

Mastering the game of Go with deep neural networks and tree search

Nature, Jan, 2016



Roadmap

What this paper is about?

- Deep Learning
- Search problem
- How to explore a huge tree (graph)

AlphaGo Video

<https://www.youtube.com/watch?v=53YLZBSS0cc>

<https://www.youtube.com/watch?v=g-dKXOlsf98>

AlphaGo vs European Champion (Fan Hui 2-Dan^{rank*})



October 5 – 9, 2015

<Official match>

- Time limit: 1 hour
- AlphaGo Wins (5:0)

AlphaGo vs World Champion (Lee Sedol 9-Dan)



March 9 – 15, 2016

<Official match>

- Time limit: 2 hours

Venue: Seoul, Four Seasons Hotel

THE ULTIMATE GO CHALLENGE

AlphaGo

Lee Sedol

2015

BORN

1983

~5 dan pro

RANK

9 dan pro

0

TITLES

47



Lee Sedol

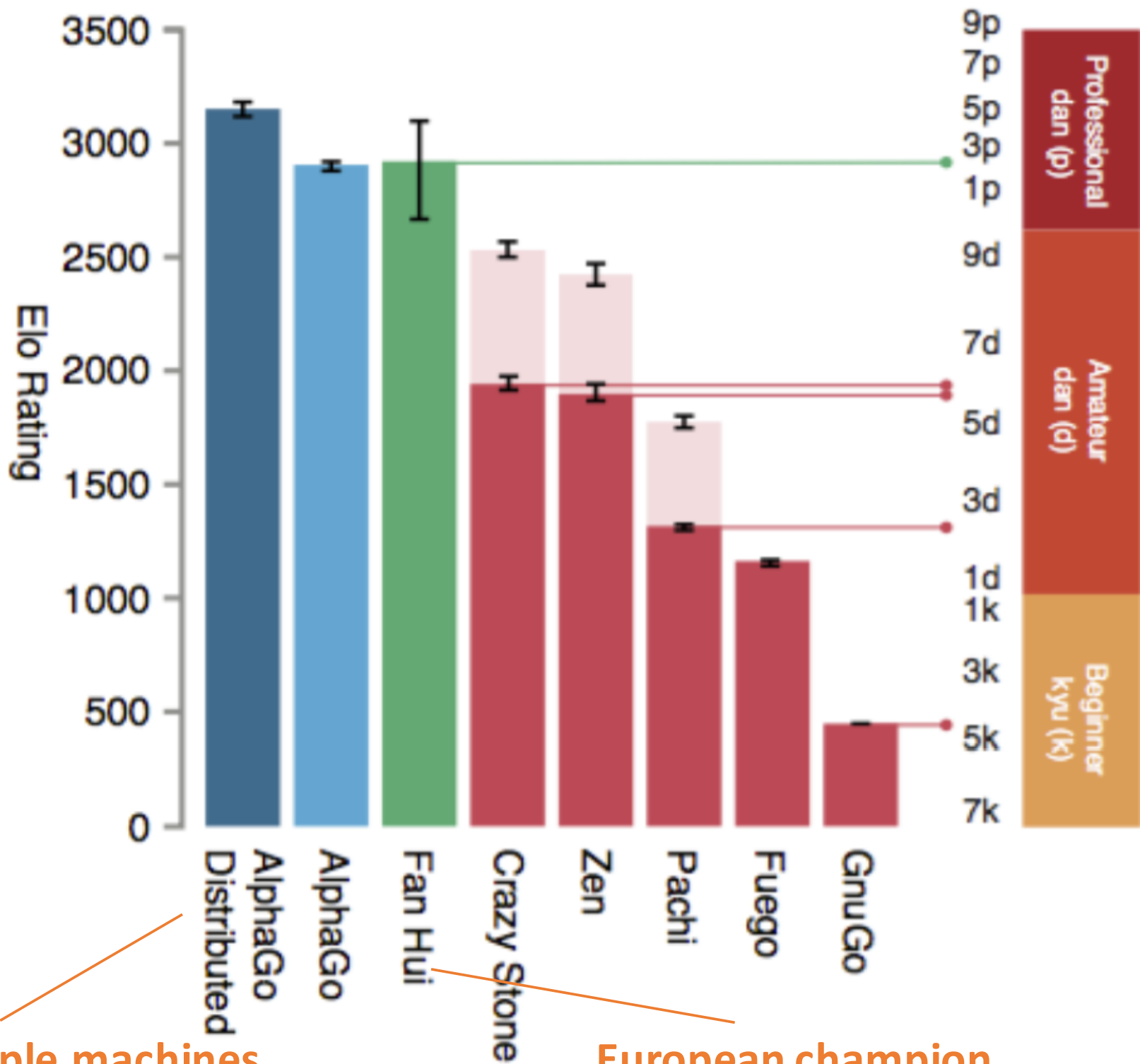
[wiki](#)



Photo source: [Maeil Economics 2013/04](#)

Lee Sedol



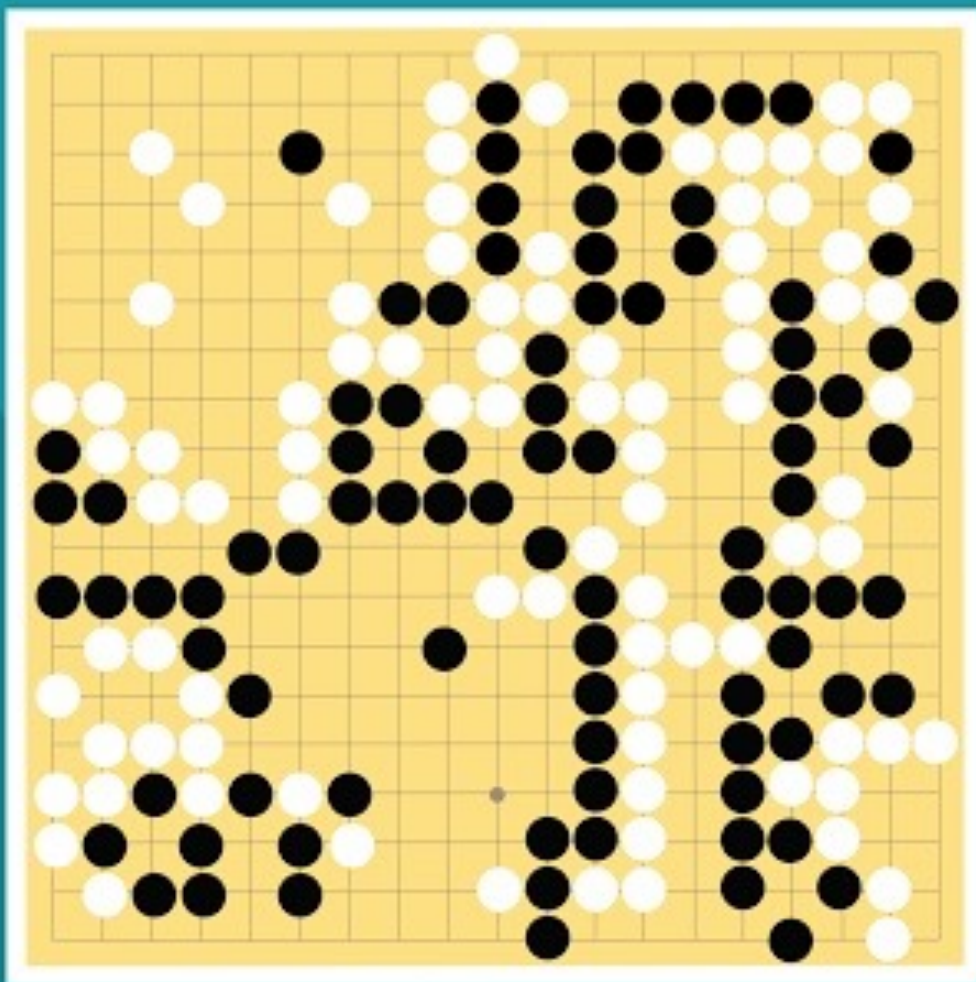


= multiple machines

European champion

The Game





THE ULTIMATE GO CHALLENGE

GAME 1 OF 5

9 MARCH 2016



AlphaGo

vs



Lee Sedol

RESULT

W+
Res

NUMBER
OF MOVES

186

TIME
WHITE

1h
55m

TIME
BLACK

1h
32m





THE ULTIMATE GO CHALLENGE

GAME 2 OF 5

10 MARCH 2016



AlphaGo
Won 2 of 5

Lee Sedol
Won 0 of 5

RESULT

**B+
Res**

NUMBER
OF MOVES

211

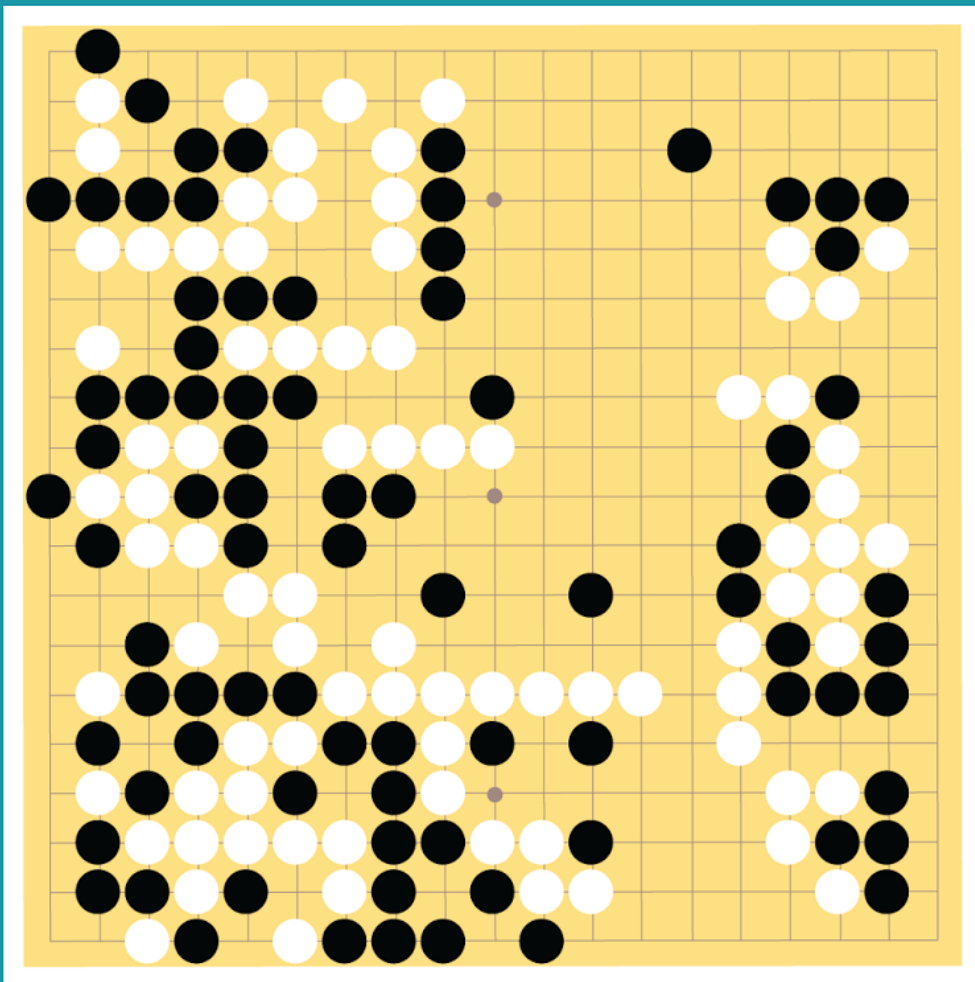
TIME
BLACK

2h+

TIME
WHITE

2h+





THE ULTIMATE GO CHALLENGE

GAME 3 OF 5

12 MARCH 2016



vs



AlphaGo

Won 3 of 5

Lee Sedol

Won 0 of 5

RESULT

W+
Res

NUMBER
OF MOVES

176

TIME
WHITE

1h
51m

TIME
BLACK

2h+





© Google

THE ULTIMATE GO CHALLENGE

GAME 4 OF 5

13 MARCH 2016




vs




AlphaGo
Won 3 of 5

Lee Sedol
Won 1 of 5



RESULT

**W+
Res**

NUMBER
OF MOVES

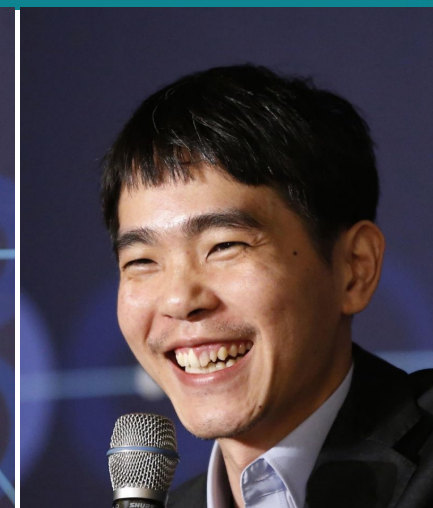
180

TIME
BLACK

**1h
59m 6s**

TIME
WHITE

2h+



Go Elo Ranking

For older ratings, check the [History](#) page. There is also a [History of top ladies](#).

Rank	Name	♂ ♀	Flag	Elo
1	Ke Jie	♂		3622
2	Google DeepMind AlphaGo			3595
3	Park Junghwan	♂		3551
4	Lee Sedol	♂		3532
5	Shi Yue	♂		3529
6	Iyama Yuta	♂		3527
7	Kim Jiseok	♂		3513
8	Zhou Ruiyang	♂		3512
9	Park Yeonghun	♂		3510
10	Mi Yuting	♂		3507
11	Lian Xiao	♂		3504
12	Tang Weixing	♂		3487
13	Tuo Jiaxi	♂		3484

<http://www.goratings.org/history/>

Lee Sedol VS Ke Jie

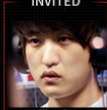
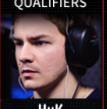
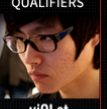
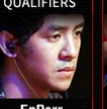
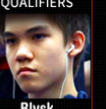


How about Other Games?

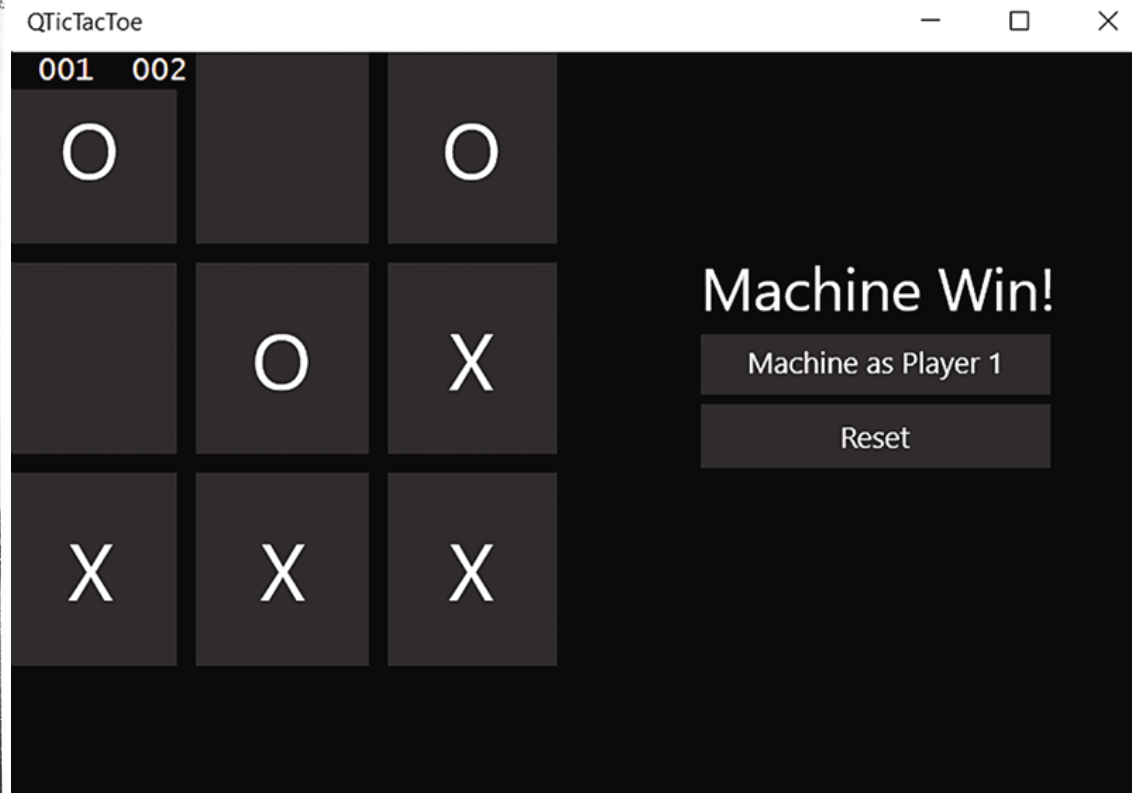
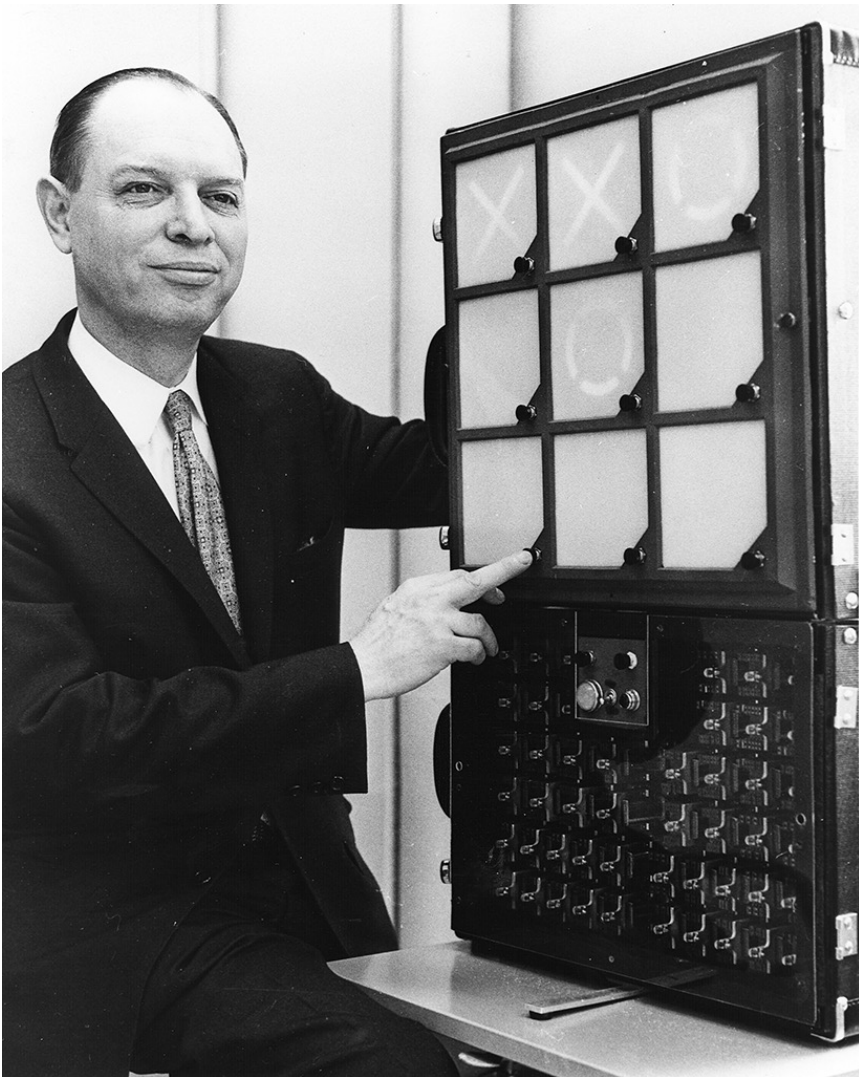


FINAL 16 PLAYERS

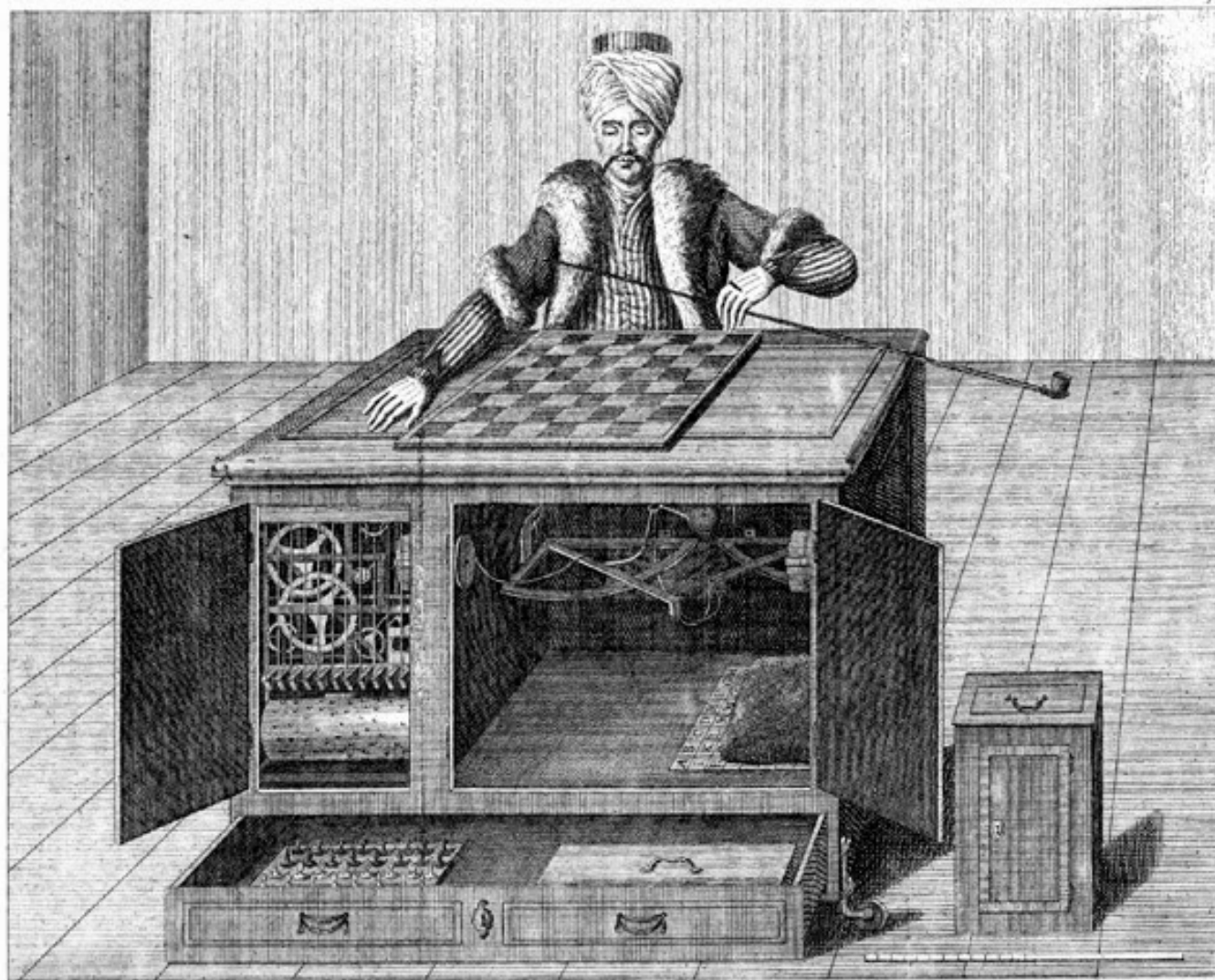


INVITED	INVITED	SOUTH KOREA QUALIFIERS	SOUTH KOREA QUALIFIERS	SOUTH KOREA QUALIFIERS	EUROPEAN QUALIFIERS	EUROPEAN QUALIFIERS	AUSTRALIAN QUALIFIERS
							
Flash	PartiG	Solar	Rogue	Journey	First	YoDa	Iaguz
South Korea	South Korea	South Korea	South Korea	South Korea	South Korea	South Korea	Australia
TAIWAN QUALIFIERS	TAIWAN QUALIFIERS	AMERICAN QUALIFIERS	AMERICAN QUALIFIERS	APAC #2 REPLACEMENT	APAC QUALIFIERS	SEA QUALIFIERS	SEA QUALIFIERS
							
Sen	Has	HuK	viOLet	Ian	Cloudy	EnDerr	Blysk
Taiwan	Taiwan	Canada	South Korea	Taiwan	China	Philippines	Singapore

Tic Tac Toe



Chess



W. de Kempelen del.

Chr. a. Mechel excud. Basilea.

P. G. Piatz sc.

Der Schach-Spieler, wie er vor dem Spiele gezeiget wird von vorne. Le Joueur d'Échecs, tel qu'on le montre avant le jeu, par devant.

Chess (1996)



Deep Blue (1996)



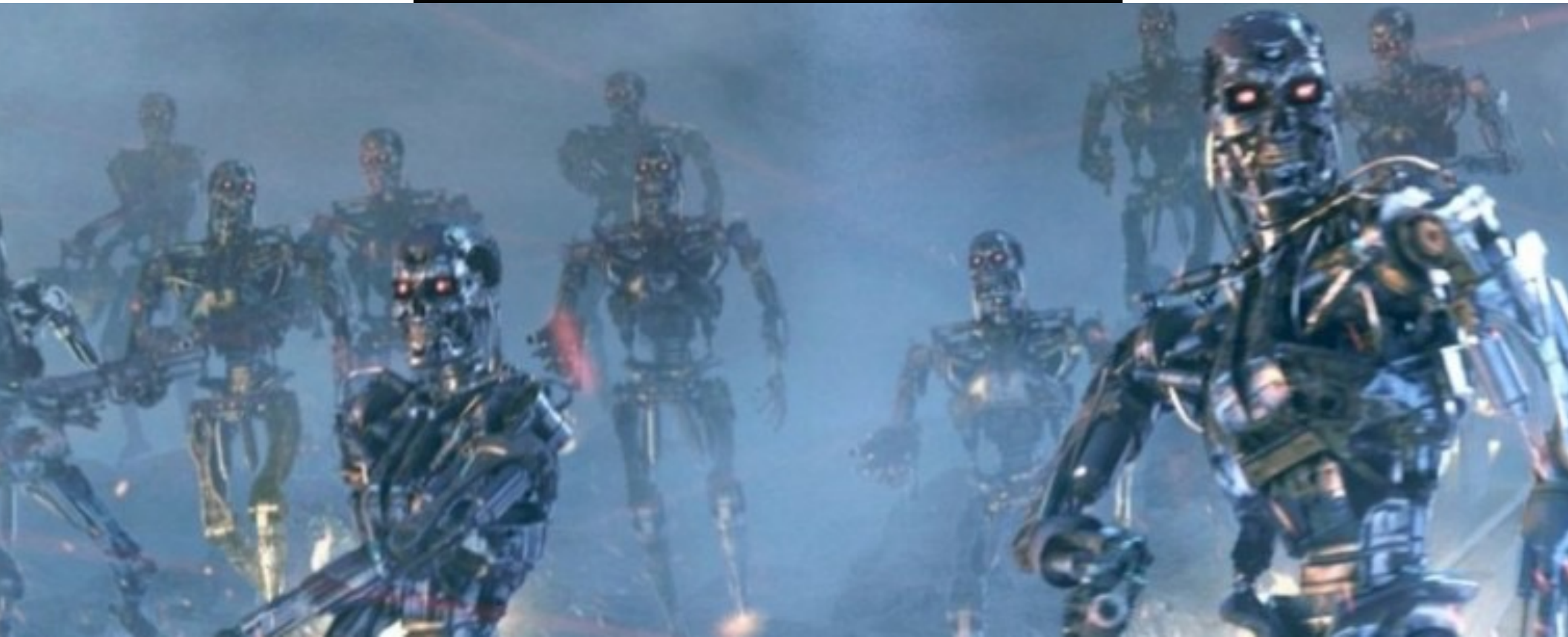
The 1996 match

Game #	White	Black	Result	Comment
1	Deep Blue	Kasparov	1-0	
2	Kasparov	Deep Blue	1-0	
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	Kasparov offered a draw after the 23rd move.
6	Kasparov	Deep Blue	1–0	
<i>Result: Kasparov–Deep Blue: 4–2</i>				

The 1997 rematch

Game #	White	Black	Result	Comment
1	Kasparov	Deep Blue	1–0	
2	Deep Blue	Kasparov	1–0	
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	
<i>Result: Deep Blue–Kasparov: 3½–2½</i>				

AlphaGo is the Skynet?



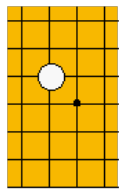
Go Game

GO

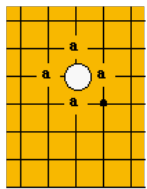
"DELUXE"
A GAME OF ORIENTAL STRATEGY



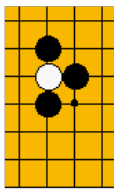
Simple Rules



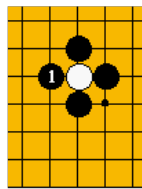
Dia. 3



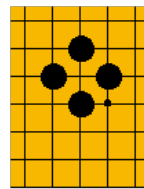
Dia. 4
liberties



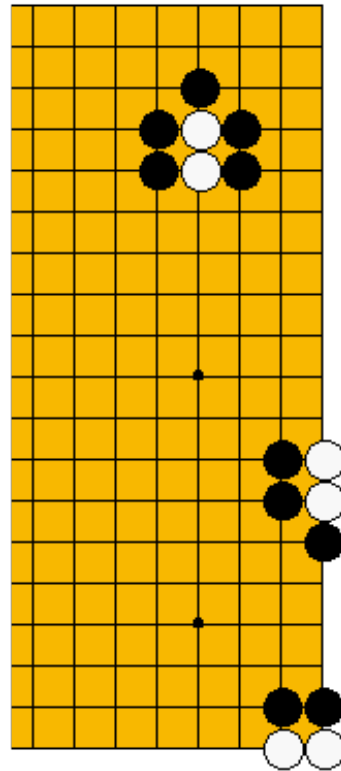
Dia. 5
atari



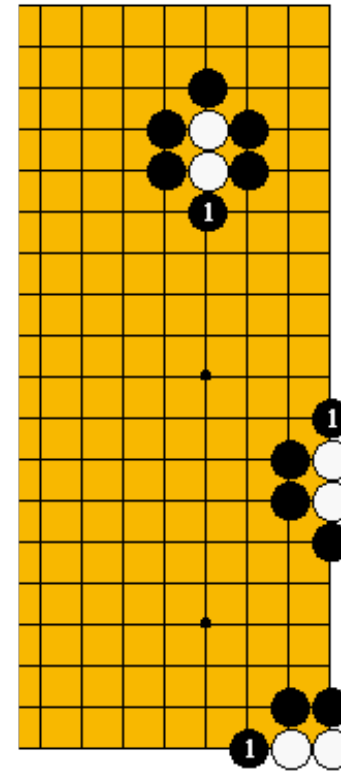
Dia. 6
capture



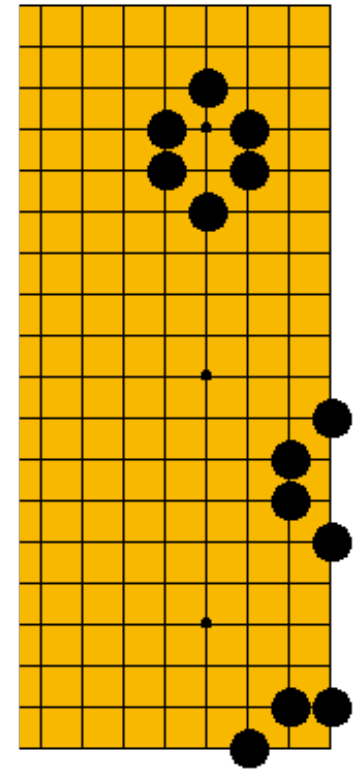
Dia. 7
result



Dia. 18

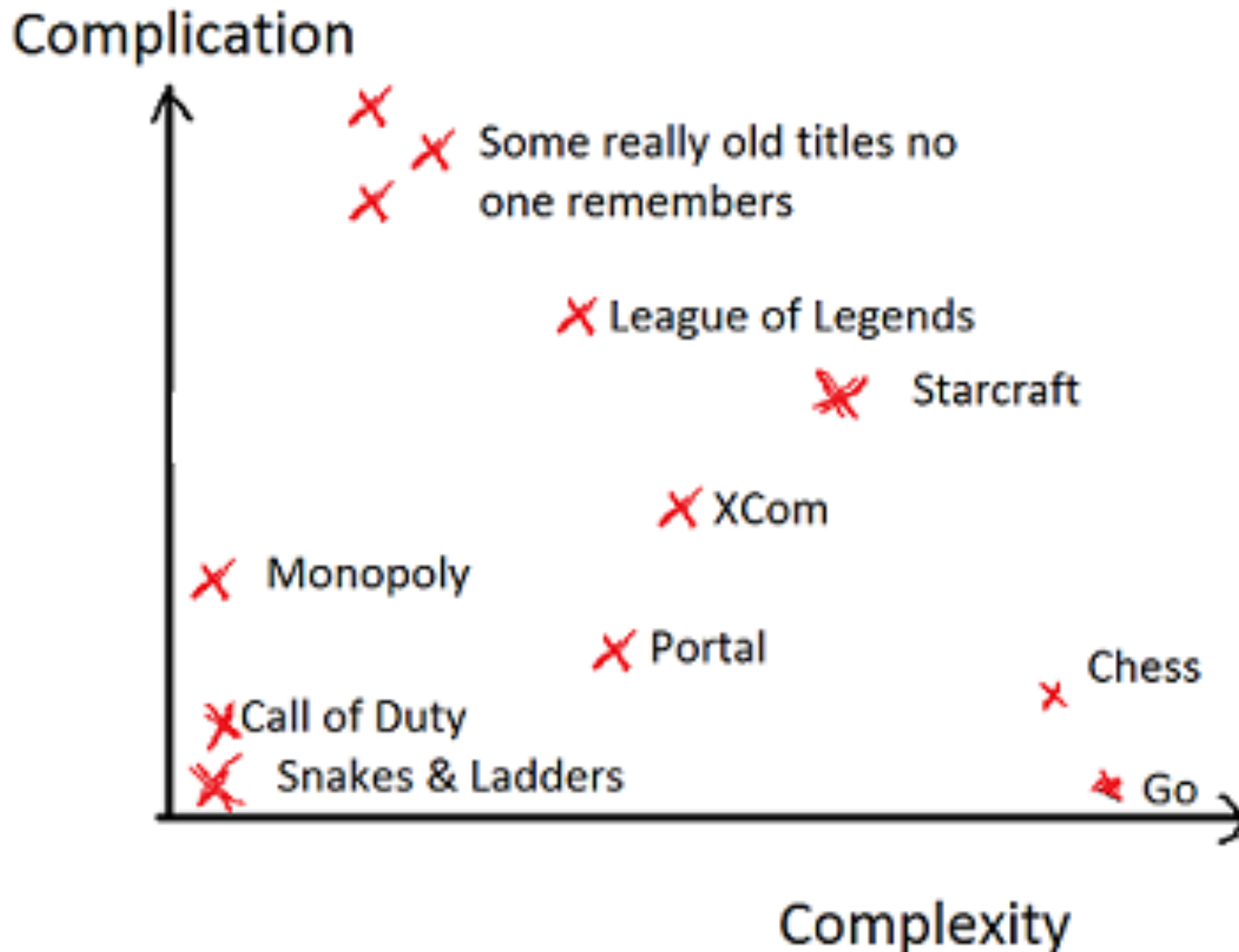


Dia. 19

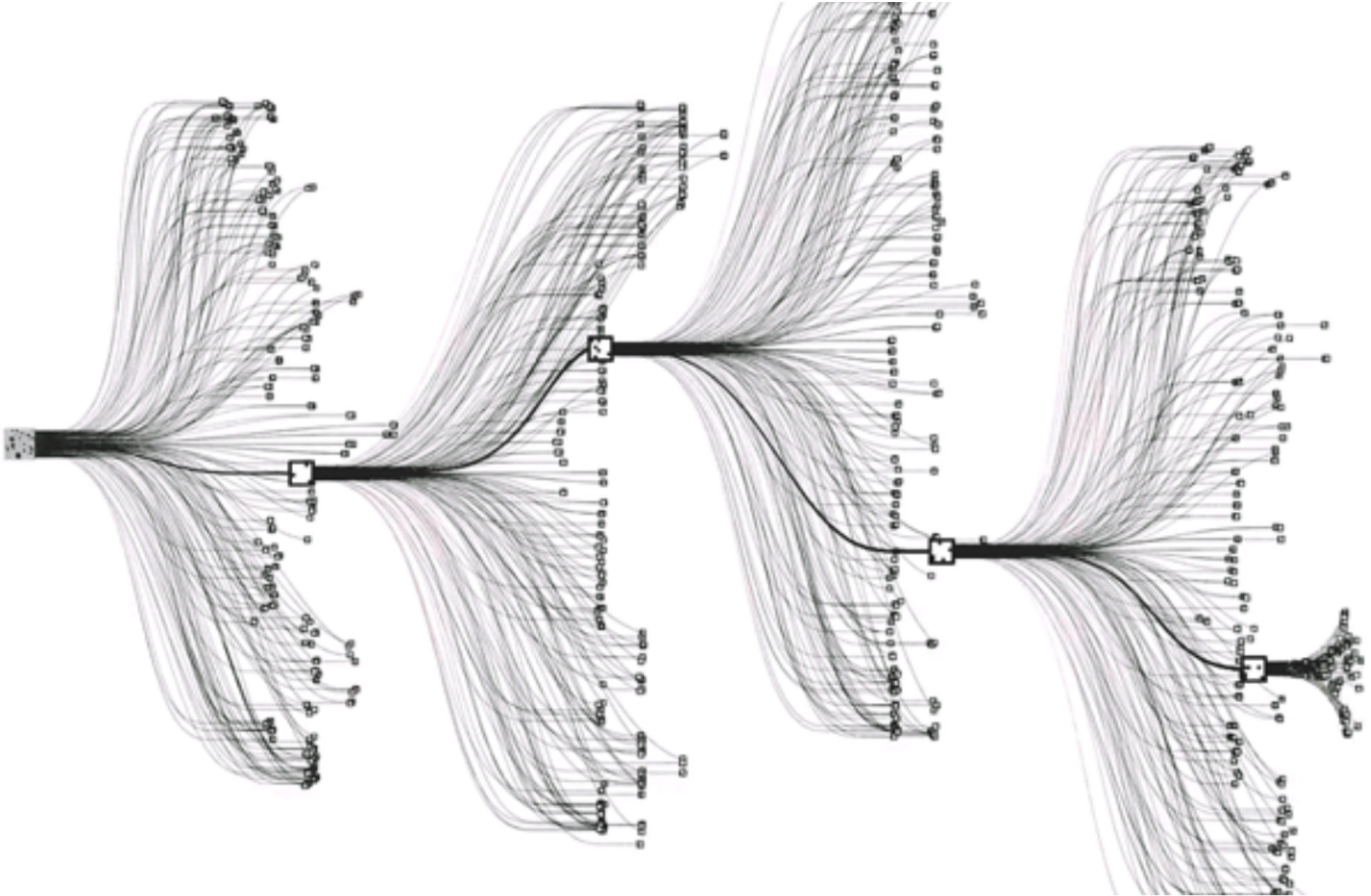


Dia. 20

High Complexity



High Complexity





Kigo



Game Move Settings Help



New



Start Game



Finish Game



Undo



Redo



Pass Move



Hint



Show Move Numbers

A B C D E F G H J

9

8

7

6

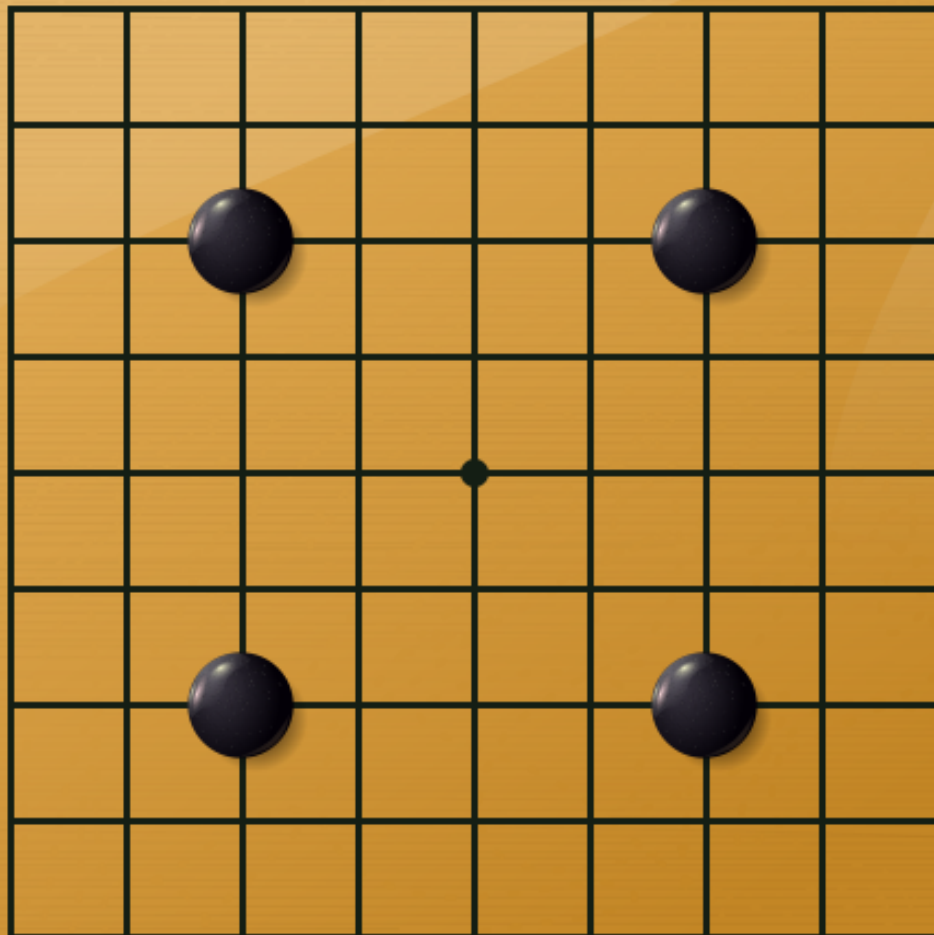
5

4

3

2

1



A B C D E F G H J

Game Setup

Board size:



Tiny (9x9)



Small (13x13)



Normal (19x19)



Custom:

19

Handicap:

4 Stones

Komi:

4.5 Points



Computer

Weak



Strong



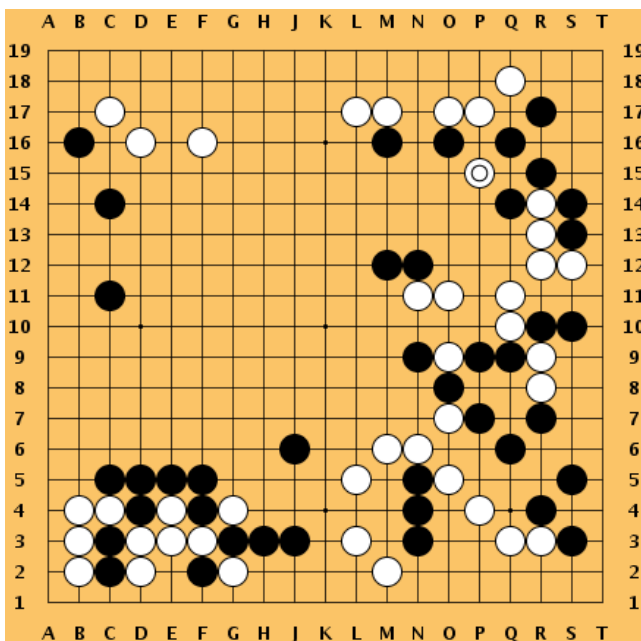
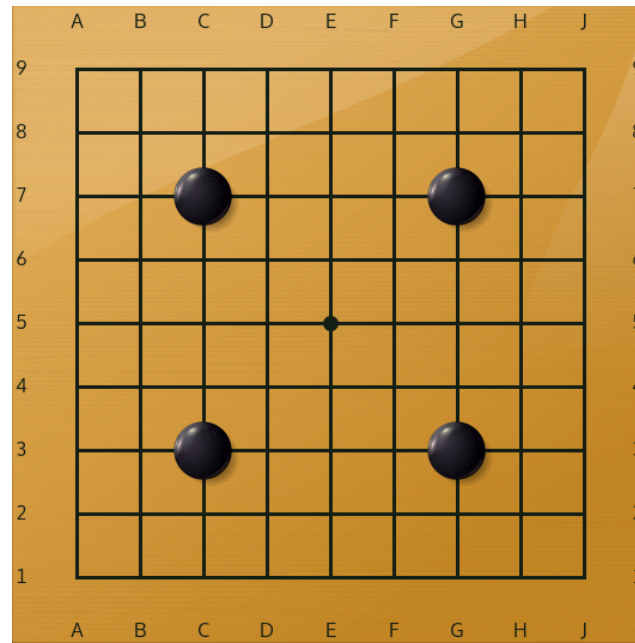
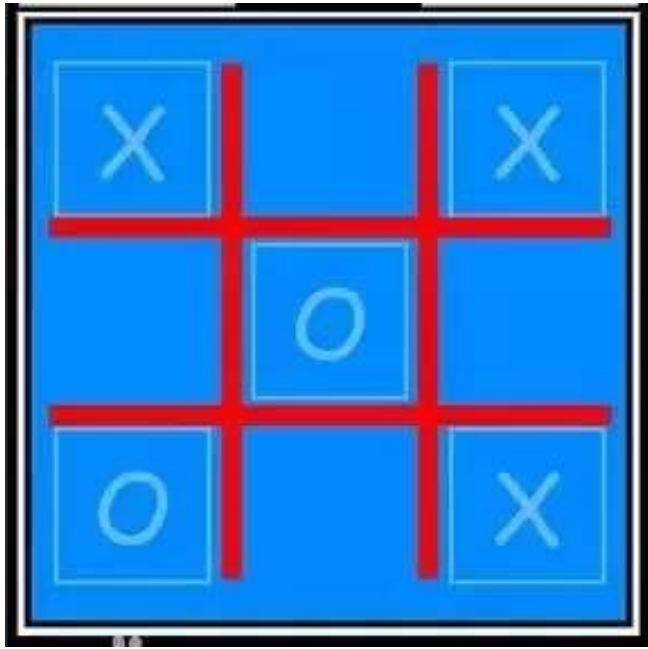
Computer

Name:

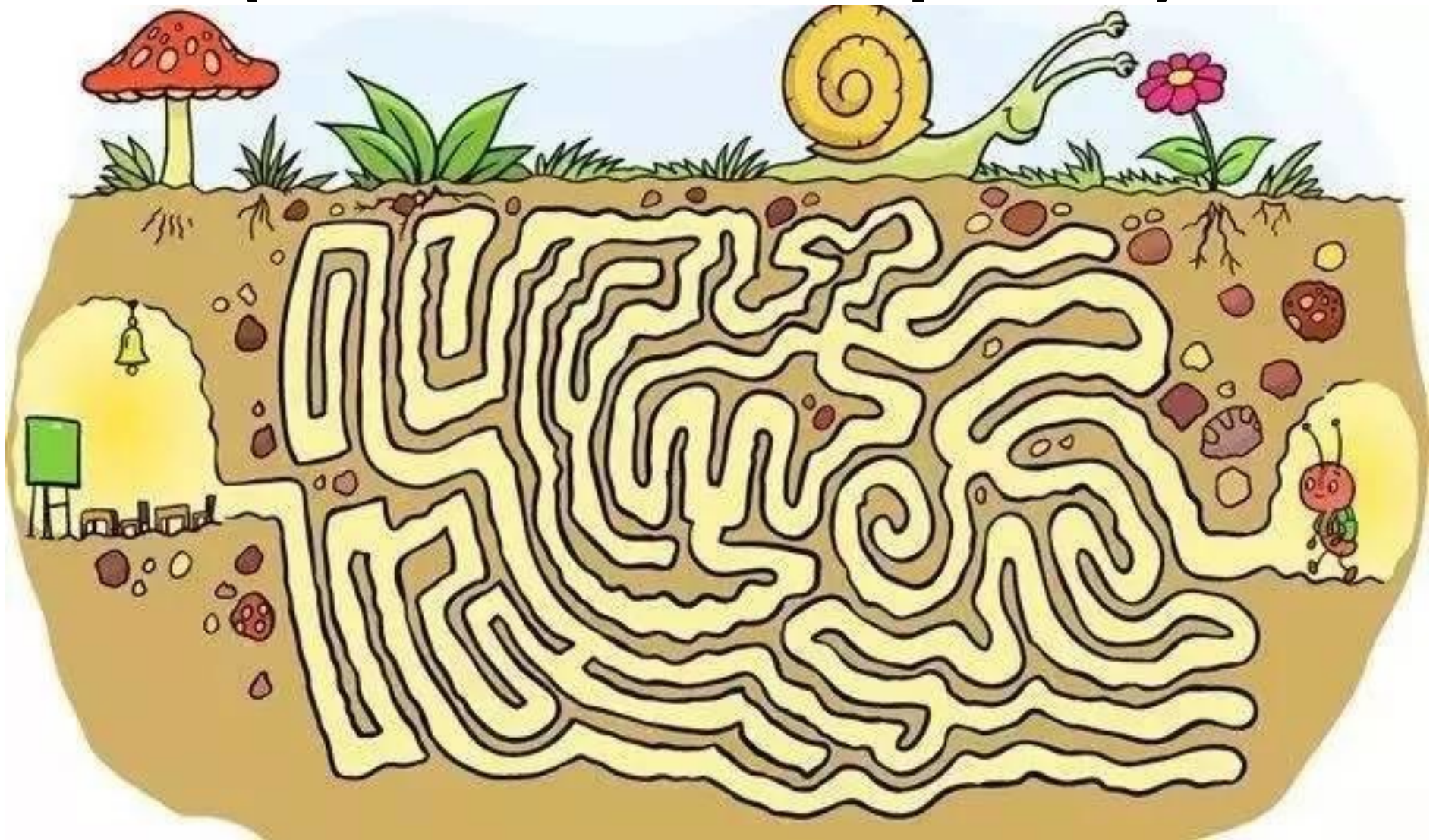
Black Player

▶ Start Game

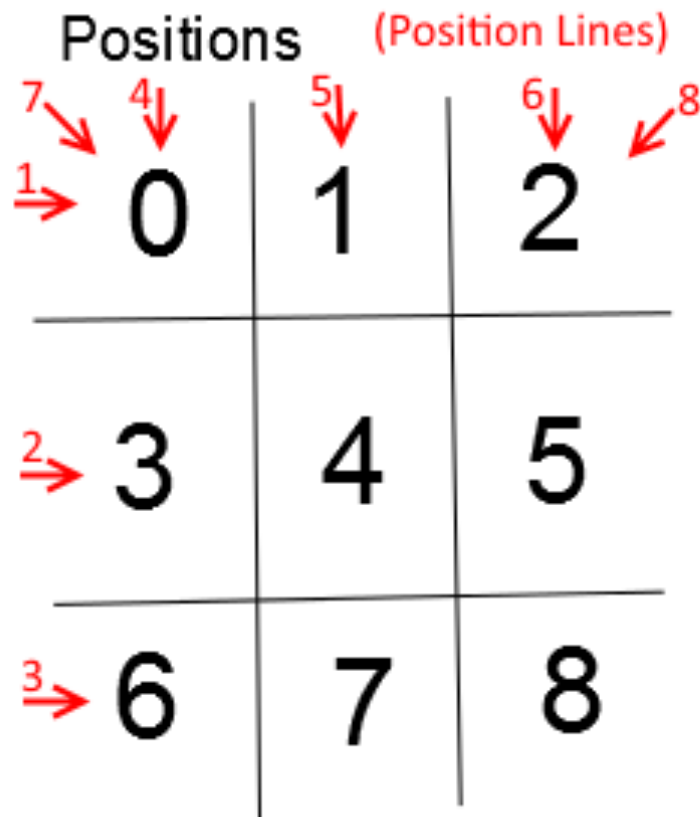
Different Games



Search Problem (the search space)



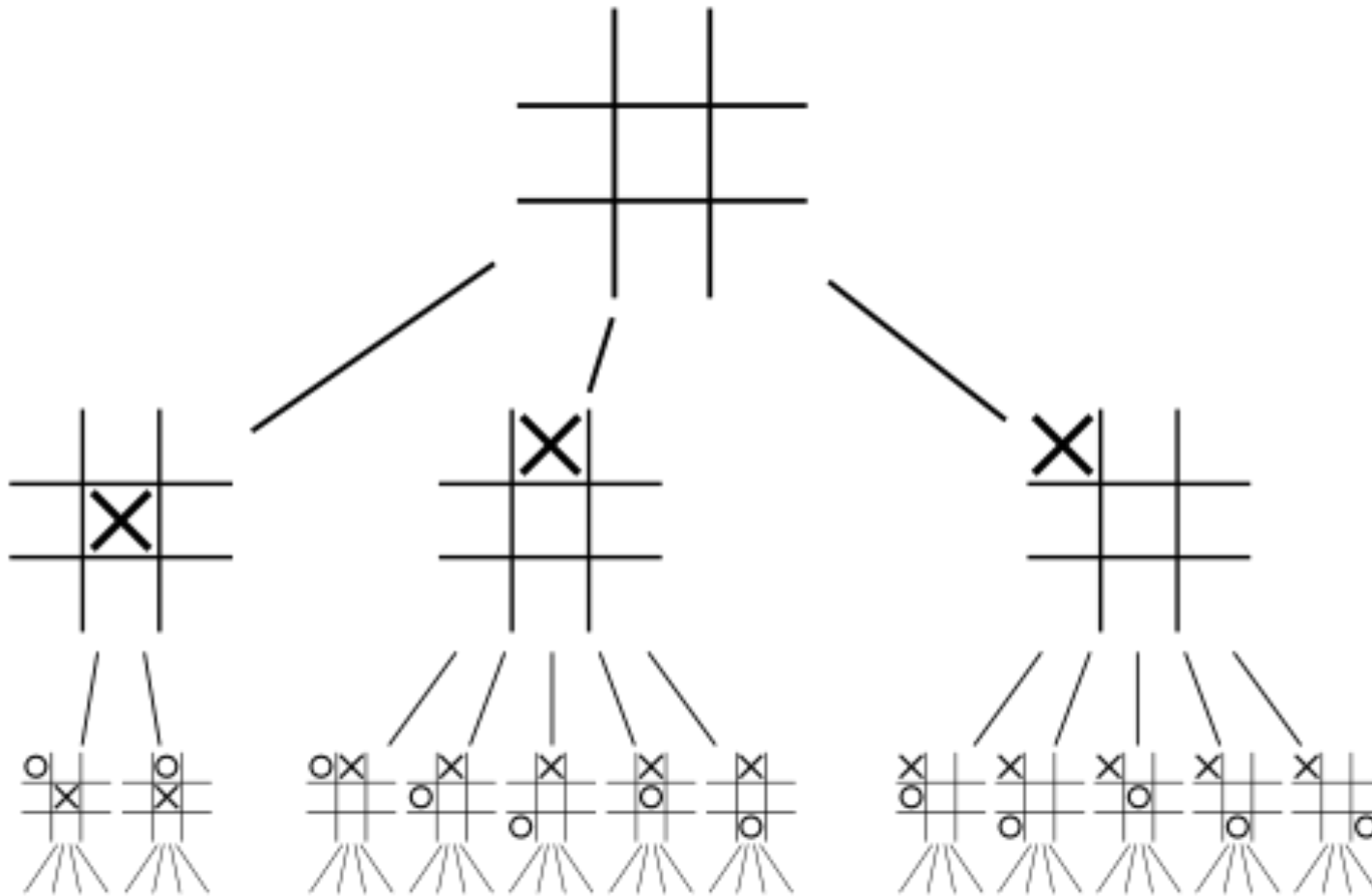
Tic Tac Toe



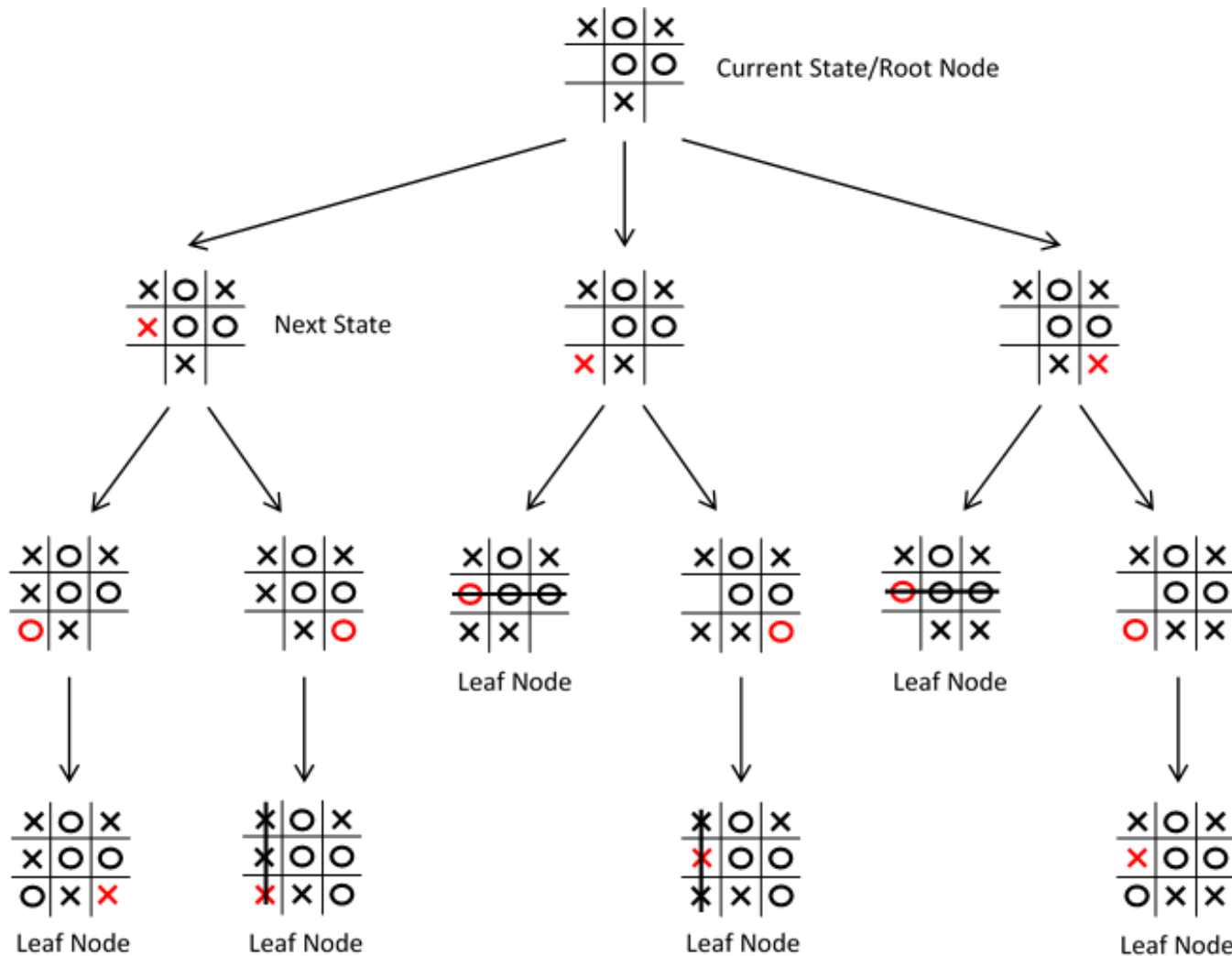
Position States

- X O

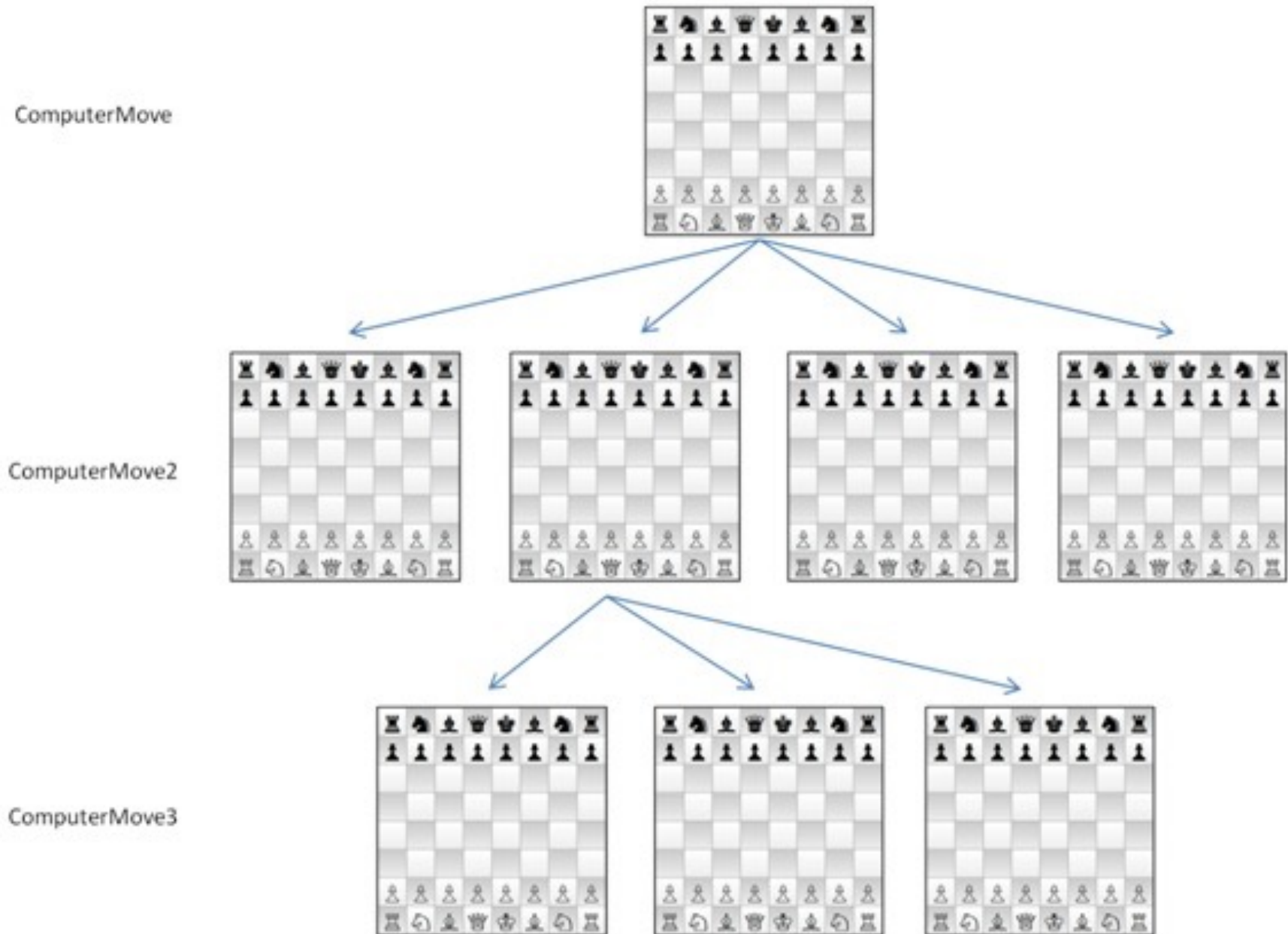
Tic Tac Toe



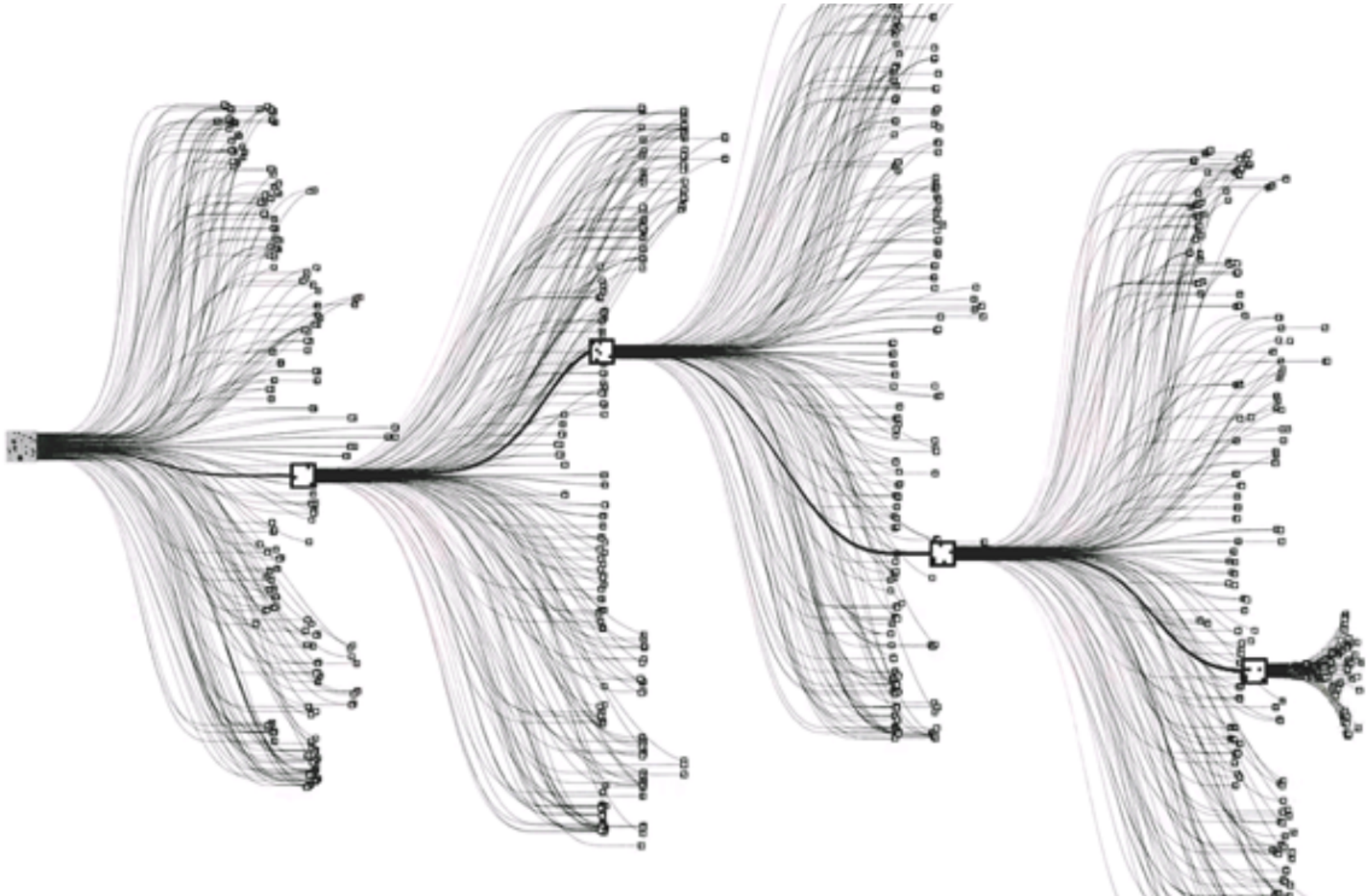
The “Tree” in Tic Tac Toe



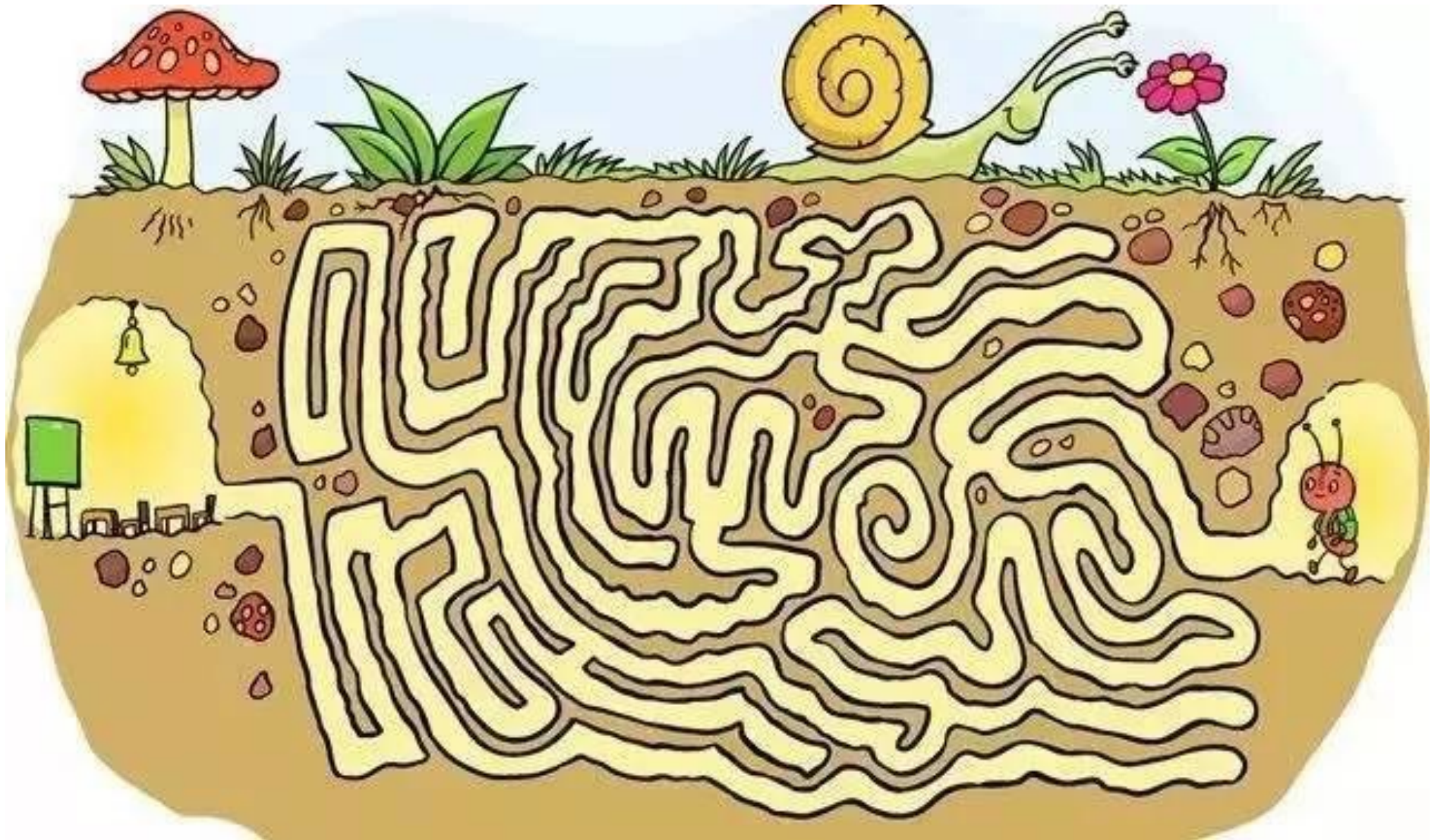
The “Tree” of Chess



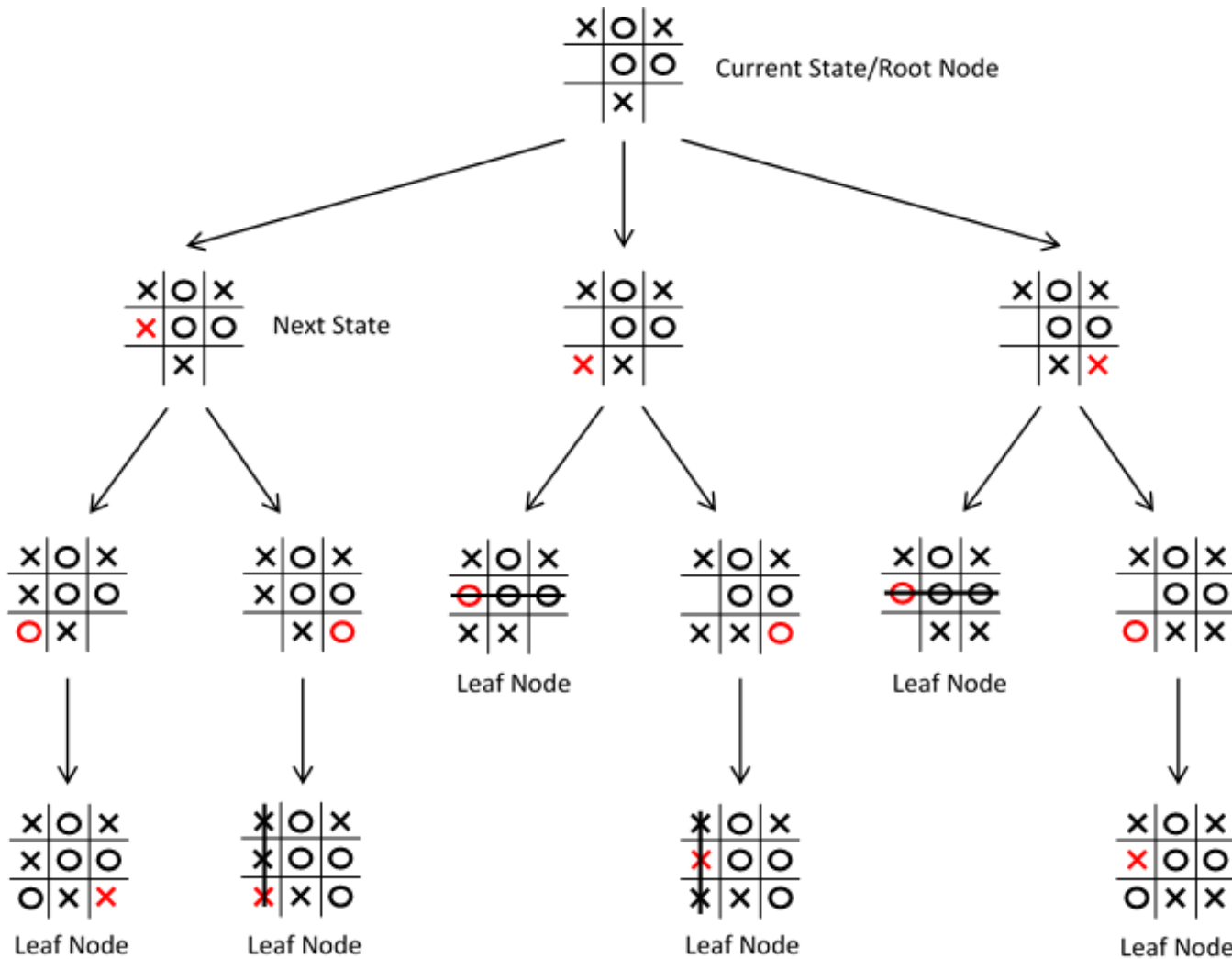
The “Tree” of Go Game



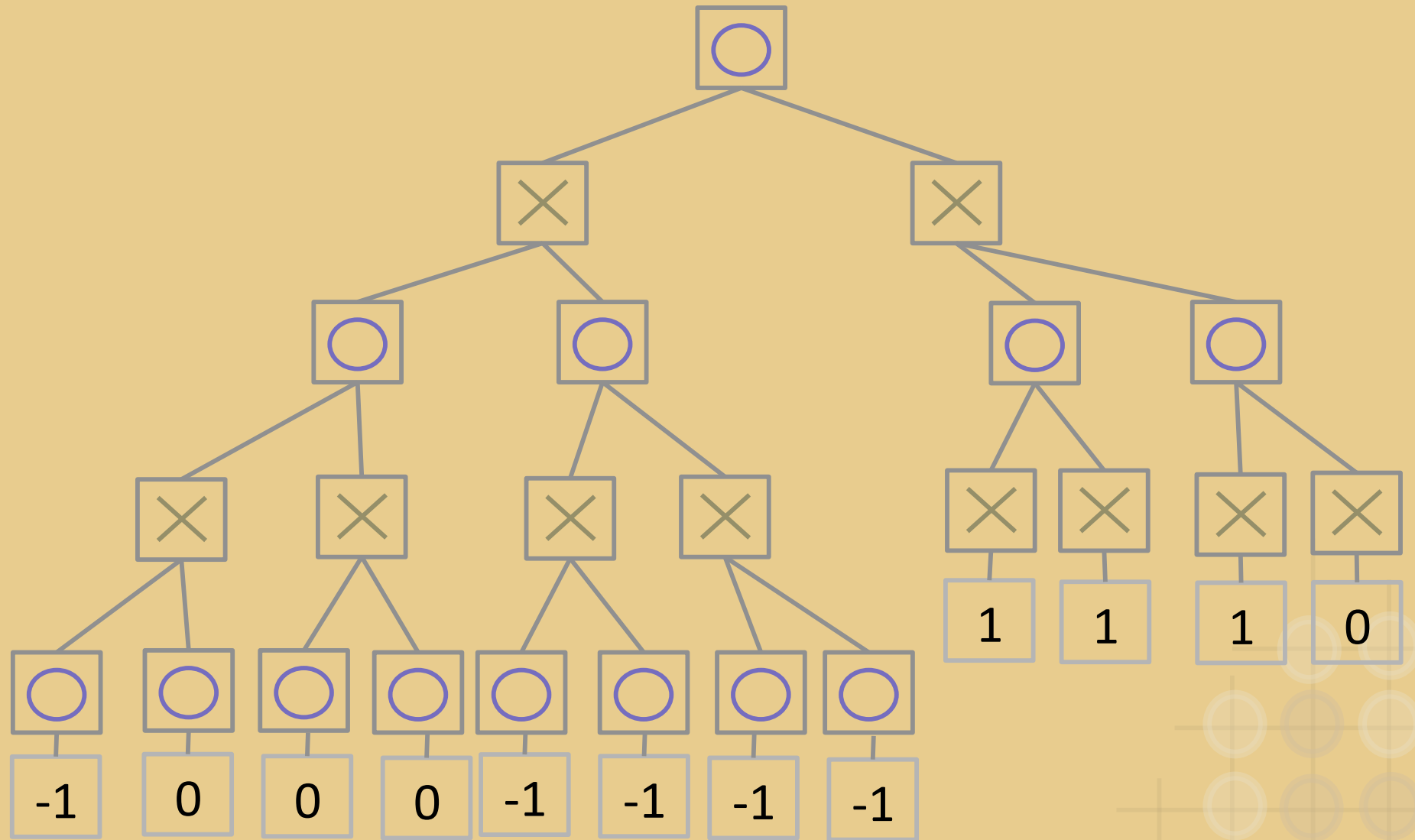
Search Problem (how to search)



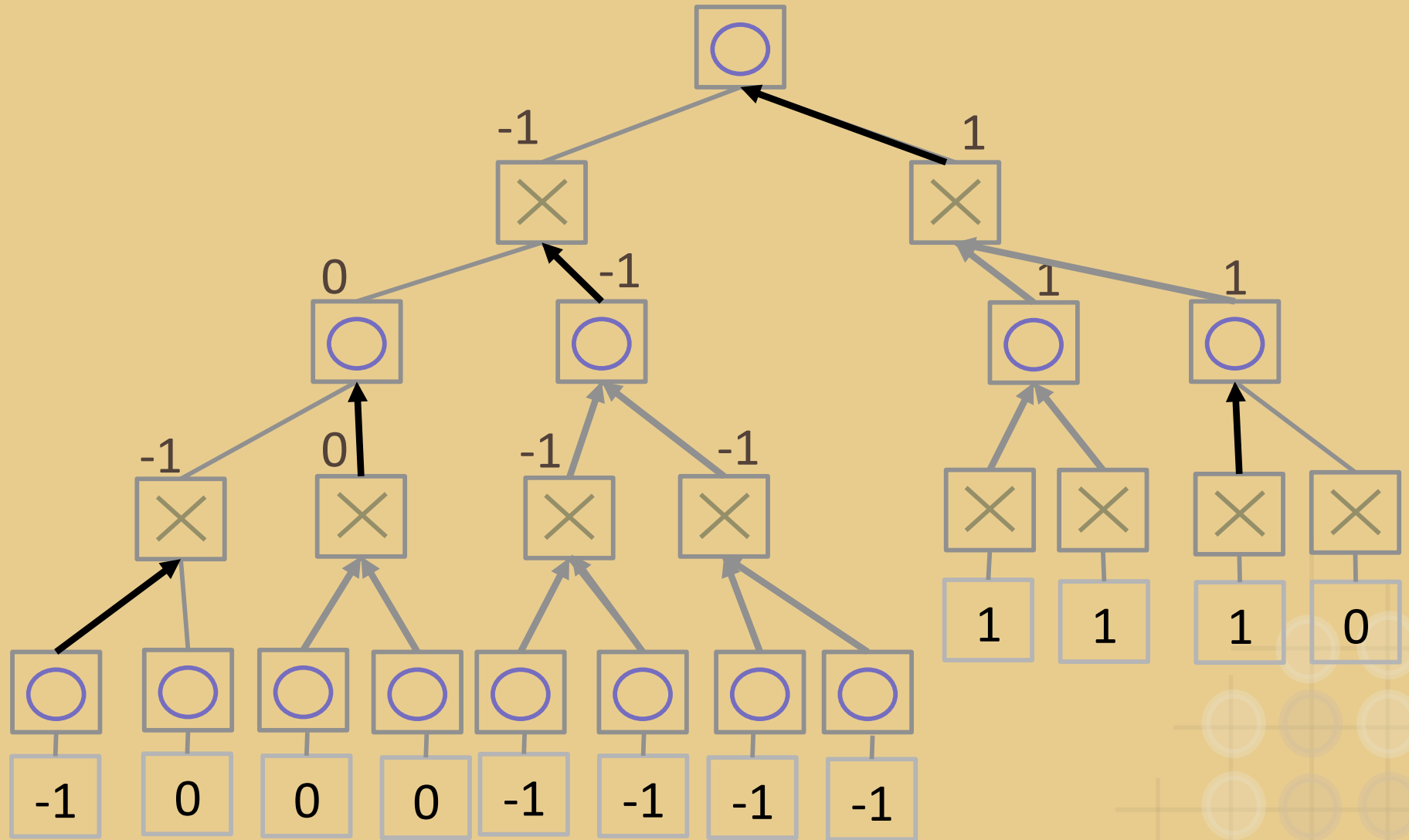
MiniMax in Tic Tac Toe



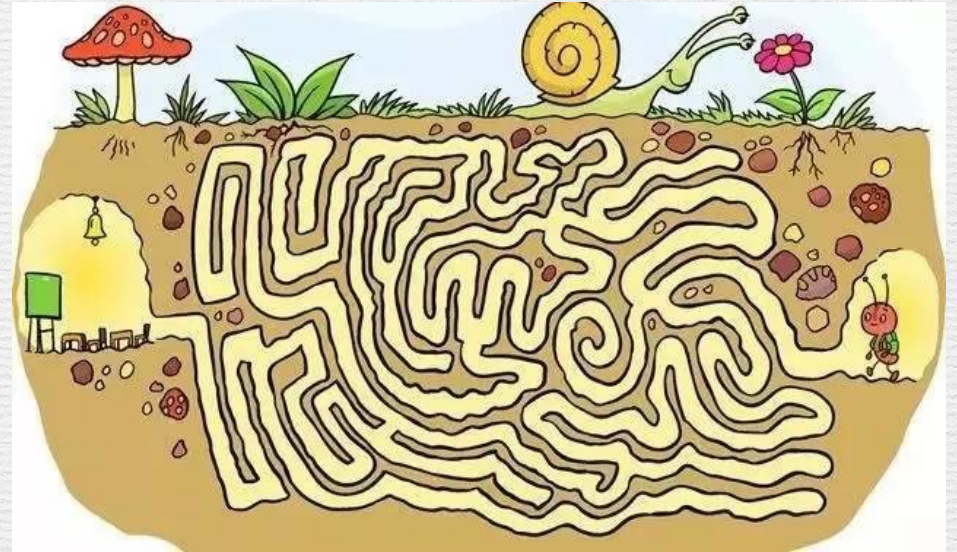
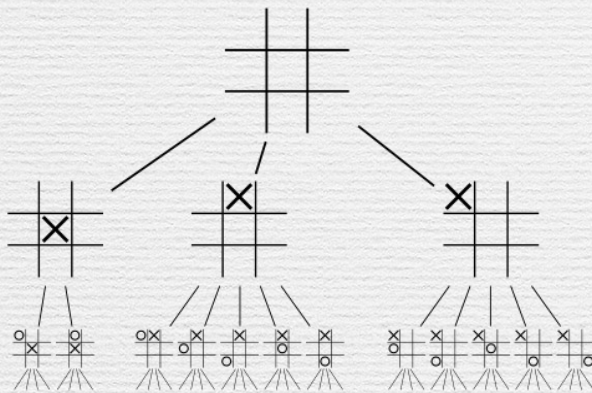
Adversarial Search – MiniMax



Adversarial Search – MiniMax



What is the problem?



1. Generate the Search Tree
2. use MinMax Search

The Size of the Tree

Tic Tac Toe:

$$b = 9, d = 9$$

Chess:

$$b = 35, d = 80$$

Go:

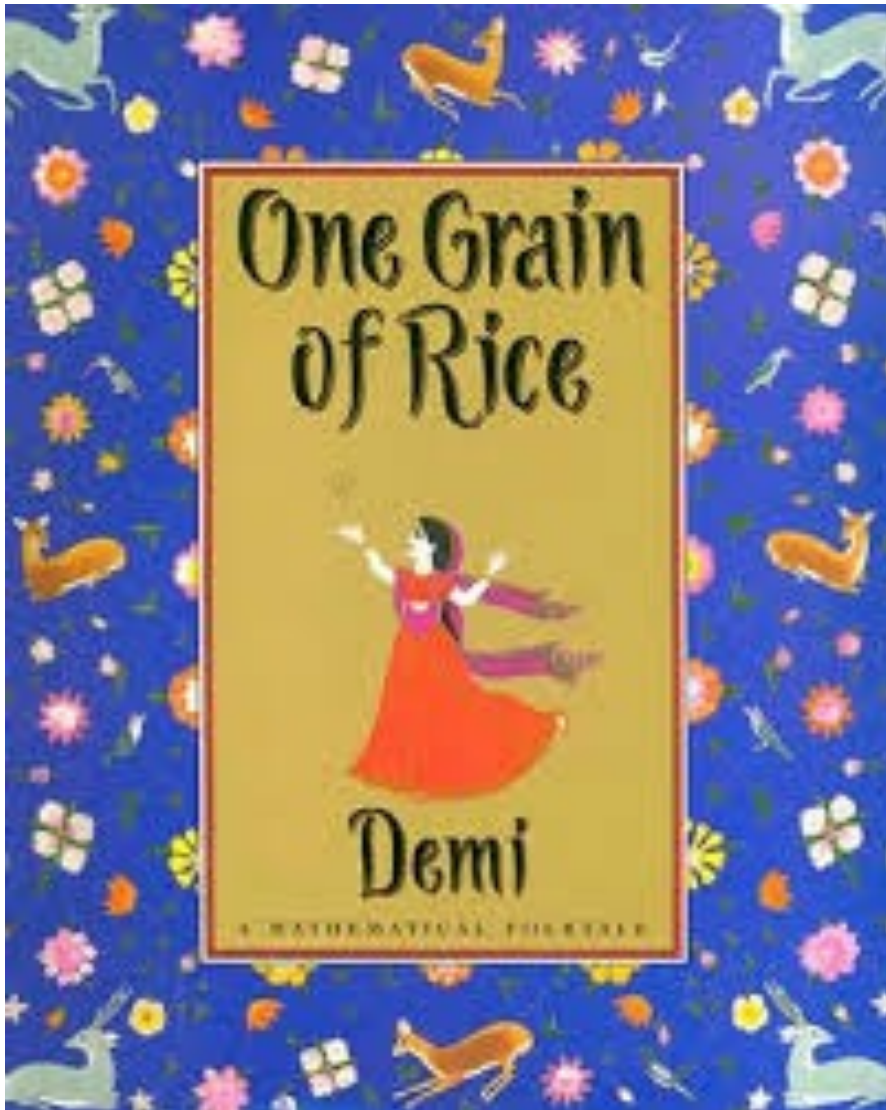
$$b = 250, d = 150$$

b : number of legal move per position

d : its depth (game length)

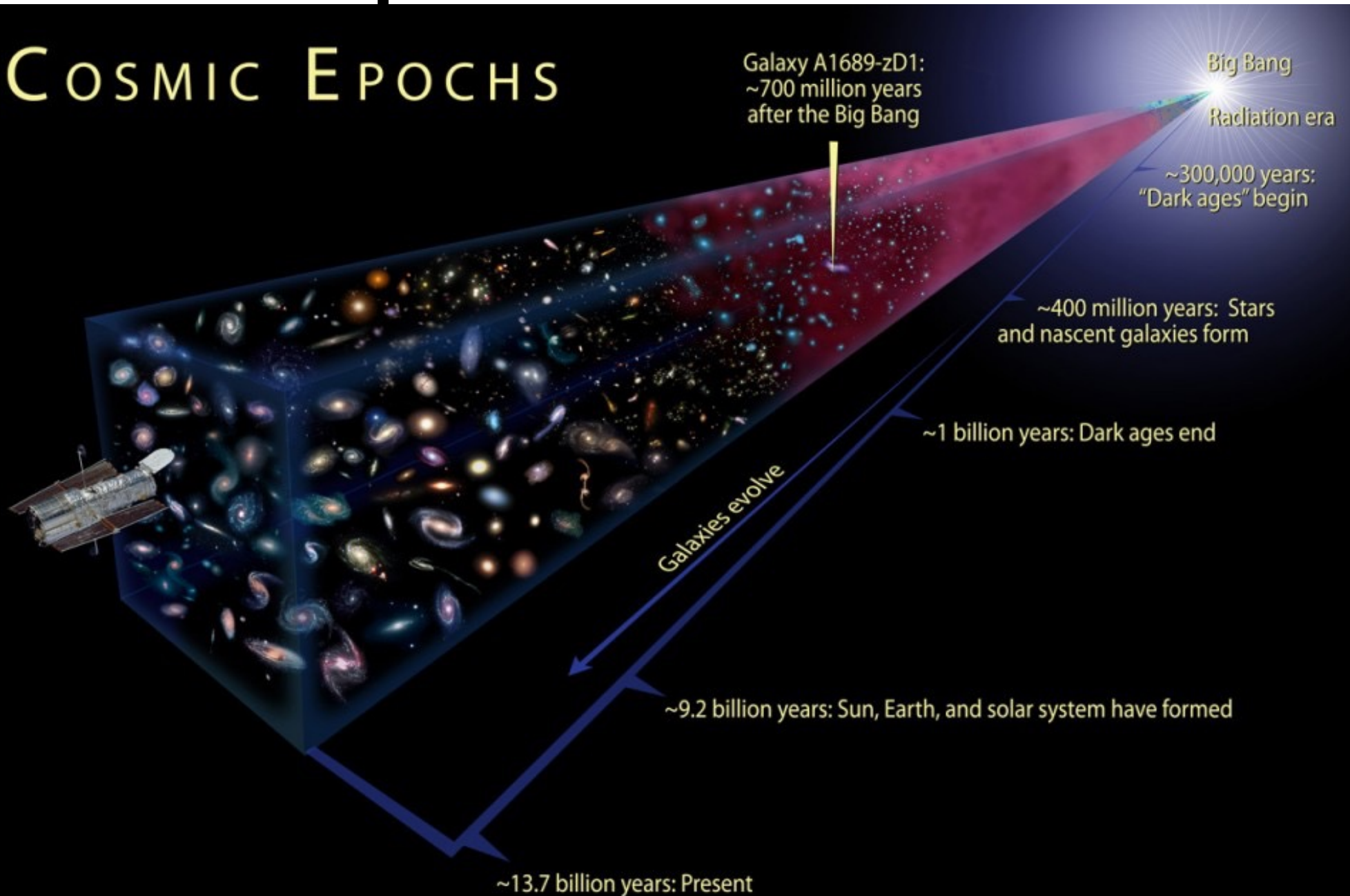
One Grain of Rice

<https://www.youtube.com/watch?v=byk3pAlGPgU>



The “Space” of GO Game

COSMIC EPOCHS



How about other Games?

Tic Tac Toe:

$b = 9, d = 9$

Chess:

$b = 35, d = 80$

Go:

$b = 250, d = 150$

- Flappy bird?
- Angry Bird?
- Starcraft?
- learning a language
- Write a paper
- Get a MS/PhD degree
- Finding a job
- Life



How to solve?

Chess (1996)



Monte Carlo



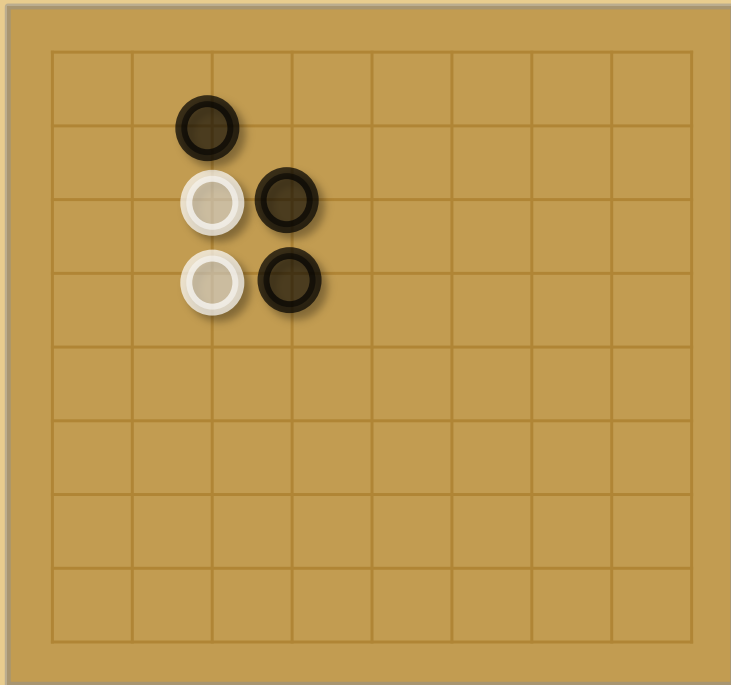
Las Vegas



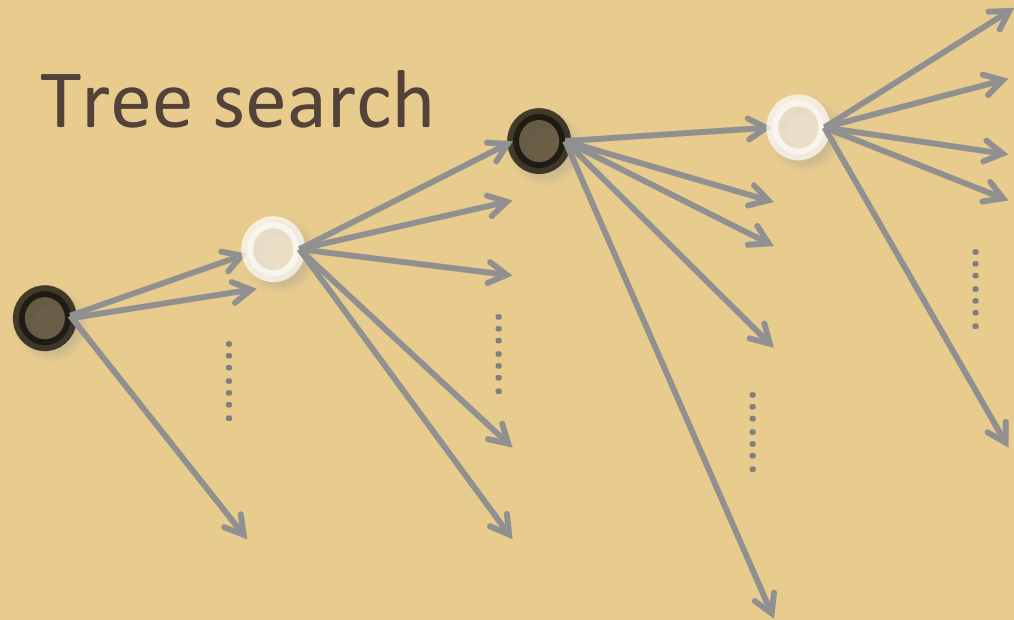
Two Types of Randomized Algorithms

1. **Las Vegas Algorithm:** Always produces the correct solution (ie. RandomizedQuickSort)
2. **Monte Carlo Algorithm:** Does not always return the correct solution.
 - Good Las Vegas Algorithms are always preferred, but they are often hard to come by.

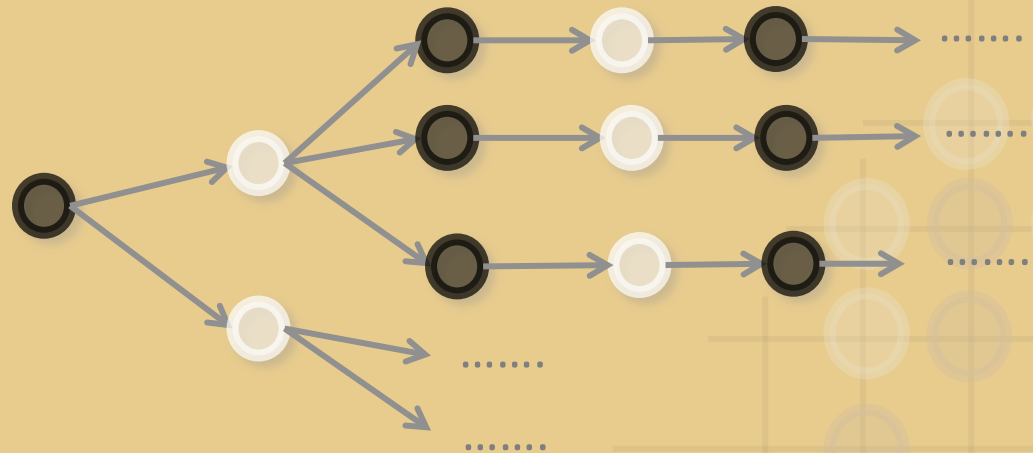
Monte Carlo Tree Search



Tree search



Monte Carlo search



Monte Carlo Tree Search

- Tree Search + Monte Carlo Method

- Selection
- Expansion
- Simulation
- Back-Propagation

