A Brief History of Computer Go

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

Why?

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

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)
2016: AlphaGo Defeats Go Legend Lee Sedol 4-1 (lots more 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)

March 2016: AlphaGo beats Lee Sedol 4-1
Mastering the game of Go with deep neural networks and tree search

Arsenal of AlphaGo
Monte Carlo Tree Search
Deep Neural Networks
Supervised Learning
Huge Data Set

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

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**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

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

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

**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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**Supervised Learning for Go**

- **Input:** Board Position
- **Output:** probability of each move

Deep NN Internal Layers

Trained for 3 weeks on 30 million expert moves

• 57% prediction accuracy!
**Reinforcement Learning**

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

- **Observation & Reward**
  - Practice
  - Environment

**TD-Gammon (1992)**

- 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!

**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**

**Idea**: use deep NN for rollout evaluation

**Problem**: deep NN takes too long (msec) to evaluate
Monte Carlo Tree Search

**Solution:** use deep NN for selection phase
- Evaluate once per tree node
- Use probabilities to bias search toward actions that look good to deep NN

Monte Carlo Tree Search

**Solution:** train smaller network for rollout
- Less accurate but much faster

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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?**

- 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