CHALMERS
UNIVERSITY OF TECHNOLOGY

RULE-BASED ARTIFICIAL INTELLIGENCE

PART TWO

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Today

- Monday:
  - Breadth first
  - Depth first
  - Dijkstra’s Algorithm (lowest-cost-search)
  - Informed search - taking heuristics into account
  - Best-first search
  - A*
- Thursday:
  - Applications of rule-based AI
  - Relationship between Search and Reinforcement Learning

Acknowledgements:

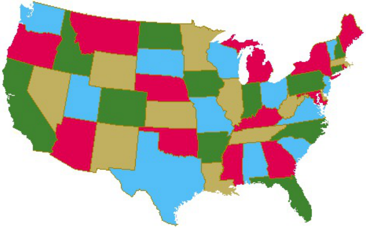
Moa Johansson for sharing materials

No learning here. The Chalmers minibus moves on a virtual track and breaks if any of the 8 LIDAR detectors detects motion nearby.

No learning here. A fixed algorithm that takes a map and two locations (a start and a goal) as its input

Theorem Proving

- Mathematics is a language (English, logic or otherwise)
- Theorems equal sentences
- Proofs are lists of sentences
- No data means ML is less powerful
- Rule-based AI can help here



Theorem Proving

- Four-Colour Theorem (1976)
- Kepler Conjecture (1998)
- Optimal solution Rubik's Cube (2010)
- Minimum Clues for Sudoku (2012)

Proof Verification

- The Fundamental Theorem of Algebra
- The Fundamental Theorem of Arithmetic
- Ramsey's Theorem
- The Central Limit Theorem
- Gödel's First Incompleteness Theorem
- The Laws of Large Numbers

System Verification

Prove properties of:

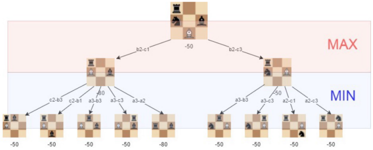
- Hardware
- Financial
- Medical
- Transport (e.g. safety in the Métro de Paris)

Testing versus Proofing

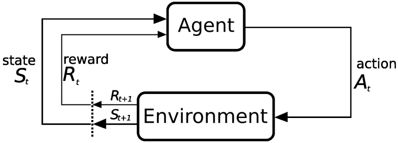
Testing can only cover a fraction of a sytem, so it is not suitable for large function-critical systems. Theorem-proving (a form of rule-based AI) gives a much higher level of reliability (when it can be used).

To solve chess:

- We use a Mini-Max algorithm
- The recursive tree of all possible moves is explored to a given depth
- The position is evaluated at the "leaves" of the tree



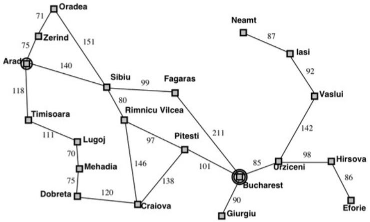
Recall: Reinforcement Learning



To solve chess:

- Agent acting in (non-deterministic) unknown environment
- Rewards for “good” states
- Learn a policy to maximise rewards
- Explore / Exploit
- Multiple runs in same environment to gather experience

Recall: Search Algorithms



To solve chess:

- Environment model is known upfront
- Costs are known upfront
- Actions are (typically) assumed to be deterministic
- If we take action to drive from A to B, assume we really do get there
- Use model to search for a plan to achieve a goal

Recall: Reinforcement versus Search

Reinforcement Learning:

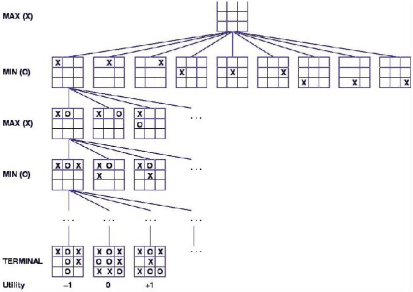
- Good for large or (partially) unknown environments
- Multiple runs to learn from experience
- Can be time consuming
- Learns a policy
- Can cope quite well with non-determinism

Search:

- Needs a known model of environment
- Does not need training and can be efficient in moderate sized envroments
- Produces a plan
- Assumes deterministic outcome of actions

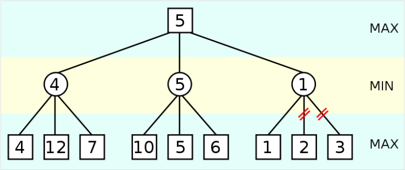
$\longrightarrow$ Both can also be combined (e.g. AlphaZero)

Adversarial Search and Games: Min-Max Search



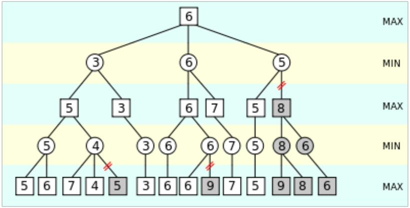
- Alternate beween two players “Max” and ”Min”
- Max want to get to a final state with high utility
- Min wants the opposite
- Check utility of all final states
- Propagate utility-values up the search tree

Adversarial Search and Games: Min-Max Search



- Utility values are propagated from leaves up the tree
- Assume plays optimally
- Min always plays the minimal value
- Max always choose the maximal value

Adversarial Search and Games: Pruning



- Alpha-beta pruning
- Nodes that will never be visited can be removed
- Reduces search, especially if tree is even larger
- Search tree may still be large though. . .

Adversarial Search and Games: Heuristic Evaluation

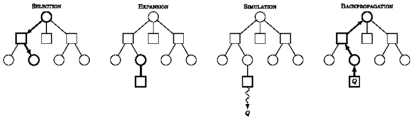
- Pruning is not enough for games with very large search spaces! (such as Chess, Go, . . .)
- One solution is to do some limited search up to a resource bound
- Use a **heuristic evaluation function** to **estimate utility** of non-terminal nodes:
  - *Chess* - no strong pieces, expert knowledge about “good” positions. . .
  - *score based on simulations* of the game from here on

Monte Carlo Tree Search

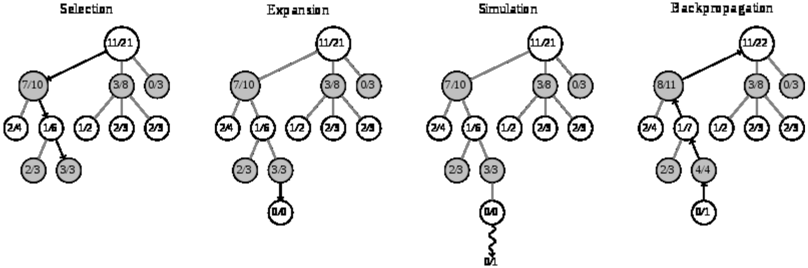
- Go:
  - 250 possible moves each turn (19×19 board)
  - 150 moves in a typical game
  - between 250^{150} and 10^{360} possible moves
- Search algorithmscan only look ahead $4-5$ moves
- Value of state estimated as average utility over multiple simulations (or playouts) of complete games
- How to choose good moves?
- Neural network + RL

Monte Carlo Tree Search

- Selection
  - Selection policy determines most promising node to explore next
- Expansion
  - Generate new child node
- Simulation
  - Playout from new node. Playout policy determines moved
- Back-Propagation
  - Use results from simulation to update nodes going up the tree



Monte Carlo Tree Search



Monte Carlo Tree Search

- The 4 stages of search are repeated until reacing a time-limit
  - Search can be interrrupted at any time – will still produce an answer
  - More compute might give better answer, but always get something
- Then, returns action with highest number of playouts
  - Not most wins?
  - Intuition: best explored path – often coincides with most wins

Summary

Module 1	Intro and Python
Module 2	Regression and Classification
Module 3	Clustering
Module 4	Bayesian Statistics and Models
Module 5	Markov, Kernels, Trees, Reinforcement Learning
Module 6	Ethics and Artificial Intelligence
Module 7	Machine Learning and Neural Networks
Module 8	Search Algorithms

Glossary

TERM	DEFINITION
Data Science	Extracting meaning from (big) data
Applied Data Science	Translating between problem and method domain for stakeholders
Stratification	Divide data into homogeneous subpopulations before analysis
Distributions	Types of functions, with mode, mean, and median
Discrete distributions	Uniform, Binomial, Geometric, Hypergeometric, Poisson, Negative binomial
Continuous distributions	Uniform, Normal (Gaussian), Student's t, Exponential, Chi-Square, Beta
Linear regression	Seeks to find the line $y = f(x)$ which minimises the sum of the squared errors over all points

Glossary

TERM	DEFINITION
Least squares linear regression	Estimate the regression using shortest distances
Residual	Deviation of observation from regression line
Correlation	Degree of linear relation between two variables
Causation	How one event influences another (still a philosophical conundrum)
Classification	Assigning a label to a set of data from a discrete set of possibilities
Classifiers	K-Nearest Neighbours, Logistic Regression, Support Vector Machines, Decision Tree Classifiers/Random Forests, Naive Bayes, Linear Discriminant Analysis

Glossary

TERM	DEFINITION
Confusion Matrix	Actual versus Predicted Classification
Accuracy	The number of correct predictions divided by the total number of predictions made
Precision	The number of correct positive predictions divided by the total number of positives
Recall	The number of correct positive predictions divided by the number of true positive and false negatives
Specificity	The number of correct negative predictions divided by the total number of true negatives and false positives
Cross-validation	Generalising results to an *independent* data-set
DBSCAN	Density-Based Spatial Clustering of Applications with Noise

Glossary

TERM	DEFINITION
Bayes' Rule	$P(A \mid B) = \frac{P(B\|A)P(A)}{P(B)}$
Frequentism	Probabilities arerelative frequenciesof the event in a large number of trials
Bayesianism	Probabilities are reasonable expectationof an event, quantifying personal beliefs and prior information, and including the degree of certainty in those beliefs
Entropy	The level of "information" in a variable's outcomes
Joint Probability distributions	Distribution of all possible pairs of outputs of two probability distributions
Markov Processes	A Markov processis a random process where the next state *only* depends on the current state
Markov Chains	A Markov chainis a Markov process that jumps between states at discrete times

Glossary

TERM	DEFINITION
Ethics	Philosophy of *right* and *wrong*
Utilitarianism	The most good for the most people, considering everyone equally
Deontologicalism	Rule-based ethics - we do something because we have a duty to do so
Virtue Ethics	Focus on our virtues and vices
Artificial Intelligence	AI is the study of agents that receive percepts from the environment and perform actions
Weak AI	Acting intelligently
Strong AI	Being intelligent
Sentience	The capacity for phenomenal experience or qualia – being able to be happy, feel pain, or suffer
Sapience	The capacity for higher intelligence, such as self-awareness and being able to reason and respond

Glossary

TERM	DEFINITION
Machine Learning	A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P if its performance at tasks in T, as measured by P, improves with experience E
Rule based AI	Acts on a set of Facts using a set of Rules (If-Then Statements)
Artificial Neural Networks	Systems inspired by the biological neural networks
Perceptron	A computational model of a natural neuron
Graphs	Nodes, Edges, Start Node and Goal Nodes
Heuristic functions	A heuristic function is a function h that assigns a non-negative real number $h(p)$ to each path p

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