AlphaZero
The new Chess King

How a general reinforcement learning algorithm became the world's strongest chess engine after 9 hours of self-play

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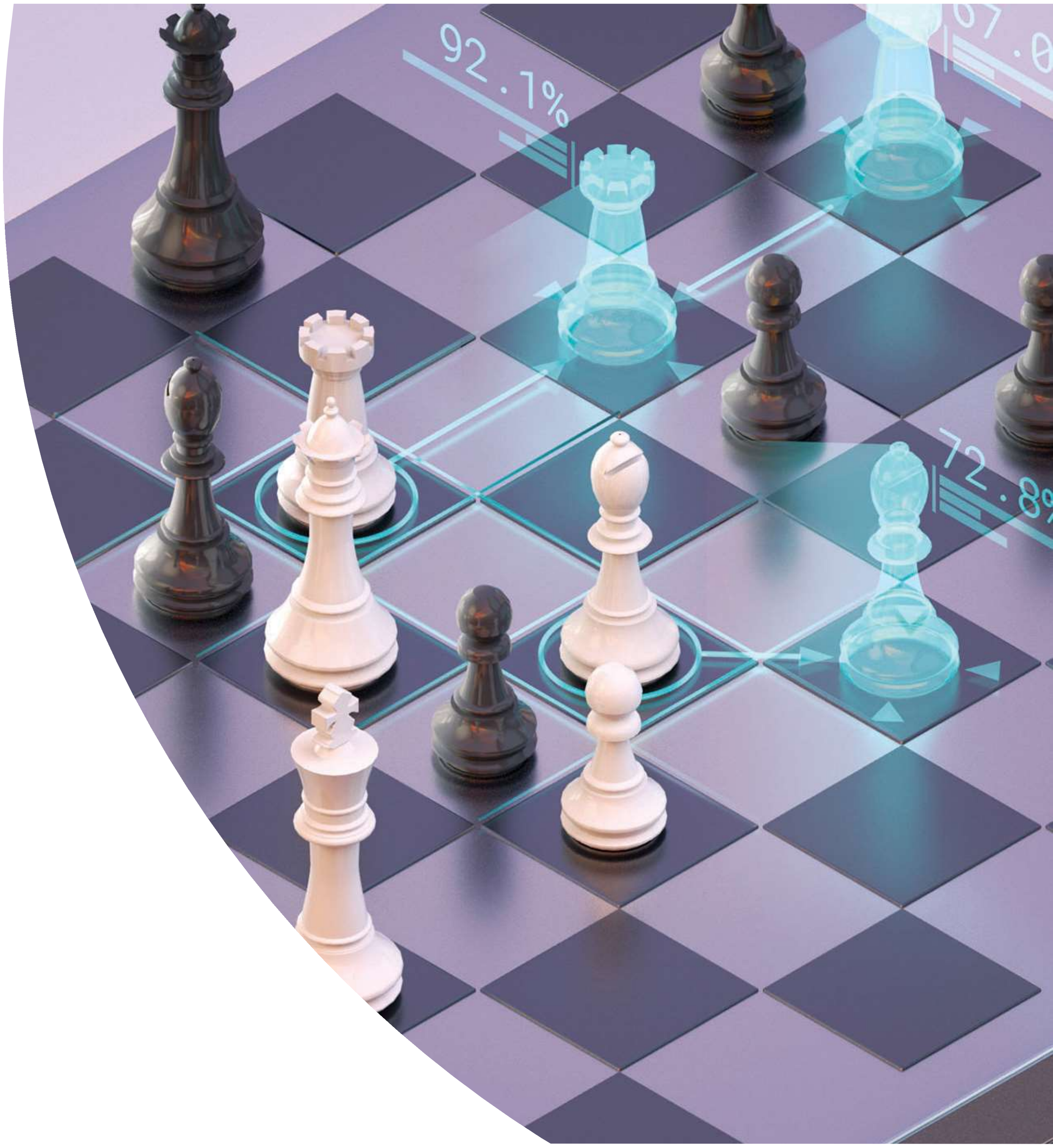


Complexity of a Chess Game

- **20** possible start moves, **20** possible replies, etc.
- **400** possible positions after **2** ply (half moves)
- **197 281** positions after **4** ply
- 7^{13} positions after 10 ply (5 White moves and 5 Black moves)
- **Exponential explosion**!
- Approximately **40 legal moves** in a typical position
- About **10^{120}** possible chess games and **10^{47}** different chess positions

Solving Chess, is it a myth?

Chess Complexity Space

- The estimated number of possible chess games is 10^{120}
  - Claude E. Shannon
  - 1 followed by 120 zeroes!!!
- The estimated number of reachable chess positions is 10^{47}
  - Shirish Chinchalkar, 1996
- Modern GPU's performs 10^{13} flops
- If we assume one million GPUs with 10 flops per position we can calculate 10^{18} positions per second
- It will take us 1 600 000 000 000 000 000 000 years to solve chess

Assuming Moore's law works in the future

- Todays top supercomputers delivers 10^{16} flops
- Assuming 100 operations per position yields 10^{14} positions per second
- Doing retrograde analysis on supercomputers for 4 months we can calculate 10^{21} positions.
- When will Moore's law allow us to reach 10^{47} positions?
- Answer: in 128 years, or around year 2142!

http://chessgpgpu.blogspot.no/2013/06/solving-chess-facts-and-fiction.html

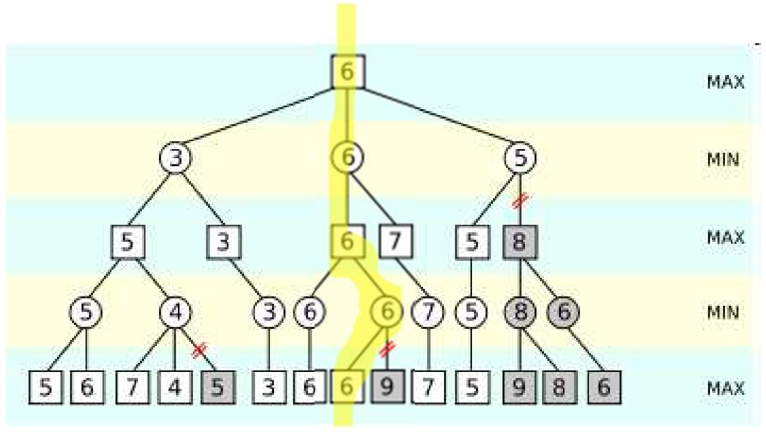
History of Computer Chess

- Chess is a good fit for computers: **Clearly defined rules, Game of complete information, Easy to evaluate (judge) positions, Search tree is not too small or too big**
- 1950: Programming a Computer for Playing Chess (Claude Shannon)
- 1951: First chess playing program (on paper) (Alan Turing)
- 1958: First computer program that can play a complete chess game
- 1981: Cray Blitz wins a tournament in Mississippi and achieves master rating
- 1989: Deep Thought loses 0-2 against World Champion Garry Kasparov
- 1996: Deep Blue wins a game against Kasparov, but loses match 2-4
- 1997: Upgraded Deep Blue wins 3.5-2.5 against Kasparov
- 2005: Hydra destroys GM Michael Adams 5.5-0.5
- 2006: World Champion Vladimir Kramnik looses 2-4 against Deep Fritz (PC chess engine)
- 2014: Magnus Carlsen launches “Play Magnus “ app on iOS where anyone can play against a chess engine that emulates the World Champion’s play at different ages
- 2017: AlphaZero beats world champion program Stockfish 64-34 without losing a game after learning chess from scratch by 9 hours of self-playing
- 2019: Leela Chess Zero beats Stockfish 53,5-46,5 in TCEC season 15 superfinal
- 2020: Stockfish 12 using NNUE beats Leela Chess Zero 54.5-45.5 in TCEC 19 superfinal

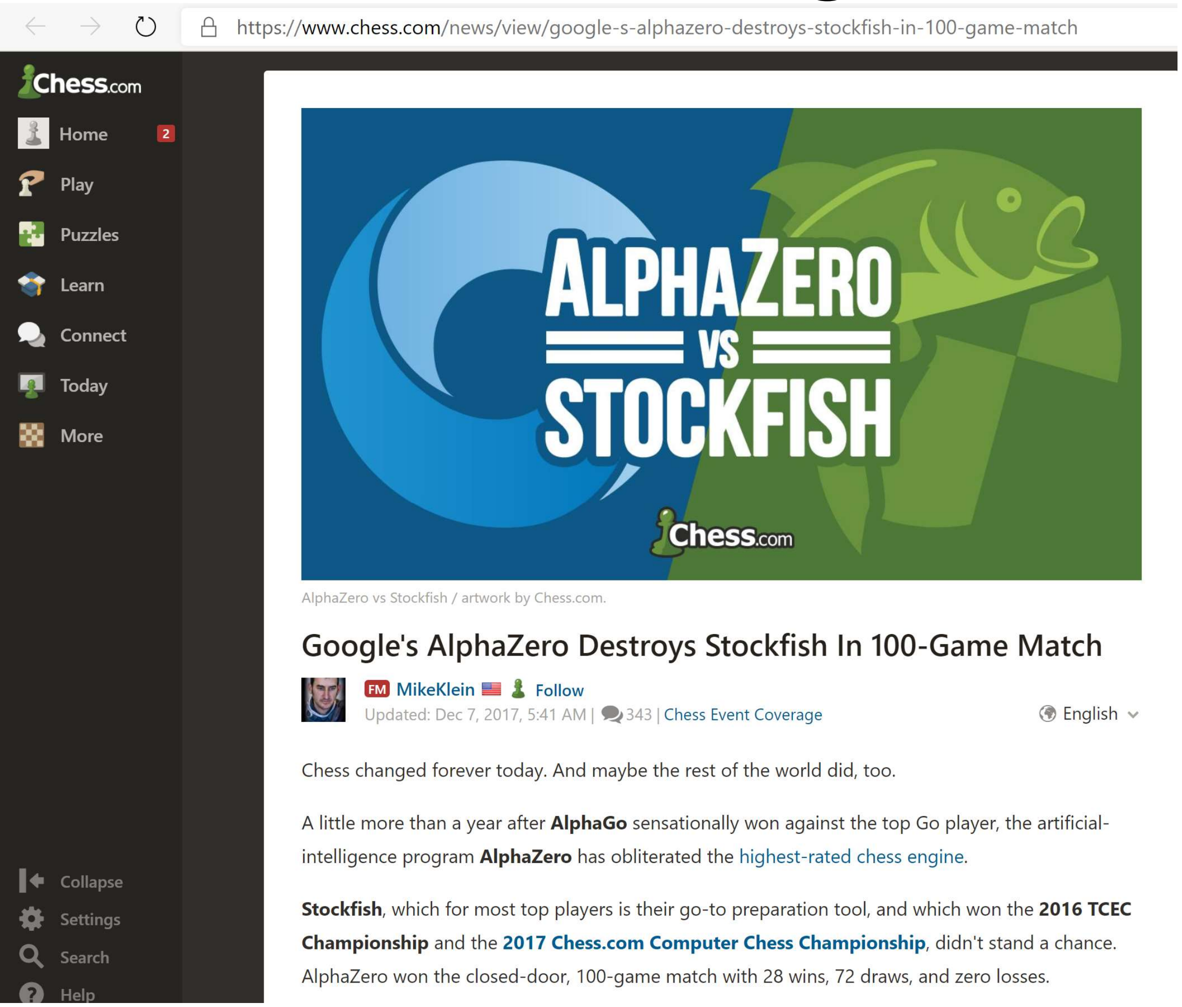
Traditional Chess Engines

Traditional chess engines (including world computer chess champion **Stockfish**):

- Highly optimized **alpha-beta search algorithm**, searching 30-40 ply (half moves) ahead
- Striving for an optimal **move ordering** (analyze the best move first) in order to prune the search tree the most (bringing branching factor down from ~40 to less than 2)
- **Linear evaluation function** (of chess positions) with carefully tuned weights for a myriad of positional and dynamic features.
- Final evaluation of root node corresponds to score of leaf node in the **principal variation** (PV) – consisting of "best" moves from White and Black



2017: A new King is Born


https://www.chess.com/news/view/google-s-alphazero-destroys-stockfish-in-100-game-match

AlphaZero vs Stockfish / artwork by Chess.com.

Google's AlphaZero Destroys Stockfish In 100-Game Match

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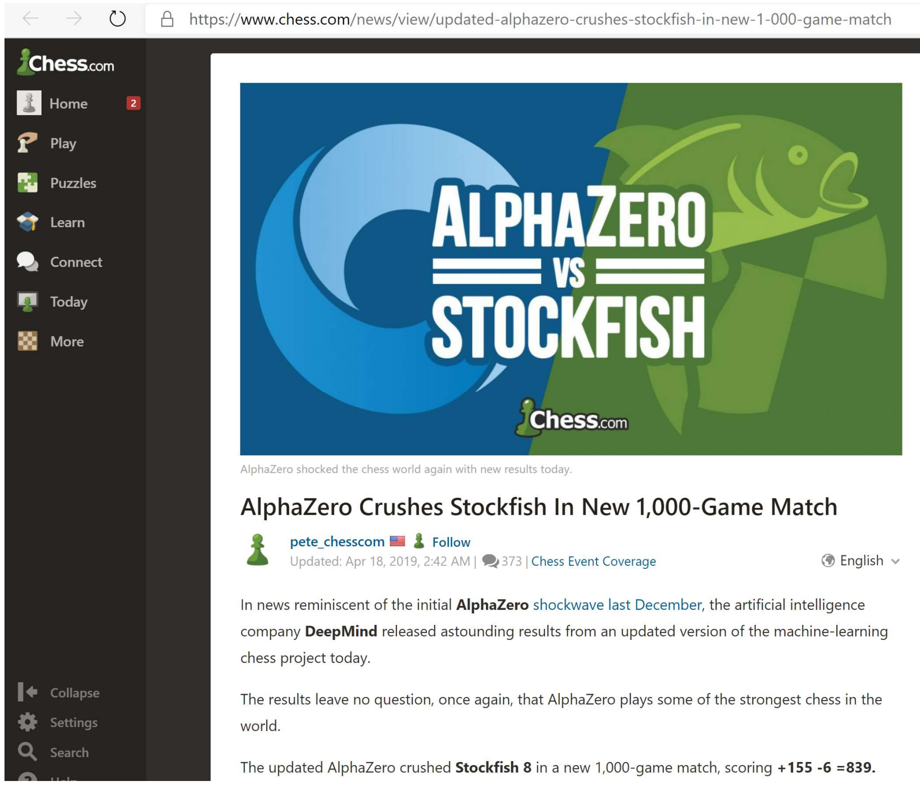
Updated: Dec 7, 2017, 5:41 AM | 343 | Chess Event Coverage English

Chess changed forever today. And maybe the rest of the world did, too.

A little more than a year after **AlphaGo** sensationally won against the top Go player, the artificial-intelligence program **AlphaZero** has obliterated the highest-rated chess engine.

Stockfish, which for most top players is their go-to preparation tool, and which won the **2016 TCEC Championship** and the **2017 Chess.com Computer Chess Championship**, didn't stand a chance. AlphaZero won the closed-door, 100-game match with 28 wins, 72 draws, and zero losses.


https://www.chess.com/news/view/updated-alphazero-crushes-stockfish-in-new-1-000-game-match

AlphaZero shocked the chess world again with new results today.

AlphaZero Crushes Stockfish In New 1,000-Game Match

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In news reminiscent of the initial **AlphaZero** shockwave last December, the artificial intelligence company **DeepMind** released astounding results from an updated version of the machine-learning chess project today.

The results leave no question, once again, that AlphaZero plays some of the strongest chess in the world.

The updated AlphaZero crushed **Stockfish 8** in a new 1,000-game match, scoring **+155 -6 =839.**

AlphaZero in two Sentences

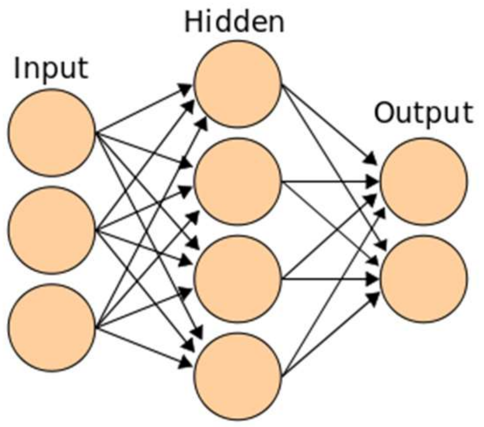
- AlphaZero uses **Monte Carlo tree search** (MCTS) in combination with a **policy network** (gives move probabilities; coming up with candidate moves) and a **value network** (for evaluating a position).
- Starting from **random play**, and given **no domain knowledge** except the game rules, AlphaZero by **self-playing** was able within 24 hours to train its neural networks up to **superhuman** level of play in the games of **chess** and **shogi** (Japanese chess) as well as **Go**, and convincingly defeated a world-champion program in each case.

AlphaZero vs Stockfish

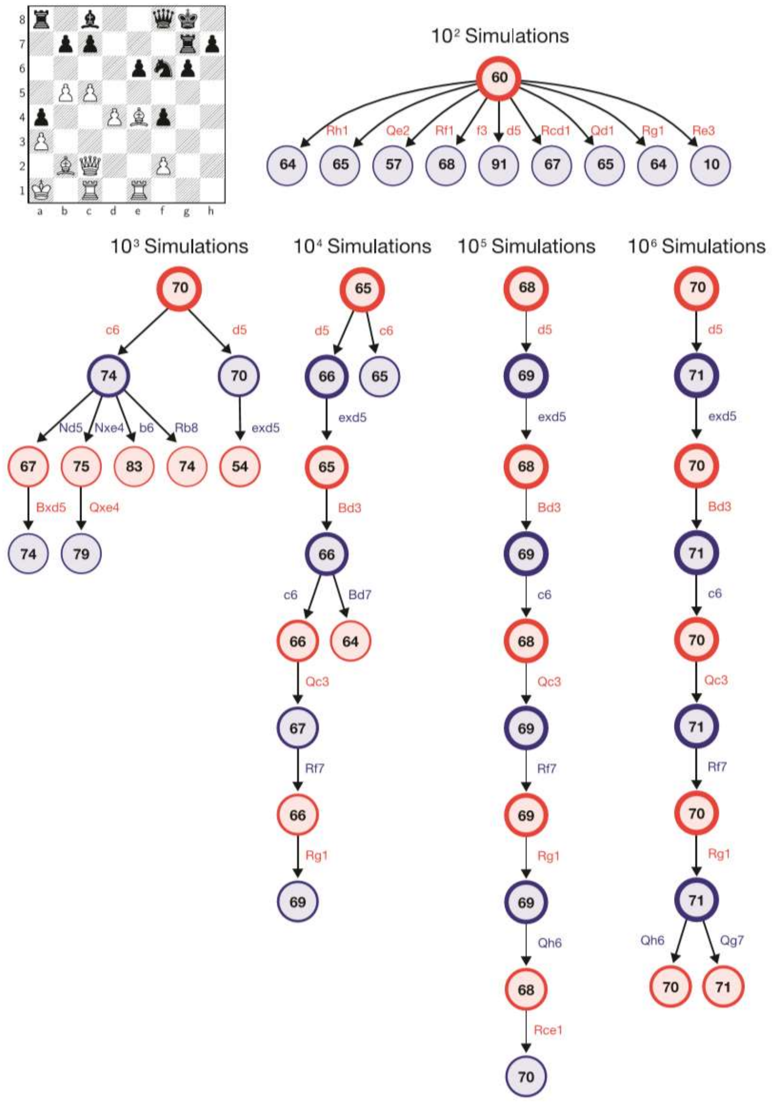
Concepts	AlphaZero (AI based chess engine)	Stockfish (tradition chess engines)
Search algorithm	Monte Carlo Tree Search (MCTS) - probabilistic; computes averages over the position evaluations within a subtree	Alpha-beta - searching for the very best variation (PV)
Selecting which moves to look at (first)	Deep Neural Network (policy network)	Move ordering heuristics (Killer moves, Zero-Move, Iterative Deeper Depth-First Search, etc.)
Evaluation chess positions (leaf nodes)	Deep Neural Network (value network)	Linear, hand-crafted function (starting with version 12 in 2020, Stockfish uses an efficiently updatable neural network (NNUE))
Domain knowledge	Only basic chess rules (how the pieces moves, size of board, definition of check mate, etc.) (MuZero (2020) is able to learn the rules of the game)	Advanced concepts like king safety, pawn structure, etc. built into evaluation function

Deep Neural Network

- (Artificial) Neural Network is a type of graph inspired by the **human brain**, with **signals flowing** from a set of input nodes to a set up output nodes.
- The **nodes** ("artificial neurons") of one or more (hidden) **layers** receive one or more **inputs**, and after being **weighted**, **sum** them to produce an **output**.
- The sum is passed through a nonlinear function known as an **activation function**.
- A **deep neural network** (DNN) is a neural network with **multiple layers** (>2, but could be 100's) between the input and output layers.
- Alpha Zero uses one DNN for finding **candidate moves** (policy network) and one DNN for **evaluating** a chess **position** (value network).



Monte Carlo Tree Search Example



- The focus of Monte Carlo tree search is on the analysis of the **most promising moves**, expanding the search tree based on **random sampling** of the search space.
- Starts out broad, narrows down search space quickly
- AlphaZero uses playouts of games during **self-training**, but not during match play.

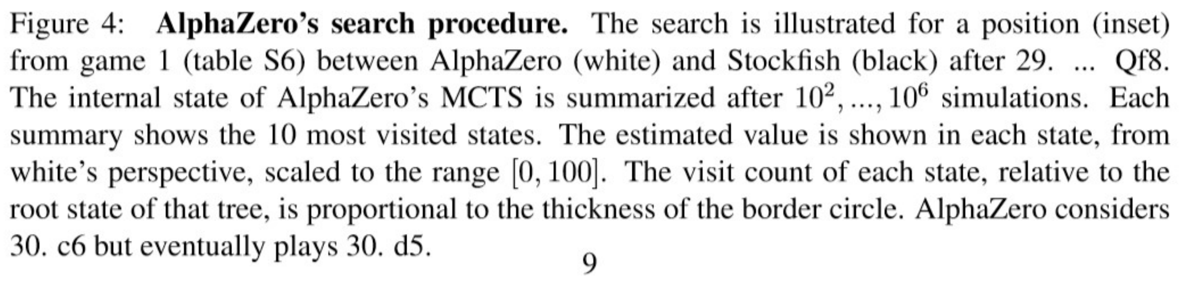


Figure 4: **AlphaZero's search procedure.** The search is illustrated for a position (inset) from game 1 (table S6) between AlphaZero (white) and Stockfish (black) after 29. ... Qf8. The internal state of AlphaZero's MCTS is summarized after $10^2, ..., 10^6$ simulations. Each summary shows the 10 most visited states. The estimated value is shown in each state, from white's perspective, scaled to the range $[0, 100]$. The visit count of each state, relative to the root state of that tree, is proportional to the thickness of the border circle. AlphaZero considers 30. c6 but eventually plays 30. d5.

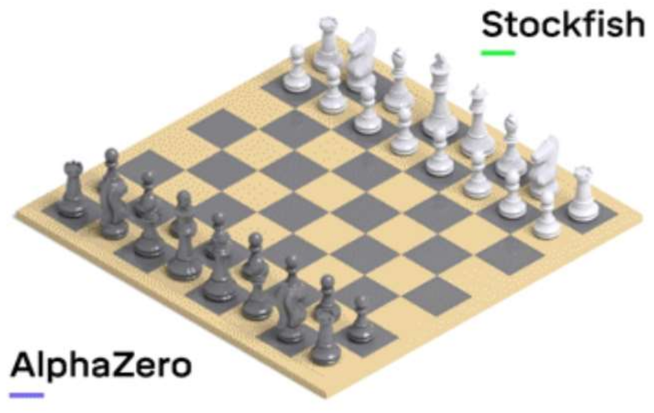
9

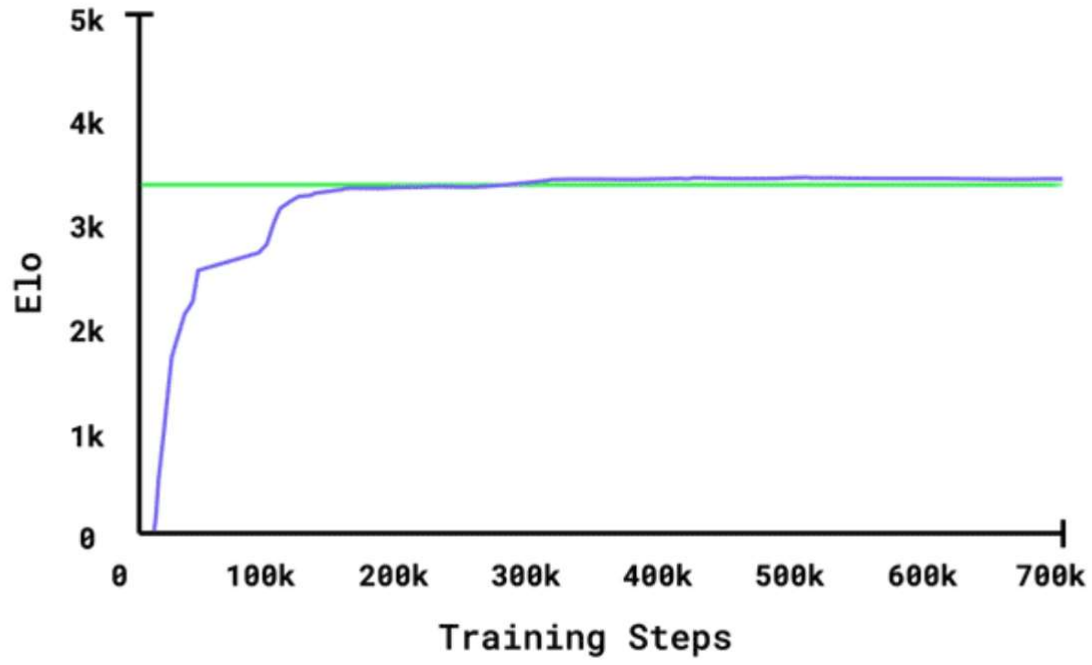
(From page 9 of open access version of Science Journal paper "A general reinforcement learning algorithm that masters chess, shogi, and Go through self-play")

Reinforcement learning

- To learn a game, an untrained neural network plays millions of games against itself via a process of trial and error called reinforcement learning.
- For each move during **self-play** MCTS performed 800 **simulations**, each extending the search by one move while assessing the value of the resulting position.
- At first, it plays completely **randomly**.
  - Too avoid endless random games, they were stopped after X moves and judged a draw.
  - Now and then some random game would result in a **win** or **loss**.
- Over time the system learns from wins, losses, and draws to **adjust** the **parameters** of the neural network, making it more likely to choose advantageous moves in the future.
- **Positions** occurring during a won (lost) game is **adjusted** positively (negatively) in **value network**
- After a won game, **connections** in **policy network** are **strengthened** for moves recommended (and played) by AlphaZero.
- During **9 hours** of self play, AlphaZero played **44 millions games** against itself (1K games / sec).
- Training for a **longer** period gave **diminishing return**, probably due to the large number of **draws** (>90%) that started to occur during self-play.

Chess



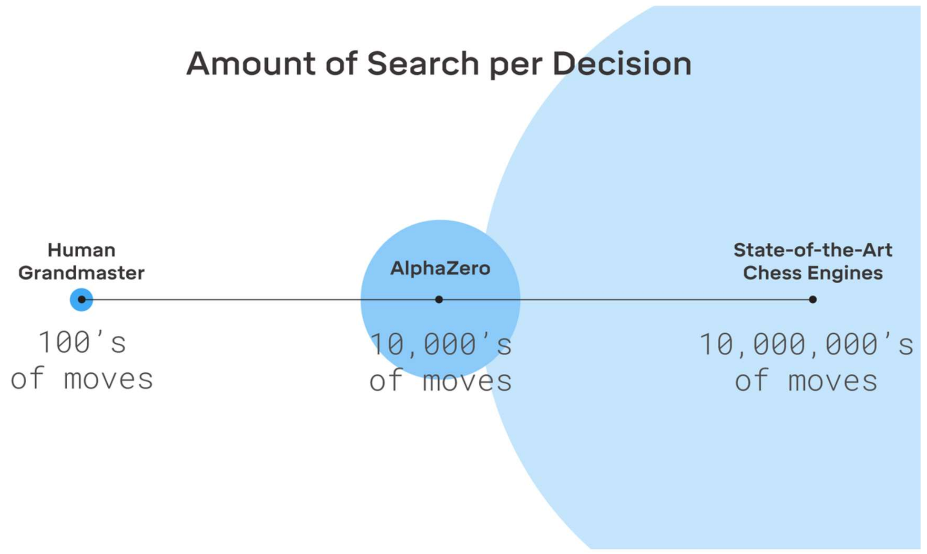


In chess, AlphaZero first outperformed Stockfish after just 4 hours; in shogi, AlphaZero first outperformed Elmo after 2 hours; and in Go, AlphaZero first outperformed the version of AlphaGo that beat the legendary player Lee Sedol in 2016 after 30 hours. Note: each training step represents 4,096 board positions.

(https://deepmind.com/blog/alphazero-shedding-new-light-grand-games-chess-shogi-and-go/)

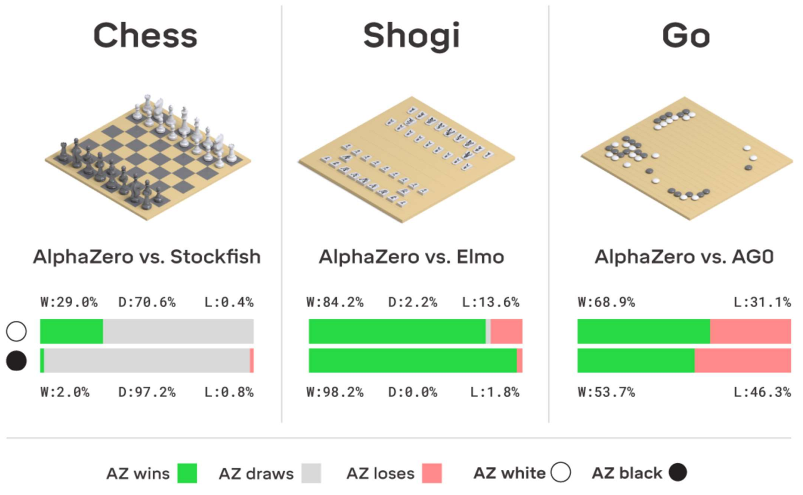
During Match Play

- The trained policy and value networks are used to guide MCTS to select the most promising moves in games.
- For each move, AlphaZero searches only a small fraction of the positions considered by traditional chess engines.
- It searches only 60 thousand positions per second, compared to roughly 60 million for Stockfish



Squaring off against Stockfish

- The fully trained AlphaZero were tested against Stockfish which is considered the strongest commercial chess engine.
- Stockfish used 44 CPU cores whereas AlphaZero used a machine with 4 first-generation **TPUs** and 44 CPU cores. (A first generation TPU is roughly similar in inference speed to commodity hardware such as an **NVIDIA Titan V GPU**, although the architectures are not directly comparable.)
- All matches were played using time controls of three hours per game, plus an additional 15 seconds for each move.
- AlphaZero convincingly defeated 2016 edition of Stockfish, winning 155 games and losing just six games out of 1,000.



AlphaZero Playing Style

- AlphaZero independently discovered and played common human motifs during its self-play training such as **openings**, **king safety**, **pawn structure** and **piece mobility**.
- Being self-taught and therefore unconstrained by conventional wisdom about the game (including any pre-defined **value** of each **chess piece**), it developed its own **intuition** and **strategies** (e.g. restrict opponents king by advancing with rook’s pawn up the board).
- Since AlphaZero takes an average of assessed outcomes as the value of the root node (instead of PV), it has a “**human**” way of playing: *“It looks like I will have all the chances here – there must be something good”*, without calculating all the way to checkmate.

Non-Linear vs Linear Eval Function

- A non-linear, deep neural network provides a more powerful evaluation function, but may also introduce larger worst-case generalization errors then a linear function.
- When combining a non-linear eval function with alpha-beta search which computes an explicit minimax, the biggest errors in eval function are typically propagated directly to the root of the subtree (Principle Variation - PV).
- By contrast, AlphaZero’s MCTS averages over the position evaluations within a subtree, rather than computing the minimax evaluation of that subtree.

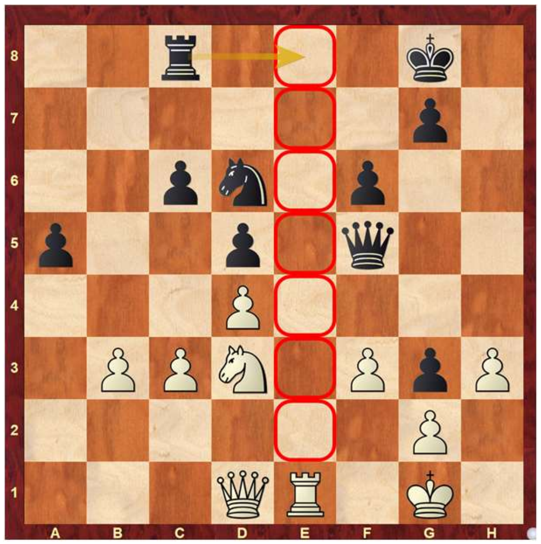
Why did AlphaZero beat Stockfish?

- Stockfish’s handcrafted linear evaluation function was outperformed by AlphaZero’s non-linear deep neural net.
- The **very best variation** (PV - principal variation) is not necessarily best after all if **evaluation** of the final position (leaf node) is **wrong**!

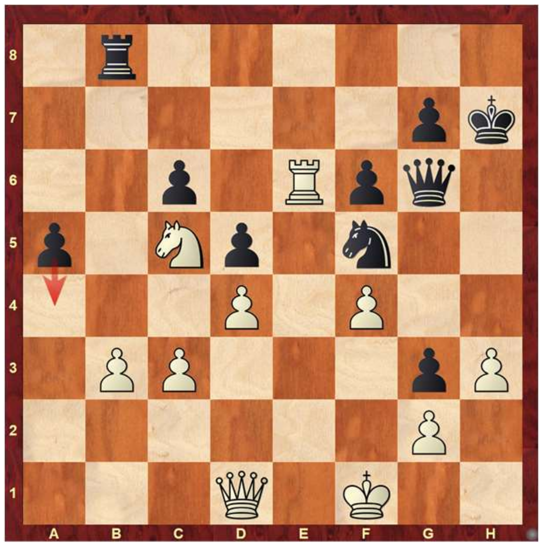
Two examples:

- AlpaZero grasps when to occupy an open line with a rook, and when to ignore the open line
- AlphaZero has superb understanding of piece activity (mobility) – for both itself and the opponent – and how piece activity can compensate for material deficit

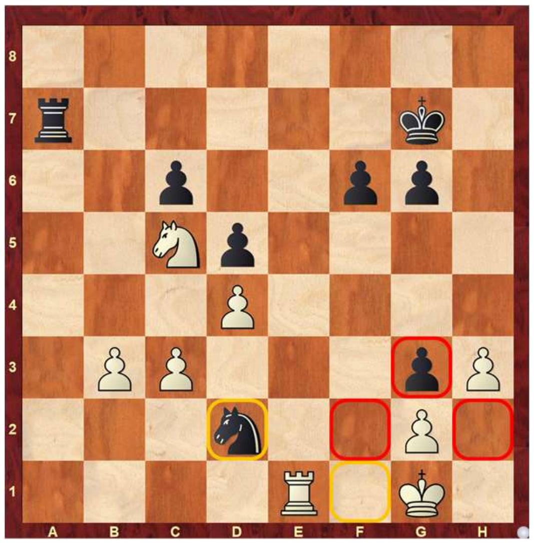
Game 255: Stockfish (White) vs AlphaZero (Black)



After 41 moves
SF: 0.00 - AZ: 59.8% (for Black)
Stockfish's linear evaluation function gives White a positional plus value for occupying the only open line on the board with its rook



Before 74...a4!!
AZ: 67.7% (for Black)
SF drifted slowly into bigger and bigger trouble because PV continued to involve Black exchanging off rooks, which is equal (0.00), but which is not Black's only (or even best) plan.



After 92...Ra7
White's king is trapped in a cage, forcing White's rook to stay on the first rank to protect against back-rank mate. (White resigned on move 143)

Stockfish Strikes Back

- Stockfish 12 released in September 2020 switched to an efficiently updatable neural network (NNUE) for evaluation instead of a linear function. SF12 easily beat Leela Chess Zero 54.5-45.5 in TCEC Season 19 super final.
- NNUE was first developed for Shogi engines.
- Consists of of a 4 layers neural network.
- Half search speed of Stockfish 11, but much faster than Leela Chess Zero.

Sources

- AlphaZero creator DeepMind: https://deepmind.com/blog/alphazero-shedding-new-light-grand-games-chess-shogi-and-go/
- Science Journal article of Dec 7, 2018: “A general reinforcement learning algorithm that masters chess, shogi, and Go through self-play”
  - https://science.sciencemag.org/content/362/6419/1140 / (behind pay wall)
  - Open access version of Science paper (PDF format)
- The book «Game Changer», by Matthew Sadler and Natasha Regan (New in Chess, 2019): https://www.newinchess.com/game-changer
- Leela Chess Zero: https://en.wikipedia.org/wiki/Leela_Chess_Zero
  - free, open-source, neural network based chess engine that beat Stockfish 53,5 – 46,5 (+14 -7 =79) in the Superfinal of season 15 of Top Chess Engine Championship (TCEC) in May 2019.
- Chess Programming Wiki: https://www.chessprogramming.org/Main_Page
- MuZero: https://deepmind.com/blog/article/muzero-mastering-go-chess-shogi-and-atari-without-rules

We are hiring!

[Nov 2021] There's an open position for a (backend) Software Engineer in my team in Microsoft Development Center Norway, Oslo. Check out the link below for more details. I am happy to answer any questions.

https://lnkd.in/dKRaEz5f