Introduction to AI

SEARCH

Pedro Meseguer
Institut d'Investigació en Intel·ligència Artificial (IIIA)
Consejo Superior de Investigaciones Científicas (CSIC)

IIIA-CSIC INSTITUT D'INVESTIGACIÓ EN INTEL·LIGÈNCIA ARTIFICIAL

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1.Introduction

Example: 8-puzzle

1	5	2
4		3
6	7	8

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1. 8 puzzle

- It is a 3x3 board with 8 numbered tiles and a hole (= blank space).
- A tile adjacent to the blank space can slide into the blank space.
- The objective is to reach the goal state.

1	2	3
8		6
7	5	4

initial state

1	2	3
8		4
7	6	5

goal state

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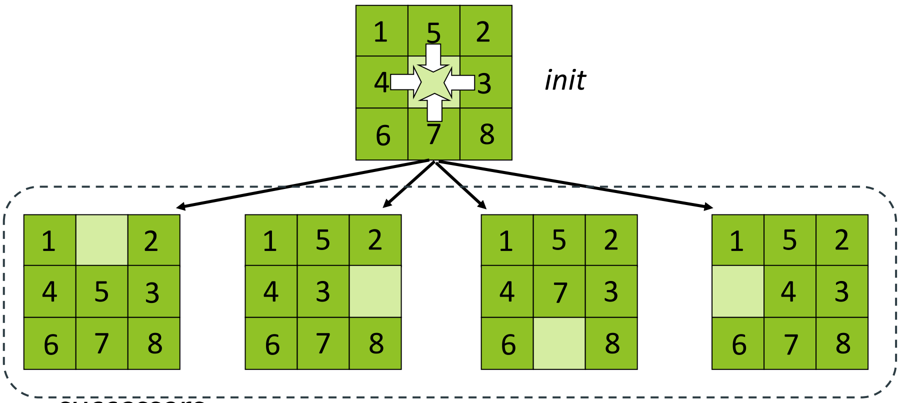
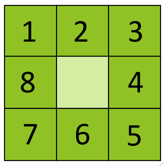
1.Example: Path finding in the 8 puzzle



successors. . . . . . .



goal

Sequence of movements
(more than one)
from init to goal

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1.Off-line search

Two separate phases:

1. Solution computation
2. Solution execution

Search for a complete solution	Execution

AI [search] is only concerned with the first phase

- Solution execution does not affect that solution: in general, this does not happen in the real world
- For problems in very controlled environments

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2.Concepts

- State: a possible problem configuration
- State space: all possible configurations (directed graph)
- Operators:
    - legal actions
    - they generate <u>*successors*</u> of a state
- States: initial and goal
  explicit ***may be implicit***
- Solution:
    - sequence operators initial to goal
      (*sometimes*) goal state
- Problem instance: state-space plus initial and goal states

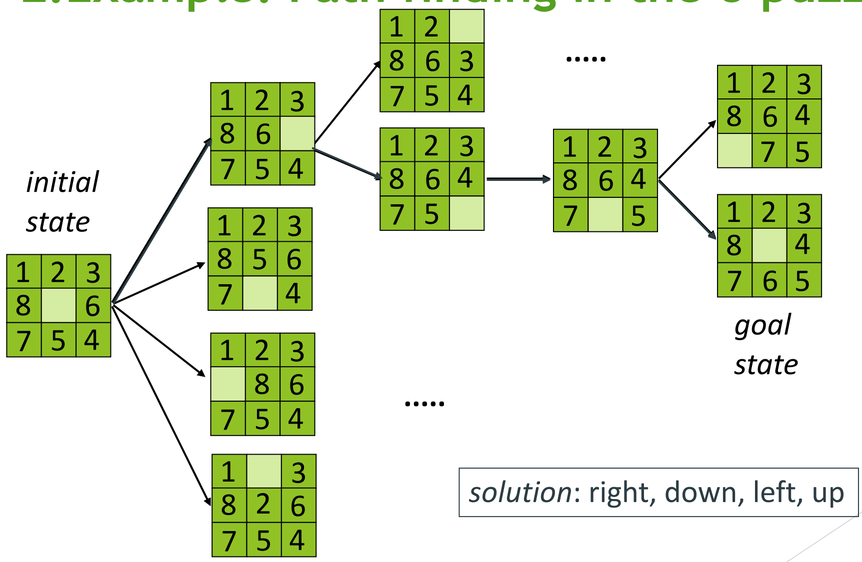
2.Example

- State:

1	5	2
4	3	
6	7	8

- State space: directed graph; 9! nodes; arcs are actions
- Operators:
    - legal actions are move the blank up, down, right, left
    - they generate <u>*successors*</u> of a state
- States: initial and goal
  explicit ***may be implicit*** *(test)*
- Solution:
    - sequence of operators from initial to goal
- Problem instance: well defined

2.Example: Path finding in the 8 puzzle



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2.Off-line systematic search: tree search

Systematic traversal of the state-space:

- It guarantees to find a solution, if one exists.
- Rubik's cube / Sliding puzzles: 8-puzzle, 15-puzzle, 24-puzzle

Exploring the state space of a problema as a tree:

- Root: initial state
- 1st level: the sucessors of root
- 2nd level: the sucessors of sucessors of the root
- …
- dth level: the sucessors of nodes at level d-1

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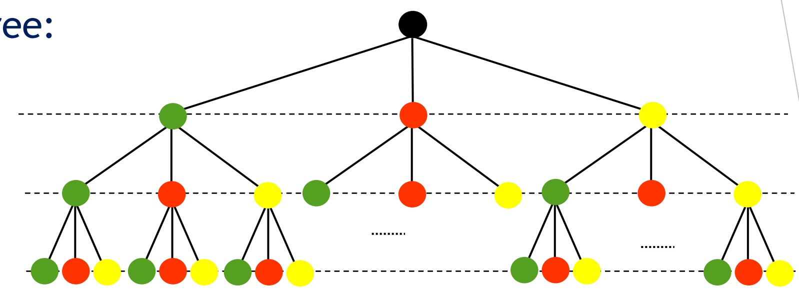
2.Off-line systematic search: blind search

Search tree:



Depth-first search (DFS): explore by **branches**

Breath-first search (BFS): explore by **levels**

2.Off-line systematic search: A* algorithm

A* algorithm:

- important in systematic search: best-first heuristic search
- known from long time (since 1968)

A* expand nodes (=generate successors) with mínimum f

- node lists: open (to be expanded) and closed (already expanded)
- where f(x) = g(x) + h(x)
  - g(x): the cost already spent to reach x from init
  - h(x): the expected cost to reach a solution from x *(heuristic)*
- expand the node with mínimum f in open list : gen. its successors

2.Off-line systematic search: heuristics

Heuristic:
- Estimates the distance to the closest goal
- Admissibility: never overestimates the real distance
- A* with an admissible heuristic: an optimal path to the goal
- Cheap to compute (impact in practice)

Examples of heuristics:
- 8-puzzle:
  - #tiles out of place
  - Sum Manhattan distance for each tile out of place

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2.Off-line systematic search: combinatorial explosion

Size of state space grows quickly as problem size increases
- Sliding puzles:
  - 8-puzzle 9!
  - 15-puzzle 16!
  - 24-puzzle 25!
- Main reason of the failure of early AI

The state space of these problems is divided in two, unnconected parts of the same size

Search (weak methods)
- are overhelmed by huge state spaces
- only work for *toy problems (memo causing AI winter 1966)*

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2.Off-line local search

- Optimization: min cost function; solution: global minimum
- May fail finding a solution, even if it exists
- Simplest: Hill-climbing
- Often inspired by natural processes:
  - simulated annealing
  - genetic algorithms
  - ants algorithms

- Basically,
  - they do not keep track of states previously visited
  - look forward for immediate improvement (greediness)

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2.Off-line local search: hill-climbing

Hill-climbing: minimize f(x)

- Generate sucessors of current state
- From x move to y such that f(x) > f(y): the move improves cost function
- Stochastic search

Local optima:

- $f(x) \leq f(w)$, for all w in succ(x)
- how escape from local minima?

Escape strategies:

- Accept moves to to states of higher function values with low probability (simulated annealing).

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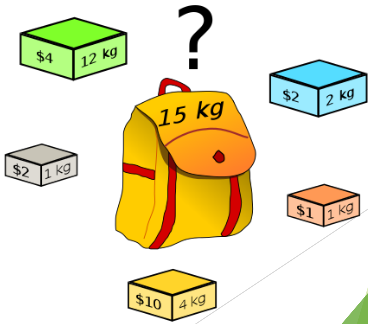
2.Off-line local search: genetic algorithms

Knapsack problem:

Given a set of items, each with a weight and a value, determine the number of each item to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible.


Holland
1975



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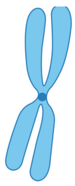
Genetic algorithms: Chromosome / fitness function

A candidate solution is a vector = chromosome

1	0	1	0	0



To discriminate among chromosomes:

***fitness function* F(V):** total value of vector V

F(1 0 1 0 0) = \$2 + \$10 = \$12

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2.Off-line local search: genetic algorithms

- Parallel search: a pool of solutions randomly generated (strings)
- Combines: exploration & exploitation

- Applying operators: generation(i) → offspring, generation (i+1)

- Operators:
  - Selection : two strings are selected
  - Crossover: old strings are cut → new strings are obtained
  - Mutation: some bits may change randomly

Iterative process:
  - Several generations are produced, each with better individuals
  - Until a solution is found or exhaust resources

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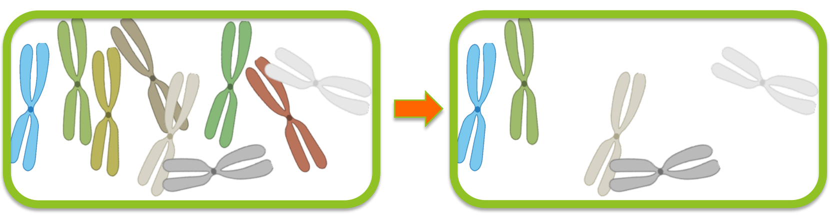
Genetic algorithms: Selection

For reproduction we select:

- The best chromosomes, according to the fitness function



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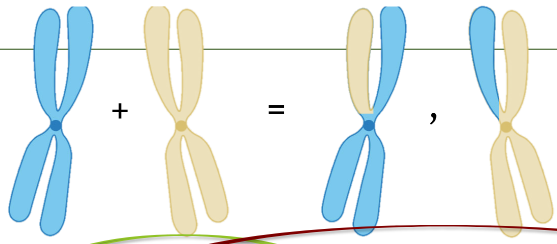
Genetic algorithms: Reproduction (crossover)



\$12	1	0	1	0	0
\$13	0	1	1	1	0

+ =

\$14 | 1 | 0 | | 1 | 1 | 0 | , \$11 | 0 | 1 | | 1 | 0 | 0 |

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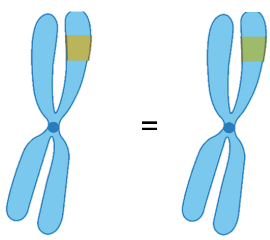
Genetic algorithms: Mutation



\$14 | 1 | 0 | | 1 | 1 | 0 | → \$15 | 1 | 1 | | 1 | 1 | 0 |

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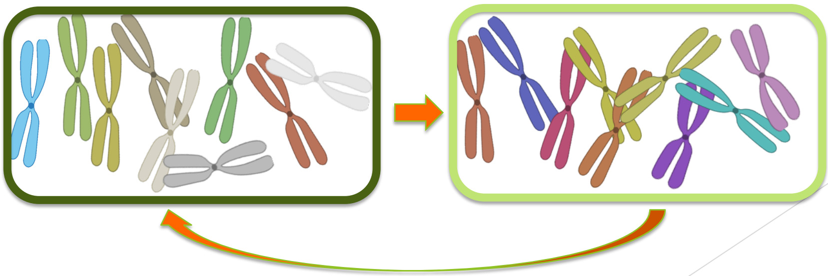
Genetic algorithms: New generation

Adjust the selection, crossover and mutation to obtain a new generation of K cromosomes.

The new generation replaces the old one.

The whole process repeats.



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2.Off-line local search: suboptimality

When finding a solution:

- no guarantee that the path is optimal (= mínimum cost)

Often

- good quality solutions
- efficiency achieved

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3.On-line search

- Off-line search:

Search for a complete solution	Execution

- unrealistic in many domains

- On-line search: interleave
  - Solution computation
  - Solution execution
- Domains:
  - Unknown terrain
  - Dynamic
- Families:
  - Single-agent
  - Two agents in games, adversarial search

3 On-line search: single-agent

Age of Empires

Warcraft III

3.On-line search: single-agent approaches

- Two families:
  - Incremental search
  - Real-time search
- Basic difference: time for first move
- If time for first move could be high
  - Incremental search
- Otherwise
  - Real-time search

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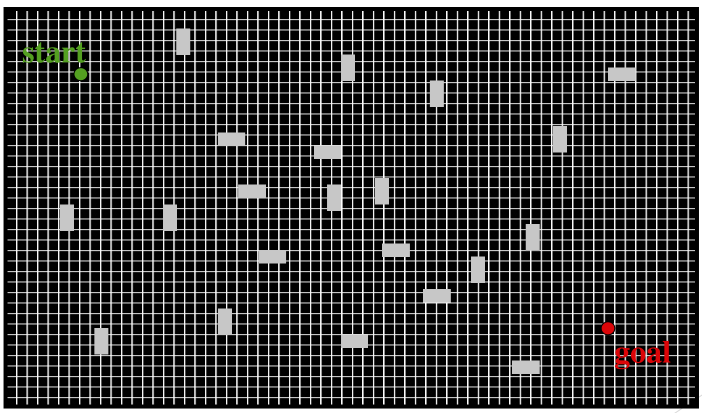
On-line search: Path-finding in unknown terrain



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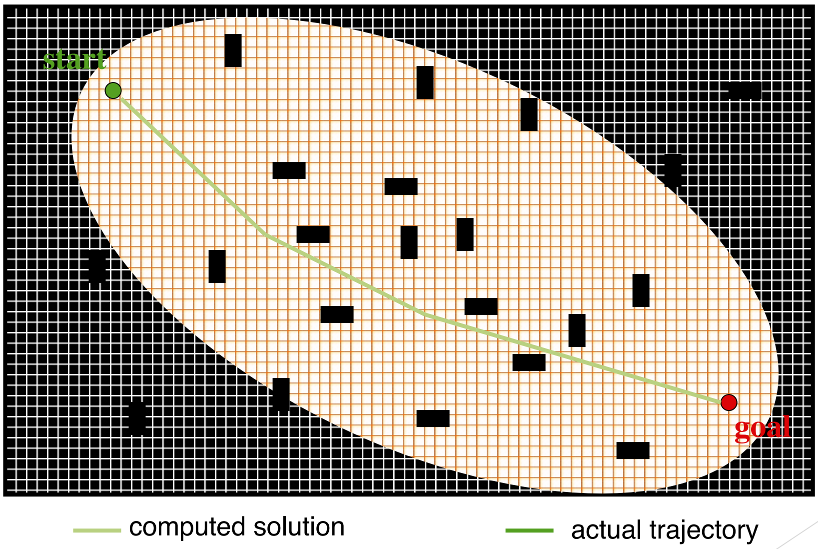
Off-line Search: A*



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On-line search: Incremental

- As classical heuristic (off-line) search
- Suitable for **unknown environments**
- On-line search:

Search for a complete solution from the start state	Execution
If unfeasible, search for a new complete solution from the current state	Execution

. . . . iterates until finding a goal

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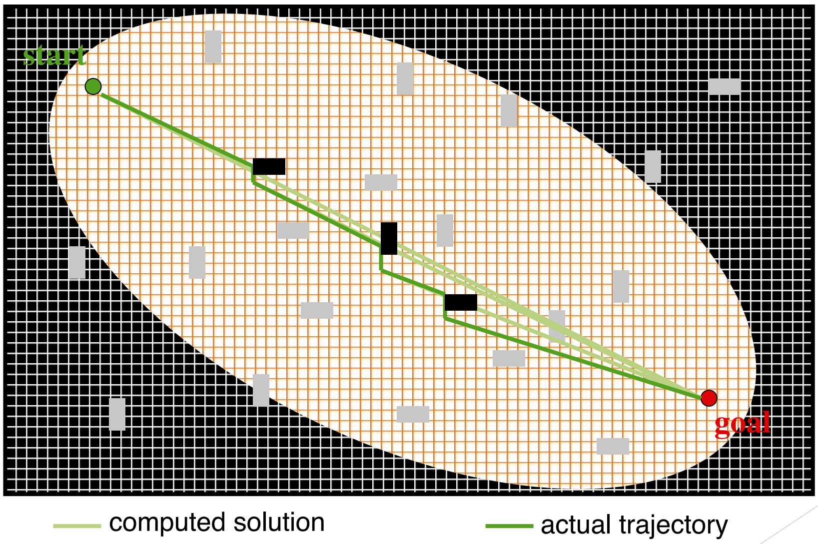
On-line search: incremental, D*



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Real-Time Heuristic Search

- Search on a local space around the current state
- As result of search:
  - Heuristic of some states are updated (*learning space*)
  - Move(s) in the local search space
- Solution is no optimal:
  - approaches converge to optimality after repeated exec.
- Interleave search and action execution
- On-line search:

Search	Execution	Search	Execution	Search	Execution

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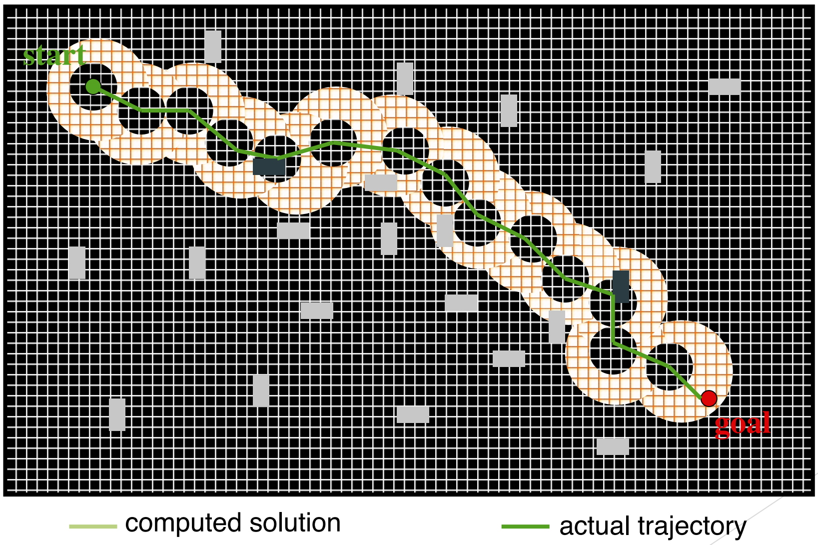
Real-time Search: LRTA*



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3.On-line search. Two agents, zero sum, perfect information games: adversarial search

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3.On-line search. Two agents, zero sum, perfect information games: adversarial search

- Two players: A and B
- Perfect information:
  - Each player knows all the information of the opponent
  - No random elements
  - *Chess, checkers, otello,go*
- Excluded:
  - Incomplete information games: *poker, bridge*
  - Stochastic games (dices): *backgammon*
- Zero-sum: if utility for A is *x* => utility for B is *-x*

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Game Programs

- Programs world championship: *checkers, othello*
- Program with good performance: *chess, go*
  - important: since 1956, *chess* was an IA goal
  - *Deep Blue* won *Kasparov* in 1997
  - *AlphaGo* won *Lee Sedol* in 2015
- Clear economic importance
- Strategies:
  - *brute-force*: search in spaces of billions of nodes
  - *smart* sampling, if the problem is too large

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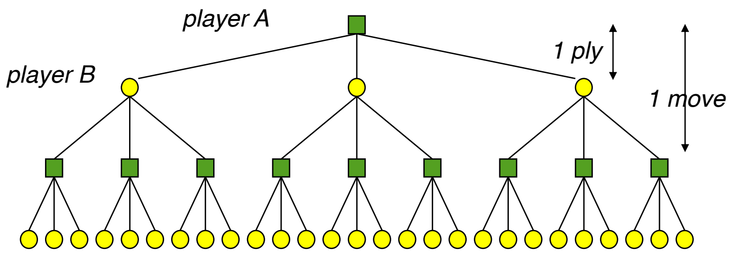
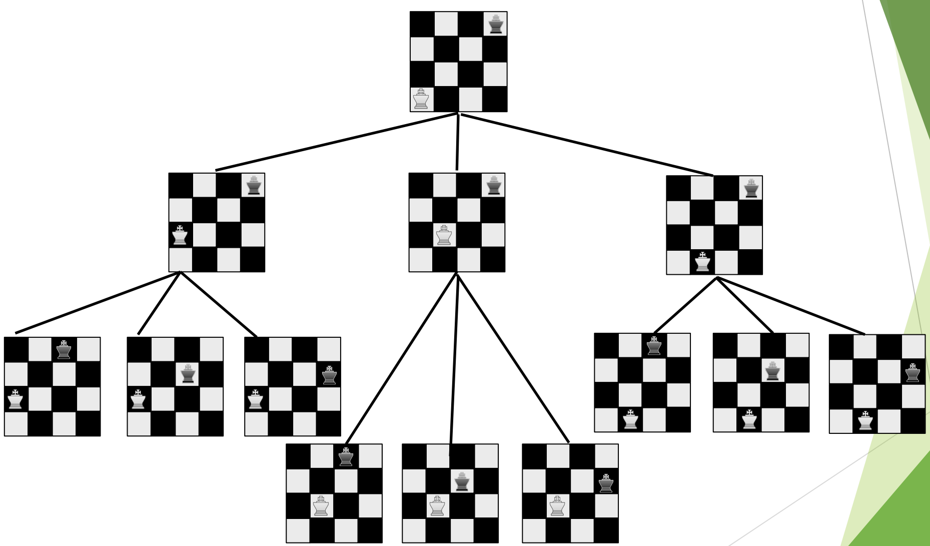
Game Tree



- Players alternate by levels
- Node successors: all legal moves that the current player can do

Example: Chess



MiniMax Main Idea

Search and back-propagate the value of the terminals (from Alan Turing, late 40's) Turing chess program

Terminal nodes: value 1, -1, 0 (A wins, B wins, draw)

Two types of nodes: **max** wins with 1 / **min** wins with -1

Back-propagation:

- **max**: the maximum of the values of the children
- **min**: the minimum of the values of the children

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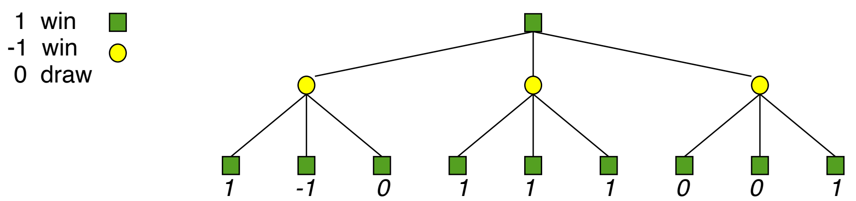
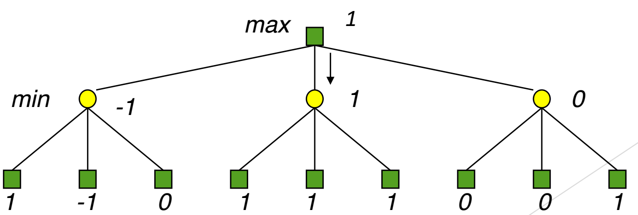
MiniMax Game Tree



What is the best move? Back-propagate values from node terminals, assuming that each player selects the most favourable move for him/her



EAIA

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3.On-line adversarial search: Go

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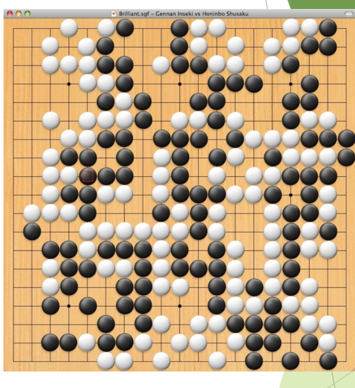
However, for *Go* this approach does not work!



- *Go*:
  - complex (branching~250), large (depth~150), very dynamic (no quiescence)
  - no good evaluation function
- Brute-force approaches do not work
- What about some kind of sampling? → Monte Carlo Tree Search (from 2005 on)

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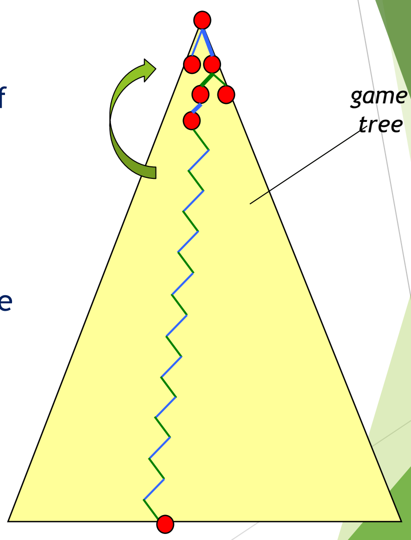
Monte Carlo Tree Search (MCTS)

Basic idea:

- keep (develop and store) a small part of the game tree close to the root: partial tree
- from the fringe of that partial tree, run a simulation until a terminal node
- update node statistics in the partial tree

Iterate until some limit (time or #iterations); then select the *best* move



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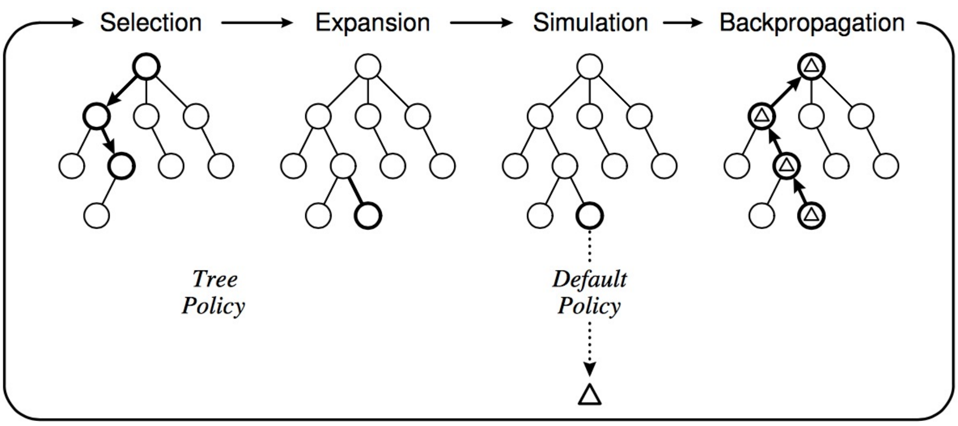
MCTS: Phases



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4.Search names: Nils Nilsson

- (1933 – 2019)
- Full profesor Stanford
- One of the big old names
- Among the creators of the A* algorithm (1968)
- Shakey robot -> STRIPS planner (1971) [*planning*]

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4.Search names: Judea Pearl

- (1936 –)
- Full professor UCLA (retired)
- Known by his books: *Heuristics*, 1984; *Probabilistic Reasoning*, 1988; *Causality*, 2000
- Contributions to: Bayesian networks [*uncertainty*]

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4.Search names: Richard Korf

- (195? —)
- Full profesor UCLA
- Many contributions to systematic search:
  - Off-line search: frontier search
  - On-line search: real-time heuristic search

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4.Search names: Sven Koenig

- (195? —) German
- Full profesor USC (Southern California)
- Many contributions to single-agent search:
  - Partially known, non-stationary, non-deterministic domains
  - [*multi agent planning, robotics, videogames*]

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4.Search names: Deep Blue

- 1997, program developed by IBM
- Mastering chess, won to the world champion Gary Kasparov
- Combination of:
  - Parallel alpha-beta search
  - Variable depth (Singular extensions)
  - Library of openings and endings

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4.Search names: AlphaGo

AlphaGo

- 2015, program developed by Google DeepMind
- Mastering the Go game (more difficult than chess), won a 5-games match against the unofficial world champion Lee Sedol
- Combination of
  - Monte-Carlo Tree Search
  - Deep neural networks

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5.Wrap-up (I)

- Basics:
  - A state
  - State-space of a problem
  - Successors of a state
  - Path-finding
- Off-line search
  - Systematic search
  - Local search:
    - hill climbing [local optima, global optimum]
    - genetic algorithms:
      - chromosome, fitness function
      - selection, crossover, mutation

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5.Wrap-up (II)

- On-line search
  - Single agent search
    - Incremental search
    - Real-time search
  - Two-agent, adversarial search
    - Game tree
    - Games: chess, go
- Search names: Nilsson, Pearl, Korf, Koenig,
  Deep Blue, Alpha Go
- Algorithms mentioned: DFS, BFS, A*, genetic, MiniMax
- Examples: 8-puzzle, knapsack

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Further reading

- Russel & Norvig 3rd ed:
  3.1, 3.2, 3.3, 4.1, 5.1, 5.2, 5.7 plus
  Bibliographical Notes chapters 3, 4 and 5

- Heuristics (Pearl, 1984)

- Korf's talk at ICAPS 2018 (very instructive, no local search)
  https://www.youtube.com/watch?v=X6qCBcubZIE

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