How AI Won at Go and So What?

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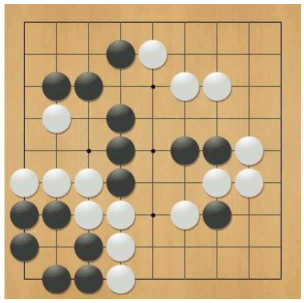
Garry Kasparov vs. Deep Blue (1997)

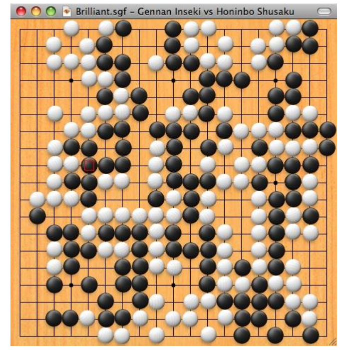
Deep Mind’s AlphaGo vs. Lee Sedol (2016)

Watson vs. Ken Jennings (2011)

Computer Go



9x9 (smallest board)



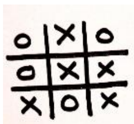
19x19 (standard board)

- “Task Par Excellence for AI” (Hans Berliner)
- “New Drosophila of AI” (John McCarthy)
- “Grand Challenge Task” (David Mechner)

A Brief History of Computer Go

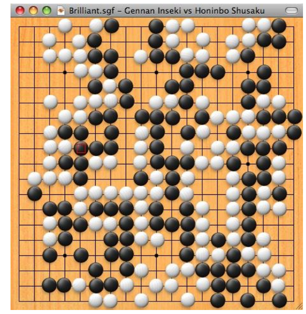
- *1997:* Super human Chess w/ Alpha-Beta + Fast Computer
- *2005*: Computer Go is impossible!

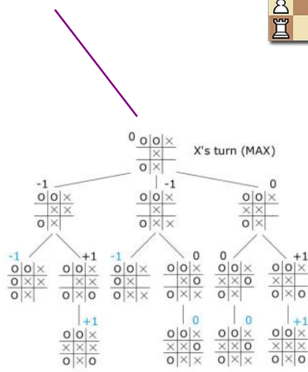
Why?

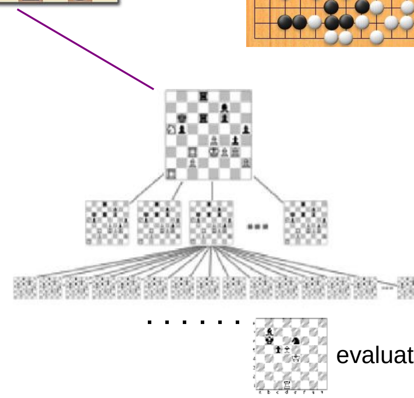


VS

VS

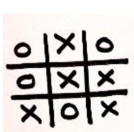




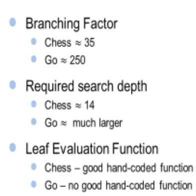


evaluation = 0.7

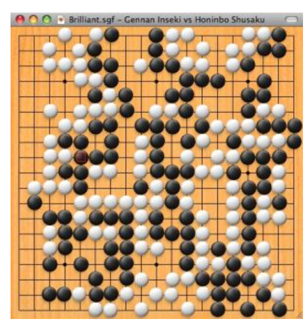
Lookahead Tree

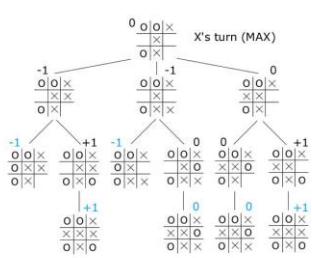


VS



VS





MiniMax Tree

- Branching Factor
  - Chess ≈ 35
  - Go ≈ 250
- Required search depth
  - Chess ≈ 14
  - Go ≈ much larger
- Leaf Evaluation Function
  - Chess – good hand-coded function
  - Go – no good hand-coded function

A Brief History of Computer Go

- *1997:* Super human Chess w/ Alpha-Beta + Fast Computer
- *2005*: Computer Go is impossible!
- *2006*: Monte-Carlo Tree Search applied to 9x9 Go (bit of learning)
- *2007*: Human master level achieved at 9x9 Go (bit more learning)
- *2008*: Human grandmaster level achieved at 9x9 Go (even more)

Computer GO Server rating over this period:
1800 ELO → 2600 ELO

- *2012*: Zen program beats former international champion Takemiya Masaki with only 4 stone handicap in 19x19
- ***2015: DeepMind's AlphaGo Defeats European Champion 5-0***
(lots of learning)

AlphaGo

- Deep Learning + Monte Carlo Tree Search + HPC
- Learn from 30 million expert moves and self play
- Highly parallel search implementation
- 48 CPUs, 8 GPUs (scaling to 1,202 CPUs, 176 GPUs)

Image: AP/ Lee Jin-man

March 2016 :
AlphaGo beats Lee Sedol 4-1

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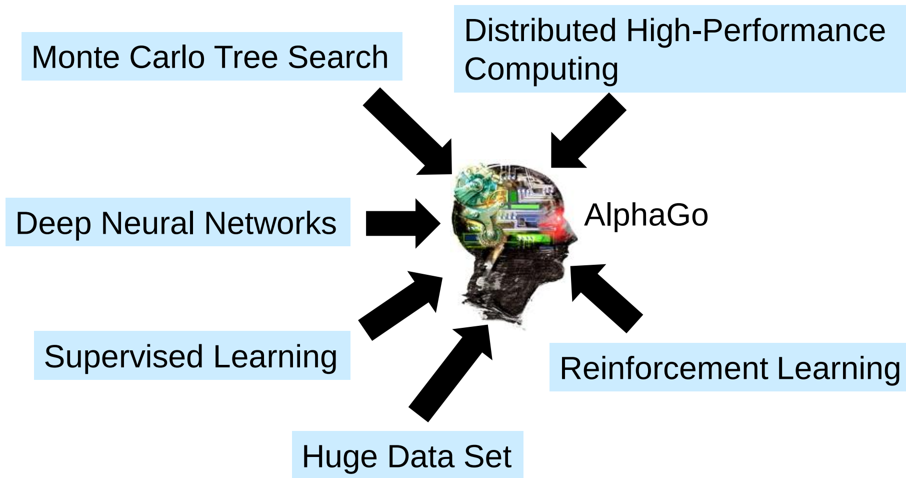
Arsenal of AlphaGo



Mastering the game of Go with deep neural networks and tree search
Nature, 529, January 2016.

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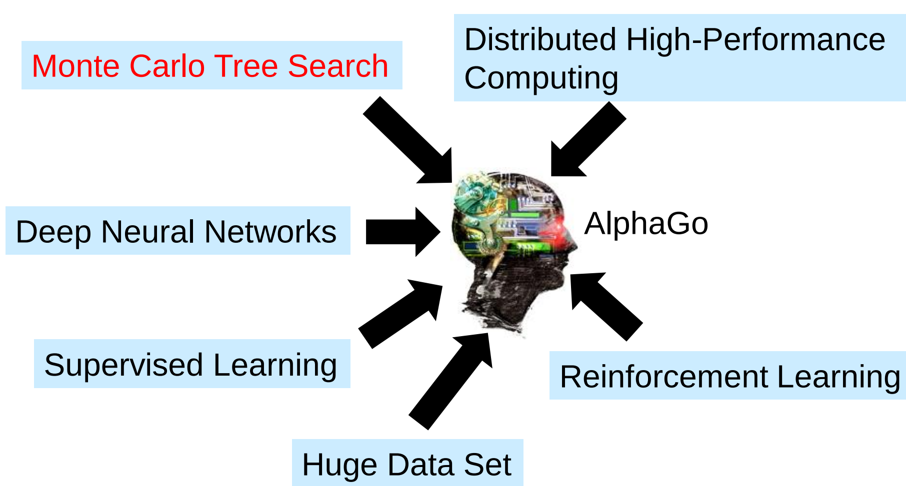
Arsenal of AlphaGo



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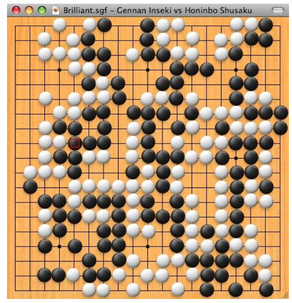
Monte Carlo Tree Search

Idea #1: board evaluation function via random rollouts

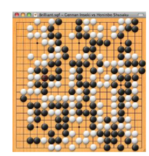


Evaluation Function:

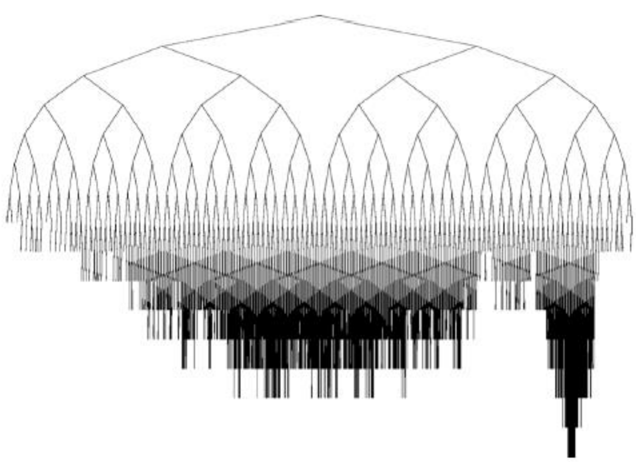
- play many random games
- evaluation is fraction of games won by current player
- surprisingly effective

Even better if use rollouts that select better than random moves

Monte Carlo Tree Search

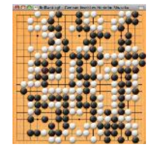


Idea #2: selective tree expansion



Non-uniform tree growth

Monte Carlo Tree Search



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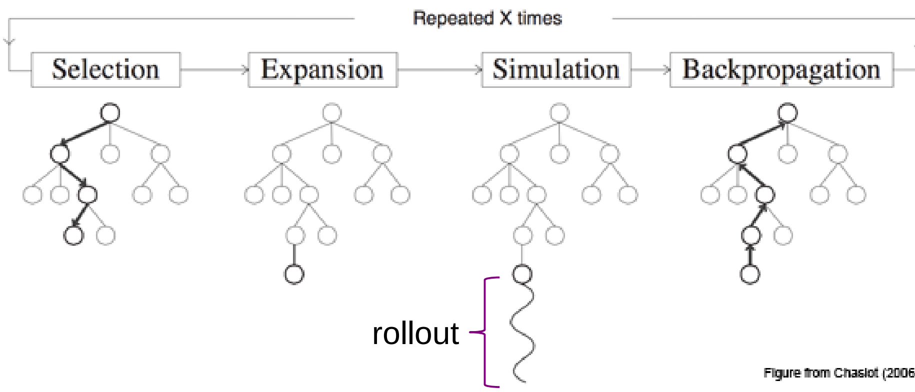
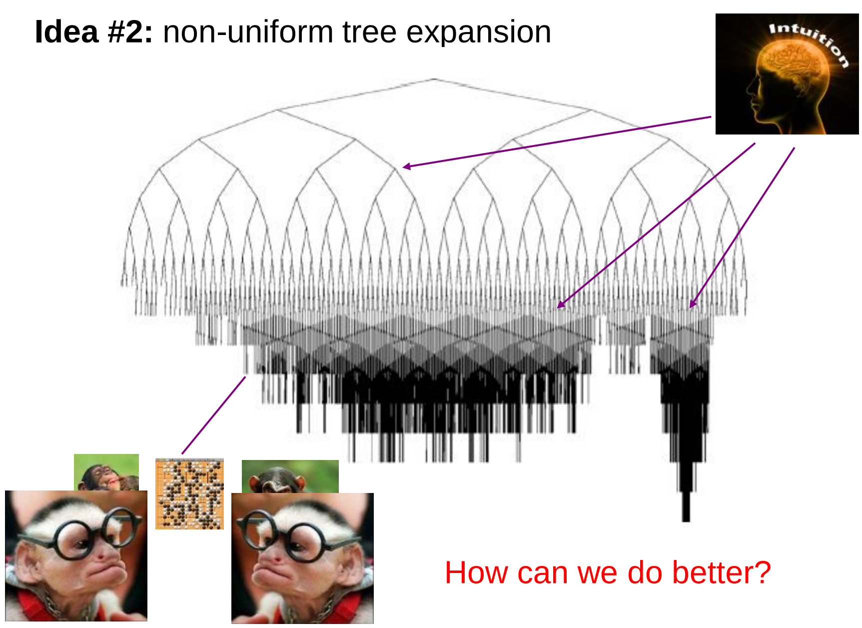


Figure from Chaslot (2006)

Monte Carlo Tree Search

Idea #2: non-uniform tree expansion



How can we do better?

Arsenal of AlphaGo

Monte Carlo Tree Search

Distributed High-Performance Computing

Deep Neural Networks

AlphaGo

Supervised Learning

Reinforcement Learning

Huge Data Set

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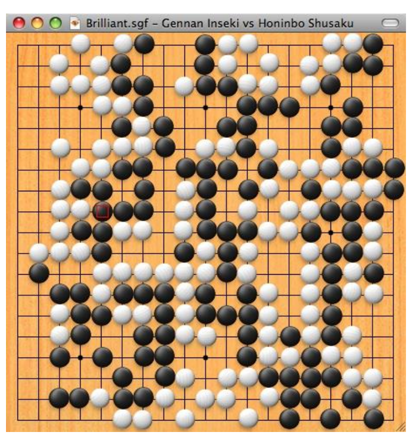
Learning to Predict Good Moves



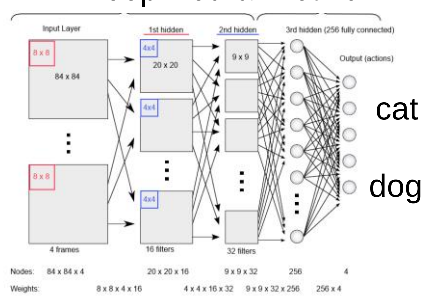
Idea: treat Go board as an image—use modern computer vision

Deep Neural Networks

How can you write a program to distinguish cats from dogs in images?

Machine Learning: show computer example cats and dogs and let it decide how to distinguish them

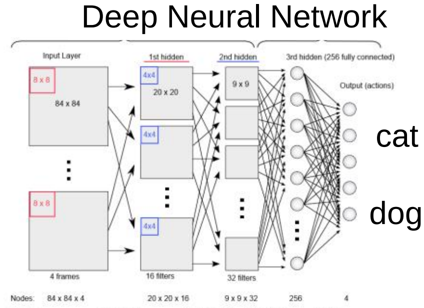
Deep Neural Network



Deep Neural Networks

State-of-the-Art Performance: very fast GPU implementations allow training giant networks (millions of parameters) on massive data sets

Deep Neural Network



Deep Neural Networks

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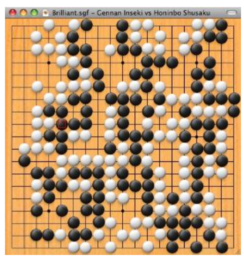
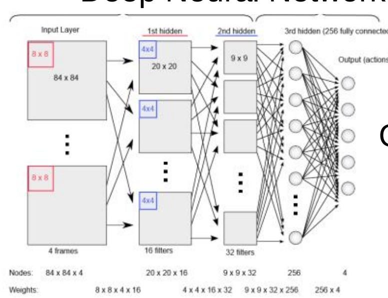
Could a Deep NN learn to predict expert Go moves by looking at board position? Yes!



Deep Neural Network



Go Move

Arsenal of AlphaGo

Monte Carlo Tree Search

Distributed High-Performance Computing

Deep Neural Networks

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Supervised Learning

Reinforcement Learning

Huge Data Set

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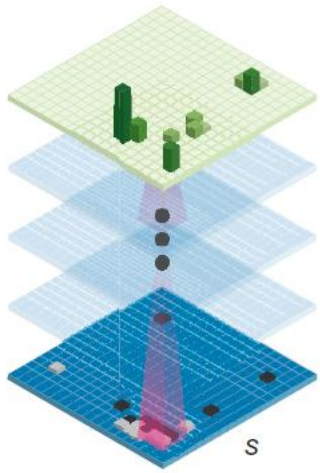
Supervised Learning for Go

Output: probability of each move



Deep NN Internal Layers

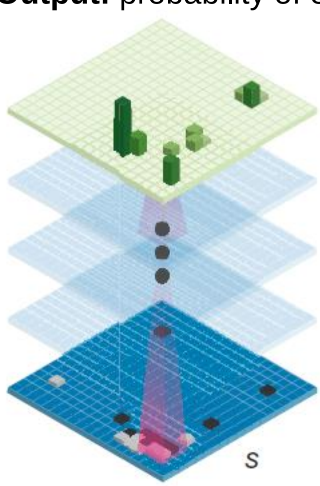
Trained for 3 weeks on 30 million expert moves

- 57% prediction accuracy!

Input: Board Position

Supervised Learning for Go

Output: probability of each move ~~being played by an expert~~ leading to a win

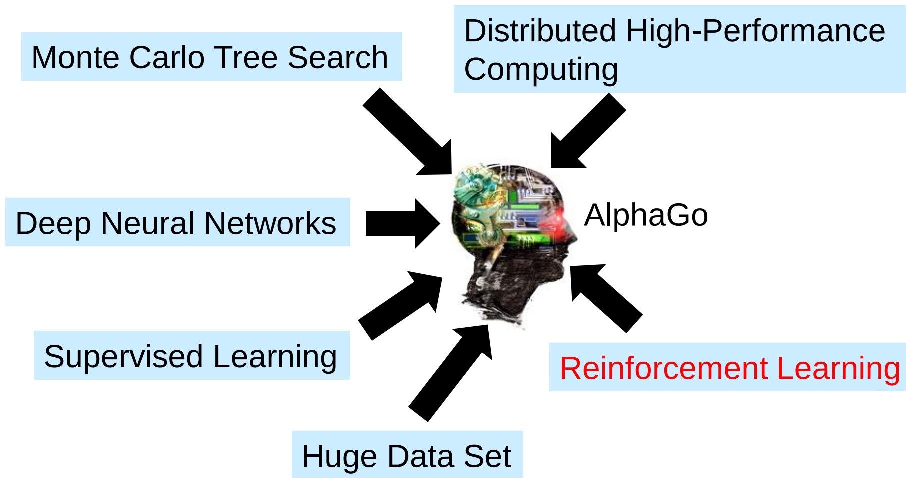


AlphaGo has still not played a game of Go!

Could it improve further by playing?

Input: Board Position

Arsenal of AlphaGo



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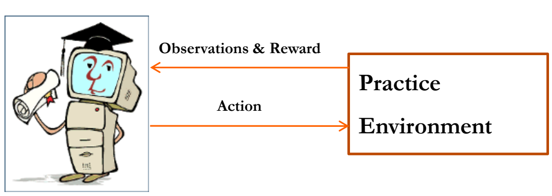
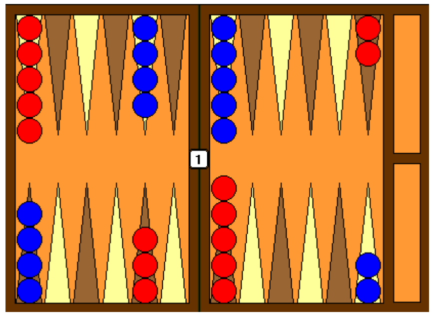
Reinforcement Learning

Reinforcement Learning: learn to act well in an environment via trial-and-error that results in positive and negative rewards



TD-Gammon (1992)



Backgammon

- Neural network with 80 hidden units (1 layer)
- Used Reinforcement Learning for 1.5 Million games of self-play
- One of the top (2 or 3) players in the world!

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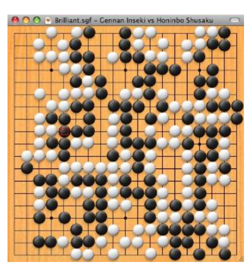
Learning from Self Play

AlphaGo



AlphaGo

Reinforcement Learning : learn from positive and negative rewards (win = +1 and loss = -1 in Go)

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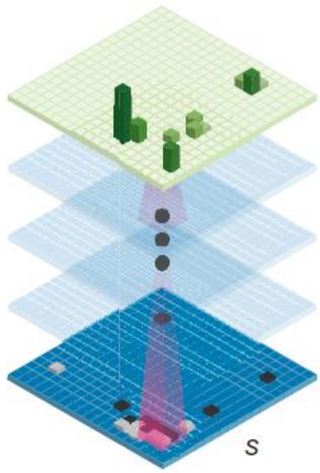
Reinforcement Learning for Go

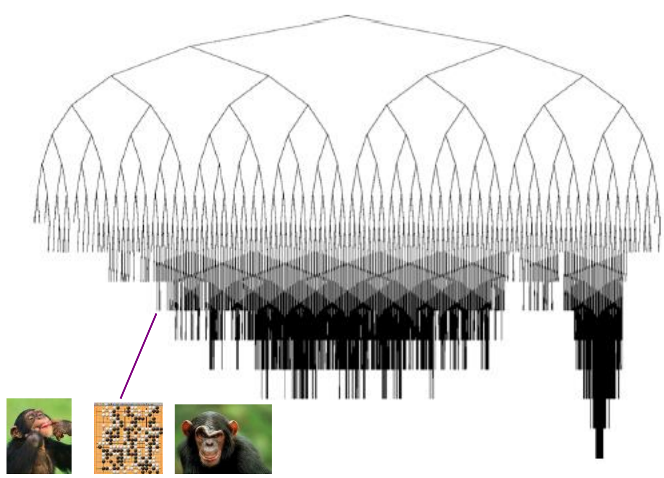
Output: probability of each move



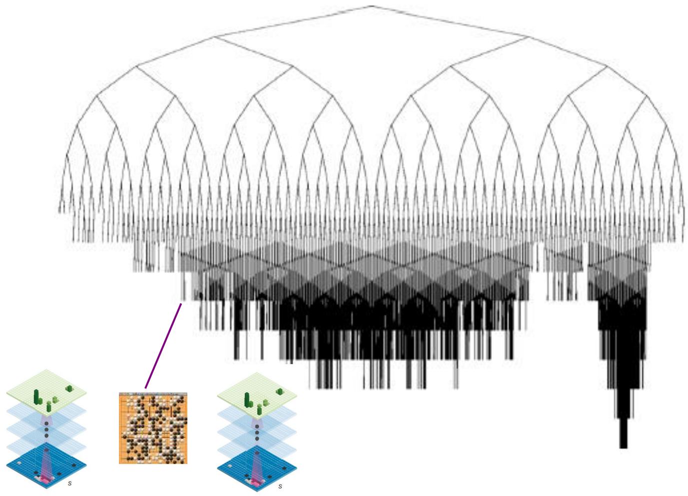
Input: Board Position

- Start with Deep NN from supervised learning.
- Continue to train network via self play.
- AlphaGo did this for months.
- 80% win rate against the original supervised Deep NN
- 85% win rate against best prior tree search method!
- Still not close to professional level

Monte Carlo Tree Search

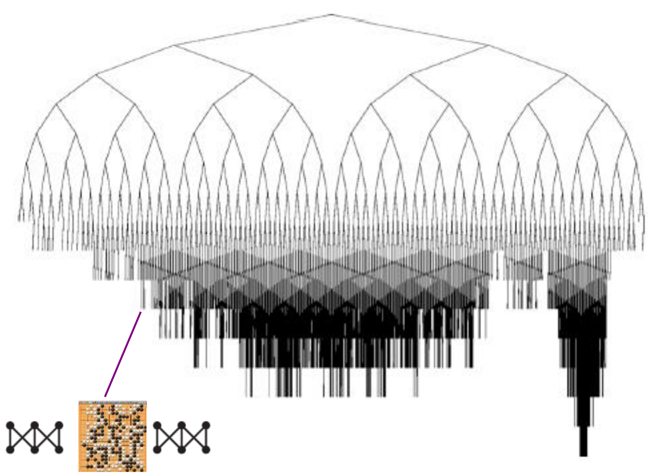


Monte Carlo Tree Search



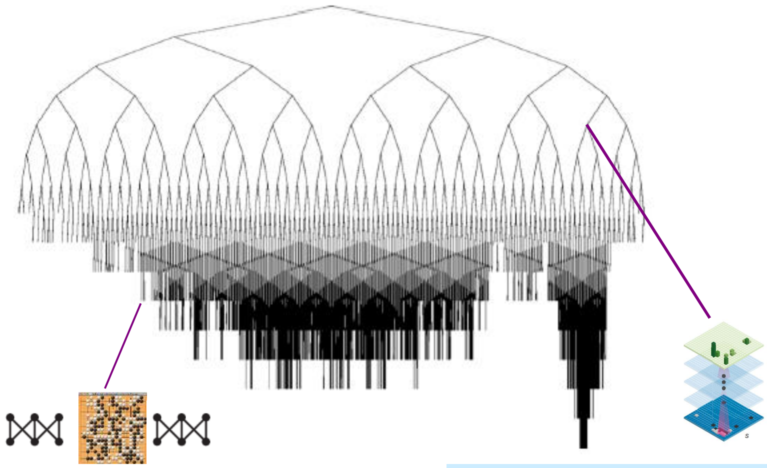
Problem: takes too long long to evaluate (msec per board)

Monte Carlo Tree Search



Solution: use smaller networks
(less accurate but fast)

Monte Carlo Tree Search



Solution: use smaller networks (less accurate but fast)

Use expensive network to guide tree expansion

AlphaGo

- Deep Learning + Monte Carlo Tree Search + HPC
- Learn from 30 million expert moves and self play
- Highly parallel search implementation
- 48 CPUs, 8 GPUs (scaling to 1,202 CPUs, 176 GPUs)

Image: AP/ Lee Jin-man

2015 :
AlphaGo beats European Champ (5-0)

lots of self play

March 2016 :
AlphaGo beats Lee Sedol (4-1)

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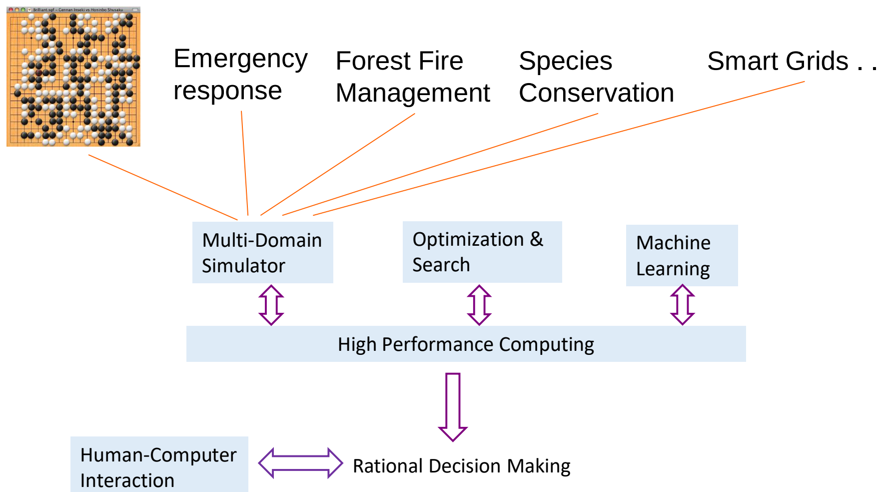
Computers are good at Go now – So What?



Computers are good at Go now – So What?

- The idea of combining search with learning is very general and widely applicable
- Deep Networks are leading to advances in many areas of AI now
  - Computer Vision
  - Speech Processing
  - Natural Language Processing
  - Bioinformatics
  - Robotics
- It is a very exciting time to be working in AI

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