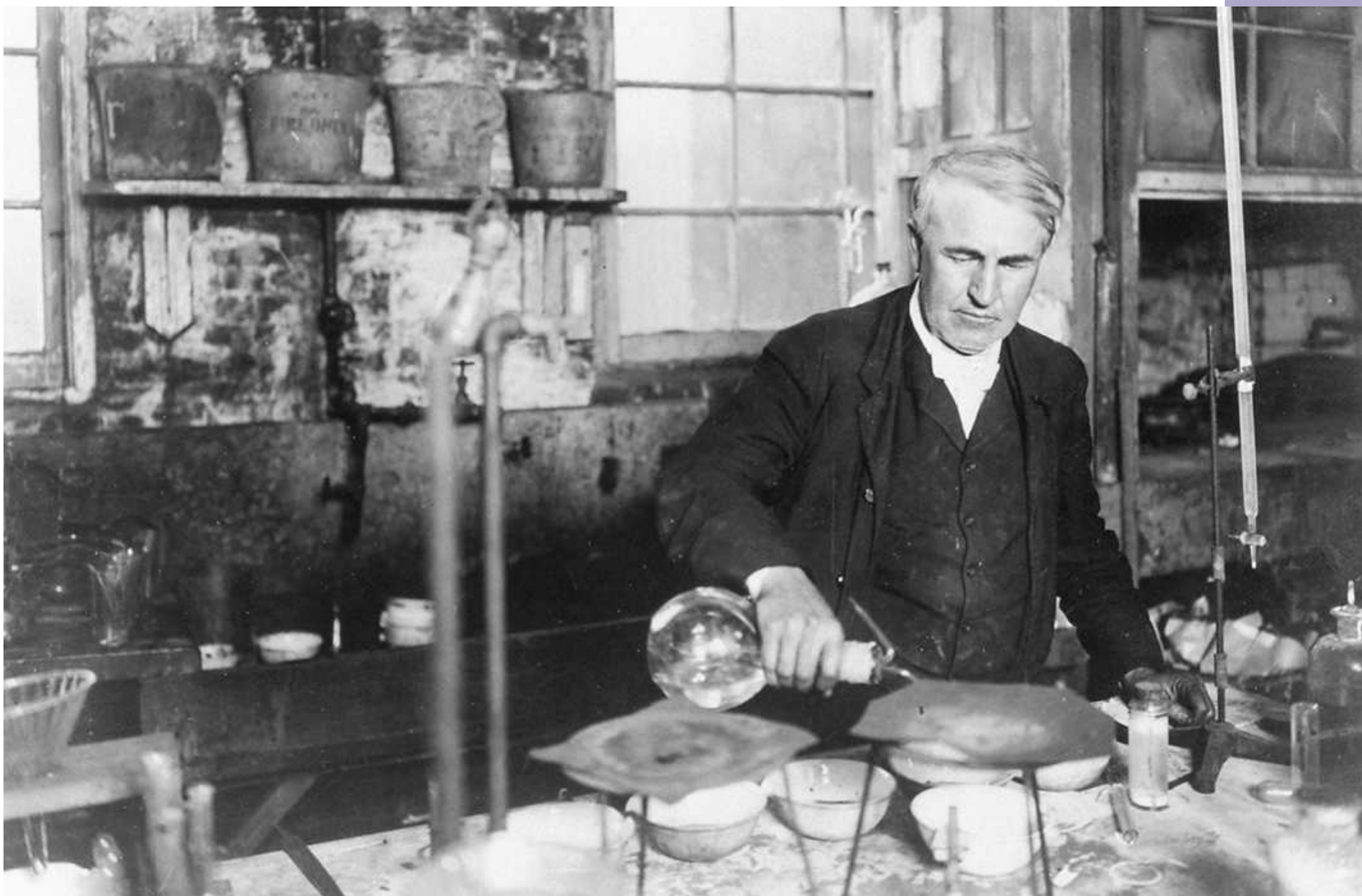
The IEEE consists of 300 local sections and 1,200 student chapters as well as 40 societies and councils that cover a wide range of technical interest areas. The largest of the institute's societies is the IEEE Computer Society.

The IEEE Computer Society

Tracing its origins back to 1946, the Computer Society is the leading provider of technical information and services to the world's computing professionals. The society's mission is to advance computer and information processing science and technology; promote professional interaction; and keep members up-to-date on the latest developments.

The growth of the IEEE Computer Society mirrors the growth of the computing profession. Society membership has expanded from less than 10,000 in the 1950s to more than 100,000 in 2002. About 60 percent of these members work in industry, with the rest in government and academia. They include computer scientists, computer engineers, electrical engineers, information scientists, software engineers, information technology managers, and practitioners in emerging classifications. Students comprise about 10 percent of the membership. With 41 percent of its constituents living outside of the United States, the society is truly a global organization.

To serve the profession, the Computer Society supports a variety of activities. It publishes a wide array of magazines and archival transactions and delivers more than 15,000 editorial pages in 20 titles every year. The society also is a leading publisher of conference proceedings, which contain peer-reviewed papers containing the latest technical information. These proceedings stem from the many technical workshops, symposia, and conferences the society sponsors or cosponsors each year. Additionally, more than



Thomas Alva Edison (1847–1931), who helped bring electricity to the masses, was a cofounder of the American Institute of Electrical Engineers (AIEE), which merged with the Institute of Radio Engineers (IRE) to form the IEEE.

30 technical committees in specialty areas organize meetings, produce newsletters, and provide networking opportunities for Computer Society members.

Society Functions

The society is a leader in developing standards for the computing industry, supporting more than 200 standards development groups in twelve major technical areas. Among these standards are wireless networking, web page engineering, and software engineering. IEEE standards are widely adopted by industry to assure consistent operability and functionality. One example is the IEEE 1012 Software Verification and Validation standard, which, among other uses, helps to ensure airplane and nuclear power plant safety and provide consistent performance of cell phones, beepers, and video games.

In addition to these activities, the society develops curriculum recommendations for programs in computer science and engineering and related disciplines. The society has supported the major computer science accreditation board in the United States and has participated in international accreditation efforts.

Undergraduate and graduate students play an important role in the Computer Society's conferences, technical activities, and student chapter activities. Students receive significantly discounted rates for publications and conference fees, and several conferences offer student travel grants or opportunities to attend for free by volunteering to work at the conferences. Many conferences encourage student paper submissions and award a “best student paper” certificate.

Students create and support chapters of their own at academic institutions worldwide. The society currently has more than 150 student chapters. Student chapters sponsor a newsletter written by and for students which is distributed three to four times yearly with the society’s flagship magazine, *Computer*, and is available under the name *looking .forward* on the society’s web site at <www.computer.org/students>.

The society sponsors a program of student awards and scholarships. The IEEE Computer Society International Design Competition (CSIDC) is a computer science and engineering system design competition open to undergraduate teams around the world. The Richard E. Merwin Scholarship awards up to four annual scholarships for exemplary undergraduate or graduate Computer Society student chapter volunteers. The Lance Stafford Larson Outstanding Student Scholarship is given to a student submitting the best student paper on a computer-related subject. The Upsilon Pi Epsilon/Computer Society Award was created to encourage academic excellence and offers up to four awards annually. Upsilon Pi Epsilon is the International Honor Society for the Computing Sciences. SEE ALSO Association of Computing Machinery; Computer Professional.

Guylaine M. Pollock

Internet Resources

IEEE Computer Society web site. <http://www.computer.org>

Institute of Electrical and Electronics Engineers, Inc. web site. <http://www.ieee.org/>

“looking .forward.” IEEE Computer Society Student Newsletter. <http://www.computer.org/students/looking/>

Integrated Circuits

Integrated circuits are electronic devices that contain many **transistors**, **resistors**, **capacitors**, and connecting wires in one package. Integrated circuits, also called ICs or chips, were invented in 1959 and have become critical components in virtually all electronic devices, including computers, radios, televisions, and videocassette recorders. The microprocessor is the most complex integrated circuit, and also the most complex single device of any kind, ever produced.

Integrated circuits are produced on a piece of semiconductor crystal. As its name implies, a semiconductor is a material that conducts electricity better than an insulator, but not as well as a conductor. The conductivity can be adjusted by introducing other elements into the crystal during manufacture. Conductivity is also changed by applying an electric field to the crystal.

Elements Used as Semiconductors

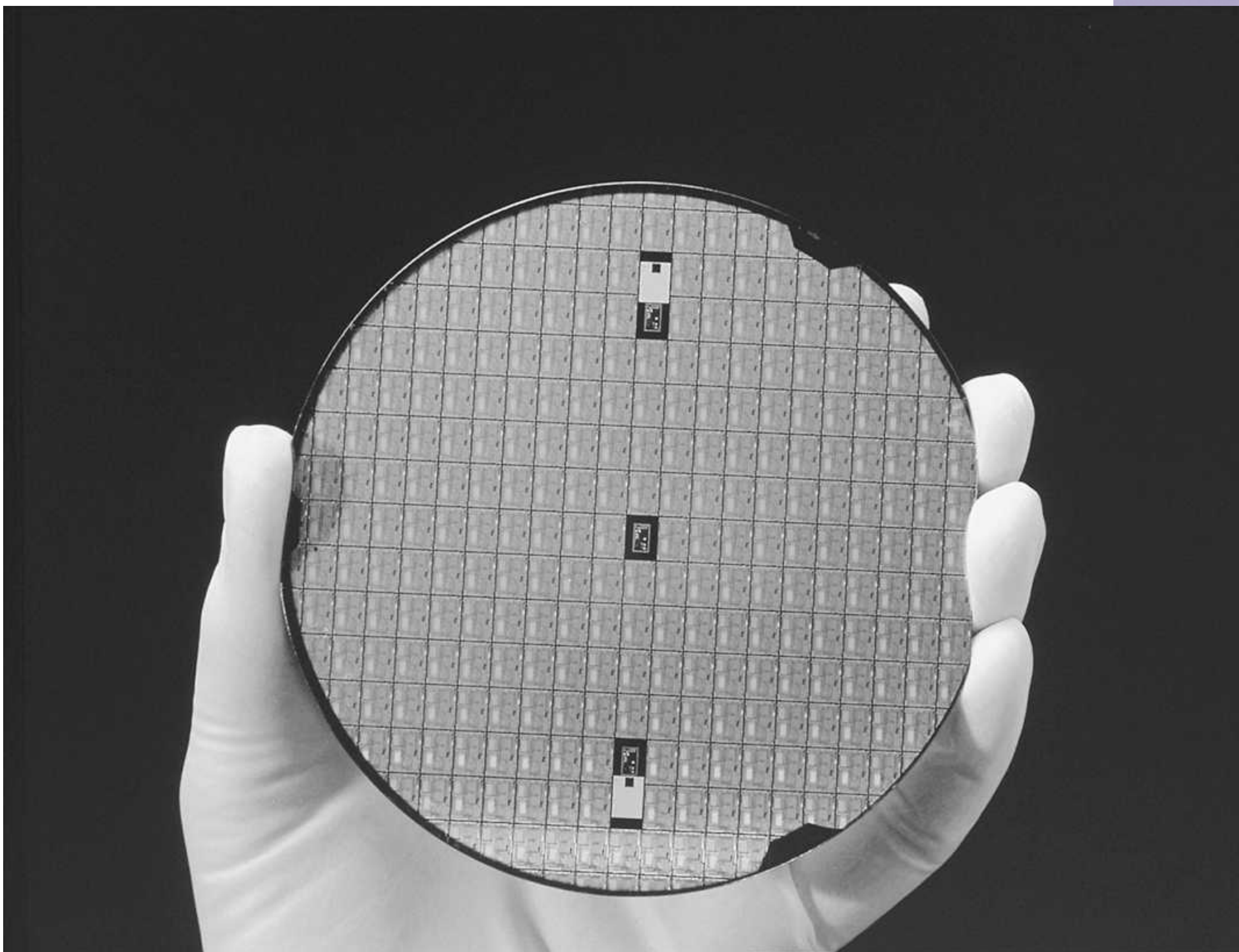
Silicon is the most commonly used semiconductor. It is the second most common element in the Earth’s crust, after oxygen. To be used in an inte-

transistors the plural of transistor, which is a contraction of TRANSfer resISTOR; semiconductor device, invented by John Bardeen, Walter Brattain, and William Shockley, which have three terminals; can be used for switching and amplifying electrical signals

resistors electrical components that resist the flow of current

capacitors fundamental electrical components used for storing electrical charges

silicon a chemical element with symbol Si; the most abundant element in the Earth’s crust and the most commonly used semiconductor material



Many individual integrated circuits are aligned on this circular wafer of silicon.

grated circuit, silicon must be processed to extreme purity. The silicon is heated until it melts, and is allowed to cool very slowly. If cooled too quickly, silicon has a tendency to crack, which would render it unusable for use in an integrated circuit. Once cooled, the silicon **ingot** is sliced into thin sheets. Many identical integrated circuits are formed simultaneously on each sheet.

In the periodic table of the elements, silicon is one of the group IV elements. This means each atom has four electrons in its outer shell available for combination with other atoms. It also means each atom would like to have four more electrons from adjacent atoms to fill up the outer shell. These characteristics cause pure silicon to form a crystalline structure. **Germanium**, the second most popular semiconductor material, is also in group IV, directly below silicon in the periodic table.

For a semiconductor to be useful, trace amounts of other elements must be carefully added to the crystal. This process is called **doping**. Phosphorous and boron are common doping elements. Phosphorous is a group V element that has five electrons in its outer shell. The extra electrons from the phosphorous atoms, each with a negative charge, are available to conduct electricity. Silicon doped with phosphorous is called N-type (for negative) silicon.

ingot a formed block of metal (often cast) used to facilitate bulk handling and transportation

germanium a chemical often used as a high performance semiconductor material; chemical symbol Ge

doping a step used in the production of semiconductor materials where charged particles are embedded into the device so as to tailor its operational characteristics

AFTER THE TRANSISTOR

Walter Brattain, John Bardeen, and William Shockley were awarded the 1956 Nobel Prize in Physics for the invention of the transistor. After inventing the transistor, Brattain and Bardeen continued in basic research, Bardeen concentrating on the area of superconductivity, which is the complete absence of resistance to electric current in some materials at low temperatures. In 1972 he was awarded a second Nobel Prize in Physics for his work in superconductivity, the first person ever to receive two Nobel Physics prizes. Shockley left Bell and founded Shockley Semiconductor near Palo Alto, California, the first semiconductor firm in the area that eventually became known as Silicon Valley.

In a similar way, boron, a group III element, is used to produce P-type silicon. Other elements from groups III and V may be used as well. N-type and P-type silicon together can form transistors, the most important elements in an integrated circuit.

Transistors in Integrated Circuits

The transistor was invented at Bell Labs in 1947 by Walter Brattain (1902–1987), John Bardeen (1908–1991), and William Shockley (1910–1989). They were interested in developing a solid state amplifier that would replace the **vacuum tube**. Vacuum tubes are large, consume a lot of power to heat the filament, and are subject to filament burn out.

vacuum tube an electronic device constructed of a sealed glass tube containing metal elements in a vacuum; used to control electrical signals

Transistors are much smaller, less costly, and more efficient than vacuum tubes. The transistor is a three-terminal solid state electronic device. The terminals are called the collector, the emitter, and the base. Electricity is conducted between the collector and emitter to a greater or lesser extent depending on the current of the base. This allows a small base current to control a much larger current in the collector.

As transistors came into widespread use, circuit designs using large numbers of them were limited by a problem: connecting them together. The solution to this problem occurred independently to Jack Kilby (1923–) at Texas Instruments and Robert Noyce (1927–1990) at Fairchild Semiconductor in 1959. Many transistors could be produced on one semiconductor base simultaneously. Noyce also determined how to produce resistors, diodes, capacitors, and connecting wires on the silicon chip. The integrated circuit was born.

Types of Integrated Circuits

A transistor can be operated either as an amplifier or as a switch. When used as an amplifier, the transistor collector current replicates the base current but at a much larger scale. This amplification enables a small signal, such as that produced by a microphone, to be reproduced with enough power to drive a large device, such as loud speakers. A transistor used as an amplifier is said to be operating in its linear range, neither all the way on nor all the way off. Linear integrated circuits are used in signal processing analog signals, such as in radios and communications systems and also in analog computers.

In digital integrated circuits, transistors are used as switches. The transistor is not operating in its linear range; there is no attempt to make the output replicate the input. Instead it is either fully on or fully off, representing either a logic one or zero. Digital integrated circuits are the heart and brains of digital computers.

The first digital integrated circuits implemented logic gates and simple memories using flip-flops. A gate is a logic device with no memory; the output at any time is determined by the inputs at that time. The simplest gate is a one input device called a "not" gate. The output is simply the opposite of the input. In a two-input "and" gate, the output is one (true) if both inputs are one, and zero otherwise. In a two-input "or" gate, the output is one (true) if either input is one, and zero otherwise. Other gates include "nand" (an "and" gate followed by a "not" gate), and "nor" gates. A flip-flop is a one-bit memory. It can be made by interconnecting the inputs and outputs of two "nand" gates. A flip-flop can be flipped to a one state or flopped to a zero state. It remains in a state until switched to the other. Gates and flip-flops are the most basic computer building blocks.

Smaller and More Powerful

Over time, the complexity of integrated circuits has increased, while the size of features continues to shrink. The feature size of an integrated circuit is indicated by the width of a "wire," measured in microns (one micron is one millionth of a meter).

In 1971 Intel produced the first microprocessor, designated 4004. It contained 2,300 transistors, used 10 micron technology, and powered an electronic calculator. The original IBM-PC was based on the Intel 8088 processor, which was first produced in 1979 and contained 29,000 transistors (3 micron technology). In 1989 Intel introduced the 80486 processor, containing 1.2 million transistors (0.8 micron technology). In 1999 the company began production of the Pentium III Xeon processor, with 28 million transistors on a silicon chip (0.18 micron technology). A year later, it debuted its Pentium IV processor, which featured 42 million transistors on a silicon chip (0.13 micron technology). The same trend toward smaller and more powerful devices is evident in memory chips, and in microprocessors from other manufacturers, such as Texas Instruments, Motorola, Advanced Micro Devices, and International Business Machines. SEE ALSO Generations, Computers; Microcomputers; Minicomputers; Transistors.

Donald M. McIver

Bibliography

Queisser, Hans. *The Conquest of the Microchip*, trans. Kristallene Krisen. Munich: R. Piper GmbH and Co. KG, 1985.

Riordan, Michael, and Lillian Hoddeson. *Crystal Fire: The Birth of the Information Age*. New York: W. W. Norton, 1997.

Internet Resources

Intel Corporation. <www.intel.com>

RACE FOR A PATENT

Jack Kilby and Robert Noyce individually filed patent applications at nearly the same time. Noyce received the first patent award, probably because his application was more narrowly worded. Eventually Kilby was awarded a patent also, and a bitter legal dispute ensued. It was resolved in 1966 when Fairchild and Texas Instruments agreed to cross-license their patent rights to each other. Noyce, who originally worked at Shockley Semiconductor, later left Fairchild and founded the Intel Corporation, which became the most successful manufacturer of microprocessors in the world.

Intel Corporation

The Intel Corporation of Santa Clara, California, was founded in 1968 by Robert Noyce (1927–1990), co-inventor of the **integrated circuit**, and his colleague Gordon Moore (1929–), the originator of "Moore's law." The name Intel was a shortened form of Integrated Electronics. Noyce and Moore were joined by Andy Grove and the three, all formerly from Fairchild Semiconductor, led the firm on its initial mission to produce the world's first semiconductor-based memory chips. The company went on to commercialize the microprocessor, the product that Intel is best known for today.

integrated circuit a circuit with the transistors, resistors, and other circuit elements etched into the surface of a single chip of semiconducting material, usually silicon

In 1969 a Japanese manufacturer, Busicom, commissioned Intel engineers to design a set of a dozen custom chips for its new family of scientific calculators. At the time, all logic chips were custom-designed for each customer's product. Logic chips perform calculations and execute programs, unlike memory chips, which store instructions and data.

MOORE'S LAW

In 1965, three years before he helped found Intel, Gordon Moore observed that the number of transistors on a microprocessor doubles every eighteen to twenty-four months. He concluded that the trend would cause computing power to rise exponentially over time. His prediction, now known as Moore's law, has held true in the years since, though some industry experts believe the physical limitations of silicon will cause it to fail at some future time.

The resulting trend toward ever-smaller chip design explains the falling prices of microprocessors. As Moore has noted, "If the auto industry advanced as rapidly as the semiconductor industry, a Rolls Royce would get a half a million miles per gallon, and it would be cheaper to throw it away than to park it."

silicon a chemical element with symbol Si; the most abundant element in the Earth's crust and the most commonly used semiconductor material

Intel engineer Marcian "Ted" Hoff improved on Busicom's idea. Instead of designing twelve custom chips, he recommended a set of only four chips for logic and memory, which featured a central processing unit. Although Busicom was satisfied with this alternative approach, Hoff realized its full potential—the design team had created the first general-purpose microprocessor chip, though the term "microprocessor" would not appear for many years.

But, there was a problem. Intel did not own the rights to the new technology—Busicom did. Hoff urged company officials to buy the design from its former client. But others in the company claimed that Intel's future lay in fast and inexpensive memory chips, not in logic chips. Eventually, Hoff's side won by arguing that the success of the new logic chips would enhance the market for memory chips.

Busicom, strapped for cash, agreed to sell the rights for the four-chip set for $60,000. Intel used that agreement as the basis for its microprocessor business, eventually becoming a powerful global corporation. Sales in 2000 reached $33.7 billion.

In 1971, armed with its new technology, Intel engineers introduced the model 4004 microprocessor, which sold for $200 and could perform 60,000 operations per second. It was the size of a thumbnail, featured 2,300 transistors on a sliver of **silicon**, and could deliver the same amount of computing power as the first electronic computer, ENIAC. In 1972 the model 8008 microprocessor featured 3,500 transistors. Although that was powerful at the time, it was primitive compared to the Pentium IV processor offered in 2000, which had 42 million transistors.

A series of chips followed, each more powerful than the previous one. By 1981 Intel's 16-bit 8086 and 8-bit 8088 processors took the design world by storm, winning an unprecedented 2,500 design awards in a single year. That year, IBM selected the Intel 8088 microprocessor to run its first desktop personal computer, the IBM-PC.

The significance of the IBM alliance was not immediately evident. An Intel sales engineer who worked on the IBM project said, "At the time, a great account was one that generated 10,000 units a year. Nobody comprehended the scale of the PC business would grow to tens of millions of units every year." The success of the IBM-PC helped change the company's direction. In 1986 Intel left the memory-chip market to focus on microprocessors and, under the leadership of Andy Grove who succeeded Moore as CEO in 1987, the company became the world's dominant supplier of microprocessors.

Moore's law, which predicts ever-more complex circuits, drives Intel's designers. By constantly reducing the size of transistors within chips, Intel has reduced their cost. Smaller chips are cheaper because more of them can be made from a single expensive silicon wafer. There are additional benefits. Smaller chips work faster, system reliability is increased, and power requirements are reduced.

To make these tiny chips successfully, Intel's manufacturing technology has had to improve constantly. The earliest chips were made by workers wearing smocks. In 2001 microprocessors are created in a sterile environment, called cleanrooms, which are thousands of times cleaner than those of twenty-five years ago. Robots move the silicon wafers from process to

Year	Event	Number of transistors
1971	4004, first 4-bit microprocessor	2,300
1972	8008, first 8-bit microprocessor	3,500
1978	8086, first 16-bit microprocessor	29,000
1982	80286 microprocessor	134,000
1985	Intel386™, first Intel 32-bit microprocessor	275,000
1989	Intel486™, first Intel 32-bit microprocessor with integrated cache memory	1,180,000
1993	Pentium processor	3,100,000
1995	Pentium Pro processor	5,500,000
1997	Pentium II processor	7,500,000
1999	Pentium III processor	24,000,000
2000	Pentium IV processor	42,000,000
2001 (scheduled release date)	Itanium, 64-bit microprocessor	(to be announced)

Figure 1. Key Intel Microprocessors

process. Operators working in these cleanrooms wear non-linting, anti-static fabric, called bunny suits, with face masks, safety glasses, gloves, shoe coverings, and even special breathing equipment.

As Intel grew to become the world's largest chipmaker, its dominant market share did not go unnoticed by competitors and the federal government. In 1998 the Federal Trade Commission announced an investigation into allegations of anti-competitive business practices. The company cooperated fully during the nine-month inquiry. The case was settled before it went to court.

Intel continues to explore possible barriers to microprocessor design. In 2000 company engineers demonstrated a 0.13-micron process technology using an ultra tiny transistor gate and the thinnest of thin films. In time, this advance will allow the company to manufacture chips with transistors that are approximately 1/1000th the width of a human hair.

Time magazine named Intel CEO Andy Grove, a Hungarian immigrant born Adras Gróf, as its 1997 Man of the Year as "the person most responsible for the amazing growth in the power and innovative potential of microchips." SEE ALSO Apple Computer, Inc.; Bell Labs; Integrated Circuits; Microchip; Microcomputers; Microsoft Corporation.

Ann McIver McHoes

Bibliography

Jackson, Tim. *Inside Intel, Andy Grove and the Rise of the World's Most Powerful Chip Company*. New York: Dutton, 1997.

Ramo, Joshua. "Man of the Year: Andrew W. Grove—A Survivor's Tale." *Time*, December 29, 1997: 54.

Yu, Albert. *Creating the Digital Future*. New York: Free Press, 1998.

Internet Resources

Intel Homepage. <http://www.intel.com>

Interactive Systems

Interactive systems are computer systems characterized by significant amounts of interaction between humans and the computer. Most users have grown up using Macintosh or Windows computer operating systems, which

Interactive systems encompass many types of computer systems, including video games. In many such games, the user interacts with the computer in an attempt to navigate through virtual challenges, including combatting evil or saving the world.

are prime examples of graphical interactive systems. Editors, CAD-CAM (Computer Aided Design-Computer Aided Manufacture) systems, and data entry systems are all computer systems involving a high degree of human-computer interaction. Games and simulations are interactive systems. Web browsers and Integrated Development Environments (IDEs) are also examples of very complex interactive systems.

Some estimates suggest that as much as 90 percent of computer technology development effort is now devoted to enhancements and innovations in interface and interaction. To improve efficiency and effectiveness of computer software, programmers and designers not only need a good knowledge of programming languages, but a better understanding of human information processing capabilities as well. They need to know how people perceive screen colors, why and how to construct unambiguous icons, what common patterns or errors occur on the part of users, and how user effectiveness is related to the various mental models of systems people possess.

Types of Interactive Systems

The earliest interactive systems were command line systems, which tightly controlled the interaction between the human and the computer. The user was required to know the commands that might be issued and how the arguments were to be ordered. Both the UNIX operating system and DOS (Disk Operating System) are classic examples. Users were required to enter data in a particular sequence. The options for the output of data were also tightly controlled, and generally limited. Such systems generally put a high demand on the user to remember commands and the syntax for issuing these commands.

Command line systems gradually gave way to a second generation of menu-, form-, and dialog-based systems that eased some of the demands on memory. An Automatic Teller Machine is a good example of a form-based program where users are given a tightly controlled set of possible actions. Data entry systems are frequently form- or dialog-oriented systems offering the user a limited set of choices but greatly relieving the memory demands of the earlier command line systems.

A third generation of interactive computing was introduced by Xerox Corporation in 1980. The Xerox Star was the result of a half dozen years of research and development during which the mouse, icons, the desktop metaphor, windows, and bit-mapped displays were all brought together and made to function. The Xerox Star was replicated in the Lisa and Macintosh first offered by Apple Computer Inc. in the mid-1980s. The windows, icon, menu, and pointer (or WIMP) approach was made universal by Microsoft in the Windows family of operating systems introduced in the 1990s. With the maturation of WIMP interfaces, also known as **graphical user interfaces** (or GUIs—pronounced "gooey"), interaction moved from command-based to direct manipulation.

In command-based systems, the user specifies an action and then an object on which that action is to be performed. In a direct manipulation system, an object is selected, and then the user specifies the action to be performed on that object. The most recent developments in interactive systems have focused on **virtualization**, visualization, and agents. The following sections describe in more detail the nature of the current generation of direct manipulation systems and the coming generation of agents and virtual systems.

THE XEROX 8010 STAR

Office professionals of today arrive at their cubicles, log onto their computers, and enter the company's network where they have access to shared files, programs, and printers. All of the tools needed to prepare and distribute correspondence, documentation, and presentations are located right on their desktops—their desktop computers, that is. But that was not always the case. The Xerox Corporation pioneered the concept of an automated office system when it introduced the "Xerox 8010 Star" in 1981. Complete with recycling bins and file cabinets, the Xerox 8010 Star was the forerunner of the modern desktop computer.

graphical user interfaces technologies whereby graphical objects are placed on a computer screen for interaction with the user—examples are icons, menus, and buttons

virtualization as if it were real; making something seem real, e.g., a virtual environment

The Importance of Understanding Human Capabilities

It is important that users be able to understand how to use a highly interactive computer system. Cognitive science professor Donald A. Norman describes the human-computer interaction in terms of the "gulfs of execution and evaluation." Basically, this means that the user has a goal in mind and must reformulate that goal in terms of a plan that ultimately involves the execution of a series of actions on the system. These actions result in changes in the state of the system, which must be perceived, interpreted, and evaluated by the user. Computer system developers need to understand how human beings perceive, interpret, evaluate, and respond to these computer actions.

Although even a cursory review of the literature on human perception, human information processing, and human motor skills is far beyond this brief overview, it may be useful to consider a very select set of principles developed from that literature. Hundreds of research studies have been done on the limits of short-term memory. These include research on how information is "chunked," on how many "chunks" can be kept in memory at one time, and at how the number of chunks varies when the information is sensory or symbolic. Similarly, there are hundreds of research studies on how to best access information in long-term memory. For example, by "priming" a subject with some fact that requires access to long term memory, the access time for closely related concepts can be improved. Finally, there are thousands of studies on the **acuity** of and variation in human sensory and motor capabilities. All of these studies have led to principles for:

acuity sharpness or keenness, especially when used to describe vision

- menu construction, related to the limits of short term memory;
- system design based on metaphors that activate areas of long term memory;
- the target size of buttons and icons, based on studies of motor skills;
- the use of visual and auditory cues, based on human sensory capabilities and limits.

Although these references are only the tip of a vast and growing field of research in human perception and use of data provided by computers, they represent the kinds of developments that are moving interactive system design from an art to an engineering science.

Direct Manipulation Systems

As noted earlier, a direct manipulation system is one in which the user is able to select an object and then specify which actions are to be taken. This is in opposition to command line systems where the user would normally specify an action and then select an object upon which the action was to be performed. This fundamental **paradigm** shift caused a number of changes in how these systems were designed and implemented in code.

paradigm an example, pattern, or way of thinking

The basic programming paradigm had to change from the process-driven approach to an event-driven perspective. In earlier systems, the program's main process would control what the user could do. Now, it was possible for the user to initiate a broad series of actions by selecting an "object"—a window, an icon, or a text box, for example. This required some method for collecting events and handling them. The X Window System on Unix was one of the early popular systems for doing this. Each graphical component of the interface was capable of producing one or more events. For example, a window might be opened or closed generating an event. Similarly, a button might be pressed, or the text in a text box might be changed. There are mouse events as well—such as when a mouse enters a window or moves over a button. These events are dispatched to a window manager. For Apple systems and all the Windows systems since Windows 95, this functionality is built into the operating system.

The programmer's task is to display a coordinated set of components that can generate events. The programmer is also required to write code that will initiate some action when an event occurs. These code fragments are called event-handling functions. Once the programmer has defined the objects that might generate events and the code to respond to those events, the final programming task is to "register" the event handlers as having an interest in certain classes of events produced by certain objects. When those events occur, the window manager dispatches them to the appropriate event handler. In object-based and object-oriented programming environments, this task of handling events is made easier through object classes which associate default event-handling methods with specific classes of objects. For example, the code for how the appearance of a button is changed when it is pressed may be provided as a default method of the button objects. Similarly, the class may provide default button release code. The programmer simply needs to add additional code that performs some application-specific action when the button is released.

Visualization, Virtualization, and Agents/Embedded Systems

Throughout the 1980s and 1990s, there were numerous efforts to take advantage of the human ability to process information visually. At the simplest level, consider that a human looking at an image on a television screen has no problem in discerning a pattern that consists of millions of individual **pixels** per second, changing in both time and space. Or consider the example provided in Figure A. Ask yourself what pattern is represented by the following set of numbers: a set of X,Y pairs with the X value being the upper value in each column and the Y value being the lower value?

pixels single picture elements on a video screen; the individual dots making up a picture on a video screen or digital image

47	42	93	122	63	85	105	133	137
58	100	35	46	126	133	131	108	68

Figure A.

Even knowing they are pairs of X,Y coordinates, most people have trouble seeing a pattern in this numerical example. If however, these points are plotted, or visualized, a pattern emerges rather quickly as shown in Figure B. Visualization systems manipulate information at high levels of aggregation, making the information more accessible to users. The aggregates may be records, documents, or any other entity defined as an object. Working with large numbers of objects that have multiple attributes, we can map these attributes to the interface in such a way as to visualize the data or simulate some process. The visualization of abstract data to sensory interfaces is central to software including geographic information systems and **data mining** applications, among others.

data mining a technique of automatically obtaining information from databases that is normally hidden or not obvious

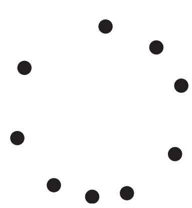


Figure B.

In the 1990s, researchers began to experiment with extending interactive systems from symbolic interaction—icons, mice, and pointers—to virtual systems. In these systems, every effort was made to allow the user to explore a virtual world with little or no translation to symbolic form. Thus, with visualization techniques and new forms of input devices, such as data gloves, hand movements could be used to manipulate virtual objects represented graphically in a virtual world. This virtual environment was presented to the user via two display screens, each of which provided a slightly different perspective, giving the user a stereoscopic view of a virtual space that appeared to have depth. Work on virtual and artificial reality continues on a number of specialized fronts, including a field known as **telemedicine**.

telemedicine the technology that permits remote diagnosis and treatment of patients by a medical practitioner; usually interactive bidirectional audio and video signals

agents systems (software programs and/or computing machines) that can act on behalf of another, or on behalf of a human

embedded systems another term for "embedded computers"; computers that do not have human user oriented input/output devices; they are directly contained within other machines

pattern recognition a process used by some artificial-intelligence systems to identify a variety of patterns, including visual patterns, information patterns buried in a noisy signal, and words patterns imbedded in text

speech recognition the science and engineering of decoding and interpreting audible speech, usually using a computer system

The next generation of interactive systems, represented by agents in embedded systems, will again change how humans and computers interact. Direct manipulation environments will still be around for many years to come. At the same time, we have begun to see both **agents** and **embedded systems** make their appearance. Embedded systems can be as simple as the analog sensor systems that open a department store door, or turn on lights when someone enters a room. At a more complex level, most cars being built today include air bag deployment systems and antilock brakes that operate invisibly by gathering data from the environment and inserting computer control between our actions and the environment. As air bag deployment systems become more complex, they react based not simply on acceleration data, but also based on the weight of the individuals occupying the seat and their relative position (leaning forward or back) on the seat.

As the information processing of sensory inputs becomes more complex, these embedded systems begin to act like agents. For example, programs that monitor typing activity and automatically correct spelling errors are beginning to mature. Although early versions frustrated sophisticated users, more advanced versions are demonstrating their ability to learn user preferences and new forms of errors to correct. The perceptive user will note that the most recent applications remember lots of things about user activity—which web sites they frequent, for example, or where they hold meetings and with whom they meet. In the next generation, programs will use these data stores to communicate on the user's behalf with agents of other users.

In summary, new systems are emerging where the interface between the human and the computer system is becoming invisible. When the programs are very complex and act on behalf of the user, they are called "agents." These agents make use of increasingly sophisticated methods of data acquisition. Agents are evolving from using stores of data acquired from user activity to acquiring real-time data based on new information including facial and gesture **pattern recognition** and **speech recognition**. Increasingly, these agents will perform tasks such as storing and retrieving files for the user and undertaking simple actions such as making or confirming appointments. The help feature in Microsoft's *Office* software is an example of an active agent that observes user activity and offers help based on actions that suggest it may be needed, from formatting documents to correcting common spelling and grammatical errors. SEE ALSO Game Controllers; Games; Hypermedia and Multimedia; Mouse.

Michael B. Spring

Bibliography

Baecker, Ronald M., and William A. S. Buxton, eds. *Readings in Human-Computer Interaction: A Multidisciplinary Approach.* Los Altos, CA: Morgan-Kaufmann Publishers, 1987.

Card, Stuart K., Thomas P. Moran, and Allen Newell. *The Psychology of Human-Computer Interaction.* Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.

Johnson, Jeff, et al. "The Xerox Star: A Retrospective." *IEEE Computer* 22, no. 9 (1989): 11–30.

Norman, Donald A. *The Psychology of Everyday Things.* New York: Basic Books, 1988. (Also published as *The Design of Everyday Things*, 1990.)

Perlman, Gary, Georgia K. Green, and Michael S. Wogalter, eds. *Human Factors Perspectives on Human-Computer Interaction: Selections from Proceedings of Human Fac-*

tors and Ergonomics Society Annual Meetings 1983-1994. Santa Monica, CA: HFES, 1995.

Shneiderman, Ben. *Designing the User Interface: Strategies for Effective Human-Computer Interaction*, 3rd ed. Reading, MA: Addison-Wesley Publishing, 1997.

Smith, David, et al. "Designing the Star User Interface." *Byte* April (1982): 242–283.

Weiser, Mark. "The Computer for the Twenty-First Century." *Scientific American* 256, no. 3 (1991): 94–104.

Internet

The Internet is a computer network that was designed to interconnect other computer networks. Its origins lie in the ARPANET, an experimental network designed for the U.S. Department of Defense Advanced Research Projects Agency (ARPA) in 1969. The original ARPANET had some features that were unique in its day.

The first unique feature was that it supported peer to peer networking. In this system, each computer has the same rights and abilities as any other computer on the network. The commercial computer networks at that time were hierarchical, where some devices performed special control functions, and other devices had to wait for permission to transmit from the controller.

Another unique feature of ARPANET was that it was not designed with a particular application or set of applications in mind. The designers created a network whose uses were not fully specified. As a result, ARPANET was designed to be transparent to applications. This allowed new Internet applications to be developed by placing the necessary functions (usually computer software) in end user devices rather than in the network. Thus, new applications did not require changes to the network.

Yet another unique feature of ARPANET was that it allowed organizations to have operational control of their local networks while still allowing them to be interconnected. This made it possible for a computer at a Burger King restaurant to communicate with a computer at a McDonald's restaurant without forcing the management at either restaurant to give up local autonomy for the privilege of communicating with each other.

In the 1980s, ARPANET split into a military component and a civilian section. The civilian part became known as NSFnet, in acknowledgement of support from the National Science Foundation. Other developments in this decade included the development of **local area networks (LANs)**, which pushed peer to peer networking closer to many end users, and the microcomputer, or personal computer, which made it possible for many people to have dedicated computer access. NSFnet was limited by its charter to educational and not-for-profit organizations. Although commercial firms began to see the advantages of NSFnet, they were not able to participate fully in this new age of communications until NSFnet was **privatized** in 1993.

The Internet has grown in leaps and bounds since privatization, fueled by the emergence of a new application, the World Wide Web, and the resources of the private sector.

The Internet has become a change agent in many areas of the economy. Examples of this include retail sales, business to business transactions, tele-

local area networks (LANs) high-speed computer networks designed for users who are located near each other

privatized to convert a service traditionally offered by a government or public agency into a service provided by a private corporation or other private entity

INTERNATIONAL INTERNET-FREE DAY

On Sunday, January 27, 2002, a British organization called for an International Internet-Free Day. As announced on the nonprofit DoBe.org web site, hosted by the Institute for Social Inventions in the United Kingdom, the event was held in an effort to motivate people to turn off their computers for a day, chat in person with family and friends, and go out and participate in activities such as listening to concerts and poetry readings, taking a walk, visiting a museum or art gallery, or just getting outdoors. Event organizers encouraged people to spend time participating in group activities to counter the social isolation they sometimes experience by communicating so often via the web.

The Internet allows easy access to a wealth of information from around the globe. In India, for example, Tibetan spiritual leader the Dalai Lama helped launch the web site of Kiran Bedi, the first woman to become part of the Indian Police Service.

phone and video carriage, and music distribution. In fact, few industries have not been touched in a significant way by the Internet. Many industries have reorganized themselves as a direct result of the economic changes brought about by Internet-based applications.

For the most part, computers on the Internet communicate via two communications protocols: the Transmission Control Protocol (TCP) and the Internet Protocol (IP). The role of finding a path through a complex network is left to IP. This is a "best effort" protocol, in that it does the best it can to deliver a packet to the desired destination, but makes no promises. Thus, if a portion of the network failed, IP would attempt to reroute around the failure if it could, but would not guarantee that all packets would survive intact. Many applications require stronger assurances than this, and that is the role of TCP. The TCP is a communications protocol that operates between two end devices, ensuring that the complete information that was transmitted arrives safely at the destination. If some of the information is lost by IP, TCP retransmits it until it is received correctly. Thus, the two protocols operate in tandem to provide a complete, reliable service to end users.

The Internet differs from telephone networks in that information is broken into packets, each of which is treated separately, much like a letter. The Internet allocates its resources to individual packets as needed. By contrast, the telephone network treats a telephone call as a stream of information, and allocates resources to that call (or stream of information) regardless of whether the users are speaking or are silent. In a packet network, resources are allocated only when there is information to transmit. This packet switching feature is commonly found in computer networks.

Physically, the Internet consists of special purpose computers called **routers** that are interconnected with each other. Routers are equivalent to switches in the telephone network, in that they decide what to do with a packet when it arrives from a neighboring router. This decision is aided by a routing table, which is used by the router to determine where the packet should be sent next. The routing tables are constructed by the routers themselves, which communicate with each other so that efficient paths through the network can be found for packets traveling between any pair of destinations, and so that congested or failed routers can be avoided.

routers network devices that direct packets to the next network device or to the final destination

Today, many users access the Internet through **Internet Service Providers (ISPs)**. For a monthly fee, an ISP provides users with a way of accessing the Internet (usually via a dialup modem), an electronic mail address and mailbox, and, often, a page that can be viewed by World Wide Web browsers. These retail ISPs often interconnect with large, high capacity backbone ISPs, which provide the transport functions so that a packet from one user can reach any other user.

Internet Service Providers (ISPs) commercial enterprises which offer paying subscribers access to the Internet (usually via modem) for a fee

The Internet is a constantly changing resource. It has had a deep impact on industries and on the lives of many Americans. The collection of computer networks known as the Internet will probably continue to affect society in ways that we are still trying to understand. SEE ALSO E-COMMERCE; GOVERNMENT FUNDING, RESEARCH; INTERNET: APPLICATIONS; INTERNET: BACKBONE; INTERNET: HISTORY; INTRANET; NETWORKS; ROUTING; TELECOMMUNICATIONS; WORLD WIDE WEB.

Martin B. Weiss

Bibliography

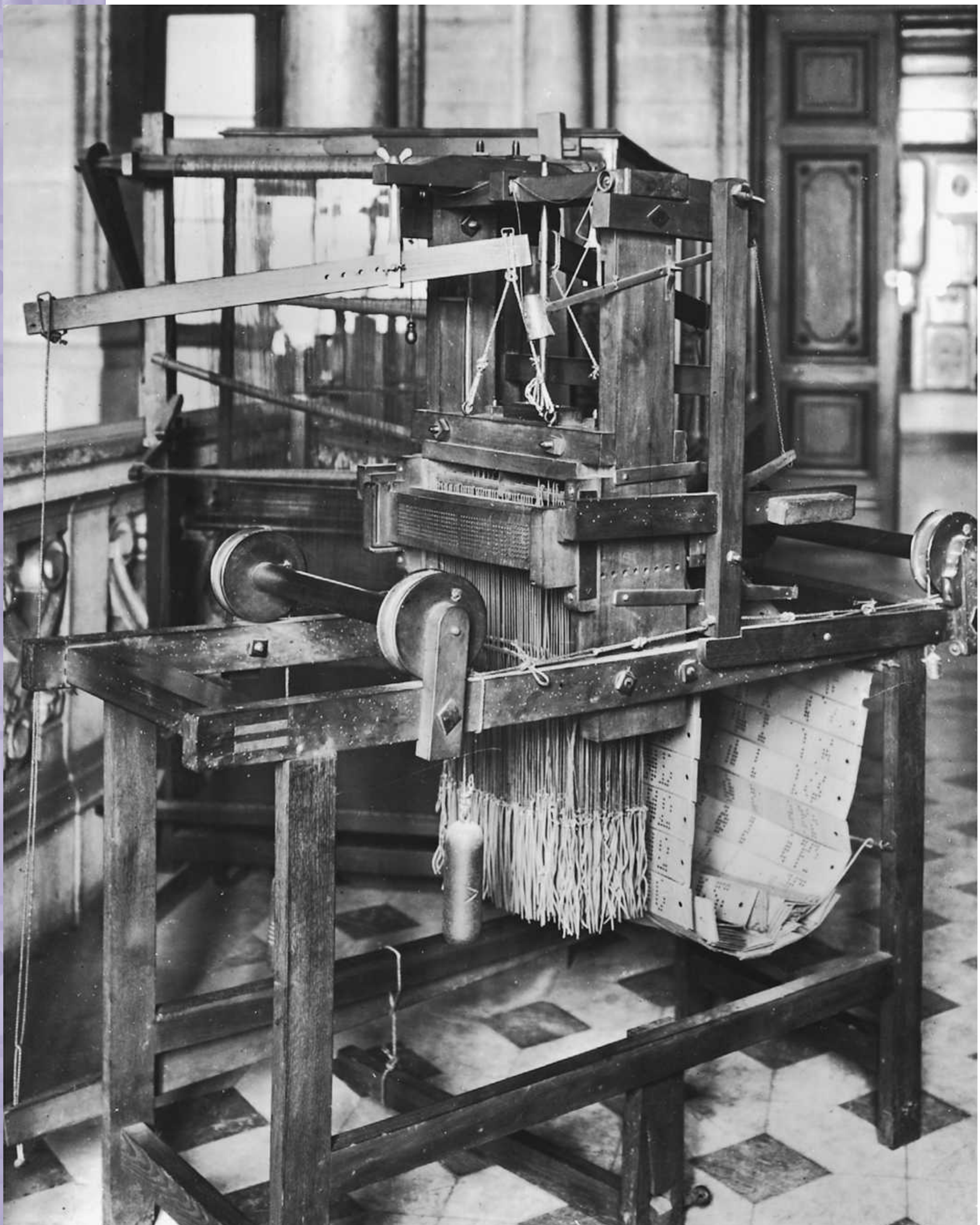
Dodge, Martin, and Rob Kitchin. *The Atlas of Cyberspace.* New York: Addison-Wesley, 2001.

Sutherland, Keith. *Understanding the Internet: A Clear Guide to Internet Technologies.* Boston: Butterworth-Heinemann, 2000.

Jacquard's Loom

Punched cards, used today to provide data and instructions to computers, were invented in the late eighteenth century by French inventor Joseph-Marie Jacquard (1752–1834) and were used to automate the weaving industry in France.

Jacquard was born on July 7, 1752 in a small village near Lyon. Both his parents worked in the weaving trade. At the age of ten, he went to work as a drawboy with his father. Drawboys had the tedious job of maneuvering by hand the weighted cords that controlled the pattern in the weaving of silk fabrics. Jacquard later invented a mechanical device to replace the drawboys. He started working on it in 1790, but his efforts were interrupted by the French Revolution. He finally succeeded in presenting a new silk drawloom at the Paris Exhibition in 1801. He completed an automated



Jacquard's loom, featuring punched cards, revolutionized the weaving industry.

loom with punched cards controlling the weaving of very complicated patterns in 1805.

How are threads woven into a piece of cloth? Some, the warp, run lengthwise; others, the woof, run crosswise. In the loom, each thread of the warp can be lifted by a hook connected to a rod. At each weaving step, a thread of the woof is carried crosswise. A pattern in the fabric is created by lifting the warp threads, changing the choice of threads to lift from step to step. The choice, originally made by hand, is obtained by touching the tips of all the rods to a card in which holes have been previously punched according to a program. If a rod finds a hole, the thread is lifted. At the next step, the card is changed. The holes may or may not be in the same order as before. If not, the weaving occurs in a different way. Jacquard butted the cards one after the other in a very long loop and put the loop on a drum rotating in tempo with the advance of the fabric, so that the preprogrammed pattern could be repeated at every cycle of the loop.

Jacquard's loom was not welcomed by the silk weavers, who were afraid of being replaced by this new machine. The weavers of Lyon expressed their anger by burning the new looms and even attacking Jacquard. Ultimately, the loom proved its usefulness and became generally accepted. By 1812 there were 11,000 in use in France.

The Jacquard loom was a technological breakthrough that earned its inventor a pension from French Emperor Napoleon Bonaparte as well as a gold medal and the Cross of the Legion of Honour. By 1834 there were 30,000 looms in use in Lyon alone, and they were widely used throughout Europe and England. Jacquard died on August 7, 1834, at the age of 82. SEE ALSO BABBAGE, CHARLES; HOLLERITH, HERMAN.

Ida M. Flynn

PUNCHED CARD PIRACY

Jacquard's loom revolutionized the weaving industry in France during the nineteenth century. Master weavers and skilled tradespeople spent long hours creating elaborate patterns and designs for silk cloth, which could then be transferred to the looms' punched cards. Because of the effort involved, the cards themselves became a highly-prized commodity. Reports of theft at textile mills increased, as the cards were stolen by competing mills.

Bibliography

Spencer, Donald D. *Great Men and Women of Computing*. Oakmont Beach, FL: Camelot Publishing, 1996.

Keyboard

The keyboard is the most commonly used computer input device. It translates each key pressed by the typist into a signal that the computer can understand. Keyboards can be wireless or connected to the computer by a cable.

How It Works

A keyboard consists of two parts: a set of keys that are pushed in sequence by the typist (or keyer) and an encoder that identifies each pressed key and generates a code that uniquely identifies that key. The key set includes the standard alphanumeric keys found on old typewriters and additional keys, such as cursor keys, navigation and function keys, Apple or Windows keys, and a numeric keypad. Keyboards for laptop computers have the minimum number of keys.

The encoder is a microprocessor located in the keyboard that detects each key as it is pressed and released. To do so, the encoder maintains a set of signals in a grid of intersecting rows and columns. When the typist presses a key, a connection is made on the grid. If, for example, the connection is in the first row and the third column, the encoder immediately identifies the pressed key and sends a special signal, called a "scanning code," to the computer. The computer translates the scanning code into the appropriate **binary** code and displays the character on the monitor so that the typist can verify that the correct key was pushed.

binary existing in only two states, such as "on" or "off," "one" or "zero"

The lights on the keyboard (for Caps Lock, Num Lock, Scroll Lock, and so on) are controlled by the computer, not the keyboard. For example, when the typist presses the Caps Lock key, the keyboard encoder sends the code for the Caps Lock key to the computer, and the computer turns on the keyboard's Caps Lock light.

Key Arrangement

The computer keyboard is based on the layout of early typewriters. Until the late nineteenth century, typewriter keys were arranged in alphabetical order. In 1872 Christopher Latham Sholes (1819–1890) developed the first typewriter, which featured the QWERTY keyboard (pronounced "kwer-tee"), so named because the first six letters near the top left of the keyboard are Q-W-E-R-T-Y. The new layout was designed to slow down fast typists and place the keys most likely to be hit in rapid succession on opposite sides of the typewriter. This was done so that the machine would be less likely to jam.

The arrangement resolved the jamming problem, but it created two others. First, many common letters are not located on the center row, also called the "home row." Second, some of the most common letters are concentrated on the left side, favoring left-handed typists. For example, the most common letter, "E," is a stretch for the left middle finger, and the second most common letter, "A," is typed with the left hand's weakest finger.

The QWERTY keyboard continues to be featured on the vast majority of computer keyboards in English-speaking countries even though the reason for its creation, to minimize typewriter jamming, ceased to be relevant with the invention of electric typewriters and computers.

THE FIRST TYPEWRITER

The computer keyboard is based on the typewriter invented by Christopher Latham Sholes in Milwaukee, Wisconsin. Sholes's first typewriters, patented in 1868 by Sholes, Carlos Glidden, and Samuel W. Soulé, featured a keyboard with keys arranged in alphabetical order. The machine lacked a shift key and typed only in capital letters. Although typists found the alphabetical arrangement advantageous for finding the correct keys, it had two primary disadvantages. First, the letters used most often were not easily reached. Second, when typists hit a series of neighboring keys in rapid succession, such as R-S-T, the typewriter bars would jam, requiring the typist to stop and untangle them. Sholes developed the QWERTY keyboard in 1872 to resolve both problems. It is still the standard layout because millions of typists are trained in its use.

Dvorak Keyboard

August Dvorak patented an alternative English-language layout in 1936. The top row has p, y, f, g, c, r, and l. The middle row has a, o, e, u, i, d, h, t, n, and s. The bottom row has q, j, k, x, b, m, w, v, and z. (Illustrations of the Dvorak layout are available at http://www.microsoft.com/GLOBALDEV/keyboards/keyboards.asp) Dvorak, a professor at the University of Washington, claimed that his layout could speed typing by approximately 35 percent. The Dvorak keyboard is considered by some to be a more efficient design because it concentrates the most-used keys on the center row of the keyboard. Advocates claim that Dvorak's layout allows 70 percent of the keystrokes to take place on the center row, compared to 35 percent with the standard QWERTY layout.

Although QWERTY is by far the most widely used layout, some popular operating systems (such as those by Microsoft and Apple) have a built-in option to accommodate Dvorak as well as QWERTY keyboards. In addition, one-handed Dvorak layouts are available for typists using only the right or the left hand.

Multilingual Keyboards

Many operating systems include support for keyboard layouts for non-U.S. typists. For example, Microsoft Windows operating systems support dozens of "locales"—a locale determines how the computer accommodates regional language and conventions such as keyboard layout, sort order, currency format, and date, time, and number format.

Some non-U.S. language keyboards are electronically identical to those produced for U.S. customers, but they have special key caps and a special software program, called a **driver**, to translate each keystroke into the appropriate symbol for that language. For example, a Thai-language keyboard would need a Thai driver to translate keystrokes into the correct Thai characters.

driver a special program that manages the sequential execution of several other programs; a part of an operating system that handles input/output devices

Ergonomic Keyboards

Ergonomic keyboards were developed to address hand, wrist, and arm ailments common among typists. Awkward wrist positions can lead to muscle, tendon, and nerve damage in the wrists (**carpal tunnel syndrome**) and forearms because of diminished blood supply or compression caused by inflamed tendons.

carpal tunnel syndrome a repetitive stress injury that can lead to pain, numbness, tingling, and loss of muscle control in the hands and wrists

Ergonomic keyboards claim to reduce the incidence of repetitive stress injury, including carpal tunnel syndrome, by positioning the keys for each hand in a more natural position for the typist's arms, wrists, and hands.

Many typists and computer users turn to ergonomic keyboards to help them avoid repetitive stress injuries in their hands and wrists.

Ergonomic keyboards include wavy keyboards, split keyboards, and separate keypads.

Keyboard operators should pay special attention to ergonomic factors in their work environment. The chair and keyboard should be positioned so that the typist can sit up straight with feet flat on the floor and both arms able to move freely without hitting the armrests or becoming fatigued. SEE ALSO Ergonomics.

Ann McIver McHoes

Bibliography

Beeching, William A. *Century of the Typewriter.* New York: St. Martin's Press, 1974.

Clements, Alan. *The Principles of Computer Hardware.* New York: Oxford University Press, 1985.

Current, Richard N. *The Typewriter and the Men Who Made It.* Arcadia, CA: Post-Era Books, 1988.

Lovelace, Ada Byron King, Countess of

English Mathematician and Scientist
1815–1852

Augusta Ada Byron King, Countess of Lovelace, is considered to be the first computer programmer even though she was born before computers existed, and the program she wrote was for a machine that was never built. Lovelace was born on December 10, 1815, in London, England, to Annabella Milbanke and one of England's most famous poets, George Gordon, better known as Lord Byron.

The Byrons' marriage did not last long. A month after Lovelace was born, Lady Byron took the child and left the house, never to return. Lord Byron left England shortly after the separation and had no direct contact with his daughter ever again. Although Lady Byron assumed sole control of Lovelace's upbringing, Lord Byron worried about his child from the time of his separation until his death in 1824 and asked about her constantly. Many of Lovelace's childhood letters bear the signature AAda, but her first name, Augusta, for Lord Byron's half-sister Augusta Leigh, was not used after 1816 when rumors arose of scandalous behavior between the half-siblings.

Ada Byron King, Countess of Lovelace.

Nineteenth-century society did not encourage women to use their minds, but Lady Byron was interested in developing her child's intellect and hired the best tutors for Lovelace. With the help of William Frend, her old mathematics tutor, she was able to provide science and mathematical studies to help control Lovelace's overactive imagination. By age six, according to the journal of one governess, Lovelace's morning schedule was divided into fifteen-minute lessons of arithmetic, grammar, spelling, reading, and music, while in the afternoon she studied geography, drawing, French, music, and reading.

At the age of thirteen, she corresponded with Frend, who influenced her studies in astronomy and algebra. But before long, Lovelace was studying mathematics that went beyond Frend's understanding. By the time she was thirty, Lovelace had written accurate descriptions of a new machine—the first digital computer—designed by British mathematician Charles Babbage (1791–1871). Even Babbage was astonished at the depth of her perception.

Lovelace had met Babbage at the age of seventeen when she attended a party at his house and he demonstrated the **Difference Engine**. It captured her imagination and she spent time studying its gears, rods, and wheels until she understood how the machine worked. However, their friendship did not blossom until much later.

In 1835 Lovelace married William King, who became the first Earl of Lovelace in 1838. During this time, Charles Babbage invented the **Analytical Engine**. By the time Lovelace wrote "Notes" on the Analytical Engine, she had been married eight years and had three children. Some of Lovelace's letters to her mother make clear her love for her children, while others show her being frustrated about the lack of time available to pursue her intellectual interests. Her desire to return to the study of mathematics was so intense that both her mother and husband sought ways to give her time to pursue her studies.

In 1840 Lovelace began to study mathematics with Augustus De Morgan, a famous British logician and mathematician. He was an exceptional teacher who was impressed with Lovelace's ability to learn and considered her a promising young beginner. He believed, however, that her intense study of mathematics would aggravate her health and lead to a nervous breakdown.

During the same year, Babbage attended a meeting of scientists in Turin, Italy, to explain the features of the Analytical Engine. He hoped that an eminent scientist would write an official report about his invention. He felt that this would impress the British government, which might then provide more funding for his project. Instead, a young Italian captain named Luigi Federico Menabrea, who later became prime minister of Italy, became the author.

In his paper, written in French, Menabrea described how the machine worked. This was a difficult task because the actual machine did not exist, and he had to work from Babbage's drawings, which used Babbage's own system of engineering notation. The article appeared in 1842 in the *Bibliotheque Universelle de Geneve*. A few months later, Charles Wheatstone, developer of the electric telegraph and a family friend, contacted Lovelace about translating it for the British journal *Taylor's Scientific Memoirs*.

When Babbage found out about this request, he tried to persuade Lovelace to write an entirely new article. She rejected the offer but proposed to add notes to bring Menabrea's text up to date. Lovelace was under a great deal of physical and mental stress during the time that she wrote the "Notes." She had moments of great anxiety, and although her doctors prescribed potentially dangerous remedies, her concentration did not weaken. The dual purpose of the notes, numbered A through G, was to clarify and elaborate on specific points about the machine and to gain support for it from the British government. They were not part of the original document, but were added to the end.

FAMOUS FATHER

George Gordon, the sixth Baron Byron of Rochdale, and father of Ada Byron King, the Countess of Lovelace, is considered by scholars to be one of England's most famous romantic poets. He wrote numerous plays and books, as well as tomes of poetry, including *Don Juan, The Curse of Minerva,* and *The Corsair.*

Difference Engine a mechanical calculator designed by Charles Babbage that automated the production of mathematical tables by using the method of differences

Analytical Engine Charles Babbage's vision of a programmable mechanical computer

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

Jacquard's Loom a weaving loom, developed by Joseph-Marie Jacquard (1752–1834), controlled by punched cards; identified as one of the earliest examples of programming automation

Bernoulli numbers the sums of powers of consecutive integers; named after Swiss mathematician Jacques Bernoulli (1654–1705)

The first set of notes, A through D, explains the differences between the Difference and Analytical Engines, and the use of **punched cards** that controlled the actions of the machine and allowed it to divide a complex problem into a series of smaller steps. They also compare the Analytical Engine to **Jacquard's Loom** and emphasize that the Analytical Engine uses fewer cards because the cards can return to their original position in a process called backing, which today's programmers know as a loop.

Note E gives a complicated example of how the machine can work through a problem. Lovelace described properties that are present in modern computers, such as loops within loops and if-then statements. Note F suggests that the Analytical Engine would be capable of solving problems that had not been solved before, such as astronomical tables. Note G summarizes the functions of the machine and stresses that it can follow instructions but is not capable of generating any original work. In this note Lovelace detailed how the machine could be programmed to compute the calculation of **Bernoulli numbers**. She used the information and formulas supplied by Babbage and determined where the calculations would go into the machine and where the answers would be displayed. Since Lovelace had no machine on which to test the program, printed editions of her "Notes" available today contain some errors. The "Notes" were published in 1843. Following the Victorian norm, they did not carry her full name, but only her initials, A.A.L.

Lovelace liked the outdoors and loved horses and riding, a passion that her husband shared. During her work on the "Notes," she often went riding to clear her head. Later in life, her love of horses caused her to fall heavily in debt. The full extent of her racetrack gambling is unknown because the record of such transactions is no longer available. But by the spring of 1851, she had accumulated a debt of more than 3,200 pounds, which was a substantial sum in those days. At the same time her health deteriorated and she was diagnosed with cancer. The doctors prescribed opium and morphine to relieve the pain. Lovelace died in November 1852, and was buried beside her father. Her most important accomplishment was that she envisioned multiple uses for a machine she never saw.

In the early 1970s the U.S. Department of Defense commissioned the development of a programming language that could perform concurrent processing. In 1980 the Ada Joint Program Office was created to launch and maintain the Ada computer language, named in Lovelace's honor. Its documentation became a national standard and is stored in document number MIL-STD-1815 to honor the year of her birth. SEE ALSO ANALYTICAL ENGINE; BABBAGE, CHARLES.

Ida M. Flynn

Bibliography

Baum, Joan. *The Calculating Passion of Ada Byron*. Hamden, CT: The Shoe String Press, Inc., 1986.

Stein, Dorothy. *Ada: A Life and Legacy*. Cambridge, MA: MIT Press, 1985.

Wade, Mary Dodson. *Ada Byron Lovelace: The Lady and the Computer*. New York: Dillon Press, Macmillan Publishing Co., 1994.

Mainframes

Prior to the advent of the personal computer or PC, the minicomputer, and the microcomputer, the term "computer" simply referred to mainframes. What differentiates the modern mainframe from these other classes of computers is the scope of the processing taking place. The typical mainframe today serves tens of thousands of users processing thousands of transactions every second while maintaining centralized **terabyte**-size databases. Even the mighty supercomputer, although unquestionably faster doing one thing at a time, is not up to this task.

terabyte one million million (one trillion, or 10^{12}) bytes

Surprisingly, the processors used in these machines are not much faster than those found in PCs. The architecture of the mainframe, however, provides that the processors can work together in parallel and focus primarily on the actual processing of data and instructions. They are relieved of the time-consuming duties of controlling input and output. Mundane tasks such as reading data from disk, handling transmissions to user terminals, and even reading and writing into main memory, are handled by sub-systems that may well be as powerful as the main processor.

Although a PC is designed to provide very fast processing to a single user, the mainframe must be able to control many tasks being run by many users simultaneously. Thus, the mainframe is differentiated from other computing systems in the areas of data **bandwidth**, organization, reliability, and control.

bandwidth a measure of the frequency component of a signal or the capacity of a communication channel to carry signals

Evolution of Mainframes

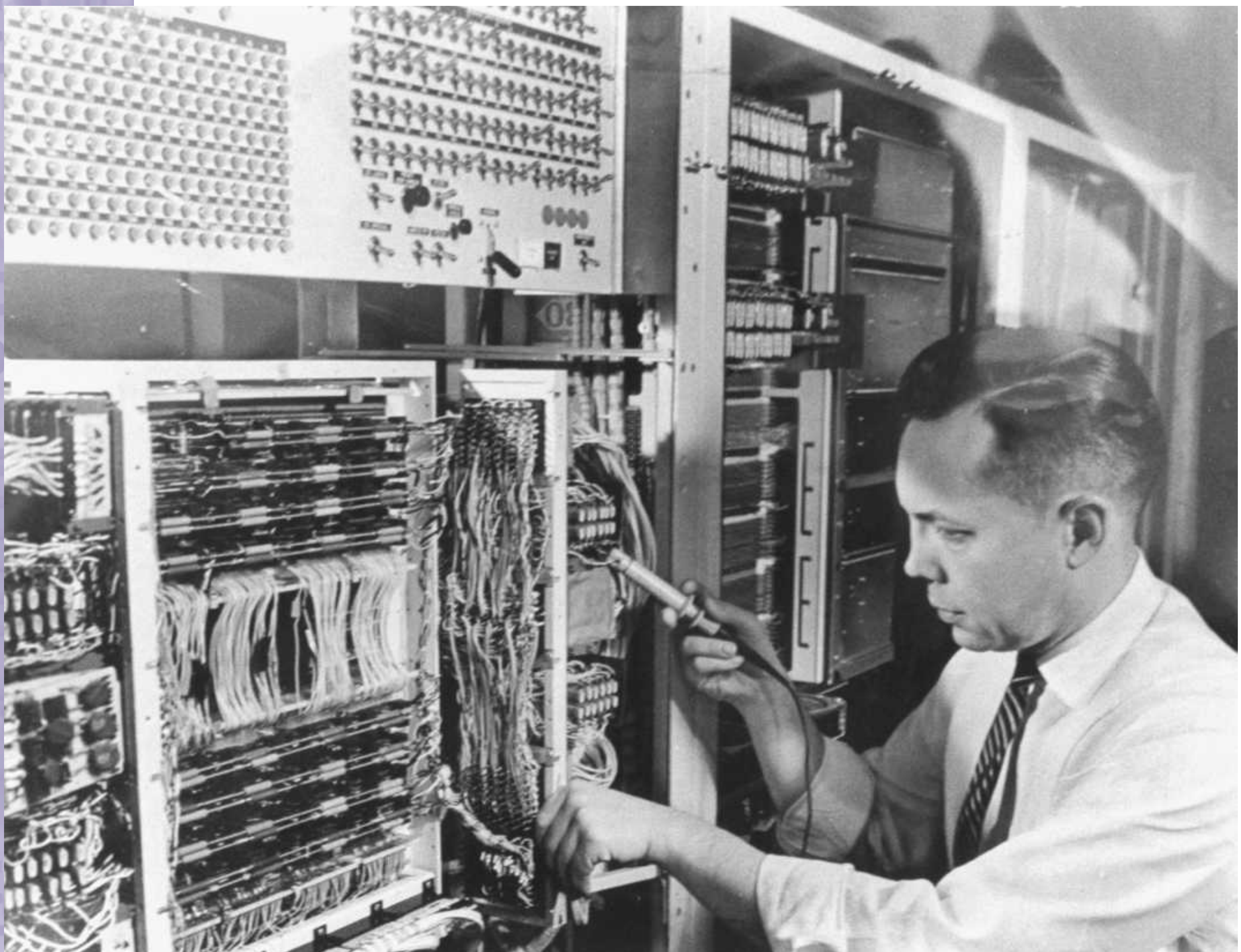
In the early 1960s, companies such as Burroughs, IBM, RCA, NCR, and Sperry Rand manufactured mainframes. Since the 1970s, the only mainframes in use are the System/390, made by IBM, or clones made by Hitachi and Fujitsu. This provides a high degree of hardware compatibility both within and across manufacturer lines. The System/390 evolved from the System/360, which was initially introduced by IBM in 1965.

Over time, the physical size and cost of mainframes have been reduced dramatically. What once cost millions and filled a large data center can now literally fit in a single 48.7-centimeter (19-inch) wide cabinet for a few hundred thousand dollars. Power consumption and heat dissipation have also been reduced. In the 1970s and 1980s, mainframes gave off so much heat they had to be cooled with chilled water.

The fifth generation machines on the market now use Complimentary Metal Oxide Semiconductor, or CMOS, technology and require no special cooling. They can provide up to 12 parallel 650 MHz processors, 32 GB memory, and several terabytes of disk storage. Compare that to a typical PC with a single 500 MHz processor, 64 MB of memory, and 10 GB of disk storage!

Mainframe vs. Personal Computer

Another contrast to the PC is the type of jobs the mainframes run. Transaction processing jobs run constantly in real-time and must be available more than 99.99 percent of the time. The reboots and lock-ups common with PCs are simply not acceptable. Thousands of individual users can log in



Early mainframes were very large machines. Rapid advances in technology have enabled designers to create smaller machines with expanded power.

simultaneously from a variety of sources such as computer terminals, ATM machines, or Internet web sites, and complete a single transaction.

Time-sharing jobs can be started when needed from a computer terminal by authorized users who then use the mainframe as their own big PC. Finally, batch jobs are started automatically by the system at regular times according to a strict predetermined schedule. Batch jobs are used to do the periodic processing required on the data being received from transaction and time-sharing jobs. Closing the accounting books at month-end or copying disk files to tape for backup are examples of batch type processing.

Mainframe Components

Unlike the single box used by the PC, the mainframe has many components. Typically, they include the following.

Operating System. Although many would argue that the operating system (OS) is software and therefore not a component, it is in fact the most important and complex component of the mainframe. The OS used in the largest of mainframes, including clones, is IBM's OS/390, running Multiple Virtual Systems (MVS). The OS/390 also runs Virtual Memory

(VM), VSE, and Unix. MVS has proven itself to be the only OS capable of handling the multiple processing requirements of today's largest businesses.

A key feature of MVS is Job Control Language (JCL), which enables the operators to automate all jobs, scheduling their running times, and handling exceptions that occur. Within MVS, a software sub-system called Customer Information Control System (CICS) enables the concurrent processing of transactions by thousands of users. There are many other subsystems such as IMS and DB/2 for database, Time-Sharing Option (TSO) for user jobs, VTAM for telecommunications, and RACF for security. The OS runs the overall system and provides the environment in which application programs can do the actual jobs users want to accomplish. The vast majority of mainframe application programs are written in COBOL (Common Business Oriented Language).

Central Processing Unit. Similar to the processor in a PC, the central processing unit (CPU) decodes instructions, performs calculations, and issues instructions to other components. Unlike the PC, however, the mainframe will typically have many CPUs connected in parallel. It is the job of the OS to dispatch jobs to parallel processors in an efficient manner. To date, this has proven to be a formidable task. Although once a separate component of the mainframe, main storage—also known as high speed memory or **random access memory (RAM)**—is now typically packaged within the CPU. This is done to increase the speed of data transfer.

Channels. The job of the channel is to connect the CPU and main storage to other components of the mainframe configuration. The channel ensures that data are moved in an orderly fashion and verifies the integrity of the data. The cables used for these channels once consisted of dozens of small coaxial cables that created quite a congested area under the computer room floor. **Fiber optic** cable has resolved this problem while dramatically increasing data transfer speeds.

Disk Storage Subsystems

Disk storage subsystems provide for the long term storage and quick retrieval of large amounts of data. They use a magnetically coated disk spinning at high speed. The latest in this technology incorporates RAID, a random array of inexpensive disks. RAID spreads data across many small disk drives similar to those used in a PC, and uses a method called **parity** to recreate data should one drive fail. The bad drive can then be replaced without turning off the system or losing any data.

Mass Storage Devices. Over the years, many schemes have been developed to increase the capacity of data storage. Recent advances in disk storage technology have rendered obsolete many of these devices, such as magnetic strip and optical disk storage. One device that remains in common use is the tape drive. Tape is used today primarily as a means to back up data. These tapes can then be stored somewhere else to be used if a major disaster destroys the data center. In situations where truly massive amounts of data must be archived for occasional use, tapes are organized into libraries and accessed using automated equipment to find and load the tape.

random access memory (RAM) a type of memory device that supports the nonpermanent storage of programs and data; so called because various locations can be accessed in any order (as if at random), rather than in a sequence (like a tape memory device)

fiber optic transmission technology using long, thin strands of glass fiber; internal reflections in the fiber assure that light entering one end is transmitted to the other end with only small losses in intensity; used widely in transmitting digital information

parity a method of introducing error checking on binary data by adding a redundant bit and using that to enable consistency checks

dumb terminal a keyboard and screen connected to a distant computer without any processing capability

local area network (LAN) a high-speed computer network that is designed for users who are located near each other

wide area network (WAN) interconnected network of computers that spans upward from several buildings to whole cities or entire countries and across countries

Communications Controllers. To gain access to a mainframe computer, a user will typically use a **dumb terminal** or a PC programmed to act as such. The job of keeping track of which user is at which terminal and transferring data is performed by the communications controllers. The connection may be established over a local direct connection, a **local area network (LAN)**, or a **wide area network (WAN)**.

Line Printers. Although many commentators have said that computers will bring about a paperless society, there is still a tremendous amount of data output in printed form. Printers are normally attached via a print controller, although the largest and fastest can connect directly to the channel. The two major categories of printers are impact and laser. Impact printers are used for multiple carbon copies. Laser printers are the workhorse of the industry and produce the majority of output from mainframes. They not only print text, but also graphics and forms at the same time.

Conclusion

The role of the mainframe has gradually changed from that of a data processor to that of a server, with the processing being done on the user's PC. It has also been modified to interface to the Internet through the addition of TCP/IP protocols, Unix, and Java programming, to enable businesses to connect to their customers over that network. Once the only form of business computer available, the mainframe has survived the PC revolution and maintained an important function in commercial computing. SEE ALSO Central Processing Unit; Generations, Computers; Generations, Languages; Memory; Operating Systems.

Ken Doerbecker and Bob Patterson

Bibliography

Williams, Michael R. *A History of Computing Technology*. Englewood Cliffs, NJ: Prentice Hall, 1985.

Internet Resources

Amdahl Corporation. *Millenium Global Servers*. <http://www.amdahl.com/doc/products/compatible/Millennium/Millennium.html>

Hitachi Data Systems. *Guide Your IT Infrastructure into the Next Millennium.* <http://www.hds.com/trinium/product.html>

IBM Corporation. *OS/390 Overview*. <http://www.s390.ibm.com/os390/overview/>

IBM Corporation. *S/390 Parallel Enterprise Server and OS/390 Reference Guide*. <http://www.s390.ibm.com/marketing/reference.html>

Memory

The term "memory" is used to describe the computer's electronic circuitry that holds data and program instructions. It can be thought of as the computer's workspace and it determines the size and number of programs that can be run at the same time, as well as the amount of data that can be processed. Memory is sometimes referred to as primary storage, primary memory, main storage, main memory, internal storage, or random access memory (RAM). There are four major types of computer memory: random access memory, read only memory, CMOS memory, and virtual memory.

Random Access Memory (RAM)

When most people think of computer memory, random access memory (RAM) is what they mean. RAM is composed of chips. These chips can hold:

1. data for processing;
2. instructions, or programs, for processing the data;
3. data that has been processed and is waiting to be sent to an output, secondary storage, or communications device;
4. operating system instructions that control the basic functions of the computer system.

All data and instructions held in RAM are temporary. The contents can and do change as data are processed, programs are run, and instructions are carried out by the computer. RAM is a reusable computer resource.

Most RAM is said to be **volatile**. This means that when the power to the computer is turned off, or the power goes out, all contents of RAM instantaneously disappear and are permanently lost. Because RAM is temporary and volatile, other forms of more permanent storage were developed. Secondary storage is long term, non-volatile storage of data or programs outside the central processing unit (CPU) and RAM. Some of the more common types of secondary storage include magnetic tape, magnetic disk, and optical disk.

volatile subject to rapid change; describes the character of data when current no longer flows to a device (that is, electrical power is switched off)

The storage capacity of RAM varies in different types of computers. Capacity is important because it determines how much data can be processed at once and how large and complex a program may be. The computer's operating system manages RAM so that programs run properly. To understand the capacity of RAM, the following terms are used:

- Bit—a binary digit representing the smallest unit of data in the computer system. A bit can be only a 1 or a 0. In the computer, a 0 means that an electronic or magnetic signal is absent, while a 1 signifies its presence;
- Byte—a group of eight bits. A byte represents one character, one digit, or one value. The capacity of the computer's memory, RAM, is expressed in bytes or in multiples of bytes.

Data, instructions, and programs stored in RAM are really stored as bits that represent those data, instructions, and programs. These bits are stored in microscopic electronic parts called **capacitors**.

capacitors fundamental electrical components used for storing electrical charges

MULTIPLES OF BYTES

A kilobyte, abbreviated K or KB, equals 1,024 bytes, but is commonly rounded to 1,000. A megabyte, which is abbreviated M or MB, equals one million bytes (actually 1,048,576 bytes). Gigabyte, abbreviated G or GB, represents about 1 billion bytes (actually 1,073,741,824 bytes). Terabyte, abbreviated T or TB, equals about 1 trillion bytes (actually 1,009,511,627,776 bytes). A petabyte equals about 1 million gigabytes.

Read Only Memory

Read Only Memory (ROM) is a set of chips that contain portions of the operating system that are needed to start the computer. ROM is also known as firmware. ROM cannot be written to or altered by a user. It is nonvolatile memory. ROM chips come from the manufacturer with programs or instructions already stored and the only way to change their contents is to remove them from the computer and replace them with another set. ROM

COMPUTER GENERATION	MACHINE TYPE AND CAPACITY	
First Generation (1946 - 1956) Vacuum Tubes	MAINFRAME	2000 bytes (2KB)
Second Generation (1957 - 1963) Transistors	MAINFRAME	UP TO 32 KB
Third Generation (1964 - 1979) Integrated Circuits	SUPERCOMPUTER MAINFRAME MINI	UP TO 2 MB
Fourth Generation (1980 - present) Very Large Scale Integrated Circuits	SUPERCOMPUTER MAINFRAME MINI	OVER 2 GB
	MICRO	2 K - OVER 128 MB

Table 1. The capacity of computer main memory has increased over time. Table 1 illustrates the different computer generations, the types of machines in those generations, and the capacity of main memory.

chips can contain frequently used programs, such as computing routines for calculating the square root of numbers.

The most common use for ROM chips is the storage of manufacturer-specific programming such as the Basic Input Output System (BIOS). The BIOS is a critical part of the operating system that tells the computer how to access the disk drives. When the computer is started, RAM is empty and the instructions in the ROM BIOS are used by the CPU to search the disk drives for the main operating system files. The computer then loads these files into RAM and uses them.

There are three variations of ROM.

1. PROM, or programmable read only memory. PROM chips are blank chips on which programs can be written using special equipment. PROM chips can be programmed once and are usually used by manufacturers as control devices in their products.
2. EPROM, or erasable programmable read only memory. EPROM is similar to PROM, but the program can be erased and a new program written by using special equipment that uses ultraviolet light. EPROM is used for controlling devices such as robots.
3. EEPROM, electronic erasable programmable read only memory. EEPROM chips can be reprogrammed using special electric impulses. They do not need to be removed to be changed.

CMOS

CMOS (pronounced SEE MOSS) stands for "complementary metal oxide semiconductor." It is a specialized memory that contains semi-permanent vital data about the computer system's configuration. Without this data, the computer would not be able to start. CMOS is more permanent than RAM and less permanent than ROM. CMOS requires very little power to retain its contents; the chip is powered by a battery. When a change is needed in the computer system's configuration (i.e., a new hard drive is installed, more RAM is added, or the number of floppy disk drives is changed), CMOS can be updated by running a special utility program available through the operating system.

Virtual Memory

Virtual memory is a storage method where portions of a program or data are stored on magnetic disk rather than in RAM until needed, giving the illusion that main memory is unlimited. Virtual memory simulates RAM. It allows the computer to run more than one program at a time, manipulate large data files, and run large programs without having sufficient RAM. Virtual storage is slower than RAM, and is nonvolatile.

How Data and Programs Are Stored in Memory

Computer main memory can be thought of as a two-dimensional table where each cell has a unique address. See Figure 1. Each cell can store one byte of data by using eight capacitors to represent the eight bits in a byte. SEE ALSO BINARY NUMBER SYSTEM; INTEGRATED CIRCUITS; MICROCHIP; TRANSISTORS; VACUUM TUBES.

Charles R. Woratschek

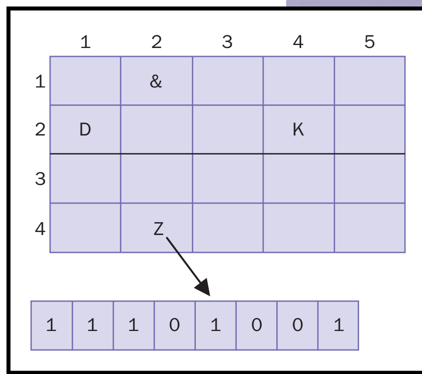


Figure 1. Cell (4,2) contains eight bits representing the letter "Z" (as it would be coded in Extended Binary Coded Decimal Interchange Code (EBCDIC)).

Bibliography

Hutchinson, Sarah E., and Stacey C. Sawyer. *Computers, Communications, and Information: A User's Introduction, Comprehensive Version*, 7th ed. Boston: Irwin McGraw-Hill, 2000.

Laudon, Kenneth C., and Jane Price Laudon. *Essentials of Management Information Systems: Transforming Business and Management*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, Inc., 1999.

Long, Larry, and Nancy Long. *Computers: Brief Edition*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, Inc., 1999.

Parsons, June Jamrich, and Dan Oja. *New Perspectives on Computer Concepts*, 3rd ed. Cambridge: Course Technology, 1998.

Microchip

Although **semiconductors** and microchips are essential components of modern computers, many people do not realize that computing machinery does not really need to be constructed with components that are normally associated with electronic equipment. In fact, some of the earliest computers were purely mechanical machines—they did not rely on electrical technology at all. For example, Charles Babbage's Analytical Engine, designed in 1834 at a time when the use of electricity was in its infancy, was a purely mechanical machine. Had Babbage actually been able to build it, his Analytical Engine would have been a bona fide computing machine.

semiconductors solid materials that possess electrical conductivity characteristics that are similar to those of metals under certain conditions, but can also exhibit insulating qualities under other conditions

Similarly, many of the early computers and calculators were mostly mechanical, using carefully constructed linkages, levers, and cogs. It is important to note that the technology used to implement computers does not define them. Instead, machines are termed computers if they are programmable—regardless of the form the programming takes. Therefore, once mechanical computers and calculators had proven themselves somewhat cumbersome and inefficient, designers looked toward the then newly emerging electro-technologies as a means for implementing computers and calculators.

Around the mid-twentieth century, the analog computer was becoming an increasingly popular tool for solving differential equations. Valve and triode devices used in analog amplification equipment were being mass-produced for the radio and wireless sets that were consumer items of the day. They were also suitable building blocks for the implementation of analog computers. Yet, while analog computers were predecessors of modern digital computers, they did not bear much resemblance to current digital computers.

To explain the development of these technologies, it is helpful to analyze their development history. Scientists and mathematicians have known since the eighteenth century that differential and integral calculus can be used to model problems in the physical sciences. Also, while solutions to differential equations can be developed manually, this process tends to be tedious. Analog computers offered a way of automating the process of generating solutions to differential and integral equations. Building blocks made from valves and **triodes** were constructed to perform specific operations that are common in the solution of differential and integral equations. Blocks that could complete arithmetic operations—such as addition, subtraction, multiplication, and division—could be assembled, along with others that affected operations like integration, differentiation, and other forms of filtering. These building blocks could be assembled and connected using temporary wiring connections—this was actually the programming of these computers.

triodes nearly obsolete electronic devices constructed of sealed glass tubes containing metal elements in a vacuum; triodes were used to control electrical signals

In the beginning, programming an analog computer was a rather labor-intensive activity and the computers themselves would consume a relatively large amount of electrical power. But their speed of computation was phenomenal compared to mechanical computers. The valves and triodes that made these machines possible are still occasionally found in **esoteric** modern audio amplifier equipment, but have been largely consigned to history. The cause of this was the invention of the semiconductor transistor device in 1948.

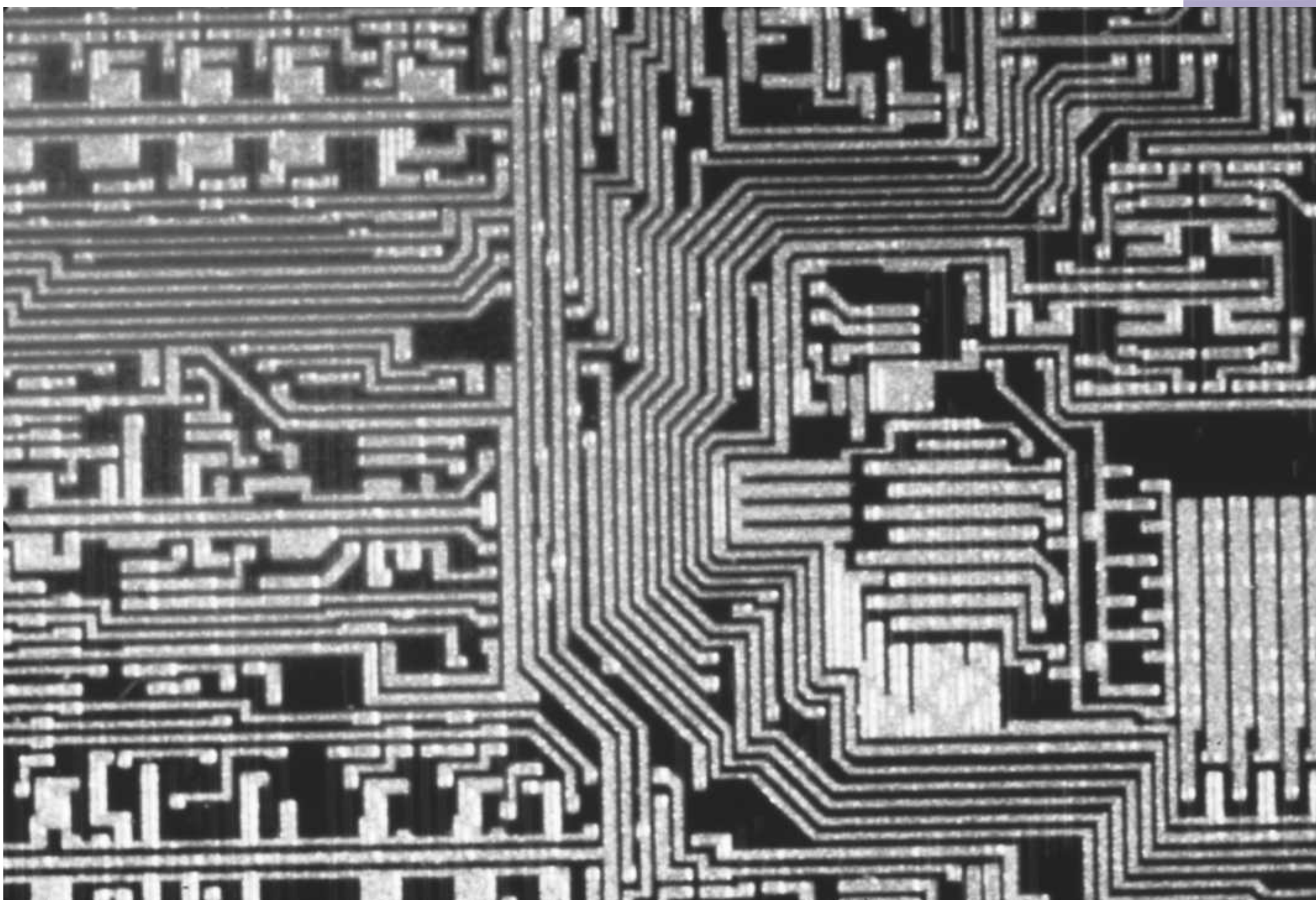
esoteric relating to a specialized field of endeavor that is characterized by its restricted size

Solid-state physicist William B. Shockley (1910–1989) described the operation of the semiconductor transistor in 1950, and its development foreshadowed a revolution in electronics. The fundamental physical difference between a conductor of electricity and an insulator is that conductors permit free flow of electrons, and insulators do not. In other words, if someone takes a piece of conducting material, like a metal, and drops a packet of electrons onto it at one point, they will almost instantaneously redistribute themselves throughout the volume of the metal sample. They will tend to spread out so that their distribution is uniform. A piece of insulating material, like polyvinyl chloride (PVC plastic), would tend to resist the redistribution of a packet of electrons. The PVC would try to prevent the localized collection of electrons from redistributing themselves—instead they would be contained in the one area making that region negatively charged.

Shockley and his contemporaries discovered that there was a certain class of materials that could sometimes be seen as acting like conductors, but with a certain amount of manipulation, the same material could be made to act as an insulator. This property made them somewhat special—they could conduct or insulate under control, making them ideal as switching devices. These materials became known as semiconductors, as a result of their unusual position logically between conductors and insulators. **Silicon** and **germanium** were identified early as semiconductor materials.

silicon a chemical element with symbol Si; the most abundant element in the Earth's crust and the most commonly used semiconductor material

germanium a chemical often used as a high performance semiconductor material; chemical symbol Ge



The detailed grooves of the silicon wafer microchip resemble a large maze.

The production process for the creation of a semiconductor is a complex multistage activity, but essentially involves minuscule semiconductor elements being impregnated with charged particles (known as doping) so as to influence their behavior in useful ways. They are bonded to conductors and encased in plastic or ceramic containers ready for use. Since this time, the word "silicon" in the context of electronics has been used synonymously with terms such as "silicon chip," "chip," and "microchip."

Silicon, germanium, and other semiconductor materials derived from metal oxides have been used ever since, along with metals such as gold, aluminium, and copper to produce semiconductor integrated circuit devices of extraordinary complexity and performance. Their successful miniaturization has meant that a great deal of functionality can be synthesized on a relatively small device. Additionally, these devices consume much less electrical power and operate at vastly greater speeds than the older valve and triode devices. Extra benefits have resulted from the perfection of the manufacturing processes as well, which has in turn lead to these devices becoming inexpensive to purchase and reliable in operation.

An entire industry of massive proportions has been supported by these developments, with its genesis in an area near San Francisco, California, which has since become known as **Silicon Valley**. Subsequently, other regions in Europe and Asia—notably Japan and South Korea—have also established credibility in the mass-production of semiconductors.

Silicon Valley an area in California near San Francisco, which has been the home location of many of the most significant information technology orientated companies and universities

OPTICAL MICROCHIP DEVELOPMENT

Sierra Monolithics Inc. of California and the IBM Corporation have teamed up to work on developing optical microchip devices. From the beginning of 2001, the two companies have spent more than $14 million on the research and development of microchip devices that bridge the gap between conventional semiconductor technologies and optical fiber communication networks. It is anticipated that the optical microchips being developed will be capable of operation in 40 gigabit networks.

For some time theorists and visionaries have proposed the idea that semiconductors might eventually be replaced in computers by devices that have the capacity to implement computer circuitry by using optics or quantum physical concepts, but these are yet to be proven beyond the research laboratory. Any replacement technology will need to possess very impressive credentials indeed if it is to be as operationally effective, as economical and efficient as devices implemented from semiconductors. SEE ALSO Microcomputers.

Stephen Murray

Bibliography

Hilton, Alice Mary. *Logic, Computing Machines, and Automation.* Washington, DC: Spartan Books, 1963.

Sedra, Adel S., and Kenneth C. Smith. *Microelectronic Circuits*, 4th ed. New York: Oxford University Press, 1997.

Wakerley, John S. *Digital Design Principles and Practices*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, 2000.

Young, E. Carol. *The New Penguin Dictionary of Electronics.* Middlesex, England: Penguin Books Ltd., 1979.

Microcomputers

Before the introduction of the personal computer or microcomputer to the general market in the 1970s, computers were physically large, complex, often unreliable, and expensive pieces of machinery. However, they operated in much the same way as they do now, loading programs from secondary storage into memory, accepting input, and executing instructions and generating output. Similarities between those early machines and the types that were to follow ended there however—the early machines were manufactured and sold into a small market, as computers were not yet consumer items. The hardware was expensive as semiconductor devices were only just becoming mainstream, and computers of the time were often accommodated in large purpose-built installations that catered to their temperamental operating requirements. The machinery needed air conditioned rooms and was maintained by squads of specialized professionals behind closed doors. As such, computers were out of the realm of the average person's experience.

The types of programs these machines usually ran generally contributed to their **esoteric** status. Programs dealing with the management of financial transactions in large batches that took many hours to run did not automatically generate much interest in most people. As a result, computing machinery was a somewhat mysterious phenomenon, and its role was restricted to operations principally involving electronic data processing to support financial management, administrative control in large organizations, and specialized scientific research. However, all this was soon to change.

esoteric relating to a specialized field of endeavor that is characterized by its restricted size

semiconductor solid material that possesses electrical conductivity characteristics that are similar to those of metals under certain conditions, but can also exhibit insulating qualities under other conditions

In 1971 the Intel Corporation of Santa Clara, California (an established manufacturer of **semiconductor** devices), responded to a particular design problem in a spectacularly successful way. Another company was considering manufacturing hand-held calculators. These calculators were still somewhat primitive because they were incapable of anything other than simple arithmetic operations and could not be programmed by the user. Nonetheless, they were becoming a fashion accessory at the time. The standard approach to the construction of calculators was to implement a design of several separate semiconductor devices. Although this approach was workable, it was somewhat inflexible—if a modification was made to the specification of the calculator, a significant amount of adjustment to the hardware design was required. This generally meant costly re-construction of prototype designs from scratch.

In response to the problem, the engineers at Intel proposed an approach whereby most of the complexity of the design was shifted into one particular device called a 4-bit microprocessor, designated the 4004. On this one occasion, it meant a lot of extra work in order to develop the microprocessor, but once the microprocessor had been completed, its function could be modified by supplying it with a different program to run. Essentially, the calculator had become a restricted type of computer. The microprocessor could accommodate changes in requirements imposed upon it by varying the controlling program it contained, thereby changing its functionality. This avoided the extra delays and re-working that would otherwise be needed, if the calculator had been developed using the conventional design approach of fixed-function devices. In addition, the programmability of the microprocessor meant that its use could be extended well beyond the limits of a hand-held calculator.

Within a few years Intel and some other manufacturers had built more powerful microprocessors using 8-bit and then 16-bit architectures. This opened the way for small-scale computers to be developed around designs based on mass-produced microprocessors. Within five years there was an array of different small computers available for people to purchase, making computing machinery finally available to consumers. These computers were termed microcomputers to distinguish them from the commercially available, business orientated **minicomputers** and **mainframe computers**.

minicomputers computers midway in size between a desktop computer and a mainframe computer; most modern desktops are much more powerful than the older minicomputers

mainframe computers large computers used by businesses and government agencies to process massive amounts of data; generally faster and more powerful than desktop computers but usually requiring specialized software

Nearly all of the microcomputers were quite primitive though—most had very small memory capacity, limited input and output device support, and could only be programmed in low-level languages. As such, they were mainly curiosities and were targeted by technically minded hobbyists and enthusiasts—mostly people who understood computing technology, but were unable to buy their own minicomputer from those that were commercially available, because they were too expensive. Steadily, as interest grew, more user-friendly machines were produced and interpreted programming languages became available, enabling people to develop and distribute programs more easily. In the early 1980s, these small computers were given the opportunity to become very useful in a practical sense, following the development of the spreadsheet by Dan Bricklin. No longer were microcomputers to remain solely within the realm of the technically inclined; for the first time they offered more general users a means of automating very labor-intensive tasks and were truly becoming a business tool.

MICROCOMPUTERS IN SPACE

In March 1999, it was announced that microcomputers would form a part of the computing systems facilities on the International Space Station. The European Space Agency (ESA) has used IBM personal microcomputers running the GNU Linux operating system to control the flight of an unmanned servicing space craft called ATV. Microcomputers can be entrusted with important real-time tasks and are no longer viewed as just elaborate typewriters.

The IBM Corporation became interested in acquiring a portion of the microcomputer market in the early 1980s. This one step did more to establish credibility in personal computing and microcomputer technology than all previous events. IBM was the epitome of corporate computing; it manufactured large computing systems for industrial and commercial

One of the first microcomputers for the mass market was the IBM Personal Computer (IBM-PC). Released in 1981, it helped start a trend for personal computing that continues to this day.

multitasking the ability of a computer system to execute more than one program at the same time; also known as multiprogramming

computing environments. For them to be involved in the world of microcomputers legitimized the whole concept. From that moment onward, microcomputers became a part of mainstream civilization.

During the first decade of microcomputer history, the hardware was hampered by operating systems that did not support **multitasking** (multiprogramming). This was recognized as something of a drawback, but it was more difficult to counter than was earlier imagined. Multitasking operating systems were steadily developed for microcomputers, but they faced several difficulties including the lack of inter-operability, the requirement of significant amounts of expensive random access memory (RAM), and the need to maintain support for older legacy applications. Eventually, many of these problems were overcome as hardware capabilities for microcomputers were enhanced and standards for networking and communication were adopted.

The sheer size of the microcomputer market has meant that more research and development spending has been directed at perfecting the technology, and now modern microcomputers offer performance levels that were only dreamed of in the earlier years. Features like voice recognition and integration with the Internet and television technologies promise more for the future. Microcomputers have become indispensable parts of client/server environments in just about all areas of commercial, industrial, educational, and domestic activity. SEE ALSO Mainframes; Minicomputers; Supercomputers.

Stephen Murray

Bibliography

Little, Gary B. *Inside the Apple IIe.* Bowie, MD: Brady Communications Company Inc., 1985.

Norton, Peter. *Inside the IBM PC.* New York: Brady Communications Company Inc., 1986.

Rodwell, Peter. *The Personal Computer Handbook.* London: Dorling Kindersley Ltd., 1983.

Zaks, Rodnay. *The CP/M Handbook with M/PM.* Berkley, CA: Sybex Inc., 1980.

Microsoft Corporation

Microsoft Corporation, a software company, was started by Bill Gates and Paul Allen in 1975 when MITS (Micro Instrumentation and Telemetry Systems) produced the first widely available personal computer in kit form, called the Altair 8800. This computer came with assembly language, making the computer difficult to use. Gates and Allen wrote a version of Beginners' All-purpose Symbolic Instruction Code (BASIC), the first computer language for personal computers, specifically for that machine and sold this software for the Altair. This version worked so well that it became the foundation of almost all personal computers at that time, including Apple products. With this modest start Microsoft paved the way for the development of two more languages, Microsoft FORTRAN (FORmula TRANslation) and Microsoft COBOL (COmmon Business Oriented Language), and sales of other successful software programs in the budding personal computer market.

The second generation of personal computing occurred when IBM entered the market in 1980. IBM asked Microsoft to develop operating system software, the computer's "nervous system," for its new personal computer based on an Intel microprocessor (the computer "brain"). Although Microsoft had focused almost exclusively on application software, it agreed to the deal, then bought the operating system from neighboring Seattle Computer Products and renamed it MS-DOS (for Microsoft Disk Operating System).

IBM's popular personal computer, produced with a **microprocessor** by Intel and utilizing MS-DOS, inspired the production of IBM clones. This in turn stimulated the creation of software and peripheral products throughout the computer industry. Microsoft and Intel products literally set the standard for the personal computer industry, thus ensuring a strong future for both companies.

microprocessor the principle element in a computer; the component that understands how to carry out operations under the direction of the running program (CPU)

Microsoft Word (introduced in 1983), Excel (1987), and PowerPoint (a product of Forethought, Inc., which was acquired in 1987 by Microsoft) were other successful applications. Combining these products into Microsoft Office, along with its operating systems, languages, business software, hardware, and computer how-to books helped Microsoft reach $140 million in sales and 900 employees on its tenth anniversary.

The CD-ROM (compact disc-read only memory), introduced in 1987, offered another opportunity for the company. Microsoft's Bookshelf, a collection of ten general-purpose applications, was the first CD-ROM for personal computers. In 1990, Microsoft became the first personal computer company to reach one billion dollars in sales in a single year.

Introducing Microsoft Windows

Computer speed and memory increased with the advent of internal hard drives in personal computers and expanded capacity of microprocessor chips.

This allowed the development of more complex software programs, such as Microsoft Windows.

Introduced in 1985, Windows did not arrive without cost and controversy. First, it functioned in a way so similar to Apple Computer's Macintosh operating system that Apple sued Microsoft for copyright infringement. Also, IBM considered Windows to be in direct competition with IBM's OS/2, a project IBM was developing with Microsoft. This led to the severing of the IBM-Microsoft partnership.

The early Microsoft Windows applications, up to version 3.1, were programs developed to operate in conjunction with MS-DOS. These programs were designed to make it possible for users to run multiple unrelated software applications at once. Windows evolved from software applications into a series of operating systems called Windows NT, Windows 95, Windows 98, Windows 2000, Windows ME, and Windows XP, which was introduced late in 2001.

Sherman Antitrust Act the act of the U.S. Congress in 1890 that is the foundation for all American anti-monopoly laws

Microsoft and Apple Computer, Inc.

In addition to its early partnership with IBM, Microsoft also had longstanding ties to Apple Computer, Inc. An early believer in Apple, Microsoft developed software applications (although not the Apple operating system) for the Apple II and later contributed significantly to software applications developed for the successful Macintosh line. In 1997, Microsoft helped bring a troubled Apple Computer, Inc. back into the market after agreeing to invest in Apple and develop Microsoft Office, Internet Explorer, and other applications specifically for Apple's Macintosh. As part of that deal, Apple agreed to drop the copyright infringement lawsuit that had been proceeding against Microsoft for many years.

FROM SCHOOLBOY TO SOFTWARE MOGUL

Bill Gates discovered the fascination of computers as a 12-year-old at the private Lakeside School in Seattle, Washington. Four years later, Gates and schoolmate Paul Allen wrote software to measure Seattle's traffic flow, and incorporated their first company, Traf-O-Data.

With two others, they formed the Lakeside Programming Group and wrote complex payroll applications for a local company. When Lakeside School bought a computer, Gates and company got the job of scheduling their own classes.

Gates went to Harvard and Allen accepted a job in Boston. There the two wrote and marketed BASIC for the Altair, the first home computer kit. When Gates dropped out of Harvard to found and run Microsoft, first in Albuquerque, New Mexico, and then in Seattle, he was on his way to becoming one of the world's richest private citizens.

Microsoft as a Monopoly?

The Windows operating system and Internet Explorer, Microsoft's World Wide Web browser, became so widely used that competitors claimed that Microsoft had become a monopoly. The Justice Department of the United States, along with the attorneys general of nineteen states and the District of Columbia, filed a lawsuit against Microsoft in 1998.

In April 2000, a court determined that Microsoft had violated the **Sherman Antitrust Act**. In his conclusions, U.S. District Judge Thomas Penfield Jackson found that ". . .Microsoft's share of the worldwide market for Intel-compatible PC operating systems currently exceeds ninety-five percent. . ." and that "Microsoft enjoyed monopoly power." He stated that Microsoft "used anticompetitive methods to achieve or maintain its position." In addition Microsoft was found to have attempted to monopolize the Internet browser market through anticompetitive acts, especially by its practice of integrating Internet Explorer with its Windows 95 operating system, thereby discouraging or prohibiting the use of other web browsers. Jackson ordered that Microsoft be split into two companies.

Although that remedy was reversed by the U.S. Court of Appeals in 2001, the appeals court agreed with both Jackson's monopoly ruling and his findings that Microsoft illegally maintained its monopoly. In October 2001,

Microsoft's corporate headquarters is built like a college campus, complete with multiple buildings, woods with jogging trails, athletic fields, museum, and store. Shuttle buses help employees get around campus.

Microsoft agreed to terms to settle the lawsuit out of court. SEE ALSO APPLE COMPUTER, INC.; INTEL CORPORATION; OPERATING SYSTEMS.

Mary McIver Puthawala

Bibliography

Cusumano Michael A., and Richard W. Selby. *Microsoft Secrets: How the World's Most Powerful Software Company Creates Technology, Shapes Markets, and Manages People.* New York: The Free Press, 1995.

Edstrom, Jennifer, and Marlin Eller. *Barbarians Led By Bill Gates.* New York: Henry Holt and Company, 1998.

Jackson, Thomas Penfield, Judge, United States District Court for the District of Columbia. *The United States of America v. Microsoft Corporation*, Action No. 1232(TPJ), pp. 5–9.

Malone, Michael S. *Infinite Loop: How Apple, the World's Most Insanely Great Computer Company, Went Insane.* New York: Doubleday, 1999.

Schlender, Brent. "Bill Gates and Paul Allen Talk." *Fortune* 132, no. 7 (1995): 68.

Minicomputers

Minicomputers (sometimes called the "mini") are defined primarily in terms of price and size. Minicomputers generally have a word size of 8–18 **bits** (register size); a memory size of 32,000–64,000 16-bit words, or 16,000–32,000 32-bit words; a processing speed of 200–300 kilo-instructions per second (KIPS); and a price in the range of $3,000 to $50,000. The large processors of the 1970s and 1980s cost from $50,000–$100,000 to several million dollars. The mini was an economical solution to low-end, smaller computing.

bits the plural of bit, a single binary digit, 1 or 0—a contraction of Binary digIT; the smallest unit for storing data in a computer

A computer user operates metallurgical testing equipment, which is controlled by a minicomputer.

The mini was relatively small, less than 0.6-meters (two-feet) wide, and mounted in a rack. Its advent also spurred the development of peripherals that had to be developed at a price consistent with that of the mini while providing satisfactory performance.

Some applications of the minicomputer were data acquisition, process control, time-sharing, and terminal and peripheral communication control. Process control systems involve data acquisition and feedback to control the process, with or without human intervention. The machine-machine system involves the use of a minicomputer as a front end communications processor or a peripheral control unit. This offloads the tasks of error checking, polling, hand-shaking, line buffering, or other formatting from the large central processor. Minicomputers were also used in stand-alone or single-user mode to do human research such as reaction time studies. The stand-alone mode was necessary to provide timing independent of other processes.

The minicomputer was capable of performing under normal environmental conditions and did not require the extensive power and air-conditioning of larger but more delicate systems. It could also be made rugged ("rugged-ized") to perform in adverse environments such as combat fronts. It was a more durable tool than many larger systems and more easily transportable. It could also be used in factories for process control, inventory and manufacturing control, or as a satellite to a larger computer, feeding data to it or acting as a peripheral device.

The growth of the minicomputer market was relatively rapid. It began in the 1960s and expanded in the early 1970s. The key to its growth was the development of large-scale integrated circuitry (LSI). **Integrated circuits** (ICs) were developed in the 1960s, initially with a single function on a chip, a logic gate or flip-flop (memory element); then with medium-scale integration (MSI), with a dozen or more functions on a chip; and, finally, large-scale integration (LSI), with more than 100 functions on a chip; and later, with very large-scale integration (VLSI). The availability of large-scale integration lowered the costs of developing a computer and also aided in the replicability of the manufacturing process. This enabled **batch processing**, as well as modular construction and the interchangeability of parts.

Minicomputer peripherals included cassette tape units, minidisks, cartridge disks, and the **cathode ray tube (CRT)**. However, there was initially a discrepancy between the cost of the **central processing unit (CPU)** and the cost of the peripherals because of declining costs in the batch processing of CPU and memory microchips.

The minicomputer system was designed to balance the needs of input/output and storage with the computing needs in a cost-effective way. The software for a mini usually consisted of an assembler, editor, several **compilers**, and utility programs. The operating systems were of various types, including paging systems. Some minicomputers were application-specific; the hardware and peripherals, as well as the software, or driver program, were tailored to the application. This was especially true of military, airborne, or other special uses of the computer. Minicomputers were used in some of the early American space launches.

It is difficult to compare the minicomputer with the personal computers of today. The personal computer is far larger in terms of memory capacity and peripheral storage capacity, and faster in processing speed. It is also considerably cheaper in absolute cost and in cost relative to performance. However, the minicomputer can be compared to the personal computer as a low-cost alternative to computing with a large system. In certain applications, such as large-scale computing or complex graphical designs, a maxicomputer or large computer—even a supercomputer—is still required.

Some of the compilers available with minicomputers were FORTRAN (FORmula TRANslator) IV, Algol, RPG, Basic (interpreter), and, eventually, C and Unix. C and the associated operating system Unix, and much of the early work at Bell Laboratories on computers and computer software, were done on the PDP-series computers (Digital Equipment's PDP-x family). Other manufacturers were Data General, Varian, Hewlett-Packard, Honeywell, and Texas Instruments.

The number of **registers** in a mini was limited. Although the PDP-11 and other members of the family had eight registers, others had fewer. Some minicomputers were single-address machines, with a single register or accumulator. Others, such as the PDP-11 and Interdata 70, were two-address machines, indicating several registers—one of which is addressed in the instruction, along with a memory location. The **I/O** was sometimes under program control, tying up the CPU or central processor, while others offered direct memory access (DMA), stealing cycles from the CPU, but otherwise operating independently of the CPU, through a separate I/O controller or channel.

integrated circuits circuits with the transistors, resistors, and other circuit elements etched into the surface of single chips of semiconducting material, usually silicon

batch processing an approach to computer utilization that queues non-interactive programs and runs them one after another

cathode ray tube (CRT) a glass enclosure that projects images by directing a beam of electrons onto the back of a screen terminal

central processing unit (CPU) the part of a computer that performs computations and controls and coordinates other parts of the computer

compilers programs that translate human-readable high-level computer languages to machine-readable code

registers a set of bits of high-speed memory used to hold data for a particular purpose

I/O the acronym for Input/Output; used to describe devices that can accept input data to a computer and to other devices that can produce output

Disk operating systems were developed for minicomputers because the amount of main memory was limited. If the operating system took up between 12 kilobytes (K) and 20K of memory and only 32K was available, a limited amount was left for user programs. The operating system was divided into resident and non-resident portions, and the non-resident portions of the operating system as well as user programs were rolled, or swapped, in and out as necessary. One machine of the PDP series implemented time-sharing by swapping whole programs in and out of main memory, with one user program resident at a time.

The minicomputer led to an unexpected development. The PDPseries of computer was expanded in 1975 to the Virtual Address eXtension (VAX) series of computers. The VAX was a 32-bit machine that was comparable to a mainframe, though not in terms of the large cost of some of the mainframes of the day (several million dollars). As of the year 2002, the VAXseries of computers was still in use in universities and elsewhere. It is a phenomenon in the fast-moving computer market.

The development of the VAXfamily of computers coincided with the development of the personal computer. The introduction of the IBM personal computer (8086/8088) in 1981 started another revolution that continues to the present day. SEE ALSO Mainframes; Microcomputers; Supercomputers.

Roger R. Flynn

Bibliography

MacEwen, Glenn H. *Introduction to Computer Systems: Using the PDP-11 and Pascal*. New York: McGraw-Hill Book Company, 1980.

Weitzman, Cay. *Minicomputer Systems: Structure, Implementation and Application*. Englewood Cliffs, NJ: Prentice Hall, Inc., 1974.

Minitel

Minitel is an interactive network in France consisting of millions of residential and business computer terminals that transmit and receive information exclusively through the country's national telephone system. The Minitel network, developed in 1978 and officially launched in 1982, performs many of the functions now available through the Internet. Minitel, however, began more than a decade before the Internet was available.

The Minitel network was originally proposed to give French residents universal access to an electronic telephone directory, to reduce the cost of paper telephone books, and to promote the nation's new telephone system run by the government communications agency, France Telecom.

To establish the Minitel network and to encourage families to subscribe to the upgraded telephone system, French households were offered a free terminal. The terminal, called "le Minitel," was a **dumb terminal**—it had no processing capabilities but used the telephone connection to dial up a central computer server, retrieve the desired information, and display it on the user's screen.

dumb terminal a keyboard and screen connected to a distant computer without any processing capability

The free terminals immediately eliminated France Telecom's annual fee for producing and distributing costly paper telephone books. Historically,

The Minitel system, which uses Videotex terminals, continues to be popular in France.

the delivery of paper telephone books had been routinely delayed for up to eighteen months. Therefore, even when they were new, the books were out of date and riddled with errors. In 1979 France Telecom calculated that the cost of distributing free electronic terminals would, by 1988, be cheaper than delivering free telephone books, which had required 20,000 metric tons (44 million pounds) of paper in 1979 and would have taken an estimated 100,000 metric tons (220 million pounds) by 1985. The potential savings moved the project forward.

The population, however, did not immediately warm to the idea. In 1980, as Minitel was being introduced, the public voiced distrust of the technology because they feared it might be shut down in a wartime situation.

Members of Parliament were also wary of a potential monopoly by France Telecom; they moved to restrict a system that would allow the agency to become too powerful too quickly. Parliament also addressed fears of electronic competition with the paper industries by guaranteeing cooperation with newspapers and other media.

Despite early obstacles, Minitel was a success by 1984 and its capabilities were broadened beyond its original charter. In addition to providing information directories, Minitel became the nation's resource for sending messages, ordering merchandise, viewing store hours or train timetables, researching theater ticket prices, or playing games—even interactive games with people in distant locations. Interactive chat rooms featuring pseudonyms and a messaging system similar to e-mail were introduced. For residents without a home phone, Minitel kiosks were installed in public places, such as post offices.

Minitel continued to grow throughout the next 14 years, and in 1998, France Telecom counted 5.6 million terminals installed, from which 176 billion calls were made to Minitel. Most terminals (64 percent) were located in residences, followed by professional locations (25 percent), businesses (10 percent), and other locations (1 percent).

By 1999 the Minitel telephone directory was receiving 150 million calls a month with an additional 100 million calls to other sites. By then, non-directory services included travel reservations, sports scores, bank account information, stock prices, administrative file access, weather forecasts, lottery results, TV schedules, classified ads, and mail order sales.

The Minitel terminal has evolved since its introduction. Early models featured a simple black and white screen. Subsequent models offered a sophisticated combination of telephone access and color computer graphics that included a telephone receiver and line. The Webphone, which France Telecom began testing in 1999, offers access to both the Internet and Minitel.

In the mid 1990s, the Minitel system was gradually made accessible from personal computers and the Internet itself. By the end of 1999, some 3 million Minitel emulators were being used on desktop computers. In 1999, of the 82 percent of Minitel users in France who also used the Internet, 14 percent had never used Minitel before the Internet was available.

Rather than replacing the original system, the Internet complements it, making the Minitel network more accessible and more popular than ever. Although the Internet is becoming increasingly widespread in France, Minitel is still the exclusive avenue for certain services and information, such as airline reservations, frozen food mail orders, and company financial profiles. Other operations, such as telephone directory scanning and train ticket reservations, are still comparatively faster using Minitel than the Internet.

One key difference between Minitel and the Internet is that Internet users can visit most sites free of charge. Minitel users, conversely, pay a fee every time they access a Minitel site. The entrepreneur or organization that sponsors the Minitel site collects part of the fee, called a payback, from France Telecom. Charges are calculated by the minute and billed directly to the user's telephone bill. Prices vary depending on the services accessed and range from a few cents to more than $1 (U.S. dollar) per minute.

MINITEL UPGRADES

To keep up with fast-changing technology, Minitel improved its services in late 2000 by introducing i-Minitel, which helps PC and Mac users connect more easily. In addition, France Telecom launched Et hop Minitel to allow businesses to post their web content via Minitel.

Minitel sites are considered more secure than comparable Internet web sites because Minitel is a closed network. Many banks and reservation agencies, therefore, prefer to maintain a Minitel site as opposed to opening an Internet web site because of the increased security benefits and the opportunity for payback revenue. SEE ALSO Apple Computer, Inc.; Bell Labs; Intel Corporation; Internet; Microsoft Corporation; Xerox Corporation.

Ann McIver McHoes and Genevieve McHoes

Bibliography

Marchand, Marie. *A French Success Story: The Minitel Saga*, trans. Mark Murphy. Paris: Larousse 1988.

Mouse

In 1963 Douglas C. Engelbart (1925–), working at the Stanford Research Institute, was investigating different ways for humans to communicate with computers. He thought that a pointing device, something that a computer user could move by hand causing a corresponding movement in an object on the screen, would be easier to use and more intuitive than the existing keyboard. The computer mouse made its debut in 1968 at a computer conference in San Francisco, but it was not widely used until the introduction of personal computers in the 1980s. Since then, it has become a very popular pointing device for operating environments that provide **graphical user interfaces (GUIs)**.

graphical user interfaces (GUIs) interfaces that allow computers to be operated through pictures (icons) and mouse-clicks, rather than through text and typing

The mouse is used in conjunction with the keyboard to perform tasks such as moving and pointing to objects displayed on the screen, selecting commands from menus, and working with drawing and painting programs. A mouse* has one, two, or three buttons that can be pressed to send to the computer signals that activate commands. As the mouse is moved around a desktop, the on-screen pointer mimics its motion. This technique provides an extremely fast and smooth way to navigate around the computer screen.

***The computer mouse gets its name from its resemblance to a real mouse: it has a small body and long tail.**

How does a computer mouse work? There are two distinct user movements that activate the mouse: moving it around a desktop, and pressing one of its buttons.

As the mouse moves around a desktop, the tracking ball—a rubber ball underneath its body—translates the mouse movements into input signals that the computer can understand. Those signals are carried to the computer by the long cable that connects the mouse to one of the computer's ports. As the ball spins, it makes contact with and rotates two rollers installed at a 90-degree angle to each other. One of the rollers reacts to back-and-forth movements of the mouse, which translate into up-and-down movements of the on-screen pointer. The other roller detects sideways movements, which translate into side-to-side movements for the on-screen pointer. Each roller is joined to a wheel, called an encoder, which has a set of tiny metal bars, called contact points, on its rim. When the rollers go around, the encoders do the same, and their contact points touch two pairs of contact bars that reach out from the mouse's cover, thus generating an electrical signal.

In addition to standard varieties, computer mice are manufactured to assist people with special needs. Here, a disabled man uses a mouse with his right hand and a pointer to touch keys with his left.

A new signal is sent every time a connection is made between the contact points and the contact bars. The total number of signals shows how far the mouse has moved: a large number of signals means it has moved a long distance. The direction in which the mouse is moving—up-and-down or sideways—is communicated by the direction in which the rollers are turning and the ratio between the number of signals from each of the rollers.

The signals sent to the computer through the mouse's tail are used by the software that empowers the mouse. This software converts the number of signals from the encoders and rollers to determine how far and in which direction the on-screen pointer will move. The frequency of signals indicates the speed needed to move the on-screen pointer.

Each of the buttons on the top of the mouse covers a tiny switch that records when a button is pressed or clicked, and the time interval between clicks. Pressing one of the buttons on the mouse sends a signal to the computer, which again is passed on to the software. Based on how many times a user clicks the button, and where the on-screen pointer is positioned during these clicks, the software will execute the task selected.

Mouse Variations

A trackball is an upside-down mouse. With a trackball, the user spins a ball with his or her fingers to determine the speed and direction of the on-screen pointer. This is useful with laptop or notebook computers and other portable computers where there may be no desktop available.

A wireless mouse, a mouse without a cord, can also be used to perform pointing and clicking actions. Wireless mice use infrared or radio signals to communicate with the computer. SEE ALSO GAME CONTROLLERS; HYPERTEXT; INTERACTIVE SYSTEMS; MICROCOMPUTERS; POINTING DEVICES.

Ida M. Flynn

Bibliography

"Input/Output." *Understanding Computers.* Alexandria, VA: Time-Life Books, 1986.

White, Ron. *How Computers Work*, 2nd ed. Emeryville, CA: Ziff-Davis Press, 1997.

Music

Computers have had an impact on all segments of the music industry. Specialized hardware and software helps train performers on instruments, such as piano and guitar, and assists with instruction in music theory, ear training, and general musicianship. Computers are used to help create new compositions and analyze existing ones. Computers can also be used to produce the raw sounds of music through synthesis and sequencing software and hardware.

Since the late 1960s, most composers and publishers have used computer notation and typesetting programs instead of engraving and hand copying to make printed scores and parts. The use of digital technology for music production, including recording and editing, and for playback is almost universal. Music can be heard and exchanged over the Internet, and computer-generated music is heard in film scores, television commercials, popular music, and classical music concerts.

However, the most significant impact of computers may be the increased ease with which people are able to participate in the making of music. Performers can create and "play" their own instruments without years of traditional training, for example, and can generate recordings and distribute them over the Internet outside the traditional studio system.

Sound Synthesis and Recording

The term "electro-acoustic" music is used to describe music in which the sounds are produced, changed, or reproduced by electronic means, or synthesized, rather than being produced by naturally resonating bodies such as the vocal cords. In traditional electronic music, sound is generated by devices such as **oscillators** that produce an electrical signal. Processors, such as mixer, filter, and reverberation modules, can then modify the signal.

This process is called **analog** synthesis because the electrical signal produced by the synthesizer is a nearly exact representation of the waveshape of the actual sound. In analog recording, the microphone converts the waveshape of the sound into an electrical signal that is pressed into the groove of a record. As the needle wiggles along this picture of the waveshape, it is converted back into an electrical signal. The analog representation of sound

oscillators electronic components that produce a precise waveform of a fixed known frequency; they can be used as time base (clock) signals to other devices

analog a quantity (often an electrical signal) that is continuous in time and amplitude

Computers have many educational uses, including the study of music. For example, students can learn how to finger various compositions by first seeing them charted on a computer screen.

is on a continuous scale; like the sweep second hand on a watch, it is able to represent any two points and all possible points in between.

digital a quantity that can exist only at distinct levels, not having values in between these levels (for example, binary)

Digital synthesis and recording are based on the idea that it is possible for the continuous waveshape of a sound to be represented by a series of numbers. This process is known as quantization. Computers are ideal machines for generating and storing those numbers. However, special hardware is required: digital to analog converters (DACs) are needed to translate numbers into electrical voltages and analog to digital converters (ADCs) are used to translate voltages into numbers.

The digital representation of sound is on a discrete scale of steps, like a digital watch that can indicate 1:00 and 1:01 but nothing in between. The waveshape of a sound is specified, or sampled, at evenly spaced points along the wave. The frequency with which the samples are taken is the sampling rate. The higher the sampling rate, the more exactly the waveshape is represented and the higher the fidelity of the resulting sound. A general principle is that the sampling rate must be at least two times the frequency of the highest sound to avoid distortion.

Figure 1 shows in simple terms how the representation of a waveshape changes if Sample Rate 1 is cut in half.

Another important issue in digital sound representation is the size of the unit used to store samples. Small units, such as eight **bits**, can store a limited range of numbers. Many values must be rounded off and information is lost. Achieving high fidelity requires a big memory, however. Representing four seconds of sound in sixteen-bit units requires approximately 700,000 **bytes**.

Digital synthesis is limited by the time required for the computer to calculate the numbers for each sample. If the time needed is greater than the sampling rate, the sound cannot be produced in real time; the values must be stored in a file that can be played back once all the calculations are complete. This makes experimentation, variation, and modification difficult.

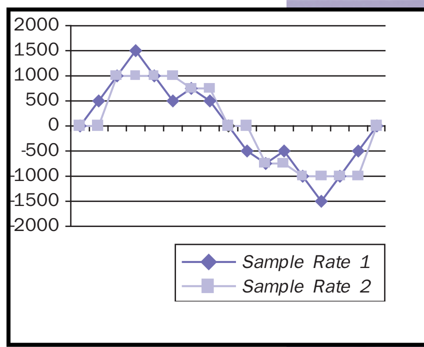


Figure 1.

bits the plural of bit, a single binary digit, 1 or 0—a contraction of Binary digIT; the smallest unit for storing data in a computer

bytes groups of eight binary digits; each represents a single character of text

Analytical Engine Charles Babbage's vision of a programmable mechanical computer

History

As early as 1843, Ada Byron King, Countess of Lovelace, suggested that Charles Babbage's **Analytical Engine**, a forerunner of the computer, might be used for music. In 1957 this vision was realized in two very different ways. Lejaren Hiller and Leonard Isaacson wrote a computer program that composed the *Iliac Suite* using the laws of chance and basic rules of music composition. This program generated a score that was played by human musicians.

The pioneering work in computer music was done using software synthesis. This is the most flexible and precise method because synthesis programs can be run on general-purpose computers.

Early music synthesis programs such as MUSIC III (1960) were written using the concept of unit generators, like the modules of analog synthesizers. In the 1960s and 1970s, most computer music was produced at universities and research institutions. Software synthesis became more widespread in the late 1980s with the introduction of low-cost, good quality, digital to analog converters for personal computers and graphical user interfaces (GUI).

By 2000 software synthesis programs included two categories: (1) graphical instrument editors in which the user simulates using an analog synthesizer by clicking on icons on the display screen; and (2) synthesis language programs in which the user specifies sounds by writing text that is interpreted by the program.

Researchers also designed special-purpose hardware for music functions. This path led to commercial digital performing instruments, including the Synclavier (1976) and the Fairlight (1979), which are widely used by performers. However, the flexibility of these machines is limited by the fixed nature of their circuitry, which cannot be modified to perform new functions. Lack of standardization was a problem in the 1970s and early 1980s. Development of the Musical Instrument Digital

COMPUTER CONCERTS

In 1957 Max Mathews built the first system for creating computer-generated sound at Bell Laboratories. The first concert of computer-generated music was held in 1958. Among the composers associated with computer music are Iannis Xenakis, Charles Dodge, and John Chowning. Recordings of early computer-generated music are available through the Computer Music Series on Wergo Records and the CDCM Computer Music Series on Centaur Records.

Interface (MIDI), released in 1983, provided a standard protocol for exchanging musical information among different brands of computers and synthesizers. SEE ALSO Analog Computing; Apple Computer, Inc.; Babbage, Charles; Digital Computing; Lovelace, Ada Byron King, Countess of; Microcomputers.

Cheryl L. Cramer

Bibliography

Dodge, Charles, and Thomas Jerse. *Computer Music: Synthesis, Composition and Performance*, 2nd ed. Belmont, CA: Wadsworth, 1997.

Hofstetter, Fred T. *Computer Literacy for Musicians*. Englewood Cliffs, NJ: Prentice Hall, 1988.

Howe, Hubert S., Jr. *Electronic Music Synthesis*. Englewood Cliffs, NJ: Prentice Hall, 1975.

Roads, Curtis. *The Computer Music Tutorial*. Cambridge, MA: MIT Press, 1996.

Napier's Bones

logarithms the powers to which certain numbers called bases are to be raised to produce particular numbers

Although John Napier is mainly remembered for the invention of **logarithms**, he considered mathematical studies as a hobby. Born in the mid-1500s into a wealthy Scottish family, Napier was able to pursue all manner of subjects from religion to politics to agriculture during his life.

In 1617, shortly before his death, Napier developed a mechanical method for performing multiplication and division. This method, known as "Napier's bones," was based upon manipulation of rods with printed digits. The rods were made of bone, ivory, wood, or metal. Napier's bones became a very popular device for calculating in England and western Europe, because most people lacked these mathematical skills.

Scottish mathematician John Napier (1550–1617) created Napier's Bones, so-called because they were made out of ivory or bone.

The set is composed of ten bones, nine of which display the multiples of a given number between one and nine. For example the "two" rod contains 02, 04 . . . 18: multiples of two. The tenth bone, known as the index, displays the numerals 1 through 9. To multiply 6 by 58, the index bone is placed beside the 5 and 8 bones. The value for 6×5 from the 58 is read from the sixth location on the five bone, i.e. 30, and it is placed in the hundreds column. Then 6×8 is read from the sixth location on the 8 bone, i.e. 48, and this is placed in the tens column. The columns are added together, resulting in 348.

This method of adding and subtracting applied to logarithmic values resulted in the development of the slide rule. As late as the 1960s, English children used Napier's bones to learn multiplication. SEE ALSO Abacus; Analog Computing; Slide Rule.

Bertha Kugelman Morimoto

Internet Resources

"Undusting Napier's Bones." Department of Computing and Electrical Engineering web site. Heriot-Watt University, Edinburgh. <http://www.cee.hw.ac.uk/~greg/calculators/napier/>

"John Napier and Napier's Bones." Maxfield and Montrose Interactive web site. <http://www.maxmon.com/1600ad.htm>

National Aeronautics and Space Administration (NASA)

The National Aeronautics and Space Administration (NASA) was formed in 1958 from the National Advisory Committee on Aeronautics (NACA) and other agencies in the military and government that might benefit from a centralization of efforts in air and space research. Within a decade, NASA had three piloted and several unpiloted space projects either complete or in the works. In the next few years, NASA introduced digital computers to aeronautics.

During its first fifteen years, NASA experienced its greatest period of influence on computing, both in hardware and software. Since the mid-1970s, NASA has become more of a user than an originator of computing technology, though several research programs still exist. NASA's need for cost-effective and innovative solutions to problems of navigation, safety, and communication has significantly influenced the development of computer technology, particularly in the application of embedded real time systems, redundancy, networks, large systems, and new computing hardware technology.

Embedded Real Time Systems

Software engineer David Parnas once said that "all systems are real time systems, it is just that some are faster than others." A real time system has to achieve its results in a time indistinguishable from when they are needed. Air traffic control, anti-lock brakes, and microwave ovens are all real time systems according to that definition. When NASA was formed, the technology of the day made real time systems considerably rare. NASA soon determined that one of the great difficulties of travel to the Moon is navigation, and it decided to design the Apollo spacecraft with a real time system for flight control. This is also known as an embedded system because the computer and its software are an integral part of the entire subsystem, like the computer in an automobile.

The first piloted NASA spacecraft was Freedom 7 with Project Mercury, which had no computer-controlled guidance on board. The second group of spacecraft was within Project Gemini. NASA chose Gemini to introduce and test the use of on board computers to provide flight control and navigation. The Gemini and subsequent Project Apollo computers had to be relatively small, about 25 kilograms (55 pounds). They had to operate in real time, since they were used in flight control. Both were a significant change from NASA's room-sized ground-based computers in size and speed, yet both were much less capable than present-day desktop computers.

For example, although personal computers now have millions of words in memory, the Apollo computer had only 36,000. And although the **ubiquitous** microprocessors in microwave ovens and automobiles have small memories, they are much faster than the 6,000 operations a second that the Gemini computer could manage. A special case of an embedded real time system is airplane flight control. NASA put a surplus Apollo digital computer into a Navy F-8 and flew it in 1972. Now, almost all military and commercial aircraft use such "fly-by-wire" systems. It was NASA's requirement for embedded real time systems on both piloted and unpiloted

ubiquitous to be commonly available everywhere

As the United States raced the Soviet Union to be the first to land men on the Moon, NASA oversaw the development of computer systems to ensure its success. In 1969 the United States launched Apollo 11, beating the Soviets in the Moon landing race.

spacecraft that led to the creation of many of the commercial and consumer systems we take for granted today.

Redundancy

Real time embedded systems in life-critical applications, such as flight control and life support, must not fail. Also, long duration unpiloted missions cannot repair a failure. Since NASA frequently conducts both types of flights, reliability has been a continuing concern to the agency. NASA most often ensures reliability through redundancy and backup, as opposed to ground-based systems that can be fixed readily. Perhaps the finest example of a redundant system is the data processing system on the space shuttle orbiter that uses four identical computers in a redundant set and a fifth identical computer running backup software. This concept has been adapted in business and industry to ensure safety and stability in computer-based operations.

NEW ISN'T ALWAYS BETTER

Many people think that NASA is such an advanced agency that it has the latest and best computers. This is largely untrue. To achieve the sort of reliability that space flight demands means using computers that are behind the state of the art and have acquired a reliability history. For instance, the computers running the space shuttle orbiter in the early 2000s represent a 40-year-old architecture.

Networks

Computer users today take high speed Internet access for granted, and rue the slowness of a 56K baud modem. "Baud" means "bits per second," a measure of the volume of communication. However, NASA ran the Mercury man-in-space program (1959–1963) with only a 1K baud connection! NASA had radar systems at Cape Canaveral and in Bermuda to track the ascent of Mercury launches. The radar information was received at a computer site near the White House on Pennsylvania Avenue in Washington, D.C., at 1,000 bits per second. The computer determined the flight path of the spacecraft and generated displays back in Florida so that the engineers could track the rocket's progress. This is one of the first uses of remote computing, and NASA built many more networks to support all kinds of spacecraft data and communications. Included in these are the complex networks and processors on board each piloted and unpiloted spacecraft.

Large Systems

When NASA was formed, the average computer system filled a room, but was still relatively small in terms of memory that could be accessed quickly. Many computers had a read/write memory of only 2,000 to 16,000 words, compared to machines in the early twenty-first century that have millions of words in storage. Magnetic tapes stored large groups of data. Apollo and other projects needed fast memories, so the IBM Corporation and other NASA suppliers experimented with large one million word memories and groups of processors. NASA has always shown an interest in big, fast machines, and has sponsored research into **parallel processing**, which is now commonplace in the world of information processing and analysis.

parallel processing the presence of more than one central processing unit in a computer, which enables the true execution of more than one program

New Hardware Technology

Initially, programs like Apollo took a conservative approach to purchasing computer hardware. Piloted space flight programs were risky enough without pushing the leading edge. However, in the case of the Apollo flight computer, the gains from using relatively untried technology outweighed the risks. Also, by the time the actual Moon flights took place, several years had passed, during which newer technology was able to amass a reliability history. NASA approved the use of **integrated circuits** in the Apollo computer design. For a short time in the early 1960s, NASA and the U.S. Air Force (for the Minuteman missile) exhausted the entire production of integrated circuits in the United States.

integrated circuits circuits with the transistors, resistors, and other circuit elements etched into the surface of single chips of semiconducting material, usually silicon

In unpiloted space probes, NASA could take even more chances. Therefore, the first projects to use CMOS (Complementary Metal Oxide Semiconductor) integrated circuit technology were the Voyager probes to the outer planets. Such low-power chips have found their way onto the upgrades of the space shuttle.

Conclusion

Since the 1960s, NASA's need for computer technology has contributed to the development of consumer and business applications of computer knowledge. The real impact of NASA on the computing industry is that it has constantly challenged its contractors to find new solutions to exotic problems, through a blend of trusted technology and cutting-edge computer science. Many parts of those solutions are passed on to consumers in the form of new uses for computers and greater reliability in computer systems. Innovations designed to help protect the lives of NASA astronauts have become part of everyday life, from time-keeping and food preparation, to computerized automobile navigational systems and airplane flight safety. SEE ALSO Apple Computer Inc.; Bell Labs; IBM Corporation; Intel Corporation; Microsoft Corporation; Xerox Corporation.

James E. Tomayko

Bibliography

Tomayko, James E. "Achieving Reliability: The Evolution of Redundancy in American Manned Spacecraft Computers." *The Journal of the British Interplanetary Society* 38, no. 12 (1985): 545–553.

——. *Computers in Space Flight: The NASA Experience*. New York, NY: Marcel Dekker, Inc., 1987. Also published as NASA Contractor Report 182505, March, 1988, reprinted on the NASA web site. <http://www.hq.nasa.gov/office/pao/History/computers/Compspace.html>

——. *Computers in Space: Journeys with NASA*. Indianapolis, IN: Alpha Books, 1994.

——. "The Fly-by-Wire Revolution in Flight Control." *American Heritage of Invention and Technology*, Winter (1992): 19–24.

——. *History of NASA's Pioneering Digital Fly-by-Wire Project*. NASA SP–4224, 2000.

Networks

In its simplest form, networking takes place between two devices that are directly connected. However, it is often impractical for devices to be directly connected, such as when devices are far apart or when more than two devices want to communicate. The solution is to attach each device to a communication network. Communication networks can be categorized on the basis of architecture and techniques to transfer data:

1. broadcast networks, where a transmission from any device is broadcast and received by all other stations;
2. circuit-switched networks, where a dedicated connection is established between devices on a network across switching nodes within the network;
3. packet-switched networks, where data are sent in smaller units, called "packets," from node to node within a network from source to destination.

topology a method of describing the structure of a system that emphasizes its logical nature rather than its physical characteristics

Basic Configurations

The basic configuration, or **topology**, of a network is the geometric representation of all the links and nodes of a network. A link is the physical communication path that transfers data from one device to another. A node is a network-addressable device. There are five basic topologies: mesh, star, tree, bus, and ring. In a mesh topology, every node has a dedicated point-to-point link to every other node, which requires $n(n - 1)/2$ links to connect n nodes. For example, a network with 5 nodes would need 10 links to connect the nodes. In a star topology, each node has a dedicated point-to-point link to a central hub. If one node wants to send data to another, it sends to the hub, which then relays the data to the destination node. A tree topology occurs when multiple star topologies are connected together such that not every node is directly connected to a central hub. In a bus topology, one long cable connects all nodes in the network; in a ring topology, each node has a dedicated point-to-point connection to the nodes on either side in a physical ring such that a signal from a source travels around the ring to the destination and back to the source.

Network devices use signals in the form of electromagnetic energy to represent data. Electromagnetic energy, a combination of electrical and magnetic fields vibrating in relation to each other, includes electrical current, radio waves, and visible light. Unguided, or wireless, media transport electromagnetic waves without using a physical conductor to guide the wave. Instead, signals are broadcast through media, such as air or water, and are thus available to any device capable of receiving them. Guided, or wired, communications direct electromagnetic waves within the physical limitations of a conductor, which may be metallic wire, a hollow tube waveguide, or optical fiber.

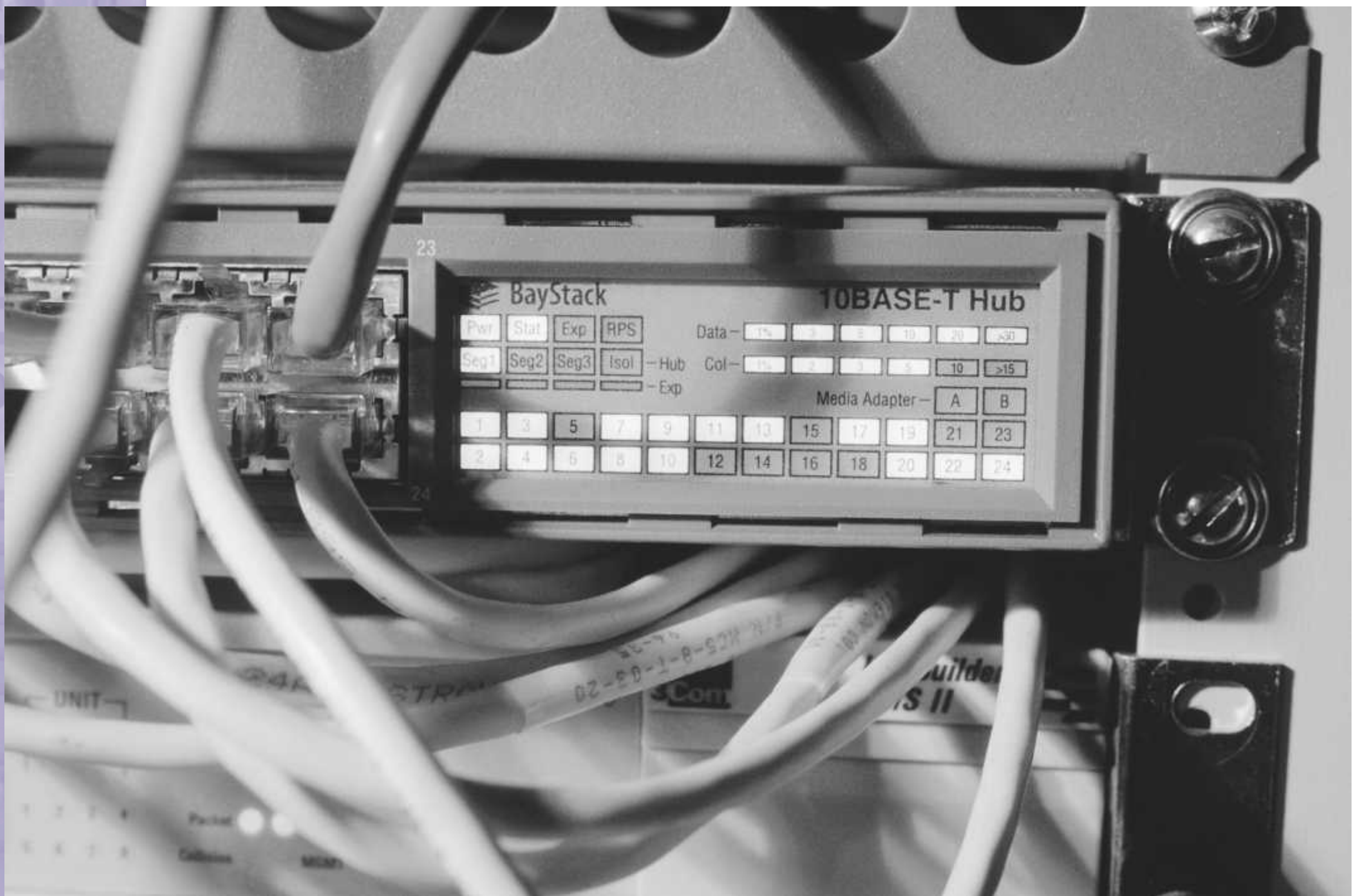
Optical fiber uses light as a transmission medium. Light is electromagnetic energy at a specific range of frequencies (430 to 750 terahertz) whose speed depends on the density of the medium through which it is traveling. Theoretically, rays of light injected into strands of pure glass at specific angles will experience total internal reflection, meaning that no loss of energy occurs when light travels down the strand. In practice, some attenuation (loss of energy) and dispersion (mixing of frequencies) does occur because of impure glass and injected light signals at multiple frequencies; however, the range of frequencies, and thus data rates, that can be supported is dramatically higher than is possible with copper cables.

Copper cabling that accepts and transports signals in the form of electrical current comes in four different types:

1. unshielded, which is used most commonly in telephone systems;
2. twisted pair, which consists of two copper conductors surrounded by an insulating material and wrapped around each other to reduce significantly the impact of noise;
3. shielded twisted pair, which has a metal foil encasing each twisted pair;
4. coaxial cable, which carries signals of higher-frequency ranges because of its different construction (a central core conductor enclosed in an insulating sheath that is encased in an outer foil, or braid, that is protected by a plastic cover).

Types of Transmission

Asynchronous Transfer Mode (ATM) is a packet-switched technology where all the packets are the same size, referred to as "cells." Asynchronous means



Many wires protrude from an Ethernet hub. The Ethernet is known for its low cost and its compatibility with existing hardware.

that the cells are independent of each other with potentially different gaps between them. The fixed cell size of 53 **bytes** allows ATM to have traffic characteristics such as increased switching speed and predictably decreased delay/cell loss, which is preferable for the convergence of real-time voice and video with data.

Other important networking techniques include Ethernet and frame relay. Ethernet is a standard for network devices communicating over a **bus topology**. Any device wishing to transmit will listen to the bus to determine whether the bus is clear; if the bus is clear, transmission can commence. If a collision between signals from different devices occurs, transmission stops and the process is repeated. Frame relay is a packet-switching protocol with no error correction that is appropriate for **fiber optic** links with their corresponding low error rates.

A **local area network (LAN)** is usually privately owned and connects nodes within a single office or building designed to share hardware, such as a printer; software, such as an application program; or data. A **wide area network (WAN)** provides long-distance transmission over large geographic areas that may constitute a nation, a continent, or even the whole world. A WAN that is wholly owned by a single company is referred to as an "enterprise network," but WANs may buy or lease network capacity from other companies. A **metropolitan area network (MAN)** is designed to extend over an entire campus or city. A MAN may be a single network, as with cable television, or a series of interconnected LANs.

bytes groups of eight binary digits; each represents a single character of text

bus topology a particular arrangement of buses that constitutes a designed set of pathways for information transfer within a computer

fiber optic transmission technology using long, thin strands of glass fiber; internal reflections in the fiber assure that light entering one end is transmitted to the other end with only small losses in intensity; used widely in transmitting digital information

Two other concepts that are relevant are the Internet and intranets. The Transmission Control Protocol/Internetworking Protocol (TCP/IP) is a set of protocols (or protocol suite) that defines how all transmissions are exchanged across the Internet. The Internet itself is a network of networks connected with the TCP/IP protocol suite connecting more than 200 million devices worldwide in virtually all populated countries. Conversely, an intranet is an organizational network of private addresses not directly accessible from the Internet. SEE ALSO INTERNET; INTRANET; TELECOMMUNICATIONS; WORLD WIDE WEB.

William Yurcik

local area network (LAN) a high-speed computer network that is designed for users who are located near each other

wide area network (WAN) interconnected network of computers that spans upward from several buildings to whole cities or entire countries and across countries

metropolitan area network (MAN) a high-speed interconnected network of computers spanning entire cities

Bibliography

Comer, Douglas E. *The Internet Book: Everything You Need to Know about Computer Networking and How the Internet Works*, 3rd ed. Englewood Cliffs, NJ: Prentice Hall, 2000.

Forouzan, Behrouz. *Introduction to Data Communications and Network*, 2nd ed. New York: McGraw-Hill, 2000.

Halsall, Fred. *Data Communications, Computer Networks and Open Systems*, 4th ed. New York: Addison-Wesley, 1996.

Stallings, William. *Data and Computer Communications*, 6th ed. New York: Macmillan, 2000.

Office Automation Systems

O

Office automation systems (OAS) are configurations of networked computer hardware and software. A variety of office automation systems are now applied to business and communication functions that used to be performed manually or in multiple locations of a company, such as preparing written communications and strategic planning. In addition, functions that once required coordinating the expertise of outside specialists in typesetting, printing, or electronic recording can now be integrated into the everyday work of an organization, saving both time and money.

Types of functions integrated by office automation systems include (1) electronic publishing; (2) electronic communication; (3) electronic collaboration; (4) image processing; and (5) office management. At the heart of these systems is often a **local area network (LAN)**. The LAN allows users to transmit data, voice, mail, and images across the network to any destination, whether that destination is in the local office on the LAN, or in another country or continent, through a connecting network. An OAS makes office work more efficient and increases productivity.

local area network (LAN) a high-speed computer network that is designed for users who are located near each other

Electronic Publishing

Electronic publishing systems include word processing and desktop publishing. Word processing software, (e.g., Microsoft Word, Corel WordPerfect) allows users to create, edit, revise, store, and print documents such as letters, memos, reports, and manuscripts. Desktop publishing software (e.g., Adobe Pagemaker, Corel VENTURA, Microsoft Publisher) enables users to integrate text, images, photographs, and graphics to produce high-quality printable output. Desktop publishing software is used on a microcomputer with a mouse, scanner, and printer to create professional-looking publications. These may be newsletters, brochures, magazines, or books.

Electronic Communication

Electronic communication systems include electronic mail (e-mail), voice mail, facsimile (fax), and desktop videoconferencing.

Electronic Mail. E-mail is software that allows users, via their computer keyboards, to create, send, and receive messages and files to or from anywhere in the world. Most e-mail systems let the user do other sophisticated tasks such as filter, prioritize, or file messages; forward copies of messages to other users; create and save drafts of messages; send "carbon copies"; and request automatic confirmation of the delivery of a message. E-mail is very popular because it is easy to use, offers fast delivery, and is inexpensive. Examples of e-mail software are Eudora, Lotus Notes, and Microsoft Outlook.

Voice Mail. Voice mail is a sophisticated telephone answering machine. It digitizes incoming voice messages and stores them on disk. When the recipient is ready to listen, the message is converted from its digitized version back to audio, or sound. Recipients may save messages for future use, delete them, or forward them to other people.

Facsimile. A facsimile or facsimile transmission machine (FAX) scans a document containing both text and graphics and sends it as electronic signals over ordinary telephone lines to a receiving fax machine. This receiving fax recreates the image on paper. A fax can also scan and send a document to a fax modem (circuit board) inside a remote computer. The fax can then be displayed on the computer screen and stored or printed out by the computer's printer.

Desktop Videoconferencing Desktop videoconferencing is one of the fastest growing forms of videoconferencing.✶ Desktop videoconferencing requires a network and a desktop computer with special application software (e.g., CUSeeMe) as well as a small camera installed on top of the monitor. Images of a computer user from the desktop computer are captured and sent across the network to the other computers and users that are participating in the conference. This type of videoconferencing simulates face-to-face meetings of individuals.

✶Videoconferencing, also known as teleconferencing, is the real-time transmission of video and audio signals to enable people in two or more locations to hold a meeting.

Electronic Collaboration

Electronic collaboration is made possible through electronic meeting and collaborative work systems and teleconferencing. Electronic meeting and collaborative work systems allow teams of coworkers to use networks of microcomputers to share information, update schedules and plans, and cooperate on projects regardless of geographic distance. Special software called **groupware** is needed to allow two or more people to edit or otherwise work on the same files simultaneously.

groupware a software technology common in client/server systems whereby many users can access and process data at the same time

Teleconferencing is also known as videoconferencing. As was mentioned in the discussion of desktop videoconferencing earlier, this technology allows people in multiple locations to interact and work collaboratively using real-time sound and images. Full teleconferencing, as compared to the desktop version, requires special-purpose meeting rooms with cameras, video display monitors, and audio microphones and speakers.

Telecommuting and Collaborative Systems. Telecommuters perform some or all of their work at home instead of traveling to an office each day,

High-tech meeting rooms help companies make more effective presentations. At some conference halls, like this one at the Chinzan-so Four Seasons Hotel in Toyko, small video screens are built into the table tops.

usually with the aid of office automation systems, including those that allow collaborative work or meetings. A microcomputer, a modem, software that allows the sending and receiving of work, and an ordinary telephone line are the tools that make this possible.

Telecommuting is gaining in popularity in part due to the continuing increase in population, which creates traffic congestion, promotes high energy consumption, and causes more air pollution. Telecommuting can help reduce these problems. Telecommuting can also take advantage of the skills of homebound people with physical limitations.

Studies have found that telecommuting programs can boost employee morale and productivity among those who work from home. It is necessary to maintain a collaborative work environment, however, through the use of technology and general employee management practices, so that neither onsite employees nor telecommuters find their productivity is compromised by such arrangements. The technologies used in electronic communication and teleconferencing can be useful in maintaining a successful telecommuting program.

Image Processing

Image processing systems include electronic document management, presentation graphics, and multimedia systems. Imaging systems convert text, drawings, and photographs into digital form that can be stored in a com-

video capture cards plug-in cards for a computer that accepts video input from devices like televisions and video cameras, allowing the user to record video data onto the computer

puter system. This digital form can be manipulated, stored, printed, or sent via a modem to another computer. Imaging systems may use scanners, digital cameras, **video capture cards**, or advanced graphic computers. Companies use imaging systems for a variety of documents such as insurance forms, medical records, dental records, and mortgage applications.

Presentation graphics software uses graphics and data from other software tools to create and display presentations. The graphics include charts, bullet lists, text, sound, photos, animation, and video clips. Examples of such software are Microsoft Power Point, Lotus Freelance Graphics, and SPC Harvard Graphics.

Multimedia systems are technologies that integrate two or more types of media such as text, graphic, sound, voice, full-motion video, or animation into a computer-based application. Multimedia is used for electronic books and newspapers, video conferencing, imaging, presentations, and web sites.

Office Management

Office management systems include electronic office accessories, electronic scheduling, and task management. These systems provide an electronic means of organizing people, projects, and data. Business dates, appointments, notes, and client contact information can be created, edited, stored, and retrieved. Additionally, automatic reminders about crucial dates and appointments can be programmed. Projects and tasks can be allocated, subdivided, and planned. All of these actions can either be done individually or for an entire group. Computerized systems that automate these office functions can dramatically increase productivity and improve communication within an organization. SEE ALSO Decision Support Systems; Desktop Publishing; Information Systems; Productivity Software; Social Impact; Word Processors.

Charles R. Woratschek

Bibliography

FitzGerald, Jerry, and Alan Dennis. *Business Data Communications and Networking*, 6th ed. New York: John Wiley & Sons, 1999.

Hutchinson, Sarah E., and Stacey C. Sawyer. *Computers, Communications, and Information: A User's Introduction*, 7th ed. Boston: Irwin McGraw-Hill, 2000.

Jackson, Maggie. "Companies Seek to End Their Offices' Paper Chase; Technology: Pioneering Businesses Go Electronic to Raise Productivity." *Los Angeles Times*, July 27, 1998.

Laudon, Kenneth C., and Jane Price Laudon. *Essentials of Management Information Systems: Transforming Business and Management*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, Inc., 1999.

Sipress, Alan. "Initiative to Encourage Telecommuting; Regional Goal Is to Double Number of People Working From Home or in Centers." *Washington Post*, April 12, 2000.

Optical Technology

Light, like radio, consists of electromagnetic waves. The major difference between the two is that light waves are much shorter than radio waves. The use of electromagnetic waves for long-distance communications was the beginning of an industry known first as wireless and later as radio. This industry was the foundation for electronics, which brought the world so many fascinating technologies.

When electronic circuits replaced the mechanical components in computers, the electronics were so fast compared to the older mechanical methods that no one ever thought the speed of the calculations would be limited by the speed of electrical signals. When engineers demanded even faster electronic circuits, the very short pulses and the tiny dimensions of their integrated circuits begged for the use of light energy rather than electrical energy. The use of light signals rather than electrical signals allowed for the design of very small and fast systems.

One of the first examples of replacing electrical signals with light was in communications. Special wires called transmission lines distribute telegraph, telephone, and television signals. In the mid-nineteenth century Samuel Morse's telegraph was extended from the East to the West Coast of the United States. The fledgling industry painfully discovered how signals transmitted long distances through wires could be degraded. Signals had to be regenerated every 10 to 20 kilometers (6 to 12 miles) depending on the quality of the transmission line. When the telephone industry came along, the situation was even worse. When cable television distributed television signals through transmission lines in the 1960s, amplification was required every few blocks. The problem of signal degradation increases with **bandwidth**. Television signals are nearly 2,000 times wider than voice signals.

bandwidth a measure of the frequency component of a signal or the capacity of a communication channel to carry signals

fiber optics transmission technology using long, thin strands of glass fiber; internal reflections in the fiber assure that light entering one end is transmitted to the other end with only small losses in intensity; used widely in transmitting digital information

Light energy can be constrained to a thin glass fiber much as electrical energy can be constrained to a wire. However, unlike wires, glass fibers can generate very little distortion even for signals of extremely wide bandwidth. Therefore, with the use of glass fiber, or **fiber optics**, broadband signals can be transmitted for much longer distances without amplifying or repeating. With fiber optics, communications systems with literally hundreds of television channels can be distributed with minimal distortion.

The glass fiber is very thin, extending from about 10 to 125 micrometers in diameter. In order for the fiber to contain light energy without loss, the index of refraction of the glass must be less on the surface of the fiber than at its center. The index of refraction is a measure of the speed of light in a medium—in this case, glass. The higher the index of refraction, the slower the light waves propagate.

The slowing of the light energy causes the light path to bend. In the glass fiber, the light energy is bent back toward the center of the fiber. This phenomenon is called total internal reflection. It insures that very little energy is lost by the fiber.

diode a semiconductor device that forces current flow in a conductor to be in one direction only, also known as a rectifier

nanometers one-thousand-millionth (one billionth, or 10^{-9}) of a meter

The light energy for the fiber is monochromatic—it has only one color or wavelength. Although the concepts of the glass fiber and total internal reflection have been known for many years, it was not until the invention of the solid-state laser **diode** and the light emitting diode (LED) that glass fibers could be used for communications.

The optimum wavelength for use with a glass fiber depends on the composition of the glass. The most common wavelengths are about 1,300 **nanometers**, which is longer than visible light in the infrared region.

Although both the laser and the LED are commonly used, the highest performance systems use laser diodes.

The state of the art in fiber optics is the use of wavelength division multiplexing (WDM), which uses a number of different wavelengths to increase the capacity of the system. The signals of different wavelengths can coexist in the fiber without mutual interference. This is similar to how a number of radio stations can operate on the same FM broadcast band without interference. The radio receiver is capable of selecting one of the stations while ignoring others.

The advantages of transmitting signals with light energy can be realized not only for long distances but for short distances as well. Even though the dimensions of a computer and the **integrated circuits** used to make them are quite small, a certain time is required for the signals to travel around the computer. In the process of computation, signals move from one part of the computer to another before a final answer is reached. If the calculation is complex, the signals may spend considerable time traveling. Because light signals can travel faster than electrical signals, the use of light signals will enhance the computer.

integrated circuits circuits with the transistors, resistors, and other circuit elements etched into the surface of single chips of semiconductor material, usually silicon

Modern conventional computer circuits can switch electrical signals on and off in less than one **nanosecond**. Some specialized logic circuits can switch in a fraction of a nanosecond, but these circuits are not suited for large integrated circuits because they consume large amounts of power and it would be impossible to remove the heat from the chip.

nanosecond one-thousand-millionth (one billionth, or 10^{-9}) of a second

Light energy can be switched in times measured in **picoseconds**. If light signals could be switched on and off by other light signals, computer logic elements could be constructed. Then, by connecting the logic elements together with light signals, an entire computer could be constructed using only light signals.

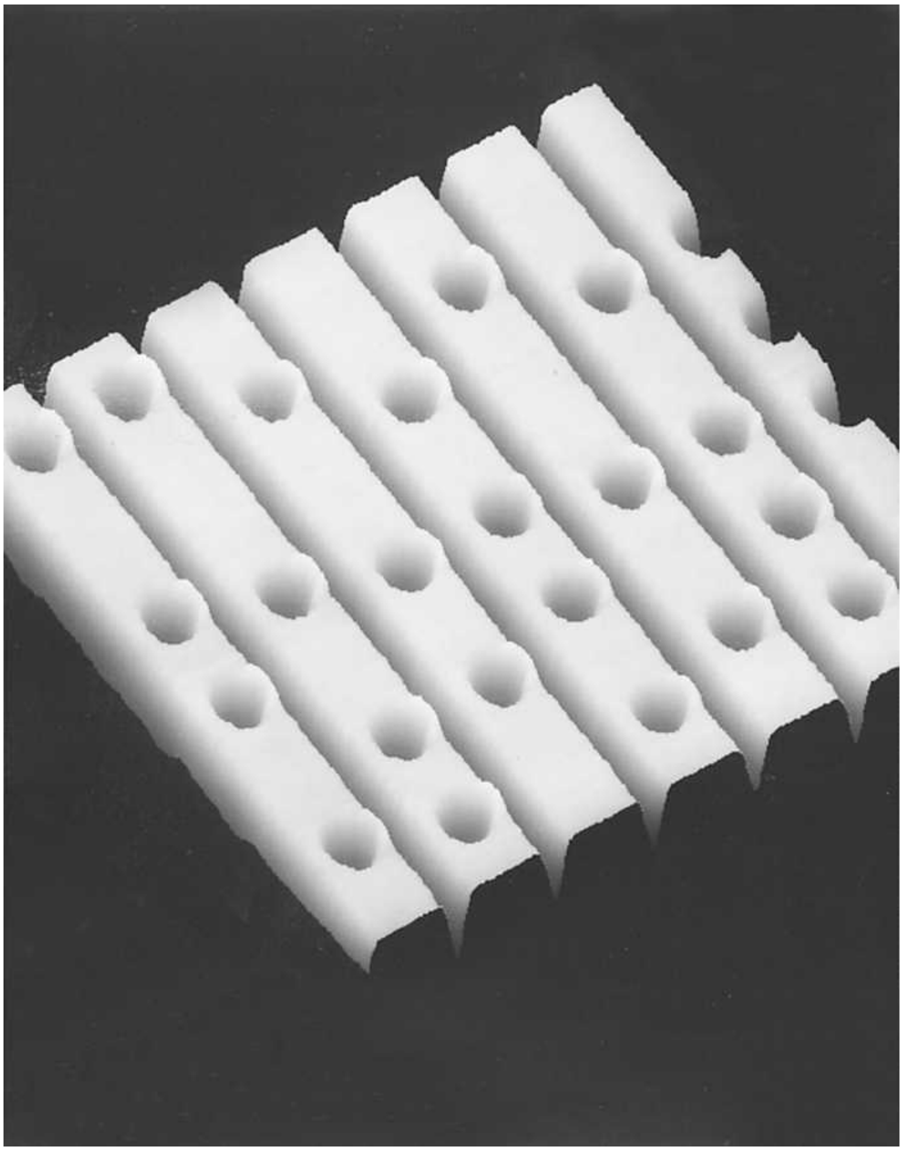
picoseconds one-millionth of a millionth of a second (one-trillionth, or 10^{-12})

To take advantage of the inherent speed of optical computing, even the computer architecture can be adapted for speed. Most calculations require sequential operations. For example, to find the hypotenuse of a right triangle, the first side is squared and then the second. The two are then added together and the square root is taken of the result. Taking the square root is a sequence of operations. In many cases the calculations are taken eight bits at a time or even a single bit at a time. A faster way of achieving this would be to square the two sides at the same time or to do the operations in parallel using two computers. It sounds wasteful to employ two computers just to solve a simple triangle. But when thousands of numbers are to be squared and added, two computers would make the process go twice as fast; three computers, three times as fast; and so on.

An architecture called "massively parallel" involves a large number of processors where each processor performs a part of the required calculation. This can involve as many as 1,000 processors. This technique is only useful if the processors can perform fast calculations and can communicate with high speed. Optical computation using massively parallel architecture would result in the fastest computers on Earth.

Switching light signals involves **esoteric** materials that exhibit what are called non-linear optical properties. One light signal can effect the propagation of another light signal in these materials and can be used to switch

esoteric relating to a specialized field of endeavor that is characterized by its restricted size



Another form of optical technology is called WORM, short for "write once, read many." Like CD-ROMs, WORM disks have large storage capacities. However, the WORM has not become as popular as the CD because the user must access it via the same type of drive that stored the data initially.

another light signal off and on. Switching is the main ingredient for making logic elements.

One important application of optical technology is mass storage. Early computers used crude storage such as paper tape and **punched cards**. One of the first computer storage media for **random access memory (RAM)** used the properties of ferromagnetic materials. Ferromagnetics are materials that are primarily made of iron. Everyone is familiar with magnetized iron and steel and how the north and south poles effect other magnets or pieces of iron or steel. Imagine a simple iron bar that has been magnetized. There are two ways the bar can be magnetized. One orientation could represent a logic zero, and the other—with the north and south poles reversed—a logic one. The first random access memories used small donut-shaped, magnetized cores. These cores would retain their magnetized state when the computer power was removed.

For removable storage, ferromagnetic films are used on tapes, strips, disks (both hard and floppy), and for credit cards, employee badges, and

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

random access memory (RAM) a type of memory device that supports the nonpermanent storage of programs and data; so called because various locations can be accessed in any order (as if at random), rather than in a sequence (like a tape memory device) similar items. Magnetic storage is vulnerable because the stored film could be erased if it is subjected to a magnetic field.

The density (bits per unit area) of the ferromagnetic film was good, but the demand for high-density storage was growing stronger. The first use of optics for high-density data storage was not for computers but for recording television signals. However, the optical videodisc failed to gain acceptance in the marketplace. The videocassette recorder (VCR) uses magnetic storage. The main advantage of the VCR was its ability to record. An offshoot of the videodisc was a smaller version called the compact disc (CD). This device was first used for digital recording of music and later for computer data; the latest application is motion pictures.

Optical disk storage technology relies on recessed pits on a reflecting surface. Light energy reflected from a laser onto the smooth polished surface of the disk would be reflected directly back to the laser. If the surface is not smooth, the energy is scattered, with only a small amount reflected directly back to the laser. As the CD is rotated, a photo detector senses the change as the pits pass by. The disk has a very long track on which the pits are positioned, and the laser light traces out the track. The ones and zeros are encoded by the change of the reflected light intensity. The length of the pit is used to encode a number of digital bits.

Because the wavelength of the light is short, the storage density of CDs is very high. The spiral track of a CD, if it were unwound, would be more than 5,000 meters (16,400 feet) long. The space between the tracks is 1.6 micrometers and the pits are between 0.833 and 3.05 micrometers long. CDs are very inexpensive to make, are resilient to damage, and are completely immune to magnetic fields. As of early 2002, a CD can store between 500 and 800 megabytes (MB) of data. SEE ALSO Music; Robotics.

Albert D. Helfrick

Bibliography

Goff, David R. *Fiber Optic Reference Guide: A Practical Guide to the Technology*. Boston, MA: Focal Press, 1999.

Hecht, Jeff. *City of Light: The Story of Fiber Optics*. New York: Oxford University Press, 1999.

———. *Understanding Fiber Optics*. Indianapolis, IN: H. W. Sams, 1987.

Holtz, Frederick. *CD-ROMs: Breakthrough in Information Storage*. Blue Ridge Summit, PA: Tab Books, 1988.

McAulay, Alastair D. *Optical Computer Architectures*. New York: John Wiley and Sons, 1991.

Pohlmann, Ken C. *The Compact Disc Handbook*, 2nd ed. Madison, WI: A-R Editions, Inc., 1992.

Pascal, Blaise

French Philosopher and Scientist
1623–1662

Blaise Pascal, who was born in 1623 in central France and died in Paris in 1662, made significant contributions to physics, mathematics, and philosophy during his short life. At the time of Pascal's birth, European scientific thought was moving rapidly from deductive reasoning to the experimental method of testing to understand natural phenomena. The established order resisted this new approach. One of the more drastic examples of this resistance was the harsh treatment that Italian astronomer Galileo (1564–1642) suffered at the hands of the Catholic Church's **Inquisition** in 1633. The church also pressured intellectuals through economic means.

Blaise Pascal.

Since the sciences, mathematics, and philosophy had not become separate disciplines, it was common for intellectuals to work in several areas. Societies formed for the presentation and discussion of works in progress in these fields. Pascal's father, a lawyer by profession and a mathematician by avocation, was a member of one such group, the Académie Mersenne, which later grew into the French Academy. Some of the more distinguished Académie participants were Gilles Personier de Roberval (1602–1675), a teacher at the Collége de France; Girard Desargues (1591–1661), an architect; Pierre de Fermat (1601–1665), a lawyer; and René Descartes (1596–1650), a philosopher and mathematician. Through meetings and correspondence with other intellectuals throughout Europe, the members contributed to and learned about advances in mathematics and science. By age fourteen, Pascal had acquired mathematical knowledge and interest that were so advanced that his father introduced him to the Académie. This young man's active and inquiring mind both challenged, and was challenged by, members of the Académie.

Earlier indications of Pascal's intellectual ability were confirmed when he mastered **Euclidean geometry** at age twelve without formal instruction. At sixteen Pascal presented a paper to the Académie on the properties of conic sections, based in part on Desargues's treatise on conical sections. This work became known as Pascal's theorem, and it forms the basis for modern projective geometry. Another geometric accomplishment was "Pascal's triangle." In the 1650s, with Fermat as a collaborator, Pascal developed the triangle to calculate possible gambling winnings under various conditions. His triangle is viewed as the preliminary work leading to the **binomial theorem**, and the **calculus** of probabilities.

Various statistical methods grew out of the solution to the wagering problem. Descartes, Roberval, and Fermat also investigated the arcs that form in **cycloids**. Each found solutions to various aspects of the problem. Pascal succeeded in finding solutions to other aspects using methods similar to integral calculus. These methods were used by German mathematician Gottfried Wilhelm Leibnitz (1646–1716) in his development of calculus. Although his first area of interest was pure mathematics, Pascal often turned his abilities to practical problems.

The most famous Pascal invention is the Pascaline, a mechanical calculating machine. He developed it as an accounting aid for his father, who was the tax collector in Normandy, France. From 1640 to 1642, Pascal built the first model. He continued to perfect the calculator for the next seven years. The calculating mechanism consisted of gears that moved a drum of printed numeric values. Open slots in the housing displayed these values. All calculations were performed through addition. Subtraction was done by adding the complement of the value to be subtracted to the other number. For example, 83 minus 25 adds 75, the complement of 25, to 83. The answer is 58, as there is no carrying of the last value. Multiplication and division were

Inquisition the establishment of a religious court (1478–1834) where Christians as well as non-Christians were prosecuted for heresy

Euclidean geometry the study of points, lines, angles, polygons, and curves confined to a plane

binomial theorem a theorem giving the procedure by which a binomial expression may be raised to any power without using successive multiplications

calculus a method of dealing mathematically with variables that may be changing continuously with respect to each other

cycloids plural of cycloid, which is a curve traced out by a point on the circumference of a circle as it rotates in a plane

TORRICELLI AND HIS HYPOTHESIS

Evangelista Torricelli (1608–1647) created the first mercury barometer by filling a 0.9 meter (3 foot) glass tube with mercury and inverting the open end into a dish of mercury. The level of mercury in the tube dropped to 71.8 centimeters (28 inches). He demonstrated that air pressure raises a liquid to a height relative to the weight of the liquid. Torricelli hypothesized that the space above the mercury in the tube was a vacuum.

performed through a series of additions. Some 300 years later, the complement method is used by today's computers to perform mathematical functions. A few of Pascal's other practical undertakings included the improvement of the barometer and the syringe.

Pascal's major contribution to the physical sciences was a series of experiments to prove Torricelli's hypothesis about the effect of atmospheric pressure on the equilibrium of fluid. The conclusions that Pascal published stating that vacuums do exist in nature brought him into direct conflict with the traditional Aristotelian assertion that "Nature abhors a vacuum." Noël, the rector of a Jesuit college, attacked Pascal's conclusions by reasserting traditional doctrine. However, Pascal's carefully constructed experiments, which took into account all possible factors that could affect the outcome, and his analysis of the results, proved conclusively that a vacuum does occur naturally. A further result of his experiments was the principle that fluids exert pressure equally in all directions. One form of pressure measurement is known as a Pascal. This work had a direct impact on the development of modern scientific experimental methods.

In later years Pascal concentrated on philosophical and religious questions. His writings, *The Pensés* and *The Provincial Letters*, are still studied by theology and philosophy students. SEE ALSO GENERATIONS, LANGUAGES; PROGRAMMING.

Bertha Kugelman Morimoto

Bibliography

Hazelton, Roger. *Blaise Pascal: The Genius of His Thought*. Philadelphia, PA: The Westminster Press, 1974.

Krailsheimer, Alban. *Pascal*. New York: Hill and Wang, 1980.

Privacy

Concern over personal privacy has risen as a result of two areas of development in computing and related technologies. First, databases used as surveillance tools for gathering, storing, and disseminating personal information have stirred fears that privacy is being eroded. This type of concern for privacy is known as information privacy. Second, vastly expanded communications abilities, including electronic mail and wireless communications networks, have raised questions about the appropriate degree of privacy for these new forms of communications. This type of concern for privacy is known as communications privacy. This article will focus mainly on information privacy.

The practice of collecting, recording, and storing personal data began long before the advent of computers. For example, the Domesday Book was a written record of a census and survey of English landowners and their property made by the order of William the Conqueror in 1085. However, computers greatly expanded the capacity and ease of data collection. This led to further uses of personal information and the need to collect more data. The U.S. government was among the first to take advantage of such technology. A variety of government functions such as taxation, social welfare, crime prevention, national security, and immigration greatly rely on information about citizens. As such, they require efficient communications, exchange, and access to information. Also, the government was a leader in the use of computerized databases because it could afford the computing power, which was initially very expensive and required expert management.

An example of a government computer database is the Federal Bureau of Investigation (FBI) National Crime Information Center (NCIC) database. Established in 1967, NCIC allows law enforcement agencies around the country to enter and share information in order to catch criminals. Although the NCIC has been praised by police officers, it has been criticized by privacy advocates and civil libertarians. They argue that the uncontrolled entry and use of data in the system, and the ease of access by both law enforcement agencies as well as non-criminal justice agencies, provide many opportunities for abuse of police power and privacy, as well as errors in content.

Besides power abuse and privacy invasion, other objections to government databases include: 1) that people whose records are accessed are not informed; 2) that the traditional presumption of innocence is replaced by a presumption of guilt if government agencies can search through huge amounts of information to find people who seem suspicious for any reason; and 3) that the Fourth Amendment, which requires the government to have probable cause or a warrant to search and seize materials from homes and businesses, is being challenged since the government needs neither criteria to search government-created computerized databases.

With the decrease in cost and size of computer equipment, and the increase in the amount of mass-produced consumer software including powerful database programs, a new demand for personal databases emerged from a different sector of society, namely the private sector. In an age where **micromarketing** is rapidly becoming the norm, the value of information increases as decision-makers find new ways to use data for strategic advantage. Companies must store and share information about individuals before conducting telemarketing campaigns or selected mailings.

micromarketing the targeting of specific products and services to smaller and smaller segments of society

The following are some examples of how the private sector is using consumer data stored in their databases for marketing purposes. American Express mines 500 billion bytes of data on how customers have spent more than $350 billion since 1991. The company then sends discount coupons and special promotions for the specific stores where customers shop. Blockbuster Entertainment Corporation uses video rental histories to generate specialized lists of recommended movies that are mailed to customers. Long-distance telephone companies use lists of subscribers to foreign-language newspapers to find potential customers for special telephone service deals. Once potential customers have been identified, the companies mail advertisements to them in the customer's native language.

One objection concerning the collection and use of such consumer data is that, in many cases, consumers are not aware of this activity. Therefore, the consumer has no opportunity to agree or disagree to the use of this information. The second grievance lies in secondary use—the use of information for a purpose other than originally intended. Most people do not object when businesses use in-house lists to send advertisements or special offers to their own customers. However, many people do mind if information collected by one business or organization is shared with or sold to another without their knowledge or consent.

PRIVACY POLICY STATEMENTS

Title V of the Graam-Leach-Blilely Act of 1999 addresses financial institution privacy from two different perspectives. Subtitle A requires financial institutions to make certain disclosures regarding their privacy policies and to give certain individuals the opportunity to prevent the institution from releasing information about them to third parties. Subtitle B criminalizes the practice used by certain data collection services and other parties of obtaining personal financial information from financial institutions by misrepresenting their right to such information.

Computer databases can undoubtedly help both businesses and consumers, but distribution, leakage, and various specific uses of the information by corporations or government agencies can have detrimental effects. The question is, how much risk are we willing to accept in exchange for convenience and the availability of useful information? Also, how can we reduce the risks while still receiving the benefits?

A number of efforts have begun to redress the privacy problem in the United States. First, there is legislation such as the Electronic Communications Privacy Act of 1986, the Computer Security Act of 1987, the Computer-Matching and Privacy Protection Act of 1988, and the Health Insurance Portability and Accountability Act of 1996. Second, industry can voluntarily comply with recommendations such as the posting of privacy policy statements on their web sites. Finally, privacy can be protected through the use of special technologies such as **encryption** products like the Anonymizer and Pretty Good Privacy, and by disabling the **cookie** on web browsers.

encryption also known as encoding; a mathematical process that disguises the content of messages transmitted

cookie a small text file that a web site can place on a computer's hard drive to collect information about a user's browsing activities or to activate an online shopping cart to keep track of purchases

Other suggested means include establishing a privacy commission to oversee privacy protection at the state and federal levels, such as exists in Canada. Another possibility is to invest individuals with property rights over personal information, thereby shifting the burden from the individual to prove why he or she considers the use of the information undesirable, to the collectors and disseminators, who would need to prove that their actions neither harm nor violate the individual's privacy. These remedies may come about if the public voices its concerns to the authorities. As noted in *The Intruders: The Invasion of Privacy by Government and Industry*, Sen. Edward Long (R-Mississippi) once pointed out: "Privacy is necessary to the development of a free and independent people. To preserve this privacy, our national lethargy and lack of knowledge must be countered." He added: "People must be made to realize that, little by little, they are losing their right to privacy. Once they become aware of this, I think they will shake off their apathy and demand action. Then, and only then, will we get strong legislation to protect a reasonable amount of our right to be left alone."

Communications Privacy Organizations and Publications

The following organizations and publications deal extensively with information and communications privacy.

Organizations:

- American Civil Liberties Union <www.aclu.org>
- Center for Democracy and Technology <www.cdt.org>
- Electronic Frontier Foundation <www.eff.org>
- Electronic Privacy Information Center <www.epic.org>
- Internet Society <www.isoc.org>
- Privacy and American Business <www.pandab.org>
- The Privacy Rights Clearinghouse <www.privacyrights.org>

Publications:

- *Privacy Forum*, a moderated listserv <www.vortex.com/privacy.html>

- *Privacy Journal* <townonline.com/privacyjournal>
- *Privacy Times* <www.privacytimes.com>.

SEE ALSO Security.

Joyce H-S Li

Bibliography

Baase, Sara. *A Gift of Fire: Social, Legal, and Ethical Issues in Computing*. Upper Saddle River, NJ: Prentice Hall, 1997.

Branscomb, Anne Wells. *Who Owns Information? From Privacy to Public Access*. New York: Basic Books, 1993.

Burnham, David. *The Rise of the Computer State*. New York: Random House, 1983.

Cavoukian, Ann, and Don Tapscott. *Who Knows: Safeguarding Your Privacy in a Networked World*. New York: McGraw-Hill, 1997.

Johnson, Deborah G., and Helen Nissenbaum, eds. *Computers, Ethics and Social Values*. Upper Saddle River, NJ: Prentice Hall, 1995.

Kling, Rob, ed. *Computerization and Controversy: Value Conflicts and Social Choices*, 2nd ed. San Diego, CA: Academic Press, 1996.

Miller, Arthur R. *The Assault on Privacy: Computers, Data Banks, and Dossiers*. Ann Arbor, MI: University of Michigan Press, 1971.

Rosenberg, Richard S. *The Social Impact of Computers*, 2nd ed. San Diego, CA: Academic Press, 1997.

Schoeman, Ferdinand David, ed. *Philosophical Dimensions of Privacy: An Anthology*. New York: Cambridge University Press, 1984.

Westin, Alan F. *Privacy and Freedom*. New York: Atheneum, 1968.

Robotics

Robotics is the study of how to design, build, use, and work with robots. Although there is no consensus regarding the definition of the term *robot*, it is commonly defined as a mechanism that can sense its environment, process what it senses, and act upon its environment based on that processing.

Precursors of Robots

Automatons—mechanisms that perform predefined tasks with some degree of **autonomy**—are the early predecessors of robots and have existed for more than 1,000 years. In the ninth century, the Chinese built a statue of Buddha surrounded by steam-powered servants that would move in a circle around the central figure. In the eighteenth century, the French constructed small mechanical "scribes" that, when powered by hand, could write up to forty pre-set characters using an attached writing implement. In the nineteenth century, automatons gave way to automation. In 1801 Joseph-Marie Jacquard (1754–1834), a French inventor, designed and built a loom that used a set of **punched cards** with which the user could produce complex tapestries simply by pushing a pedal.

autonomy the capability of acting in a self-governing manner; being able to exist independently or with some degree of independence

punched cards paper cards with punched holes which give instructions to a computer in order to encode program instructions and data

Grey Walters, a British scientist, built devices in the 1940s that moved toward lights and retreated from contact. Between 1961 and 1963, Johns Hopkins University staff built the "Hopkins Beast" that wandered the halls, stayed away from walls, and plugged itself in for recharging. All of these mechanisms are considered automatons rather than robots because they responded to stimuli without processing them first.

Early Robots

teleoperation any operation that can be carried out remotely by a communications system that enables interactive audio and video signals

artificial intelligence (AI) a branch of computer science dealing with creating computer hardware and software to mimic the way people think and perform practical tasks

The devices now called robots developed from the work of scientists in three separate fields of engineering: **teleoperation**, manufacturing, and **artificial intelligence (AI)**.

American inventor George C. Devol Jr. filed a patent in 1954 for a playback device for controlling machines. Devol's work grew from, among other things, Teleoperation, which began in the 1930s to handle nuclear materials. In 1958 Devol and Joseph Engelberger, an American entrepreneur, filed a patent for the first programmable manipulator (robot arm). The Unimation Corporation was formed in 1961 to put such devices into production. Engelberger's vision was to outfit assembly lines, such as those in automobile factories, with robot manipulators to automate the heavy lifting and assembly of large parts. General Motors (GM) installed the first industrial robot, made by Unimation, on a production line in 1962.

Also in the 1960s, scientists at the Stanford Research Institute (SRI) studied artificial intelligence on computers. They wanted to make their work more interesting and applicable to the real world, so the team built Shakey, the first mobile robot, in 1969. Shakey had a camera, a range finder, and bump sensors that allowed it to detect obstacles.

Applications of Robotics

Since the first Unimation robot, the scope and complexity of industrial tasks carried out by robots has steadily increased. Modern automotive factories use robots for assembly, welding, painting, and quality control. Innovation in the Mobile Robotics community has led to the creation of industrial robots that can autonomously harvest grain, mow lawns, and clean spacecraft.

The field of Medical Robotics has adapted and expanded many of the techniques created for robot arms into tools for doctors. A hip replacement, which traditionally requires a 30-centimeter (11.7-inch) incision, can be done with an 8-centimeter (3.1-inch) incision using robotic assistance. These improvements lead to shorter recovery periods for patients and reduce the chance of infection. Robotics allows a doctor to spend less time on standard procedures, and more time on difficult cases and unexpected complications.

Robots are also particularly useful for exploring and working in hazardous environments. Robotic rovers travel to other planets and send back information to scientists. There are robots that clean oil and gasoline tanks, and robots that remove asbestos from underground pipes. The U.S. military is putting a substantial amount of effort into developing robot scouts, advance teams, and tools to save the lives of military personnel in both offensive and defensive situations.

In the transportation field, robots are quickly gaining ground, though the mechanisms are rarely called robots. By 2000, there were automobiles that could autonomously maintain a safe distance behind other cars. Modern airplanes can take off, fly, and land without assistance from the pilot, and are therefore robots by most definitions. The near future will bring cars that do not need drivers, trains that do not need conductors, and planes that do not need pilots. Robotics and robot technologies are also widely used in amusement parks, movies, and toys.

Robotics in Science

Even more varied than the consumer and business applications of robotics are the academic disciplines that have been created to advance the state of the art. Robotics is characterized by a synergy between very practical applications and cutting-edge research. Broadly, while industry focuses on finding robotic ways of doing existing tasks, research focuses on extending the fundamental abilities of robots. This division is not a strict rule, however; many research labs produce usable robots, and industrial development routinely improves basic robotic technology. All areas of robotics are studied, to varying degrees, in academic, governmental, and industrial research laboratories.

In the 1940s, as the mechanisms being controlled in Teleoperation became more complex, *Telerobotics*, the study of remotely operated robots, was born. As Engelberger created and popularized robots in factories, researchers created the field of *Manipulation*, or the study of the physics and control of those machines. *Mobile Robotics* studies techniques for enabling robots to move through their environments. There are wheeled robots, legged robots, and treaded robots. There are robots with one, two, four, six, or more legs, and robots with combinations of treads, wheels, and legs. Medical Robotics, Space Robotics, and Industrial Robotics, among others, are also significant fields of scientific research and study.

Robotics also enhances the work of scientists in other fields. Telerobotics has enabled scientists to study the centers of volcanoes. Mobile Robotics has allowed scientists to find meteors in the Antarctic remotely and to explore the surface and atmosphere of Mars.

All fields of robotics are interdependent, as well as dependent on other engineering and science disciplines. Computer vision and sensor technology allow robots to sense their environments. Advances in artificial intelligence have led to robots with greater abilities to understand their environments, while robotics provides artificial intelligence with the physical capacity to interact with the environment. Of course, these relationships are only two examples. Fundamentally, robotics is the science of innovation by integrating and extending other technologies.

Social Implications of Robotics

When Jacquard introduced his mechanized loom, there were rebellions in Paris. Weavers were afraid that they would be run out of business. When robots are installed in automobile factories, managers rejoice, but workers are concerned that they will be replaced by machines and be out of work.

Robots are labor-saving devices, and, by definition, labor-saving devices result in lower human labor requirements. Although robots cannot replace humans in many ways, there are already hundreds of jobs that have been made easier or eliminated by robots. Throughout history, questions have been raised about the effects of automation on the workforce. There is no consensus on what exactly that effect is. This remains an ongoing debate in the robotic and industrial communities.

One thing that robots will not do any time in the near future is replace humans. Although robots can move and make decisions, and seem to have

ROBOTS IN OUR OWN IMAGE

Many robots are anthropomorphic—they look, act, or seem like humans. Scientists and engineers often design robots to look like humans or other animals. Building machines to operate autonomously is a daunting task, so researchers start with animals and people as models because they are examples of working mechanisms.

The first robot manipulator was built to look and function like an arm. The first mobile robot had a human-like "head." Most legged robots walk with gaits copied from mammals, insects, or lizards. Many sensors are designed to use the same information that humans use: cameras and computer vision allow the robot to "see"; whiskers and contact switches allow the robot to "feel"; and researchers are even working on electronic devices that will allow robots to "smell."

However, robots do not have to be anthropomorphic. Since engineers design robots from scratch, they can be tailored for whatever job they are doing. Thus, a pipe-cleaning robot could have clamps that allow it to crawl along a pipe. Many robots have "range sensors" that permit them to tell the exact distance between it and another object.

A telerobotic explorer, the Dante II investigates Crater Peak, an active volcano on Mt. Spurr in Alaska. The Dante gathers data that help volcanologists better understand geothermal activity.

emotions, robots are not self-aware. That is, they cannot think about their own existence. Scientists and philosophers have also argued that robots do not have a "consciousness" or that they lack a "soul."

Scientists disagree on how long it will be before robots are capable of operating without human assistance or are mistaken for humans. Some scientists, and many philosophers, assert that both tasks are impossible. Other scientists speculate that robots will be able to replace humans by 2030. Most scientists believe that it will take more than a hundred years, perhaps several hundred, before robots are even self-sufficient.

Robotics in Science Fiction

The idea of the robot dates back almost as far as the written word. Homer (9th or 8th century B.C.E.), in the "Iliad," describes Haephestus, the Greek god of the forge, as having golden maid servants that "look like young girls who could speak and walk and were filled with intelligence and wisdom." Early twentieth-century Czech playwright Karel Capek (1890–1938) invented the word robot in his 1921 play, *Rossum's Universal Robots (R.U.R.)*.

In that work, Rossum's Universal Robots were beings that looked and acted just like human beings and were invented to serve people. Unlike the robots we think of today, these devices were made of biological parts, but like the modern idea of robots, they were built by people to do things for people.

Between 1921 and 1940, robots made many appearances in books, stories, movies, and plays. Although some of the robots in these fictional accounts were designed to help and serve humans, the majority of them were simply evil, and even the good robots invariably ended up destroying their owner, inventor, or the entire human race. Twentieth-century American science fiction writer Isaac Asimov (1920–1992) invented the word "robotics" in "Runaround." In this 1942 short story, he uses the term to describe the study of robots. Asimov's 1950 novel, *I, Robot*, marked the first piece of writing in which robots were regarded as ultimately non-destructive, and also proposed the "three laws of robotics" that have been used or mentioned in many works of fiction since then.

"DROIDS" ON FILM

Two of the most popular robots ever featured in motion pictures are R2-D2 and C3PO from the *Star Wars* series. Displaying human emotions, including excitement and fear, these "droids" were an instant hit with audiences.

Robots have made countless appearances in movies, books, stories, and plays since 1942, and they are now represented as good as often as they are evil. More importantly, the concepts created by science fiction authors continue to motivate the scientists and engineers who design robots, such as the Personal Satellite Assistant, being built by NASA, that was directly inspired by Luke Skywalker's light saber-training robot in *Star Wars*.

The Future

In the mid-twentieth century, when computers were invented, they were easy to recognize. Computers took up entire rooms and used as much power as an entire building. Now, computers are everywhere. There is a computer on your desk, there is a computer in your television, and there is probably a computer in your toaster.

In much the same way, robots started as big machines that were obviously robots. Now, robots have taken on many different forms: automated trams in airports, automatic car washes, and even gas stations that autonomously find your gas tank, open it, and fill it, to name a few. Despite their names and appearances, these mechanisms are, in fact, robots.

As we move to the future, robots will be found everywhere, and robotics will expand to study all of their enabling technologies and their limitless applications. SEE ALSO ARTIFICIAL INTELLIGENCE; ASIMOV, ISAAC; ROBOTS.

Salvatore Domenick Desiano

Bibliography

Asimov, Isaac, and Karen A. Frenkel. *Robots: Machines in Man's Image.* New York: Harmony Books, 1985.

Kortenkamp, David, R. Peter Bonasso, and Robin Murphy, eds. *Artificial Intelligence and Mobile Robotics: Case Studies of Successful Robot Systems.* Cambridge, MA: MIT Press, 1998.

Malone, Robert. *The Robot Book.* New York, NY: Push Pin Press, 1978.

Moravec, Hans P. *Mind Children: The Future of Robot and Human Intelligence.* Cambridge, MA: Harvard University Press, 1990.

Reichardt, Jasia. *Robots: Fact, Fiction, and Prediction.* New York: Viking, 1978.

S

Security

Computer security has been a consideration of computer designers, software developers, and users for virtually as long as the computer has existed. As any Internet user knows, computer security is a critical factor in the web-connected e-world. It is also important in business, industry, and government, where internally networked computers create an environment in which confidential or **proprietary** data must be protected from unauthorized access.

proprietary a process or technology developed and owned by an individual or company, and not published openly

Computer security measures can be broken into three basic components and functions:

- Identification: "Who are you?"
- Authentication: "OK, I know who you are, but prove it."
- Authorization: "Now that I know you are you, here's what you can do in my system."

Computer security attempts to ensure that "the good guys" (authorized users) are able to access the systems and data they desire, and that "the bad guys" (unauthorized users) do not gain access. Although this is a simple idea, the implementation and maintenance of strong computer security is not easy. Multiple vendor equipment, different operating system environments, ease-of-access requirements, and (not the least) difficult users all make for hurdles in the continued operation of effective security measures.

History

The history of computer security starts, of course, with the earliest computers. The UNIVAC (Universal Automatic Computer) and ENIAC (Electronic Numerical Integrator and Computer) were each relatively secure due largely to the fact that the machines were housed in locked buildings or complexes and had few, if any, additional computers connected to them. However, it was not long before the power and capabilities of the computer expanded the number of connected users. As a result, computer designers and programmers had to consider computer security.

The development of computer security has mirrored the evolution of the computer itself and its expanding capabilities. As more and more computer devices—primarily personal computers (PCs)—have been linked together, the need for computer security has grown. Possibly the most significant impact on computer security has been the Internet. With the advent of worldwide connectivity and around-the-clock access to computer systems and data, computer security experts have struggled to keep pace.

Timeline

Here is a brief timeline of significant computer security events. Notice that as computer network capabilities have grown, so have the security concerns.

Memory Protection Hardware; Partitioning, Virtual Memory (1960). Since the late 1950s most computers contain special registers to define partitions of memory for use by separate programs and ensure that a running program cannot access the partition of another program. Virtual memory extended this by allowing each object to be separately protected as if it were in its own partition. Partitioning and virtual memory capabilities provided one of the first security protection measures in early multi-user environments.

File Access Controls (1962). Beginning in the early 1960s, time sharing systems provided files for individual users to store personal or private information. The systems were secured using file access controls to allow the owners to specify who else, if anyone, could access their files and under what circumstances. The Massachusetts Institute of Technology (MIT) Compatible Time Sharing System and the University of Cambridge's Multiple Access System were the first examples of this kind of security.

One-way Functions to Protect Passwords (1967). Password protection was the first user-centered security feature. The authentication system used during login stores **enciphered** images of user passwords but not the actual passwords. This protects passwords from being divulged if an attacker happens to read the file.

enciphered encrypted or encoded; a mathematical process that disguises the content of messages transmitted

Multics Security Kernel (1968). The Multics system at MIT made security and privacy one of its central design principles. The designers paid very careful attention to identifying a small kernel of system operations which, if correct, would guarantee that all security policies of the system would be followed. This design signified the importance of security to the computer's basic programming.

ARPANET (1969) and Internet (1977). The ARPANET (Advanced Research Projects Agency Network) was the first wide-area computer network. It started in 1969 with four nodes and became the model for today's Internet. This inter-connectedness increased the risk of unauthorized user access from outsiders and raised awareness of security issues to network administrators and owners.

Unix-Unix System Mail (UUCP); Mail Trap Doors (1975). UUCP allowed users on one UNIX machine to execute commands on a second UNIX system. This enabled electronic mail and files to be transferred automatically between systems. It also enabled attackers to erase or overwrite **configuration files** if the software programs were not correctly configured. Since there was no central administration of UUCP networks, the ARPANET command-and-control approach to controlling security problems did not apply here. By 2000, the Internet had many of the same characteristics.

configuration files special disk files containing information that can be used to tell running programs about system settings

Public Key Cryptography and Digital Signatures (1976). Cryptography is the ability to scramble messages based on a "secret," prearranged code. Public-key cryptography enables two people to communicate confidentially, or to authenticate each other, without a prearranged exchange of shared cryptographic keys. Although cryptography had been around for many years, this was the point at which it was integrated into the development of computer security.

First Vulnerability Study of Passwords (Morris and Thompson, 1978). This study demonstrated that password guessing is far more effective than deciphering password images. It found that a very high percentage of passwords could be guessed from user names, addresses, social security numbers, phones, and other information stored in the user identification files. Password guessing remains a major threat today.

In 1978 Stanley Mark Rifkin was caught after stealing more than $10 million from California's Security Pacific National Bank, which employed him as a computer consultant. Using stolen codes from the bank's money transfer system, he had the loot placed electronically into a Swiss Bank account. The fact that Rifkin nearly got away with the robbery forced banks to re-examine their security systems.

cryptosystem a system or mechanism that is used to automate the processes of encryption and decryption

callback modems security techniques that collect telephone numbers from authorized users on calls and then dial the users to establish the connections

smart cards credit-card style cards that have a microcomputer embedded within them; they carry more information to assist the owner or user

RSA Public-key Cryptosystem (1978). The RSA public-key **cryptosystem** is the oldest unbroken one of its kind that provides both confidentiality and authentication. It is based on the difficulty of determining the prime factors of a very large number as used in the secret code. RSA provided a quasi-standard in the emerging field of computer cryptography.

Electronic Cash (1978). As businesses moved onto the Internet, the means to pay for services or goods did as well. Electronic cash is one way to accomplish this. It cannot be easily created, it is anonymous, and it cannot be duplicated without detection. The protection and security of "e-cash" became yet another concern of security professionals; it continues to be a major issue.

Domain Naming System of the Internet (1983). As the ARPANET grew, the number of computer devices became large enough to make maintaining and distributing a file of their addresses unwieldy, and the network maintainers developed a system to enable quick, simple name lookups. The Directory Name Server (DNS) dynamically updated its database of name and address associations, and became yet another target for hackers and "spoofers."

Computer Viruses Acknowledged as a Problem (1984). Computer viruses are deceptive software programs that can cause damage to a computer device, most notably an individual PC. The challenges of such malicious code were first formally recognized in a study published in 1984. Coupled with growing network capabilities, viruses became a serious threat to computer security practitioners and individual users.

Novel Password Schemes (1985). By the mid-1980s, many alternatives to reusable user passwords were being explored in order to circumvent the weakness of easily guessed configurations. **Callback modems** relied on the authentic user being at a fixed location. Challenge-response systems allowed the authentic user to generate personalized responses to challenges issued by the system. Password tokens are **smart cards** that generate a new password with each use. Each of these alternatives attempted to strengthen the basic password scheme.

Distributed Authentication (1988). Authentication servers are computer devices that allow users and system processes to authenticate themselves on any system using one set of data. The data can be updated globally, and the server can pass proof of identity back to the user or process. This proof can be passed to other servers and clients and used as a basis for access control or authorization. Given the advance in distributing computing power both geographically and across platforms (servers), this advancement allowed security to keep pace with these new configurations.

Internet Worm (1988). The Internet worm was the first large-scale attack against computers connected to the Internet. Unlike a virus, it transmitted itself actively through Internet connections. Within hours, it invaded between 3,000 and 6,000 hosts, between five percent and ten percent of the Internet at the time, taking them out of service for several days. It caused much consternation and anger, and highlighted a vulnerability of large networks.

PGP (1989); PEM (1989). Electronic mail lacks protection against forgery, alteration, and interception. Privacy-enhanced Electronic Mail (PEM) and Pretty Good Privacy (PGP) provide all these services. As the Internet grew, so did the demand for these security services to help ensure user authentication and protection.

Anonymous Reposting Servers (1990). These computer servers obscure the identity of the poster or sender by substituting a random string for the sender's name. Some retain the association between sender and random string internally to facilitate reply messages. These services make tracing the original user nearly impossible.

Wily Hacker Attack (1986) and Book (1992). An attacker (hacker) intruded into computers at Lawrence Berkeley Laboratory, apparently looking for secret information. Cliff Stoll, an astronomer turned system administrator, detected the attacker from a seventy-five cent accounting discrepancy. Using a variety of techniques, Stoll helped authorities arrest the attacker, who was being paid by a foreign government. This event helped highlight the vulnerability of all systems and the need for widespread computer security.

Network Sniffing; Packet Spoofing; Firewalls (1993). Internet protocols were designed on the assumption that no one could access the actual wires and listen to the packets of data. In recent years, attackers have hooked up computers to do just that. These methods of "sniffing" have been used to detect passwords. The attackers also engage in "spoofing," or using the same computers to transmit their own packets, with false identification fields, as a way of gaining access to systems. Firewalls are routers that attempt to filter out these "spoofed" packets. Sniffing and spoofing became key security concerns as the Internet grew.

Java Security Problems (1996). Java is a language for writing small applications, called applets, that can be downloaded from an Internet server and executed locally by a Java interpreter attached to the browser. The design goal is that the interpreter be highly confined so that **Trojan horses** and viruses cannot be transmitted; that goal has yet to be met. Java has had several security problems related to malicious applet designers reading, altering, and deleting information supposedly outside the constrained environment.

Trojan horses potentially destructive computer programs that masquerade as something benign; named after the wooden horse employed by the Acheans to conquer Troy

Conclusion

Concerns about computer security will grow as computer system capabilities increase. Hackers eager to beat a new security challenge, as well as unauthorized users intent on accessing data for criminal or malicious purposes, will continue trying to circumvent security protocols designed to protect data, equipment, and users from their efforts. SEE ALSO Association for Computing Machinery; Ethics; Privacy.

Richard Archer

Bibliography

Hutt, Arthur E., Seymour Bosworth, and Douglas B. Hoyt, eds. *Computer Security Handbook*, 3rd ed. New York: Wiley, 1995.

Parker, Donn B. *Fighting Computer Crime: A New Framework for Protecting Information.* New York: Wiley, 1998.

Russell, Deborah, and G. T. Gangemi Sr. *Computer Security Basics*, rev. ed. Sebastopol, CA: O'Reilly & Associates, 1992.

Simulation

Simulation, from the Latin *simulare*, means to "fake" or to "replicate." The *Concise Oxford Dictionary of Current English* defines simulation as a "means to imitate conditions of (situation etc.) with a model, for convenience or training." Sheldon Ross of the University of California, Berkeley, states less formally that "computer simulations let us analyze complicated systems that can't be analyzed mathematically. With an accurate computer model we can make changes and see how they affect a system." Simulation involves designing and building a model of a system and carrying out experiments to determine how the real system works, how the system can be improved, and how future changes will affect the system (called "what if" scenarios). Computer simulations of systems are effective when performing actual experimentation is expensive, dangerous, or impossible.

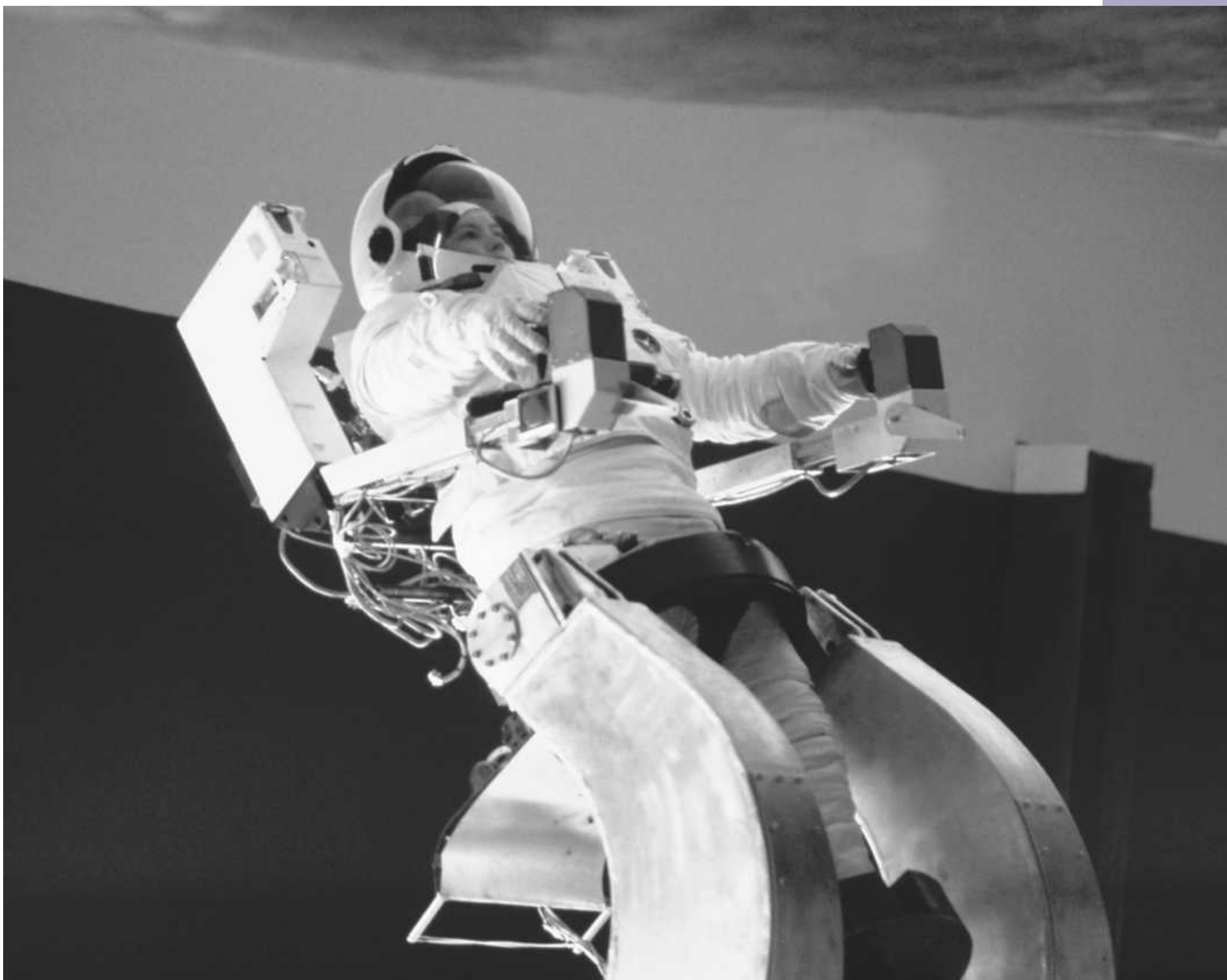
One of the principal benefits of using simulation to model a real-world system is that someone can begin with a simple approximation of the process and gradually refine it as his or her understanding of the system improves. This stepwise refinement enables good approximations of complex systems relatively quickly. Also, as refinements are added, the simulation results become more accurate.

The oldest form of simulation is the physical modeling of smaller, larger, or exact-scale replicas. Scaled-down (smaller) replicas include simulations of chemical plants and river–estuary systems. Scaled-up (larger) replicas include systems such as crystal and gene structures. Exact-scale replicas include an aircraft cockpit used for pilot training or a space shuttle simulator to train astronauts.

Simulation is central to the rise of digital computers, and the story starts, strangely enough, with the pipe organ. American inventor Edwin Link (1904–1981) received his inspiration for the first pilot training simulator while working for his father's piano and organ company in the 1930s. Link developed mechanical "trainers" that used a **pneumatic** system to simulate the movement of aircraft. During World War II (1939–1945), the Link Trainer proved the training value of flight simulation and convinced the U.S. Navy to ask that the Massachusetts Institute of Technology (MIT) develop a computer that would power a general-purpose flight simulator. This endeavor became Project Whirlwind and "evolved into the first real-time, general purpose digital computer . . . [which] made several important contributions in areas as diverse as computer graphics, time-sharing, digital communications, and ferrite-core memories," according to Thomas Hughes in his book *Funding a Revolution.*

pneumatic powered by pressurized air, supplied through tubes or pipes

In a society of limited resources and rapid technological change, training challenges are increasingly being addressed by the use of simulation-based training devices. Economic analysis supports the use of simulators as a sound investment, a flexible resource that provides a return for many years. Since the early 1960s, simulation has been one of many methods used to



Astronauts undergo rigorous training in preparation for their upcoming missions. Here, astronaut Anna Fisher gets in some practice on the manned maneuvering unit flight simulator, located at the Martin Marietta plant in Denver.

aid strategic decision-making in business and industry. As computer technology progresses and the cost of simulation for realistic training continues to decline, it is becoming increasingly possible to train simultaneously at different geographic locations and where training cannot be carried out in real life, as in shutting down a nuclear power plant after an earthquake.

Simulations can be classified as being discrete or analog. Discrete event simulation builds a software model to observe the time-based behavior of a system at discrete time intervals or after discrete events in time. For example, customers arrive at a bank at discrete intervals. Between two consecutive time intervals or events, nothing can occur. When the number of time intervals or events is finite, that simulation is called a "discrete event." The discrete event simulation software can be a high-level general-purpose programming language (C or C++) or a specialized event/data driven application (a simulator).

However, in the real world, events can occur at any time, not just at discrete intervals. For example, the water level in a reservoir with given inflow and outflow may change all the time, and the level may be specified to an infinite number of decimal places. In such cases, continuous, or analog, simulation is more appropriate, although discrete event simulation could be used as an approximation. Some systems are neither completely discrete nor completely analog, resulting in the need for combined discrete–analog simulation.

A common way to simulate the random occurrence of events is to use Monte Carlo simulation. It is named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance exhibiting random behavior, such as roulette wheels, dice, and slot machines. The random behavior in such games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. For example, when someone rolls a die, she knows that a 1, 2, 3, 4, 5, or 6 will come up, but she does not know which number will occur for any particular roll. This is the same as the variables used in computer simulations; these variables have a known range of values but an uncertain value for any particular time or event. A Monte Carlo simulation of a specific model randomly generates values for uncertain input variables over and over again (called "trials") in order to produce output results with statistical certainty, that is, providing a percentage chance that an actual output from the physical system will fall within the predicted range with virtual certainty.

Modeling is both an art and a science. It is an art to decide which features of the physical object need to be included in an abstract mathematical model. Any model must capture what is important and discard interesting features (uninteresting and irrelevant features are easy to discard). Complexity and processing performance also guide the art of deciding on a minimal set of features to be modeled from the physical object.

The science of simulation is the quantitative description of the relationship between features being modeled. These relationships dictate a model's transformation from one state to another state over time. Often when a mathematical model is eventually derived in a solvable form (closed form), it may or may not accurately represent the physical system. Computer simulation is preferable when the physical system cannot be mathematically modeled because of the complexity of variables and interacting components. Well-known examples of simulation are flight simulators and business games. However, there are a large number of potential areas for simulation, including service industries, transportation, environmental forecasting, entertainment, and manufacturing factories. For example, if a company wishes to build a new production line, the line can first be simulated to assess feasibility and efficiency.

Simulation and Computers

Although discrete event simulation can be carried out manually, it can be computationally intensive, lending itself to the use of computers and software. Simulation became widespread after computers became popular tools in scientific and business environments.

At this point, it may be helpful to define the relationship of computer simulation to the related fields of computer graphics, animation, and **virtual reality (VR)**. Computer graphics is the computational study of light and its effect on **geometric** objects, with the focus on graphics to produce meaningful rendered images of real-world or hypothetical objects. Animation is the use of computer graphics to generate a sequence of frames that,

virtual reality (VR) the use of elaborate input/output devices to create the illusion that the user is in a different environment

geometric relating to the principles of geometry, a branch of mathematics related to the properties and relationships of points, lines, angles, surfaces, planes, and solids when passed before one's eyes very quickly, produce the illusion of continuous motion. Virtual reality is focused on **immersive** human–computer interaction, as found in devices such as head-mounted displays, position sensors, and the data gloves. Simulation is the **infrastructure** on which these other fields are built—a simulation model must be created and executed and the output analyzed. Simulation is thus the underlying engine that drives the graphics, animation, and virtual reality technologies.

immersive involved in something totally

infrastructure the foundation or permanent installation necessary for a structure or system to operate

Visual interactive simulation has been available since the late 1970s. Before this, simulation models were simply "black boxes"—data going in and results coming out, with the output requiring extensive statistical processing. Using on-screen animations in a simulation model enables the status of a model to be viewed as it progresses; for example, a machine that breaks down may change color to red. This enables visual cues to be passed back to the user instantaneously so that action can be taken.

Although the simulation examples outlined here thus far have been physical systems, social situations can also be simulated in the electronic equivalent of role-playing or gaming. Both simulation and gaming can be defined as a series of activities in a sequence in which players participate, operating under overt constraints (agreed-on rules), and that usually involve competition toward an objective. The classic examples of simulation games are board games, such as chess and monopoly. Simulation games vary widely and have advanced along with time and technology, making them more interesting, enjoyable, realistic, and challenging.

According to the Interactive Digital Software Association (IDSA), the sale of interactive game simulation software for computers, video consoles, and the Internet generated revenues of $5.5 billion in 1998 for companies such as Nintendo and Sony, second only to the motion picture industry, which generated revenues of $6.9 billion in 1998. In fact, computer companies, including Intel, Apple, and AMD (Advanced Micro Devices), are increasingly designing their central processing units for gaming entertainment performance and not for office applications. SEE ALSO Analog Computing; Digital Computing.

William Yurcik

Bibliography

Banks, Jerry, John S. Carson II, and Barry L. Nelson. *Discrete-Event Simulation*, 2nd ed. Englewood Cliffs, NJ: Prentice Hall, 1996.

Hughes, Thomas. *Funding a Revolution.* New York: National Academy Press, 1999.

Khoshnevis, Behrokh. *Discrete Systems Simulation.* New York: McGraw-Hill, 1994.

Killgore, J. I. "The Planes That Never Leave the Ground." *American Heritage of Invention Technology* (Fall 1989): 56–63.

Law, Averill M., and W. David Kelton. *Simulation Modeling and Analysis.* New York: McGraw-Hill, 1991.

Macedonia, Michael. "Why Digital Entertainment Drives the Need for Speed." *IEEE Computer* 33, no. 2 (2000): 124–127.

Slide Rule

The slide rule is an analog device for performing mathematical computations. The first slide rule was created in 1630 by British mathematician

> **SLIDE RULE'S INVENTOR**
>
> English mathematician William Oughtred (1574–1660) is credited with developing the first slide rule c. 1630. Around the same time, he assembled a book on mathematics called *Clavis Mathematicae.* In addition to his mathematical pursuits, Oughtred was an Episcopal minister.

William Oughtred (1574–1660). His device was based on the logarithmic scale created by British astronomer Edmund Gunter (1581–1626) in 1620. Gunter's work, in turn, was based on the principle of **logarithm** set forth by Scottish mathematician John Napier (1550–1617) in 1614. What is known as the modern slide rule took shape during the first half of the 1800s.

The slide rule was used by scientists and engineers from 1640 through the 1960s and 1970s. The most familiar modern slide rule is basically a ruler with a sliding piece. Both parts of the device are marked with a scale of digits. The number of significant digits that a slide rule can contain is limited by the size of the rule. Circular and cylindrical slide rules were created to provide more significant digits. Circular slide rules operate on a set of **concentric circles**, while cylindrical slide rules use scales that can be manipulated by spinning them around a central rod. Today, slide rules are primarily a collector's item, having been replaced by computers and hand-held electronic calculators.

logarithm the power to which a certain number called the base is to be raised to produce a particular number

concentric circles circles that have coincident centers

Logarithms and Slide Rules

In the 1600s, John Napier determined that any real number can be expressed as a power (log) of another number and these values could be published as logarithmic tables. He discovered that adding and subtracting logs is the same as multiplying and dividing real numbers.

The common logarithmic tables express real numbers as powers of ten. For example 2 is $10^{0.3}$ and 2's log is 0.3. Also $2 \times 2 \times 2 = 8$. $0.3 + 0.3 + 0.3 = 0.9$, the log of 8. Edmund Gunter's logarithm scale arranged numbers from 1 to 10, spacing the numbers in proportion to their logs. Number 2 was spaced 0.3 from 1; 4 was 0.6 from 1, and so forth. Based on this scale, William Oughtred created the slide rule as an instrument for multiplying and dividing, based on logs. As mathematicians discovered new ways to use the slide rule, more scales were added to determine squares, roots, common logarithms, and trigonometry functions. SEE ALSO Analog Computing; Digital Computing; Napier's Bones.

Bertha Kugelman Morimoto

Bibliography

Thompson, J. E. *The Standard Manual of the Slide Rule*, 2nd ed., Princeton, NJ: D. Van Nostrand Co., Inc., 1952.

Supercomputers

Supercomputers, the world's largest and fastest computers, are primarily used for complex scientific calculations. The parts of a supercomputer are comparable to those of a desktop computer: they both contain hard drives, memory, and processors (circuits that process instructions within a computer program).

Although both desktop computers and supercomputers are equipped with similar processors, their speed and memory sizes are significantly different. For instance, a desktop computer built in the year 2000 normally has a hard disk data capacity of between 2 and 20 gigabytes and one processor with tens of megabytes of random access memory (RAM)—just enough to perform tasks such as word processing, web browsing, and video gaming.

Meanwhile, a supercomputer of the same time period has thousands of processors, hundreds of gigabytes of RAM, and hard drives that allow for hundreds, and sometimes thousands, of gigabytes of storage space.

The supercomputer's large number of processors, enormous disk storage, and substantial memory greatly increase the power and speed of the machine. Although desktop computers can perform millions of floating-point operations per second (megaflops), supercomputers can perform at speeds of billions of operations per second (gigaflops) and trillions of operations per second (teraflops).

Evolution of Supercomputers

Many current desktop computers are actually faster than the first supercomputer, the Cray-1, which was developed by Cray Research in the mid-1970s. The Cray-1 was capable of computing at 167 megaflops by using a form of supercomputing called **vector processing**, which consists of rapid execution of instructions in a pipelined fashion. Contemporary vector processing supercomputers are much faster than the Cray-1, but an ultimately faster method of supercomputing was introduced in the mid-1980s: **parallel processing**. Applications that use parallel processing are able to solve computational problems by simultaneously using multiple processors.

vector processing an approach to computing machine architecture that involves the manipulation of vectors (sequences of numbers) in single steps, rather than one number at a time

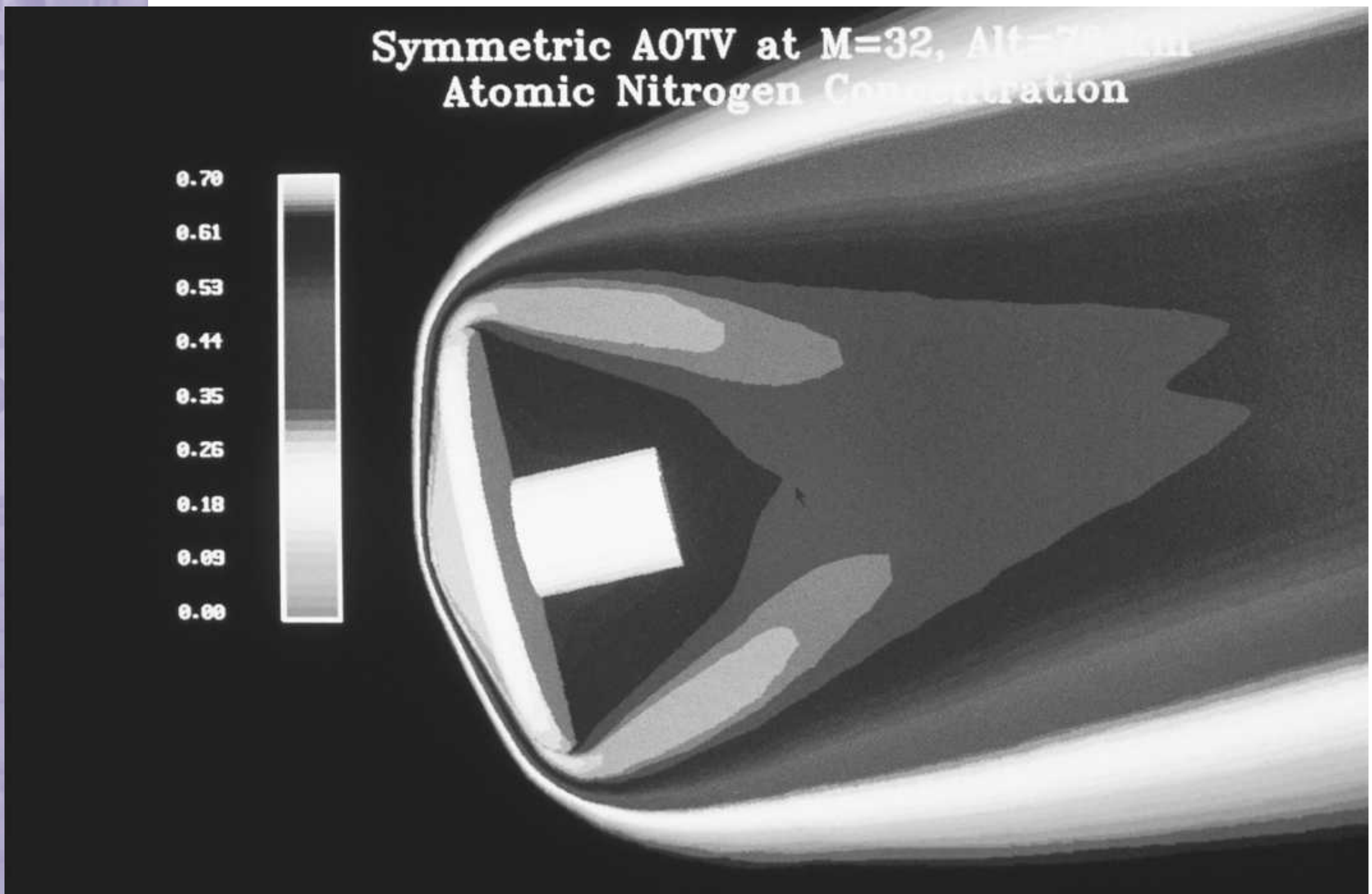
parallel processing the presence of more than one central processing unit in a computer, which enables the true execution of more than one program

Using the following scenario as a comparative example, it is easy to see why parallel processing is becoming the preferred supercomputing method. If you were preparing ice cream sundaes for yourself and nine friends, you would need ten bowls, ten scoops of ice cream, ten drizzles of chocolate syrup, and ten cherries. Working alone, you would take ten bowls from the cupboard and line them up on the counter. Then, you would place one scoop of ice cream in each bowl, drizzle syrup on each scoop, and place a cherry on top of each dessert. This method of preparing sundaes would be comparable to vector processing. To get the job done more quickly, you could have some friends help you in a parallel processing method. If two people prepared the sundaes, the process would be twice as fast; with five it would be five times as fast; and so on.

Conversely, assume that five people will not fit in your small kitchen, therefore it would be easier to use vector processing and prepare all ten sundaes yourself. This same analogy holds true with supercomputing. Some researchers prefer vector computing because their calculations cannot be readily distributed among the many processors on parallel supercomputers. But, if a researcher needs a supercomputer that calculates trillions of operations per second, parallel processors are preferred—even though programming for the parallel supercomputer is usually more complex.

Applications of Supercomputers

Supercomputers are so powerful that they can provide researchers with insight into phenomena that are too small, too big, too fast, or too slow to observe in laboratories. For example, astrophysicists use supercomputers as "time machines" to explore the past and the future of our universe. A supercomputer simulation was created in 2000 that depicted the collision of two galaxies: our own Milky Way and Andromeda. Although this collision is not expected to happen for another three billion years, the simulation allowed scientists to run the experiment and see the results now. This



Supercomputers are used to handle complex simulations that require vast computing power. The Cray supercomputer is capable of showing a simulation of a vehicle approaching Mars as it is slowed by atmospheric friction.

particular simulation was performed on Blue Horizon, a parallel supercomputer at the San Diego Supercomputer Center. Using 256 of Blue Horizon's 1,152 processors, the simulation demonstrated what will happen to millions of stars when these two galaxies collide. This would have been impossible to do in a laboratory.

Another example of supercomputers at work is molecular dynamics (the way molecules interact with each other). Supercomputer simulations allow scientists to dock two molecules together to study their interaction. Researchers can determine the shape of a molecule's surface and generate an atom-by-atom picture of the molecular geometry. Molecular characterization at this level is extremely difficult, if not impossible, to perform in a laboratory environment. However, supercomputers allow scientists to simulate such behavior easily.

Supercomputers of the Future

Research centers are constantly delving into new applications like data mining to explore additional uses of supercomputing. Data mining is a class of applications that look for hidden patterns in a group of data, allowing scientists to discover previously unknown relationships among the data. For instance, the Protein Data Bank at the San Diego Supercomputer Center is a collection of scientific data that provides scientists around the world with a greater understanding of biological systems. Over the years, the Protein Data Bank has developed into a web-based international repository for three-dimensional molecular structure data that contains detailed information on the atomic structure of complex molecules. The three-dimensional structures of proteins and other molecules contained in the Protein Data Bank and supercomputer analyses of the data provide researchers with new insights on the causes, effects, and treatment of many diseases.

Other modern supercomputing applications involve the advancement of brain research. Researchers are beginning to use supercomputers to provide them with a better understanding of the relationship between the structure and function of the brain, and how the brain itself works. Specifically, neuroscientists use supercomputers to look at the dynamic and physiological structures of the brain. Scientists are also working toward development of three-dimensional simulation programs that will allow them to conduct research on areas such as memory processing and cognitive recognition.

In addition to new applications, the future of supercomputing includes the assembly of the next generation of computational research infrastructure and the introduction of new supercomputing architectures. Parallel supercomputers have many processors, distributed and shared memory, and many communications parts; we have yet to explore all of the ways in which they can be assembled. Supercomputing applications and capabilities will continue to develop as institutions around the world share their discoveries and researchers become more proficient at parallel processing. SEE ALSO Animation; Parallel Processing; Simulation.

Sid Karin and Kimberly Mann Bruch

FASTER AND FASTER

Weather forecasters will get some help with IBM's new supercomputer, Blue Storm, when it goes into service in 2004. Designed for the European Centre for Medium-Range Weather Forecasts, the device is intended to calculate weather patterns such as storms. The super fast computer will be able to perform more than 20 trillion calculations per second. IBM representatives note that a person using a calculator would need some 17 million years to perform those same calculations.

Bibliography

Jortberg, Charles A. *The Supercomputers*. Minneapolis, MN: Abdo and Daughters Pub., 1997.

Karin, Sid, and Norris Parker Smith. *The Supercomputer Era*. Orlando, FL: Harcourt Brace Jovanovich, 1987.

Internet Resources

Dongarra, Jack, Hans Meuer, and Erich Strohmaier. *Top 500 Supercomputer Sites*. University of Mannheim (Germany) and University of Tennessee. <http://www.top500.org/>

San Diego Supercomputer Center. *SDSC Science Discovery*. <http://www.sdsc.edu/discovery/>

Tabulating Machines

Tabulating machines, or **punched card** machines, were the earliest automated data processing devices. They include keypunch machines, collators, sorters, reproducers, and tabulators. By the late 1980s, virtually all tabulating machines had been replaced by digital computer systems.

punched card a paper card with punched holes which give instructions to a computer in order to encode program instructions and data

A keypunch machine was a data entry device that punched holes in a lightweight piece of cardboard. A deck of blank cards was placed in a hopper. A keypunch operator signaled a punched card to be loaded into the punching station of the machine. As the operator typed on a keyboard, a series of dies punched predefined holes in the selected card column. One or more holes in a vertical column represented one character.

Earliest Punched Card Machines

The first machine to use punched cards was a loom designed in 1801 by a French weaver named Joseph-Marie Jacquard (1752–1834). It used punched holes in a card to direct the movement of needles, thread, and fabric on a loom so elaborate patterns could be created. In 1833 English inventor Charles Babbage (1791–1871) designed what he called the "Analytical Engine." Although Babbage's device was never fully built or operational, he conceptualized a general-purpose computer that could add, subtract, multiply, and divide in automatic sequence. It was designed to follow instructions from punched cards.

From Hollerith to IBM

In the late 1880s, Herman Hollerith (1860–1929) began developing a punched card machine to record and process data to be used in tabulating the U.S. census. In 1890 Hollerith's punched card tabulating machine was used successfully for the U.S. Census Bureau. The machine consisted of a puncher, a tabulator, and a sorter with compartments controlled by the tabulator's counters. The tabulator operated using nails, cups half-filled with mercury, and spring-actuated points. After the card was punched with data about a person, it was placed into the tabulator on a reader station. A lid was closed over the card. Wherever one of the points found a hole, it would stick down into the mercury and close an electric connection. Each electrical connection was registered on a dial that functioned as a counter. The machine was a major success and the U.S. census was completed in record time.

HOLLERITH'S INSPIRATION

Hollerith's idea of punching holes in cards to represent data came from the railroad industry. In Hollerith's time, the railroad issued tickets to passengers with physical descriptions of a passenger's hair and eye color. Conductors punched holes in the ticket to indicate that the passenger's hair and eye color matched those of the ticket owner. From this, Hollerith got the idea of making a punched "photograph" of every person to be tabulated for the census.

In 1896 Hollerith founded the Tabulating Machine Company. Shortly after 1900, Hollerith began developing a new generation of tabulating equipment. He designed a simpler keypunch mechanism, a punched card designed around numeric information in columns, an automatic feed card sorter, and an automatic feed tabulator. This new generation of equipment could accumulate numbers of any size and therefore could be applied to more business and scientific applications.

In 1911 the Computer-Tabulating-Recording Company was formed through a merger of the Tabulating Company, the Computer Scale Company, and the International Time Recording Company. In 1914 Thomas J. Watson became president of the Computing-Tabulating-Recording Company. In 1924 the Computing-Tabulating-Recording Company changed its name to International Business Machines (IBM). IBM's name would become synonymous with the punched card. Even now, the punched card is still sometimes called the "IBM card."

Punched Cards in Business and Government

The success of the 1890 census ensured that the punched card and the tabulating machine had a bright future. Punched cards and tabulating machines found many business applications. Around 1906, railroad companies began using punched cards and tabulating machines to keep track of operating expenses and records regarding the shipment of goods. In 1910 the Aetna Life and Casualty Company used punched cards and tabulating machines to compile mortality data. The government used many of Hollerith's tabulating machines during World War I (1914–1918). The army used the machines to track inventory and keep medical and psychological records

Herman Hollerith's tabulating machine, which used punched cards to tabulate results, revolutionized the way statistics, like census records, were compiled.

about soldiers. The War Industries Board used the machines to perform accounting tasks.

By the 1920s and continuing through the 1950s, punched card technology became more sophisticated. The electromechanical accounting machine (EAM) comprised a series of IBM punched-card devices that included the cardpunch (keypunch), the collator, sorter, reproducer, and tabulator. The collator was a punched card machine that merged two sorted decks of cards into one or more stacks. The sorter organized cards by routing them into separate stackers based on the content of a card column. The complete operation required passing the cards through the machine once for each column sorted. The reproducer duplicated the punched cards. The tabulator was an accounting machine that calculated totals; some even printed the results. The EAM was so successful that it became the mainstay of data processing until the 1960s.

In the 1930s the University of Iowa used punched cards for student registration. In 1933 the Agricultural Adjustment Administration began issuing punched card checks. Three years later, the Social Security Administration also issued punched card checks. During the 1940s, libraries began to use punched cards to keep track of books.

By the 1950s use of the punched card in business as a data entry source was widespread. Utility companies, department stores, and the telephone company sent punched cards with their bills and developed accounts receivable and payable systems based on the customer returning the punched card along with their payment. By the 1960s the punched card was recognized as a symbol of the computer age, as were the words "Do not fold, spindle, or mutilate"—the familiar warning printed on them.

Punched Cards Replaced

One aspect of tabulating machines that distinguishes them from modern computers is the use of an "external" program. Programs were prepared on large punched boards that wired the appropriate circuits together. These had to be changed for each operation. Today, programs are internal; they are written in a code that is stored in the computer.

The shift from using tabulating equipment to enter and process data to using a computer began with the first commercially available computer, UNIVAC I (Universal Automatic Computer). This machine was developed by John W. Mauchly (1907–1980) and J. Presper Eckert, Jr. (1919–1995) at the Remington-Rand Corporation. When UNIVAC I became successful, IBM entered the commercial computer market. In 1953 IBM introduced the IBM 650, which was designed as a logical update to its existing punched card machines. With the use of a computer to perform calculations, the tabulator was no longer needed.

In 1965 Mohawk Data Sciences delivered the first data recorder that used **magnetic tape** instead of punched cards. This recorder was the first major effort to replace the punched card as a data entry medium. An operator using a keyboard entered the data, and the data were stored directly to magnetic tape.

magnetic tape a way of storing programs and data from computers; tapes are generally slow and prone to deterioration over time but are inexpensive

Further changes in data entry occurred in 1972 when IBM introduced the 3741, a device that allowed keyed data to be stored on a diskette. Diskettes gained wide acceptance as an input medium because they were reusable, held many input records, could be read more rapidly than punched cards, were less expensive, and allowed the data on the diskette to be changed and corrected. This device rapidly began to replace the punched card as a means of entering data into a computer system. With the introduction of the **cathode ray tube (CRT)** and hard copy terminals in the late 1970s, as well as software to support such devices, punched cards and tabulating machines were no longer needed. By the late 1980s, they were fully replaced by mainframes, minicomputers, and microcomputer systems. SEE ALSO

cathode ray tube (CRT) a glass enclosure that projects images by directing a beam of electrons onto the back of a screen

Babbage, Charles; Census Bureau; Eckert, J. Presper, Jr., and Mauchly, John W.; Hollerith, Herman; IBM Corporation; Jacquard's Loom.

Charles R. Woratschek

Bibliography

Long, Larry, and Nancy Long. *Computers: Brief Edition* Upper Saddle River, NJ: Prentice Hall, 1999.

Lubar, Steven. "Do Not Fold, Spindle or Mutilate: A Cultural History of the Punched Card." *Smithsonian.* May, 1991.

Shelly, Gary B., and Thomas J. Cashman. *Introduction to Computers and Data Processing.* Brea, CA: Anaheim Publishing Company, 1980.

Shurkin, Joel. *Engines of the Mind.* New York: W. W. Norton & Company, 1996.

Telecommunications

Telecommunications is acknowledged by many observers to be the hottest industry segment in the early twenty-first century. The word telecommunications comes from "tele," which means "distant," and "communication," which means "to make common." Thus, telecommunications is about sharing (or making common) information over distance.

The telecommunications industry consists of several distinct components, including telephony, the broadcast of audio and visual signals via cable and radio frequencies, and computer communications. Telegraphy was the earliest form of telecommunications, but this technology has all but disappeared from commercial use.

telegraph a communication channel that uses cables to convey encoded low bandwidth electrical signals

Birth of Telecommunications

Telecommunications began as a one-to-one form of communicating over geographic distances. The **telegraph**, which came into commercial operation in the late 1840s, was the first modern-day example of this form of communications. Because the telegraph required trained personnel at both ends of the line, all communication between individuals had to be processed through telegraph operators. The invention of the telephone in the mid-1870s eventually supplanted telegraphy, allowing users to communicate directly with one another.

The telephone was the first technology to allow a human voice to be transmitted over significant geographic distances. Until the late 1890s, telephone callers were limited to a relatively small geographic area. The growth of telephone networks required many supplementary inventions, notably the ability to switch calls. Although it was initially limited to short distances, telephone technology evolved to allow coast-to-coast calls across the United States by 1915. In parallel with this, automatic switching exchanges began to supplant human operators as early as 1900, although manual exchanges persisted in the United States for many decades to come.

"HOY! HOY!"

Telephone inventor Alexander Graham Bell (1847–1922) and his former assistant Thomas A. Watson (1854–1934) tested out the new transcontinental telephone system in early 1915. Bell was in New York City and Watson was in San Francisco. So, what did they talk about? The conversation went like this: Bell: "Hoy! Hoy! Mr. Watson? Are you there? Do you hear me?" Watson: "Yes, Dr. Bell, I hear you perfectly. Do you hear me well?" Bell: "Yes, your voice is perfectly distinct. It is as clear as if you were here in New York."

Digital Telephony

In the 1960s, digital transmission technologies were introduced into the long distance telephone network. These were followed in short order by digital switches. These technologies allowed for improved telephone transmission

Prior to the widespread use of automatic switching exchanges, telephone operators handled the huge volume of calls via manual switchboards, physically connecting the incoming calls to the appropriate lines.

quality. Today, all domestic long distance calls and many local calls are carried digitally over **fiber optic** networks. Internationally, some calls are still carried by satellite-based communications systems while others are transmitted via undersea fiber optic cables.

fiber optic transmission technology using long, thin strands of glass fiber; internal reflections in the fiber assure that light entering one end is transmitted to the other end with only small losses in intensity; used widely in transmitting digital information

Other developments in telephony include the introduction of wireless communications for the purpose of mobility. Although these systems had been available for a very limited number of users as early as the 1950s, the development of cellular communications systems in the 1970s and 1980s enabled many more users to obtain the benefits of mobile telephone systems. By the 1990s, these systems had become widely available and very popular worldwide.

Broadcast Telecommunications

The broadcasting industry began in the 1920s as the ability to transmit speech via wireless radio became economically feasible. Prior to this, communications technology was limited to one-to-one communications—that is, one person communicating with exactly one other person. The transmission of speech over wireless systems made it possible for one sender to communicate with many receivers. Thus, one of the distinguishing features of broadcasting is that it is a one-to-many form of communication.

Until the 1950s, broadcasting and wireless communications were synonymous. All programming signals were transmitted to individual antennas that were either built in to televisions and radios or added to buildings to enhance signal reception. Around that time, communities in rural and mountainous areas, where it was difficult to receive over-the-air broadcast signals, began installing Community Antenna Television (CATV) systems. In these systems, a community would pool their resources to invest in an expensive antenna that was designed and placed for good signal reception. These superior signals were then distributed throughout the community via cables. Operators of cable systems gradually expanded their infrastructure and began to offer a rich variety of programming on these cable-based systems, making them attractive to viewers beyond their original service markets. Today, the majority of American communities are wired to provide television programming via cable systems.

Computer-Based Telecommunications

The computer networks of today had their genesis in the dedicated teleprocessing systems of the 1960s. These early computer networks were designed to support terminals communicating with a central **mainframe** computer. In the late 1960s, researchers began experimenting with different types of networks; ones that allowed any device on the network to communicate with any other device. Networks of this kind are called "peer-to-peer" networks, as each computer has the same operational privileges as any other computer.

As **minicomputers** became popular in the 1970s, networks of this kind expanded to meet new business needs and applications. Peer-to-peer networking accelerated with the development of **local area networks (LANs)** and microcomputers, better known as personal computers, in the 1980s. Concurrent with these developments in local network technologies, work continued on new systems such as wide area networks (WANs) that would be capable of interconnecting these LANs. The most **ubiquitous** and successful of these networks is the Internet.

The Internet is a network of networks designed to interconnect general purpose computers. The Internet was designed to be application-transparent, so users could develop any kind of networked application without having to make changes to the network. Thus, when the World Wide Web was developed in the late 1980s, the network could easily accommodate it. All that was needed were application programs in computers, called browsers, and hardware systems containing information, called servers, to be attached to the network. Despite many advances in technology and exponential growth in the number of computers on the network, the basic structure of the Internet remains intact.

mainframe large computer used by businesses and government agencies to process massive amounts of data; generally faster and more powerful than desktop computers but usually requiring specialized software

minicomputers computers midway in size between a desktop computer and a mainframe computer; most modern desktops are much more powerful than the older minicomputers

local area networks (LANs) high speed computer networks that are designed for users who are located near each other

ubiquitous to be commonly available everywhere

Telecommunications Industry Challenges

The telecommunications industry is facing new technological pressures from the phenomenon of convergence. Since all major forms of communication are now transmitted primarily with digital technology, it is a relatively small matter for any of the network types—CATV, telephone, or computer—to carry any type of information. So, for example, although CATV systems were originally designed for broadcast television service, technologies have converged such that cable systems carry not just television programming, but also high speed data for computer use and voice data for telephony.

The evolution of telecommunications has changed more than the physical aspects of our telecommunications networks. Along with the technological changes described earlier, dramatic changes have occurred in the way telecommunications companies do business in this industry, as well as in the way governments regulate the various networks. Advances in technology and evolving user expectations will continue to drive change in the telecommunications industry. SEE ALSO Apple Computer, Inc.; Bell Labs; Intel Corporation; Microsoft Corporation; Xerox Corporation.

Martin B. Weiss

Bibliography

Carne, E. Bryan. *Telecommunications Primer: Data, Voice, and Video Communications.* Upper Saddle River, NJ: Prentice Hall, 1999.

Dodd, Annabel Z. *The Essential Guide to Telecommunications*, 3rd ed. Upper Saddle River, NJ: Prentice Hall, 2001.

Green, James H. *The Irwin Handbook of Telecommunications Management*, 3rd ed. New York: McGraw-Hill, 2001.

Transistors

Transistors are used in almost every electronic device now made. A transistor is an electrically controlled resistor that has three terminals: two for the end-to-end flow of electrical current and one for the electrical signal that controls its end-to-end resistance. John Bardeen (1908–1991), Walter H. Brattain (1902–1987), and William B. Shockley (1910–1989) invented the transistor in 1947. Billions of transistors have been made since then, many of them inside the **integrated circuits** that make up the processors and memory modules of modern computers. The transistor is such an important device, and its invention was such a scientific breakthrough, that its three inventors were awarded the Nobel Prize in 1956.

integrated circuits circuits with the transistors, resistors, and other circuit elements etched into the surface of single chips of semiconducting material, usually silicon

vacuum tubes electronic devices constructed of sealed glass tubes containing metal elements in a vacuum; used to control electrical signals

NO ROYALTIES FOR BELL

The inventors of the transistor worked at Bell Labs, the research and development branch of what was then the Bell System. In 1956, as part of settling a ten-year federal anti-trust suit, the Bell System agreed to waive royalties on all its patents, retroactive to 1946. So, the Bell System never collected a cent of royalty on its patent for the transistor, which was invented in 1947.

Impact of the Transistor

Since early in the twentieth century, **vacuum tubes** had been used in electronic circuits, like amplifiers, to make electronic equipment, like radios. Even the first computer, built before the invention of the transistor, was made with vacuum tubes. But vacuum tubes were large, they consumed and dissipated a lot of energy, and they had a short lifetime before they burned out.

In the 1950s, only shortly after the transistor's invention, battery-powered portable radios were introduced. They were called "transistor radios," or simply "transistors," and were extremely popular. By the end of the 1950s, transistors were used regularly in digital circuits. Then it became possible to put entire circuits on a single chip, making what are called "integrated circuits." Digital electronics then became significantly faster and cheaper, leading to the advent of personal calculators and computers.

The small size of early individual transistors is shown here as the transistor's dimensions are compared to that of a paper clip.

Hand-held calculators were introduced in the late 1960s. The market competition on price and functionality was so fierce that consumers were almost afraid to buy one, worried that their purchase would become obsolete quickly. Personal computers were introduced in the late 1970s, and there was a similar explosion of low price and higher functionality in the PC market.

Integration of circuits also made electronics lighter, so complex electronics could fit inside satellites. As crystal growing and **photolithography** improved during the last decades of the twentieth century, it has become easier to increase the number of transistors on a single chip, and they have become cheaper to produce and much faster.

Transistor Basics

Transistors are made from crystals of **semiconductor** material, typically **silicon**. With +4 **valence**, silicon lies near the center of the periodic table of the chemical elements. The elements on its left, the metals with valence +1 and +2, are good conductors (low resistors) of electricity and those on its right, the non-metals with valences 0 through -2, are poor conductors (high resistors). The elements in the center can be good or poor conductors, depending on their chemical composition and physical structure; so they are called "semiconductors."

photolithography the process of transferring an image from a film to a metal surface for etching, often used in the production of printed circuit boards

semiconductor solid material that possesses electrical conductivity characteristics that are similar to those of metals under certain conditions, but can also exhibit insulating qualities under other conditions

silicon a chemical element with symbol Si; the most abundant element in the Earth's crust and the most commonly used semiconductor material

valence a measure of the reactive nature of a chemical element or compound in relation to hydrogen

When silicon forms a crystal, each atom's four outer electrons are tied to surrounding atoms in covalent bonds. Since these electrons are not very free to move, the crystal is a poor conductor. However, if the crystal is not pure, and some of the atoms in the crystal, called "impurities," have valence +5 or +3, then any extra electron or any "hole," where an electron could fit in the crystal, can conduct electricity.

Impurities with +5 valence are called "donors" because they donate an extra electron to the crystal. Impurities with +3 valence are called "acceptors" because they contribute a hole in which an extra electron could be accepted into the crystal. A crystal with a majority of donor impurities is called an "N-type" semiconductor because electricity conducts by negative electrons. A crystal with a majority of acceptor impurities is called a "P-type" semiconductor because electricity conducts by positive holes (actually, electrons hop from hole to hole in the opposite direction).

The effect of donor impurities (extra electrons) is canceled by the effect of acceptor impurities (holes where electrons could go). So, a silicon crystal's ability to conduct electricity can be controlled by varying the type and density of impurities when making the crystal—or by electrically controlling the impurities' effect, as in a silicon transistor.

How Are Transistors Made?

Although a single transistor resides on a tiny "chip" of crystalline silicon, transistors are manufactured in batches. The process begins with a thin circular "wafer," about the size and shape of a CD-ROM (compact disc-read only memory), that is sliced off a large cylinder of pure crystalline silicon. Imagine inscribing an imaginary square inside the circle on the surface of the wafer and partitioning the square into an N-by-N array containing N^2 imaginary cells. A process called "photolithography" allows the creation of N^2 transistors, one inside each cell, simultaneously.

The wafer is coated with a substance, called "photo-resist," and then exposed to a black-and-white pattern as if the pattern were being photographed and the coated wafer were the film in the camera. The white areas of the pattern correspond to the upper surfaces of the end regions (called the emitter and collector) of all N^2 transistors. Light hits the wafer in these white areas of the pattern and chemically alters the photo-resist there. The wafer is dipped in a solvent that dissolves away the chemically altered photo-resist, where the pattern had been white, but not the unaltered parts, where the pattern had been black.

The wafer is then heated in an air-tight oven, filled with a gas of donor impurities. Although the wafer is not heated enough to melt the silicon, it is hot enough that some of the gas atoms diffuse from the surface into the body of the material. Donor impurities fix themselves into the crystal structure, but only under the open places in the photo-resist. The wafer is cooled and removed from the oven. The emitter and collector regions of N^2 separate transistors have been embedded in the wafer.

The patterned photo-resist is washed away and the wafer is given a second fresh coat of photo-resist. Again, the wafer is exposed to a black-and-white pattern, but this time the white areas of the pattern correspond to the upper surfaces of the control regions (called the base) of all N^2 transistors.

After similar chemical processing, the wafer is heated again in an air-tight oven, filled this time with a gas of acceptor impurities. They fix themselves into the crystal structure, but again only under the open places in the photo-resist. The wafer is cooled and removed from the oven. The base regions of N^2 separate transistors have been embedded in the wafer, in between and touching the respective emitter and collector regions previously made. The N^2 complete transistors are all disconnected from each other, but they are also disconnected from any wires. So, photolithography is performed a third time on the wafer.

The patterned photo-resist is washed away again and the wafer is given a third fresh coat of photo-resist. This time, the wafer is exposed to a black-and-white pattern, where the white areas of the pattern correspond to small openings on the upper surfaces of all three regions of all N^2 transistors. After similar chemical processing, the wafer is "sputtered" (like being spray-painted) with a metal. The metal forms a small blob that adheres to the wafer's surface, but only in the open places in the photo-resist. When the photo-resist is washed off, the metal on top of the photo-resist washes away with it, leaving the small blobs. These blobs are the electrical contacts on the three regions of each transistor.

The wafer is then sliced and diced into its N^2 chips. For each chip, wires are attached to the transistor's three metal blobs and the chip is encapsulated, with only the three wires sticking out. Transistors can be made extremely small, or many transistors can be constructed on the same chip. Transistors on the same chip can even be connected together, by thin P-type or N-type regions, in complex "integrated" circuits, like amplifiers, digital circuits, or memories.

How Does a Transistor Work?

Suppose a silicon chip has an N-type region on one side, a P-type region on the other side, and a distinct junction in the middle where the two regions touch each other. Any loose charges—electrons on the N-side and holes on the P-side—naturally wander around a little; this is called "diffusion." Any electrons from the N-side that cross the junction into the P-side, combine with holes there, and any holes from the P-side that cross the junction into the N-side, combine with electrons there.

There are two effects. First, the region around the junction becomes depleted of any free carriers of charge. Second, the negative charge accumulating on the P side of the junction and the positive charge accumulating on the N-side of the junction act to repel further diffusion.

Now, suppose a battery is connected to this chip. Connecting the battery's positive terminal to the N-side and its negative terminal to the P-side, called a "reverse bias," attracts the carriers in each side away from the junction, reinforcing the depletion region near the junction. So, very little current flows.

Connecting the battery's positive terminal to the P-side and its negative terminal to the N-side, called a "forward bias," overcomes the charge barrier at the junction and pushes the appropriate carriers toward the junction. Since this forces continuing electron-hole combinations, the chip is a good conductor (low resistor) in this direction. An electronic device, like

SMALLER AND SMALLER

In 2001 another team from Bell Labs made transistor history when they produced an organic transistor from a single molecule. The tiny transistor and about 10 million others could all fit together on the head of a pin. This fast evolving science could lead to significant advances in flexible electronics.

this PN semiconductor chip, that allows current to flow in one direction but not the other, is called a "diode."

There are several kinds of transistors; the two most popular are the Field Effect Transistor (FET) and the Bipolar Junction Transistor (BJT). This article describes only the BJT.

The BJT

A BJT has three regions in series: the emitter, the base, and the collector. Each region has a connecting wire. The two outer regions, the emitter and collector, have the same kind of impurity and the base in the middle has the opposite kind of impurity. A "PNP" transistor has P-type silicon in its emitter and collector and N-type silicon in its base region. An "NPN" transistor is the opposite.

A BJT consists of two "back-to-back" diodes. If the collector-base diode is reverse-biased, one expects little current to flow through the device, from emitter to collector. If the emitter-base diode is forward-biased, carriers move through the base region to its connecting wire. But, if the base region is made extremely thin, perhaps only 5 percent of the carriers in the base reach the wire and 95 percent reach the collector, even through the reverse-biased diode. One sees that the emitter-to-collector current is .95/.05 = 19 times greater than the emitter-to-base current and we can control the end-to-end emitter-to-collector flow by controlling a smaller flow in the emitter-to-base. The FET is a little different, but it has the same effect.

A transistor can increase the intensity of, or the amplification of, an electrical signal. The electrical signal received from a microphone has insufficient intensity to make an audible sound in a speaker. The electrical signal received from the head of a CD-ROM drive has insufficient intensity to be processed by digital electronics. However, a series of transistors can amplify an electrical signal so that the output signal from the last "stage" of a multistage is sufficient to create the desired effect.

The basic building blocks of digital design can be implemented as simple transistor circuits. Since circuits like these can be integrated, making it possible to fit many of them on a single chip, one begins to appreciate how this technology has had such a huge impact on computing.

Conclusion

The ease with which transistors regenerate digital signals is probably the single most important factor that underlies the success of today's digital electronics, digital transmission, and digital computing. Computers were once large and expensive machines that only large corporations, universities, and government agencies could own. This is, of course, no longer the case. More than any other technology, the transistor is responsible for making computers so small and fast and inexpensive that they are now relatively common household appliances used by people of all ages for work, education, entertainment, and communication. SEE ALSO Generations, Computers; Integrated Circuits; Vacuum Tubes.

Richard A. Thompson

Bibliography

Amos, Stanley W., and Michael R. James. *Principles of Transistor Circuits: Introduction to the Design of Amplifiers, Receivers and Digital Circuits.* Boston: Newnes, 2000.

Riordan, Michael, and Lilliam Hoddeson. *Crystal Fire: The Invention of the Transistor and the Birth of the Information Age.* New York: W. W. Norton, 1998.

Turing, Alan M.

British Mathematician and Cryptographer
1912–1954

Alan M. Turing.

Alan Mathison Turing was one of the leading theoreticians in computer science. Turing was something of a visionary in that his hypothetical "Turing Machine" set the standard for the description of computation and its relation to human computing.

Education

Turing was born on June 23, 1912, to upper-middle-class parents in London, England. He was educated in traditional British schools including St. Michael's, a day school, where he learned Latin; Hazelhurst, a preparatory boarding school, where he studied to pass Great Britain's Common Entrance exam; Sherbourne, a high-school-level boarding institution, where he prepared for university admission; and finally, King's College, Cambridge, for university.

Upon graduation from the university, he won a research scholarship of 200 British pounds per year, which enabled him to stay on another year and try for a King's fellowship. This required a dissertation, which he wrote on the Gaussian error function, the Central Limit Theorem in statistics. In 1935 he was one of forty-five students who won the King's fellowship. This enabled him to attend Princeton University in the United States.

At Princeton he had contact with John von Neumann (1903–1957), who is widely credited as the inventor of the "stored program" computer, although this concept pre-dated him through the work of Charles Babbage (1791–1871). Turing also worked with Alonzo Church (1903–1995), one of the leading logicians of the day during his time at Princeton. He eventually earned his Ph.D. from Princeton in 1938. His dissertation, "Systems of Logic Based on Ordinals," was on the axioms of mathematics.

The Turing Machine

In 1936 Turing wrote an article describing a general machine for computation. It is taken as a description of a hypothetical computing machine, although Turing had in mind the human computer performing a typical calculation or computation. He suggested that the machine would need a tape of indefinite length to serve as a data storage device; a set of instructions; the ability to read, write, and manipulate cells on the tape; and the ability to move forward and backward along the tape. With this system, a single symbol would be stored in a cell, with the computing device able to read the value in the cell, write to the cell, or erase the value stored there. It would take action based on the contents of the cell, write, erase, move forward or backward.

The Turing Machine is widely regarded as the general model of a computing device, and its basic premise is sometimes still used to determine whether a computation or other problem can be solved by a general purpose computer. If it can be solved using the Turing Machine principles and methods, it can be done with a general-purpose computer.

Although the concept of the Turing Machine was not immediately accepted, nor even widely known in its day, it has come to be the standard in computing theory. As a result, the Association of Computing Machinery (ACM) has instituted an award in Turing's name which is given to the most accomplished practitioners and theoreticians of its field.

Turing's Career

Turing worked with or was friends with many of the leading scientists of his day including Donald Michie (1923–), who became famous for his work in machine learning; Claude Shannon (1916–2001), the developer of mathematical communication theory; E.C. Titchmarsh (1899–1963), an Oxford mathematician; and M.V. Wilkes (1913–), among others. He met Shannon at Bell Laboratories, where he worked for a time with the speech encryption unit during World War II.

As a war-time cryptographer, Turing worked for the British government, deciphering codes for Allied military operations. This occurred at Bletchley Park, for the Government Code and Cypher School. He also worked for the government secret service, in speech encryption, and was an envoy to Washington, D.C., as a liaison for the encryption and decryption effort.

After the war, Turing went to work at the National Physical Laboratory, and then, in 1948, at the University of Manchester, where he worked with one of the early computers. Although he developed a plan for an early computer, the ACE, or Automatic Computing Engine, it was never implemented.

"CAN A MACHINE THINK?"

"Can a machine think?" has become a rallying cry of the artificial intelligence community and other computer scientists investigating human behavior. It is one that interested Turing beginning in the 1930s and before, and one to which he devoted considerable energy.

Turing also devised "a Turing test" that is still used to determine humanlike behavior in the development of artificial intelligence, albeit imperfectly. He indicated that a computer and a person (or a male and a female) could be isolated in a separate room and interrogated by an "observer." If the observer, asking whatever questions he or she wanted, could not tell the difference between the answers given by the two, then there was no difference in their behavior. This is, of course, not entirely certain, but it gives an operational definition of "humanlike" behavior, in determining if indeed a computer "can think."

Turing was appointed to the Order of the British Empire, and, in 1951, elected a fellow of the Royal Society. Although he was considered a slow student during his early schooling, Turing was later acknowledged as one of the innovative thinkers of his time. He received a number of honors during his lifetime, but he has received greater acclaim in the decades since his death.

Personal Life

Turing was avidly interested in solitary pursuits such as bicycling, running, and general exploration of the countryside. He was said to have been a playful sort, once he trusted a person's friendship, although it is also reported that this was not always an easy accomplishment.

At one point, Turing was engaged to be married to Joan Clark, a colleague at Bletchley Park, although this never materialized. He was also befriended by and was a friend to Lyn Newman, the wife of Max Newman, a professor of mathematics at Cambridge.

Turing's professional life was complicated by the fact that he was an avowed homosexual in an era when this was not publicly accepted. In 1952 he was arrested and subsequently required to undergo treatment, which led to a certain amount of embarassment, though he tried to minimize this. He continued to work at Manchester on several projects: the computer, mathematics, and his interest in human cognition and the development of living things. However, this period was to be shortlived. Turing died a short time later, on June 7, 1954.

The circumstances of Turing's death are unresolved. He died of cyanide poisoning; a partially eaten apple was found nearby his body, but it was never examined. Although Turing's mother attributed the death to a tragic accident, the coroner's office ruled it a suicide. SEE ALSO Artificial Intelligence; Codes; Mathematics; Turing Machine.

Roger R. Flynn

Bibliography

Hodges, Andrew. *Alan Turing: The Enigma of Intelligence*. London: Unwin Paperbacks, 1983.

Internet Resources

The Alan Turing Homepage. <http://www.turing.org.uk/turing/>

Turing Machine

British mathematician Alan Turing (1912–1954) described what became known as the "Turing Machine" in his 1936 paper, "On Computable Numbers, with an application to the *Entscheidungsproblem*," which was published in the *Proceedings of the London Mathematical Society* in early 1937. The machine was actually a concept, not a piece of equipment, but its principles set the stage for the development of digital computers later in the twentieth century.

The machine can be described as a finite state control device (meaning that it has a finite number of states that control its operations), with a tape of unlimited length, divided into squares, upon which symbols may be written or stored. A sequence of actions can take place when a symbol is scanned by a read/write head and the machine is in a certain state. The sequence of actions is the "program."

At any point in time, the finite state control will be in one state and the tape head will be scanning a single symbol, or square, on the tape. On the basis of this symbol and the current state, it will write a symbol on the square, or choose to leave the symbol alone, move the tape one square to the left or the right, and change to a "new" (possibly the same) state. All this constitutes a "move" of the basic machine.

The purpose of the machine was to provide a method for deciding mathematical questions. Turing had become interested in the foundations of logic, and one of the unsolved or open questions was the "decideability" problem.

The problem, posed in 1928 by German mathematician David Hilbert (1862–1943), was: "could there exist, at least in principle, a definite method or procedure by which all mathematical questions could be decided?"

The key to answering the question lay in the provision of a method, and this is what Turing's machine was to provide. The machine would be given a set of instructions to carry out some process or procedure, and the procedure would be carried out in order to answer a particular question. A different procedure would be provided for each problem. However, one could imagine a procedure for each particular problem being written on a single Turing Machine that would interpret the instructions to mimic or emulate the other machines.This would be a Universal Turing Machine, capable of carrying out any problem or program supplied to it.

The Turing Machine was intended to reproduce the actions or the activities of a human carrying out a computation. In this sense, it introduced a definition of computing that was "mechanical," i.e., it could be carried out by following a set of instructions. Thus, the Turing Machine can be considered as a device or a set of devices for carrying out an **algorithm**.

algorithm a rule or procedure used to solve a mathematical problem—most often described as a sequence of steps

An algorithm is a mathematical procedure that comes to a halt after a finite number of steps, no matter what the values given for the variables. A mathematical procedure is one that can be performed mechanically, without risk of unexpected situations, once the value of the variables has been provided. A decision algorithm is one that gives a "yes" or "no" answer to a particular problem in a finite number of steps. A problem is said to be "algorithmically decideable" if a decision algorithm exists for it.

TURING'S MENTOR

Alonzo Church (1903–1995) was one of Alan Turing's instructors at Princeton. He is remembered for his belief that recursiveness (or repetitiveness) plays a key role in solving logical problems. In 1944 he issued the book *Introduction to Mathematical Logic.*

The *Entscheidungsproblem*, proposed by Hilbert in 1928 and written about by Turing in 1936, was the problem of decideability. Ultimately, Turing analyzed the formulas or functions of the predicate calculus or predicate logic and concluded that it was not possible, for a Turing Machine or other logical method, to answer all mathematical questions. This same conclusion was reached independently by Alonzo Church (1903–1995), an American logician, shortly before. Turing and Church later worked together at Princeton University, where Turing was a graduate student and Church a faculty member.

Turing developed this idea for a mathematical machine in 1936. He did so to answer a specific question. The Turing Machine's value extends beyond its inventor's original purpose, however. It provided an abstract model of computation, a conceptual device that could compute any effective procedure, i.e., one that comes to a halt after a finite number of steps. Although Turing's machine was never implemented, its conceptualization served as a model in the development of the digital computer, a machine that could be programmed to perform any computable task. The conceptual Turing Machine is still studied by computer scientists, logicians, and philosophers. SEE ALSO TURING, ALAN M.

Roger R. Flynn

Bibliography

Boolos, George S., and Richard C. Jeffrey. *Computability and Logic*, 3rd ed. Cambridge, UK: Cambridge University Press, 1989.

Hodges, Andrew. *Alan Turing: The Enigma of Intelligence*. London: Unwin Paperbacks, 1983.

Strathern, Paul. *Turing and the Computer.* New York: Anchor Books, 1999.

Internet Resources

Buena Vista University. <http://www.bvu.edu/faculty/schweller/Turing.html>

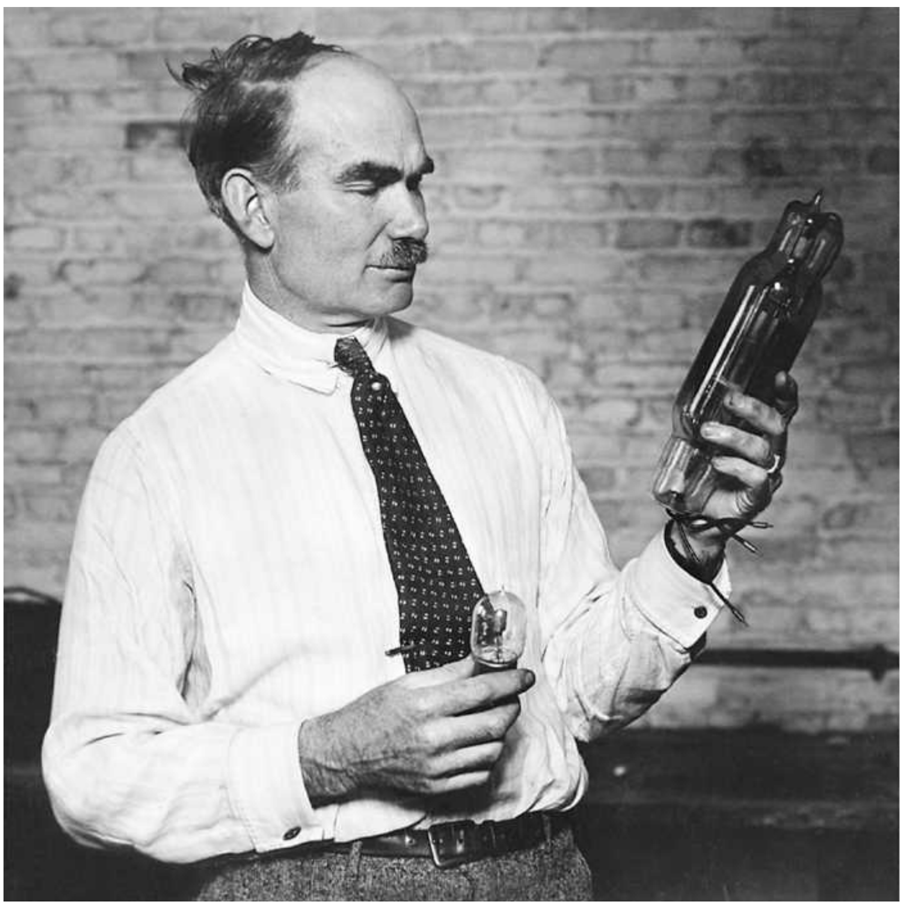
Vacuum Tubes

A vacuum tube is an electronic device used for the processing of electrical signals. It consists of two or more electrodes inside a metal or glass tube which has been evacuated, hence the name.

In the mid-1800s Sir William Crookes (1832–1919) performed early experiments with passing electric current through an evacuated glass tube. In 1883 Thomas Edison (1847–1931) noticed that current would flow between two electrodes inside a light bulb if the negative electrode was heated. John Ambrose Fleming (1849–1945) constructed the first practical **diode tube**, containing two electrodes. When the heated electrode, called the cathode, was at a negative voltage compared to the other electrode, called the anode or plate, electrons flowed from the cathode to the anode. When the voltages were reversed, electron flow was prevented.

diode tube an obsolete form of diode that was made of metal elements in a sealed and evacuated glass tube

This type of action is called *rectification*; it is used to change alternating current into direct current. This is a basic operation needed in radio receivers to demodulate a radio frequency signal into audio.



American inventor Lee De Forest holds up his Audion vacuum tube. The invention of this device changed the history of communication, making live radio broadcasts a possibility.

Later, Lee De Forest (1873–1961) developed a tube with three electrodes, called a triode. The third electrode was called a grid. It was a fine mesh placed between the cathode and the anode. De Forest discovered that a small change in voltage on the grid produced a large change in current flow between the cathode and anode. A positive voltage attracts the electrons from the cathode toward the anode and produces a larger current. A negative voltage repels the electrons and produces less current. Thus, the current flow is proportional to the voltage of the grid. Called *amplification*, this discovery was central to the growth of the electronics industry.

Further developments in vacuum tube technology led to the development of the tetrode, which contained four electrodes; the pentode with five electrodes; and others. The additional electrodes are used to enhance the amplification action of the basic triode: extending power, availability, frequency, efficiency, or fidelity.

The cathode of all vacuum tubes must be heated. The heat is supplied by passing a high direct current through the cathode or, more commonly, by providing another element, called a filament, near the cathode and passing high current through it. The filament is not considered an electrode since it is electrically isolated from the other elements and its sole purpose is to heat the cathode. It is the filament that produces the characteristic glow of the vacuum tube.

The filament represents many of the disadvantages of the vacuum tube. It requires a lot of power, which is essentially wasted energy since it does not add to the output power of the device. In a large device, a cooling system is needed to remove the heat generated by this process. Also, filament burn-out is the most common failure mechanism of most vacuum tubes.

Vacuum Tubes in Computers

The first practical electronic digital computer was the Electronic Numerical Integrator and Computer (ENIAC), built in 1946 at the University of Pennsylvania's Moore School of Electrical Engineering. It weighed 33 metric tons (60,000 pounds), contained 18,000 vacuum tubes, and consumed 150,000 watts of electricity. It was originally designed to be able to compute artillery **ballistics** tables for the U.S. Ballistics Research Lab. However, it was a general purpose computer that could be programmed by connecting the machine's modules with cables.

Prior to ENIAC, mathematicians computed ballistics tables with mechanical adding machines, a process that took up to twenty hours for each one. Because ENIAC was electronic—rather than mechanical—and programmable, it was able to perform about 5,000 integer additions per second, reducing the time required to generate a ballistics table to about thirty seconds. (By comparison, a modern **supercomputer** can perform more than one billion floating point operations per second.)

Of course, the reliability of ENIAC was a real concern. As noted earlier, a vacuum tube filament is susceptible to burn out. Some felt that a device with so many tubes would never work long enough to produce useful results. By de-rating the tubes (running them with less than full rated voltage and current), the ENIAC team managed to keep the system running for several days without failure. This was a significant accomplishment.

ballistics the science and engineering of the motion of projectiles of various types, including bullets, bombs, and rockets

supercomputer a very high performance computer, usually comprised of many processors and used for modeling and simulation of complex phenomena, like meteorology

ENIAC ANNIVERSARY

In 1996, in commemoration of the fiftieth anniversary of ENIAC, the Moore School of Electrical Engineering, University of Pennsylvania, designed and built "ENIAC-on-a-chip." The chip is about 7.44 millimeters by 5.29 millimeters and contains about 175,000 transistors. It has the same functional architecture as the original ENIAC, however the programming cables have been replaced by a transistorized switching network. It is programmed and displays its results via a personal computer.

Still, reliability was a continual problem for ENIAC and other vacuum tube-based computers. Another significant cause of failure with these early computers was large insects that crawled between vacuum tube electrodes and caused short circuits. The process of finding and fixing these short circuits was called *debugging*. The term has endured; it is used today to refer to the process of finding and fixing errors in the computer's program, or software.

Vacuum Tubes Today

Although they have been replaced with **transistors** and other **integrated circuits** in many low-power applications, vacuum tubes are still used in many high-power applications, including specialized sensors and television and computer display devices.

The only type of vacuum tube used in modern computer systems is the **cathode ray tube (CRT)**, which is the main component in a computer display monitor. The cathode assembly in a cathode ray tube is called an electron gun. Located in the narrow tube neck, it generates a very narrow beam of electrons that are accelerated at high speed toward the anode. The anode is a large rectangular screen coated with **phosphors** that glow when struck by the beam.

The electron beam is guided by a strong magnetic field induced by deflection coils around the tube neck. The electron beam traces a **raster scan pattern** that covers the entire surface of the screen at a speed higher than the human eye can detect. The intensity of the beam determines the brightness of the spot.

Colors seen on the computer screen are produced by different phosphors that glow red, green, or blue. A color tube has three electron guns, one for each color. Each gun can only "see" spots on the tube corresponding to its color. Other colors are made by combinations of varying intensities of the three primary colors. The cathode ray tube has become so common in computer display devices that the acronym *CRT* has come to be synonymous with the entire display unit. SEE ALSO Early Computers; Generations, Computers; Integrated Circuits; Transistors.

Donald M. McIver

transistors the plural of transistor, which is a contraction of TRANSfer resISTOR; semiconductor device, invented by John Bardeen, Walter Brattain, and William Shockley, which has three terminals; can be used for switching and amplifying electrical signals

integrated circuits circuits with the transistors, resistors, and other circuit elements etched into the surface of single chips of semiconducting material, usually silicon

cathode ray tube (CRT) a glass enclosure that projects images by directing a beam of electrons onto the back of a screen

phosphors coating applied to the back of glass screens on cathode ray tubes (CRTs) that emits light when a beam of electrons strike the surface

raster scan pattern a sequence of raster lines drawn on a cathode ray tube such that an image or text can be made to appear

END OF THE LINE?

Although the CRT was still being used in many computers as of 2002, industry experts suggest that the CRT's days are numbered. Flat panel displays, using liquid crystal display (LCD), are becoming more and more popular. As the price of the space-saving flat panels decreases, CRTs may begin to disappear from the marketplace.

Bibliography

Bell, David. *Electronic Devices and Circuits*. Englewood Cliffs, NJ: Prentice Hall, 1986.

Benedict, R. Ralph. *Electronics for Scientists and Engineers*, 2nd ed. Englewood Cliffs, NJ: Prentice Hall, 1976.

Internet Resources

"ENIAC-on-a-Chip." Moore School of Electrical Engineering, University of Pennsylvania. <http://www.ee.upenn.edu/~jan/eniacproj.html>

"John W. Mauchly and the Development of the ENIAC Computer." Van Pelt Library, University of Pennsylvania. <http://www.library.upenn.edu/special/gallery/mauchly/jwmintro.html>

Virtual Reality in Education

Flying over the Mississippi River from Canada to the Gulf of Mexico and continuing on to South America, learning about the migratory habits of

A nursing student in Hong Kong learns more about performing surgery through the use of virtual reality equipment.

swans; walking across a busy intersection; or becoming a hydrogen molecule as you bond with a second hydrogen molecule and an oxygen molecule to form a drop of water—these are just a few examples of the experiences offered by virtual reality technology today. And now, climbing the Eiffel Tower, fishing in the Chesapeake Bay, and investigating the far regions of the world are closer to becoming virtually possible in the very near future because of recent advances in computer technology.

Scientists and educators are working together throughout the United States to introduce "virtual reality" to teachers and students via CAVEs, **ImmersaDesks**, **ImmersaWalls**, and **head-mounted displays (HMD)**. The CAVE is a standard 3.05 meter by 3.05 meter by 3.05 meter (10 foot by 10 foot by 10 foot) space, with three walls, a ceiling, and a floor, and refers to Cave Automated Virtual Environment. The student typically wears a pair of stereographic glasses that enhances images and carries the standard CAVE wand that is used to help the student as bird/pedestrian/molecule navigate the virtual environment. The desks, walls, and head-mounted displays that are now available are less costly alternatives to the CAVE, and are alternatives that are also portable.

The emergence of virtual reality as an instructional aid in the classroom is just beginning. Although there are numerous examples of educational applications in use throughout the United States today, the growth of virtual reality has not reached anywhere near its potential in the classroom and be-

ImmersaDesks large 4 × 5 foot screens that allow for stereoscopic visualization; the 3-D computer graphics create the illusion of a virtual environment

ImmersaWalls large-scale, flat screen visualization environments that include passive and active multi-projector displays of 3-D images

head-mounted displays (HMD) helmets worn by a virtual reality (VR) participant that include speakers and screens for each eye, which display three-dimensional images yond. This article explores several examples of how scientists and educators are collaborating to develop new ways of learning, including considering the student's ability to learn by being totally immersed in that learning environment.

At George Mason University, for example, Chris Dede and his colleagues have developed a SpaceScience World that consists of three applications, referred to as NewtonWorld, MaxwellWorld, and PaulingWorld. In NewtonWorld, students are introduced to the laws of motion from multiple reference points, including becoming a ball hovering above the ground, colliding with another ball, and virtually experiencing motion with neither gravity nor friction being a factor. MaxwellWorld allows the student to experience an electrostatic field from multiple reference points that are influenced by force and energy. And finally, PaulingWorld introduces chemical bonding and molecular structures, such as becoming a drop of water through the bonding of hydrogen and oxygen molecules, or even becoming complex proteins as a result of manipulating amino acids. Such activities are described in Dede's book *Learning the Sciences of the 21st Century: Research, Design, and Implementing Advanced Technology Learning Environments.*

At the University of Illinois, recent research has focused on providing opportunities to learn important safety skills for students of all ages across K-12 (kindergarten to twelfth grade), including those with disabilities. Frank Rusch and his colleagues were motivated to combine the emergence of virtual reality technologies and self-instructional strategies in the promotion of traffic safety among school children, including students with disabilities The CAVE provided multiple opportunities for school children to learn street-crossing skills without having to cross real streets, reducing the time needed for instructional learning to occur and reducing safety-related concerns during training.

In this demonstration, Rusch, Umesh Thakkar, and Laird Heal sought to determine whether students could use a self-instructional sequence in their navigating with a wand as they crossed three different intersections (an intersection with two-way stop signs, an intersection with four-way stop signs, and an intersection with electronic lights); each intersection virtually displayed three levels of difficulty (simple, typical, and complex). Difficulty was directly related to how many cars crossed the intersections, including a Porsche driven by ex-basketball star Dennis Rodman. Utilizing their own verbally generated cues, eighty-one students learned to cross the three intersections, with little or no differences between those students with disabilities versus those without.

Virtual reality is becoming increasingly important as a learning tool in the school as well as in university laboratories where CAVEs are typically located. Recent research has investigated the use of an ImmersaDesk in an effort to teach students to better understand concepts that do not fit with their pre-existing conceptualizations by guiding them through a series of exercises that confront their pre-existing knowledge with alternative ideas. For example, young students are quick to disbelieve their teachers when they are told that the world is round. For most young students, the earth is simply flat, and they do not have the cognitive capacity, nor the conceptual firepower, to make the leap from what they see and experience (a flat Earth) to what they do not see (a spherical Earth).

VR CAVES

CAVE is an acronym for the CAVE Automated Virtual Environment, a room-sized advanced visualization tool that combines high-resolution, stereoscopic projection and 3-D computer graphics to create the illusion of complete sense of presence in a virtual environment.

The Round Earth Project at the University of Illinois at Chicago, as described in *The Round Earth Project: Deep Learning in a Collaborative Virtual World*, has conducted a series of studies to better comprehend the emergence of complex understandings when given the opportunity to become involved in virtual representations of the Earth as a globe as seen from a spaceship. Using an ImmersaDesk, A. Johnson and his colleagues found that they could teach new concepts like a round Earth versus a flat Earth. They allowed students to assume the role of astronauts and provided the astronauts with activities that displayed the Earth as round versus flat. The ImmersaDesk is a standard desk with a 15.4 centimeter by 10.3 centimeter (6 inch by 4 inch) screen placed on it. Students use stereographic glasses and a wand, just as they would in the CAVE.

Virtual reality will continue to make important contributions to education. In the very near future, high schools should be able to utilize Walls and Desks to learn new concepts, to use HMDs to help students who are easily distracted to learn, and to teach increasingly complex concepts outside of the textbook. SEE ALSO VIRTUAL REALITY.

Frank R. Rusch, William Sherman, and Umesh Thakkar

Bibliography

Dede, C., M. Salzman, B. Loftin, and K. Ash. "Using Virtual Reality Technology to Convey Abstract Scientific Concepts." In *Learning the Sciences of the 21st Century: Research, Design, and Implementing Advanced Technology Learning Environments*, eds. M. J. Jacobson and R. B. Kozma. Hillsdale, NJ: Lawrence Erlbaum, 2000.

Johnson, A., T. Moher, S. Ohlsson, and M. Gillingham. *The Round Earth Project: Deep Learning in a Collaborative Virtual World.* Chicago: University of Illinois at Chicago, 1997.

Rusch, F. R., D. S. Millar, R. E. Cimera, D. L. Sheldon, U. Thakkar, D. A. Chapman, Y. H. Khan, D. D. Moore, and J. S. LeBoy. "Crossing Streets: A K-12 Virtual Reality Application for Understanding Knowledge Acquisition." *Proceedings of the IEEE Virtual Reality Annual International Symposium* (1997): 211+.

Rusch, F. R., U. Thakkar, D. A. Chapman, L. Heal, and B. F. Wallace. "Investigating Student's Ability to Cross Intersections Utilizing Self-Instructional Strategies in the CAVE." *Proceedings for the Seventeenth IASTED International Conference on Applied Informatics: A Publication of the International Association of Science and Technology for Development* (1999): 275–278.

Sherman, W. R., and A. B. Craig. "Literacy in Virtual Reality: A New Medium." *Computer Graphics* 29 (1995): 37–42.

Thakkar, U., and D. A. Chapman. "Virtual Reality and Education Programs for Educators." *Computer Graphics* 31 (1997): 35–37.

Viruses

Less than a generation ago, computer viruses were considered an urban myth. They were found more often in movies than on actual computer systems. Now, however, malicious software constitutes a material threat to businesses, government, and home computer users.

Currently, there are three categories of malicious software threats: viruses, worms, and Trojan horses. All of these threats are built from the same basic instructions and computer logic that make up application programs on one's computer such as word processors, games, or spreadsheets. Like traditional application programs, malicious software is written by people and must be intentionally designed and programmed to self-replicate or cause damage.

While almost all Trojan horses attempt to cause harm to the computer system, more than 70 percent of all computer viruses and worms are designed only to self-replicate. Those viruses, worms, and Trojan horses that do inflict intentional damage to computer systems are said to deliver a "payload." Common payloads include formatting a hard drive, deleting files, or gathering and sending passwords to an attacker. These threats typically have trigger criteria. They wait until the criteria are met before delivering the payload (for example, waiting until July 28 to reformat the hard drive).

The typical malicious software author is male between fourteen and twenty-five years of age (only a few female virus writers are known). These demographics are expected to change as organized crime, terrorist groups, and rogue organizations begin to target the Internet. In addition, many governments around the world are researching how to use malicious software for both offensive and defensive information warfare.

Viruses

A virus is a computer program that is designed to replicate itself from file to file (or disk to disk) on a single computer. Viruses spread quickly to many files within a computer, but they do not spread between computers unless people exchange infected files over a network or share an infected floppy diskette.

By 1990, there were roughly 50 known computer viruses. During the late 1990s, the number of viruses skyrocketed more than 48,000! Despite the many thousand virus strains that exist, very few viruses have found their way out of research labs to end-user computers. Based on industry statistics, of the more than 48,000 known computer viruses, only 200 to 300 are in general circulation at any one time.

Viruses are classified by the type of file or disk that the virus infects:

- Boot viruses attach themselves to floppy diskettes and hard drives. When a user boots from an infected floppy diskette or hard drive, the virus is activated and the computer becomes infected. The virus spreads to other floppy diskettes as they are used on the system.
- Application viruses spread from one application to another on the computer. Each time an infected application program is run, the virus takes control and spreads to other applications.
- Macro viruses spread through documents, spreadsheets, and other data files that contain computer macros. A macro is a small, self-contained program that is embedded directly within a document or spreadsheet file. Typically, macros are used to automate simple computer tasks such as summing a set of numbers in a spreadsheet. Modern macros are powerful enough to copy themselves between documents or spreadsheets.
- Script viruses infect other script files on the computer. Script viruses, which are written in high-level script languages such as Perl or Visual Basic, gain control when a user runs an infected script file.

VIRAL ORIGINS

What was the first mainstream computer virus? It is widely believed that it was the Pakistani Brain boot virus. It first began making the rounds in 1986.

A typical computer virus works as follows: First, the user runs infected program A. Program A immediately executes its viral logic. The virus locates a new program, B, that it thinks it can infect. The virus checks to see if the program is already infected. If program B is already infected, the virus goes back to locate another program to infect. If it is not already infected, the virus appends a copy of its logic to the end of program B and changes program B such that it, too, will run the malicious logic. The virus then runs program A so the user does not suspect any malicious activities.

Viruses can be written in numerous computer programming languages including assembly language, scripting languages (such as Visual Basic or Perl), C, C++, Java, and macro programming languages (such as Microsoft's VBA).

Worms

A worm is a computer program that exploits a computer network to copy itself from one computer to another. The worm infects as many machines as possible on the network, rather than spreading many copies of itself on a single computer, as a computer virus does. Usually, a worm infects (or causes its code to run on) a target system only once; after the initial infection, the worm attempts to spread to other machines on the network. Because computer worms do not rely on humans to copy them from computer to computer, they can spread much more rapidly than computer viruses.

The first computer worms were written at Xerox Palo Alto Research Center in 1982 to understand how self-replicating logic could be leveraged in a corporation. A bug, however, in the worm's logic caused computers on the Xerox network to crash. Xerox researchers had to build the world's first "antivirus" solution to remove the infections. In 1987 the "CHRISTMA EXEC" worm made millions of copies of itself in the IBM and BITNET e-mail systems. In 1988 the "Internet" worm spread itself to roughly 6,000 machines (10 percent of the Internet at the time).

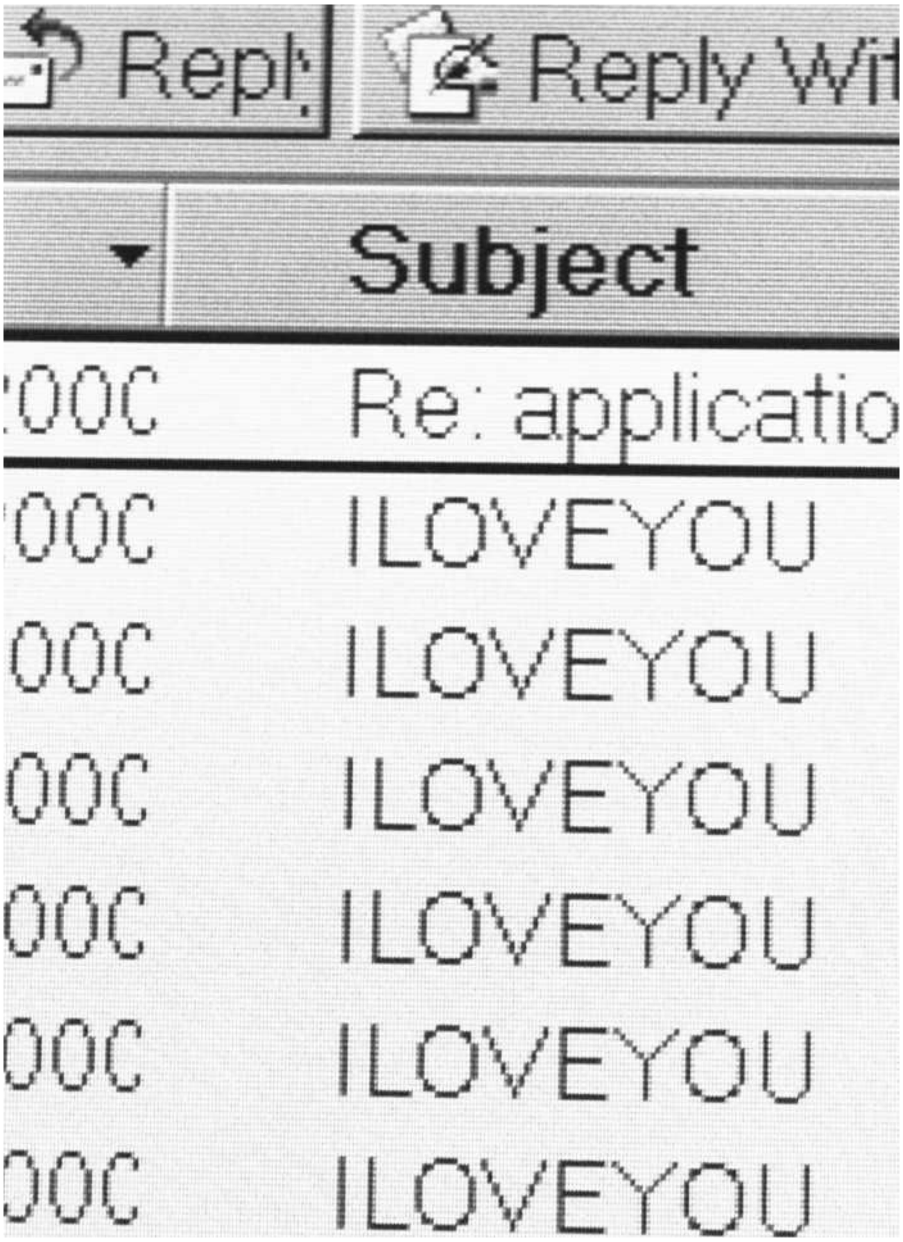
More recently, worms such as Melissa, ExploreZip, and LoveLetter have captured the attention of the public and the media due to their vast ability to spread over the Internet. These worms, collectively, produced millions of copies of themselves, and caused millions—some say billions—of dollars of damage.

The typical computer worm works as follows: The user unknowingly runs a worm program. The worm accesses a "directory" source, such as an e-mail address list, to obtain a list of target computers on the network. The worm sends itself to each of the target computers. A user on a target computer receives a copy of the worm in e-mail, unknowingly runs the worm e-mail attachment, and starts the process over again.

Some worms, like the Internet worm of 1988, automatically connect to target computers and use a "back door" to install and run themselves on the target without human intervention. Like viruses, computer worms can be written in assembly language, scripting languages, macro languages, or in high level languages like C, C++, or Java.

The Trojan Horse

Trojan horses are software programs that are designed to appear like normal computer programs, yet, when run, can cause some type of harm to the



When the ILOVEYOU virus struck in 2000, it wreaked havoc on corporate, government, and home computers worldwide. Thinking they were being greeted with warm wishes, some unsuspecting computer users opened the viral attachment and infected their computers instead.

host computer. Most often, Trojan horses either steal information (such as passwords or files) from the computer or damage the contents of the computer (by deleting files). Because Trojan horses do not attempt to replicate themselves like viruses or worms, they are placed into their own class of computer threat. Like viruses and worms, Trojan horses can be written in virtually any computer language.

Detection Avoidance

Virus and worm authors have invented a number of techniques to avoid detection by antivirus software. Three of the more interesting techniques are the polymorphic virus, the retrovirus, and the stealth virus.

The term "polymorphic" means many-formed. Polymorphic viruses (or worms) mutate themselves each time they spread to a new file or disk.

This behavior eliminates any consistent digital fingerprint and makes virus detection much more difficult. These digital pathogens avoid detection in the same way that HIV (human immunodeficiency virus) and other viruses evade the human immune system.

Computer retroviruses actively seek out and disable antivirus programs. The retrovirus deletes components of the antivirus program as an offensive attack to prevent detection.

Finally, stealth viruses inject themselves into the computer operating system and actively monitor requests to access infected files. The virus automatically disinfects infected files before they are accessed by other software on the computer, then reinfects them at a later time. This technique enables the viruses to sneak past antivirus software because every time the antivirus program attempts to scan an infected file, the virus disinfects the file first.

Legality of Virus Writing

While computer virus writing is not considered an illegal act in the United States, intentionally spreading malicious programs is a crime punishable by fine or imprisonment. Countries outside the United States are beginning to draft computer crime laws that are far stricter than those in the United States. For instance, Germany has laws restricting mass exchange of computer viruses for any reason and Finland has recently made writing a computer virus an illegal act.

Industry watchers expect a great deal of future legislation in this area as computer threats increasingly affect mainstream computer users. SEE ALSO Ethics; Hackers; Hacking; Programming; Security.

Carey Nachenberg

Bibliography

Atkins, Derek, et al. *Internet Security, Professional Reference.* Indianapolis, IN: New Riders Publishing, 1996.

Cohen, Frederick B. *A Short Course on Computer Viruses*, 2nd edition. New York: John Wiley & Sons, 1994.

Watson, Thomas J., Sr.

American Business Executive
1874–1956

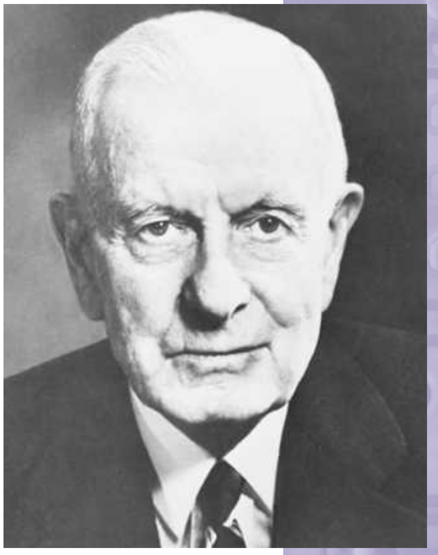
Thomas John Watson, born on February 17, 1874, was neither an inventor nor a technician, but his contributions to computer science were substantial nonetheless. During Watson's forty-two years of leadership at IBM Corporation, his marketing and management skills and his emphasis on research and development helped create the Computer Age. He died on June 19, 1956.

The fifth child of an immigrant Scots-Irishman, Watson was born in a four-room cabin in Painted Post, New York. He showed no affinity for the family farm and lumber business and chose to study business and accounting instead. After a year at the Miller School of Commerce in Elmira, New

York, he accepted a bookkeeping job at the then relatively high salary of $6 a week. He was seventeen years old.

The job was shortlived, however, as Watson succumbed to the lure of the open road and the life of a traveling salesman, peddling pianos, organs, and sewing machines off the back of a wagon. He soon joined forces with a more established salesman named C. B. Barron, this time selling stock in the Northern New York State Building and Loan Association.

During this period, Watson began honing the selling skills that would someday earn him the nickname of the world's greatest salesman. But first there were a few bumps on the road: Barron absconded with the money they had earned, and Watson was fired. However, fortune smiled on Watson in October 1895, when he took a sales job with the National Cash Register Company (NCR) and was soon outperforming everyone in NCR's Buffalo, New York, office.



Thomas J. Watson Sr.

By 1912, after a series of rapid promotions, Watson had risen to second-in-command at NCR's corporate headquarters in Dayton, Ohio. At the age of thirty-eight, this tall, strikingly handsome man was one of the town's most eligible bachelors—but not for long. He met Jeannett Kittredge, daughter of a prominent businessman, at a country club dinner, and a year later they were married. The couple eventually had four children: Thomas, Jr.; Jane; Helen; and Arthur.

During the NCR years, to raise the morale of a dispirited sales force, Watson adopted his famous motto "THINK" and placed framed placards with that single word throughout the company's offices. Years later, he would use that same slogan at IBM, a company he was soon to join.

Watson's departure from NCR was preceded by two serious impediments to his career path. The first of these was an accusation by the company's main competitor, American Cash Register Company, that Watson and twenty-nine other executives had violated the Sherman Antitrust Act* by engaging in unfair business practices, some designed to eliminate the second-hand trade in business machines. Although Watson was sentenced to one year in jail and a $5,000 fine, the verdict was quickly appealed and eventually set aside. Nonetheless, the widely publicized trial did little for his standing at NCR. In addition, there was a public disagreement with NCR President John H. Patterson, and shortly thereafter Watson was dismissed.

***Named after American Senator John Sherman, the Sherman Antitrust Act (1890) was intended to reduce business practices that limited economic competition.**

Watson was recruited by Charles R. Flint, the founder of what was to become IBM, and on May 1, 1914, he became general manager of the Computing-Tabulating-Recording Company (CTR), a small conglomerate in need of a major turnaround. Watson was intrigued by the product line, particularly the tabulating machine invented by Herman Hollerith (1860–1929) to help tally census results. Believing that automated accounting and record keeping had great commercial potential, Watson focused on the tabulating-machine division. Later that year, as CTR president, he borrowed the funding for research and development and began a transformation of the company. In 1924, at the age of fifty, he became chief executive officer and changed CTR's name to International Business Machines Corporation (IBM), reflecting his vision of the future.

To realize that vision, Watson motivated his employees through slogans and songs, a company newspaper and school, a country club that any

IN HIS FATHER'S FOOTSTEPS

Thomas J. Watson Jr. (1914–1993) took the helm of IBM shortly before his father's death. Leading IBM from 1956 until 1971, he is credited for bringing IBM from the tabulator era into the Computer Age. After his retirement, he spent several years as U.S. Ambassador to the Soviet Union.

employee could join for a dollar a year, and the promise of lifetime employment. One of his slogans was "World peace through world trade." A master of sales promotion, he understood the needs of the customer and met those needs through continuous funding of engineering and research. It was primarily Watson's support that ensured the development of Howard Aiken's Mark I calculator—the first digital computer made in the United States and IBM's first step into the Computer Age. Advancements continued and in 1952 IBM introduced its first production computer, the 701, and the company was firmly established in the computer business.

Watson retired as president of the firm in 1949 to become chairman of the board, and on May 8, 1956, he passed on executive power to his eldest son, Thomas Watson Jr. Six weeks later, he died of a heart attack at the age of eighty-two. SEE ALSO HERMAN HOLLERITH; IBM CORPORATION; MAINFRAMES.

Karen E. Esch

Bibliography

Belden, Thomas, and Marva Belden. *The Lengthening Shadow: The Life of Thomas J. Watson.* Boston: Little, Brown, 1962.

Fishman, Katharine Davis. *The Computer Establishment.* New York: Harper and Row, 1981.

Levinson, Harry, and Stuart Rosenthal. *CEO: Corporate Leadership in Action.* New York: Basic Books, 1984.

Rodgers, William. *THINK: A Biography of the Watsons and IBM.* New York: Stein and Day, 1969.

Slater, Robert. "Thomas J. Watson, Sr.: Founder of IBM." In *Portraits in Silicon.* Cambridge, MA: MIT Press, 1987.

Watson, Thomas J., Jr., and Peter Petre. *Father, Son and Co.* New York: Bantam Books, 1990.

Window Interfaces

"Window interfaces" refers to the commonly used way to organize a computer monitor's screen space for interaction with a human user. Screen space is organized into regions called "windows." Each window utilizes some screen space for computer–human interaction. Typically, a computer system with window interfaces also supports the mouse and the keyboard as interactive devices for user input.

Two Styles of Window Interfaces

There are various styles of organizing the windows on a screen. One approach is to treat the screen as a desktop and the windows as documents on the desktop. The windows may overlap one another so that some windows partially or completely obscure other windows. Only those windows that stay on top are fully visible. Users can use the mouse to drag the windows around on the screen or to bring a certain window to the top. Figure 1 illustrates overlapping windows on a screen.

Another way to organize windows is by tiling: subdividing screen space so that the windows do not overlap and arranging the windows like tiles to

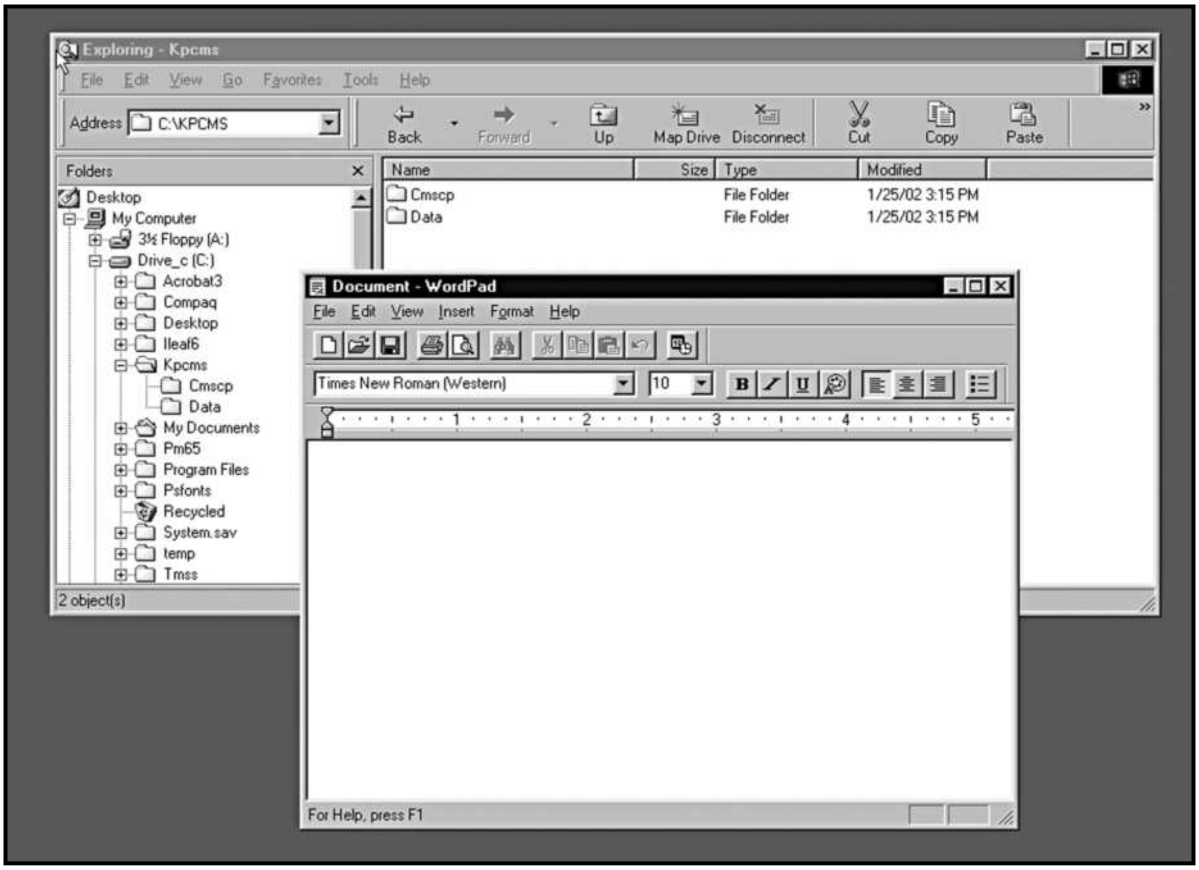


Figure 1: Overlapping windows.

fill the screen space. Figure 2 (see p. 214) illustrates tiling windows. Tiling attempts to keep all the windows entirely visible at the same time.

General Operations on Windows

Window interfaces allow users to work on multiple tasks at the same time. Windows supports certain standard operations that are both versatile and practical:

1. *Dragging* a window to a different position on the screen;
2. *Resizing* the dimensions of a window;
3. *Iconifying* a window (to suspend the use of a window, the user may hide the window in use, turning it into an **icon** on the desktop, that is, the screen);
4. *Restoring* a window from an icon (an icon is simply a small window that supports the restore operation);
5. *Closing* a window.

icon a small image that is used to signify a program or operation to a user

Typically, someone uses the mouse to perform these operations. The mouse moves a corresponding cursor on the screen.

A window has other designated areas, some of which are like buttons. Figure 3 (see p. 215) identifies specific button areas of a window. The mouse cursor can be placed over a designated area and then pressed to invoke the desired operation on the window. For example, a window can be **dragged**

dragged to have been moved by the application of an external pulling force; quite often occurring in graphical user interfaces when objects are moved with a mouse

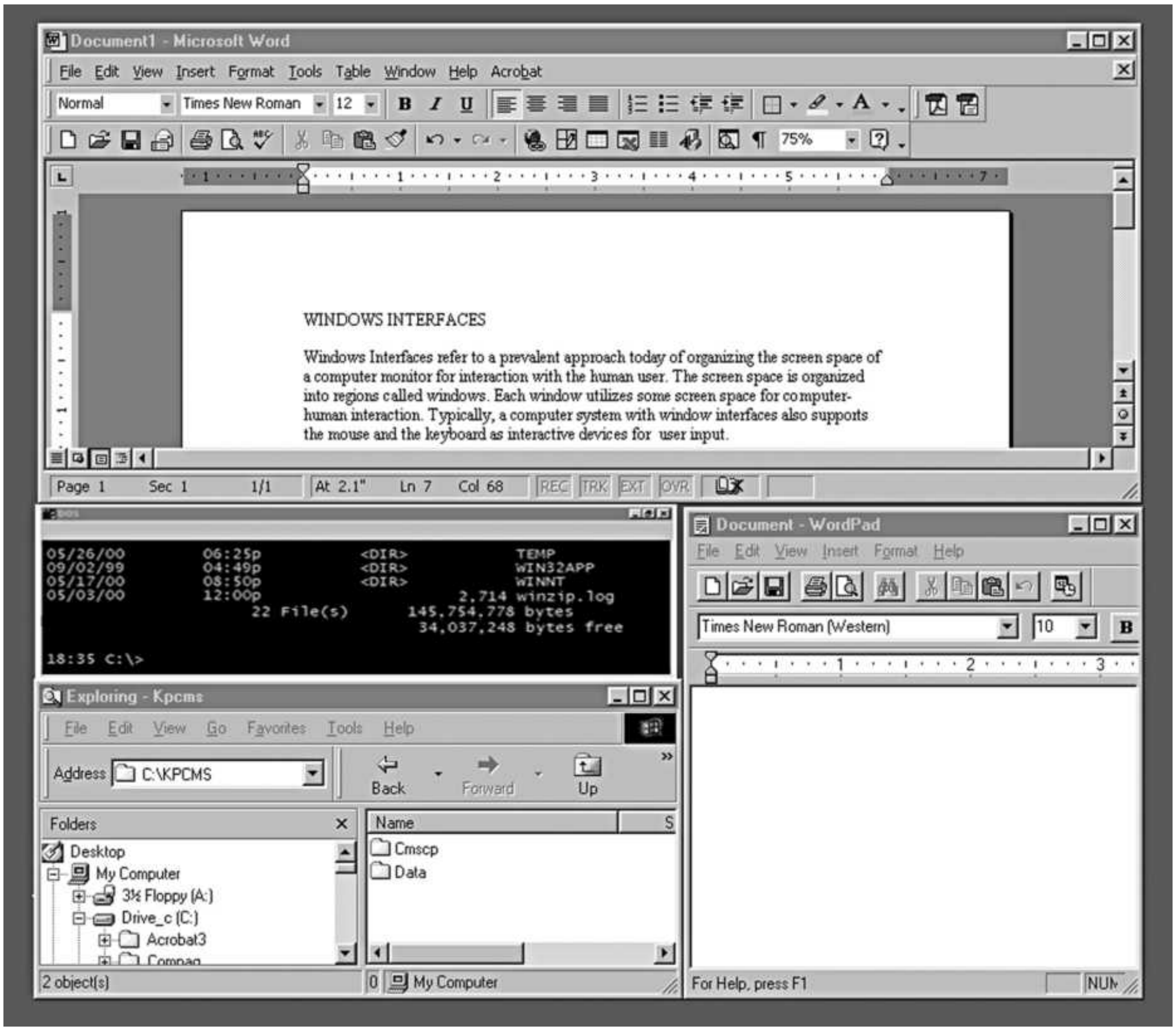


Figure 2: Tiling windows.

title bar the top horizontal border of a rectangular region owned by a program running in a graphical user interface (GUI); it usually contains the program name and can be used to move the region around

to a new location by placing the cursor over the **title bar** of a window and moving the mouse while keeping the button pressed down; when the mouse button is released, the window stays at the new location on the screen. (A mouse with more than one button most often uses the left button to invoke the operation.)

When the cursor is on the Close button, a window can be closed by clicking on the mouse button—that is, pressing the button down and releasing it momentarily. A window can be iconified by clicking over the Iconify button. A window can be restored from an icon by double-clicking over the icon—that is, clicking two times quickly. The border around a window is often the area specifically designated to resize the window. When the cursor is over the window border, the system may even change the appearance of the cursor, indicating that the user can now resize the window. The mouse button can then be held down and the window border dragged to resize the window to the desired dimensions.

Other Features

Many other functions can be performed in a windows environment. A sampling of these operations follows.

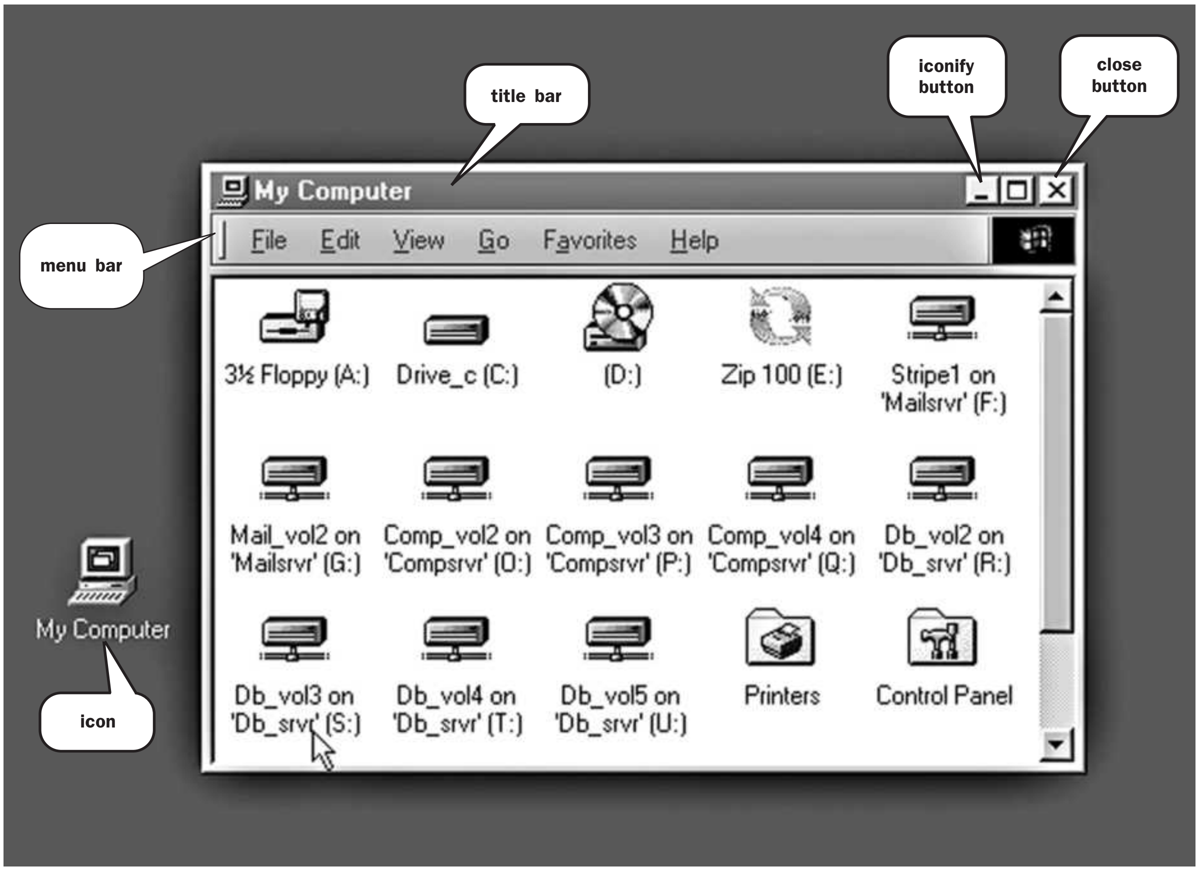


Figure 3: Button area of the window.

Focus Window—For Keyboard Input. These are the common window operations in application programs using window interfaces. A user may use the window to interact with a program in many other application-specific ways. If a user wants an application program to read keyboard input as it is being typed, the program can display the keys in a window as typing progresses. However, because there are multiple windows, one of the windows needs to be designated the Focus window to receive keyboard input. Usually, a simple mouse click or any operation on the window brings it into focus to receive keyboard input. The Focus window usually will have a slightly different appearance to indicate this distinction.

Menu Bar. Another common application design is to use a menu bar in the window. The menu bar is a designated area strip labeled with menu items. When the mouse cursor is placed over a **menu label**, the menu label becomes highlighted. A click on the mouse button will then bring up a **drop-down menu**. A user can then move the mouse cursor to any item in the menu to select an operation and then click on a menu item to invoke the operation. Figure 4 (see p. 216) shows selecting the Close operation in the menu under the File menu label.

Scroll Bar. Sometimes the screen space in the window is not large enough, and parts of the program output may be obscured. A common practice in program design is to use a scroll bar, which allows the user to move the window within a larger, imaginary screen space for output. Scrolling the window then exposes other parts of program output. Figure 5 (see p. 217) illustrates a scroll bar. Clicking on the **direction buttons** scrolls the win-

menu label the text or icon on a menu item in a program with a graphical user interface

drop-down menu a menu on a program with a graphical user interface that produces a vertical list of items when activated

direction buttons buttons on a program with a graphical user interface that provide a way of navigating through information or documents

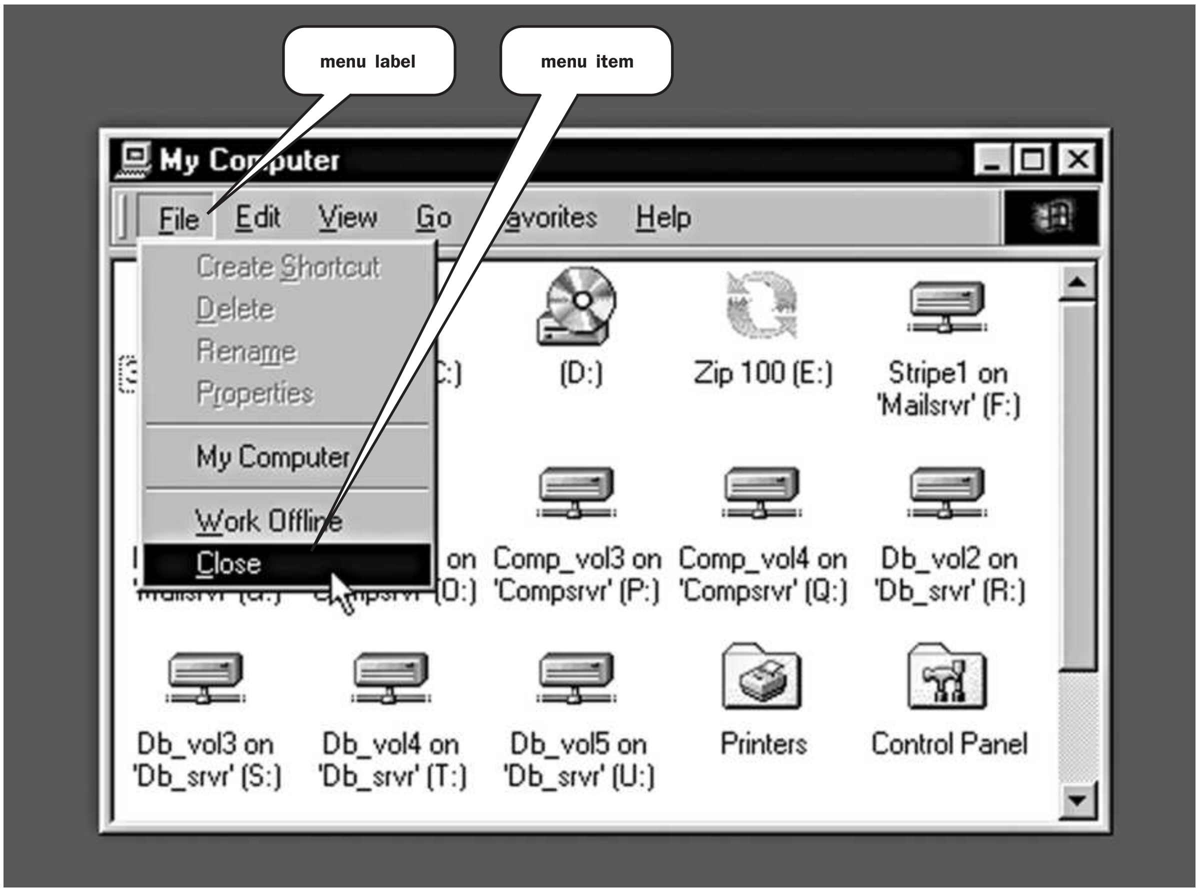


Figure 4: Selecting the Close operation on the file menu.

thumbnail an image which is a scaled down copy of a much larger image; used to assist in the management of a large catalog of images

dow in increments along the indicated direction. A user may also scroll the window smoothly with the mouse by placing the cursor over the **thumbnail** on the scroll bar, holding down the mouse button, and moving the thumbnail in the desired direction.

Application Wizard. A powerful application of windows is their ability to provide online help information with an application wizard. When a user needs help working with a particular program, the program will, on the user's request, hold the progress of the program at that stage and pop up a separate window to provide helpful information online. The program can provide help that is specific to the task at hand and even guide the user through the rest of the task. This style of intelligent online help is provided by an application wizard, a common example of which is the Office Assistant in Microsoft Word 2000.

Customizable Look and Feel. Most any implementation of window interfaces is highly customizable. The look and feel of window interfaces may be quite different, but the fundamental generic operations are not.

Brief History of Window Interfaces

In the mid-1970s, the Xerox Palo Alto Research Center first used the Alto computer to access multiple computers as an intelligent gateway. The Alto computer divided the monitor screen into windows, each of which could run a different program or access a different computer in the network. Later, Xerox, in the Dynabook project, developed a programming language

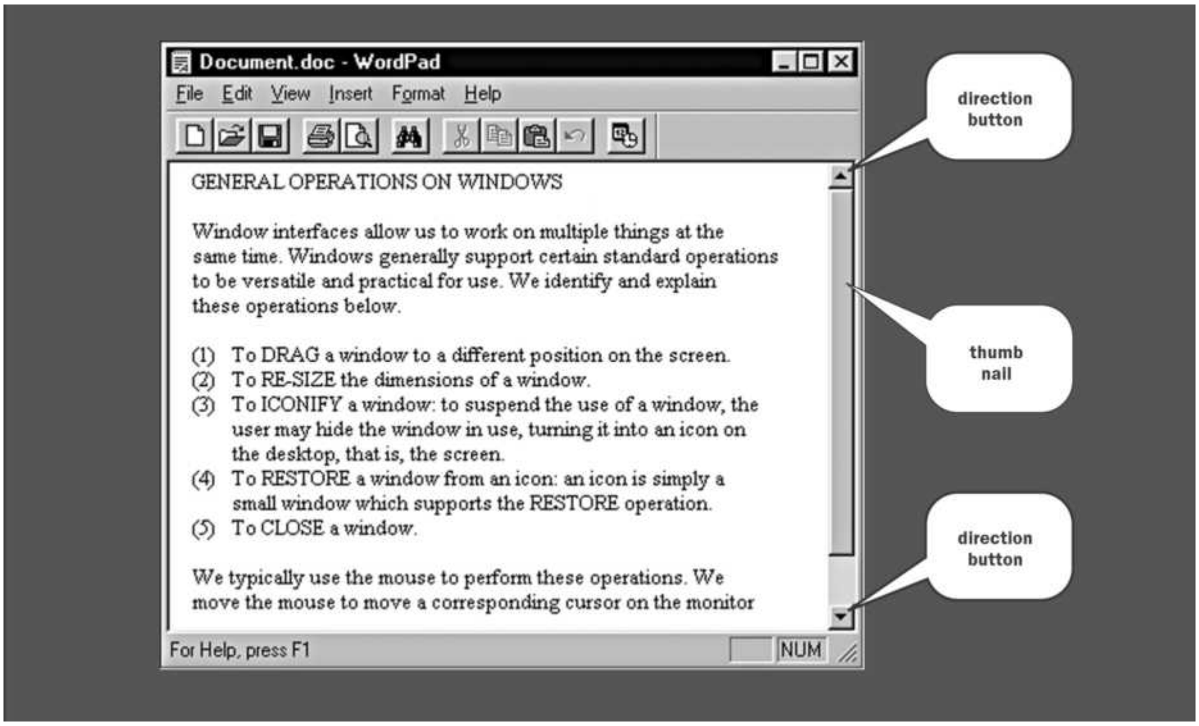


Figure 5: Scroll bar in the window

called Smalltalk. Designed into the execution of Smalltalk was the use of multiple overlapping windows on the screen for interaction with the human user.

During the 1980s, while the use of interactive computer graphics was becoming commonplace, window interfaces caught on. The Macintosh computer and the later Sun workstation applied the desktop metaphor to the monitor screen, using overlapping windows on the screen as if they were documents on the desk; each window provided screen real estate for human–computer interaction.

Another system for window interfaces on networked computers, called X-Windows, was developed by an industry consortium led by the Massachusetts Institute of Technology (MIT). Soon this system became the industry standard. Today, many derivative systems of X-Windows are available from various computer vendors for use on the Unix platform, including Linux. Macintosh, from Apple Computer, Inc., continues to carry its own system of window interfaces. Microsoft Corporation rode on the success of marketing DOS (Disk Operating System) on the Intel-based personal computer developed by IBM, called the "IBM-PC" during the late 1980s, and imitated the Macintosh window interfaces to develop Windows on DOS. Windows became very popular on its release in the early 1990s, and Microsoft has developed later versions, called Windows 95, Windows 98, and Windows 2000, including Windows NT, which was developed in the early 1990s for networked computers. For the most part, all these systems are similar in their user-interface design. SEE ALSO Apple Computer, Inc.; Microsoft Corporation; Xerox Corporation.

Peter Y. Wu

SHAPING A NEW IDEA

Until the late 1980s, windows had been mostly rectangular. At that time, however, Sun Microsystems developed a system called NeWs (for "networked windows") for workstations in a local area network. NeWs supported windows of various shapes but was soon discontinued.

Bibliography

Goldberg, Adele, and David Robson. *Smalltalk-80: The Language and Its Implementation.* Reading, MA: Addison Wesley, 1983.

Hiltzik, Michael. *Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age.* New York: Harper Business, 2000.

Reiss, Levi, and Joseph Radin. *X-Window Inside and Out*. Berkeley, CA: Osborne/McGraw-Hill, 1992.

World Wide Web

To some people, the term "World Wide Web" is synonymous with "Internet," but others define it as a graphical interface for using many parts of the Internet. The World Wide Web has become one of the best known and most used aspects of the Internet.

The Internet itself began as an experiment created by the Advanced Research Projects Agency of the U.S. Department of Defense (DoD) in the 1960s. It was a network called ARPANET (Advanced Research Projects Agency Network). The first networked computers of ARPANET were connected in 1965; a low-speed telephone line brought together a computer in California and another in Massachusetts. As it grew, ARPANET connected DoD sites with university research facilities worldwide, but not in a linear way. The connections were made so that if several of them were broken, many sites would still be in full contact with one another. The non-linear connections reminded people of a web, and that is where some people believe that the name World Wide Web originated.

MOSAIC

Mosaic was the first popular graphical World Wide Web browser. It was released on the Internet in early 1993 by the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign. Mosaic is distinguished from other early web browsers by its ease of use and the addition of inline image to web documents.

In 1972 ARPANET was given its first public demonstration at an International Conference on Computer Communications. It was still primarily an entity within the domain of the DoD and its university research partners. During the next decade, however, the corporate world began to enter the networked computer world. In 1979 CompuServe was the first service to offer electronic mail communication. By 1985, the Internet was heavily used to support communications among researchers and technology developers in a variety of academic and corporate fields.

Once people outside of the original group of users obtained access, this network began linking with other networks and the Internet began its fast growth. Soon software was developed that took advantage of "clickable buttons" and non-linear connections. This software was written in code called **Hypertext Markup Language (HTML)**. It allowed users to move from place to place on the web without having to follow a set path, and without having to type in strings of text commands as they previously had to do.

Hypertext Markup Language (HTML) an encoding scheme for text data that uses special tags in the text to signify properties to the viewing program (browser) like links to other documents or document parts

graphical user interface (GUI) an interface that allows computers to be operated through pictures (icons) and mouse-clicks, rather than through text and typing

In 1990 Tim Berners-Lee wrote the first **graphical user interface (GUI)** browser program for the Internet. He called it "WorldWideWeb," although the name was later changed to Nexus, to avoid confusing the program itself with the larger entity that became known as the World Wide Web.

By October 1993, there were at least 200 known HTTP (Hypertext Transfer Protocol) servers on the web, and the Mosaic browser had been released for all common computer platforms, including PC/Windows and Macintosh computers. America Online, which was first available to

Macintosh and Apple II users in 1989, launched a Windows-based online service and reached 500,000 subscribers by the end of 1993.

The next year, Marc Andreessen, who was one of the developers of the Mosaic browser, formed the company that would become known as Netscape, which is also the name of the company's popular web browser. Also in 1994, Stanford University Ph.D. candidates David Filo and Jerry Yang began compiling an online guide to interesting sites on the Internet. Once known as *Jerry's Guide to the World Wide Web*, the list was renamed *Yahoo!* What started as a hobby turned into a rapidly growing business by the following year.

Popular web browser packages include Netscape Navigator and Microsoft Internet Explorer; online service providers also offer proprietary packages that include browsers and search capabilities. Since new sites are added to the World Wide Web almost by the minute, search engines are widely used to seek out sites that match the needs of **web surfers**. Search engines use a variety of ways to categorize information, depending on the engine. Many offer keyword searches and use **Boolean operators** to make searches effective. Among the most popular search engines are names such as Yahoo!, Google, AltaVista, and Lycos. Metasearch sites, such as CNet's search.com and others, combine the resources of multiple search engines to answer a user's query for information.

The World Wide Web has influenced our society in major ways. Businesses, individuals, schools, non-profit organizations, even churches, use web

YAHOO!

David Filo and Jerry Yang developed the first online navigational guide to the Internet while attending Stanford University. They originally called it *Jerry's Guide to the World Wide Web.* The two students developed a means to bookmark and categorize their favorite web sites. Today, Yahoo!, an acronym for *Yet Another Hierarchical Officious Oracle,* provides custom searching to nearly 220 million people each month.

web surfers people who "surf" (search) the Internet frequently

Boolean operators fundamental logical operations (for example "and" and "or") expressed in a mathematical form

The Internet has made communicating with family, friends, and business partners as easy as sending an e-mail, or, in this case, as easy as dialing up a web phone.

sites to offer information to anyone who wants it. Classes and courses are offered via the Internet, and people can use the World Wide Web to keep in touch with family who are away from home, via e-mail or personal web pages, and meet new friends in countries they have never visited. It is now nearly impossible to have any contact with books, magazines, television, or radio and not be offered a web address, also known as a **Uniform Resource Locator (URL),** to visit.

Uniform Resource Locator (URL) a reference to a document or a document container using the Hyper Text Transfer Protocol; consisting of a hostname and path to the document

Widespread access to the Internet and the World Wide Web has created new issues in the areas of ethics, economics, privacy, and protection of individual rights. In many schools and public libraries, debate continues over whether and how to restrict access to certain types of web sites. The ease of sharing and reusing graphics, text, and music files has led to concerns about copyright and protecting the rights of the creators of music, video, photographs, graphic art, and original documents. The cost of providing, maintaining, and updating online resources has also resulted in controversy about free access vs. paid subscriptions. As a medium for information, education, entertainment, and commerce, the World Wide Web is still in its early stages. SEE ALSO Browsers; Hypermedia and Multimedia; Hypertext; Internet; Networks; Search Engines.

Shirley Campbell

Internet Resources

"A Brief History of the Internet." *Internet Society (ISOC).* <http://www.isoc.org/internet-history/brief.html>

"A Little History of the World Wide Web From 1945–1995." *The World Wide Web Consortium.* <http://www.w3.org/History.html>

Xerox Corporation

The roots of Xerox Corporation and its history of innovation started growing back in 1938. In October of that year, patent attorney Chester Carlson (1906–1968) invented the first xerographic image. Carlson believed that the world needed an easier and cheaper way to make copies of important documents. Previously, carbon paper, printing presses, or retyping were required to create a document copy.

However, it took nearly ten long years before Carlson could find a company that would develop his invention into a useful product. The Haloid Company, a small photo-paper maker in Rochester, New York, took on the challenge and promise of xerography. In 1949 Haloid introduced its first xerographic machine. Slow and messy, it required several steps to produce a decent copy—but it worked.

INSIDE THE COPIER

Xerography, invented by Chester Carlson, began the copying revolution. In xerography, an original image is transferred when light is projected onto an electrically charged surface. The image attracts oppositely charged toner particles, which are then fused into place on the copy paper, reproducing the original image.

Birth of the Office Copier

Not until 1959, twenty-one years after Carlson invented xerography, was the first convenient plain-paper office copier unveiled. By that time, Haloid had changed its name to Haloid Xerox Inc. The Xerox 914 copier—so named because it could copy pages up to nine by fourteen inches—could make copies quickly at the touch of a button. It was a phenomenal success! By 1962, some 10,000 copiers had been shipped. By 1963, Xerox Corporation

Chester F. Carlson created the first Xerox copier, eventually making carbon copies obsolete.

had dropped the "Haloid" and had grown to a $22.5 million company, up from $2 million just four years earlier.

Xerox Corporation's inventive researchers and engineers went on to develop hundreds of industry-leading hardware and software products after the Xerox 914. By 2000 Xerox had become a $19 billion company selling document management equipment at almost every price and speed, including color and black-and-white digital copiers, network printers, fax machines, multifunction devices, and software.

That first plain-paper office copier truly revolutionized the office—not only replacing carbon paper but also changing the way people used documents to communicate. Xerox's growing body of knowledge about office processes, as well as expertise in engineering, manufacturing, and technology, made Xerox the perfect breeding ground for new ideas about how to make the office—and office workers—operate better.

THE XEROX ALTO

One of the world's first personal computers, the Xerox Alto, was born in 1973. The Alto was a prototype workstation, not an actual product that Xerox launched. But its development and technologies helped create the personal computer industry.

graphical user interface (GUI) an interface that allows computers to be operated through pictures (icons) and mouse-clicks, rather than through text and typing

smart matter materials, machines, and systems whose physical properties depend on the computing that is embedded within them

From Copiers to Computers

In 1970 Xerox gathered a team of world-class researchers to study the way that information was created, transported, and shared. Their mission was to create "the architecture of information." The scientists of the new Palo Alto Research Center (PARC) in Palo Alto, California, were encouraged to dream, invent, and discover, as well as to push the outer limits of current technology. At the time, computers were still room-sized devices that only the most expert computer programmers could manage. But the PARC scientists' vision was to create simpler computers that could help people work together even more powerfully than a copier could.

By 1973 pioneering PARC researchers had changed the course of the computer industry and developed the world's first personal computer, known as the Alto. The Alto embodied several PARC innovations, including a **graphical user interface (GUI)**, what-you-see-is-what-you-get (WYSIWYG) editing, overlapping "windows," and the first commercial mouse, so users could point-and-click their way through tasks. All of these features are standard components in Apple Macintosh and Microsoft Windows-based personal computers today.

PARC scientists also recognized a far more powerful role for computers to play. They networked, or connected, Altos via another PARC invention, the Ethernet, to further enhance people's ability to interact. Ethernet ultimately became a global standard for interconnecting computers on local area networks.

PARC also invented the laser printer, which was a natural extension of Xerox's expertise in putting marks onto paper. Laser printers allowed users of the Alto—and users of its successor, the Star, launched commercially in 1981—to simplify putting an exact copy of what they saw on their computer screens onto paper.

These, and dozens of other pioneering technologies from PARC, fundamentally changed the office—and the world. Xerox did not fully commercialize its personal computer technologies because at the time, the corporation remained focused on the core business from which it started: copiers. Instead, companies such as Apple Computer, Microsoft, and other Silicon Valley start-ups visited Xerox PARC's labs, licensed or replicated the technologies, and applied them to their own products and businesses.

Xerox's innovation continues through its research centers today, and PARC is widely regarded as one of the top corporate research facilities in the world. PARC scientists aggressively create new ways to manage electronic documents, inventing better tools for tapping the resources of the World Wide Web, building knowledge into **smart matter**, and researching how people create and manage electronic and paper information. Although the personal computer revolution is largely past, Xerox PARC remains part of the continuing evolution of computing technology for the future. SEE ALSO Apple Computer, Inc.; Bell Labs; Intel Corporation; Microsoft Corporation; National Aeronautics and Space Administration (NASA).

Kara K. Choquette

Bibliography

Brown, John Seely, and Paul Duguid. *The Social Life of Information*. Boston: Harvard Business School Press, 2000.

Kearns, David T., and David A. Nadler. *Prophets in the Dark*. New York: Harper-Collins, 1992.

Smith, Douglas K., and Robert C. Alexander. *Fumbling the Future*. New York: William Morrow, 1988.

Internet Resources

Xerox Palo Alto Research Center. <http://www.parc.xerox.com>

Xerox Corporation. <http://www.xerox.com>

Photo and Illustration Credits

The illustrations and tables featured in Computer Sciences *were created by GGS Information Services. The photographs appearing in the text were reproduced by permission of the following sources:*

Volume 1

Gale Research: **1**; AP/Wide World Photos, Inc.: **4, 35, 39, 44, 60, 82, 91, 136, 148, 190, 209, 219**; Courtesy of the Library of Congress: **6, 25, 52, 58, 83, 98, 103, 126, 150, 193, 211**; Kobal Collection/Warner Bros.: **9**; Kobal Collection: **11**; Archive Photos/Reuters/Sell: **16**; National Audubon Society Collection/Photo Researchers, Inc.: **19**; CORBIS/Bettmann: **22, 41, 73, 86, 165, 201, 221**; AT&T Archives: **28**; U.S. Census Bureau: **33**; Elena Rooraid/Photo Edit: **48**; Photo Edit: **66**; IBM Corporate Archives: **70, 163**; Colin Braley/Reuters/Getty Images: **94**; Adam Hart-Davis/National Audubon Society Collection/Photo Researchers, Inc.: **105**; Michael S. Yamashita/CORBIS: **110**; Reuters NewMedia Inc./CORBIS: **116**; UPI/CORBIS-Bettmann: **118, 176**; Associated Press/AP: **121**; Doris Langley Moore Collection: **122**; Astrid & Hanns-Frieder Michler/Photo Researchers, Inc.: **133**; Microsoft Corporation: **139**; Ted Spiegel/CORBIS: **140**; Prestige/Getty Images: **143**; Richard T. Nowitz/CORBIS: **146**; U.S. National Aeronautics and Space Administration (NASA): **152**; Robert Cattan/Index Stock Imagery/PictureQuest: **156**; Dave Bartruff/Stock, Boston Inc./PictureQuest: **159**; Courtesy Carnegie Mellon University Field Robotics Center/NASA: **172**; Roger Ressmeyer/CORBIS: **179, 184**; Hulton-Deutsch Collection/CORBIS: **187**; Granger Collection, Ltd.: **197**; Larry Chan/Reuters/Getty Images: **204**; Microsoft programs: 213, 214, 215, 216, 217.

Volume 2

Thomas E. Kurtz: **2**; Courtesy of the Library of Congress: **4, 18, 99, 112**; CORBIS/Bettmann: **13**; U.S. National Aeronautics and Space Administration (NASA): **16**; Roger Ressmeyer/CORBIS: **25, 92, 115, 118, 150, 179, 215**; A/P Wide World Photos, Inc.: **31, 36, 40, 65, 73, 89, 110, 133, 136, 143, 161, 165, 167, 171, 199, 205, 212, 221**; UPI/CORBIS-Bettmann: **34, 169, 217, 219**; Courtesy of BT Archives: **46**; CORBIS: **53**; Andrew Syred/National Audubon Society Collection/Photo Researchers, Inc.: **62**; Richard Pasley/Stock, Boston Inc./PictureQuest: **70**; Bob Krist/CORBIS: **77**; Patrik Giardino/CORBIS: **79**; Rob Crandall/Stock, Boston Inc./PictureQuest: **84**; Mario Tama/Getty Images: **94**; AFP/CORBIS: **98**; Custom Medical Stock Photo: **140**; William McCoy/Rainbow/PictureQuest: **147**; Courtesy of Niklaus Wirth: **157**; Reuters NewMedia Inc./CORBIS: **175**; Paul Almasy/CORBIS: **188**; Detlev Van Ravenswaay/Picture Press/CORBIS-Bettmann: **193**; James Marshall/CORBIS: **203**.

Volume 3

Bill Lai/Rainbow/PictureQuest: **2**; Agricultural Research Service/USDA: **5**; Carlos Lopez-Barillas/Getty Images: **8**; A/P Wide World Photos, Inc.: **11, 19, 28, 39, 89, 102, 106, 111, 118, 131**; Laima Druskis/Stock, Boston Inc./PictureQuest: **13**; Bojan Brecelj/CORBIS: **17**; JLM Visuals: **23**; Mediafocus: **24**; Ed Kashi/Phototake NYC: **30**; Reuters NewMedia Inc./CORBIS: **34**; Royalty Free/CORBIS: **42**; Srulik Haramaty/Phototake NYC: **46**; Mark

Antman/Phototake, NYC: **52**; CORBIS/Bettmann: **55, 206, 211**; Hulton-Deutsch Collection/CORBIS: **56**; Walter A. Lyons: **60, 210**; Smith & Santori/Gale Group: **62**; Darren McCollester/Getty Images: **69**; Richard Palsey/Stock, Boston Inc./PictureQuest: **73**; Ed Kashi/CORBIS: **79**; Index Stock Imagery: **81**; AFP/CORBIS: **85**; Montes De Oca & Associates: **92**; Millard Berry: **95**; Courtesy of NASA/JPL/NIMA/Visible Earth: **100**; Courtesy of the Library of Congress: **108, 124**; Nehau Kulyk/Photo Researchers, Inc.: **116**; CORBIS: **122**; U.S. Department of Education/National Audubon Society Collection/Photo Researchers, Inc.: **125**; Bob Rowan/Progressive Image/CORBIS: **133**; Bill Ross/CORBIS: **137**; Geoff Tompkincon/National Audubon Society Collection/Photo Researchers, Inc.: **141**; Clive Freeman/Photo Researchers, Inc.: **143**; Roger Ressmeyer/CORBIS: **150**; Free Software Foundation: **157**; Kenneth Eward/BioGrafx/National Audubon Society Collection/Photo Researchers, Inc.: **163**; Steven McBride/Picturesque/PictureQuest: **168**; Michael S. Yamashita/CORBIS: **175**; Photo Researchers, Inc.: **178**; Chris Hondros/Getty Images: **181**; David Silverman/Getty Images: **183**; U.S. National Aeronautics and Space Administration (NASA): **188**; Jim Sugar Photography/CORBIS: **200**; Leif Skoogfors/CORBIS: **205**.

Volume 4

A/P Wide World Photos, Inc.: **2, 15, 23, 29, 33, 41, 44, 59, 75, 100, 147, 151, 162, 168, 177, 180, 184, 186, 190, 195, 197, 201, 203**; Gene M. Amdahl: **4**; Vittoriano Rastelli/CORBIS: **7**; Jim Sugar Photography/CORBIS: **10**; NNS: **22**; John Maher/Stock, Boston Inc./PictureQuest: **26**; Kenneth Eward/Photo Researchers, Inc.: **35**; Steve Chenn/CORBIS: **47**; Christopher Morris/Black Star Publishing/PictureQuest: **50**; Jonathan Elderfield/Getty Images: **54**; Courtesy of the Library of Congress: **56, 103, 163**; Amy Ritterbush/Stock, Boston Inc./PictureQuest: **64**; AFP/CORBIS: **66, 113, 125, 131, 134**; Reuters NewMedia Inc./CORBIS: **70, 89, 108, 120, 194**; Shahn Kermani/Getty Images: **76**; Associated Press/AP: **78, 93, 95**; Patricia Nagle/Center for Instructional Development and Distance Education/University of Pittsburgh: **85**; Alec Sarkas/Center for Instructional Development and Distance Education/University of Pittsburgh: **87**; Kobal Collection/MGM/UA: **106**; Space Imaging: **115**; Courtesy of USGS Landsat 7 Team at the Eros Data Center and NASA's Visible Earth: **116**; Reuters/News and Observer-Jim/Archive Photos, Inc.: **122**; Reuters/Getty Images: **128**; Oleg Nikishin/Getty Images: **139**; Netscape Communicator browser window (c) 1999 Netscape Communications Corporation—used with permission (Netscape Communications has not authorized, sponsored, endorsed, or approved this publication and is not responsible for its content): **155, 156, 157, 159**; YBSHY/CORBIS: **165**; James King-Holmes/Science Photo Library/The National Audubon Society Collection/Photo Researchers, Inc.: **171**; Carnegie Mellon University: **173**; Microsoft Visual Basic program: 209, 210, 211.

Glossary

abacus: an ancient counting device that probably originated in Babylon around 2,400 B.C.E.

acuity: sharpness or keenness, especially when used to describe vision

address bus: a collection of electrical signals used to transmit the address of a memory location or input/output port in a computer

aerodynamics: the science and engineering of systems that are capable of flight

agents: systems (software programs and/or computing machines) that can act on behalf of another, or on behalf of a human

aggregate: a numerical summation of multiple individual scores

ailerons: control surfaces on the trailing edges of the wings of an aircraft—used to manage roll control

ALGOL: a language developed by the ALGOL committee for scientific applications—acronym for ALGOrithmic Language

algorithm: a rule or procedure used to solve a mathematical problem—most often described as a sequence of steps

all-points-addressable mode: a technique for organizing graphics devices where all points (pixels) on the screen are individually accessible to a running program

alpha beta pruning: a technique that under certain conditions offers an optimal way to search through data structures called "trees"

alphanumeric: a character set which is the union of the set of alphabetic characters and the set of single digit numbers

ambient: pertaining to the surrounding atmosphere or environment

ambiguity: the quality of doubtfulness or uncertainty; often subject to multiple interpretations

amortized: phasing out something in until it is gradually extinguished, like a mortgage loan

amplitude: the size or magnitude of an electrical signal

analog: a quantity (often an electrical signal) that is continuous in time and amplitude

analogous: a relationship of logical similarity between two or more objects

analytic simulation: modeling of systems by using mathematical equations (often differential equations) and programming a computer with them to simulate the behavior of the real system

Analytical Engine: Charles Babbage's vision of a programmable mechanical computer

animatronics: the animation (movement) of something by the use of electronic motors, drives, and controls

anthropomorphic: having human form, or generally resembling human appearance

anti-aliasing: introducing shades of gray or other intermediate shades around an image to make the edge appear to be smoother

applet: a program component that requires extra support at run time from a browser or run-time environment in order to execute

approximation: an estimate

arc tangent: the circular trigonometric function that is the inverse of the tangent function; values range from $-\Pi/2$ to $\Pi/2$

artificial intelligence (AI): a branch of computer science dealing with creating computer hardware and software to mimic the way people think and perform practical tasks

ASCII: an acronym that stands for American Standard Code for Information Interchange; assigns a unique 8-bit binary number to every letter of the alphabet, the digits (0 to 9), and most keyboard symbols

assembler: a program that translates human-readable assembly language programs to machine-readable instructions

assembly language: the natural language of a central processing unit (CPU); often classed as a low-level language

asynchronous: events that have no systematic relationship to one another in time

attenuation: the reduction in magnitude (size or amplitude) of a signal that makes a signal weaker

authentication: the act of ensuring that an object or entity is what it is intended to be

automata theory: the analytical (mathematical) treatment and study of automated systems

automaton: an object or being that has a behavior that can be modeled or explained completely by using automata theory

autonomous: self governing, or being able to exist independently

autonomy: the capability of acting in a self-governing manner; being able to exist independently or with some degree of independence

axioms: statements that are taken to be true, the foundation of a theory

Bakelite: an insulating material used in synthetic goods, including plastics and resins

ballistics: the science and engineering of the motion of projectiles of various types, including bullets, bombs, and rockets

bandwidth: a measure of the frequency component of a signal or the capacity of a communication channel to carry signals

bar code: a graphical number representation system where alphanumeric characters are represented by vertical black and white lines of varying width

base-2: a number system in which each place represents a power of 2 larger than the place to its right (binary)

base-8: a number system in which each place represents a power of 8 larger than the place to its right (octal)

base-10: a number system in which each place represents a power of 10 larger than the place to its right (decimal)

base-16: a number system in which each place represents a power of 16 larger than the place to its right (hexadecimal)

batch processing: an approach to computer utilization that queues noninteractive programs and runs them one after another

Bayesian networks: structures that describe systems in which there is a degree of uncertainty; used in automated decision making

Bernoulli numbers: the sums of powers of consecutive integers; named after Swiss mathematician Jacques Bernoulli (1654-1705)

binary: existing in only two states, such as "on" or "off," "one" or "zero"

binary code: a representation of information that permits only two states, such as "on" or "off," "one" or "zero"

binary coded decimal (BCD): an ANSI/ISO standard encoding of the digits 0 to 9 using 4 binary bits; the encoding only uses 10 of the available 16 4-bit combinations

binary digit: a single bit, 1 or 0

binary number system: a number system in which each place represents a power of 2 larger than the place on its right (base-2)

binary system: a machine or abstraction that uses binary codes

binomial theorem: a theorem giving the procedure by which a binomial expression may be raised to any power without using successive multiplications

bit: a single binary digit, 1 or 0—a contraction of Binary digIT; the smallest unit for storing data in a computer

bit mapped display: a computer display that uses a table of binary bits in memory to represent the image that is projected onto the screen

bit maps: images comprised of bit descriptions of the image, in black and white or color, such that the colors can be represented by the two values of a binary bit

bit rate: the rate at which binary bits can be processed or transferred per unit time, in a system (often a computer communications system)

bit serial mode: a method of transferring binary bits one after another in a sequence or serial stream

bitstream: a serialized collection of bits; usually used in transfer of bits from one system to another

Boolean algebra: a system developed by George Boole that deals with the theorems of undefined symbols and axioms concerning those symbols

Boolean logic: a system, developed by George Boole, which treats abstract objects (such as sets or classes) as algebraic quantities; Boole applied his mathematical system to the study of classical logic

Boolean operators: fundamental logical operations (for example "and" and "or") expressed in a mathematical form

broadband access: a term given to denote high bandwidth services

browsers: programs that permits a user to view and navigate through documents, most often hypertext documents

bugs: errors in program source code

bus: a group of related signals that form an interconnecting pathway between two or more electronic devices

bus topology: a particular arrangement of buses that constitutes a designed set of pathways for information transfer within a computer

byte: a group of eight binary digits; represents a single character of text

C: a programming language developed for the UNIX operating system; it is designed to run on most machines and with most operating systems

cache: a small sample of a larger set of objects, stored in a way that makes them accessible

calculus: a method of dealing mathematically with variables that may be changing continuously with respect to each other

Callback modems: security techniques that collect telephone numbers from authorized users on calls and then dial the users to establish the connections

capacitates: fundamental electrical components used for storing electrical charges

capacitor: a fundamental electrical component used for storing an electrical charge

carpal tunnel syndrome: a repetitive stress injury that can lead to pain, numbness, tingling, and loss of muscle control in the hands and wrists

cartography: map making

cathode ray tube (CRT): a glass enclosure that projects images by directing a beam of electrons onto the back of a screen

cellular automata: a collection or array of objects that are programmed identically to interact with one another

cellular neural networks (CNN): a neural network topology that uses multidimensional array structures comprised of cells that work together in localized groups

central processing unit (CPU): the part of a computer that performs computations and controls and coordinates other parts of the computer

certificate: a unique electronic document that is used to assist authentication

chaos theory: a branch of mathematics dealing with differential equations having solutions which are very sensitive to initial conditions

checksum: a number that is derived from adding together parts of an electronic message before it is dispatched; it can be used at the receiver to check against message corruption

chromatic dispersion: the natural distortion of pulses of light as they move through an optical network; it results in data corruption

cipher: a code or encryption method

client: a program or computer often managed by a human user, that makes requests to another computer for information

client/server technology: computer systems that are structured using clients (usually human driven computers) to access information stored (often remotely) on other computers known as servers

coaxial cable: a cable with an inner conducting core, a dielectric material and an outer sheath that is designed for high frequency signal transmission

cognitive: pertaining to the concepts of knowing or perceiving

collocation: the act of placing elements or objects in a specific order

commodity: raw material or service marketed prior to being used

compiled: a program that is translated from human-readable code to binary code that a central processing unit (CPU) can understand

compiled executable code: the binary code that a central processing unit (CPU) can understand; the product of the compilation process

compilers: programs that translate human-readable high-level computer languages to machine-readable code

computer-aided design (CAD): the use of computers to replace traditional drawing instruments and tools for engineering or architectural design

computer-assisted tomography: the use of computers in assisting with the management of X-ray images

computer peripheral: a device that is connected to a computer to support its operation; for example, a keyboard or a disk drive unit

concatenates: the joining together of two elements or objects; for example, words are formed by concatenating letters

concentric circles: circles that have coincident centers

conceptualization: a creative process that is directed at envisaging a structure or collection of relationships within components of a complex system

concurrency control: the management and coordination of several actions that occur simultaneously; for example, several computer programs running at once

concurrent: pertaining to simultaneous activities, for example simultaneous execution of many computer programs

configuration files: special disk files containing information that can be used to tell running programs about system settings

cookie: a small text file that a web site can place on a computer's hard drive to collect information about a user's browsing activities or to activate an online shopping cart to keep track of purchases

copyrights: the legal rules and regulations concerning the copying and redistribution of documents

cosine: a trigonometric function of an angle, defined as the ratio of the length of the adjacent side of a right-angled triangle divided by the length of its hypotenuse

counterfeiting: the act of knowingly producing non-genuine objects, especially in relation to currency

crawls: severe weather warnings that are broadcast on the bottom of TV screens

cross-platform: pertaining to a program that can run on many different computer types (often called hardware platforms)

CRT: the acronym for cathode ray tube, which is a glass enclosure that projects images by directing a beam of electrons onto the back of a screen

cryptanalysis: the act of attempting to discover the algorithm used to encrypt a message

cryptanalyst: a person or agent who attempts to discover the algorithm used to encrypt a message

cryptography: the science of understanding codes and ciphers and their application

cryptosystem: a system or mechanism that is used to automate the processes of encryption and decryption

cuneiform: in the shape of a wedge

cybercafe: a shop, cafe, or meeting place where users can rent a computer for a short time to access the Internet

cybernetics: a unified approach to understanding the behavior of machines and animals developed by Norbert Wiener (1894-1964)

cycloids: pertaining to circles, in either a static way or in a way that involves movement

dark fiber: a fiber optic network that exists but is not actively in service, hence the darkness

data mining: a technique of automatically obtaining information from databases that is normally hidden or not obvious

data partitioning: a technique applied to databases (but not restricted to them) which organizes data objects into related groups

data reduction technique: an approach to simplifying data, e.g. summarization

data warehousing: to implement an informational database used to store shared data

de facto: as is

de jure: strictly according to the law

debug: the act of trying to trace, identify, and then remove errors in program source code

decimal system: a number system in which each place represents a power of 10 larger than the place to its right (base-10)

decision trees: classifiers in which a sequence of tests are made to decide the class label to assign to an unknown data item; the sequence of tests can be visualized as having a tree structure

deformations: mechanical systems where a structure is physically misshapen, e.g., dented

degrade: to reduce quality or performance of a system

delimiters: special symbols that mark the beginnings and/or endings of other groups of symbols (for example to mark out comments in program source code)

demographics: the study of the statistical data pertaining to a population

densities: measures of the density of a material; defined as the mass of a sample of material, divided by its volume

deregulation: the lowering of restrictions, rules, or regulations pertaining to an activity or operation (often commercial)

die: the silicon chip that is the heart of integrated circuit fabrication; the die is encased in a ceramic or plastic package to make the completed integrated circuit (IC)

dielectric: a material that exhibits insulating properties, as opposed to conducting properties

Difference Engine: a mechanical calculator designed by Charles Babbage that automated the production of mathematical tables by using the method of differences

differential analyzer: a computer constructed in the early 1930s by Vannevar Bush at Massachusetts Institute of Technology (MIT); it solved differential equations by mechanical integration

digital: a quantity that can exist only at distinct levels, not having values in between these levels (for example, binary)

digital certificates: certificates used in authentication that contain encrypted digital identification information

digital divide: imaginary line separating those who can access digital information from those who cannot

digital library: distributed access to collections of digital information

digital signature: identifier used to authenticate the sender of an electronic message or the signer of an electronic document

digital subscriber line (DSL): a technology that permits high-speed voice and data communications over public telephone networks; it requires the use of a DSL modem

digital subscriber loop (DSL): the enabling of high-speed digital data transfer over standard telephone cables and systems in conjunction with normal telephone speech data

digital watermarks: special data structures permanently embedded into a program or other file type, which contain information about the author and the program

digitizes: converts analog information into a digital form for processing by a computer

diode: a semiconductor device that forces current flow in a conductor to be in one direction only, also known as a rectifier

diode tube: an obsolete form of diode that was made of metal elements in a sealed and evacuated glass tube

direction buttons: buttons on a program with a graphical user interface that provide a way of navigating through information or documents

discrete: composed of distinct elements

disintermediation: a change in business practice whereby consumers elect to cut out intermediary agencies and deal directly with a provider or vendor

distance learning: the form of education where the instructor and students are separated by either location or time (or both), usually mediated by some electronic communication mechanism

distributed denial of service (DDoS): an attack in which large numbers of messages are directed to send network traffic to a target computer, overloading it or its network connection; typically, the attacking computers have been subverted

distributed systems: computer systems comprised of many individual computers that are interconnected and act in concert to complete operations

documentation: literature in a human-readable form that is referred to in support of using a computer or computer system

domain: a region in which a particular element or object exists or has influence; (math) the inputs to a function or relation

doping: a step used in the production of semiconductor materials where charged particles are embedded into the device so as to tailor its operational characteristics

dot.com: a common term used to describe an Internet-based commercial company or organization

dragged: to have been moved by the application of an external pulling force; quite often occurring in graphical user interfaces when objects are moved with a mouse

DRAM: the acronym for Dynamic Random Access Memory; high density, low cost and low speed memory devices used in most computer systems

driver: a special program that manages the sequential execution of several other programs; a part of an operating system that handles input/output devices

drop-down menu: a menu on a program with a graphical user interface that produces a vertical list of items when activated

dumb terminal: a keyboard and screen connected to a distant computer without any processing capability

duplex: simultaneous two-directional communication over a single communication channel

dynamic: changing; possessing volatility

dynamic links: logical connections between two objects that can be modified if the objects themselves move or change state

e-books: short for electronic books; books available for downloading onto an e-book reader

EBCDIC: the acronym for Extended Binary Coded Decimal Interchange Code, which assigns a unique 8-bit binary number to every letter of the alphabet, the digits (0-9), and most keyboard symbols

egress: to move out of an object, system, or environment

electromagnetic: a piece of metal that becomes magnetic only when electricity is applied to it; in general, the more electricity applied to metal, the stronger its magnetism

electromagnetic relays: switches that have a high current carrying capacity, which are opened and closed by an electromagnet

electromagnetic spectrum: a range of frequencies over which electromagnetic radiation can be generated, transmitted, and received

embedded computers: computers that do not have human user orientated I/O devices; they are directly contained within other machines

embedded systems: another term for "embedded computers"; computers that do not have human user orientated input/output devices; they are directly contained within other machines

emoticons: symbols or key combinations used in electronic correspondence to convey emotions

enciphered: encrypted or encoded; a mathematical process that disguises the content of messages transmitted

encryption: also known as encoding; a mathematical process that disguises the content of messages transmitted

end-effector: the end piece of a robotic arm that can receive various types of grippers and tools

end users: computer users

enterprise information system: a system of client and server computers that can be used to manage all of the tasks required to manage and run a large organization

entropy: a measure of the state of disorder or randomness in a system

ephemeris: a record showing positions of astronomical objects and artificial satellites in a time-ordered sequence

ergonomic: being of suitable geometry and structure to permit effective or optimal human user interaction with machines

esoteric: relating to a specialized field of endeavor that is characterized by its restricted size

ether: a highly volatile liquid solvent; also, the far regions of outer space

ethernets: a networking technology for mini and microcomputer systems consisting of network interface cards and interconnecting coaxial cables; invented in the 1970s by Xerox Corporation

Euclidean geometry: the study of points, lines, angles, polygons, and curves confined to a plane

expert system: a computer system that uses a collection of rules to exhibit behavior which mimics the behavior of a human expert in some area

fiber optics: transmission technology using long, thin strands of glass fiber; internal reflections in the fiber assure that light entering one end is transmitted to the other end with only small losses in intensity; used widely in transmitting digital information

field searching: a strategy in which a search is limited to a particular field; in a search engine, a search may be limited to a particular domain name or date, narrowing the scope of searchable items and helping to eliminate the chance of retrieving irrelevant data

file transfer protocol (FTP): a communications protocol used to transfer files

filter queries: queries used to select subsets from a data collection, e.g., all documents with a creation date later than 01/01/2000

firewall: a special purpose network computer or software that is used to ensure that no access is permitted to a sub-network unless authenticated and authorized

firing tables: precalculated tables that can give an artillery gunner the correct allowances for wind conditions and distance by dictating the elevation and deflection of a gun

floating point operations: numerical operations involving real numbers where in achieving a result, the number of digits to the left or right of the decimal point can change

flowcharts: techniques for graphically describing the sequencing and structure of program source code

fluid dynamics: the science and engineering of the motion of gases and liquids

Freedom of Information Act (FOIA): permits individuals to gain access to records and documents that are in the possession of the government

freon: hydrocarbon-based gases used as refrigerants and as pressurants in aerosols

frequency bands: ranges of signal frequencies that are of particular interest in a given application

frequency modulation: a technique whereby a signal is transformed so that it is represented by another signal with a frequency that varies in a way related to the original signal

full-text indexing: a search engine feature in which every word in a document, significant or insignificant, is indexed and retrievable through a search

fuzzy logic: models human reasoning by permitting elements to have partial membership to a set; derived from fuzzy set theory

gallium arsenide: a chemical used in the production of semiconductor devices; chemical symbol GaAs

gates: fundamental building blocks of digital and computer-based electric circuits that perform logical operations; for example logical AND, logical OR

Gaussian classifiers: classifiers constructed on the assumption that the feature values of data will follow a Gaussian distribution

gbps: acronym for gigabits per second; a binary data transfer rate that corresponds to a thousand million (billion, or 109) bits per second

geometric: relating to the principles of geometry, a branch of mathematics related to the properties and relationships of points, lines, angles, surfaces, planes, and solids

germanium: a chemical often used as a high performance semiconductor material; chemical symbol Ge

GIF animation: a technique using Graphic Interchange Format where many images are overlaid on one another and cycled through a sequence to produce an animation

GIF image: the acronym for Graphic Interchange Format where a static image is represented by binary bits in a data file

gigabit networking: the construction and use of a computer network that is capable of transferring information at rates in the gigahertz range

gigabytes: units of measure equivalent to a thousand million (billion, or 109) bytes

gigahertz (GHz): a unit or measure of frequency, equivalent to a thousand million (billion, or 109) hertz, or cycles per second

Global Positioning System (GPS): a method of locating a point on the Earth's surface that uses received signals transmitted from satellites to calculate position accurately

granularity: a description of the level of precision that can be achieved in making measurements of a quantity; for example coarse granularity means inexpensive but imprecise measurements

graphical user interface (GUI): an interface that allows computers to be operated through pictures (icons) and mouse-clicks, rather than through text and typing

groupware: a software technology common in client/server systems whereby many users can access and process data at the same time

gyros: a contraction of gyroscopes; a mechanical device that uses one or more spinning discs which resist changes to their position in space

half tones: black and white dots of certain sizes, which provide a perception of shades of gray

ham radio: a legal (or licensed) amateur radio

haptic: pertaining to the sense of touch

Harvard Cyclotron: a specialized machine (cyclotron) developed in 1948 at Harvard University; it is used to carry out experiments in sub-atomic physics and medicine

head-mounted displays (HMD): helmets worn by a virtual reality (VR) participant that include speakers and screens for each eye, which display three-dimensional images

hertz (Hz): a unit of measurement of frequency, equal to one cycle per second; named in honor of German physicist Heinrich Hertz (1857-1894)

heuristic: a procedure that serves to guide investigation but that has not been proven

hexadecimal: a number system in which each place represents a power of 16 larger than the place to its right (base-16)

high-bandwidth: a communication channel that permits many signals of differing frequencies to be transmitted simultaneously

high precision/high recall: a phenomenon that occurs during a search when all the relevant documents are retrieved with no unwanted ones

high precision/low recall: a phenomenon that occurs when a search yields a small set of hits; although each one may be highly relevant to the search topic, some relevant documents are missed

high-speed data links: digital communications systems that permit digital data to be reliably transferred at high speed

hoaxes: false claims or assertions, sometimes made unlawfully in order to extort money

holistic: looking at the entire system, rather than just its parts

hydraulic: motion being powered by a pressurized liquid (such as water or oil), supplied through tubes or pipes

hydrologic: relating to water

hyperlinks: connections between electronic documents that permit automatic browsing transfer at the point of the link

Hypertext Markup Language (HTML): an encoding scheme for text data that uses special tags in the text to signify properties to the viewing program (browser) like links to other documents or document parts

Hypertext Transfer Protocol (HTTP): a simple connectionless communications protocol developed for the electronic transfer (serving) of HTML documents

I/O: the acronym for input/output; used to describe devices that can accept input data to a computer and to other devices that can produce output

I/O devices: devices that can accept "input" data to a computer and to other devices that can produce "output"

icon: a small image that is used to signify a program or operation to a user

illiquid: lacking in liquid assets; or something that is not easily transferable into currency

ImmersaDesks: large 4 x 5 foot screens that allow for stereoscopic visualization; the 3-D computer graphics create the illusion of a virtual environment

ImmersaWalls: large-scale, flat screen visualization environments that include passive and active multi-projector displays of 3-D images

immersive: involved in something totally

in-band: pertaining to elements or objects that are within the limits of a certain local area network (LAN)

inference: a suggestion or implication of something based on other known related facts and conclusions

information theory: a branch of mathematics and engineering that deals with the encoding, transmission, reception, and decoding of information

infrared (IR) waves: radiation in a band of the electromagnetic spectrum within the infrared range

infrastructure: the foundation or permanent installation necessary for a structure or system to operate

ingot: a formed block of metal (often cast) used to facilitate bulk handling and transportation

ingress: the act of entering a system or object

init method: a special function in an object oriented program that is automatically called to initialize the elements of an object when it is created

input/output (I/O): used to describe devices that can accept input data to a computer and to other devices that can produce output

intangible: a concept to which it is difficult to apply any form of analysis; something which is not perceived by the sense of touch

integrated circuit: a circuit with the transistors, resistors, and other circuit elements etched into the surface of a single chip of semiconducting material, usually silicon

integrated modem: a modem device that is built into a computer, rather than being attached as a separate peripheral

intellectual property: the acknowledgement that an individual's creativity and innovation can be owned in the same way as physical property

interconnectivity: the ability of more than one physical computer to operate with one or more other physical computers; interconnectivity is usually accomplished by means of network wiring, cable, or telephone lines

interface: a boundary or border between two or more objects or systems; also a point of access

Internet Protocol (IP): a method of organizing information transfer between computers; the IP was specifically designed to offer low-level support to Transmission Control Protocol (TCP)

Internet Service Provider (ISP): a commercial enterprise which offers paying subscribers access to the Internet (usually via modem) for a fee

interpolation: estimating data values between known points but the values in between are not and are therefore estimated

intranet: an interconnected network of computers that operates like the Internet, but is restricted in size to a company or organization

ionosphere: a region of the upper atmosphere (above about 60,000 meters or 196,850 feet) where the air molecules are affected by the sun's radiation and influence electromagnetic wave propagation

isosceles triangle: a triangle that has two sides of equivalent length (and therefore two angles of the same size)

iterative: a procedure that involves repetitive operations before being completed

Jacquard's Loom: a weaving loom, developed by Joseph-Marie Jacquard (1752-1834), controlled by punched cards; identified as one of the earliest examples of programming automation

Java applets: applets written in the Java programming language and executed with the support of a Java Virtual Machine (JVM) or a Java enabled browser

joysticks: the main controlling levers of small aircraft; models of these can be connected to computers to facilitate playing interactive games

JPEG (Joint Photographic Experts Group): organization that developed a standard for encoding image data in a compressed format to save space

k-nearest neighbors: a classifier that assigns a class label for an unknown data item by looking at the class labels of the nearest items in the training data

Kbps: a measure of digital data transfer per unit time—one thousand (kilo, K) bits per second

keywords: words that are significant in some context or topic (often used in searching)

kilohertz (kHz): a unit or measure of frequency, equivalent to a thousand (or 103) hertz, or cycles per second

kinematics: a branch of physics and mechanical engineering that involves the study of moving bodies and particles

kinetics: a branch of physics or chemistry concerned with the rate of change in chemical or physical systems

labeled data: a data item whose class assignment is known independent of the classifier being constructed

lambda calculus: important in the development of programming languages, a specialized logic using substitutions that was developed by Alonzo Church (1903-1995)

LEDs: the acronym for Light Emitting Diode; a diode that emits light when passing a current and used as an indicating lamp

lexical analyzer: a portion of a compiler that is responsible for checking the program source code produced by a programmer for proper words and symbols

Library of Congress Classification: the scheme by which the Library of Congress organizes classes of books and documents

light emitting diode (LED): a discrete electronic component that emits visible light when permitting current to flow in a certain direction; often used as an indicating lamp

linear: pertaining to a type of system that has a relationship between its outputs and its inputs that can be graphed as a straight line

Linux operating system: an open source UNIX operating system that was originally created by Linus Torvalds in the early 1990s

liquid crystal display (LCD): a type of crystal that changes its level of transparency when subjected to an electric current; used as an output device on a computer

local area network (LAN): a high-speed computer network that is designed for users who are located near each other

logarithm: the power to which a certain number called the base is to be raised to produce a particular number

logic: a branch of philosophy and mathematics that uses provable rules to apply deductive reasoning

lossy: a nonreversible way of compressing digital images; making images take up less space by permanently removing parts that cannot be easily seen anyway

low precision/high recall: a phenomenon that occurs during a search when a large set of results are retrieved, including many relevant and irrelevant documents

lumens: a unit of measure of light intensity

magnetic tape: a way of storing programs and data from computers; tapes are generally slow and prone to deterioration over time but are inexpensive

mainframe: large computer used by businesses and government agencies to process massive amounts of data; generally faster and more powerful than desktop computers but usually requiring specialized software

malicious code: program instructions that are intended to carry out malicious or hostile actions; e.g., deleting a user's files

mammogram: an X-ray image of the breast, used to detect signs of possible cancer

Manhattan Project: the U.S. project designed to create the world's first atomic bomb

mass spectrometers: instruments that can identify elemental particles in a sample by examining the frequencies of the particles that comprise the sample

mass spectrometry: the process of identifying the compounds or elemental particles within a substance

megahertz (MHz): a unit or measure of frequency, equivalent to a million (or 106) hertz, or cycles per second

memex: a device that can be used to store personal information, notes, and records that permits managed access at high speed; a hypothetical creation of Vannevar Bush

menu label: the text or icon on a menu item in a program with a graphical user interface

metadata: data about data, such as the date and time created

meteorologists: people who have studied the science of weather and weather forecasting

metropolitan area network (MAN): a high-speed interconnected network of computers spanning entire cities

microampere: a unit of measure of electrical current that is one-millionth (10-6) amperes

microchip: a common term for a semiconductor integrated circuit device

microcomputer: a computer that is small enough to be used and managed by one person alone; often called a personal computer

microprocessor: the principle element in a computer; the component that understands how to carry out operations under the direction of the running program (CPU)

millisecond: a time measurement indicating one-thousandth (or 10-3) of a second

milliwatt: a power measurement indicating one-thousandth (or 10-3) of a watt

minicomputers: computers midway in size between a desktop computer and a mainframe computer; most modern desktops are much more powerful than the older minicomputers

minimax algorithm: an approach to developing an optimal solution to a game or contest where two opposing systems are aiming at mutually exclusive goals

Minitel: network used in France that preceded the Internet, connecting most French homes, businesses, cultural organizations, and government offices

mnemonic: a device or process that aids one's memory

modalities: classifications of the truth of a logical proposition or statement, or characteristics of an object or entity

modem: the contraction of MOdulator DEModulator; a device which converts digital signals into signals suitable for transmission over analog channels, like telephone lines

modulation: a technique whereby signals are translated to analog so that the resultant signal can be more easily transmitted and received by other elements in a communication system

modules: a generic term that is applied to small elements or components that can be used in combination to build an operational system

molecular modeling: a technique that uses high performance computer graphics to represent the structure of chemical compounds

motherboard: the part of the computer that holds vital hardware, such as the processors, memory, expansion slots, and circuitry

MPEG (Motion Picture Coding Experts Group): an encoding scheme for data files that contain motion pictures—it is lossy in the same way as JPEG (Joint Photographic Experts Group) encoding

multiplexes: operations in ATM communications whereby data cells are blended into one continuous stream at the transmitter and then separated again at the receiver

multiplexor: a complex device that acts as a multi-way switch for analog or digital signals

multitasking: the ability of a computer system to execute more than one program at the same time; also known as multiprogramming

mylar: a synthetic film, invented by the DuPont corporation, used in photographic printing and production processes, as well as disks and tapes

nanocomputing: the science and engineering of building mechanical machines at the atomic level

nanometers: one-thousand-millionth (one billionth, or 10-9) of a meter

nanosecond: one-thousand-millionth (one billionth, or 10-9) of a second

nanotechnology: the design and construction of machines at the atomic or molecular level

narrowband: a general term in communication systems pertaining to a signal that has a small collection of differing frequency components (as opposed to broadband which has many frequency components)

National Computer Security Center (NCSC): a branch of the National Security Agency responsible for evaluating secure computing systems; the Trusted Computer Systems Evaluation Criteria (TCSEC) were developed by the NCSC

Network Control Protocol (NCP): a host-to-host protocol originally developed in the early 1970s to support the Internet, which was then a research project

network packet switching: the act of routing and transferring packets (or small sections) of a carrier signal that conveys digital information

neural modeling: the mathematical study and the construction of elements that mimic the behavior of the brain cell (neuron)

neural networks: pattern recognition systems whose structure and operation are loosely inspired by analogy to neurons in the human brain

Newtonian view: an approach to the study of mechanics that obeys the rules of Newtonian physics, as opposed to relativistic mechanics; named after Sir Isaac Newton (1642-1727)

nonlinear: a system that has relationships between outputs and inputs which cannot be expressed in the form of a straight line

O-rings: 37-foot rubber circles (rings) that seal the joints between the space shuttle's rocket booster segments

OEM: the acronym for Original Equipment Manufacturer; a manufacturer of computer components

offline: the mode of operation of a computer that applies when it is completely disconnected from other computers and peripherals (like printers)

Open Systems Interconnections (OSI): a communications standard developed by the International Organization for Standardization (ISO) to facilitate compatible network systems

operands: when a computer is executing instructions in a program, the elements on which it performs the instructions are known as the operands

operating system: a set of programs which control all the hardware of a computer and provide user and device input/output functions

optical character recognition: the science and engineering of creating programs that can recognize and interpret printed characters

optical computing: a proposed computing technology which would operate on particles of light, rather than electric currents

optophone: a system that uses artificial intelligence techniques to convert images of text into audible sound

orthogonal: elements or objects that are perpendicular to one another; in a logical sense this means that changes in one have no effect on the other

oscillator: an electronic component that produces a precise waveform of a fixed known frequency; this can be used as a time base (clock) signal to other devices

oscilloscopes: measuring instruments for electrical circuitry; connected to circuits under test using probes on leads and having small screens that display the signal waveforms

out-of-band: pertaining to elements or objects that are external to the limits of a certain local area network (LAN)

overhead: the expense or cost involved in carrying out a particular operation

packet-switched network: a network based on digital communications systems whereby packets of data are dispatched to receivers based on addresses that they contain

packet-switching: an operation used in digital communications systems whereby packets (collections) of data are dispatched to receivers based on addresses contained in the packets

packets: collections of digital data elements that are part of a complete message or signal; packets contain their destination addresses to enable reassembly of the message or signal

paradigm: an example, pattern, or way of thinking

parallel debugging: specialized approaches to locating and correcting errors in computer programs that are to be executed on parallel computing machine architectures

parallel processing: the presence of more than one central processing unit (CPU) in a computer, which enables the true execution of more than one program

parametric: modeling a system using variables or parameters that can be observed to change as the system operates

parity: a method of introducing error checking on binary data by adding a redundant bit and using that to enable consistency checks

pattern recognition: a process used by some artificial-intelligence systems to identify a variety of patterns, including visual patterns, information patterns buried in a noisy signal, and word patterns imbedded in text

PDF: the acronym for Portable Document Format, developed by Adobe Corporation to facilitate the storage and transfer of electronic documents

peer-to-peer services: the ways in which computers on the same logical level can interoperate in a structured network hierarchy

permutations: significant changes or rearrangement

personal area networking: the interconnectivity of personal productivity devices like computers, mobile telephones, and personal organizers

personal digital assistants (PDA): small-scale hand-held computers that can be used in place of diaries and appointment books

phosphor: a coating applied to the back of a glass screen on a cathode ray tube (CRT) that emits light when a beam of electrons strikes its surface

photolithography: the process of transferring an image from a film to a metal surface for etching, often used in the production of printed circuit boards

photonic switching: the technology that is centered on routing and managing optical packets of digital data

photons: the smallest fundamental units of electromagnetic radiation in the visible spectrum—light

photosensitive: describes any material that will change its properties in some way if subjected to visible light, such as photographic film

picoseconds: one-millionth of a millionth of a second (one-trillionth, or 10-12)

piezoelectric crystal: an electronic component that when subjected to a current will produce a waveform signal at a precise rate, which can then be used as a clock signal in a computer

PIN (personal identification number): a password, usually numeric, used in conjunction with a cryptographic token, smart card, or bank card, to ensure that only an authorized user can activate an account governed by the token or card

ping sweeps: technique that identifies properties belonging to a server computer, by sending it collections of "ping" packets and examining the responses from the server

piracy: the unlawful copying and redistribution of computer software, ignoring the copyright and ownership rights of the publisher

pixel: a single picture element on a video screen; one of the individual dots making up a picture on a video screen or digital image

pixilation: the process of generating animation, frame by frame

plug-in: a term used to describe the way that hardware and software modules can be added to a computer system, if they possess interfaces that have been built to a documented standard

pneumatic: powered by pressurized air, supplied through tubes or pipes

polarity: the positive (+) or negative (−) state of an object, which dictates how it will react to forces such as magnetism or electricity

polarizer: a translucent sheet that permits only plane-polarized light to pass through, blocking all other light

polygon: a many-sided, closed, geometrical figure

polynomial: an expression with more than one term

polypeptide: the product of many amino acid molecules bonded together

population inversion: used in quantum mechanics to describe when the number of atoms at higher energy levels is greater than the number at lower energy levels—a condition needed for photons (light) to be emitted

port: logical input/output points on computers that exist in a network

port scans: operations whereby ports are probed so that information about their status can be collected

potentiometer: an element in an electrical circuit that resists current flow (a resistor) but the value of the resistance can be mechanically adjusted (a variable resistor)

predicate calculus: a branch of logic that uses individuals and predicates, or elements and classes, and the existential and universal quantifiers, all and some, to represent statements

privatized: to convert a service traditionally offered by a government or public agency into a service provided by a private corporation or other private entity

progenitor: the direct parent of something or someone

propositional calculus: a branch of logic that uses expressions such as "If ... then ..." to make statements and deductions

proprietary: a process or technology developed and owned by an individual or company, and not published openly

proprietary software: software created by an individual or company that is sold under a license that dictates use and distribution

protocol: an agreed understanding for the sub-operations that make up a transaction, usually found in the specification of inter-computer communications

prototype: a working model or experimental investigation of proposed systems under development

pseudocode: a language-neutral, structural description of the algorithms that are to be used in a program

public key information: certain status and identification information that pertains to a particular public key (i.e., a key available for public use in encryption)

public key infrastructure (PKI): the supporting programs and protocols that act together to enable public key encryption/decryption

punched card: a paper card with punched holes which give instructions to a computer in order to encode program instructions and data

quadtrees: data structures resembling trees, which have four branches at every node (rather than two as with a binary tree); used in the construction of complex databases

quality-of-service (QoS): a set of performance criteria that a system is designed to guarantee and support as a minimum

quantification: to quantify (or measure) something

quantum-dot cellular automata (QCA): the theory of automata as applied to quantum dot architectures, which are a proposed approach for the development of computers at nanotechnology scales

quantum mechanical: something influenced by the set of rules that govern the energy and wave behavior of subatomic particles on the scale of sizes that are comparable to the particles themselves

queue: the ordering of elements or objects such that they are processed in turn; first-in, first-out

radar: the acronym for RAdio Direction And Ranging; a technique developed in the 1930s that uses frequency shifts in reflected radio waves to measure distance and speed of a target

radio telescopes: telescopes used for astronomical observation that operate on collecting electromagnetic radiation in frequency bands above the visible spectrum

random access memory (RAM): a type of memory device that supports the nonpermanent storage of programs and data; so called because various locations can be accessed in any order (as if at random), rather than in a sequence (like a tape memory device)

raster: a line traced out by a beam of electrons as they strike a cathode ray tube (CRT)

raster scan pattern: a sequence of raster lines drawn on a cathode ray tube such that an image or text can be made to appear

read only memory (ROM): a type of memory device that supports permanent storage of programs

real-time: a system, often computer based, that ensures the rates at which it inputs, processes, and outputs information meet the timing requirements of another system

recursive: operations expressed and implemented in a way that requires them to invoke themselves

relational database: a collection of records that permits logical and business relationships to be developed between themselves and their contents

relay contact systems: systems constructed to carry out logic functions, implemented in relays (electromechanical switches) rather than semiconductor devices

resistors: electrical components that slow the flow of current

retinal scan: a scan of the retina of the eye, which contains a unique pattern for each individual, in order to identify (or authenticate) someone

robotics: the science and engineering of building electromechanical machines that aim to serve as replacements for human laborers

routers: network devices that direct packets to the next network device or to the final destination

routing: the operation that involves collecting and forwarding packets of information by way of address

satellite: an object that orbits a planet

scalar: a quantity that has magnitude (size) only; there is no associated direction or bearing

scalar processor: a processor designed for high-speed computation of scalar values

schematic: a diagrammatic representation of a system, showing logical structure without regard to physical constraints

scripting languages: modern high-level programming languages that are interpreted rather than compiled; they are usually cross-platform and support rapid application development

Secure Sockets Layer (SSL): a technology that supports encryption, authentication, and other facilities and is built into standard UNIX communication protocols (sockets over TCP/IP)

semantics: the study of how words acquire meaning and how those meanings change over time

semiconductor: solid material that possesses electrical conductivity characteristics that are similar to those of metals under certain conditions, but can also exhibit insulating qualities under other conditions

semiconductor diode laser: a diode that emits electromagnetic radiation at wavelengths above about 630 nanometers, creating a laser beam for industrial applications

sensors: devices that can record and transmit data regarding the altitude, flight path, attitude, etc., so that they can enter into the system's calculations

sequentially: operations occurring in order, one after another

server: a computer that does not deal directly with human users, but instead handles requests from other computers for services to be performed

SGML: the acronym for Standard Generalized Markup Language, an international standard for structuring electronic documents

shadow mask: a metal sheet behind the glass screen of a cathode ray tube (CRT) that ensures the correct color phosphor elements are struck by the electron beams

shareware: a software distribution technique, whereby the author shares copies of his programs at no cost, in the expectation that users will later pay a fee of some sort

Sherman Antitrust Act: the act of the U.S. Congress in 1890 that is the foundation for all American anti-monopoly laws

signaling protocols: protocols used in the management of integrated data networks that convey a mix of audio, video, and data packets

SIGs: short for "Special Interest Group," SIGs concentrate their energies on specific categories of computer science, such as programming languages or computer architecture

silica: silicon oxide; found in sand and some forms of rock

silicon: a chemical element with symbol Si; the most abundant element in the Earth's crust and the most commonly used semiconductor material

silicon chip: a common term for a semiconductor integrated circuit device

Silicon Valley: an area in California near San Francisco, which has been the home location of many of the most significant information technology orientated companies and universities

silver halide: a photosensitive product that has been used in traditional cameras to record an image

simplex: uni-directional communication over a single communication channel

simputers: simple to use computers that take on the functionality of personal computers, but are mobile and act as personal assistants and information organizers

sine wave: a wave traced by a point on the circumference of a circle when the point starts at height zero (amplitude zero) and goes through one full revolution

single-chip: a computer system that is constructed so that it contains just one integrated circuit device

slide rule: invented by Scotsman John Napier (1550-1617), it permits the mechanical automation of calculations using logarithms

smart card: a credit-card style card that has a microcomputer embedded within it; it carries more information to assist the owner or user

smart devices: devices and appliances that host an embedded computer system that offers greater control and flexibility

smart matter: materials, machines, and systems whose physical properties depend on the computing that is embedded within them

social informatics: a field of study that centers on the social aspects of computing technology

softlifting: the act of stealing software, usually for personal use (piracy)

software-defined networks (SDNs): the same as virtual private networks (VPNs), where the subscriber can set up and maintain a communications system using management software, on a public network

sonar: the science and engineering of sound propagation in water

SONET: the acronym for Synchronous Optical NETwork, a published standard for networks based on fiber optic communications technology

sound card: a plug-in card for a computer that contains hardware devices for sound processing, conversion, and generation

source code: the human-readable programs that are compiled or interpreted so that they can be executed by a computing machine

speech recognition: the science and engineering of decoding and interpreting audible speech, usually using a computer system

spider: a computer program that travels the Internet to locate web documents and FTP resources, then indexes the documents in a database, which are then searched using software that the search engine provides

spreadsheet: an accounting or business tool that details numerical data in columns for tabulation purposes

static: without movement; stationary

stellar: pertaining to the stars

subnet: a logical section of a large network that simplifies the management of machine addresses

supercomputer: a very high performance computer, usually comprised of many processors and used for modeling and simulation of complex phenomena, like meteorology

superconductivity: the property of a material to pass an electric current with almost no losses; most metals are superconductive only at temperatures near absolute zero

swap files: files used by an operating system to support a virtual memory system, in which the user appears to have access to more memory than is physically available

syllogistic statements: the essential tenets of western philosophical thought, based on hypotheses and categories

synchronization: the time domain ordering of events; often applied when events repeatedly occur simultaneously

synchronized: events occurring at specific points in time with respect to one another

synchronous: synchronized behavior

synergistic: relating to synergism, which is the phenomenon whereby the action of a group of elements is greater than their individual actions

syntactic analyzer: a part of a compiler that scans program source code ensuring that the code meets essential language rules with regard to structure or organization

syntax: a set of rules that a computing language incorporates regarding structure, punctuation, and formatting

tangible: of a nature that is real, as opposed to something that is imaginary or abstract

task partitioning: the act of dividing up work to be done so that it can be separated into distinct tasks, processes, or phases

taxonomy: the classification of elements or objects based on their characteristics

TCP: the acronym for Transmission Control Protocol; a fundamental protocol used in the networks that support the Internet (ARPANET)

TCP/IP networks: interconnected computer networks that use Transmission Control Protocol/Internet Protocol

TCP/IP protocol suite: Transmission Control Protocol/Internet Protocol; a range of functions that can be used to facilitate applications working on the Internet

telegraph: a communication channel that uses cables to convey encoded low bandwidth electrical signals

telemedicine: the technology that permits remote diagnosis and treatment of patients by a medical practitioner; usually interactive bi-directional audio and video signals

telemetry: the science of taking measurements of something and transmitting the data to a distant receiver

teleoperation: any operation that can be carried out remotely by a communications system that enables interactive audio and video signals

teletype: a machine that sends and receives telephonic signals

terabyte: one million million (one trillion, or 1012) bytes

thermal ignition: the combustion of a substance caused by heating it to the point that its particles have enough energy to commence burning without an externally applied flame

thermodynamic: relating to heat energy

three-body problem: an intractable problem in mechanics that involves the attempts to predict the behavior of three bodies under gravitational effects

thumbnail: an image which is a scaled down copy of a much larger image; used to assist in the management of a large catalog of images

time lapse mode: to show a sequence of events occurring at a higher than natural speed so it looks like it is happening rapidly rather than in real time

title bar: the top horizontal border of a rectangular region owned by a program running in a graphical user interface (GUI); it usually contains the program name and can be used to move the region around

tomography: the process of capturing and analyzing X-ray images

T1 digital circuitry: a type of digital network technology that can handle separate voice and/or digital communications lines

topographic: pertaining to the features of a terrain or surface

topology: a method of describing the structure of a system that emphasizes its logical nature rather than its physical characteristics

trademark rights: a trademark is a name, symbol, or phrase that identifies a trading organization and is owned by that organization

trafficking: transporting and selling; especially with regard to illegal merchandise

training data: data used in the creation of a classifier

transaction processing: operations between client and server computers that are made up of many small exchanges that must all be completed for the transaction to proceed

transducers: devices that sense a physical quantity, such as temperature or pressure, and convert that measurement into an electrical signal

transistor: a contraction of TRANSfer resISTOR; a semiconductor device, invented by John Bardeen, Walter Brattain, and William Shockley, which has three terminals; can be used for switching and amplifying electrical signals

translational bridges: special network devices that convert low-level protocols from one type to another

Transmission Control Protocol (TCP): a stream-orientated protocol that uses Internet Protocol (IP); it is responsible for splitting data into packets, transferring it, and reassembling it at the receiver

transmutation: the act of converting one thing into another

trigonometry: a branch of mathematics founded upon the geometry of triangles

triodes: nearly obsolete electronic devices constructed of sealed glass tubes containing metal elements in a vacuum; triodes were used to control electrical signals

Trojan horse: potentially destructive computer program that masquerades as something benign; named after the wooden horse employed by the Acheans to conquer Troy

tunneling: a way of handling different communication protocols, by taking packets of a foreign protocol and changing them so that they appear to be a locally known type

Turing machine: a proposed type of computing machine that takes inputs off paper tape and then moves through a sequence of states under the control of an algorithm; identified by Alan Turing (1912-1954)

1200-baud: a measure of data transmission; in this case the rate of 1200 symbols (usually bits) per second

twisted pair: an inexpensive, medium bandwidth communication channel commonly used in local area networks

ubiquitous: to be commonly available everywhere

ultrasonic: the transmission and reception of sound waves that are at frequencies higher than those audible to humans

Uniform Resource Locator (URL): a reference to a document or a document container using the Hypertext Transfer Protocol (HTTP); consists of a hostname and path to the document

Universal Product Code (UPC): the first barcode standard developed in 1973 and adopted widely since

UNIX: operating system that was originally developed at Bell Laboratories in the early 1970s

uplinks: connections from a client machine to a large network; frequently used when information is being sent to a communications satellite

vacuum tube: an electronic device constructed of a sealed glass tube containing metal elements in a vacuum; used to control electrical signals

valence: a measure of the reactive nature of a chemical element or compound in relation to hydrogen

variable: a symbol, such as a string of letters, which may assume any one of a set of values known as the domain

vector graphics: graphics output systems whereby pairs of coordinates are passed to the graphics controller, which are interpreted as end points of vectors to be drawn on the screen

vector processing: an approach to computing machine architecture that involves the manipulation of vectors (sequences of numbers) in single steps, rather than one number at a time

vector supercomputer: a highly optimized computing machine that provides high performance using a vector processing architecture

velocities: vector quantities that have a magnitude or speed and a direction

Venn diagrams: diagrams used to demonstrate the relationships between sets of objects, named after John Venn, a British logician

venture capitalists: persons or agencies that speculate by providing financial resources to enable product development, in the expectation of larger returns with product maturity

video capture cards: plug-in cards for a computer that accepts video input from devices like televisions and video cameras, allowing the user to record video data onto the computer

video compression algorithms: special algorithms applied to remove certain unnecessary parts of video images in an attempt to reduce their storage size

virtual channel connection: an abstraction of a physical connection between two or more elements (or computers); the complex details of the physical connection are hidden

virtual circuit: like a virtual channel connection, a virtual circuit appears to be a direct path between two elements, but is actually a managed collection of physical connections

Virtual Private Networks (VPNs): a commercial approach to network management where privately owned voice and data networks are set up on public network infrastructure

virtual reality (VR): the use of elaborate input/output devices to create the illusion that the user is in a different environment

virtualization: as if it were real; making something seem real, e.g. a virtual environment

visible speech: a set of symbols, comprising an alphabet, that "spell" sounds instead of words

visualization: a technique whereby complex systems are portrayed in a meaningful way using sophisticated computer graphics systems; e.g., chemical molecules

volatile: subject to rapid change; describes the character of data when current no longer flows to a device (that is, electrical power is switched off)

waveform: an abstraction used in the physical sciences to model energy transmission in the form of longitudinal or transverse waves

web surfers: people who "surf" (search) the Internet frequently

wide area network (WAN): an interconnected network of computers that spans upward from several buildings to whole cities or entire countries and across countries

wireless lavaliere microphones: small microphones worn around the speakers' necks, which attach to their shirts

wireless local area network (WLAN): an interconnected network of computers that uses radio and/or infrared communication channels, rather than cables

workstations: computers (usually within a network) that interact directly with human users (much the same as "client computers")

xerography: a printing process that uses electrostatic elements derived from a photographic image to deposit the ink

XML: the acronym for eXtensible Markup Language; a method of applying structure to data so that documents can be represented

Topic Outline

APPLICATIONS

Agriculture
Aircraft Flight Control
Aircraft Traffic Management
Airline Reservations
Architecture
Art
Astronomy
Biology
Chemistry
Chess Playing
Computerized Manufacturing
Data Mining
Data Processing
Data Warehousing
Decision Support Systems
Desktop Publishing
Digital Images
Digital Libraries
Distance Learning
Document Processing
Economic Modeling
Educational Software
Electronic Campus
Electronic Markets
Expert Systems
Fashion Design
Film and Video Editing
Games
Geographic Information Systems
Home Entertainment
Home System Software
Image Analysis: Medicine
Information Retrieval
Information Systems
Integrated Software
Journalism
Legal Systems
Library Applications
Mathematics
Medical Systems
Molecular Biology
Music
Music Composition
Music, Computer
Navigation
Office Automation Systems
Optical Technology
Pattern Recognition
Photography
Physics
Political Applications
Process Control
Project Management
Railroad Applications
Robotics
Security
Security Applications
Simulators
Space Travel and Exploration
Speech Recognition
System Analysis
Systems Design
Technology of Desktop Publishing
Telephony
Virtual Private Network

Music Composition
Music, Computer
Photography

FILM, VIDEO AND PHOTOGRAPHY

Animation
Digital Images
Film and Video Editing
Hypermedia and Multimedia
JPEG, MPEG
Photography

GOVERNMENT

Census Bureau
Computer Fraud and Abuse Act of 1986
Copyright
Government Funding, Research
Information Technology Standards
Minitel
National Aeronautics and Space Administration (NASA)
Patents
Political Applications
Privacy

HARDWARE, COMPUTERS

Analytical Engine
Cache Memory
CAD/CAM, CA Engineering
Central Processing Unit
Chip Manufacturing
Computer System Interfaces
Digital Logic Design
Integrated Circuits
Mainframes
Memory
Memory Devices
Microchip
Microcomputers
Minicomputers
Storage Devices
Supercomputers
Tabulating Machines
Vacuum Tubes
Virtual Memory

HARDWARE, TELECOMMUNICATIONS

Bandwidth
Bridging Devices
Cache Memory
Cell Phones
Cellular Technology
Communication Devices
Fiber Optics
Firewalls
Information Technology Standards
Laser Technology
Networks
Optical Technology
Telecommunications
Telephony
Transmission Media
Wireless Technology

HISTORY, COMPUTERS

Analytical Engine
Babbage, Charles
Early Computers
Early Pioneers
Generations, Computers
Hollerith, Herman
Internet
Jacquard's Loom
Mainframes
Microchip
Microcomputers
Minicomputers
Pascal, Blaise
Supercomputers
Tabulating Machines
Turing Machine
Vacuum Tubes
Virtual Memory

HISTORY, LANGUAGES

Algol-60 Report
Assembly Language and Architecture
Compilers
Generations, Languages
Java Applets

JavaScript
LISP
Logo
Markup Languages
Object-Oriented Languages
Procedural Languages
Programming
SQL
SQL: Databases
Visual Basic

HUMAN INTERACTION

Computer System Interfaces
Human Factors: User Interfaces
Hypertext
Integrated Software
Interactive Systems
Speech Recognition
User Interfaces
Window Interfaces

INFORMATION RELATED TOPICS

Information Access
Information Overload
Information Retrieval
Information Systems
Information Theory
Library Applications
Search Engines
System Analysis
Systems Design

INNOVATION

Artificial Intelligence
Artificial Life
Data Mining
Data Visualization
Data Warehousing
Desktop Publishing
Digital Images
Digital Libraries
Embedded Technology (Ubiquitous Computing)
Fiber Optics
Global Positioning Systems
Laser Technology
Mobile Computing
Molecular Computing
Nanocomputing
Optical Character Recognition
Optical Technology
Pattern Recognition
Personal Digital Assistants
Robotics
Robots
Satellite Technology
Scientific Visualization

INPUT AND OUTPUT DEVICES

Display Devices
Game Controllers
Graphic Devices
Input Devices
Keyboard
Magnetic Stripe Cards
Mouse
Pointing Devices
Printing Devices
Reading Tools
Sound Devices
Touch Screens
Video Devices
Word Processors

INTERNET

Authentication
Browsers
Credit Online
Cybercafe
E-banking
E-commerce
E-commerce: Economic and Social Aspects
E-journals and E-publishing
E-mail
Electronic Markets
Entrepreneurs
Internet
Internet: Applications
Internet: Backbone

Internet: History
Intranet
Search Engines
Virtual Private Network
Wireless Technology
World Wide Web

LIBRARIES

Digital Libraries
Distance Learning
E-books
E-journals and E-publishing
E-mail
Electronic Campus
Library Applications

MATHEMATICS

Binary Number System
Boolean Algebra
Codes
Coding Techniques
Cryptography
Information Theory

MEDICINE

Artificial Life
Biology
Cybernetics
Digital Images
Image Analysis: Medicine
Knowledge-Based Systems
Laser Technology
Medical Systems
Molecular Biology
Molecular Computing
Neural Networks
Pattern Recognition
Scientific Visualization

MUSIC

JPEG, MPEG
Music
Music Composition
Music, Computer
Sound Devices

NETWORKS

Asynchronous and Synchronous Transmission
Asynchronous Transfer Mode (ATM)
ATM Transmission
Bandwidth
Boolean Algebra
Bridging Devices
Communication Devices
Embedded Technology (Ubiquitous Computing)
Fiber Optics
Firewalls
FTP
Global Positioning Systems
Information Technology Standards
Information Theory
Intranet
Network Design
Network Protocols
Network Topologies
Networks
Routing
Satellite Technology
Security
Security Applications
Security Hardware
Security Software
Serial and Parallel Transmission
Service Providers
TCP/IP
Telecommunications
Telephony
Telnet
Transmission Media
Virtual Private Network
Wireless Technology

PEOPLE

Amdahl, Gene Myron
Asimov, Isaac
Babbage, Charles
Bardeen, John (See entry: Bardeen, John, Brattain, Walter H., and Shockley, William B.)
Bell, Alexander Graham

Boole, George
Brattain, Walter H. (See entry: Bardeen, John, Brattain, Walter H., and Shockley, William B.)
Computer Professional
Computer Scientists
Cormack, Allan (See entry: Cormack, Allan, and Hounsfield, Godfrey Newbold)
Cray, Seymour
Eckert, J. Presper, Jr. (See entry: Eckert, J. Presper, Jr., and Mauchly, John W.)
Early Pioneers
Entrepreneurs
Feynman, Richard P.
Glushkov, Victor M.
Gross, Alfred J.
Hewlett, William
Hollerith, Herman
Hopper, Grace
Hounsfield, Godfrey Newbold (See entry: Cormack, Allan, and Hounsfield, Godfrey Newbold)
Kemeny, John G.
Lovelace, Ada Byron King, Countess of
Marconi, Guglielmo
Mauchly, John W. (See entry: Eckert, J. Presper, Jr., and Mauchly, John W.)
Morse, Samuel
Newell, Allen
Nyquist, Harry
Organick, Elliot
Pascal, Blaise
Péter, Rózsa
Shannon, Claude E.
Shockley, William B. (See entry: Bardeen, John, Brattain, Walter H., and Shockley, William B.)
Simon, Herbert A.
Turing, Alan M.
Wang, An
Watson, Thomas J., Sr.
von Neumann, John
Zuse, Konrad

PRECURSORS TO COMPUTERS

Abacus
Jacquard's Loom
Napier's Bones
Slide Rule

PROGRAMMING

Algorithms
Binary Number System
Boolean Algebra
Design Tools
Procedural Languages
Programming

PUBLISHING

Desktop Publishing
Hypertext
Markup Languages
Technology of Desktop Publishing

SECURITY

Authentication
Cookies
Digital Signatures
Firewalls
Global Surveillance
Hackers
Hacking
Invasive Programs
Privacy
Security
Security Applications
Security Hardware
Security Software
Social Impact
Software Piracy
Urban Myths
Virtual Private Network
Viruses

SOCIAL ISSUES

Assistive Computer Technology for Persons with Disabilities
Authentication
Censorship: National, International
Computer Fraud and Abuse Act of 1986
Computer Professional

Compatibility (Open Systems Design)
Computer Scientists
Cookies
Copyright
Credit Online
Cybercafe
Digital Libraries
Digital Signatures
Distance Learning
E-banking
E-books
E-commerce
E-commerce: Economic and Social Aspects
E-journals and E-publishing
E-mail
Electronic Campus
Electronic Markets
Entrepreneurs
Ergonomics
Ethics
Fiction, Computers in
Global Surveillance
Government Funding, Research
Home Entertainment
Information Access
Information Overload
Journalism
Library Applications
Medical Systems
Mobile Computing
Open Source
Patents
Personal Digital Assistants
Political Applications
Privacy
Service Providers
Social Impact
Software Piracy
Technology of Desktop Publishing
Telephony
Urban Myths
Virtual Private Network
Virtual Reality in Education
World Wide Web

SOFTWARE

Agents
Browsers
Compilers
Database Management Software
Geographic Information Systems
Human Factors: User Interfaces
Integrated Software
Office Automation Systems
Open Source
Operating Systems
Procedural Languages
Productivity Software
Search Engines
Simulation
Spreadsheets
User Interfaces
Window Interfaces

STUDY AREAS

Artificial Intelligence
Artificial Life
Expert Systems
Information Theory
Molecular Computing
Nanocomputing

TECHNOLOGY, DEVICES

Abacus
Analytical Engine
ATM Machines
Bandwidth
Bridging Devices
Cache Memory
CAD/CAM, CA Engineering
Cell Phones
Cellular Technology
Central Processing Unit
Communication Devices
Computer System Interfaces
Display Devices
Game Controllers
Global Positioning Systems
Graphic Devices

TECHNOLOGY, TECHNIQUES

Image Analysis: Medicine
Information Technology Standards
Information Theory
Interactive Systems
Invasive Programs
JPEG, MPEG
Knowledge-Based Systems
Laser Technology
Magnetic Stripe Cards
Mobile Computing
Molecular Computing
Nanocomputing
Network Design
Network Protocols
Network Topologies
Neural Networks
Operating Systems
Optical Technology
Parallel Processing
Pattern Recognition
Process Control
Routing
Satellite Technology
Scientific Visualization
Search Engines
Security
Security Applications
Security Software
Serial and Parallel Transmission
Simulation
TCP/IP
Telnet
Transmission Media
User Interfaces
Virtual Private Network
Virtual Reality
Viruses
Weather Forecasting
Window Interfaces
Wireless Technology

TELECOMMUNICATIONS, PEOPLE AND ORGANIZATIONS

Bardeen, John (See entry: Bardeen, John, Brattain, Walter H., and Shockley, William B.)
Bell, Alexander Graham
Bell Labs
Brattain, Walter H. (See entry: Bardeen, John, Brattain, Walter H., and Shockley, William B.)
Gross, Alfred J.
Institute of Electrical and Electronics Engineers (IEEE)
Marconi, Guglielmo
Morse, Samuel
Nyquist, Harry
Shannon, Claude E.
Shockley, William B. (See entry: Bardeen, John, Brattain, Walter H., and Shockley, William B.)

TELECOMMUNICATIONS, TECHNOLOGY AND DEVICES

Asynchronous and Synchronous Transmission
Asynchronous Transfer Mode (ATM)
ATM Transmission
Authentication
Bandwidth
Bridging Devices
Cell Phones
Cellular Technology
Coding Techniques
Communication Devices
Cookies
Cryptography
Digital Libraries
Digital Signatures
Distance Learning
Electronic Campus
Electronic Markets
Embedded Technology (Ubiquitous Computing)
Fiber Optics
Firewalls
FTP
Global Positioning Systems
Information Technology Standards
Information Theory
Internet
Internet: Applications

Volume 1 Index

Note: Page numbers in **boldface type** *indicate article titles; those in italic type indicate illustrations. A cumulative index, which combines the terms in all volumes of* Computer Sciences, *can be found in volume 4 of this series.*

A

D

E

H

J

T

U

V

W

X

Y

Z