Chess and AI

A love story

Giovanni Squillero
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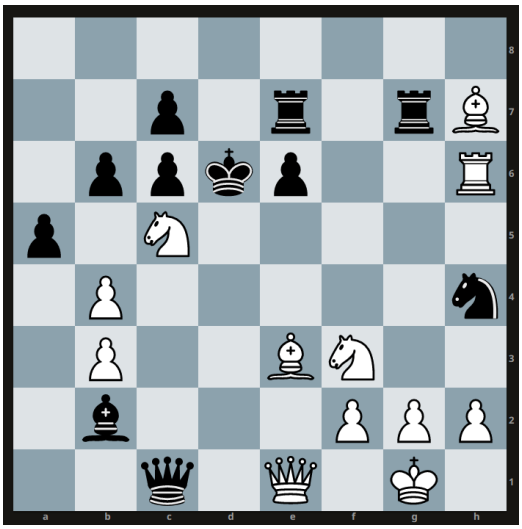
1

White to move



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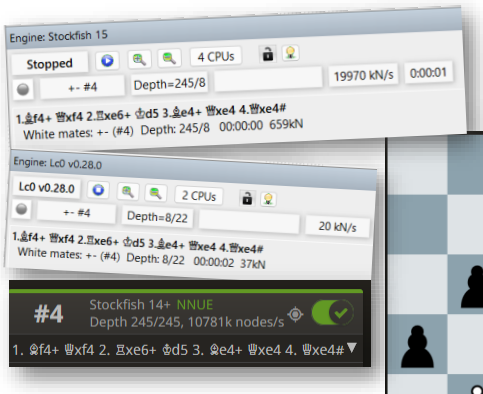
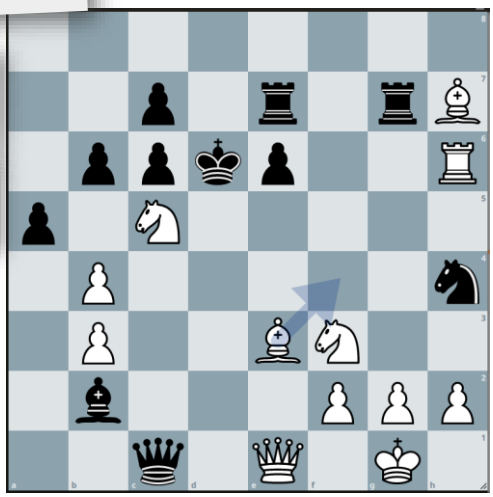
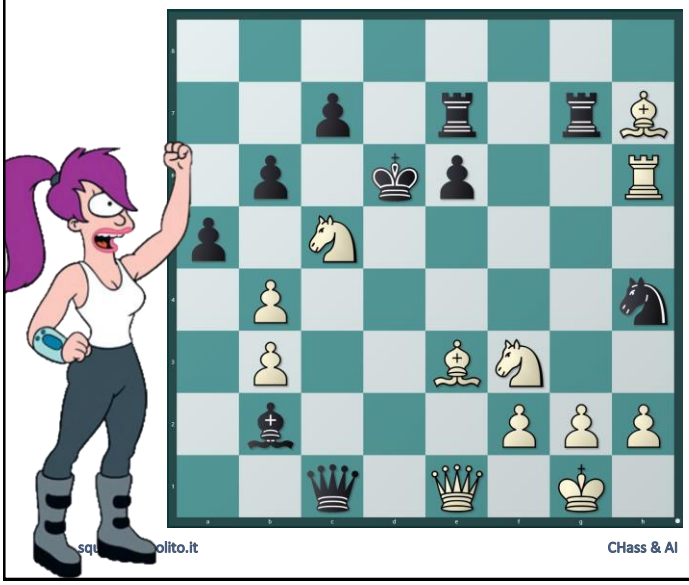
Solution

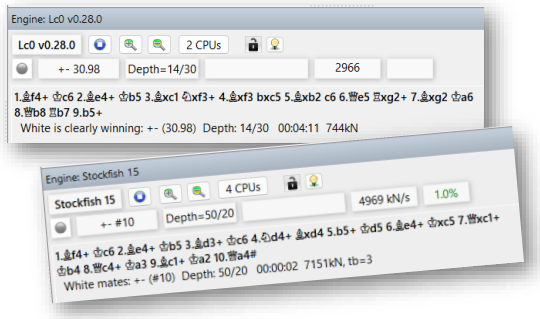




White to move (2)

White to move (2)





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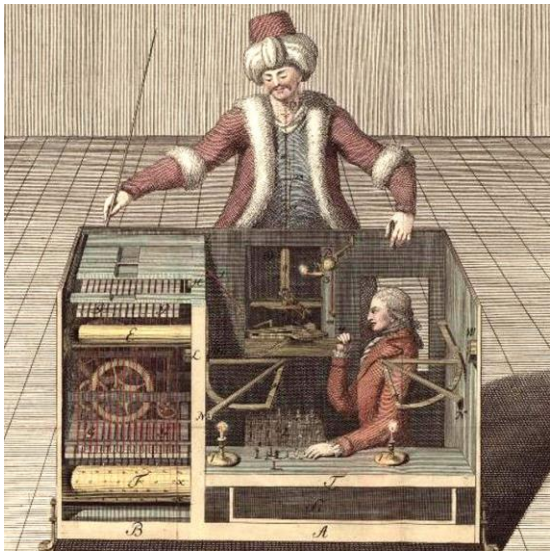
1770–1854: The Turk

- First machine able to play chess at a good level
- Run from 1770 to 1854 (when it was destroyed in a fire)

6

1857: The Turk

- First machine able to play chess at a good level
- Run from 1770 to 1854 (when it was destroyed in a fire)
- Discovered to be a **hoax** in 1857



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More Fake

- 1868: Ajeeb (عجيب)
  - "Particularly intriguing" piece of faux mechanical technology
  - Played against Harry Houdini, Theodore Roosevelt, and O. Henry (William Sydney Porter) — also played checkers
- 1876: Mephisto
  - Remotely controlled

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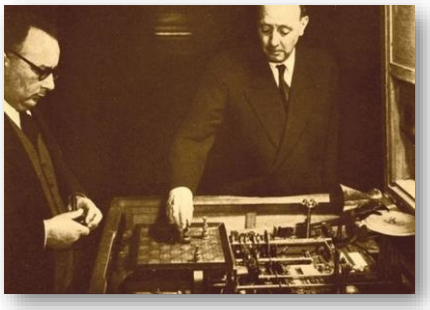
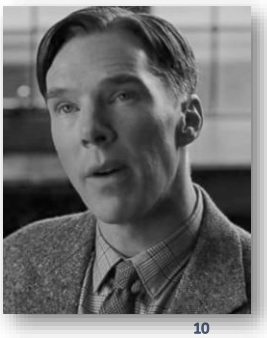
1912: El Ajedrecista

- Automaton built in 1912 by Leonardo Torres y Quevedo
  - True autonomous machine capable of playing chess
  - Only endgames **KRvK**, moving the white king and rook to checkmate the black king moved by a human opponent
- It checkmates the opponent every time
  - … but does not checkmate in the minimum number of moves, nor within 50 moves



1948: Turochamp

- Originally developed by Alan Turing and David Champernowne
  - Turing failed to hack a Ferranti Mark 1 version in 1951
  - Turing run the program "by hand" against Alick Glennie in 1952
  - Depth: 2 + some heuristics
- Working version in 1951 for Ferranti Mark 1
  - Able to solve mate-in-2 problems
- Recreation of Turochamp constructed in 2012
  - Played against Kasparov at the Alan Turing Centenary Conference



- Originally develop… …id Champernowne
  - Turing failed to ha… …n 1951
  - Turing run the pro… …Glennie in 1952
  - Depth: 2 + some h…
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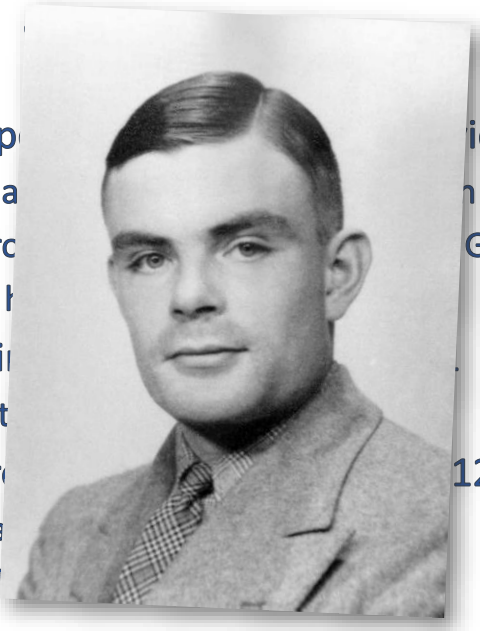
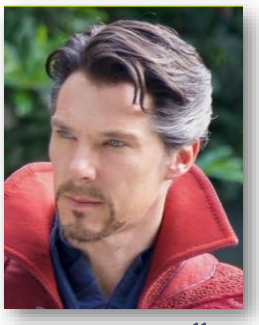
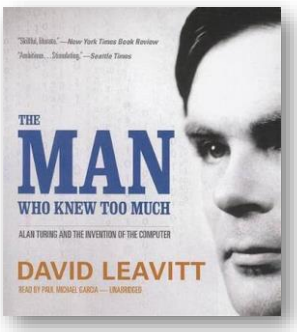
  - Played against Ka… Alan Turing Cent…

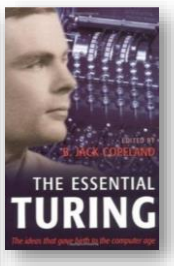


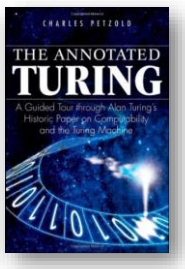


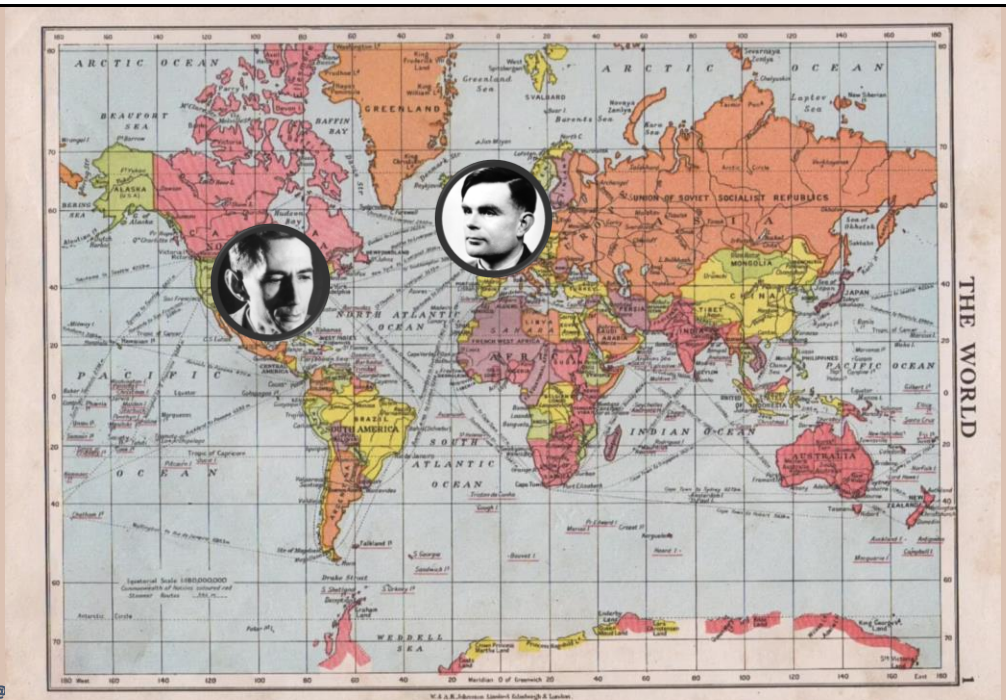
Suggested Readings

- David Leavitt
  - ***The Man Who Knew Too Much: Alan Turing and the Invention of the Computer***, 2006
  - ***L'uomo che sapeva troppo***, 2016 (Carolina Sargian, traduttore)









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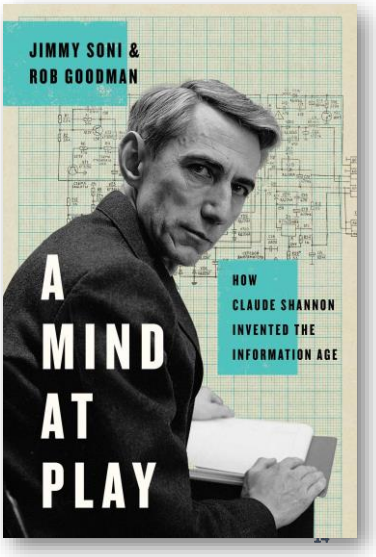
Suggested Readings

Jimmy Soni & Rob Goodman:

A Mind at Play: How Claude Shannon Invented the Information Age

Simon & Schuster, 2017



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1949: Caissac

- Named after Caïssa, the fictional "patron goddess of chess"
- 150 relay switches to perform calculation
- 10÷15 s/move
- Only endgame, max 6 pieces

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?

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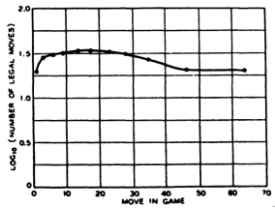
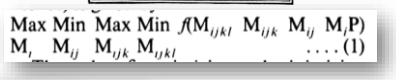
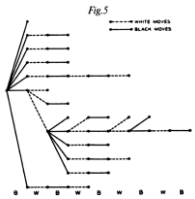
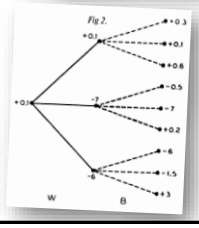
1950: Theory

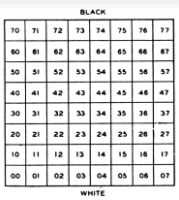
- Claude Shannon: "Programming a Computer for Playing Chess", *Philosophical Magazine*
- Minimax
- Static evaluation:
  - Includes: material; pawn formation; position; commitments; mobility











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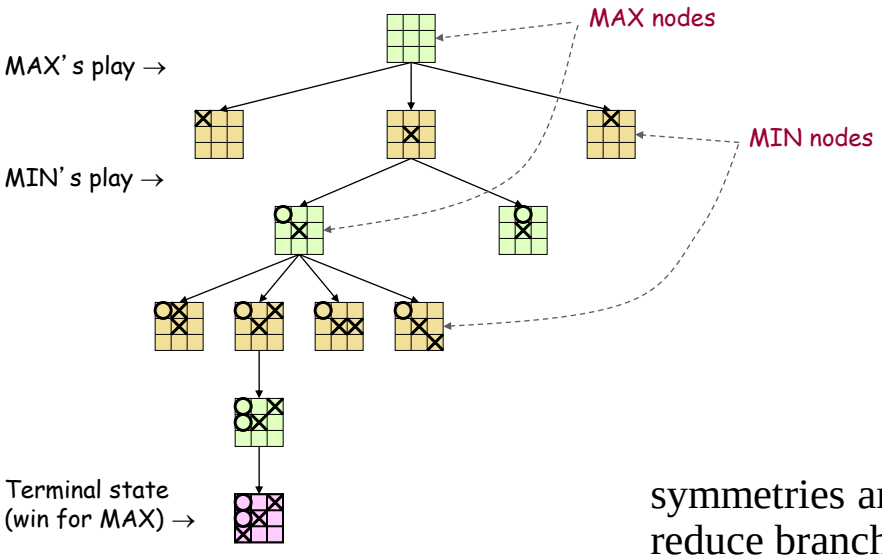
Game Tree (Tic-Tac-Toe)



symmetries are used to reduce branching factor

1950: Theory

- Type A: **Brute-force** search, every variation to a given depth
- Type B: **Selective** search, "important" branches only

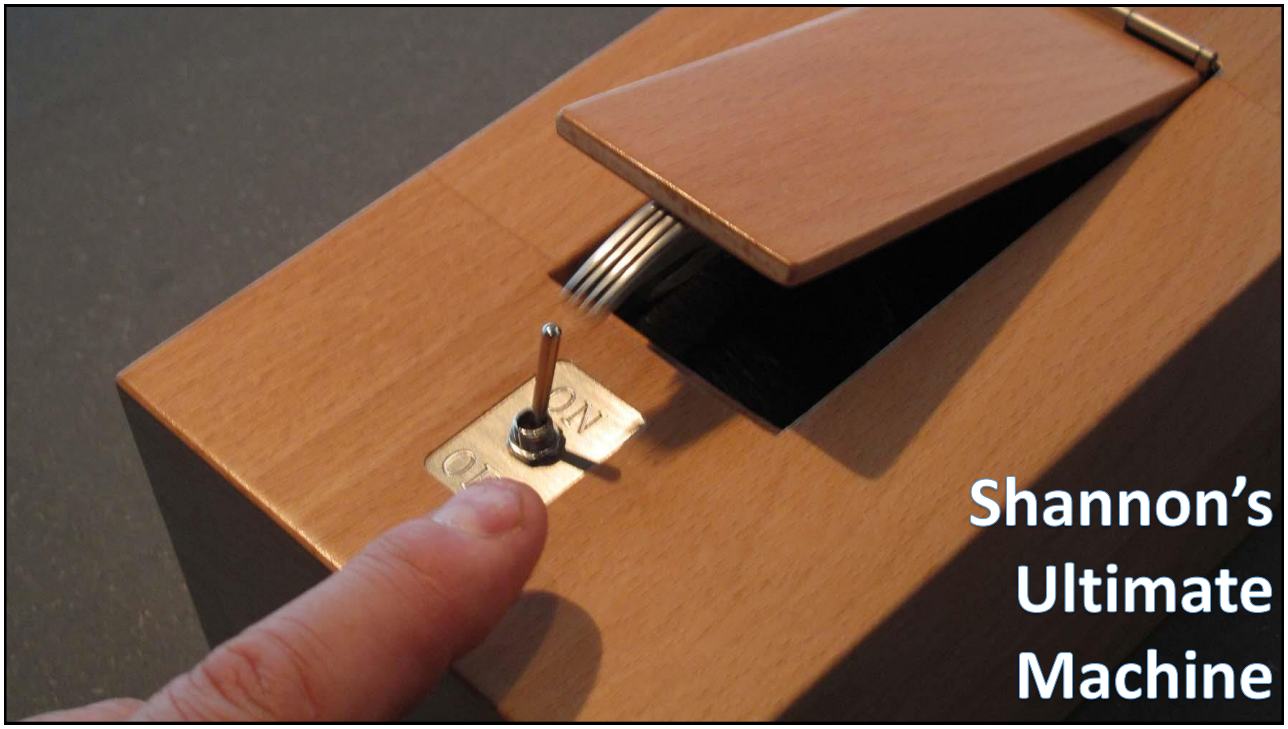
party. This is conservative for our calculation since the machine should calculate out to checkmate, not resignation. However, even at this figure there will be 10^{120} variations to be calculated from the initial position. A machine operating at the rate of one variation per micro-microsecond would require over 10^{90} years to calculate its first move!

Solving Chess

- Shannon estimated 10^{120} possible *variations*

- Atoms in the universe: 10^{80}
- Seconds in 1 year: $\pi\ 10^{7}$
- Nanoseconds in 1 second: 10^{9}
- Years since the big bang: 10^{10}

- If all atoms in the universe had been doing static evaluation at nanosecond speed since the big bang: 10^{106}



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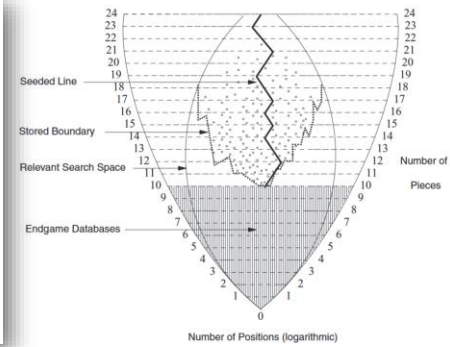
Solving Checkers

- J. Schaeffer, N. Burch, Y. Björnsson, A. Kishimoto, M. Müller, R. Lake, P. Lu, S. Sutphen, "Checkers Is Solved", 2007
- *Only* 500,995,484,682,338,672,639 positions

The game of checkers has roughly 500 billion billion possible positions (5×10^{20}). The task of solving the game, determining the final result in a game with no mistakes made by either player, is daunting. Since 1989, almost continuously, dozens of computers have been working on solving checkers, applying state-of-the-art artificial intelligence techniques to the proving process. This paper announces that checkers is now solved: Perfect play by both sides leads to a draw. This is the most challenging popular game to be solved to date, roughly one million times as complex as Connect Four. Artificial intelligence technology has been used to generate strong heuristic-based game-playing programs, such as Deep Blue for chess. Solving a game takes this to the next level by replacing the heuristics with perfection.

Pieces	Number of positions
1	120
2	6,972
3	261,224
4	7,092,774
5	148,688,232
6	2,503,611,964
7	34,779,531,480
8	406,309,208,481
9	4,048,627,642,976
10	34,778,882,769,216
Total 1–10	39,271,258,813,439
11	259,669,578,902,016
12	1,695,618,078,654,976
13	9,726,900,031,328,256
14	49,134,911,067,979,776
15	218,511,510,918,189,056
16	852,888,183,557,922,816
17	2,905,162,728,973,680,640
18	8,568,043,414,939,516,928
19	21,661,954,506,100,113,408
20	46,352,957,062,510,379,008
21	82,459,728,874,435,248,128
22	118,435,747,136,817,856,512
23	129,406,908,049,181,900,800
24	90,072,726,844,888,186,880
Total 1–24	500,995,484,682,338,672,639



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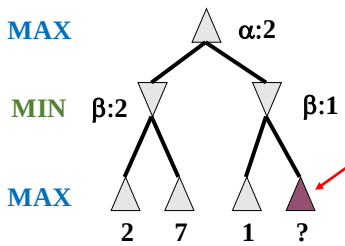
1959–1962: The Kotok-McCarthy Program

- A.k.a., "A Chess Playing Program for the IBM 7090 Computer"
- Shannon Type-B (selective search)
- Alpha-beta pruning

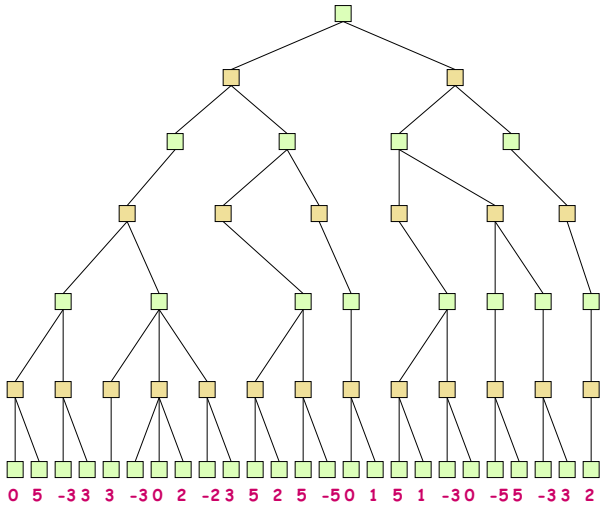
Alpha-beta Pruning

- **"If you have an idea that is surely bad, don't take the time to see how truly awful it is"** (Pat Winston, MIT)
- Reinvented a number of times by Richards, Hart, Levin, Edward, Newell, Simon, McCarty, Kotok, Samuel…
- Refined by Knuth and Moore



- **We don't need to compute the value at this node**
- No matter what it is, it can't affect value of the root node
- Compute upper (α) **&** lower (β) bounds on final mini-max values as we go to identify such cases

Alpha-beta Pruning



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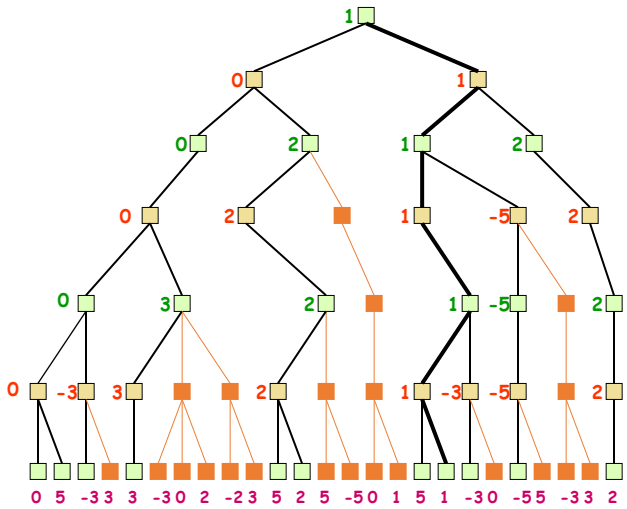
With alpha-beta we avoided computing a static evaluation metric for 14 of the 25 leaf nodes



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The Levy—McCarthy Bet

- In 1969 chess master David Levy bet **$1000** with John McCarthy that he could defeat any chess playing program in the next **10 years**
- Levy won the bet — in 1979 he defeated the best chess programs of the day

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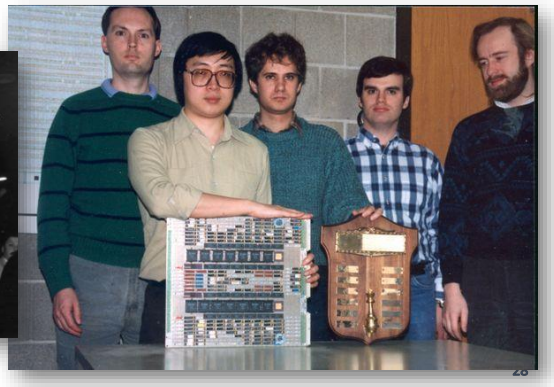
The Levy—McCarthy Bet (again)

- In 1969 Levy extended his bet for the next 10 years
- He eventually lost the bet to **Deep Though**



Feng-hsiung Hsu
許峰雄
C.B. (Crazy Bird)

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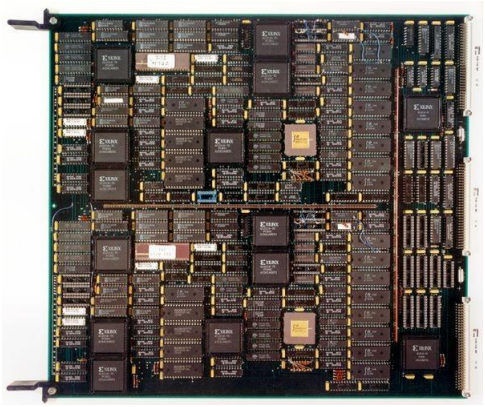
Deep Thought

- Feng-hsiung Hsu's special-purpose **chess chip**
  - Evaluate **500M** position/s
  - Horizon: **10-11** moves + "extensions"
  - Once found checkmate in **35** moves**!**
- First machine to beat a grandmaster in a tournament



Deep Thought (1989)

- Lost a 2-game match to then chess world champion Garry Kasparov

Suggested Readings

Douglas Adams

Guida galattica per gli autostoppisti
(Il ciclo completo e un racconto inedito)

Mondadori (1999)

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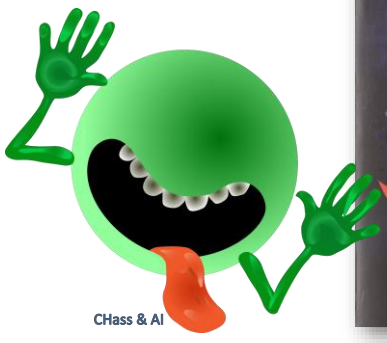

CHass & AI

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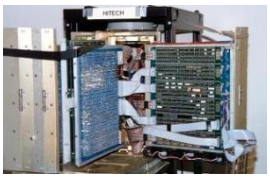
List of Early Computer/Programs

Name	Author(s)	Year	Features
The Bernstein Chess Program	Alex Bernstein et al.	1958	Shannon Type B
NSS Chess Program	Allen Newell, Cliff Shaw, Herbert Simon	1958	Shannon Type B, Alpha-Beta approx.
Kotok-McCarthy-Program	Alan Kotok, John McCarthy et al.	1962	Shannon Type B, Alpha-Beta
ITEP Chess Program	Georgy Adelson-Velsky et al.	1963	Shannon Type A, Alpha-Beta
The Greenblatt Chess Program	Richard Greenblatt et al.	1967	Shannon Type B, Transposition Table, Opening Book
The Technology Chess Program	James Gillogly et al.	1970	Shannon Type A, Pondering
Kaissa	Mikhail Donskoy et al.	1970	Shannon Type A, Bitboards, Null Move Pruning
Chess 4.0	David Slate, Larry Atkin	1973	Shannon Type A, Bitboards
Belle	Ken Thompson, Joe Condon	1978	Shannon Type A, Chess Hardware
Cray Blitz	Robert Hyatt, Albert Gower, Harry Nelson	1983	Shannon Type A, Dynamic Tree Splitting
HiTech	Hans Berliner et al.	1985	Alpha-Beta or B*, Chess Hardware
Deep Thought	Feng-hsiung Hsu et al.	1986	Shannon Type A, Chess Hardware



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Deep Blue (February 1996)

Deep Blue (February 1996)

- Six-game chess match, Kasparov won by 4-2
- **February 10th 1996**: The first time that a chess-playing computer defeated a **reigning** world champion in standard chess tournament settings (40 moves in 2h)
- The real **turning point** (a milestone in the history of artificial intelligence)

Deep Blue (February 1996)

Game #	White	Black	Result	Method of conclusion
1	**Deep Blue**	Kasparov	1–0	Resignation
2	**Kasparov**	Deep Blue	1–0	Resignation
3	Deep Blue	Kasparov	½–½	Draw by mutual agreement
4	Kasparov	Deep Blue	½–½	Draw by mutual agreement
5	Deep Blue	**Kasparov**	0–1	Resignation
6	**Kasparov**	Deep Blue	1–0	Resignation
Result: Kasparov–Deep Blue: 4–2				

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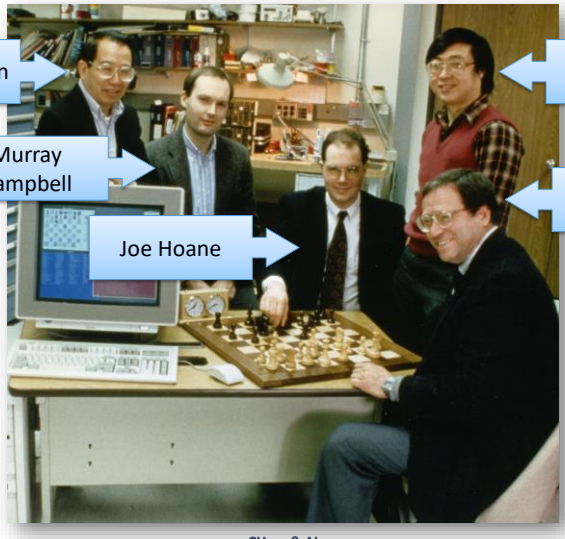
Deep Blue (1997)

Game #	White	Black	Result	Method of conclusion
1	**Kasparov**	Deep Blue	1–0	Resignation
2	**Deep Blue**	Kasparov	1–0	Resignation
3	Kasparov	Deep Blue	½–½	Draw by mutual agreement
4	Deep Blue	Kasparov	½–½	Draw by mutual agreement
5	Kasparov	Deep Blue	½–½	Draw by mutual agreement
6	**Deep Blue**	Kasparov	1–0	Resignation
Result: **Deep Blue–Kasparov: 3½–2½**				

Deep Blue

Deep Blue Team



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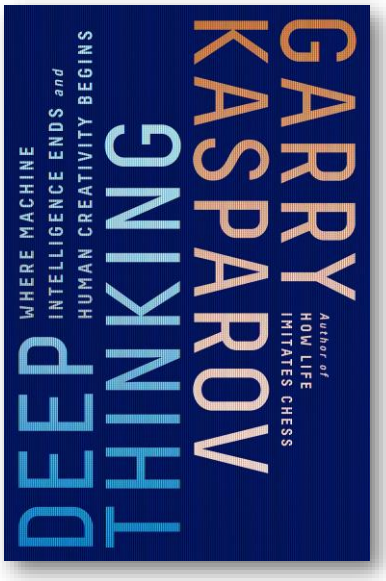
Suggested Readings

Gary Kasparov

Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins

PublicAffairs (2017)



Deep Blue

- Minimax with alpha-beta pruning
- Custom hardware
  - IBM RS/6000 SP Supercomputer (30 PowerPC 604e)
  - 480 custom 600 µm CMOS VLSI **chess chips** and "some" FPGAs
- Static evaluation (200M position/s)
  - Fast vs. Slow evaluations
  - 8,000 blocks with **adapted** weights
- Opening book: 4,000 positions (+ 700,000 GM games)
- Endgame database

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Stockfish

Domain knowledge, extensions, heuristics in TCEC world champion *Stockfish*:

Board Representation: Bitboards with Little-Endian Rank-File Mapping (LERF), Magic Bitboards, BMI2 - PEXT Bitboards, Piece-Lists, **Search:** Iterative Deepening, Aspiration Windows, Parallel Search using Threads, YBWC, Lazy SMP, Principal Variation Search. **Transposition Table:** Shared Hash Table, Depth-preferred Replacement Strategy, No PV-Node probing, Prefetch **Move Ordering:** Countermove Heuristic, Counter Moves History, History Heuristic, Internal Iterative Deepening, Killer Heuristic, MVV/LVA, SEE, **Selectivity:** Check Extensions if SEE >= 0, Restricted Singular Extensions, Futility Pruning, Move Count Based Pruning, Null Move Pruning, Dynamic Depth Reduction based on depth and value, Static Null Move Pruning, Verification search at high depths, ProbCut, SEE Pruning, Late Move Reductions, Razoring, Quiescence Search, **Evaluation:** Tapered Eval, Score Grain, Point Values Midgame: 198, 817, 836, 1270, 2521, Endgame: 258, 846, 857, 1278, 2558, Bishop Pair, Imbalance Tables, Material Hash Table, Piece-Square Tables, Trapped Pieces, Rooks on (Semi) Open Files, Outposts, Pawn Hash Table, Backward Pawn, Doubled Pawn, Isolated Pawn, Phalanx, Passed Pawn, Attacking King Zone, Pawn Shelter, Pawn Storm, Square Control, Evaluation Patterns, **Endgame Tablebases:** Syzygy TableBases

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Go (圍棋)

- Invented more than **2,500** years ago (played during Zhou dynasty)
- Played by alternately placing black and white stones on the vacant intersections of a **19×19** grid
- The objective is to control a larger territory than the opponent
- ≈**200** possible alternatives for each move, ≈10^{170} possible positions
  - … prior to 2015, the best Go programs only managed to reach amateur dan level

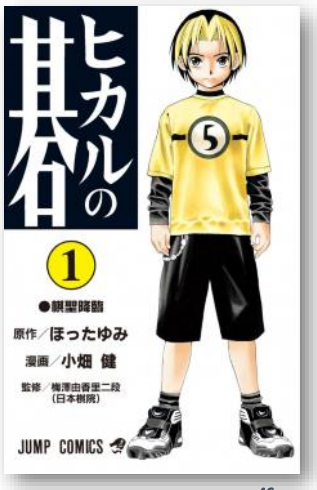
Suggested Readings

Yumi Hotta, Takeshi Obata

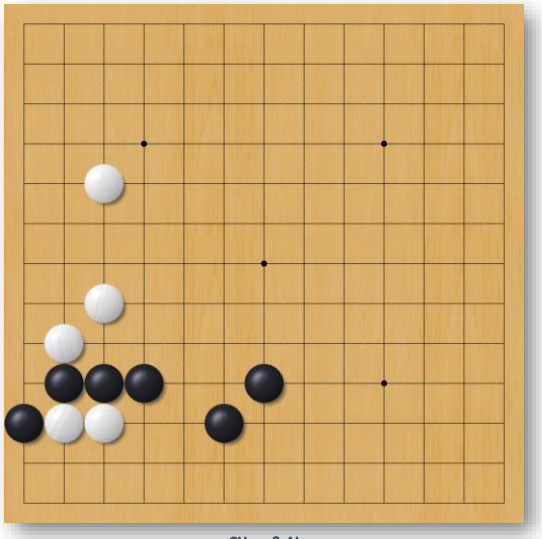
Hikaru no Go

Weekly Shōnen Jump (1999–2003)

(23 tankōbon volumes)



White to move



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Arthur Samuel (1959)

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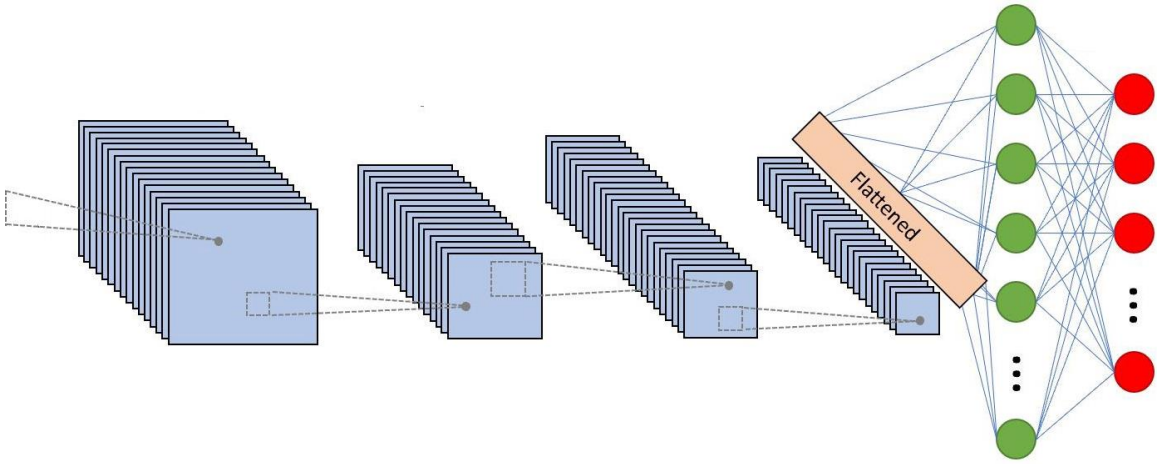
Neural Network (1943–)



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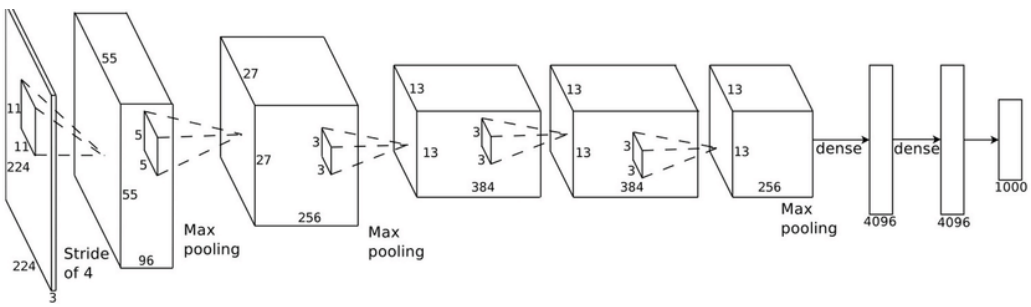

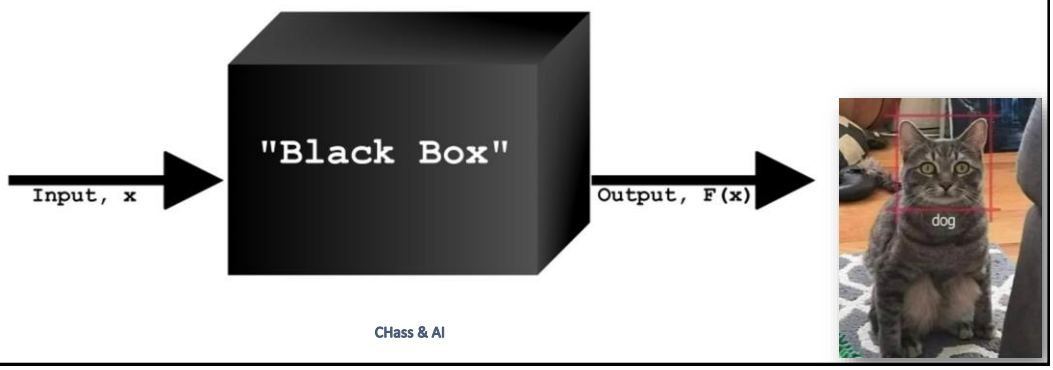

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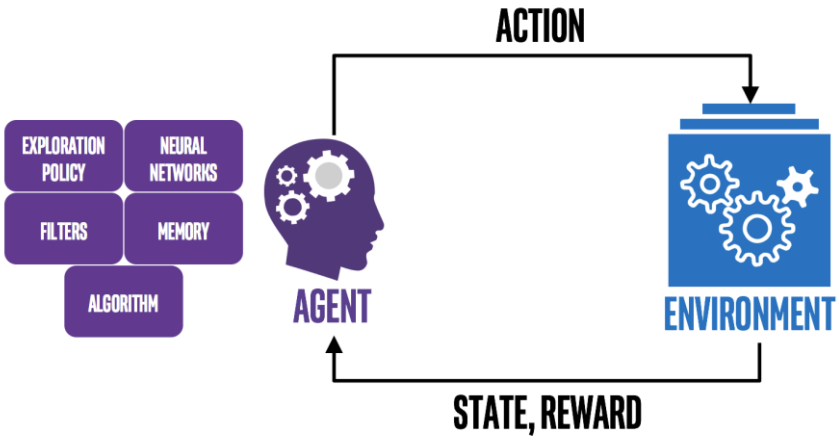
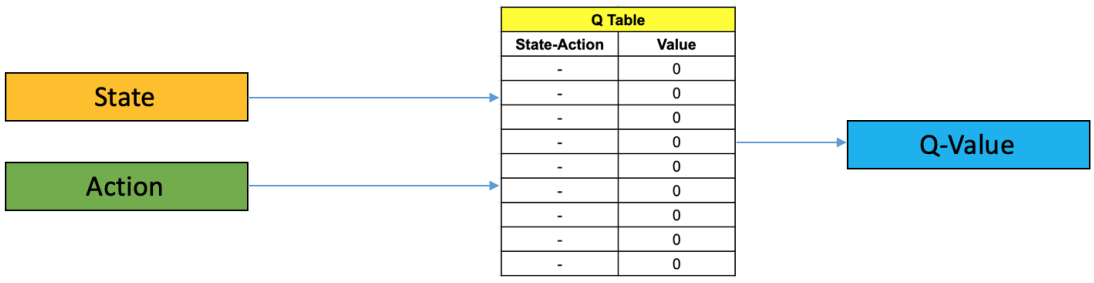
Reinforcement Learning (1960s?)

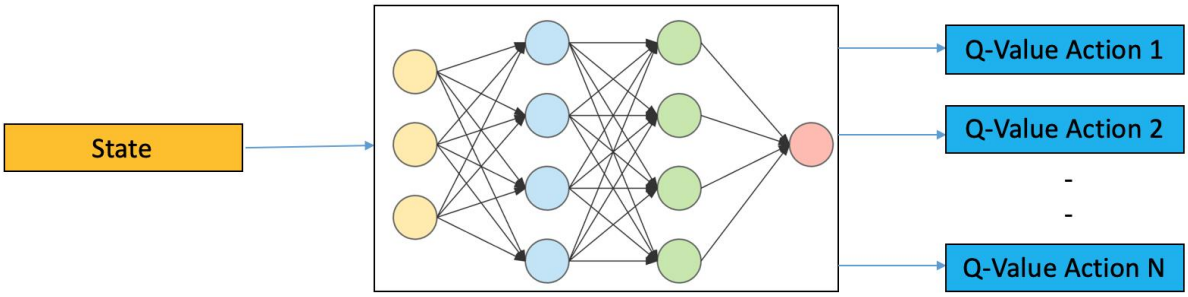


Q Learning

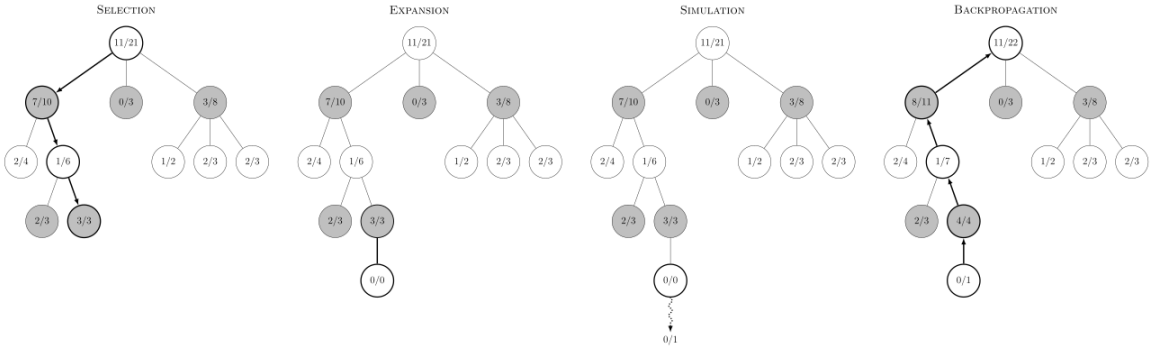


State-Action	Value
-	0
-	0
-	0
-	0
-	0
-	0
-	0
-	0
-	0

Deep Q Learning



Montecarlo Tree Search (2006)



AlphaGo (2016)

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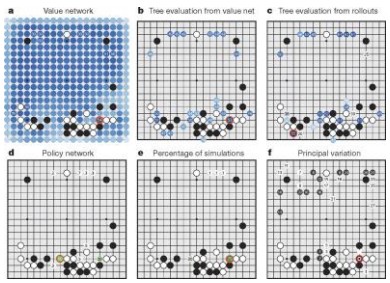
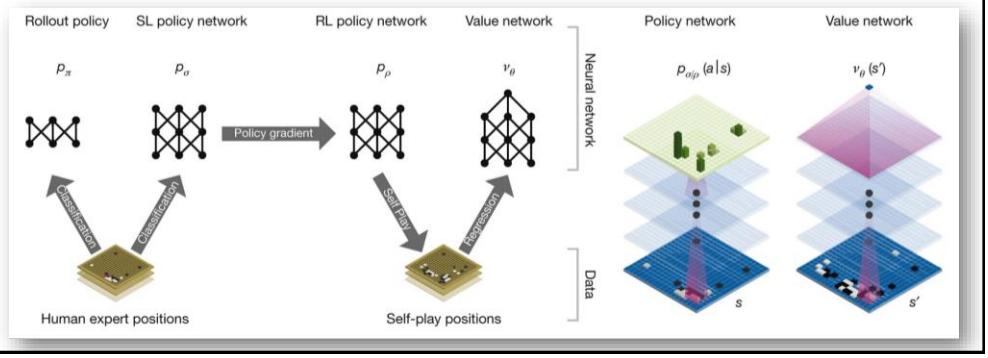
AlphaGo (2016)

- Two "deep" neural networks
- Reinforcement Learning
- Montecarlo Tree Search





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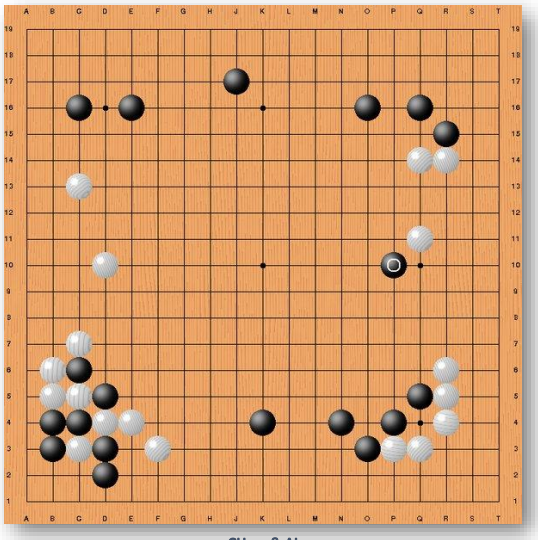
2nd Game: Move 37



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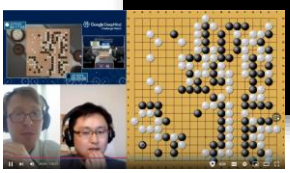
Suggested "Readings"



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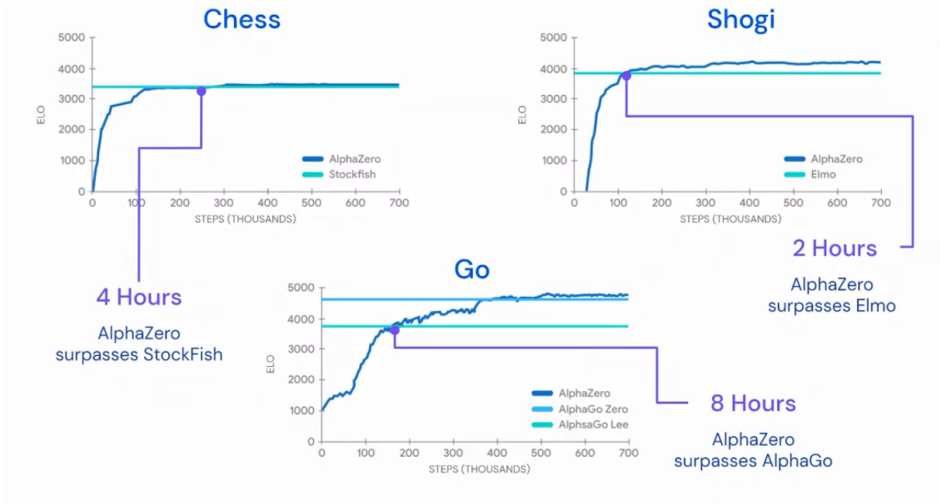
AlphaZero

- AlphaGo Fan (2015) — Won vs. Fan Hui
- AlphaGo Lee (2016) — 4:1 vs. Lee Sedol
- AlphaGo Master (2017) — 60:0 vs. professional players
- AlphaGo Zero (2017) — 100:0 vs. AlphaGo Lee; 89:11 vs. AlphaGo Master
- **AlphaZero (2017)** — 60:40 vs. AlphaGo Zero

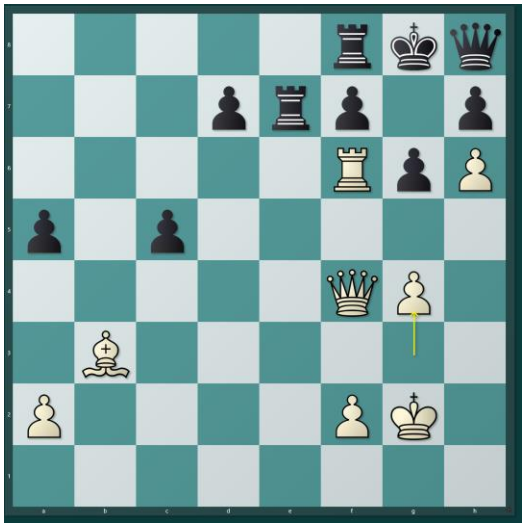
Learn from Self Play



Amount of Search Required

- State-of-the-art Chess Engine
  - **10,000,000** positions
- AlphaZero
  - **10,000** positions
- Human GM
  - **100** positions

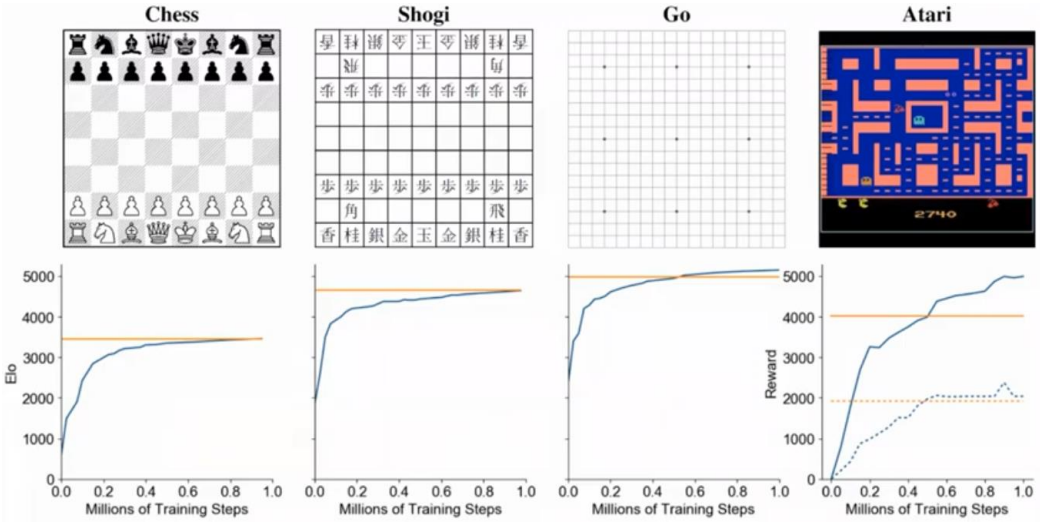
AlphaZero's Zugzwang Game



MuZero

- AlphaGo Fan (2015) — Won vs. Fan Hui
- AlphaGo Lee (2016) — 4:1 vs. Lee Sedol
- AlphaGo Master (2017) — 60:0 vs. professional players
- AlphaGo Zero (2017) — 100:0 vs. AlphaGo Lee; 89:11 vs. AlphaGo Master
- AlphaZero (2017) — 60:40 vs. AlphaGo Zero
- **MuZero (2019)**

MuZero Performances



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Computational intelligence

01URROV

A.A. 2021/22

Course Language
Inglese

Course degree
Master of science-level of the Bologna process in Ingegneria Informatica (Computer Engineering) - Torino

Course structure

Teaching	Hours
Lezioni	42
Esercitazioni in laboratorio	18

Teachers

Teacher	Status	SSD	h.Les	h.Ex	h.Lab	h.Tut	Years teaching
Squillero Giovanni	Professore Associato	ING-INF/05	42	0	0	0	2

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