Bootstrapping Artificial Intelligence

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Advances in Computer Games
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Outline

- Theme: Improve AI using AI

- Science Fiction
- Learning for Search
- Search for Search
- Search for Learning
- Algorithm Discovery
- Perspectives

Science Fiction

[Irving John Good 1965]

“Let an ultraintelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an “intelligence explosion,” and the intelligence of man would be left far behind…. Thus the first ultraintelligent machine is the last invention that man need ever make, provided that the machine is docile enough to tell us how to keep it under control.”

Science Fiction

Bootstrapping AI [Pitrat 2019]

“One day, we will have an artificial AI researcher which will advance AI much better than ourselves. I am working since many years on such a system: CAIA (Chercheur Artificiel en Intelligence Artificielle). If we succeed, AI will improve much more efficiently than when we are painfully trying to develop it.”

Science Fiction

Moore’s law for everything [Sam Altman 2021]

“This technological revolution is unstoppable. And a recursive loop of innovation, as these smart machines themselves help us make smarter machines, will accelerate the revolution’s pace.”

Jacques Pitrat

- Theorem Proving and Metatheorems [Pitrat 1970]
- General Game Playing [Pitrat 1968]
- Explanation Based Learning and Chess [Pitrat 1976]
- Metaknowledge [Pitrat 1990]
- The system observes itself to improve
- Maciste and Malice: Metaknowledge and solvers
- CAIA (Artificial Researcher in Artificial Intelligence)
- http://bootstrappingartificialintelligence.fr/

Learning for Search

Introspect

- Introspect [Cazenave 1996] learns to play Go from zero knowledge by self-play
- Self-observation to improve itself
- Explanation of the solved games
- Theorem proving in Go
- Generates hundreds of thousands of lines of C++ code that solve Go problems

Code Generation as Theorem Proving

- Partial evaluation of the rules of Go to directly generate knowledge from scratch [Cazenave 1998]
- Theorem proving in first order logic
- Hundreds of thousands of lines of C++ code generated
- Generating logic metaprograms that generate logic programs [Cazenave 1999]

Futamura Projections

- Futamura proposed three projections that compile programs [Futamura 1971]

- Partial evaluation of an interpreter with respect to a program produces a version of the interpreter that only runs that program
- It is written in the implementation language of the interpreter.
- It does not require the source code to be resupplied.
- It runs faster than the original combination of the interpreter and the source.
- It compiles the program in the language of the interpreter.

- This is the first Futamura projection

- There are three Futamura projections:

  1. Specializing an interpreter for given source code, yielding an executable.
  2. Specializing the specializer for the interpreter (as applied in #1), yielding a compiler.
  3. Specializing the specializer for itself (as applied in #2), yielding a tool that can convert any interpreter to an equivalent compiler.

Game AI Projections

- Replace the Interpreter with the Generating Program and replace the program with the Game Rules.

- Generating Programs for the Game Rules produces a program that selects relevant moves to try in the search.

- This is the first Game AI projection

- There are three Game AI projections:

  1. Generating Programs for given Game Rules.

  2. Specializing the program generator on the Game Rules to have a faster program generator for a game.

  3. Specializing the specializer for the program generator to have a better specializer.

Search for Search

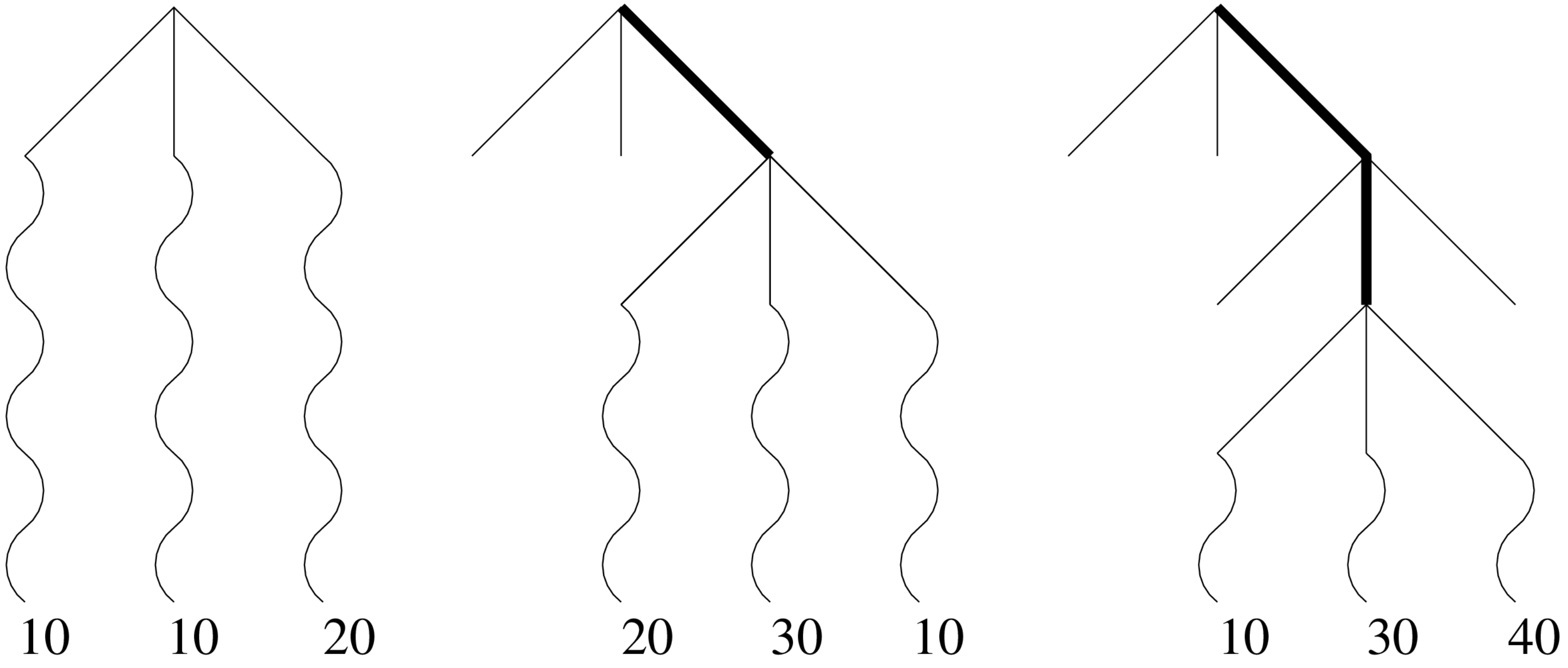
Abstract Proof Search

- Uses search to improve search [Cazenave 2000]
- Same behavior as Introspect
- Search replaces generated knowledge
- Relevancy zones [Thomsen 2001] = Explanations

Nested Monte Carlo Search

- Reflexive Monte Carlo Search [Cazenave 2007]
- Monte Carlo search is used to improve Monte Carlo Search
- Nested Monte Carlo Search [Cazenave 2009]

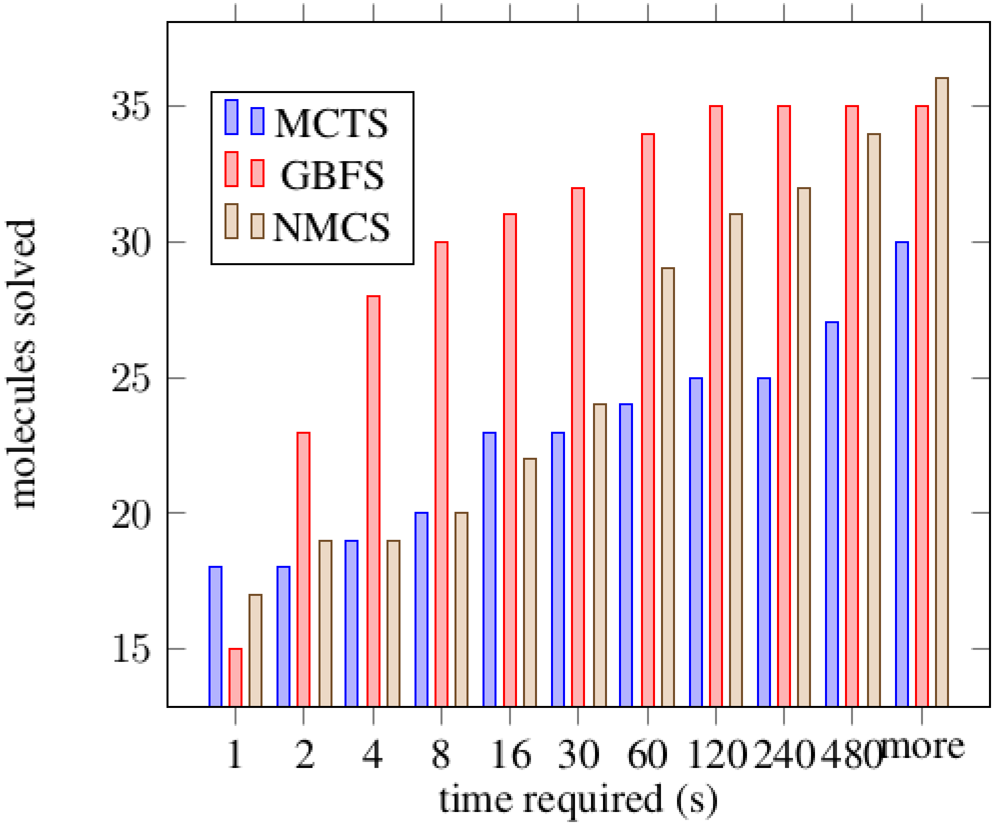
Nested Monte-Carlo Search



Retrosynthesis

- Find a set of chemical reactions that enable to synthetize a given molecule.
- The state space is an AND/OR tree as in games.
- DF-PN and MCTS have been used to find retrosynthesis pathways.
- Alphachem [Segler et al. 2017].
- AiZynthFinder [Genheden et al. 2020].

Retrosynthesis



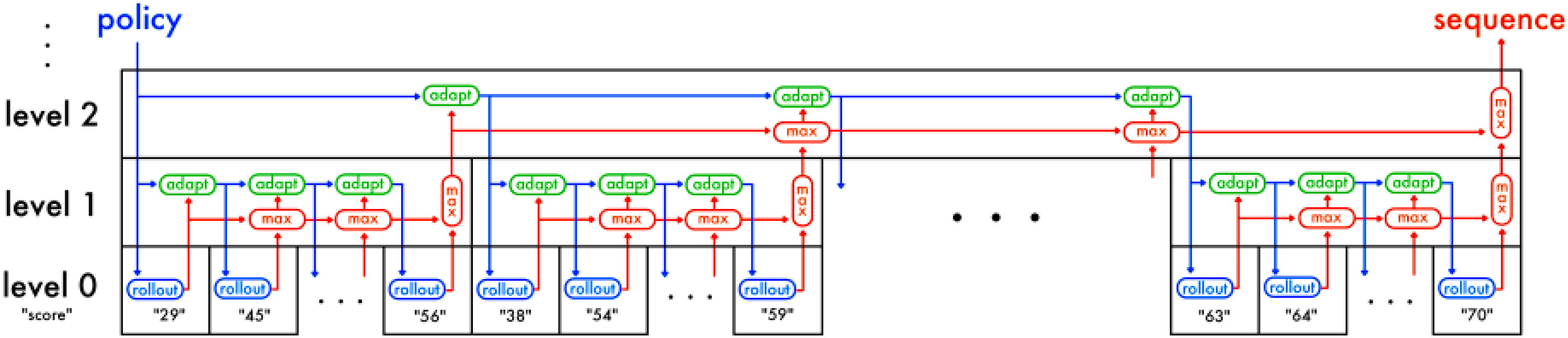
Applications

Nested Monte Carlo Search :

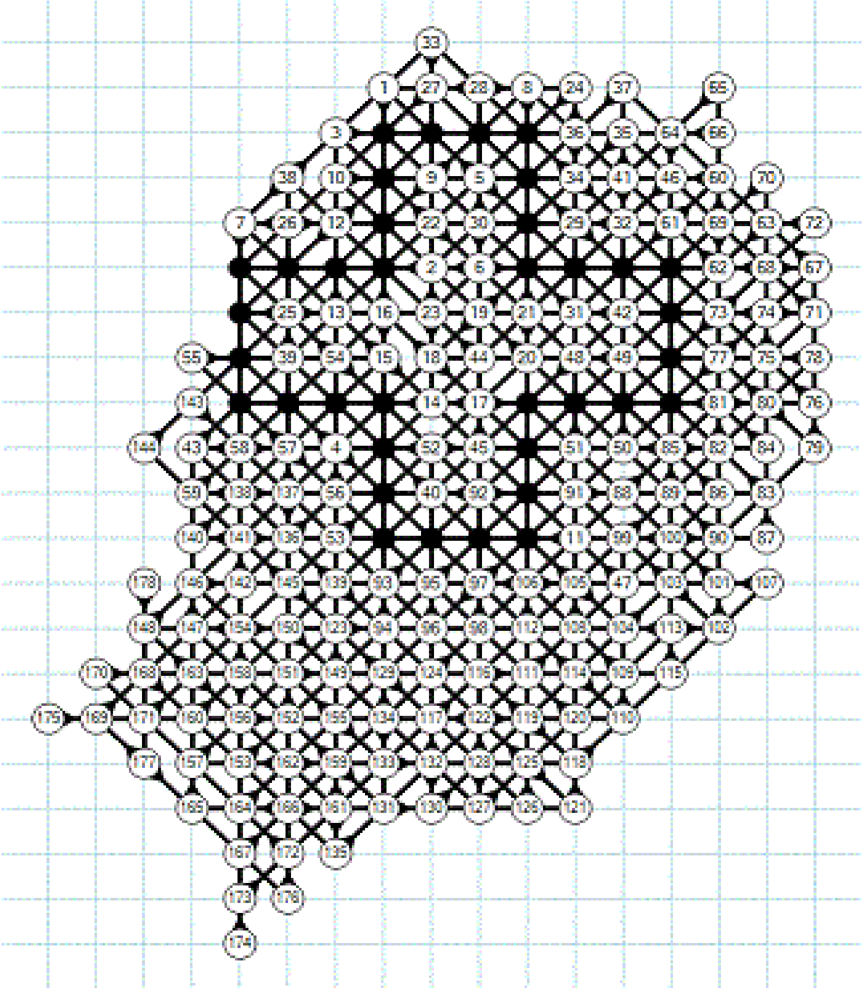
- Morpion Solitaire [Cazenave 2009]
- SameGame [Cazenave 2009]
- Sudoku [Cazenave 2009]
- Expression Discovery [Cazenave 2010]
- The Snake in the Box [Kinny 2012]
- Cooperative Pathfinding [Bouzy 2013]
- Software Testing [Poulding et al. 2014]
- Heuristic Model-Checking [Poulding et al. 2015]
- Pancake problem [Bouzy 2015]
- Games [Cazenave et al. 2016]
- Cryptography [Dwivedi et al. 2018]
- RNA inverse folding problem [Portela 2019]
- Perfect Rectangle Packing [Doux et al. 2022]
- Retrosynthesis [Roucairol et al. 2023]
- …

Nested Rollout Policy Adaptation

- Bootstrapping the policy [Rosin 2011]
- Nested levels of policies and of sequences of actions



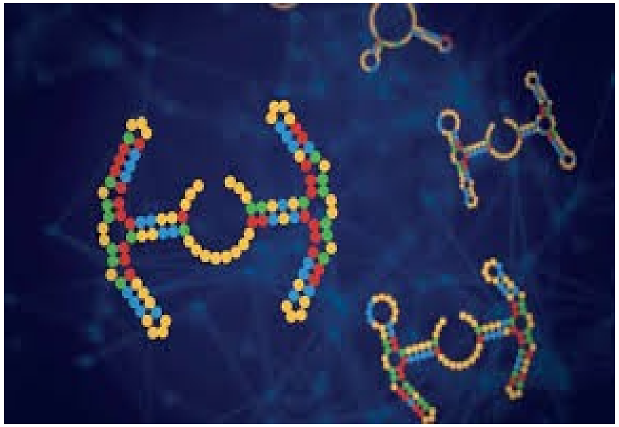
Morpion Solitaire



World record [Rosin 2011]

Eterna 100

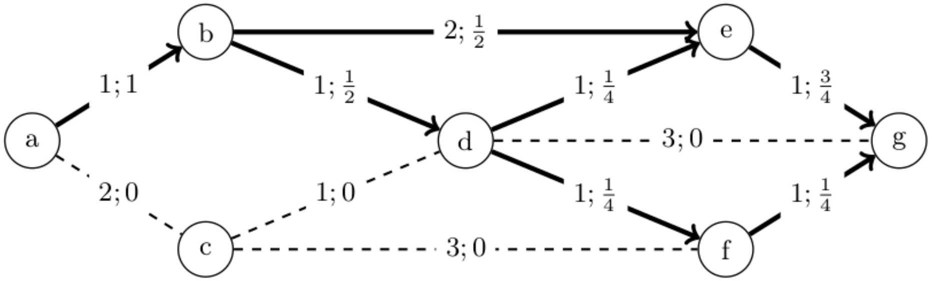
- Find a RNA sequence that has a given folding



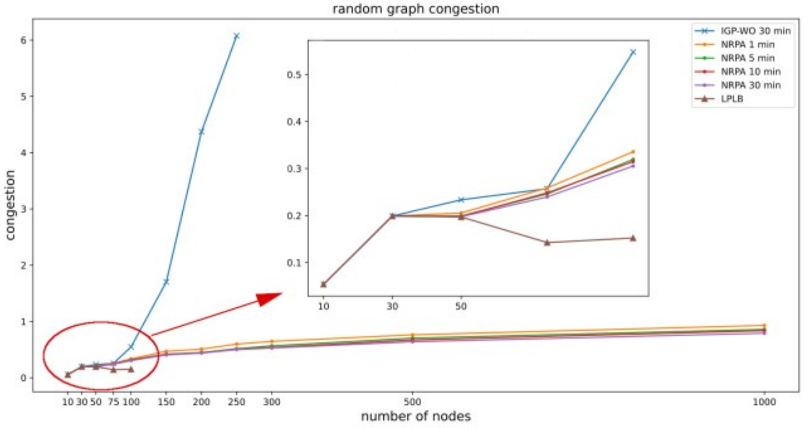
- 95/100 sequences found [Cazenave & Fournier 2020]

Network Traffic Engineering

- Provide routing configurations in networks that:
  - Miminize ressources
  - Preserve QoS.

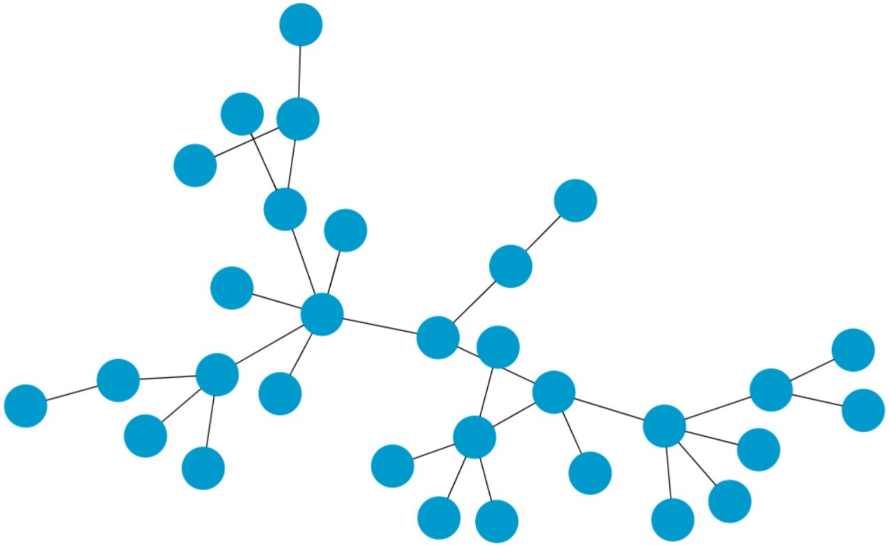


- Better than local search [Dang & al. 2021]:



Refutation of Spectral Graph Theory Conjectures

- Conjecture 3. Collins. Given a tree T, CPA(T) form an unimodal sequence and its peak pA(T) is at the same place as pD(T).



- Better than Deep RL [Roucairol & Cazenave 2022]

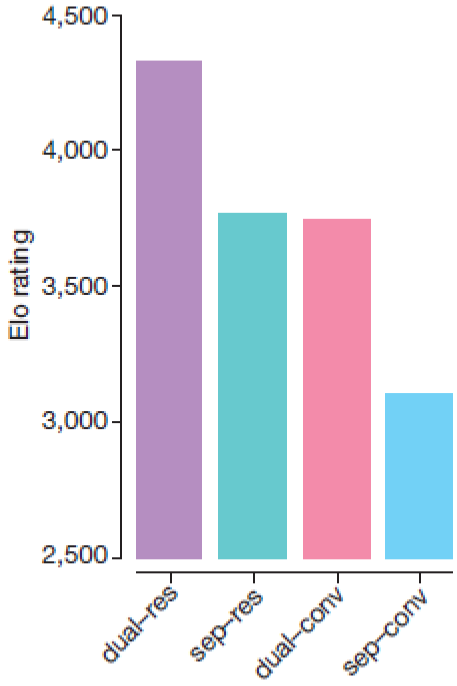
Nested Rollout Policy Adaptation

- Morpion Solitaire [Rosin 2011]
- CrossWords [Rosin 2011]
- Traveling Salesman Problem with Time Windows [Cazenave et al. 2012]
- 3D Packing with Object Orientation [Edelkamp et al. 2014]
- Multiple Sequence Alignment [Edelkamp et al. 2015]
- SameGame [Cazenave et al. 2016]
- Vehicle Routing Problems [Edelkamp et al. 2016, Cazenave et al. 2020]
- Graph Coloring [Cazenave et al. 2020]
- RNA Inverse Folding [Cazenave & Fournier 2020]
- Network Traffic Engineering [Dang & al. 2021]
- Slicing 5G [Elkael et al. 2021]
- Refutation of Spectral Graph Theory Conjectures [Roucairol & Cazenave 2022]
- …

Search for Learning

Neural Architecture Search

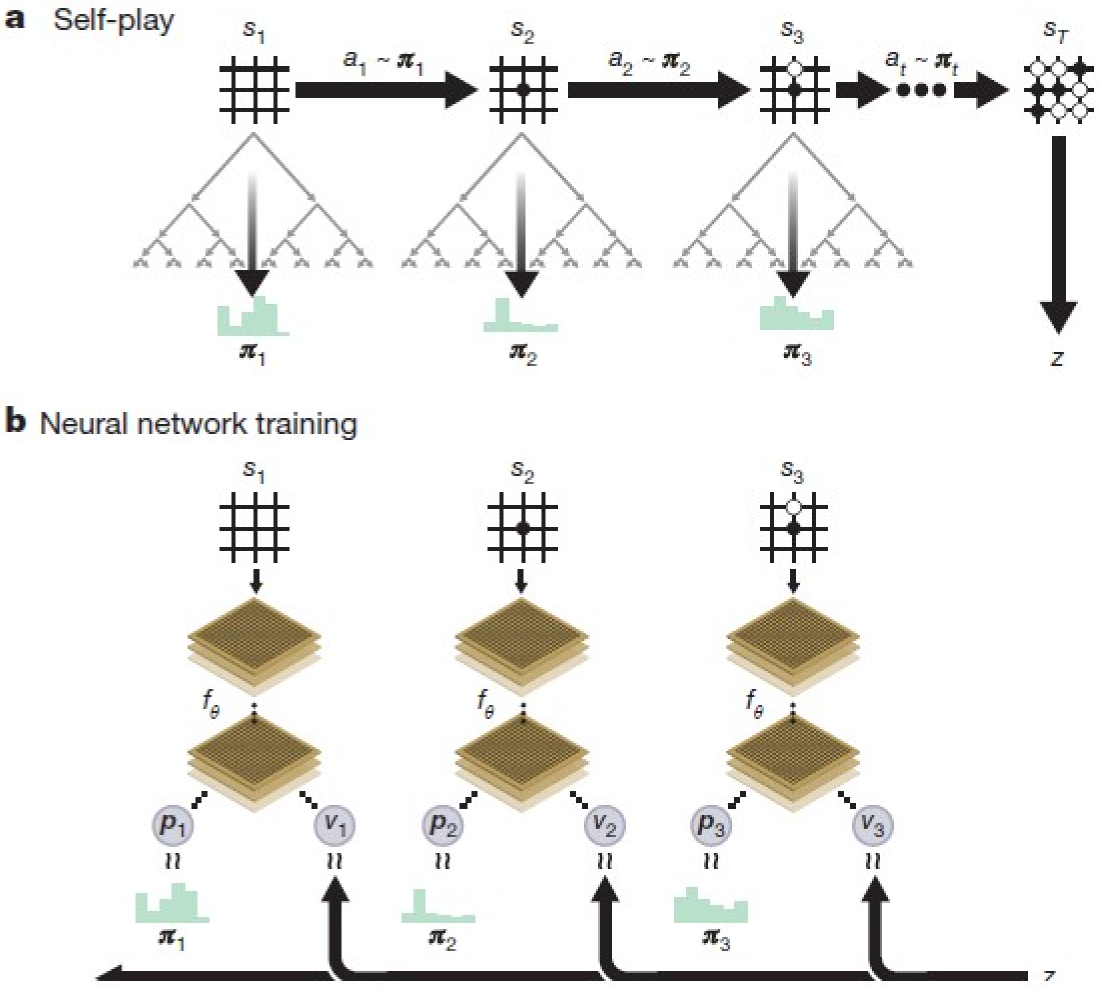
- Search for neural networks architectures
- Neural architecture is very important for the performance of game playing programs
- Residual networks in AlphaGo Zero: 600 Elo
- Policy and value heads in AlphaGo Zero: 600 Elo
- Many papers on the use of search for discovering effective neural networks architectures



Expert Iteration

- Using an expert to train a model [Anthony & al. 2017]
- Using search with a neural network to generate data of better quality
- Learn the policy and the value from this data
- This is the algorithm used in Alpha Zero to learn to play Go, Chess and Shogi.

Alpha Zero

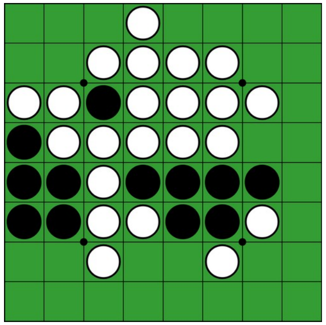
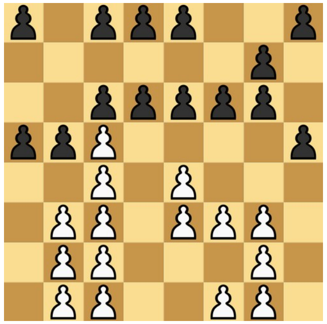
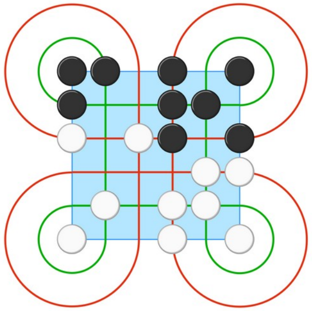
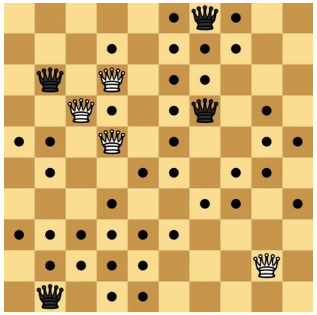
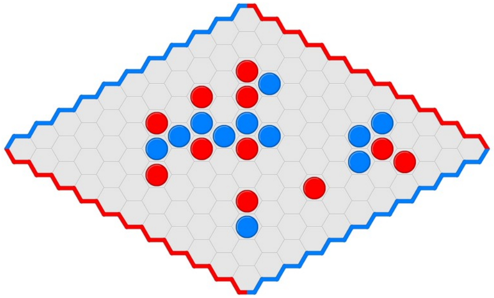
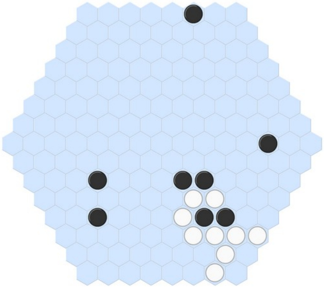
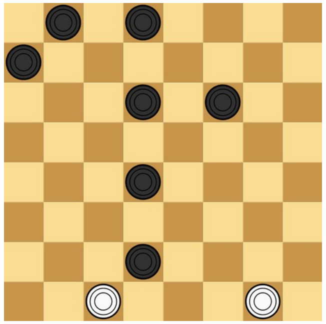

a Self-play
s_1
$a_1 \sim \pi_1$
s_2
$a_2 \sim \pi_2$
s_3
$a_t \sim \pi_t$
s_T
π_1
π_2
π_3
z
b Neural network training
s_1
s_2
s_3
f_θ
f_θ
f_θ
p_1
v_1
p_2
v_2
p_3
v_3
π_1
π_2
π_3
z

Polygames

- Polygames [Cazenave & al. 2020] is the open source implementation by Facebook FAIR of Alpha Zero.
- It has been applied to many games.
- It uses a fully convolutional policy head.
- It uses average global pooling in the value head.
- It makes it invariant to board size.
- It has beaten the best Havannah player.

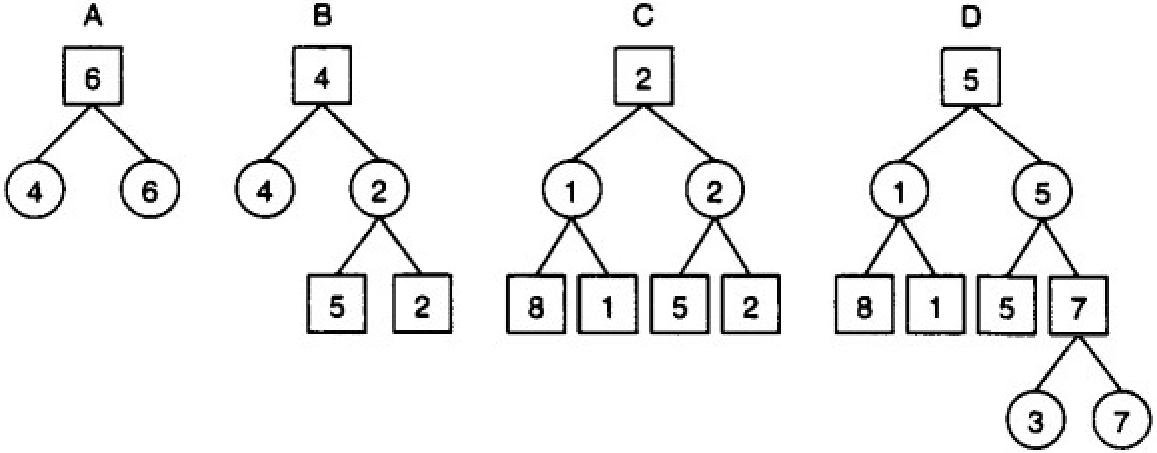
Athénan

- 16 gold medals at the 2023 Computer Olympiad!
- Amazons, Arimaa, Ataxx, Breakthrough, Canadian Draughts, Chinese Chess, Clobber, Havannah (8×8), Havannah (10×10), Hex (11×11), Hex (13×13), Hex (19×19), Lines of Action, Othello (10×10), Santorini, Surakarta.

Unbounded Minimax

- Principle = Extend the most promising leaf.
- Asymmetric growing of the search tree.



Descent

- Only uses a value network.
- Self play without prior knowledge.
- Learns the scores inside the trees developed by the Unbounded MiniMax.
- Minimax Strikes Back [Cohen-Solal & Cazenave 2023].

Algorithm Discovery

Algorithm Discovery

- Using an algorithm to discover an algorithm
- Alpha Zero or Mu Zero can be used to play the game of algorithm discovery.

Algorithm Discovery

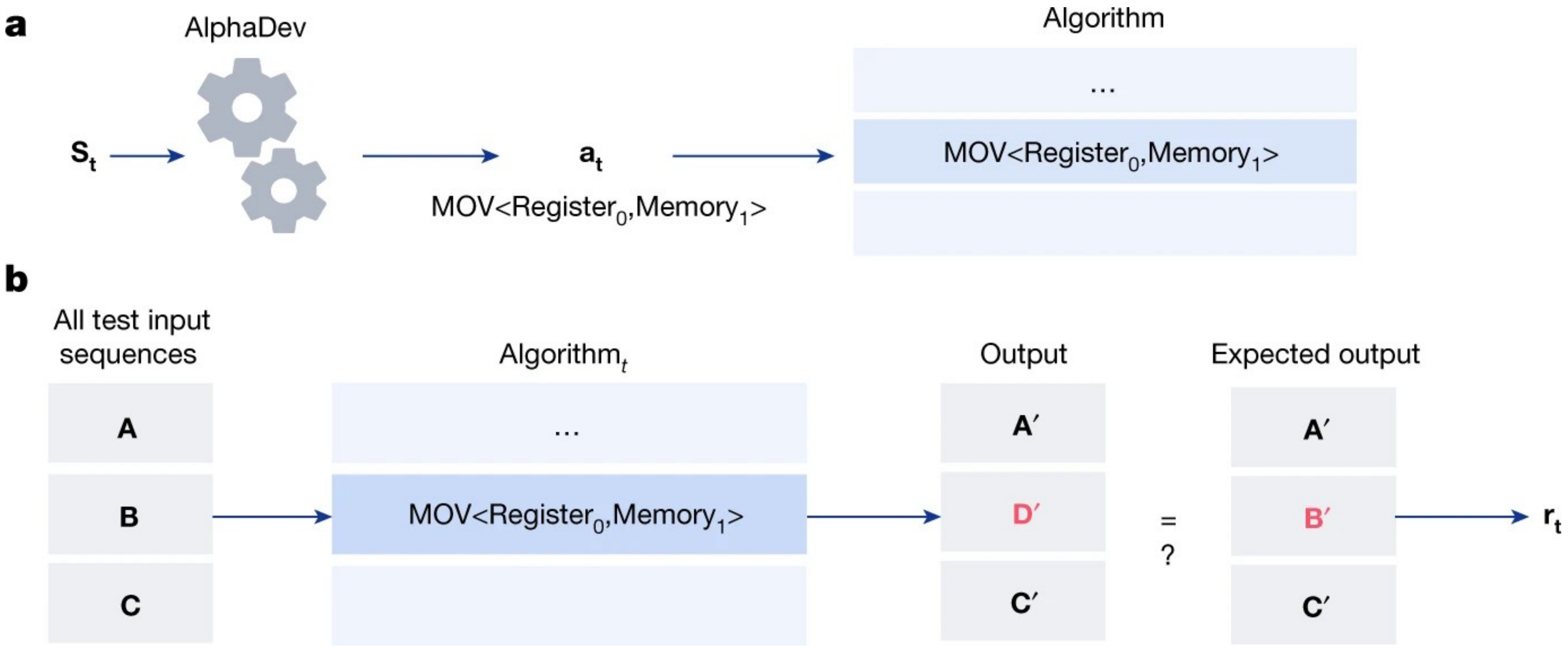
Monte Carlo Tree Search and Deep Reinforcement Learning to discover new fast matrix multiplication algorithms [Fawzi & al. 2022]

The international journal of science / 6 October 2022
nature
MATRIX GAMES
Deep reinforcement learning opens route to faster algorithms for matrix multiplication
Protecting Peru
Preferential practice

Algorithm Discovery

- AlphaDev [Mankowitz & al. 2023]:

  Faster sorting algorithms discovered using deep reinforcement learning



Discovery of MCTS Algorithms

- Evolving Monte-Carlo Tree Search Algorithms [Cazenave 2007]
- Inventing new bandits for MCTS with Genetic Programming.

Discovery of MCTS Algorithms

- Nested Monte Carlo Search can be used to discover mathematical expressions and algorithms [Cazenave 2010]
- It can replace Genetic Programming to discover new Monte Carlo Search algorithms with a Monte Carlo Search algorithm

LLM

Baptiste Roziere thesis: Unsupervised Translation of Programming Languages [Roziere 2022]

LLM for code generation

Copilot

ChatGPT

Code Llama

Killian Susini thesis: Search and LLM for automatic code generation

Perspectives

- Athénan for combinatorial optimization problems
- Athénan for algorithm discovery
- Monte Carlo Search to discover bandits
- Combine search with LLM for algorithm discovery
- Generate endgame knowledge for games
- Try Game AI projections
- Search and LLM for code generation

Conclusion

- Search and Learning reinforce each other
- Applications in games and combinatorial optimization problems
- Bootstrapping gave superhuman game programs
- AI can discover new algorithms
- AI can improve AI