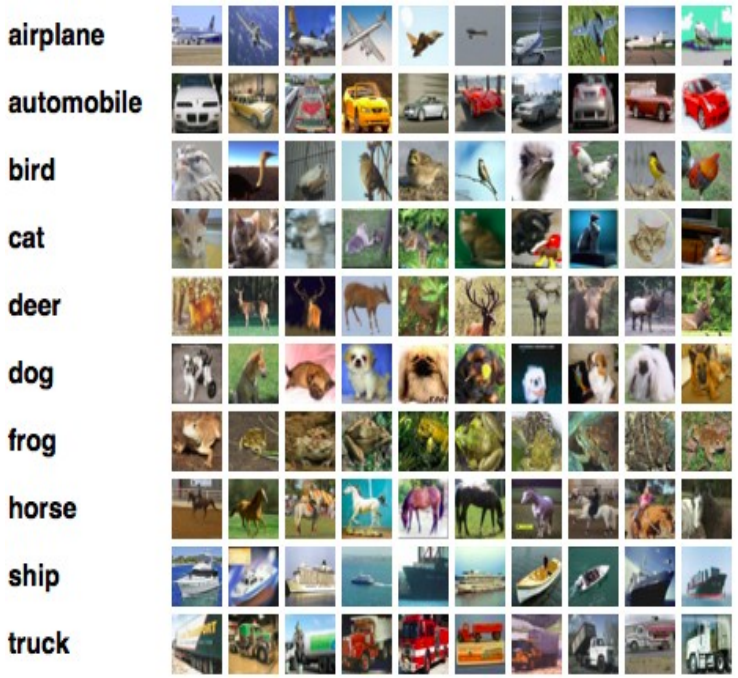
CS6700:
Reinforcement Learning

B. Ravindran

J Slot: W: 2 – 3:15, Th 3:30 – 4:45
Tutorial: M: 5 – 5:50

Machine Learning

Learn functions from input to output from data



Learning to Control

- Familiar models of machine learning
  - Learning from data.

- How did you learn to cycle?
  - Trial and error!
  - Falling down hurts!
  - Evaluation, not instruction
  - Reinforcement Learning

- Walk, Talk, etc.

Reinforcement Learning

- A trial-and-error learning paradigm
  - Rewards and Punishments
- Learn about a system through interaction
- Inspired by behavioural psychology!
  - Pavlov's dog

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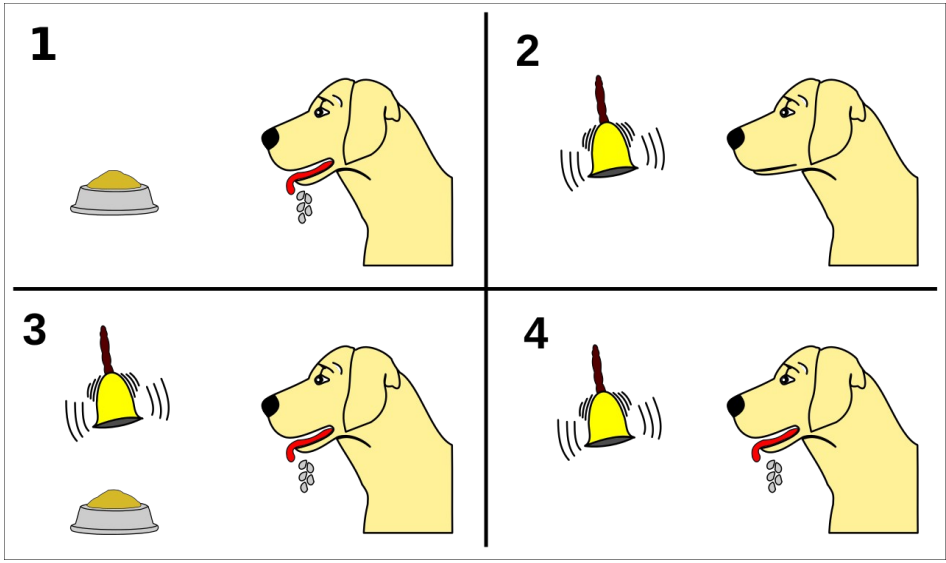

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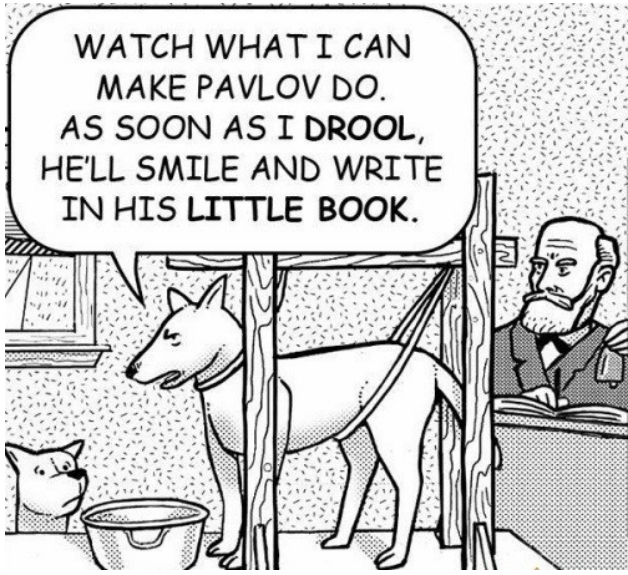
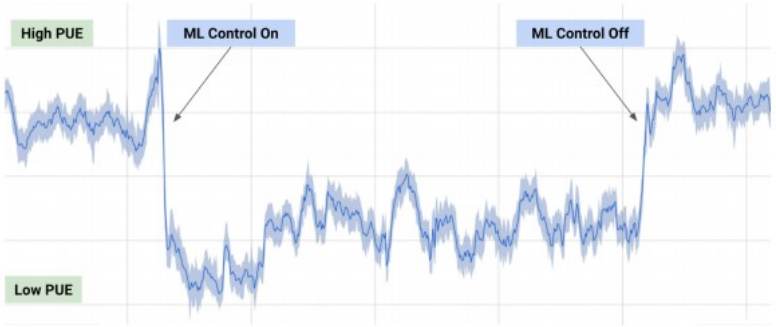
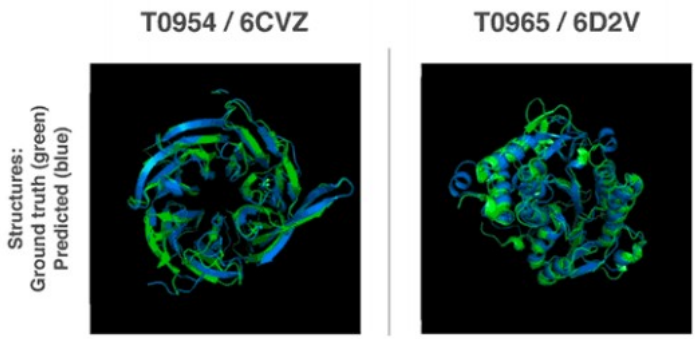


Reinforcement Learning Works!

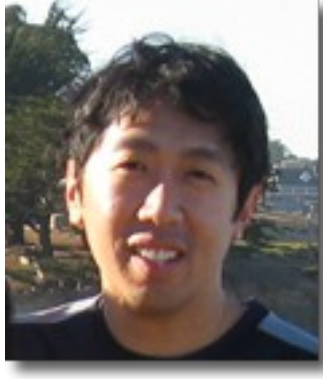




Why RL

- Complex Dynamics
  - Helicopter control

Helicopter Control

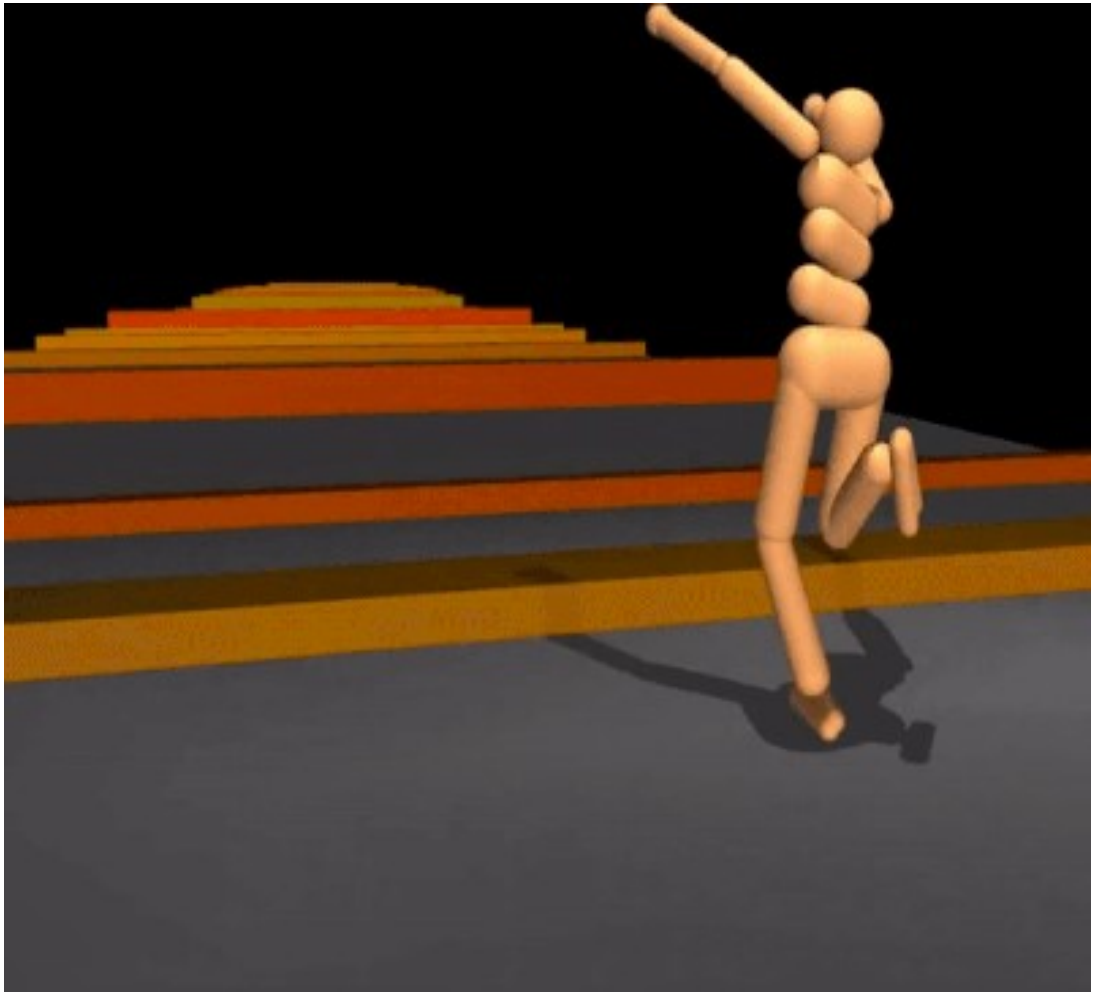


Why RL

- Complex Dynamics
  - Helicopter control
  - Humanoid control

Humanoid Control

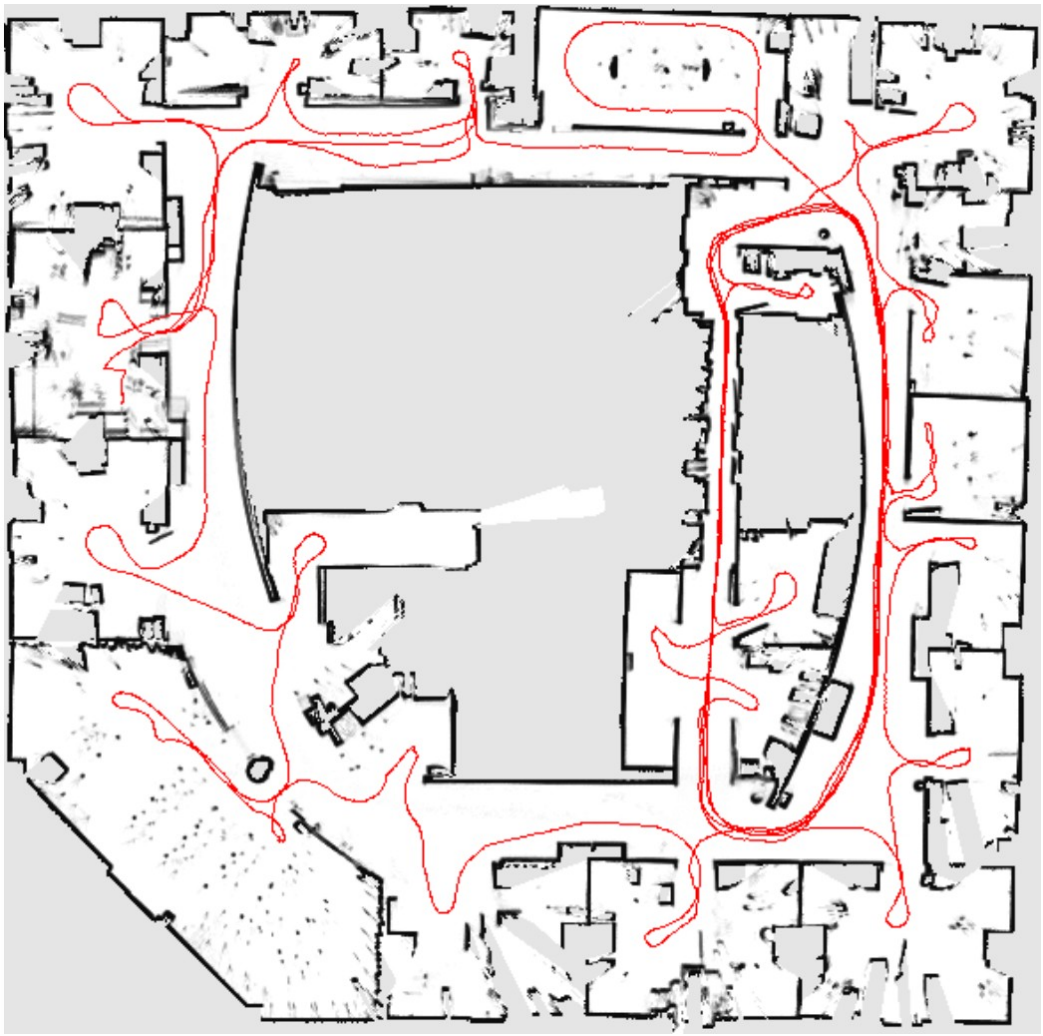
Humanoid Running!



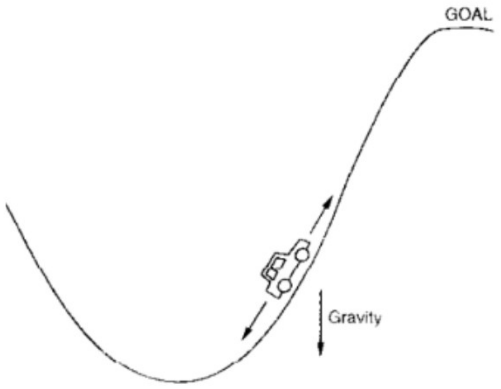
Why RL

- Complex Dynamics
- Complex Workspace

Path Planning



Path Planning

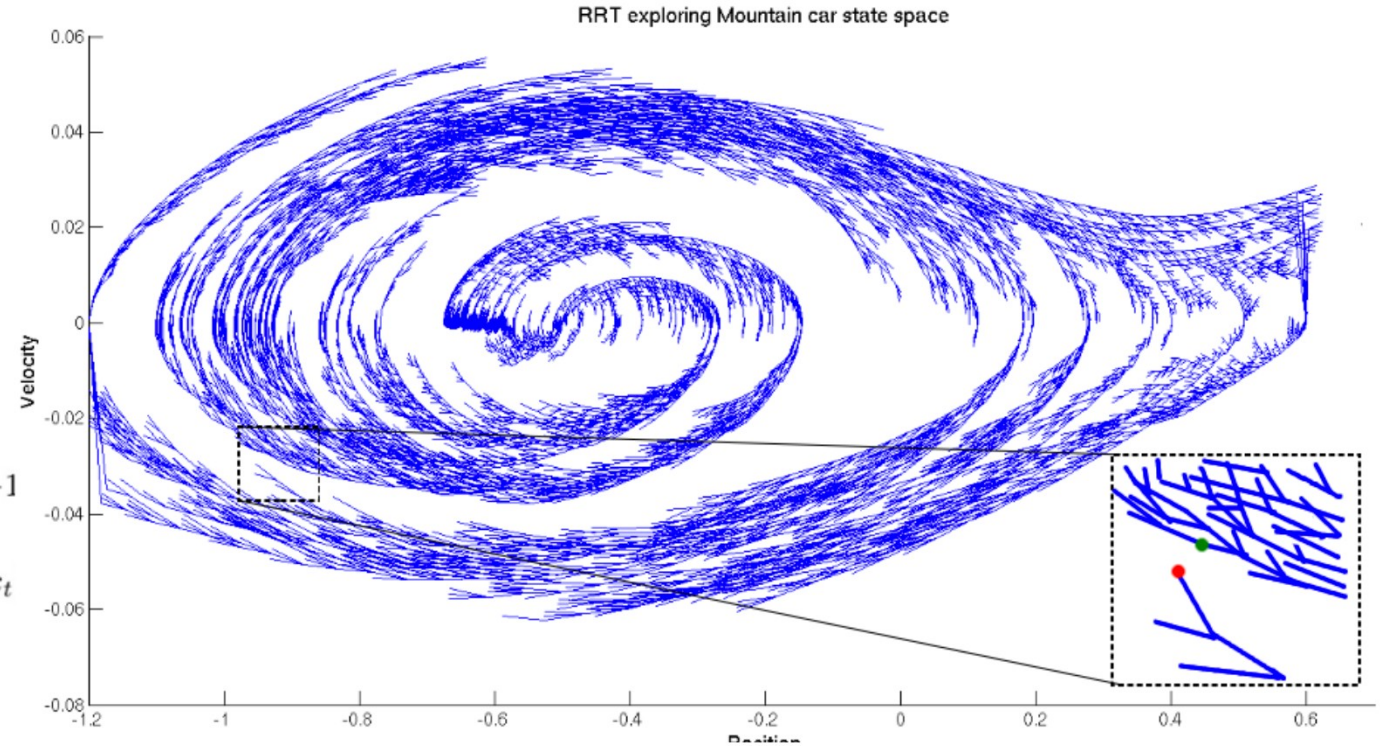


State :– (x, v), Control :– $\{+1, 0, -1$

$x_{t+1} = x_t + v_t$

$v_{t+1} = v_t + 0.001u_t - 0.0025\cos(3x_t$

-1 reward till goal



- Learn distance function ICRA 2014

Cluttered Workspace

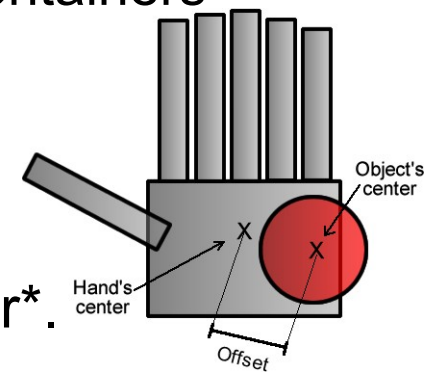
Why RL

- Complex Dynamics
- Complex Workspace
- Stochastic sensing and actuation

Visual Attention ICRA 2012

Manipulation Task:

- Goal: To put as many objects as possible inside the containers
- Uncertainty: Location of objects and containers
  - Duration: 5 minutes each trial
  - We implement our model using the iCub simulator*.



*Metta el al, "The iCub humanoid robot: An open platform for research in embodied cognition," *Proc. ACM Perf. Metrics for Inf. Sys.* 2008, 50-56.

Why RL

- Complex Dynamics
- Complex Workspace
- Stochastic sensing and actuation
- Human-in-the-loop Learning
  - Instructions
  - Imitation

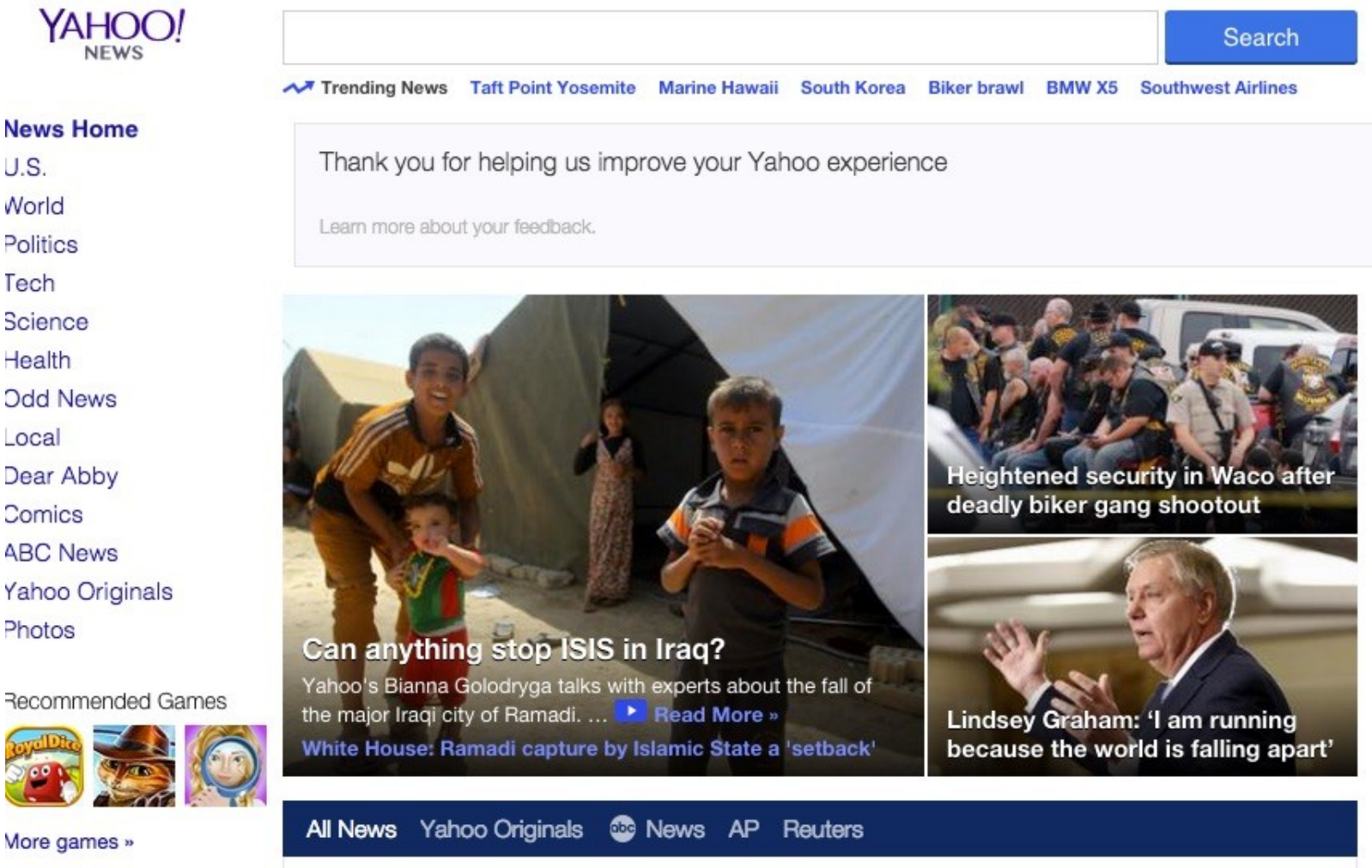
Interpreting Instructions FLAIRS 2012

- Show Video

Why RL

- Complex Dynamics
- Complex Workspace
- Stochastic sensing and actuation
- Human-in-the-loop Learning
- Cognitively motivated Learning
- Customization/Personalization

Customization



Ad Selection

Shop for Florists in Chennai on Google

Sponsored

Online Flowers Delivery
₹1,749
Ferns N Petals

Message In A Bottle with teg
₹349
Ferns N Petals

Classic Bunch - online flower ...
₹499
FlowerAura
Special offer

Online Flower Delivery
₹599
Ferns N Petals

Relish Of Heavenly Treat
₹1,399
Ferns N Petals

Florists In Chennai - Same Day Delivery Within 4 Hrs - floweraura.com
Ad www.floweraura.com/Online-Florist/Chennai
Online **Flowers** & Gifts Delivery @ Rs 399. Best Price, 100% Smile Guaranteed.
Delivery in 4 Hrs · Mid-Night Delivery · No Hidden Cost · Free Shipping · Flowers Starting @ Rs 399
Types: Cakes, Flowers, Gifts, Chocolate

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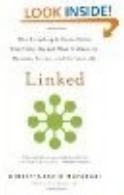
Order **Flowers** Now For Express Delivery within 2-3 hrs Anywhere in **Chennai**.

Recommendation

Really?

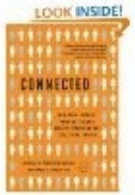
Customers Who Bought This Item Also Bought



Linked: How Everything Is Connected to... by Albert-Laszlo Barabasi

★★★★☆ (116)

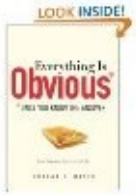
$10.38



Connected: The Surprising Power of Our... by Nicholas A. Christakis

★★★★☆ (42)

$10.87

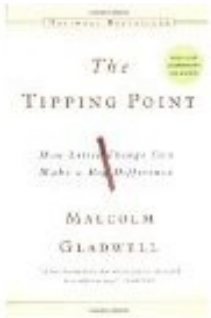


Everything Is Obvious: *Once You Know the Answer by Duncan J. Watts

★★★★☆ (54)

$17.16

Your Recent History Also Bought



The Tipping Point: How Little...

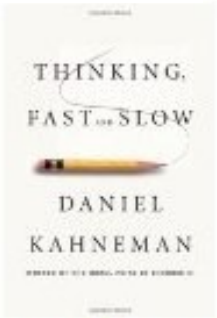
› Malcolm Gladwell

★★★★☆ (1,262)

Paperback

$9.59

Fix this recommendation



Thinking, Fast and Slow

› Daniel Kahneman

★★★★☆ (91)

Hardcover

$16.65

Fix this recommendation

Adapt: Why Success Always Starts...

› Tim Harford

★★★★½ (31)

Hardcover

$17.82

Fix this recommendation

Comment Recommendation

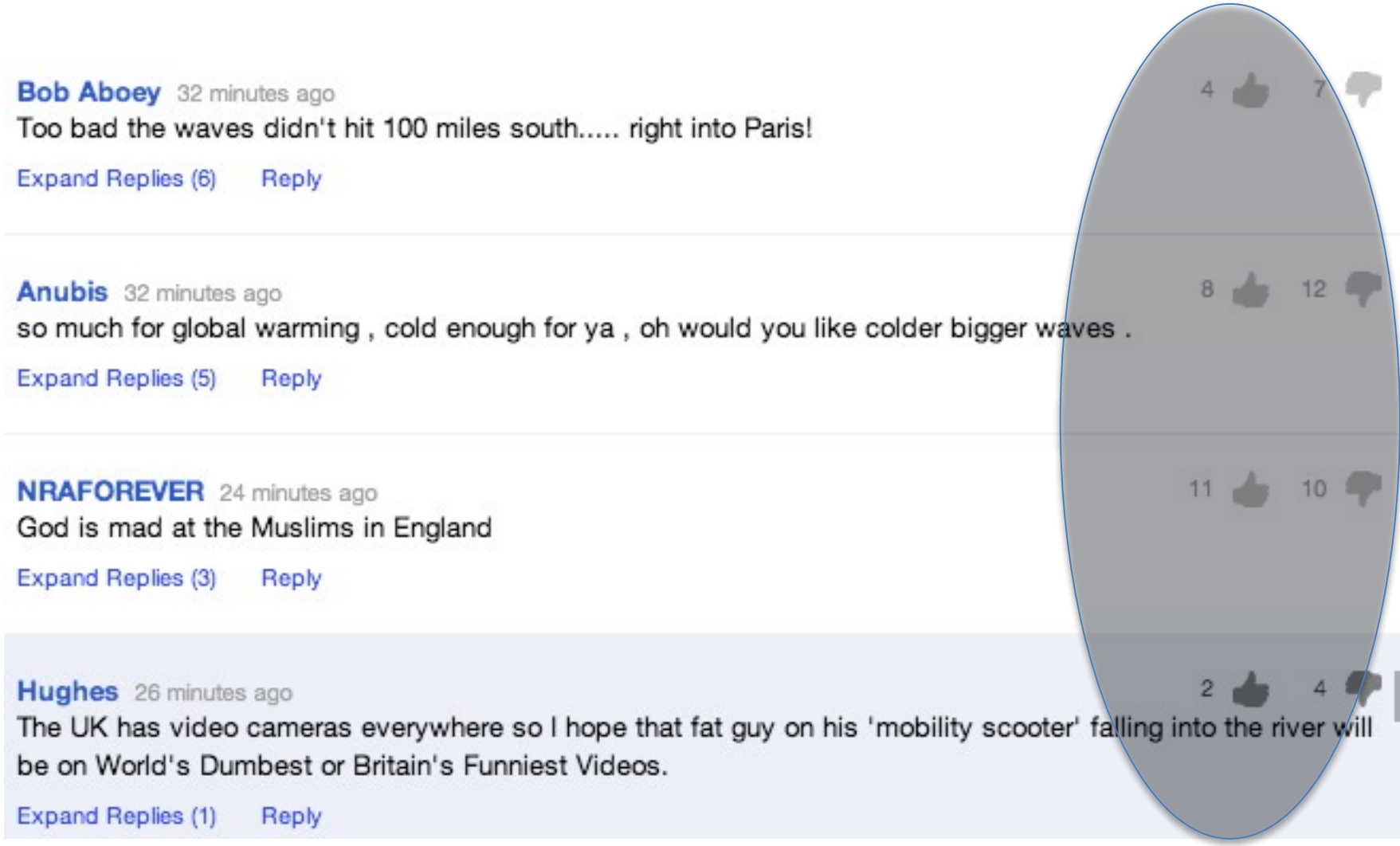
Bob Aboey 32 minutes ago 4 7
Too bad the waves didn't hit 100 miles south..... right into Paris!
Expand Replies (6) Reply

Anubis 32 minutes ago 8 12
so much for global warming , cold enough for ya , oh would you like colder bigger waves .
Expand Replies (5) Reply

NRAFOREVER 24 minutes ago 11 10
God is mad at the Muslims in England
Expand Replies (3) Reply

Hughes 26 minutes ago 2 4
The UK has video cameras everywhere so I hope that fat guy on his 'mobility scooter' falling into the river will be on World's Dumbest or Britain's Funniest Videos.
Expand Replies (1) Reply

Comment Recommendation



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Why RL

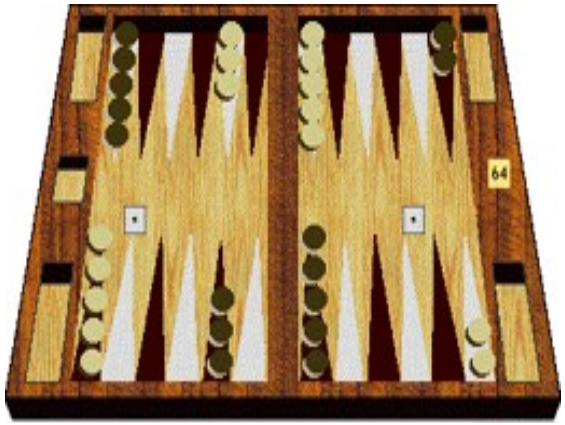
- Complex Dynamics
- Complex Workspace
- Stochastic sensing and actuation
- Human-in-the-loop Learning
- Cognitively motivated Learning
- Customization/Personalization
- Going beyond human knowledge
  - Learn through Self-Play

Human Level Backgammon player

TD-Gammon (Tesauro 92, 94, 95)

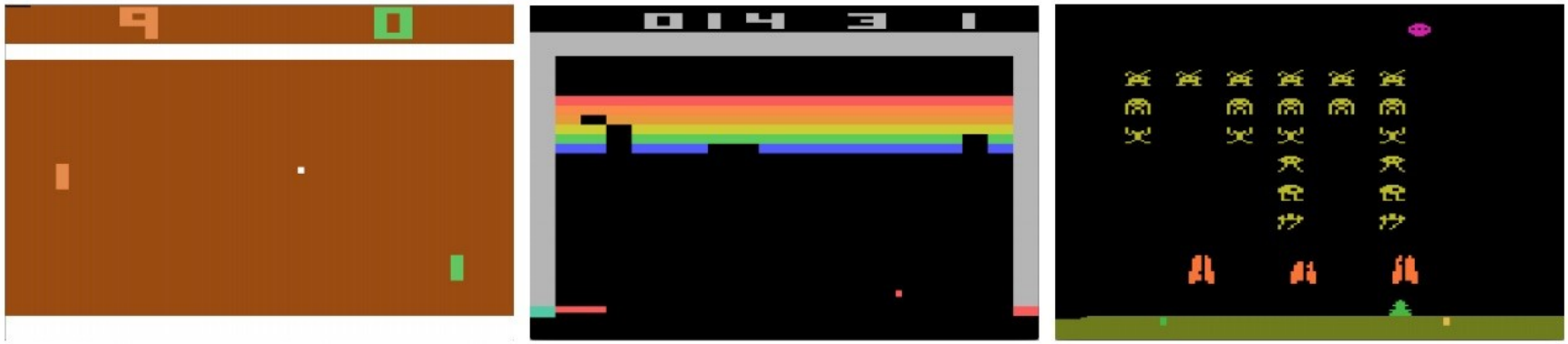
Beat the best human player in 1995

Learnt completely by *self play*



New moves not recorded by humans in centuries of play

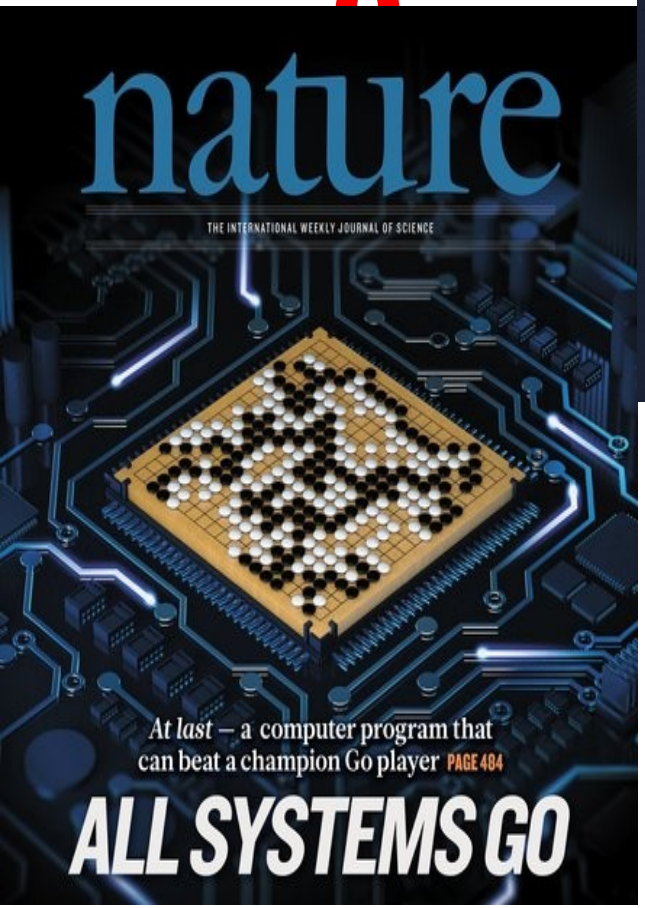
Game Playing – Arcade Games

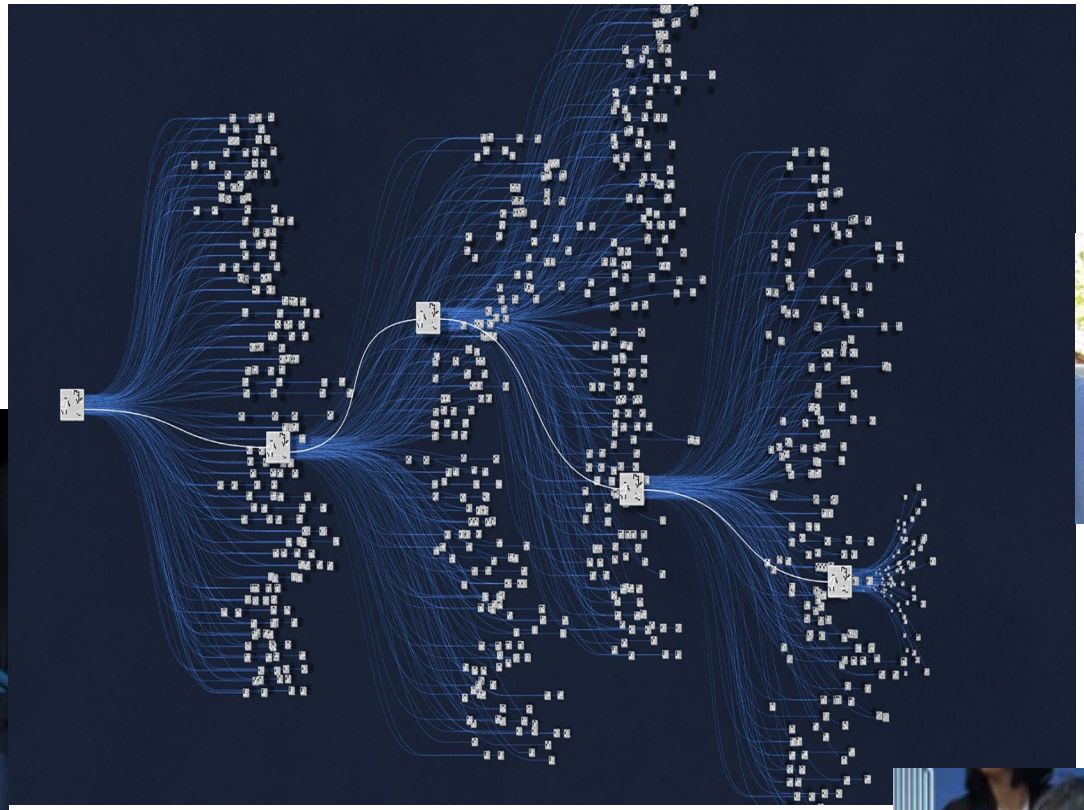


- Learnt to play from video input!
- Learnt from scratch
- Used a complex *neural network!*
- Considered one of the hardest learning problems solved by a computer!

Deepmind's Atari Player

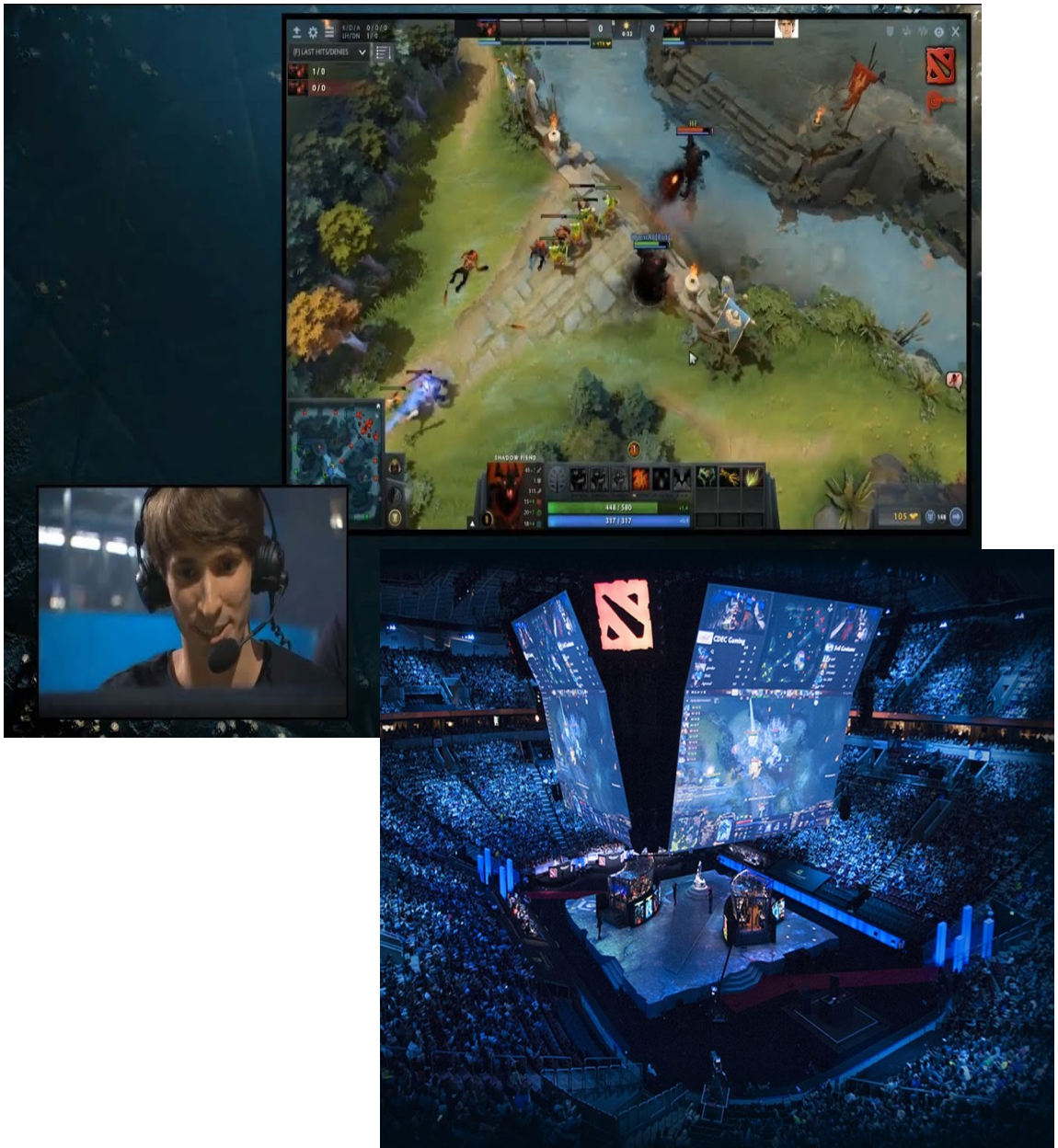
AlphaG
o





- Branching factor : Go 250 vs 35 Chess
- AlphaGo Master defeated the 18-time World Champion* 4-1.

Defence of the Ancients 2 (DoTA 2)



- The AI bot won 1v1 matches against top players in the world at the International DoTA Championships.
- 100 different heroes. 100 different items. Many different tactics. **Much more complex than board games.**
- Trained for 2 weeks by using just self-play.

- The full game is played 5v5. Multi-agent coordination required. Still being developed.

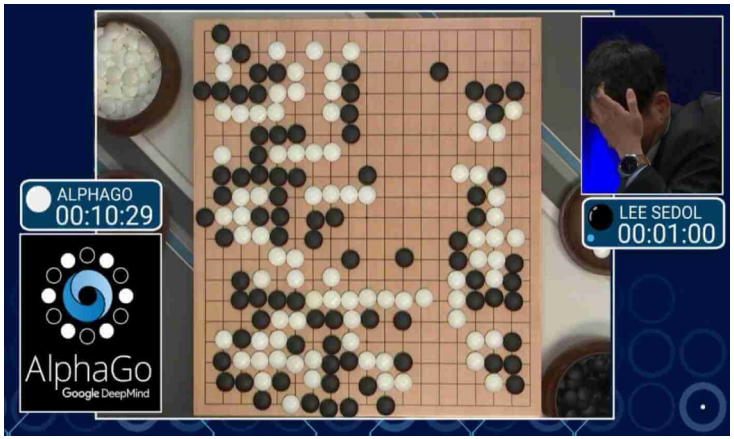
AlphaZero: A general AI Algorithm

- A general AI agent; Not limited to Go. Superhuman Performance on Chess, Shogi and Go.
- *No human data:* Trained from Scratch RL by playing against itself.
- *No human features:* Only the raw positions from the board are provided to the agent.
- *Simpler Search:* No randomized Monte Carlo Rollouts. Use a Neural Network to evaluate.
- Beat AlphaGo Lee by **100 – 0**
- Beat Stockfish and Elmo on Chess and Shogi.

AlphaGo

Move 37

With the 37th move in the match's second game, AlphaGo landed a surprise on the right-hand side of the 19-by-19 board that flummoxed even the world's best Go players, including Lee Sedol. "That's a very strange move," said one commentator, himself a nine dan Go player, the highest rank there is. "I thought it was a mistake," said the other. Lee Sedol, after leaving the match room, took nearly fifteen minutes to formulate a response. Fan Gui—the three-time



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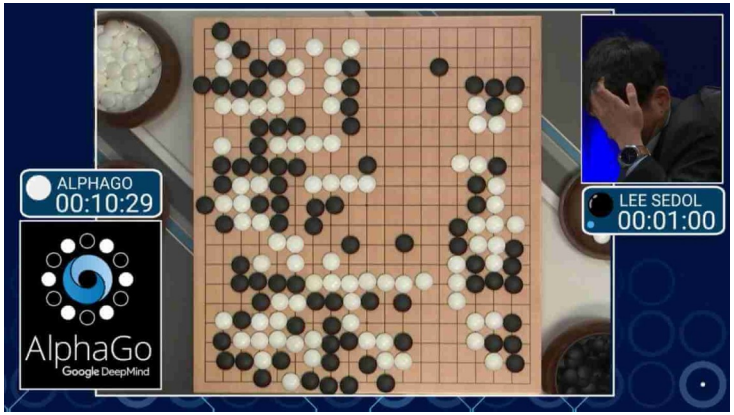
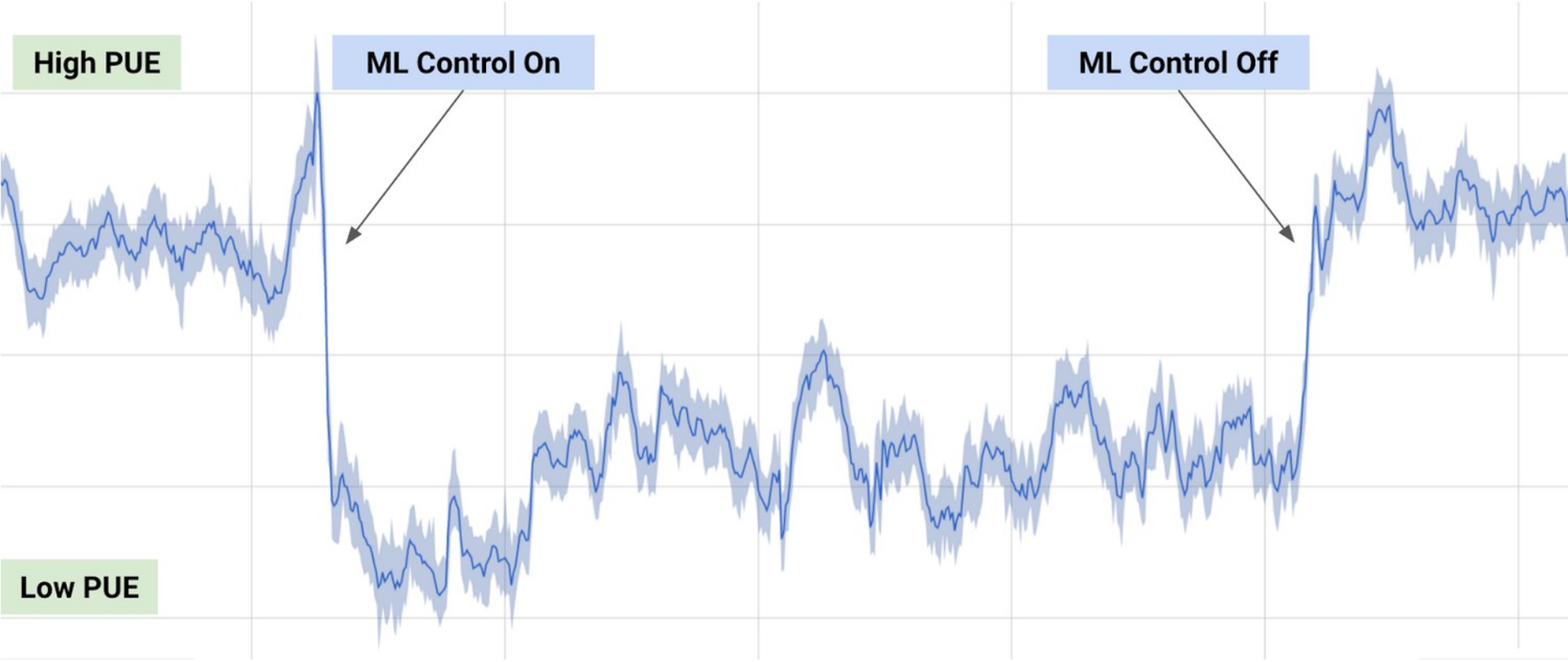


Why RL

- Complex Dynamics
- Complex Workspace
- Stochastic sensing and actuation
- Human-in-the-loop Learning
- Cognitively motivated Learning
- Customization/Personalization
- Going beyond human knowledge
  - Improving heuristics

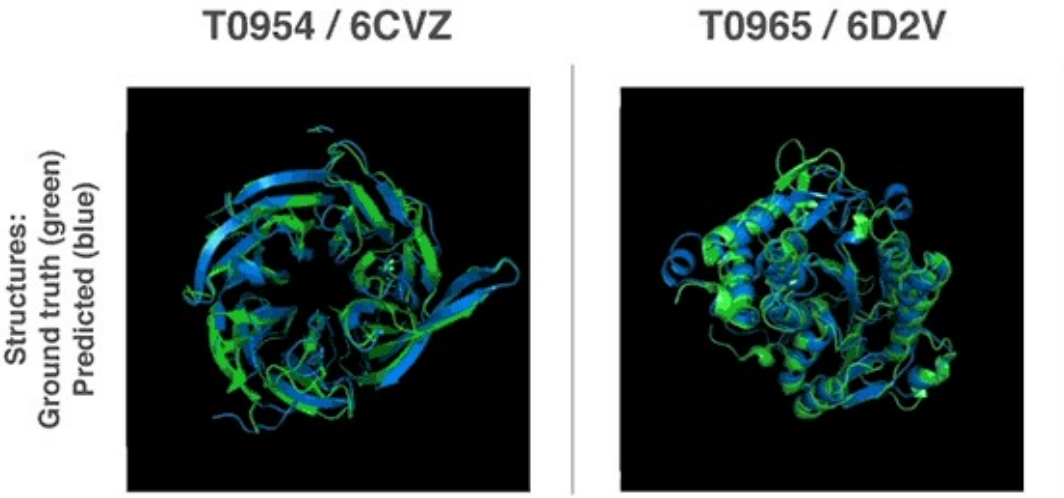
Power Management

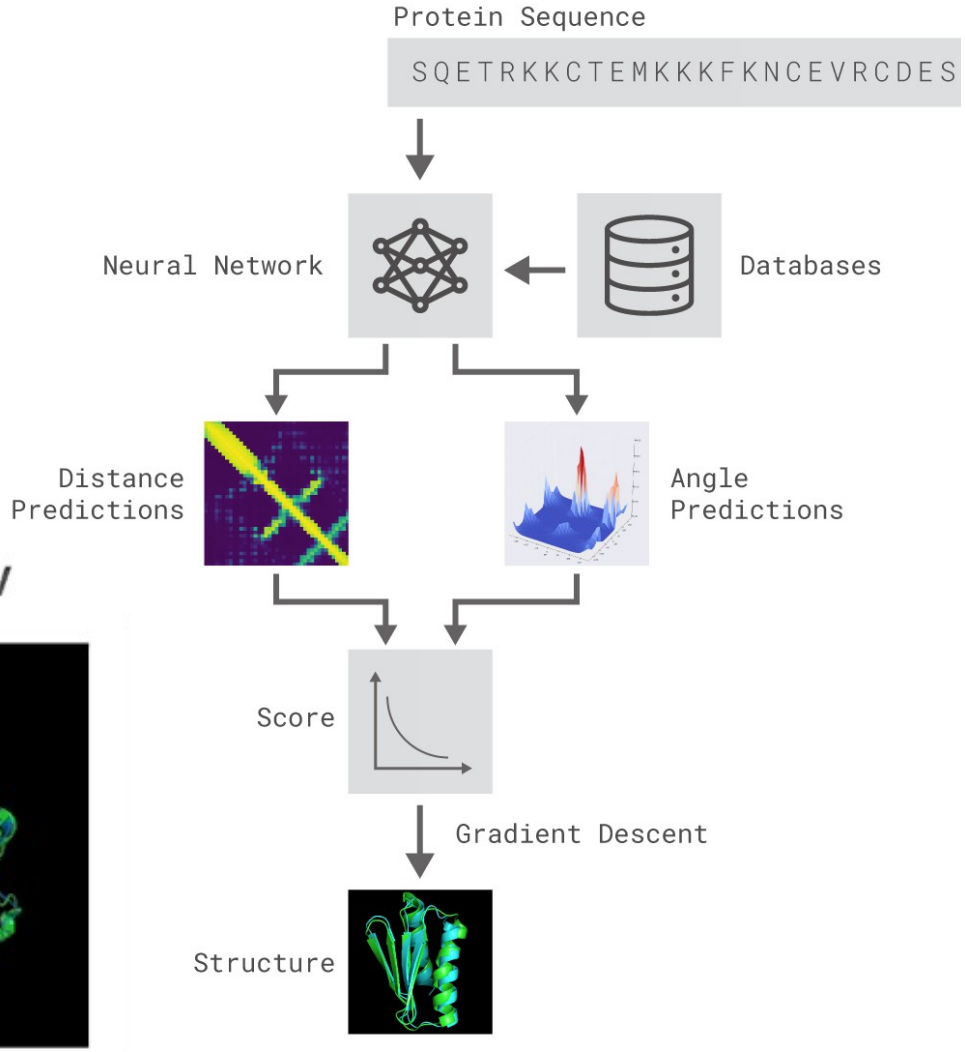
- Reduced Google Data Centre cooling bill by 40%



AlphaFold

- Protein Folding: One of the hardest problems in biology
- An AI agent achieved 25% improvement over best human effort

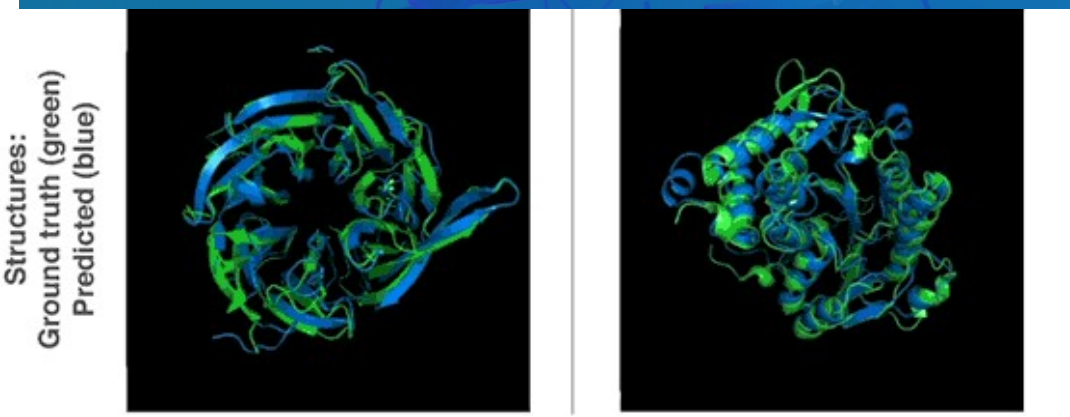


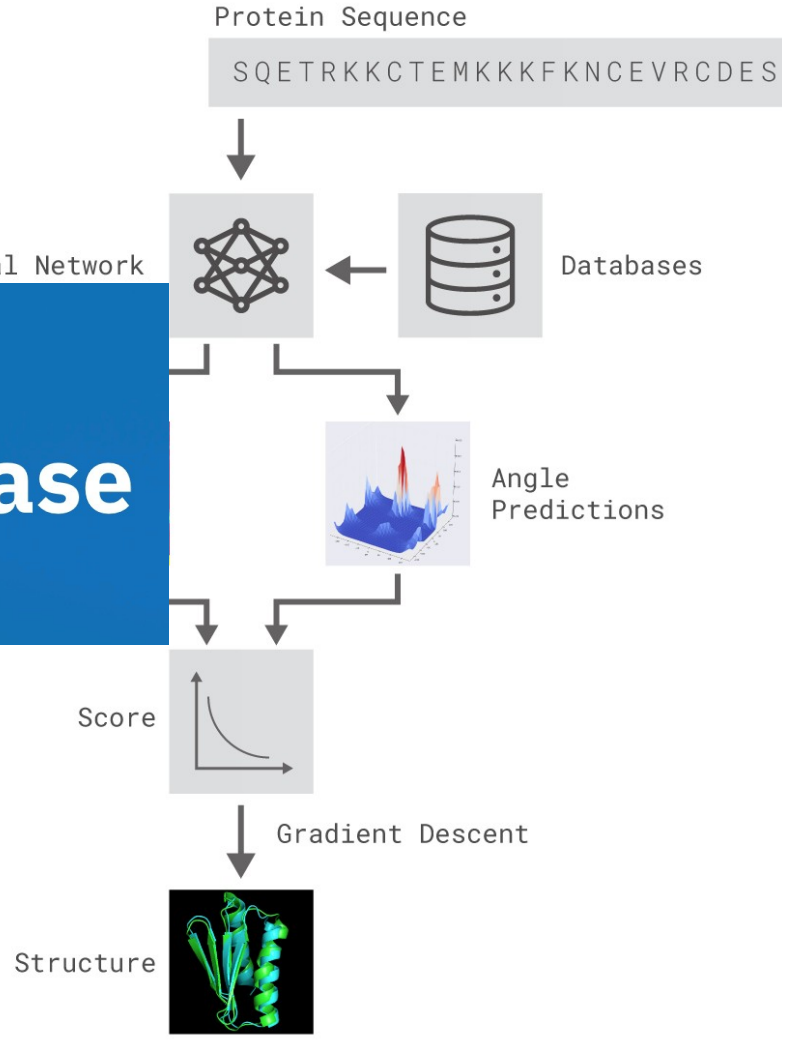


AlphaFold 2.0

- Protein Folding: One of the hardest problems in biology

SOLVED?

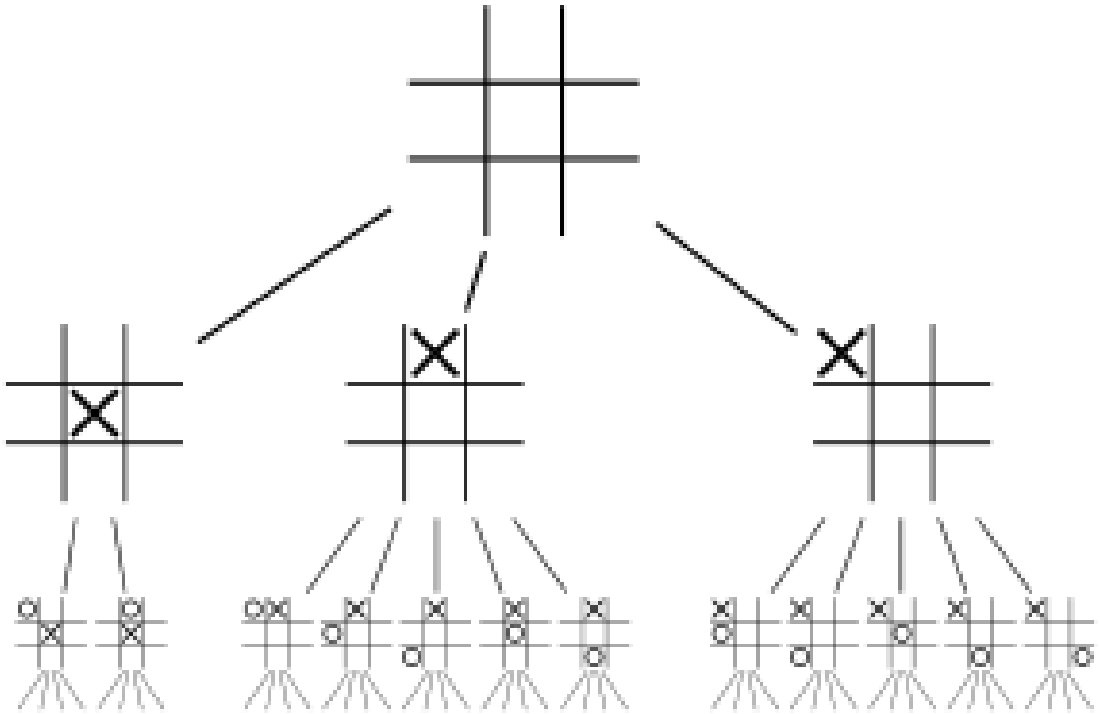




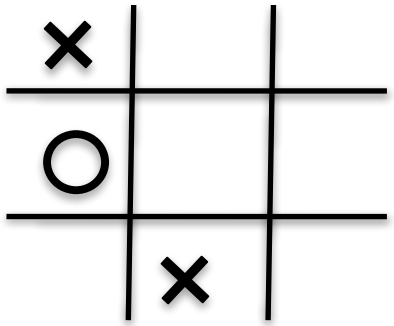
Other Applications

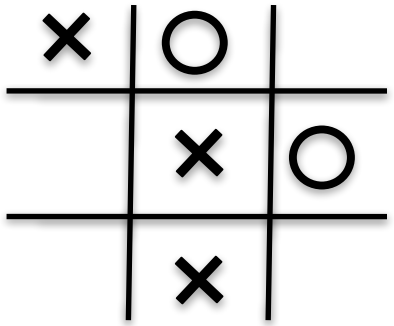
- Optimal Control
  - Robot Navigation
  - Chemical Plants
- Combinatorial Optimization
  - Elevator Dispatching
  - VLSI placement and routing
  - Job-shop scheduling
  - Routing algorithms
  - Call admission control
- More
  - Intelligent Tutoring Systems
- Computational Neuroscience
  - Primary mechanism of learning
- Psychology
  - Behavioral and operant conditioning
  - Decision making
- Operations Research
  - Approximate Dynamic Programming
- More
  - Dialogue systems

Tic-Tac-Toe

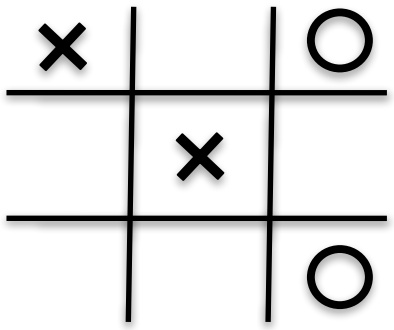


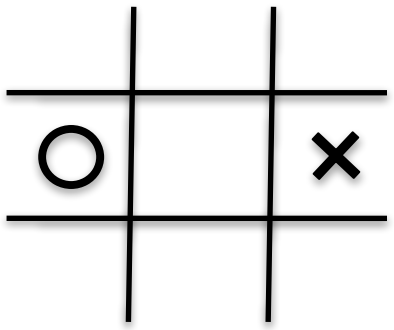
Supervised Learning





Current Positions





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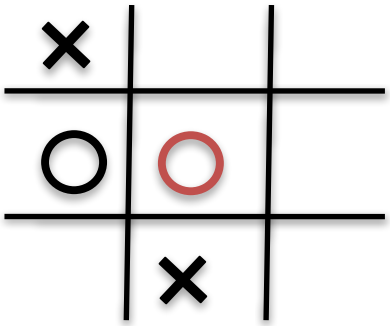
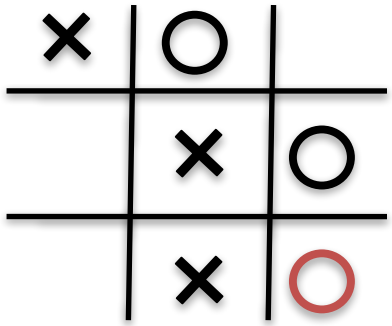
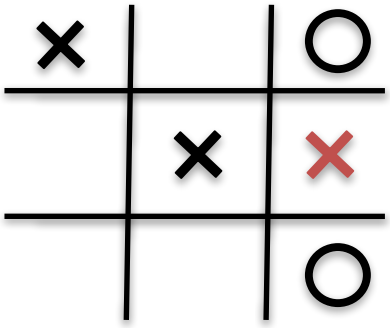
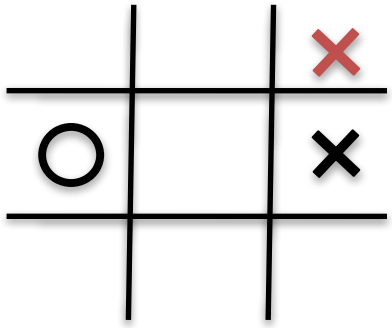




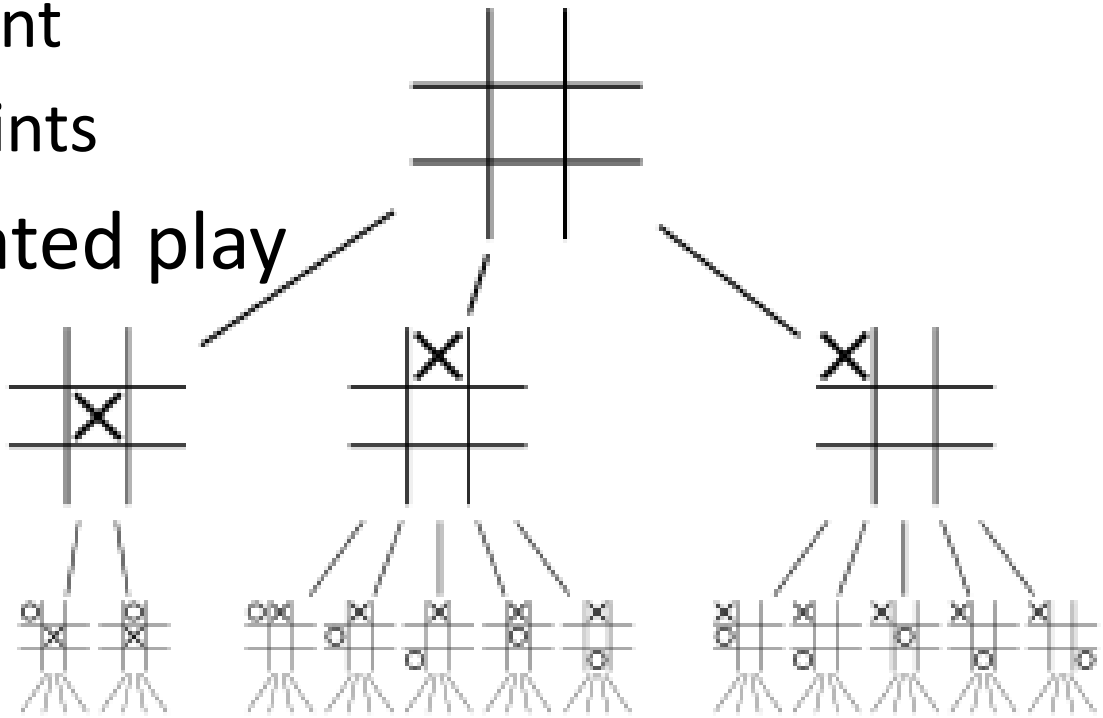
Expert Moves





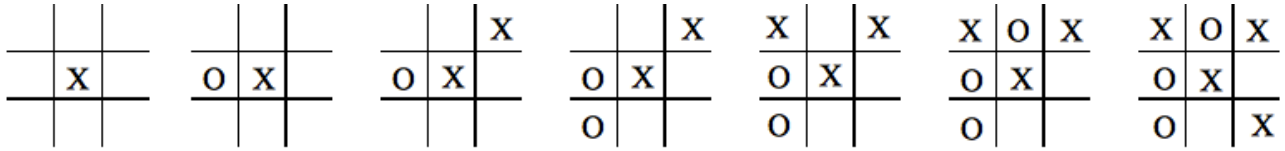
Reinforcement Learning

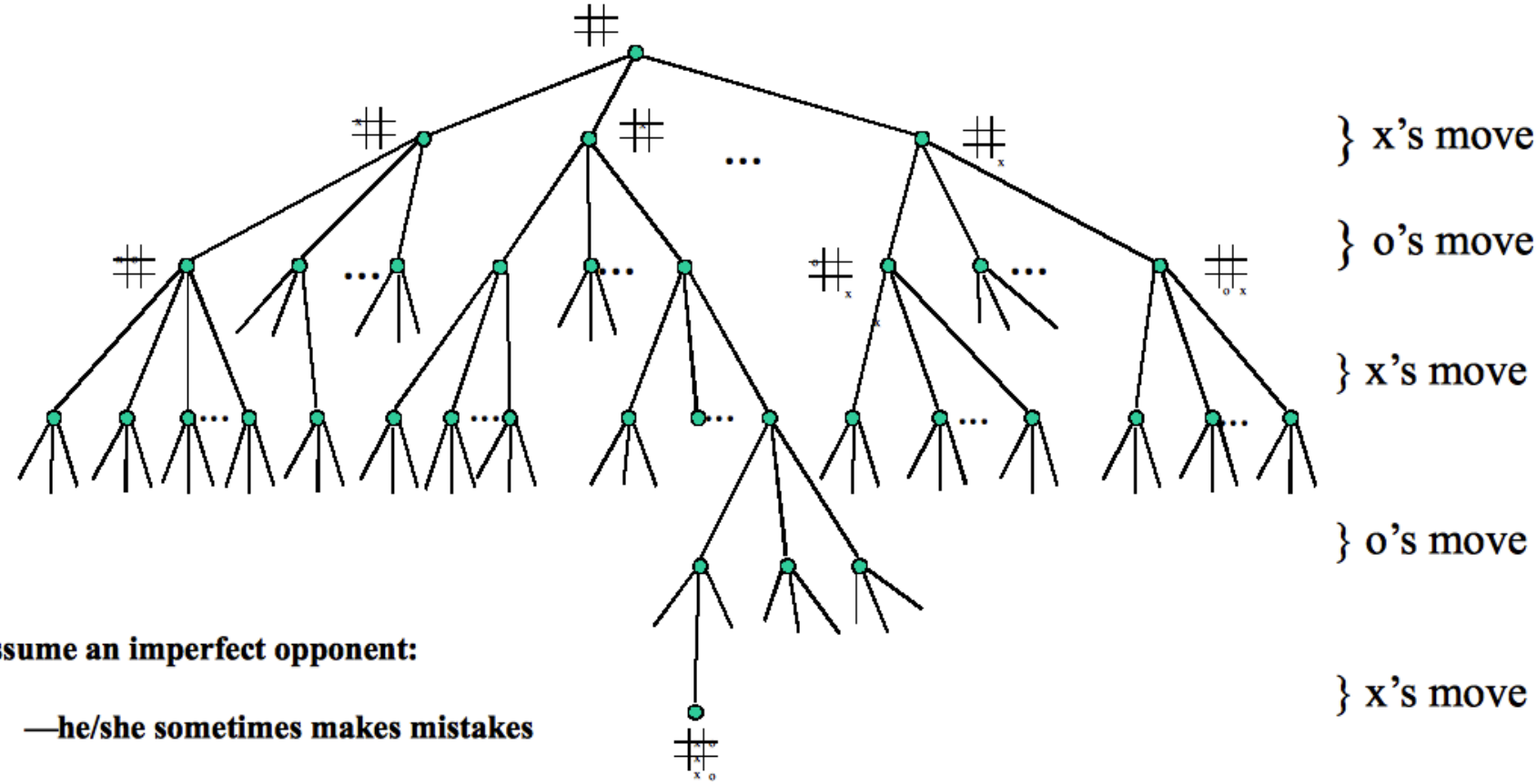
- Learn from evaluation
  - Win gives 1 point
  - Loss gives -1 point
  - Draw gives 0 points
- Learn from repeated play



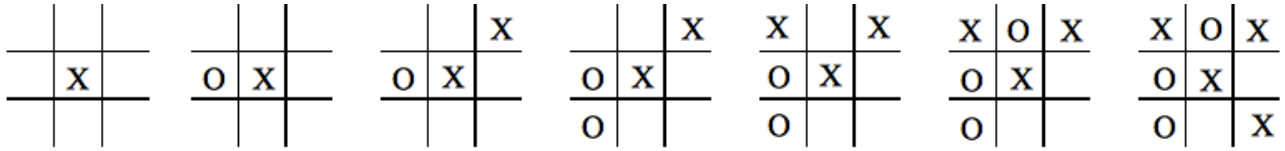
MENACE Michie and Chambers ’60

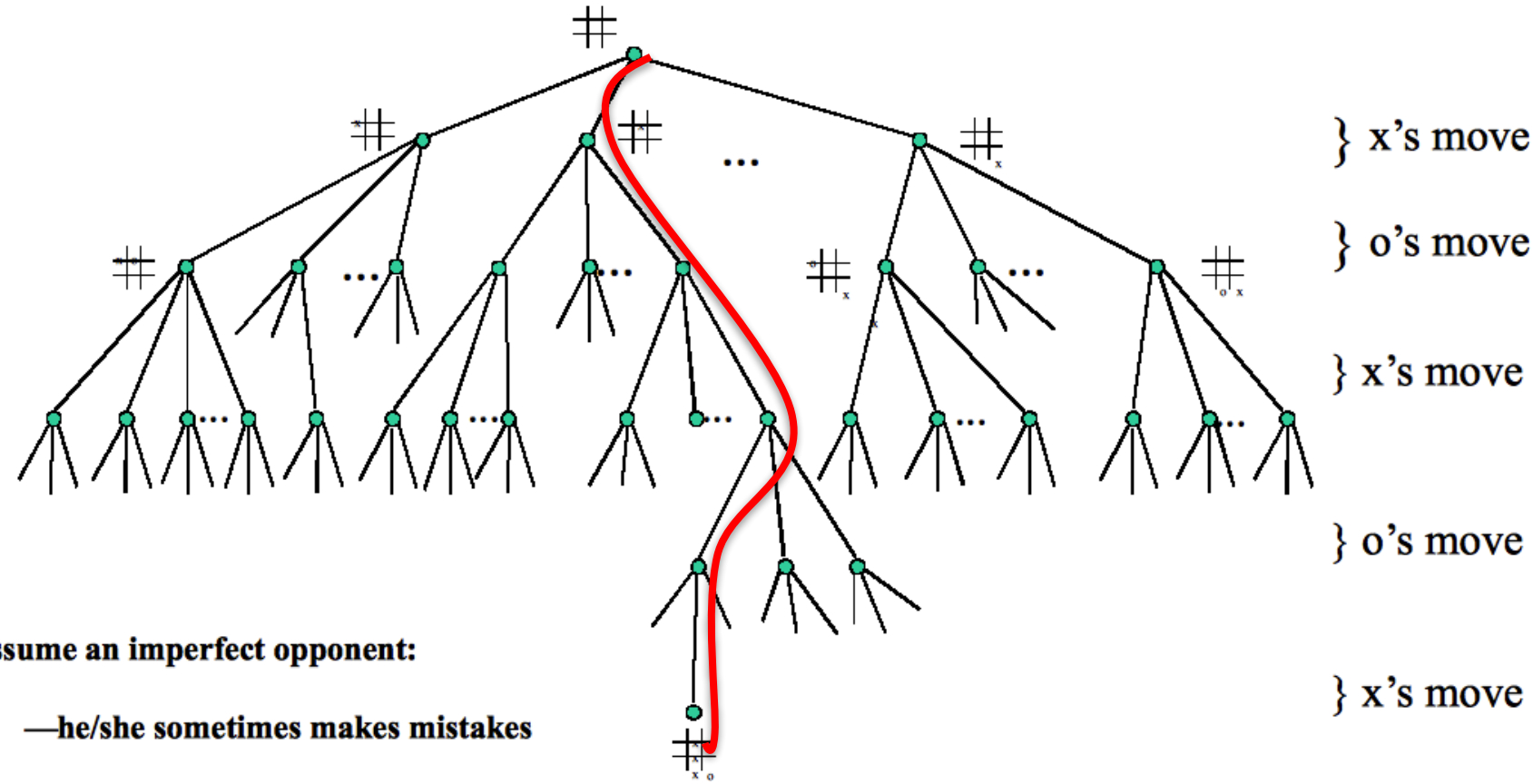
More Tic-Tac-Toe





More Tic-Tac-Toe

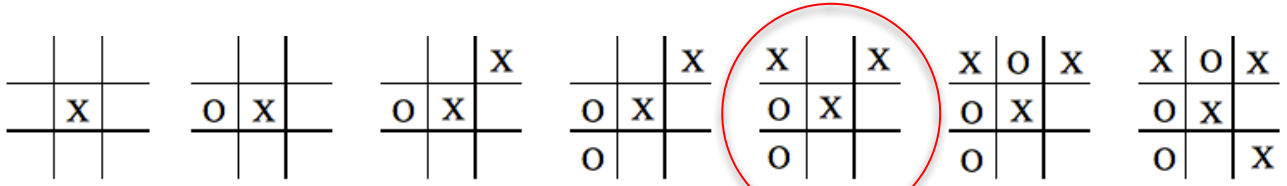


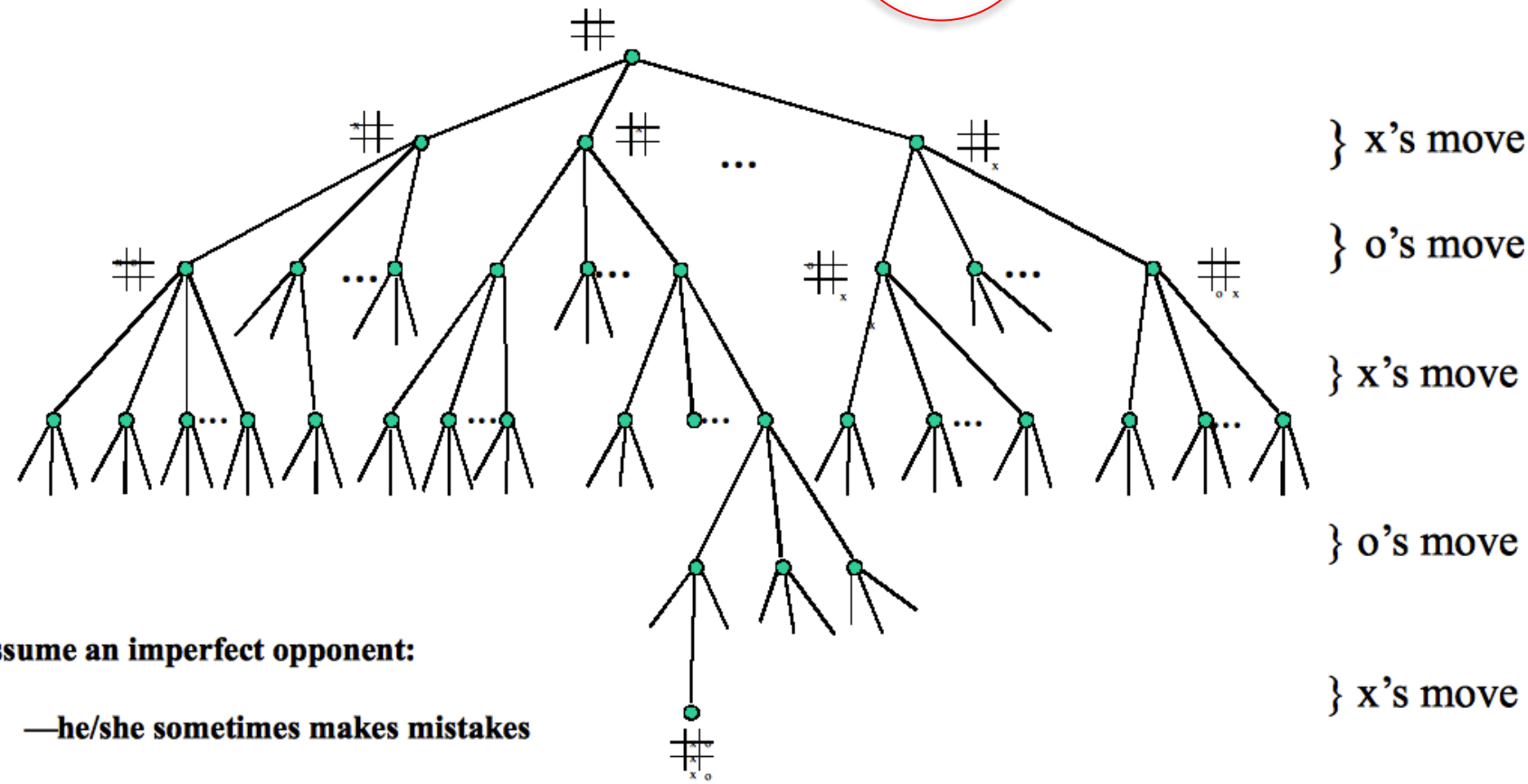


Assume an imperfect opponent:

—he/she sometimes makes mistakes

More Tic-Tac-Toe





Assume an imperfect opponent:

—he/she sometimes makes mistakes

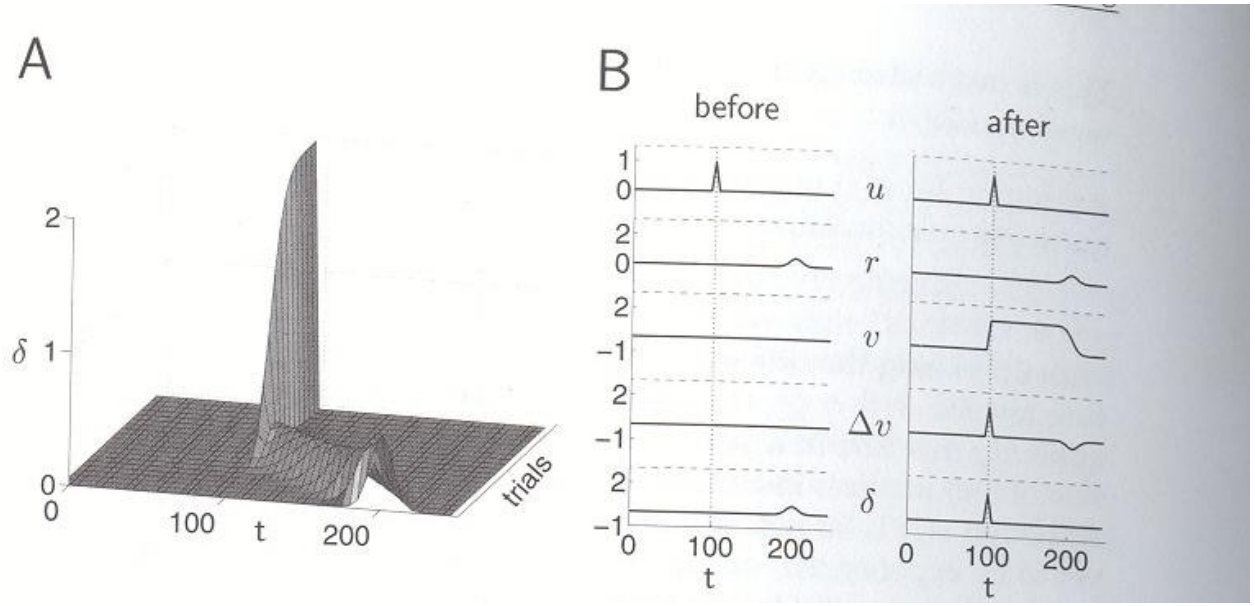
Temporal Difference

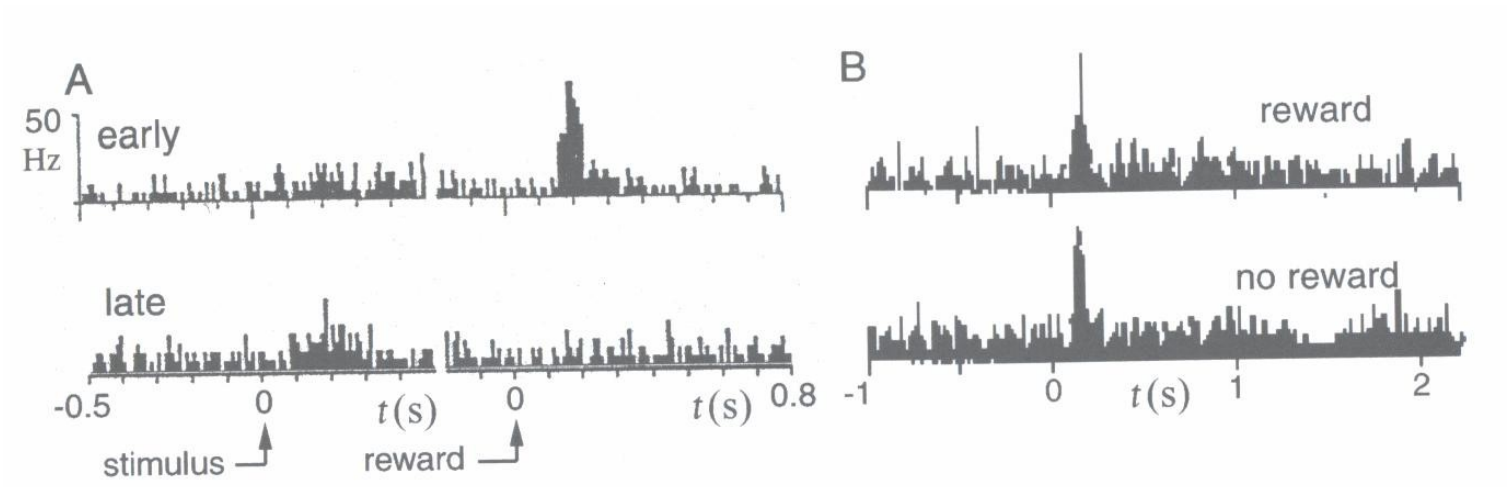
Barto, Sutton, Anderson '83

- Simple rule to explain complex behaviors
- Intuition: Prediction of outcome at time $t+1$ is better than the prediction at time t. Hence use the later prediction to adjust the earlier prediction.
- Has also had profound impact in behavioral psychology and neuroscience!



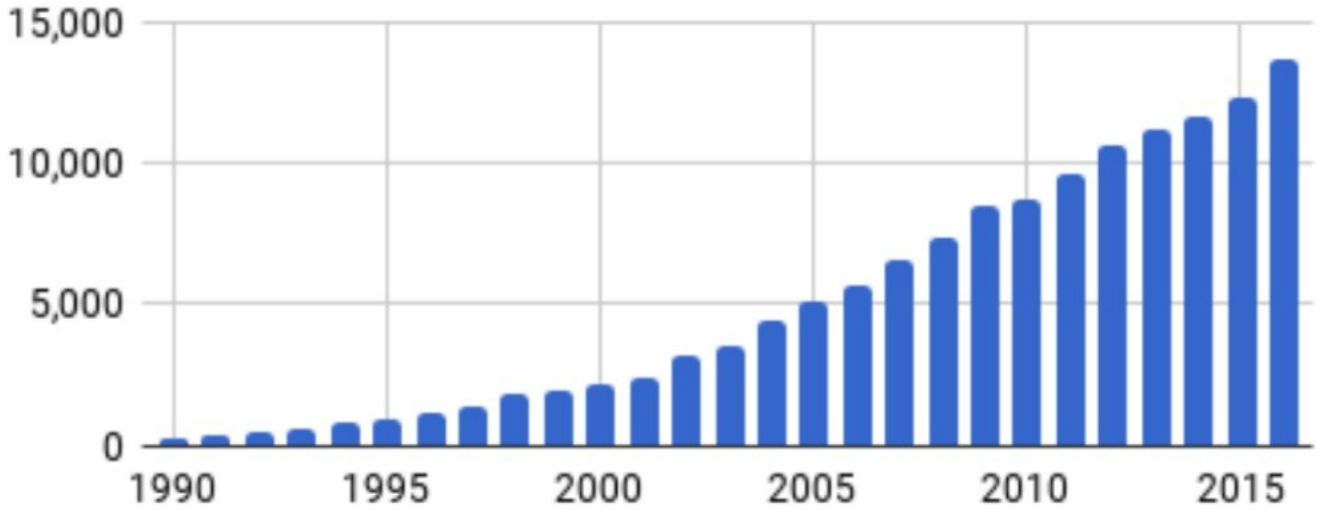
TD in the Brain





What's Next

- Deep Reinforcement Learning has revived excitement in the community



From: Henderson et al. "Deep Reinforcement Learning that Matters". Arxiv 2017. https://arxiv.org/pdf/1709.06560.pdf

What's Next

- Deep Reinforcement Learning has revived excitement in the community
- But many fundamental questions still to be addressed
- Goal: Omnivorous learning – consume any information to learn
  - Closer to how humans learn

Administrivia

Textbook: Sutton, R. S., and Barto, A. G. "Reinforcement Learning: An Introduction", 2nd Edition. MIT Press.

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Written Exam 1	14%
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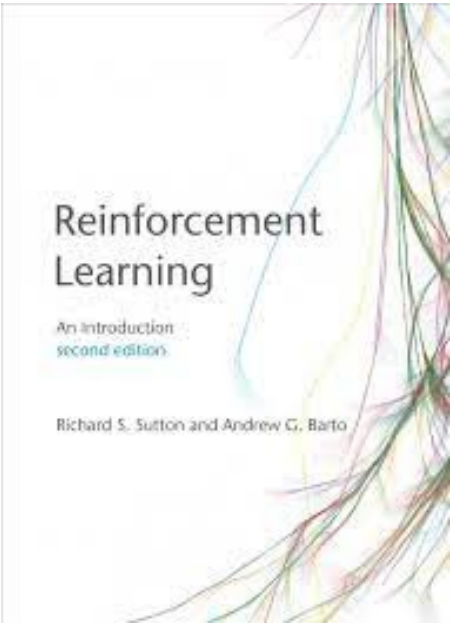

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