



GPU TECHNOLOGY
CONFERENCE

AGENDA ▾ ATTEND ▾ PRESENT ▾ EXHIBIT ▾ MORE ▾

SILICON VALLEY ▾

WORKSHOPS MARCH 17, 2019 | CONFERENCE MARCH 18-21, 2019

"A good traveler has no fixed plans and is not intent on arriving." - Lao Tzu

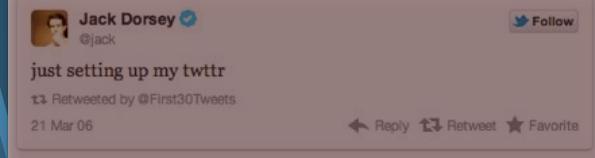
Demystifying Deep Reinforcement Learning – Part 1 : DQN

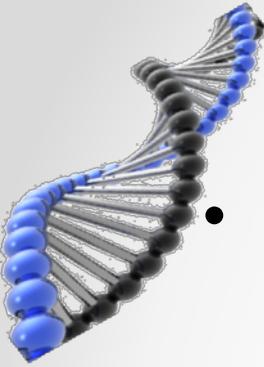
All observations are my own & do not represent my employer's or anyone else's

krishna sankar
@ksankar

“ I WOULD LIKE
TO DIE
ON MARS.
JUST NOT ON IMPACT ”

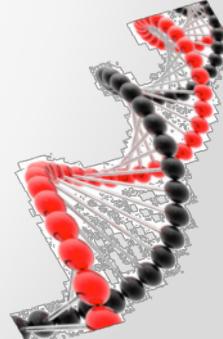
- ELON MUSK -

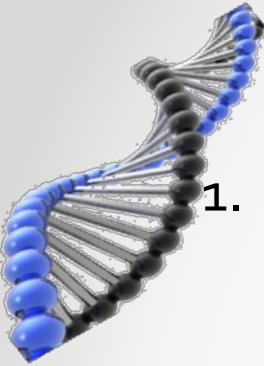




GTC 2019 SV : Lab Overview

- Deep Reinforcement Learning
 - Principles, Paradigms & Equations in 2 Parts
 - https://gptechconf2019.smarteventscloud.com/connect/sessionDetail.ww?SESSION_ID=279058
 - https://gptechconf2019.smarteventscloud.com/connect/sessionDetail.ww?SESSION_ID=279064
- Part 1 : Start from the Fundamentals
 - Program Value Methods
 - Monte Carlo, TD & Q-learning
 - DQN and it's extensions
- Part 2 : Policy Gradients
 - REINFORCE
 - A₃C & DDPG
 - Intro to PPO, TRPO & the rest





DRL Lab Goals

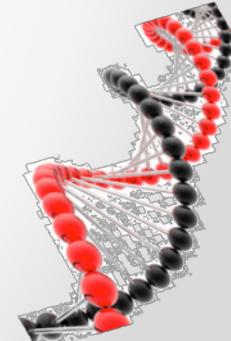
1. Get a reasonably good introduction to DRL (as much as we can do in 4 hrs)
 - Sometimes the ideas take time to rattle around the brain and sink in; they need reflection; hence we stop Part 1 at DQN and later start Policy Gradients as Part 2
2. Alleviate the Initial Barrier
 - *To Make Reinforcement Learning approachable*
 - Discuss intuition and formal notations
 - Understand the underpinnings
 - Do hands-on programming and finally,
 - *Motivate to learn, explore on your own & be proficient in Deep Reinforcement Learning*
3. We will use Autonomous Driving & AlphaGo as background examples
4. Hands on programming
 - Gridworld = Frozen Lake
 - Continuous = Cartpole
 - We will run these 2 examples throughout the lab for all the algorithms
 - With limited time, we don't want to add new examples every time





Please Do ...

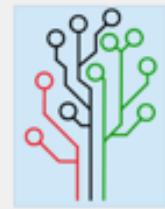
- The Programming Exercises & Quizzes
 - This is a good time to do these - you have a captivated time away from the daily trifles
- Write the formulas, at least 3 times !
 - Why write down formula ? Levine UCB classes ! Kuru Toga icon !
- Read the essential papers
 - Good comprehensive intro:
 - <https://arxiv.org/pdf/1810.06339.pdf>
 - An Introduction to Deep Reinforcement Learning
<https://arxiv.org/pdf/1811.12560.pdf>
 - Sutton Book <http://incompleteideas.net/book/the-book-2nd.html>
 - AlphaGo nature papers, movies, AlphaZero et al
<https://deepmind.com/research/alphago/>
 - Rainbow Paper <https://arxiv.org/pdf/1710.02298.pdf>
 - Minh Paper : <https://arxiv.org/abs/1602.01783>
 - DDPG Paper : <https://arxiv.org/pdf/1509.02971.pdf>





The Rules for the Teacher

1. Remember that you are not your learners...
2. Never hesitate to sacrifice ~~truth~~ for clarity 😊
3. Remember that ...
 - o ... no lesson survives first contact with learners...
 - o ... that every lesson is too short from the teacher's point of view and too long from the learner's...
 - o ... and that nobody will be more excited about the lesson than you are.



[Teaching Tech Together](#)

[EPUB and MOBI versions](#)

[Single page version](#)

[Lessons](#)

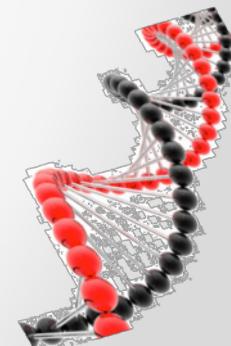
1. [Introduction](#)
2. [Building Mental Models](#)

Teaching Tech Together

Hundreds of grassroots groups have sprung up around the world to traditional classrooms. These groups exist so that people don't have teaching themselves how to teach.

There's a better way. Just as knowing a few basic facts about germs instructional design, inclusivity, and community organization can help use right now, explains why we believe they are true, and points you

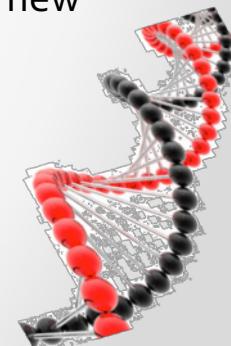
- how people learn;
- how to design lessons that work;
- how to deliver those lessons; and
- how to grow a community of practice around teaching.





You have ...

- Programming experience
 - Know about DeepLearning,
 - Experience using Tensorflow or pytorch,
 - Python programming and familiar with Jupyter/iPython notebook
- No Reinforcement Learning experience is expected or assumed
- Will cover enough of Deep Learning & Pytorch
- Why Pytorch ?
 - Easier & compact, those of you from the world of Tensorflow, this will be a new experience
 - DL is only a small part and are using simpler primitives
- Lab materials from github
 - https://github.com/xsankar/GTC_2019_DRL_LAB





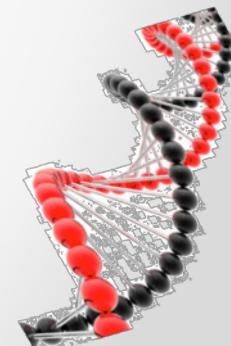
Lab notebooks & presentation

good enough

- Labs have working examples
 - Look at them as starting frameworks - for you to tweak & improve
 - Use as a study tool
 - Share your comments, clarifications, functions and algorithms as pull requests
 - And when you have mastered an algorithm or an environment, add your successes to the OpenAI Gym leaderboard
 - Consider leaderboard as a level of performance

- Lab pragmatics

- In github : https://github.com/xsankar/GTC_2019_DRL_LAB
 - No esoteric requirements
 - Requirements
 - python 3.6, pytorch, openAI gym, numpy, matplotlib, jupyter notebook
 - Miniconda works fine





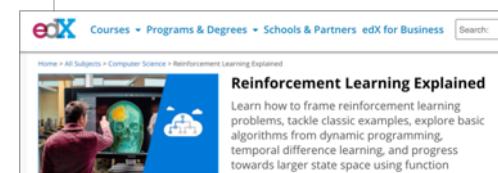
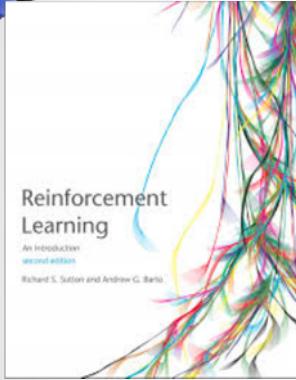
Pragmas - Deep RL Experimentation

- Be ready for (a lot of) trial-and-error
- There will be many false starts *And painful, occasionally 😊*
- Hyper-parameter tuning is important 
- Have faith; the network will learn - eventually !!
- Learning is not linear
 - Even after 90% is done, you still might have 90% to go
- Keep a log and try things (somewhat) systematically
- Too many (simultaneous) moving parts will only create chaos





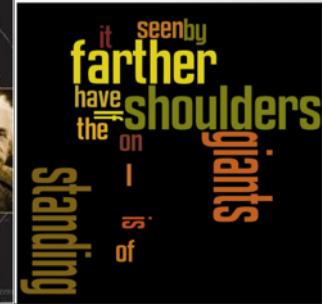
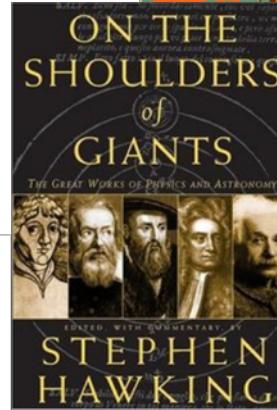
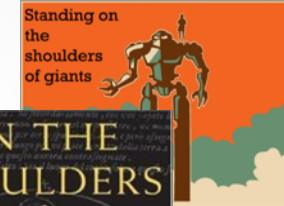
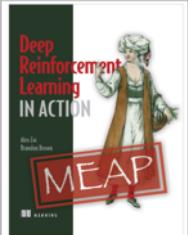
Thanks to the Giants, whose work helped me to prepare for this lab !!



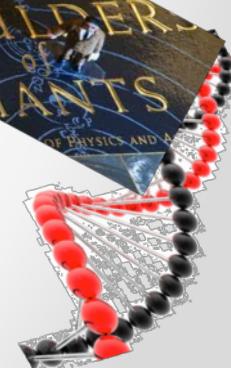
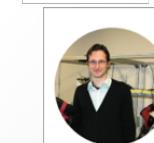
CS 294-112 at UC Berkeley



Deep Reinforcement Learning
Abbeel & Levine



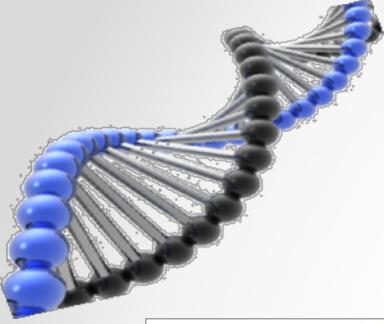
And our own
nvidians : Dana S,
Devesh K, Josh W,
Sara W, Kara M &
the gang @dli



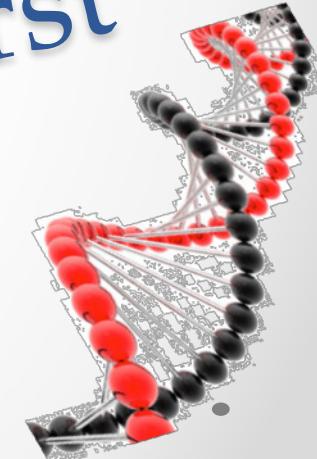


□ Agenda

- Framing
- Reinforcement learning – A Formal Expedition
- Algorithms & Programming
 - Monte Carlo, TD, SARSA, Q-Learning & DQN
- The world of AlphaGo
- Policy Gradients – REINFORCE, A₃C & DDPG
- Conclusion & Forward
- Emergency Time Reserve – Overflow !!



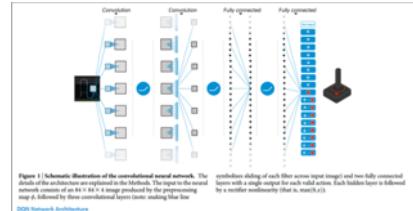
1. Framing : Open This First





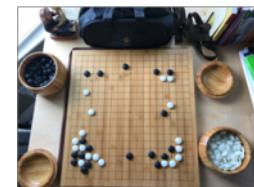
What exactly is this Reinforcement Learning ?

RL = Formal framework
Computationally efficient approach



Goal : Maximize rewards

What action does it need to take, to reach its goal
and maximize the rewards ?



Uncertain; fully observable at best

(3)

State

(2)

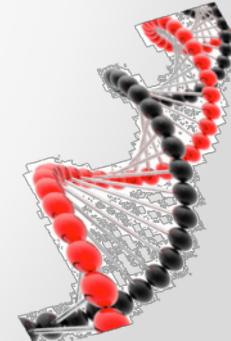
Reward

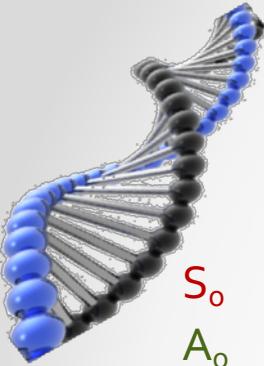
(1)

Action

Acquires new behaviors & skills
incrementally, using trial-and-error
experiences
a priori batch is OK, in some cases

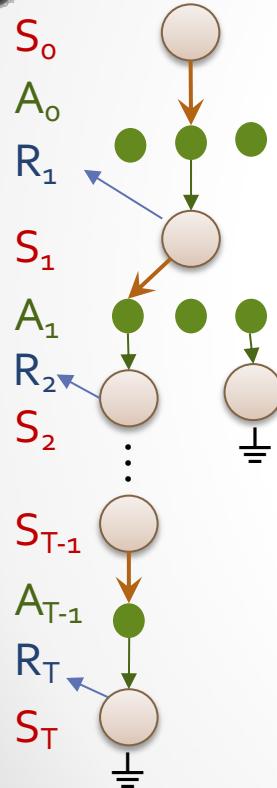
- ✓ Agent - Learn, Decide & Act
- ✓ Nothing less, nothing more !
- ✓ Interacts with the environment
- Collects Information





RL Sequence

- Agent starts at State S_0 , chooses & takes Action A_0 ,
- The environment transitions to S_1 & emits a reward R_1
- The environment also sends an observation of S_1
- Now the agent is at S_1 and can take action A_1
- The cycle continues, till the end is reached
- *Can be in 1 step, n steps or even continuous (=infinite horizon)*





1. Walking Humanoid figures - UC Berkeley

DRL in Action (?) – Video Time !!



2. Humanoid avoiding obstacles - UCB



3. Navigating Complex Roundabouts

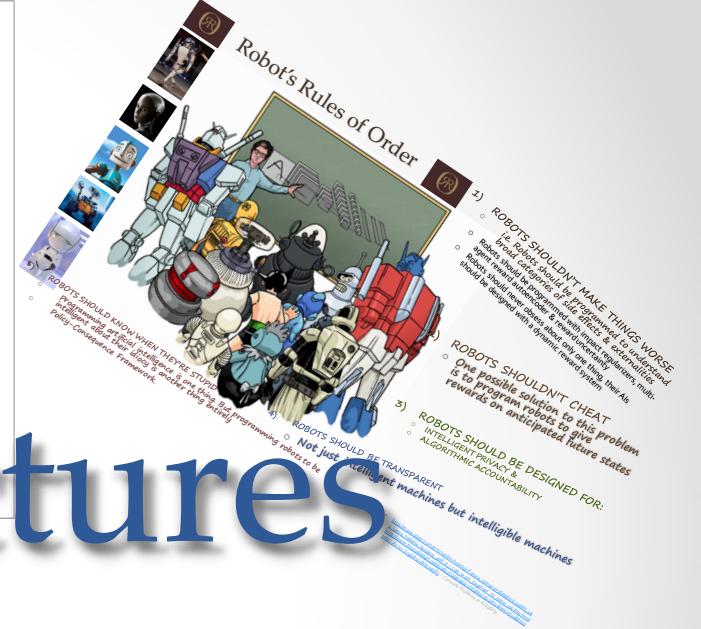
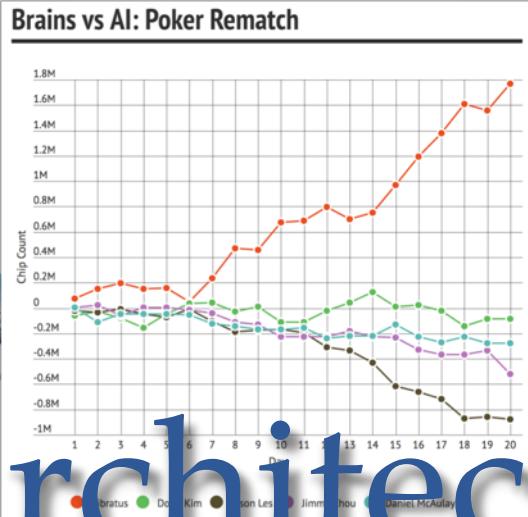


Goal of the videos : Motivation for DRL

- While, in this lab, we look at relatively smaller problems, the algorithms are very powerful and are solving much larger problems
- As you go through the lab, think of how these problems can be solved using different Reinforcement Learning mechanisms

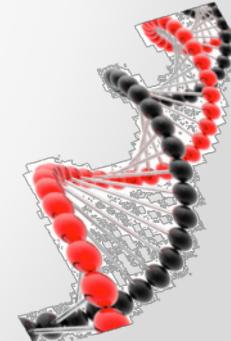


- AI is:
 - Contextual & Autonomous i.e. sense the environment, propagate current state across goals, knowledge & actions and respond appropriately.
 - Reasoning i.e. the ability to infer & actions and respond appropriately.
 - Optimal i.e. The capacity to choose one or more actions over the space of behaviors based upon a set of policies including short & long term optimization of behavior functions & goals (bounded rationality as the system can only see a limited set)
 - Remembering i.e. The capacity to hold episodic and long term beliefs, which adds representational formalisms and retrieval mechanisms
 - Reflective, Adaptive & Self-evolving i.e. the ability to learn from past actions & incorporate the lessons in future behavior
 - Interactive i.e. the capability to interact with humans with different roles (e.g. passengers, other drivers, pedestrians etc) via multiple interfaces including HMI & NLU
 - We also add the constraints of real-time, scalability, efficiency & system is deployed



Quick Context

- What is AI in our context?
- A Robot's Rules of Order
- AI Frameworks
- ...



AI is:

- Contextual & Autonomous i.e. sense the environment, propagate current state across goals, knowledge & actions and respond appropriately.
- Rational i.e. The ability to infer/perceive value/payoff of a set of actions in the current context/ beliefs, and plan accordingly
- Optimal i.e. The capacity to choose one or more actions over the space of behaviors, based upon a set of policies including short & long term optimization of cost functions & goals (bounded rationality as the system can only see a limited set)
- Remembering i.e. the capability to hold episodic and long term beliefs, which adds representational formalisms and retrieval mechanisms
- Reflective, Adaptive & Self-evolving i.e. the ability to learn from past actions & incorporate the lessons in future behavior
- Interactive i.e. the capability to interact with humans with different roles (e.g. passengers, other drivers, pedestrians et al) via multiple interfaces including NLP & NLU
- We also add the constraints of reactivity, redundancy, efficiency & scalability for the infrastructure & the framework stack where the AI system is deployed



■ Machines need to learn/understand how the world works

- ▶ Physical world, digital world, people,....
- ▶ They need to acquire some level of common sense

■ They need to learn a very large amount of background knowledge

- ▶ Through observation and action

■ Machines need to perceive the state of the world

- ▶ So as to make accurate predictions and planning

■ Machines need to update and remember estimates of the state of the world

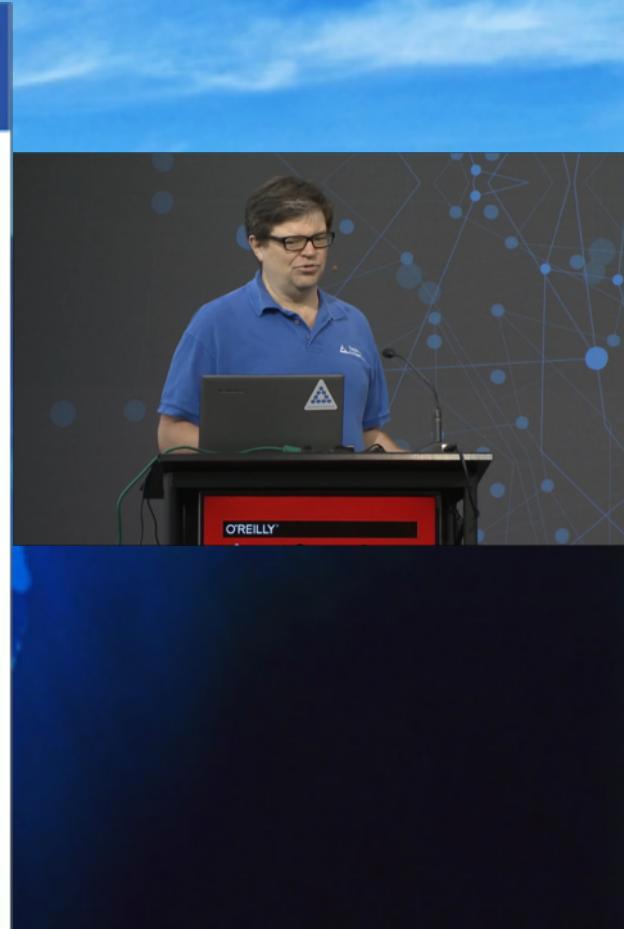
- ▶ Paying attention to important events. Remember relevant events

■ Machines need to reason and plan

- ▶ Predict which sequence of actions will lead to a desired state of the world

■ Intelligence & Common Sense =

Perception + Predictive Model + Memory + Reasoning & Planning



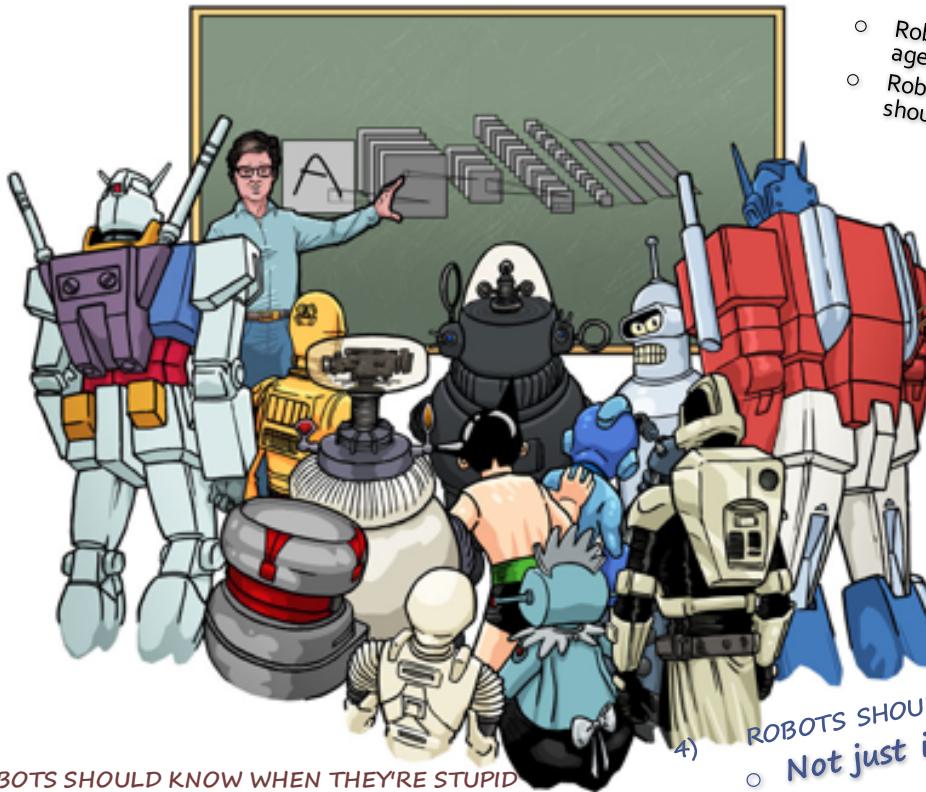
Yann LeCun Retweeted

Andrew McAfee @amcafee · 17h

@ylecun Teaching machines common sense is a "Big mountain. And we don't know how many mountains are behind it." #WHFrontiers



Robot's Rules of Order



5) ROBOTS SHOULD KNOW WHEN THEY'RE STUPID

- Programming artificial intelligence is one thing. But programming robots to be intelligent about their idiocy is another thing entirely
- Policy-Consequence Framework.

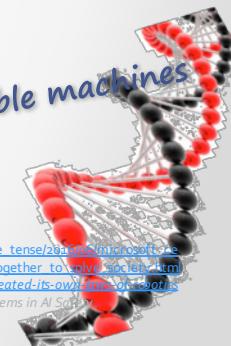
1) **ROBOTS SHOULDN'T MAKE THINGS WORSE**
i.e. Robots should be programmed to understand broad categories of side effects & externalities

- Robots should be programmed with impact regularizers, multi-agent reward autoencoder & reward uncertainty
- Robots should never obsess about only one thing, their AIs should be designed with a dynamic reward system

2) **ROBOTS SHOULDN'T CHEAT**
One possible solution to this problem is to program robots to give rewards on anticipated future states

3) **ROBOTS SHOULD BE DESIGNED FOR:**
INTELLIGENT PRIVACY & ALGORITHMIC ACCOUNTABILITY

4) **ROBOTS SHOULD BE TRANSPARENT**
Not just intelligent machines but intelligible machines



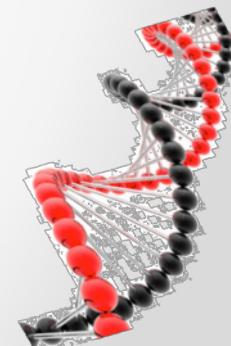
- http://www.slate.com/articles/technology/future_tense/2012/06/microsofts_o_satyajna_nadella_humans_and_a_i_can_work_together_to_save_soc.html
- <http://www.fastcodesign.com/2061230/google-created-its-own-laws-for-robots>
- <https://arxiv.org/abs/1606.06565> - Concrete Problems in AI Safety



2. Reinforcement Learning

A Formal Expedition

...





Supervised Learning

Unsupervised Learning

Reinforcement Learning

Data	Curated	Curated	Generates data while exploring
Labels	Curated	Machine Generated	Learn via interactions
Signals & Feedback			Curated Reward Signals and Goals
Actions			Actions instead of labels
Defining Characteristics	Classification, Linear Regression	Human Meaning e.g. clusters, survival analysis	Result = Decision making - winning a game, driving cars, manufacturing robots, cleaning robots, conversations, ...

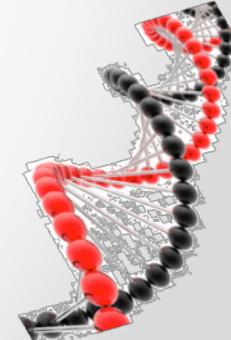




Frozen Lake !

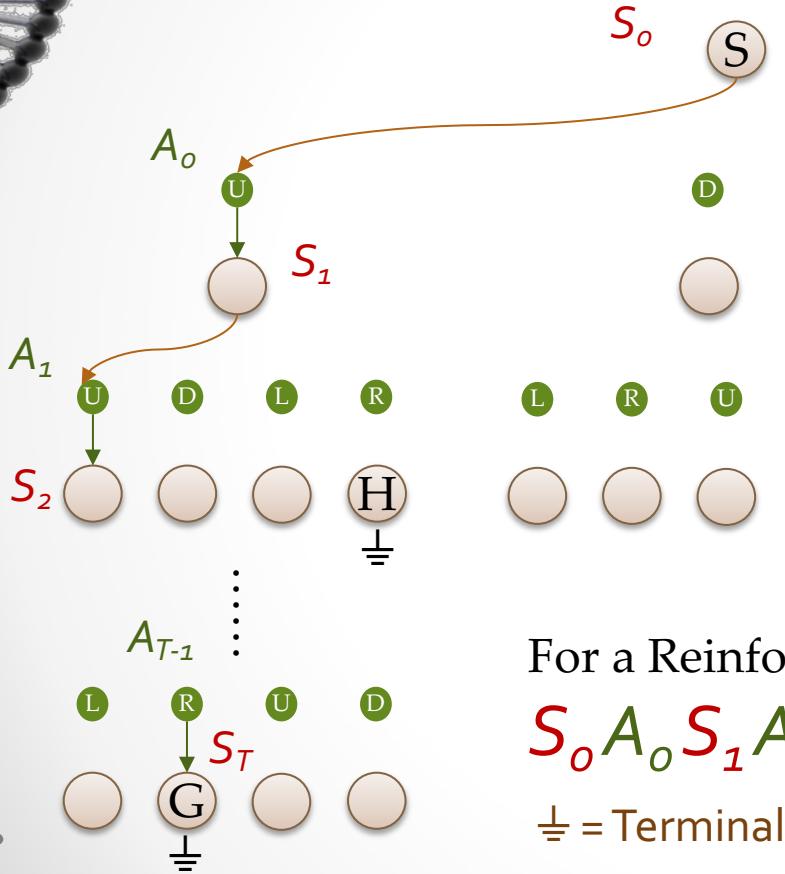


- You are in Siberia and want to visit the foothill under the rock, which is the Goal (G), starting at S
- But the lake is a little treacherous with holes(H)





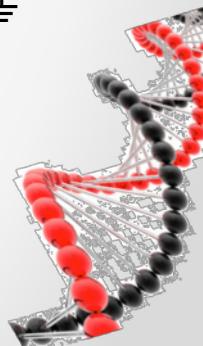
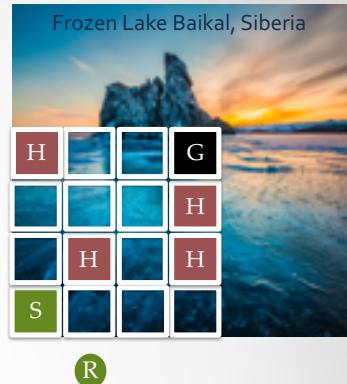
Notation : State, Action



For a Reinforcement Agent, life is a series of

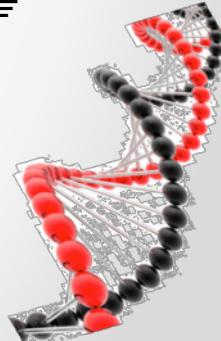
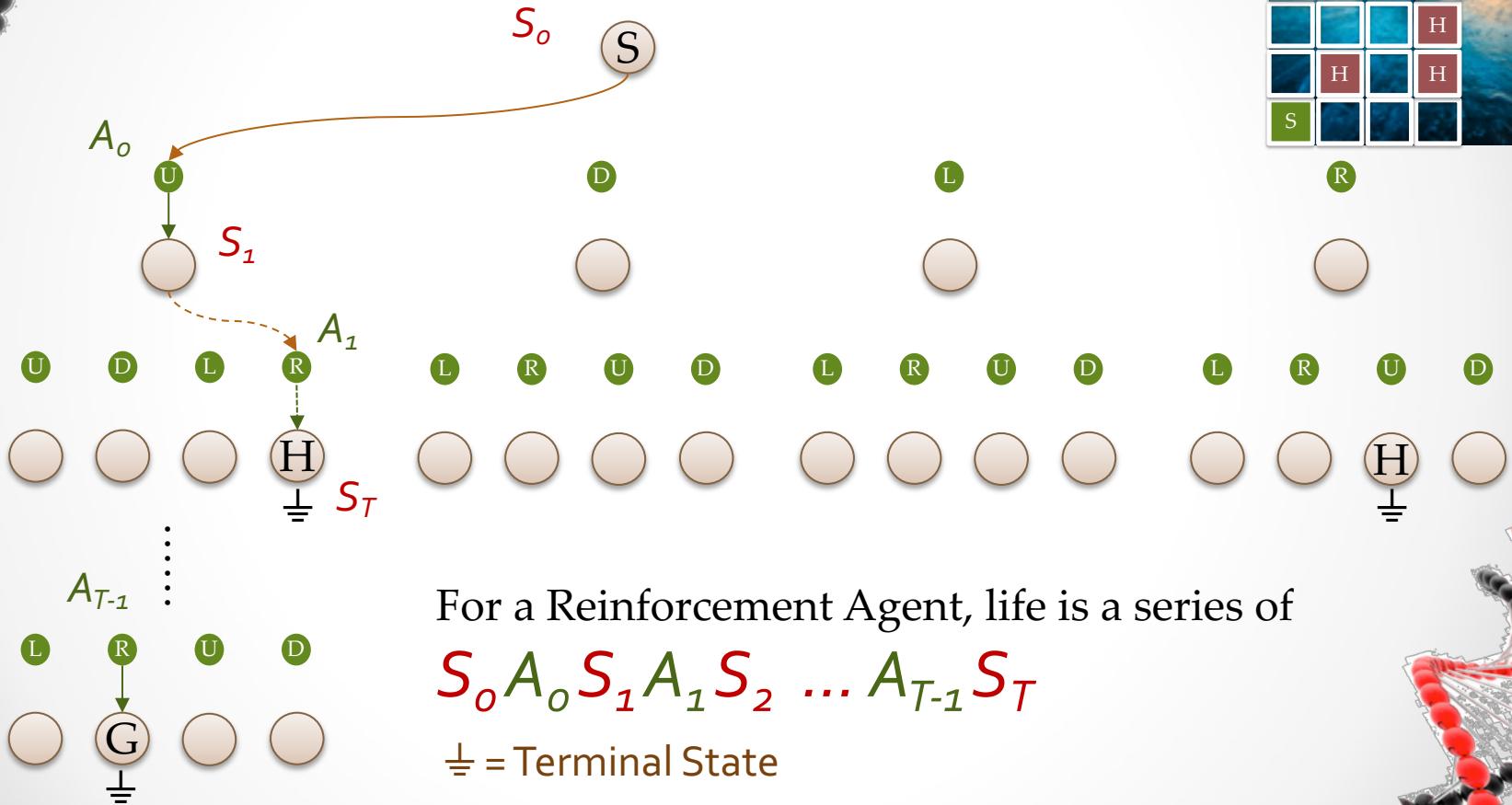
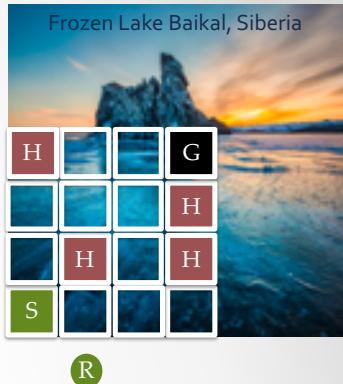
$$S_o A_o S_1 A_1 S_2 \dots A_{T-1} S_T$$

$\perp =$ Terminal State



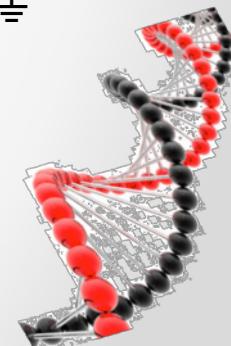
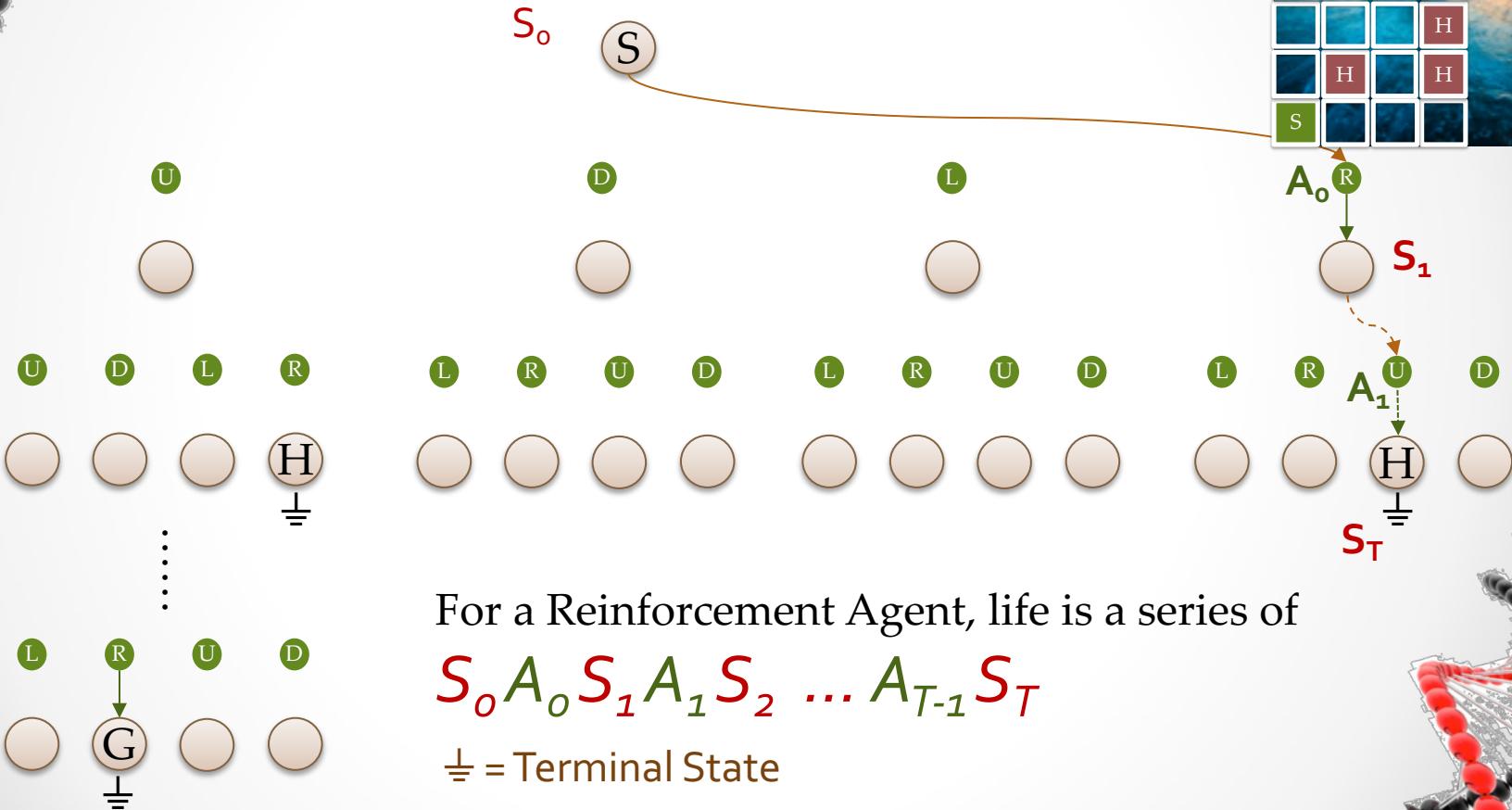


Notation : State, Action



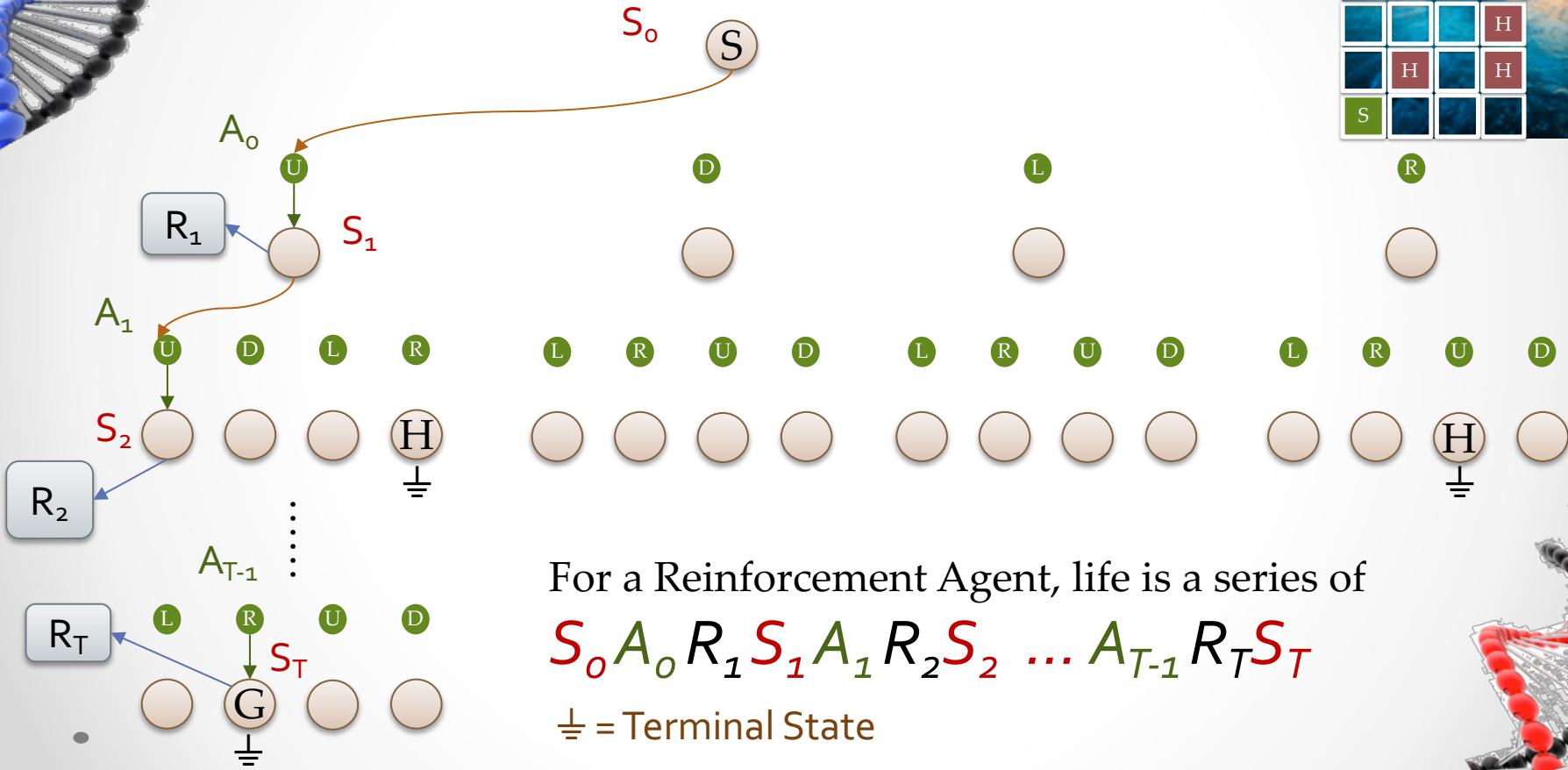
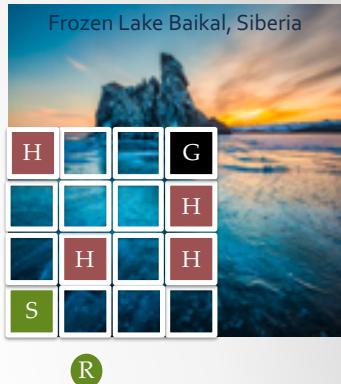


Notation : State, Action





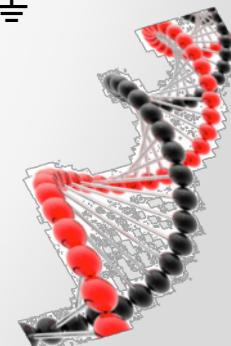
Notation : State, Action, Reward



For a Reinforcement Agent, life is a series of

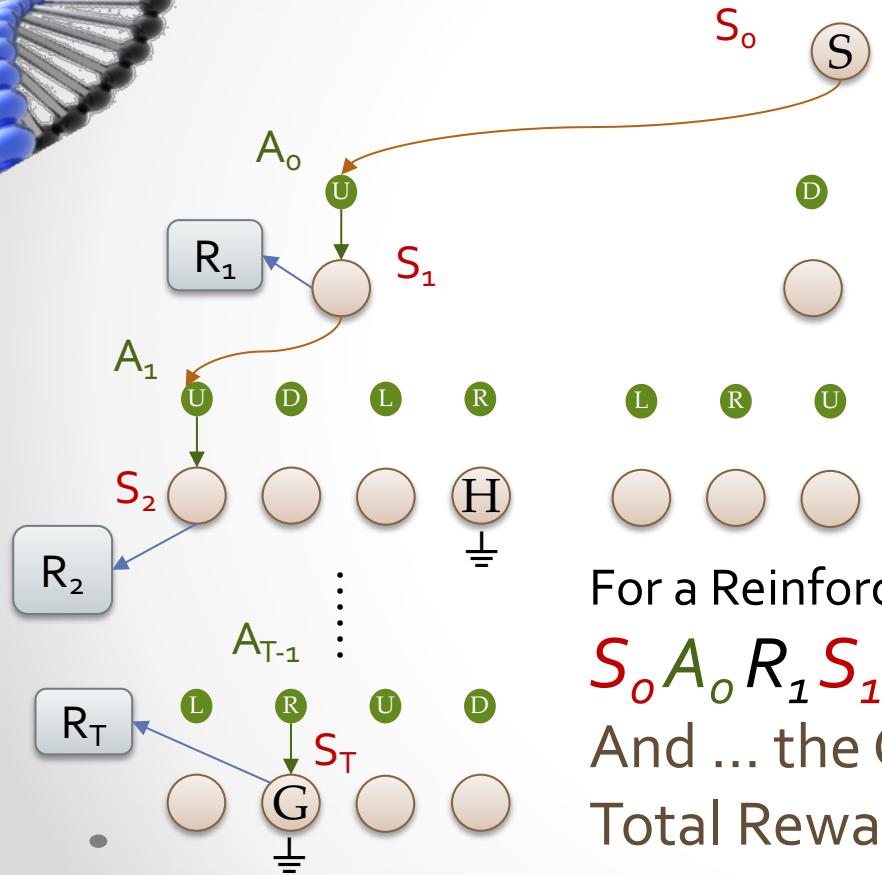
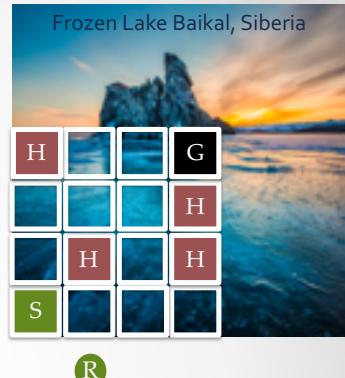
$S_o A_o R_1 S_1 A_1 R_2 S_2 \dots A_{T-1} R_T S_T$

$\perp = \text{Terminal State}$

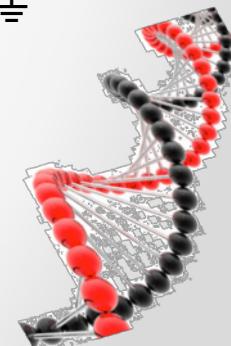




Notation : State, Action, Reward

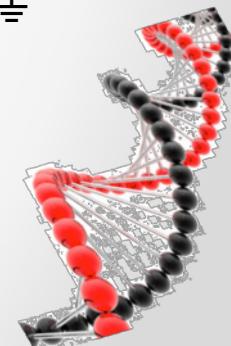
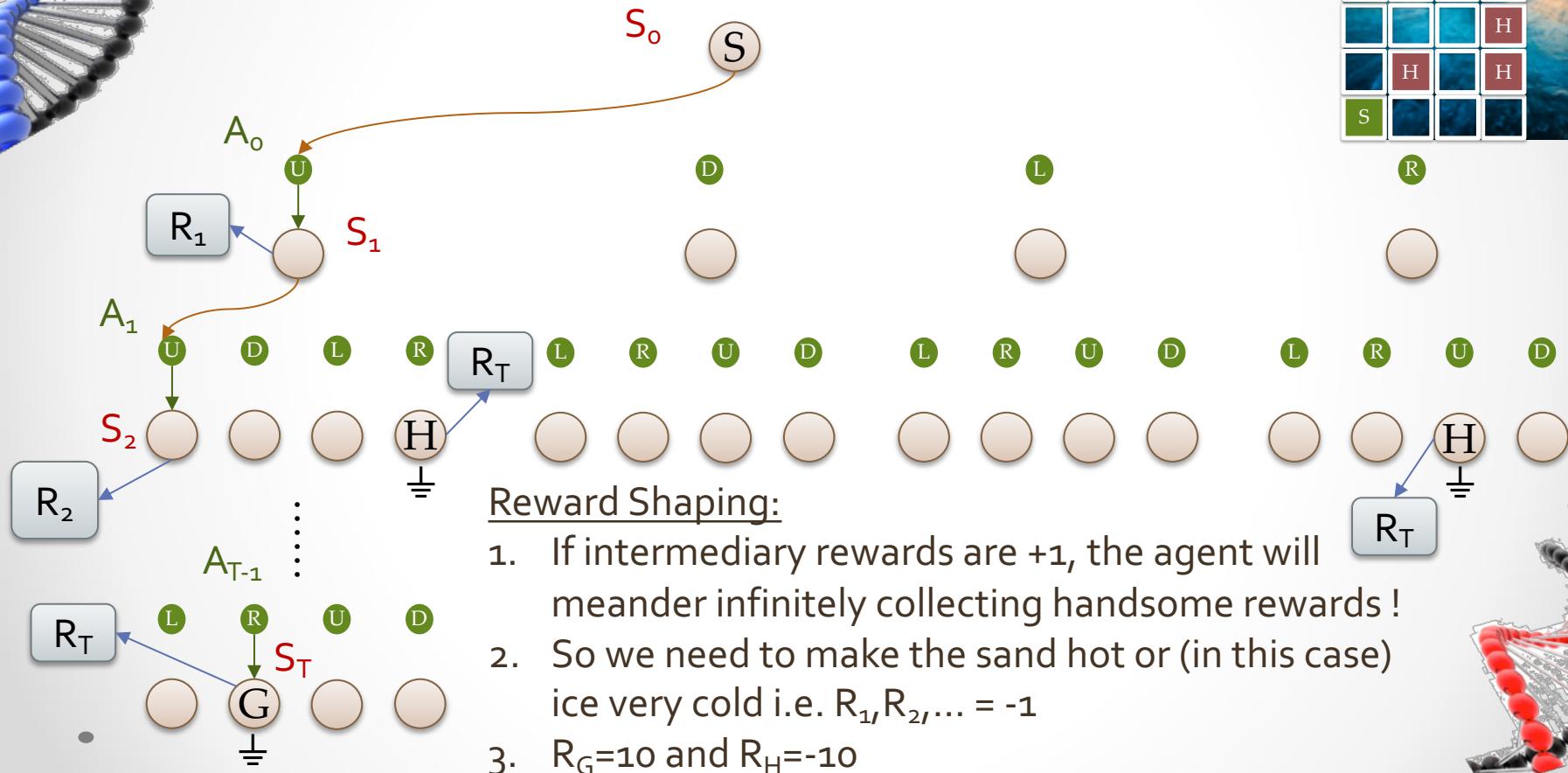
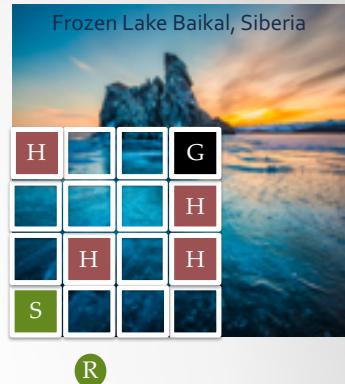


For a Reinforcement Agent, life is a series of
 $S_o A_o R_1 S_1 A_1 R_2 S_2 \dots A_{T-1} R_T S_T$
And ... the Goal is to maximize the
Total Reward $R_1 + R_2 + \dots + R_T$



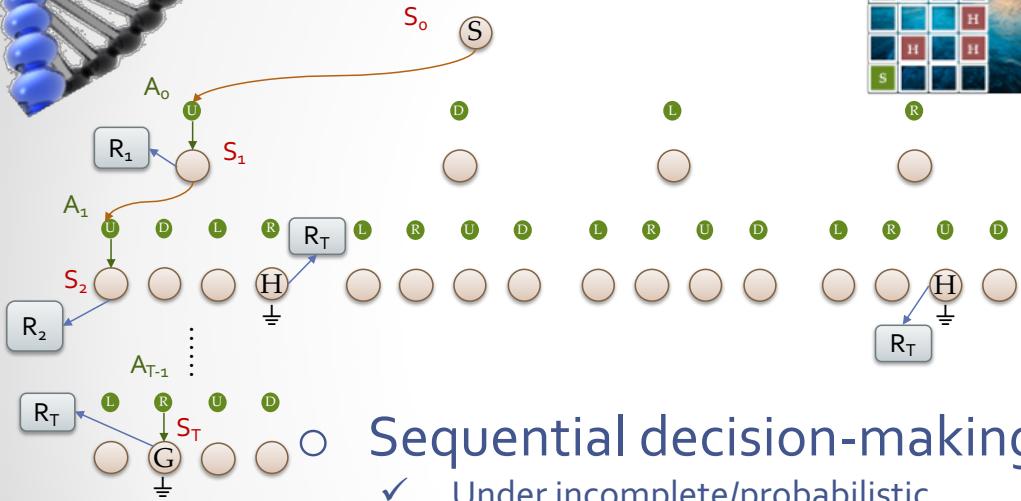


Notation : State, Action, Reward





In short DRL is ...

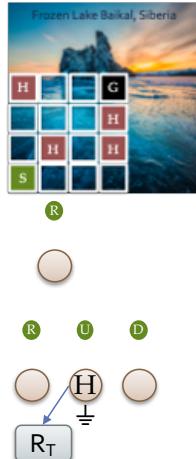
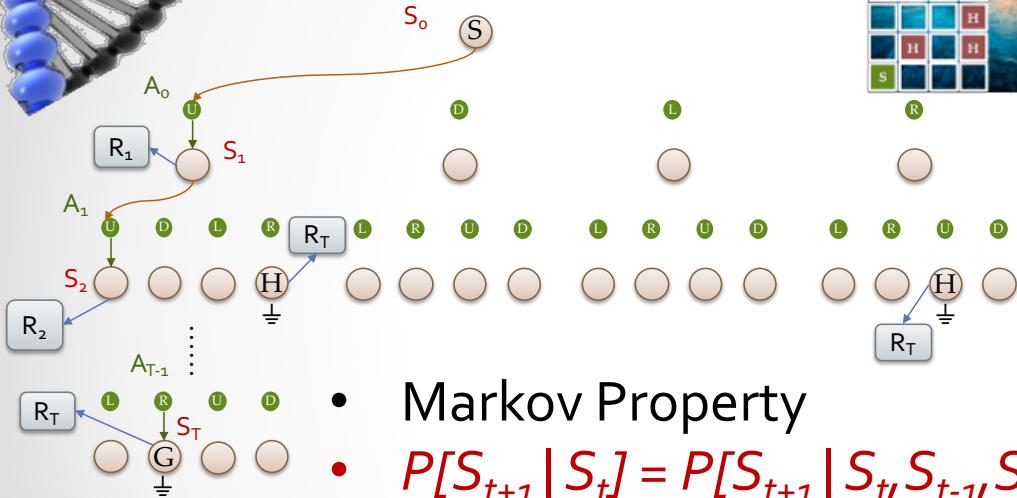


- Sequential decision-making
 - ✓ Under incomplete/probabilistic information, even if we have full observability
 - ✓ Uncertain environment
- Evaluative feedback
- Exhaustive sampling

- There is a State Space
 - State is actually an observation, need not represent the environment
 - *Encoding state requires some thought*
- There is an action space
- There are rewards
 - Goal is to maximize total rewards (= Return)
 - R_t = One step Return
- Same action need not result in same return
- Action to state transition might be stochastic



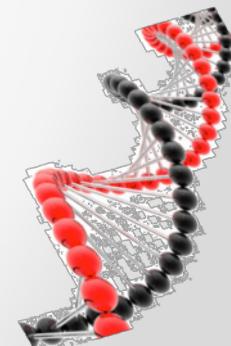
Markov Process



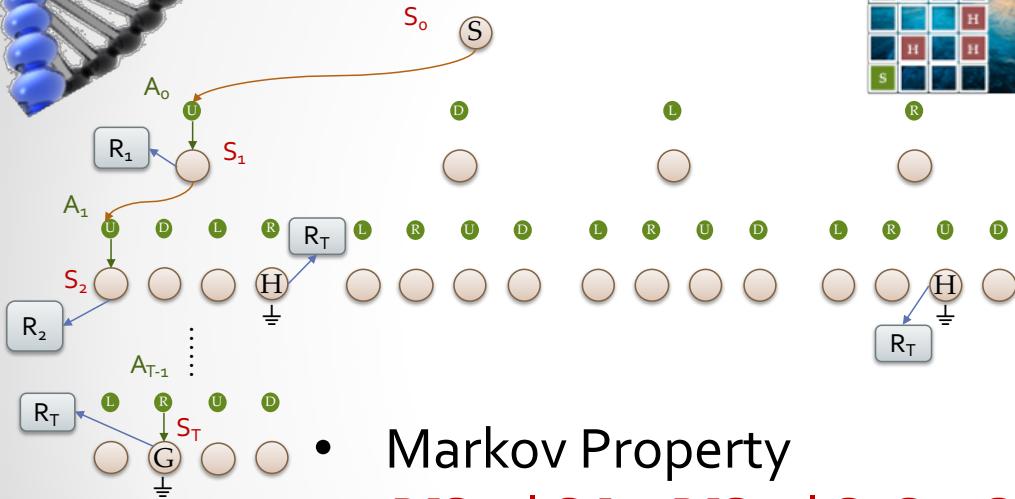
- Markov decision process formally describes an environment for Reinforcement Learning (Silver)
- Powerful Mathematical Framework for RL



- Markov Property
- $P[S_{t+1} | S_t] = P[S_{t+1} | S_t, S_{t-1}, S_{t-2}, \dots]$
- Current state is sufficient to predict the future
- A Markov process is a memoryless sequence of states S_1, S_2, S_3, \dots with the Markov Property



Markov Process



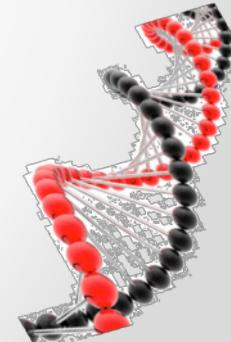
- Markov Property
- $P[S_{t+1}|S_t] = P[S_{t+1}|S_t, S_{t-1}, S_{t-2}, \dots]$
- Current state is sufficient to predict the future
- A Markov process is a memoryless sequence of states S_1, S_2, S_3, \dots with the Markov Property

- Good

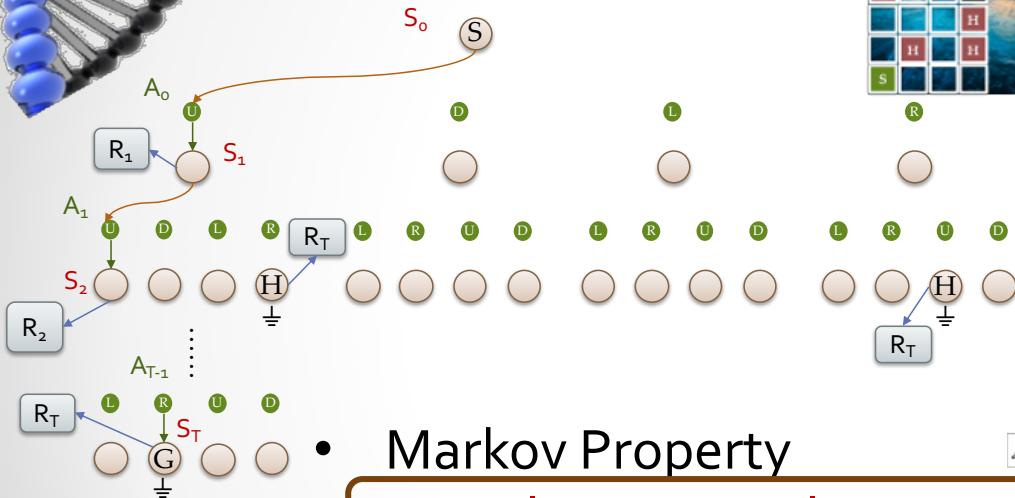
- Don't have to remember all trajectories & paths
- Don't have to consider them for decisions

- Bad

- The state has to be constructed s.t it encodes all the relevant information e.g. 4 frames in Atari RL agent



Markov Process

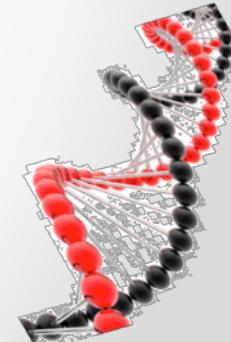


- Markov Property
- $P[S_{t+1} | S_t] = P[S_{t+1} | S_t, S_{t-1}, S_{t-2}, \dots]$
- Current state is sufficient to predict the future
- A Markov process is a memoryless sequence of states S_1, S_2, S_3, \dots with the Markov Property

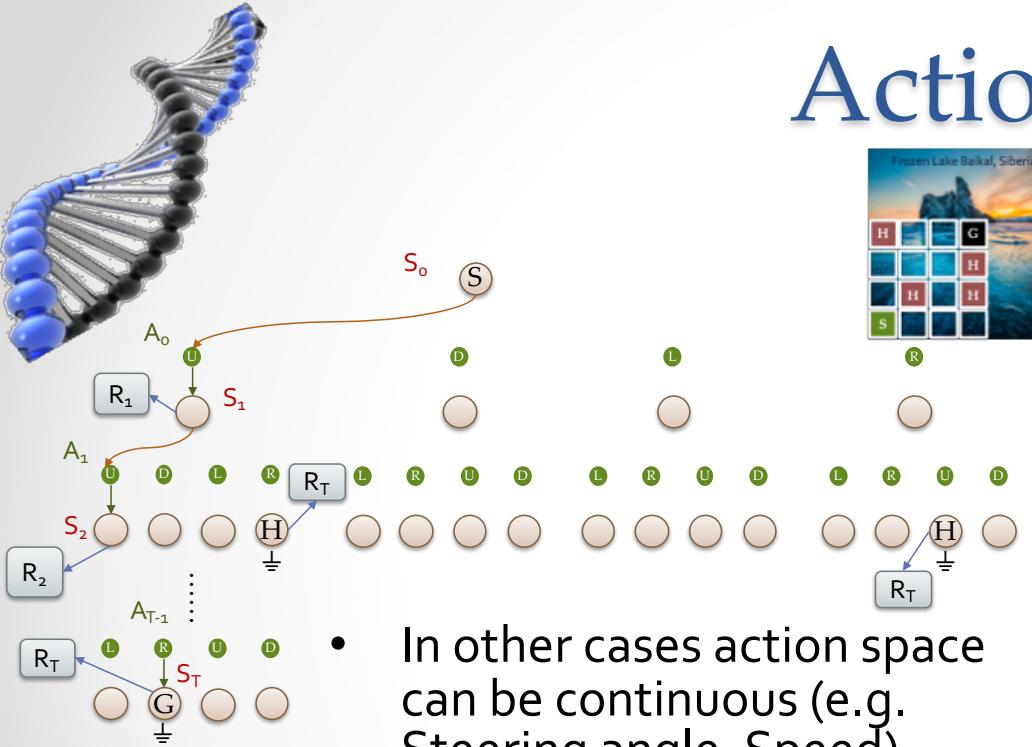


- Good
 - Don't have to remember all trajectories & paths
 - Don't have to consider them for decisions

- Bad
 - The state has to be constructed s.t it encodes all the relevant information e.g. 4 frames in Atari RL agent

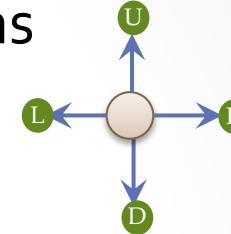


Action Space

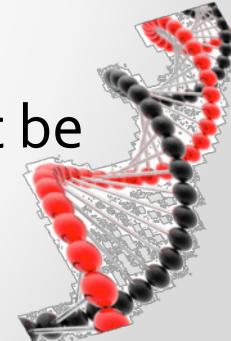


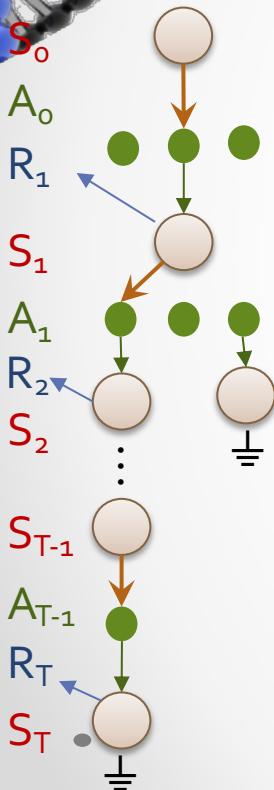
- In other cases action space can be continuous (e.g. Steering angle, Speed)
- Different actions at different states (games, parking vs. merging)
- Large Action space

- 4 actions



- Policy defines how an agent chooses the actions
- Later, we will have a lot to talk about policy
- Best action need not be deterministic
 - E.g. Rock-Paper-Scissors





Reward Space & Discounting

R_t = Reward at a time step

G_t = Total Return

Goal is to maximize this

$$G_{t(t=0)} = R_1 + R_2 + \dots + R_T$$

$$G_t = R_{t+1} + R_{t+2} + \dots + R_T$$

Add Discount factor γ to account for uncertainties,

$$G_t = \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1} \quad ..(3.8)$$

$$\gamma \in (0, 1)$$

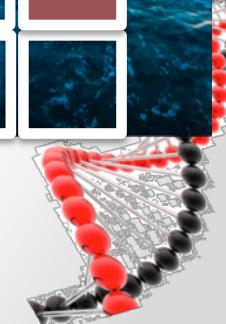
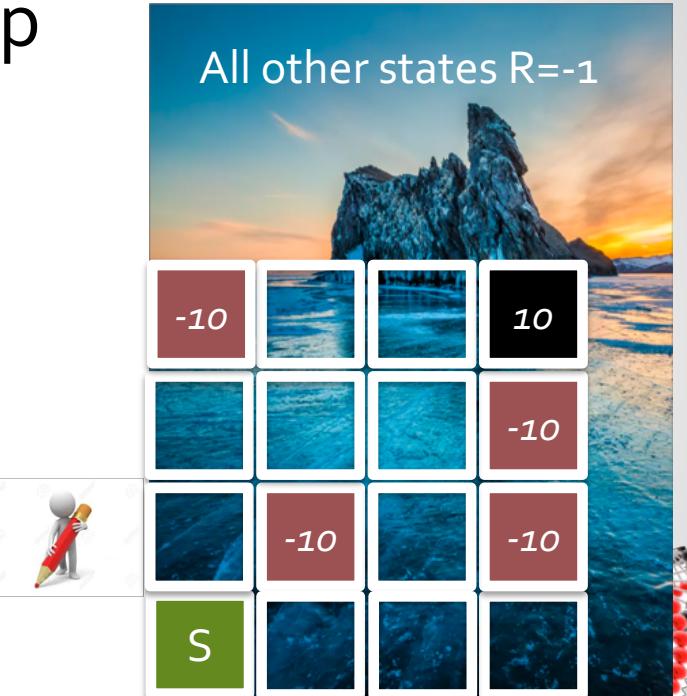
close to 0 gives "myopic"

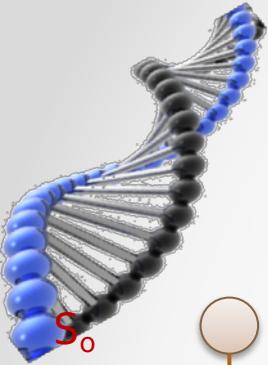
close to 1 gives "far-sighted"

$\gamma = 0.9$ for continuous,

= 1.0 for sequences that terminate

All other states $R=-1$





Reward Space & Discounting

R_t = Reward at a time step

G_t = Total Return

Goal is to maximize this

$$G_{t(t=0)} = R_1 + R_2 + \dots + R_T$$

$$G_t = R_{t+1} + R_{t+2} + \dots + R_T$$

Add Discount factor γ to account for uncertainty

$$G_t = \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1} \quad \dots (3.8)$$

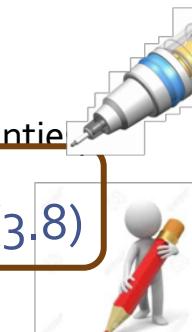
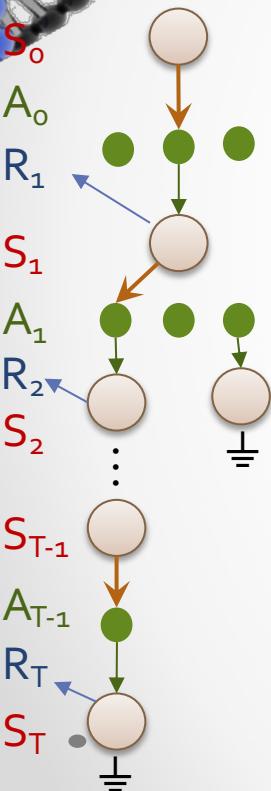
$$\gamma \in (0, 1)$$

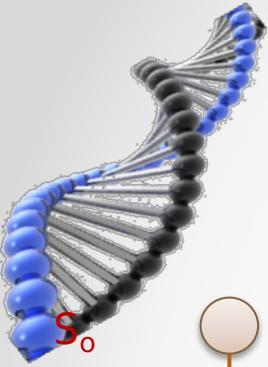
close to 0 gives "myopic"

close to 1 gives "far-sighted"

$\gamma = 0.9$ for continuous,

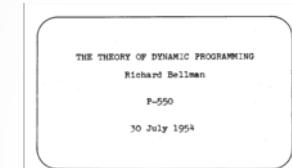
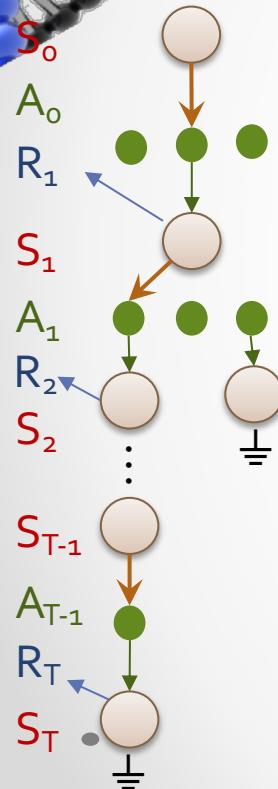
= 1.0 for sequences that terminate





Richard Bellman

Richard E. Bellman invented Dynamic Programming
His formulations form the foundation of
Reinforcement Learning



Turning to a more precise discussion, let us introduce a small amount of terminology. A sequence of decisions will be called a policy, and a policy which is most advantageous according to some preassigned criterion will be called an optimal policy.

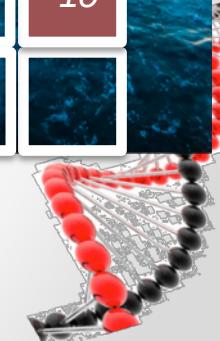
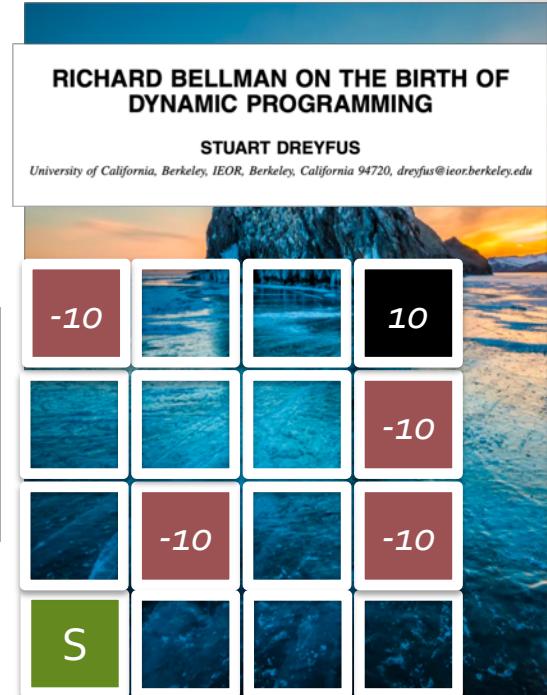
Dynamic Programming – refactor into sub problems

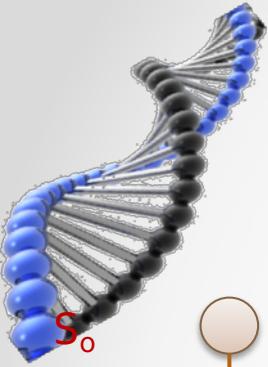
Decomposition & Aggregation

$$\begin{aligned} G_t &= \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1} \\ &= R_{t+1} + \sum_{k=1 \text{ to } \infty} \gamma^k R_{t+k+1} \\ &= R_{t+1} + \gamma G_{t+1} \dots (3.9) \end{aligned}$$



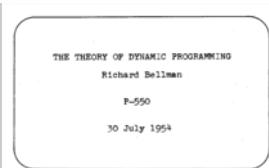
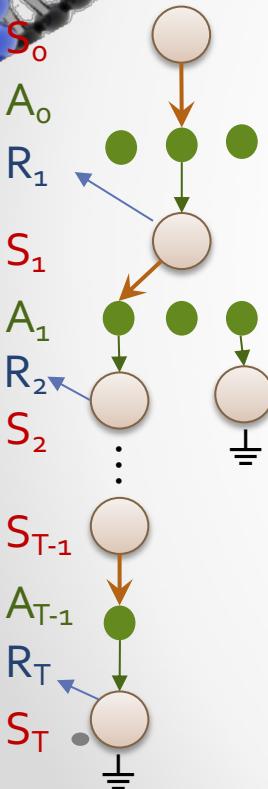
An interesting paper :
http://smo.sogang.ac.kr/doc/dy_birth.pdf





Richard Bellman

Richard E. Bellman invented Dynamic Programming
His formulations form the foundation of
Reinforcement Learning



Turning to a more precise discussion, let us introduce a small amount of terminology. A sequence of decisions will be called a policy, and a policy which is most advantageous according to some preassigned criterion will be called an optimal policy.

Dynamic Programming – refactor into sub problems

Decomposition & Aggregation

$$\begin{aligned} G_t &= \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1} \\ &= R_{t+1} + \sum_{k=1 \text{ to } \infty} \gamma^k R_{t+k+1} \\ &= R_{t+1} + \gamma G_{t+1} \dots (3.9) \end{aligned}$$

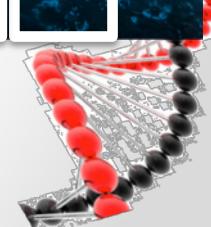


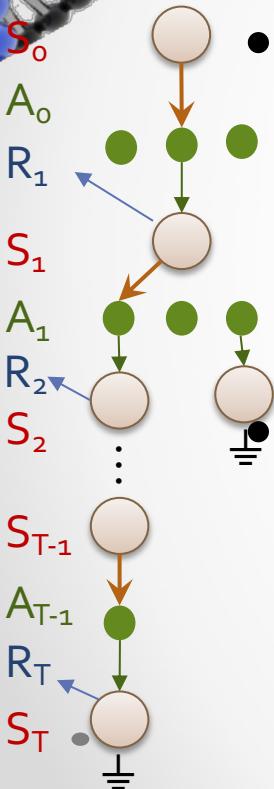
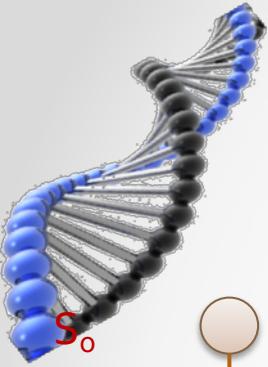
An interesting paper :
http://smo.sogang.ac.kr/doc/dy_birth.pdf

RICHARD BELLMAN ON THE BIRTH OF DYNAMIC PROGRAMMING

STUART DREYFUS

University of California, Berkeley, IEOR, Berkeley, California 94720, dreyfus@ieor.berkeley.edu



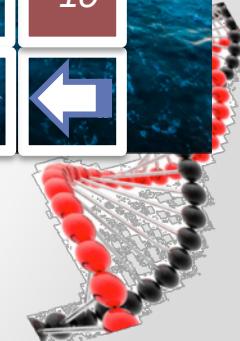


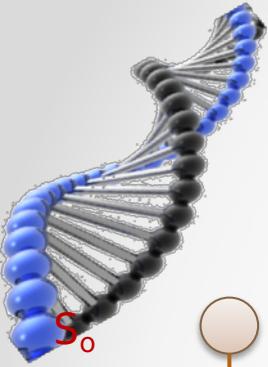
- Policy guides the decisions
- It could order actions as preferences that reflect the current understanding or belief

Or A deterministic policy as given here

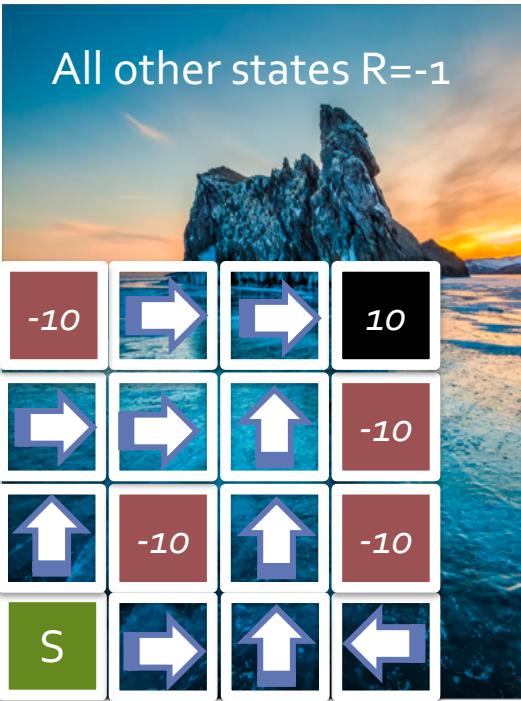
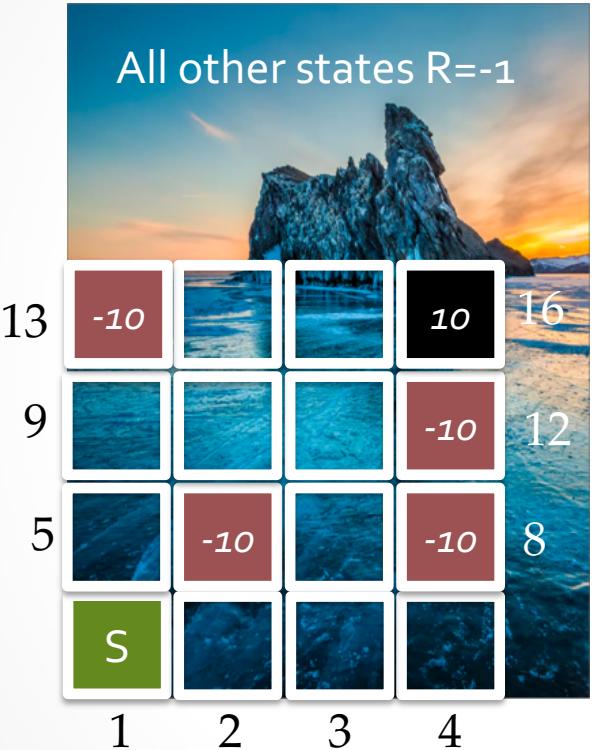
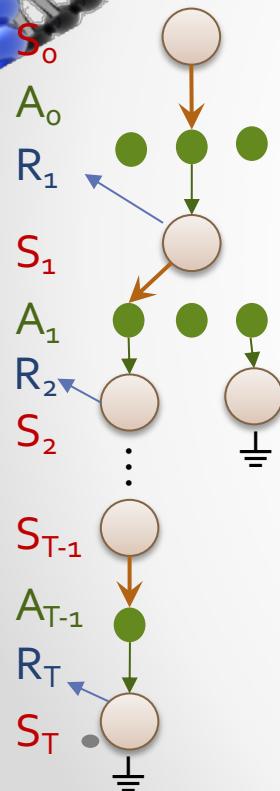
- Which is possible if we have the full model of the environment

Policy

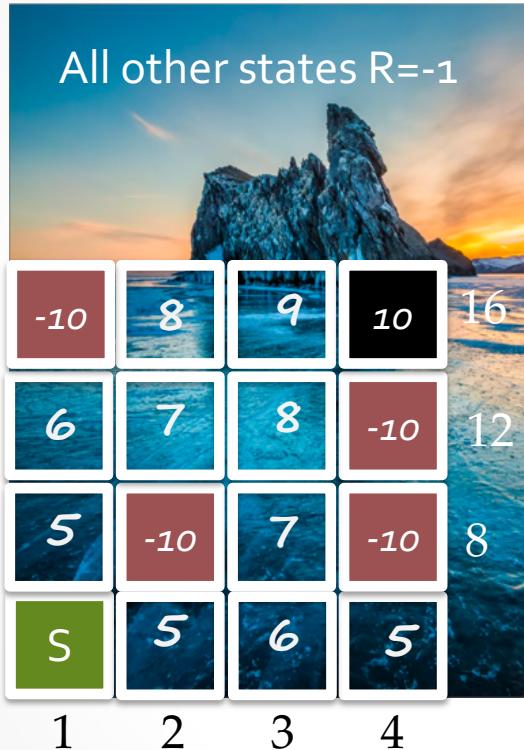
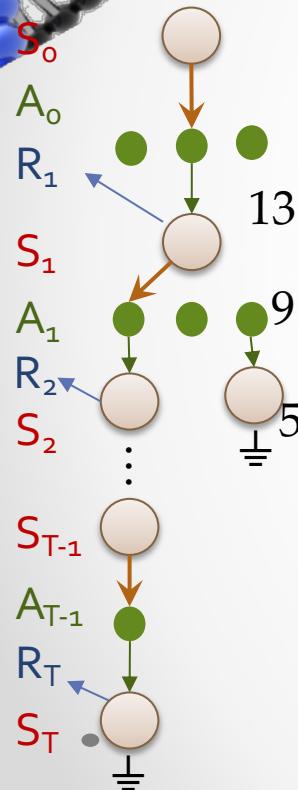
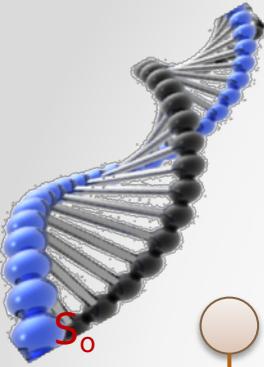




State Space & Policy



State	Action	Probability
1	U	1.0
2	R	1.0
3	U	1.0
4	L	
5	U	
6		
7	U	
8		
9	R	
10	R	
11	U	
12		
13		
14	R	
15	R	
16		



State-Value Function

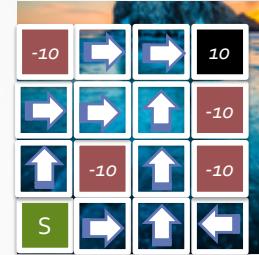
Given a policy, we can compute the value at each state using the Bellman Equation

$$G_t = R_{t+1} + G_{t+1}$$

Or

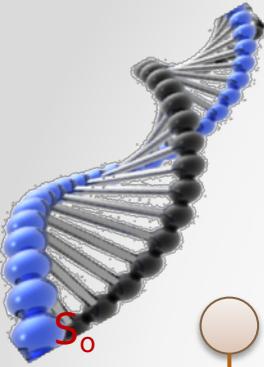
$$V_\pi(s) = R_{t+1} + V_\pi(s_{t+1} | s_t=s)$$

As shown in the diagram

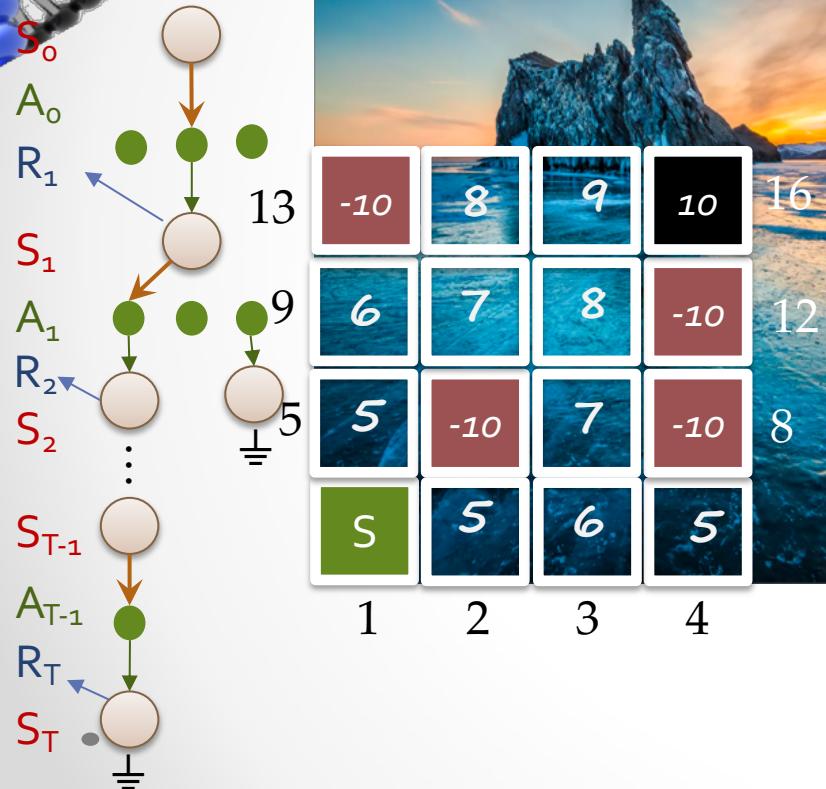


Of course, we are glossing over a lot of details, which we will explore during the rest of the lab





State-Value Function



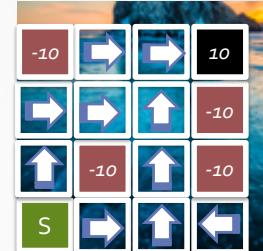
Given a policy, we can compute the value at each state using the Bellman Equation

$$G_t = R_{t+1} + G_{t+1}$$

Or

$$V_\pi(s) = R_{t+1} + V_\pi(s_{t+1} | s_t=s)$$

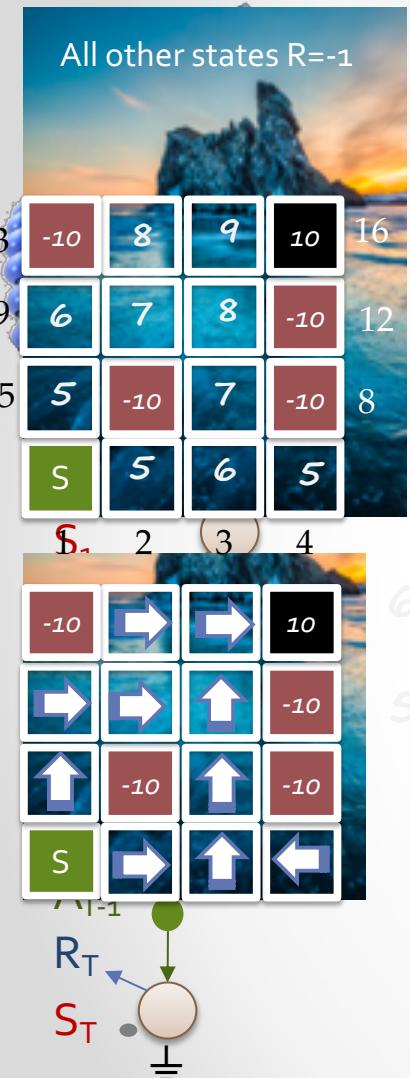
As shown in the diagram



Of course, we are glossing over a lot of details, which we will explore during the rest of the lab

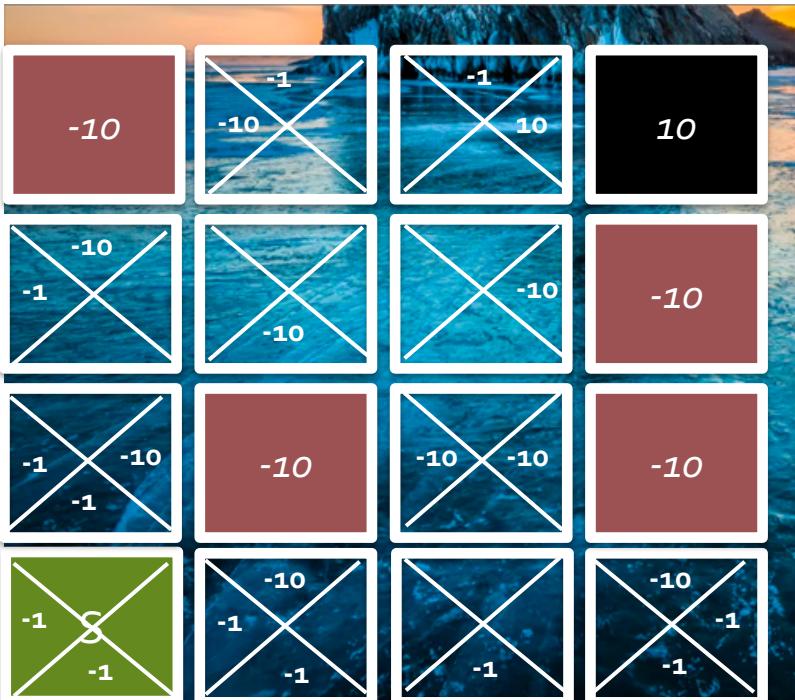


All other states R=-1



State-Action-Value Function

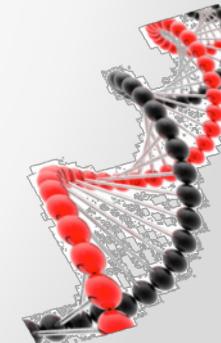
Iterative Policy Evaluation & Improvement



- $q_\pi(s, a) = v_\pi(s_{t+1}, a_t | s_t=s, a_t=a)$
 - $\pi(a|s) = q_*(s, a) = \text{argmax}_a(q(s, a'))$
 - $v_\pi(s) = R_s + q_\pi(s, \pi(s))$

Q-Table

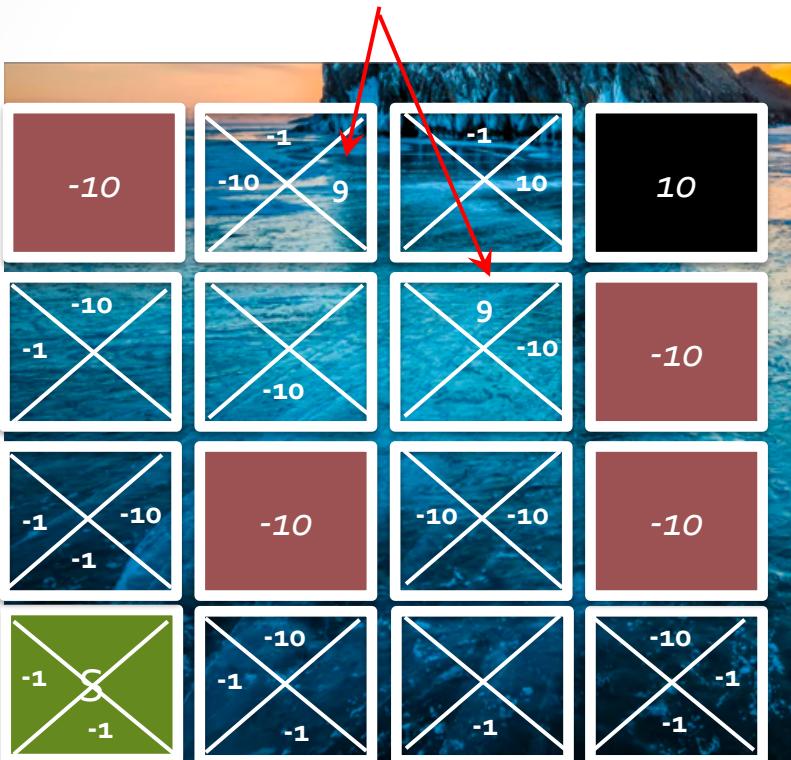
s,a	Q-Value
s_1, L	-1
s_1, D	-1
s_1, U	-10
s_2, R	6





State-Action-Value Function

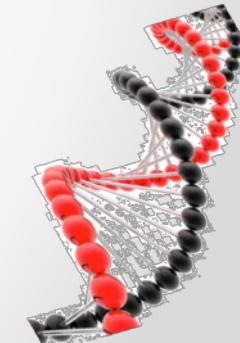
Iterative Policy Evaluation & Improvement



- $q_{\pi}(s, a) = v_{\pi}(s_{t+1}, a_t | s_t=s, a_t=a)$
- $\pi(a|s) = q_*(s, a) = \text{argmax}_a(q(s, a'))$
- $v_{\pi}(s) = R_s + q_{\pi}(s, \pi(s))$

Q-Table

s, a	Q-Value
z, L	-1
z, D	-1
z, U	-10
z, R	6

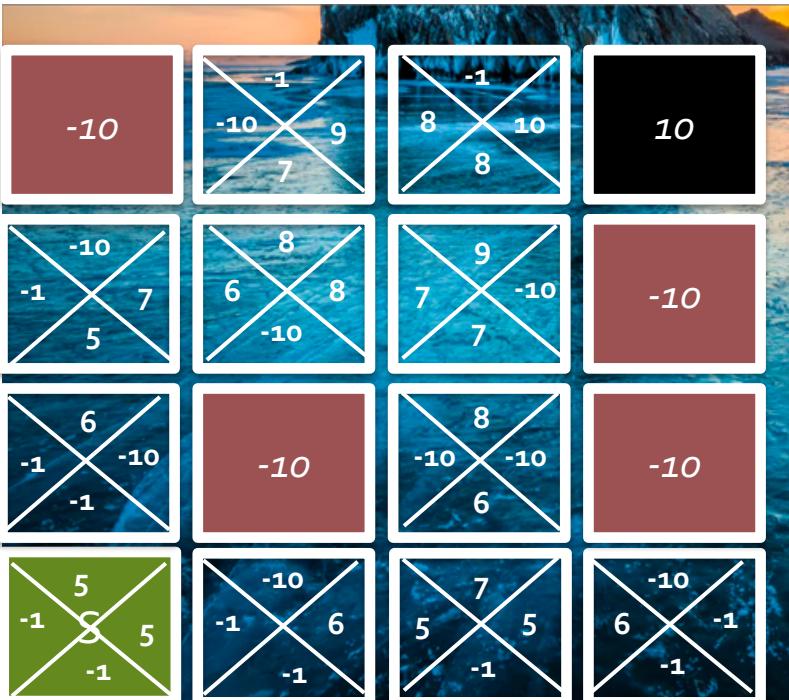


All other states $R=-1$



State-Action-Value Function

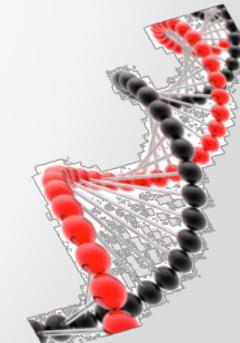
Iterative Policy Evaluation & Improvement



1. $q_{\pi}(s, a) = v_{\pi}(s_{t+1}, a_t | s_t=s, a_t=a)$
2. $\pi(a|s) = q_*(s, a) = \text{argmax}_a(q(s, a'))$
3. $v_{\pi}(s) = R_s + q_{\pi}(s, \pi(s))$

Q-Table

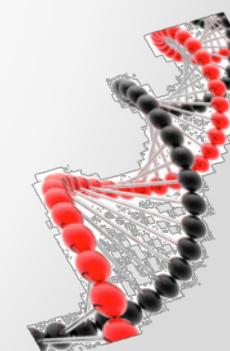
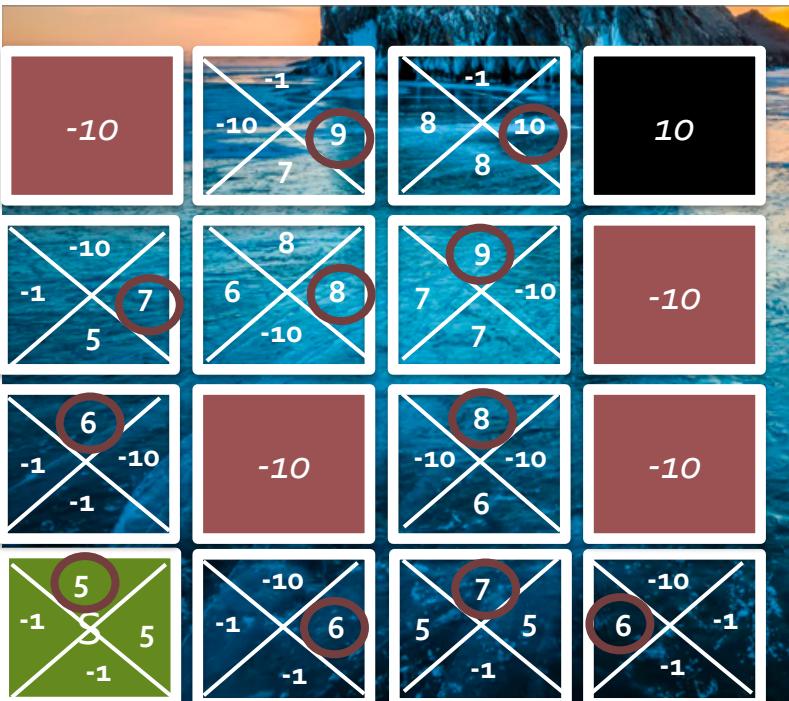
s,a	Q-Value
z,L	-1
z,D	-1
z,U	-10
z,R	6





State-Action-Value Function

Iterative Policy Evaluation & Improvement

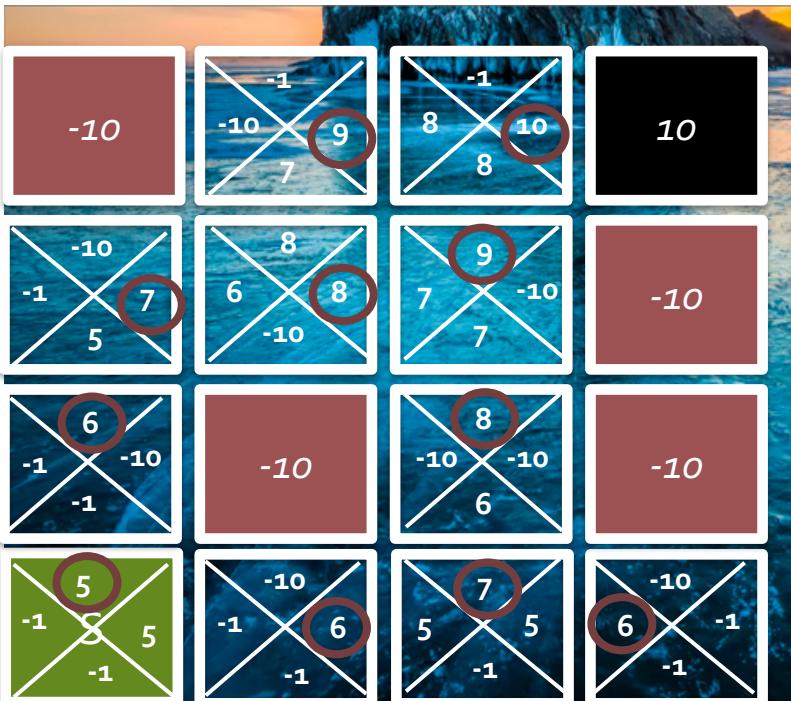


$$1. \quad q_{\pi}(s, a) = v_{\pi}(s_{t+1}, a_t | s_t=s, a_t=a)$$
</div



State-Action-Value Function

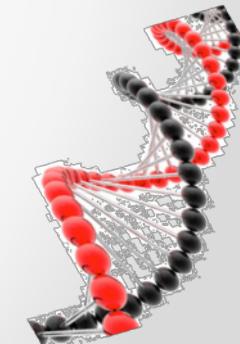
Iterative Policy Evaluation & Improvement

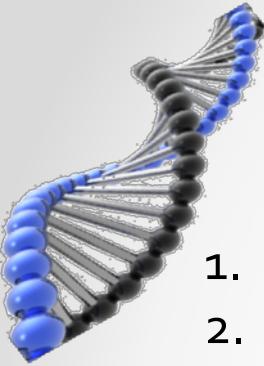


1. $q_{\pi}(s, a) = v_{\pi}(s_{t+1}, a_t | s_t=s, a_t=a)$
2. $\pi(a|s) = q_*(s, a) = \text{argmax}_a(q(s, a'))$
3. $v_{\pi}(s) = R_s + q_{\pi}(s, \pi(s))$

Q-Table

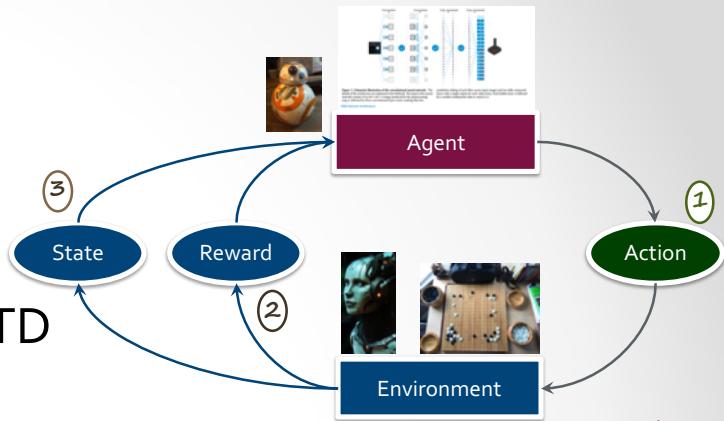
s, a	Q-Value
z, L	-1
z, D	-1
z, U	-10
z, R	6



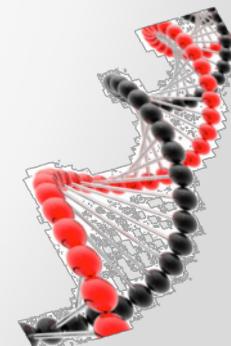


DRL Challenges

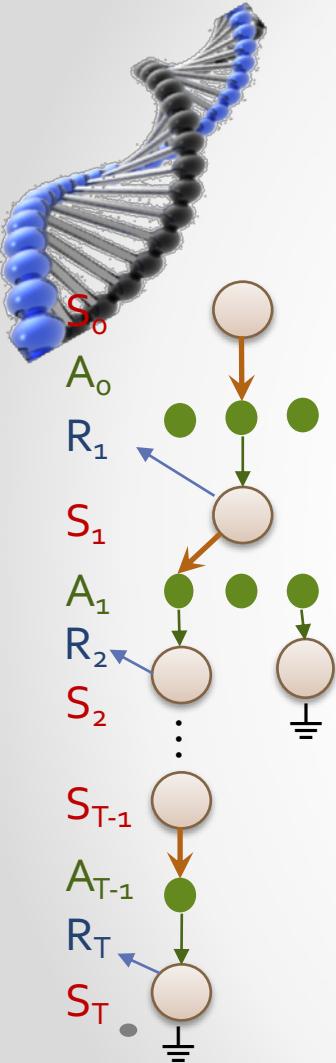
1. Exploration & Convergence – Bandit
2. Reward Shaping & Credit Assignment – TD
3. Representation
 - o DQN, CNN (LSTM,RNN Not yet) Capsule Networks/Transformer Architectures (?)
 - o Lower dimensional than tabular representation
 - o Compact as possible, but can capture the full complexity of the underlying state space
 - o Sample efficiency - replay buffer w/ DQN
 - o Atari representation
4. Generalization - DQN
 - o Atari generalization - same architecture, but trained for each game
5. Context & Content - Knowledge Graph
 - o Encode expert knowledge
 - o Atari - pixels - no knowledge
 - o If it's Tuesday, this must be Belgium - you need Tuesday Belgium 1000 times !
6. Common Sense Reasoning - Logic Representation & Traversal
7. Conversation Chain - Jarvis/Jeeves



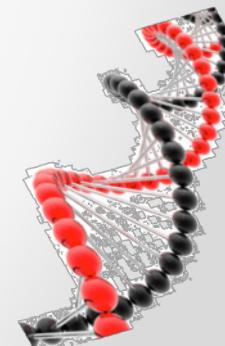
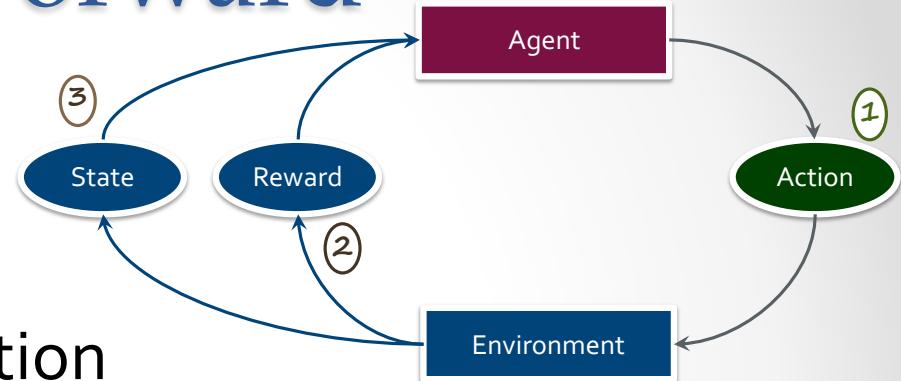
If you are planning to do
PhD (I urge all to earn a
doctorate degree in AI)
there are fertile research
topics here !!!



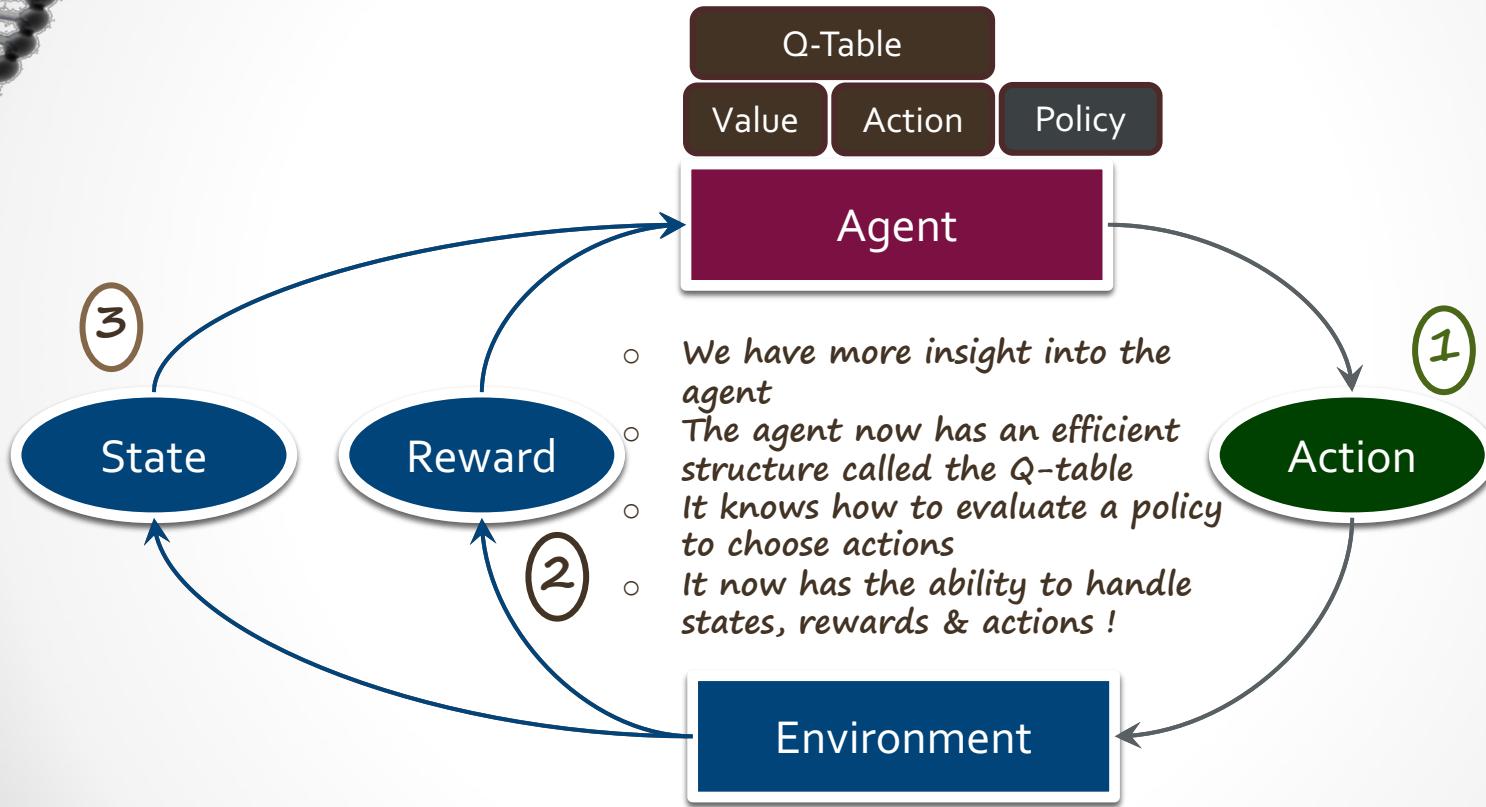
Recap & Forward



- RL Cycle
- Backup Diagram
- Value Function
- Action-Value Function
 - Value functions define a partial ordering of policies
- Policy – greedy policy ($\text{argmax}_{a'}$)
 - state sweep
- Grid World as an example
- Used Dynamic Programming in a model-based fashion
 - Decomposition & Aggregation

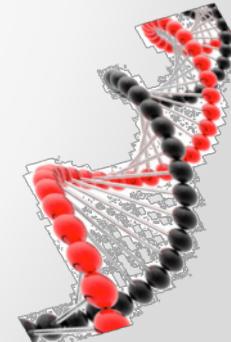
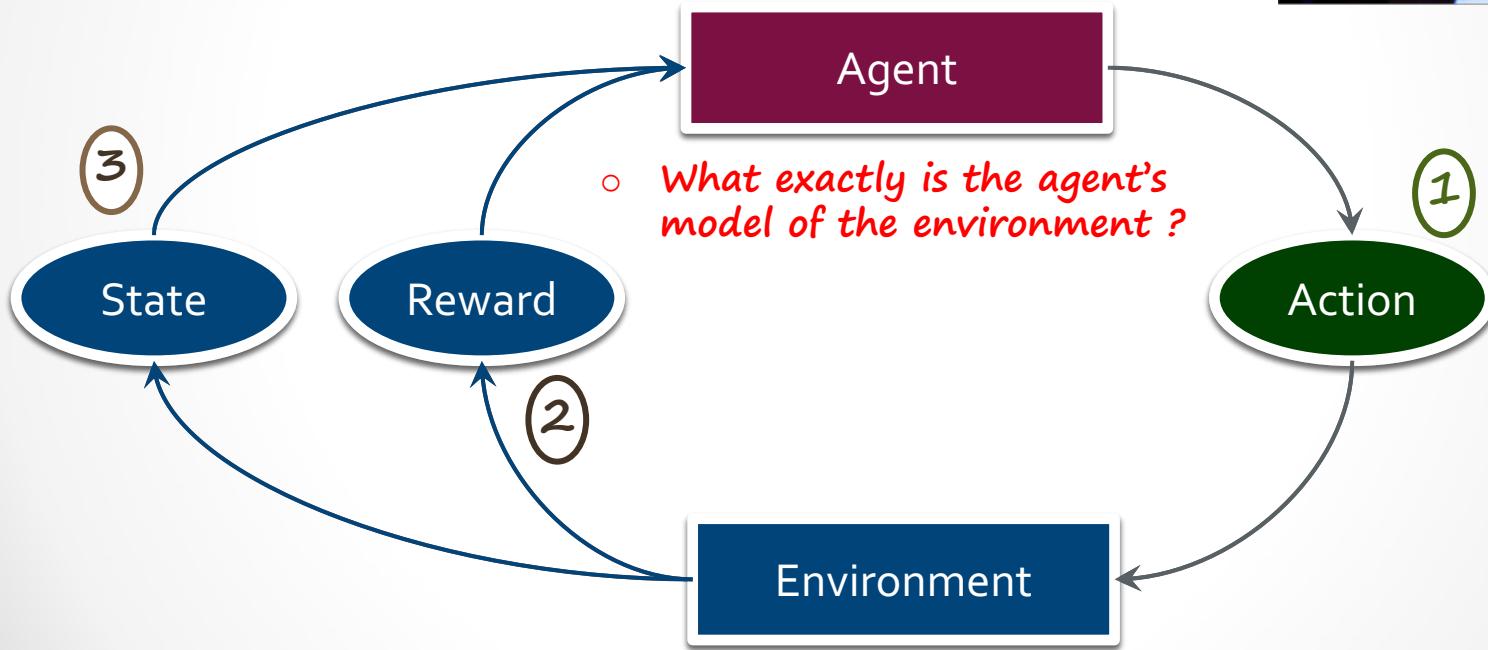


RL Flow



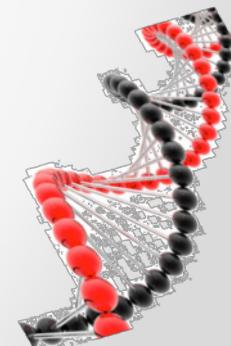
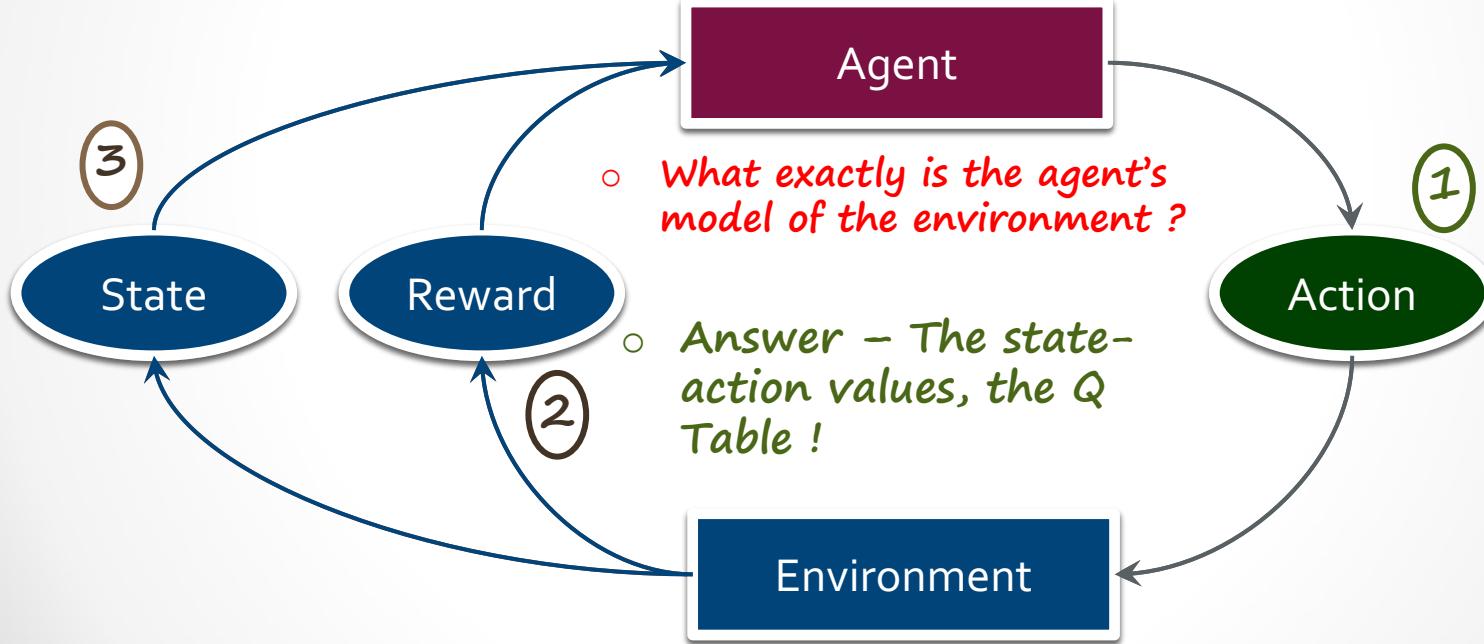


Quiz





Quiz





Examples of representation



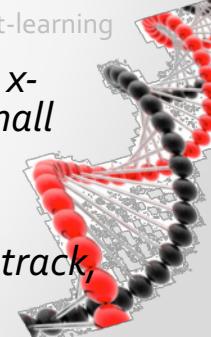
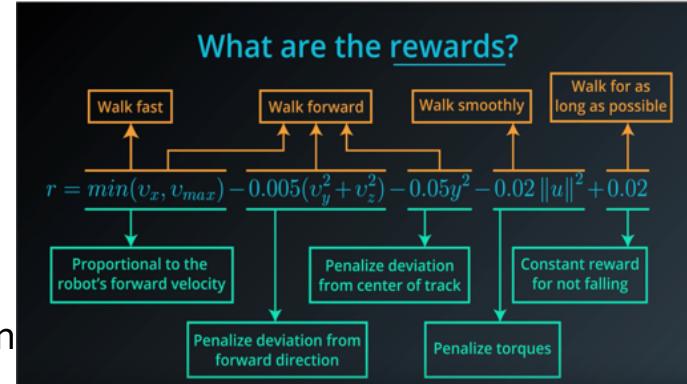
- Atari

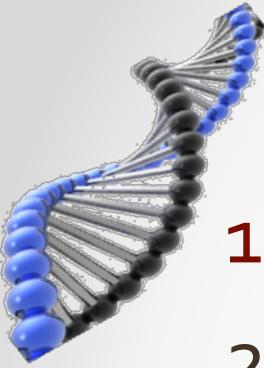
- Grey-scale, 84 X 84,
- Stacking 4 frames for context
- CNN as feature extractor, Actions 18 Joystick buttons

- Walking Humanoids

- Emergence of Locomotion Behaviors in Rich Environment
- <https://arxiv.org/abs/1707.02286>
- Algorithms : PPO, DPPO,A3C
- States – Position & Velocities of the joints, the height of the walker body above the ground, the difference between the agents position and the next sampling grid center
- Actions : Forces and directions on the 21 actuated joints with 28 DoF
- Rewards : <https://www.theverge.com/tldr/2017/7/10/15946542/deepmind-parkour-agent-reinforcement-learning>

- *The reward consists of a main component proportional to the velocity along the x-axis, encouraging the agent to make forward progress along the track, plus a small term penalizing torques.*
- *For the walker, the reward also includes the box constraints on the pose.*
- *For the quadruped and humanoid we penalize deviations from the center of the track, and the humanoid receives an additional reward per time-step for not falling*





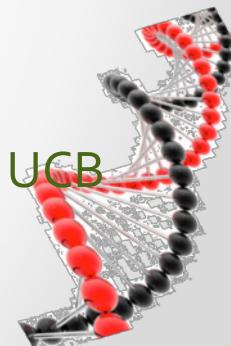
General Observation on Rewards

1. Specify the goals, not how to do it
2. Do not over specify, even a hint of how

*Enable the agent to pursue novel strategies
(e.g. Go game) and discover winning
strategies*

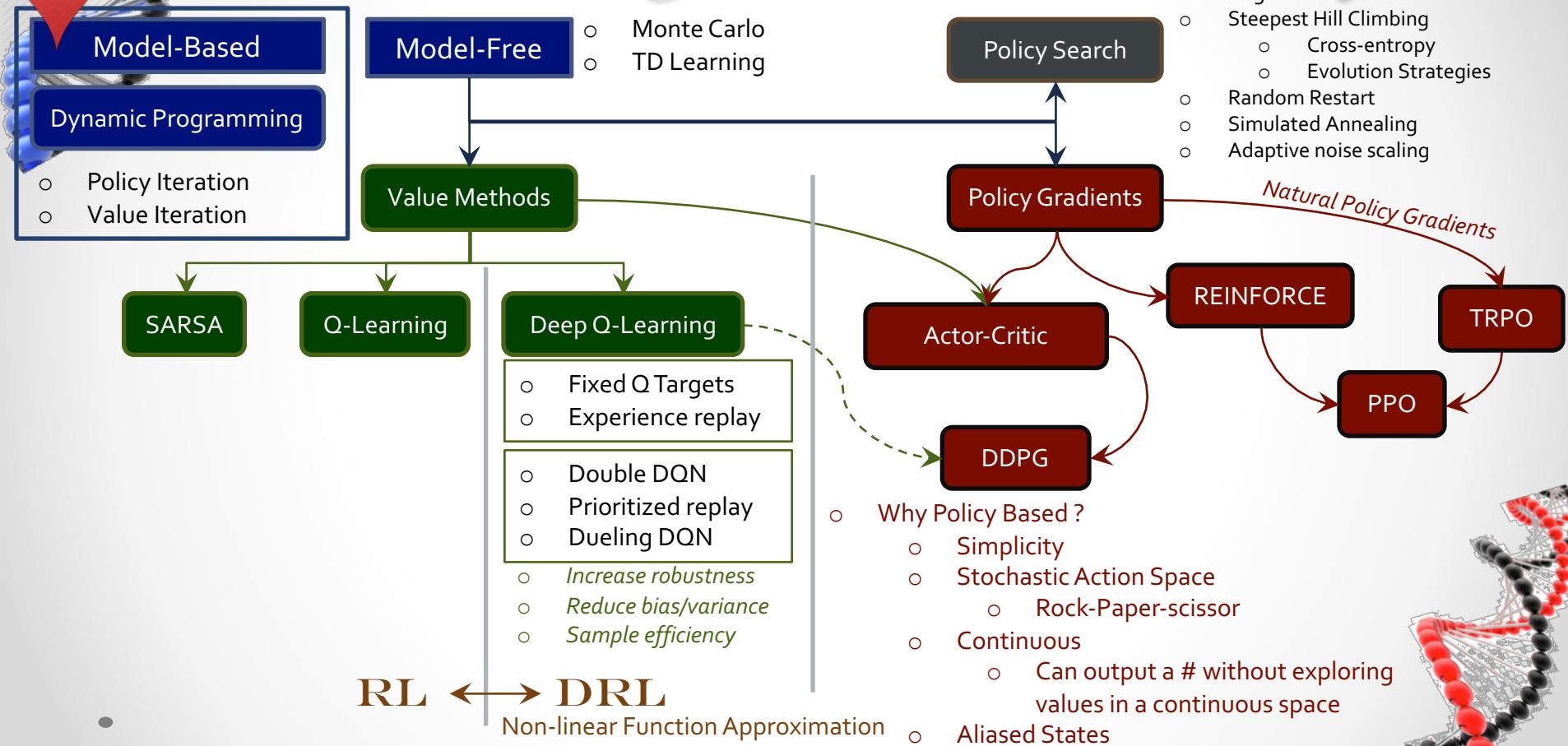
3. Rewards can change over time

- This can break stationary assumptions of mechanisms like UCB action selection and optimistic initialization





RL Algorithm Taxonomy





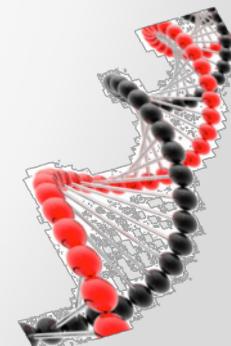
Algorithm Time

PyTorch Time

3. Algorithms & Programming : From Monte Carlo to DQN

• • •

Let us implement four algorithms and in the process discuss Monte Carlo, TD(), SARSA and Q-Learning





Notations & Definitions - Review

- Episode
Sequence of State-Action-Reward until an episode ends in T steps

- Return

$$G_t = \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1} = R_{t+1} + \sum_{k=1 \text{ to } \infty} \gamma^k R_{t+k+1} = R_{t+1} + \gamma G_{t+1}$$

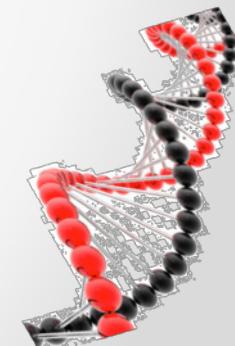
- Policy

Mapping $\pi : S \times A \mapsto [0,1]$ $\pi(a|s) = P(A_t=a | S_t=s)$

- Value

$$\begin{aligned} v_\pi(s) &= E_\pi[G_t | S_t=s] && \dots \text{state-value Function} \\ &= E_\pi[R_{t+1} + \gamma G_{t+1}(s_{t+1} | s_t=s)] \\ &= E_\pi[R_{t+1} + \gamma v_\pi(s_{t+1} | s_t=s)] \end{aligned}$$

$$q_\pi(s, a) = E_\pi[G_t | S_t=s, A_t=a] \quad \dots \text{action-value function}$$





Notations & Definitions - Review

- Episode
Sequence of State-Action-Reward until an episode ends in T steps

- Return

$$G_t = \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1} = R_{t+1} + \sum_{k=1 \text{ to } \infty} \gamma^k R_{t+k+1} = R_{t+1} + \gamma G_{t+1}$$

- Policy

Mapping $\pi : S \times A \mapsto [0,1]$

$$\pi(a|s) = P(A_t=a, S_t=s)$$

- Value

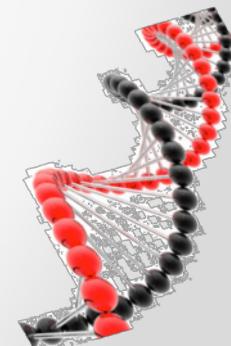
$$\begin{aligned} v_\pi(s) &= E_\pi[G_t | S_t=s] \\ &= E_\pi[R_{t+1} + \gamma G_{t+1}(s_{t+1}) | S_t=s] \\ &= E_\pi[R_{t+1} + \gamma v_\pi(s_{t+1}) | S_t=s] \end{aligned}$$

... state-value Function



$$q_\pi(s, a) = E_\pi[G_t | S_t=s, A_t=a]$$

... action-value function





Hands On #1 - Skating the Frozen Lake

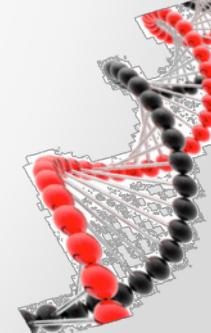
Goal:

- Get familiar with programming OpenAI Gym & it's interfaces
- Solve OpenAI Gym : Frozen Lake, given an optimum deterministic policy
- Frozen Lake deterministic : episodes before solve

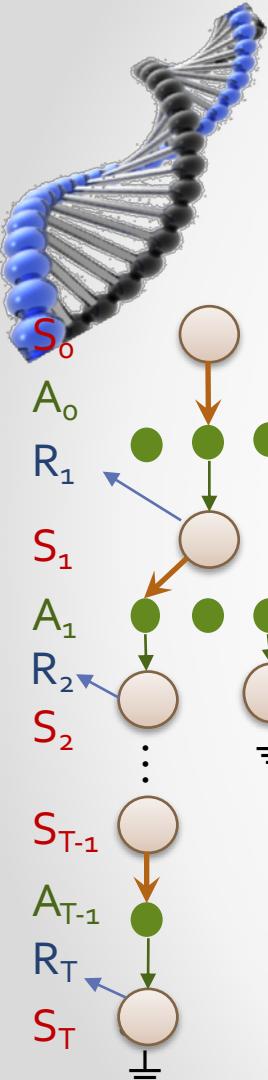
Steps:

Notebook : frozen_lake_01.ipynb

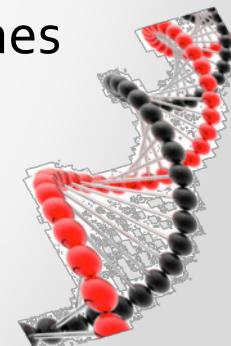
1. Understand OpenAI Setup & interface
2. Examine Random Policy Run
3. Run the cells upto 5. *Hands-on ToDo*
4. **ToDo : Create aPolicy which captures the deterministic policy**
5. Use the deterministic policy to skate to the goal
6. Metrics that can be programmed:
 - Episodes before solve
 - Solved 0.78 over 100 consecutive runs
 - Max score over 1000 episodes
 - Avg over 1000 episodes



Monte Carlo



- Model-free method
- Usually we do not have the model or the transition matrix. Then how do we arrive at G_t , $q_\pi(s, a)$ et al ?
- Monte Carlo brings deterministic expectation by repeated random sampling i.e. even though the underlying problem involves a great degree of randomness, we can infer useful information we can trust, by collecting lots of samples
- Monte Carlo estimates a value by averaging across a large number of episodes
- Remember, a state-action might be visited several times and the q-value can and will be different.
 - Averaging gives the best estimate across a large number of episodes
 - Either average (across episodes) considering only during 1st visit in an episode or
 - Consider all visits and average the value





Monte Carlo Algorithm

1. Initialize variables, set policy π
2. Generate episodes using policy π - $S_o A_o R_1 S_1 A_1 R_2 S_2 \dots A_{T-1} R_T S_T$
3. For each episode
4. For each time step
5. For each state, action pair

6. If 1st visit to (S_t, A_t)

7. Calculate the return $G_t(S_t, A_t)$ - $G_t = \sum_{k=0 \text{ to } \infty} \gamma^k R_{t+k+1}$

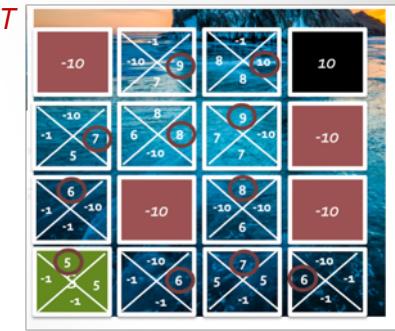
8. Add G_t to the return column - $\Sigma q(s, a)$

9. Increment $N(S_t, A_t)$

10. Average $G_t(S_t, A_t) = \Sigma q(s, a) / N(S_t, A_t)$ and

11. Return the Q table $q(s, a)$

$Q(s, a) \mapsto Q_\pi(s, a)$ for a larger number of episodes



Algorithm 9: First-Visit MC Prediction (for action values)

```

Input: policy  $\pi$ , positive integer num_episodes
Output: value function  $Q$  ( $\approx q_\pi$  if num_episodes is large enough)
Initialize  $N(s, a) = 0$  for all  $s \in \mathcal{S}, a \in \mathcal{A}(s)$ 
Initialize returns.sum( $s, a$ ) = 0 for all  $s \in \mathcal{S}, a \in \mathcal{A}(s)$ 
for  $i \leftarrow 1$  to num_episodes do
    Generate an episode  $S_0, A_0, R_1, \dots, S_T$  using  $\pi$ 
    for  $t \leftarrow 0$  to  $T - 1$  do
        if  $(S_t, A_t)$  is a first visit (with return  $G_t$ ) then
             $N(S_t, A_t) \leftarrow N(S_t, A_t) + 1$ 
            returns.sum( $S_t, A_t$ )  $\leftarrow$  returns.sum( $S_t, A_t$ ) +  $G_t$ 
        end
    end
     $Q(s, a) \leftarrow \text{returns.sum}(s, a) / N(s, a)$  for all  $s \in \mathcal{S}, a \in \mathcal{A}(s)$ 
return  $Q$ 

```

Algorithm 9: First-Visit MC Prediction (*for action values*)

Input: policy π , positive integer $num_episodes$

Output: value function Q ($\approx q_\pi$ if $num_episodes$ is large enough)

Initialize $N(s, a) = 0$ for all $s \in \mathcal{S}, a \in \mathcal{A}(s)$

Initialize $returns_sum(s, a) = 0$ for all $s \in \mathcal{S}, a \in \mathcal{A}(s)$

for $i \leftarrow 1$ **to** $num_episodes$ **do**

Generate an episode $S_0, A_0, R_1, \dots, S_T$ using π

for $t \leftarrow 0$ **to** $T - 1$ **do**

if (S_t, A_t) is a first visit (with return G_t) **then**

$N(S_t, A_t) \leftarrow N(S_t, A_t) + 1$

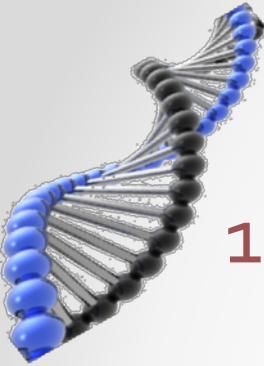
$returns_sum(S_t, A_t) \leftarrow returns_sum(S_t, A_t) + G_t$

end

end

$Q(s, a) \leftarrow returns_sum(s, a) / N(s, a)$ for all $s \in \mathcal{S}, a \in \mathcal{A}(s)$

return Q



Couple of optimizations

1. Instead of

- Do this

Increment counter $N(s) \leftarrow N(s) + 1$

Increment total return $S(s) \leftarrow S(s) + G_t$

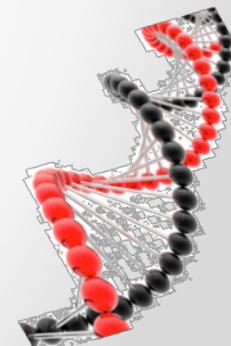
Value is estimated by mean return $V(s) = S(s)/N(s)$

$$N(S_t) \leftarrow N(S_t) + 1$$

$$V(S_t) \leftarrow V(S_t) + \frac{1}{N(S_t)} (G_t - V(S_t))$$

2. Track a running mean

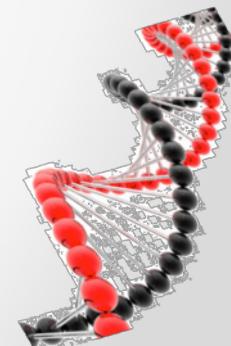
$$V(S_t) \leftarrow V(S_t) + \alpha (G_t - V(S_t))$$

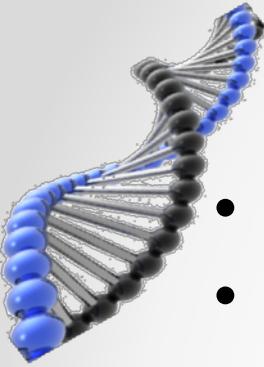




Incremental Mean

$$\begin{aligned}\mu_k &= \frac{1}{k} \sum_{j=1, k} x_j \\&= \frac{1}{k} [x_k + \sum_{j=1, k-1} x_j] \\&= \frac{1}{k} (x_k + (k-1) \mu_{k-1}) \\&= \frac{1}{k} (x_k + k \mu_{k-1} - \mu_{k-1}) \\&= \mu_{k-1} + \frac{1}{k} (x_k - \mu_{k-1})\end{aligned}$$





Policy !

- We glossed over 2 points
- Where does the π come from ?
- How do we get to



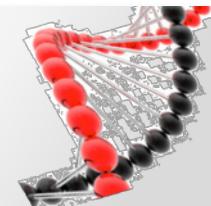
- From a Q table ?

(S,A)	$\Sigma q(s,a)$	N
1,0	-4	4
1,1	5	1
1,2	10	2
1,3	-2	2
2,0	-20	20
2,1	-10	1
2,2	4	24
..		

Algorithm 9: First-Visit MC Prediction (for action values)

```
Input: policy  $\pi$ , positive integer num_episodes
Output: value function  $Q$  ( $\approx q_\pi$  if num_episodes is large enough)
Initialize  $N(s, a) = 0$  for all  $s \in \mathcal{S}, a \in \mathcal{A}(s)$ 
Initialize  $returns\_sum(s, a) = 0$  for all  $s \in \mathcal{S}, a \in \mathcal{A}(s)$ 
for  $i \leftarrow 1$  to num_episodes do
    Generate an episode  $S_0, A_0, R_1, \dots, S_T$  using  $\pi$ 
    for  $t \leftarrow 0$  to  $T - 1$  do
        if  $(S_t, A_t)$  is a first visit (with return  $G_t$ ) then
             $N(S_t, A_t) \leftarrow N(S_t, A_t) + 1$ 
             $returns\_sum(S_t, A_t) \leftarrow returns\_sum(S_t, A_t) + G_t$ 
        end
    end
     $Q(s, a) \leftarrow returns\_sum(s, a) / N(s, a)$  for all  $s \in \mathcal{S}, a \in \mathcal{A}(s)$ 
return  $Q$ 
```

i.e. how does all this help us to make better actions ?





Policy Evaluation-Improvement Cycle

Policy Evaluation

The $q(s,a)$ tells us the utility of a policy

- Collect experience using π
- Create Q Table

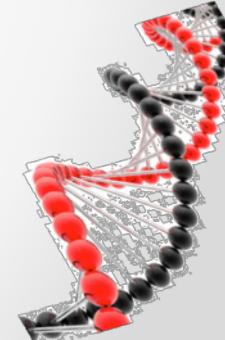
Update agent's behavior based on experience

- Construct better policy π' based on the Q values
- (optionally) Set $\pi = \pi'$
- Take action using π'

$$\pi_0 \mapsto V_{\pi_0} \mapsto \pi_1 \mapsto V_{\pi_1} \mapsto \dots \mapsto \pi_* \mapsto V_*$$

Policy Improvement

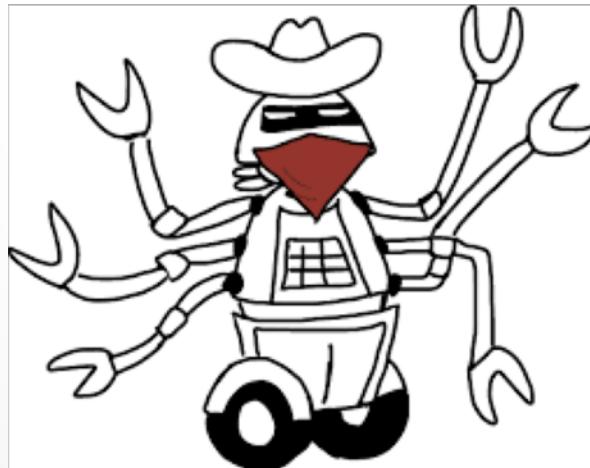
- π – Behavior Policy (sample experience)
- π' – Target Policy (to optimize behavior)
- Most Common Policies
 - Equiprobable
 - Greedy
 - ϵ -Greedy (Greedy + Equiprobable)
 - Softmax distribution





TTD (Things To Do)

- Read & Explore
 - Multi-arm bandits
 - Contextual bandits





Policy Algorithms

Equiprobable

- Random Uniform
- All actions equally possible
- *Good starting point, in an unknown environment*

Greedy

- Follow the action with the max value
- $\pi(a|s) = q_*(s,a) = \text{argmax}_{a'}(q(s,a'))$
- *Pure exploit*

Softmax

(1) To calculate the probability of selecting an action a

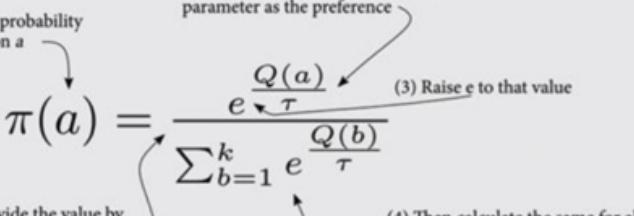
$$\pi(a) = \frac{e^{\frac{Q(a)}{\tau}}}{\sum_{b=1}^k e^{\frac{Q(b)}{\tau}}}$$

(2) Use the action-value function for that action divided by the temperature parameter as the preference

(3) Raise e to that value

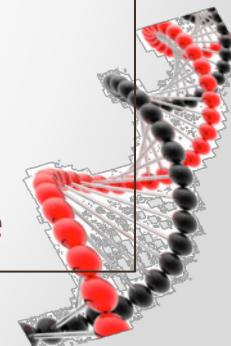
(4) Then calculate the same for all possible action and add them up

(5) Finally, divide the value by the sum to normalize the probabilities



ϵ -Greedy

- With ϵ follow equiprobable
- With $1-\epsilon$ follow greedy
- *Gives Exploration*
- ϵ – Degree of Exploration
- Decay ϵ as the agent learns more





Policy Algorithms

- A weighted probability across actions, establishing a partial ordering

Equiprobable

- Random Uniform
- All actions equally possible
- Good starting point, in an unknown environment

Softmax

(1) To calculate the probability of selecting an action a

$$\pi(a) = \frac{e^{\frac{Q(a)}{\tau}}}{\sum_{b=1}^k e^{\frac{Q(b)}{\tau}}}$$

(2) Use the action-value function for that action divided by the temperature parameter as the preference

(3) Raise e to that value

(4) Then calculate the same for all possible actions

(5) Finally, divide the value by the sum to normalize the probabilities

- Greedy
- Follow the action with the max value
- $\tau = \text{temperature, that scales the probability distribution of actions.}$
- A high temperature will tend the probabilities to be very similar, whereas
- A low temperature will exaggerate differences in probabilities between actions
- Initially, when the values are inaccurate, we are Ok with small difference between the values i.e. uniform random
- Decay τ such that as our values get better we want meaningful difference, yet have a small exploration possibility



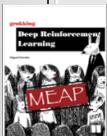
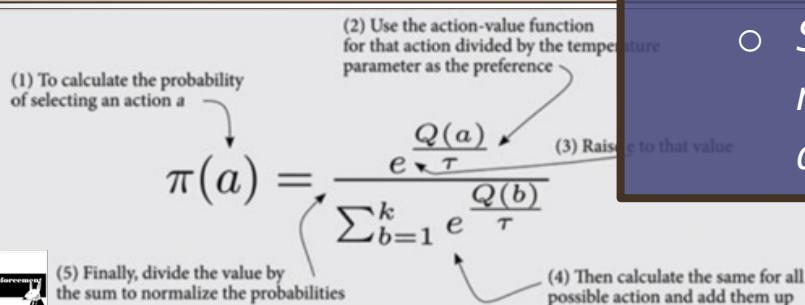


Policy Algorithms

Equiprobable

- Random Uniform
- All actions equally possible
- Good starting point, in an unknown environment

Softmax



- We all would have encountered softmax-based image classifier where there is a single correct classification to an image and there is no temporal association between each prediction.

In our RL case, we want more control over how we make these updates. $\hat{q}(s,a) = \text{argmax}_{a'}(q(s,a'))$

- First, we want to make small, smooth updates because we want to maintain some stochasticity in our action sampling to adequately explore the environment.

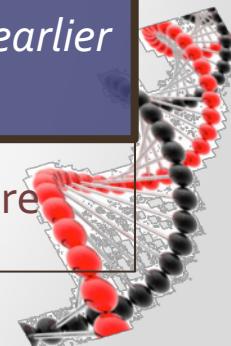
- Secondly, we want to be able to weight how much we assign credit to each action for earlier actions.

With the following equations

With $1-\epsilon$ follow greedy

Gives exploration

- Decay ϵ as the agent learns more





Equiprobable

Random Uniform

Quiz:

1. Which ϵ will always Exploit ?
2. Never Exploit ?
3. Is equiprobable a special case of ϵ -Greedy ? If so, what is ϵ for ϵ -Greedy Equiprobable ?
4. Which guarantees Exploration ?
 $\epsilon=0$? $\epsilon=0.25$? $\epsilon=0.75$? $\epsilon=0.99$? $\epsilon=1$?
5. What is a good ϵ_{start} ? ϵ_{min} for decay ?
6. What is a good policy for Rock-Paper-Scissor ? How will it work ?
7. When will ϵ -Greedy stop learning ?



Quiz



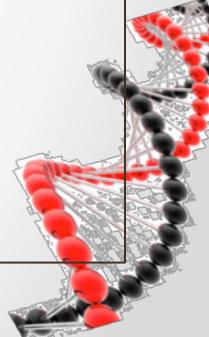
$$\pi(a|s) \leftarrow \begin{cases} 1 - \epsilon + \frac{\epsilon}{|\mathcal{A}(s)|} & \text{if } a = \arg \max_{a' \in \mathcal{A}(s)} Q(s, a') \\ \frac{\epsilon}{|\mathcal{A}(s)|} & \text{otherwise} \end{cases}$$

value

- $\pi(a|s) = q_*(s,a) = \operatorname{argmax}_{a'}(q(s,a'))$
- Pure exploit

ϵ -Greedy

- With ϵ follow equiprobable
- With $1-\epsilon$ follow greedy
- Gives exploration
- ϵ – Degree of Exploration
- Decay ϵ as the agent learns more





Quiz



Equiprobable

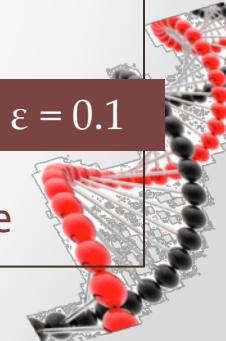
Random Uniform

$$\pi(a|s) \leftarrow \begin{cases} 1 - \epsilon + \frac{\epsilon}{|\mathcal{A}(s)|} & \text{if } a = \arg \max_{a' \in \mathcal{A}(s)} Q(s, a') \\ \frac{\epsilon}{|\mathcal{A}(s)|} & \text{otherwise} \end{cases}$$

value

Quiz:

1. Which ϵ will always Exploit ? $\epsilon = 0$: Greedy, no Exploration $a) = \operatorname{argmax}_{a'}(q(s,a'))$
 - Pure exploit
2. Never Exploit ? Trick Q. Not possible
3. Is equiprobable a special case of ϵ -Greedy ? If so, what is ϵ for ϵ -Greedy Equiprobable ? Yes. $\epsilon = 1$
4. Which guarantees Exploration ? $\epsilon > 0$
 $\epsilon=0$? $\epsilon=0.25$? $\epsilon=0.75$? $\epsilon=0.99$? $\epsilon=1$?
 - With ϵ follow equiprobable
 - With $1-\epsilon$ follow greedy
5. What is a good ϵ_{start} ? ϵ_{min} for decay ? $\epsilon = 1$: Decaying over, say 10,000 steps to $\epsilon = 0.1$
 - ϵ – Degree of Exploration
6. What is a good policy for Rock-Paper-Scissor ? How will it work ? $\epsilon = 1$: Equiprobable ϵ as the agent learns more
7. When will ϵ -Greedy stop learning ? $\epsilon = 0$: Greedy i.e. No Exploration



Algorithm 10: First-Visit GLIE MC Control

Input: positive integer num_episodes , GLIE $\{\epsilon_i\}$

Output: policy π ($\approx \pi_*$ if num_episodes is large enough)

Initialize $Q(s, a) = 0$ for all $s \in \mathcal{S}$ and $a \in \mathcal{A}(s)$

Initialize $N(s, a) = 0$ for all $s \in \mathcal{S}, a \in \mathcal{A}(s)$

for $i \leftarrow 1$ **to** num_episodes **do**

$\epsilon \leftarrow \epsilon_i$

$\pi \leftarrow \epsilon\text{-greedy}(Q)$

Generate an episode $S_0, A_0, R_1, \dots, S_T$ using π

for $t \leftarrow 0$ **to** $T - 1$ **do**

| **if** (S_t, A_t) is a first visit (with return G_t) **then**

$N(S_t, A_t) \leftarrow N(S_t, A_t) + 1$

$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \frac{1}{N(S_t, A_t)}(G_t - Q(S_t, A_t))$

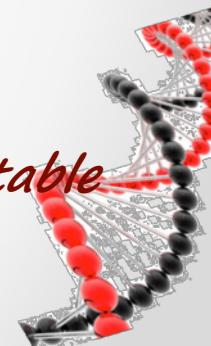
end 1. Greedy with limited Infinite Exploration

end 2. Construct a policy that is ϵ -greedy w.r.t the Q table

return π 3. Decay ϵ as the agent learns more

4. But still maintain a small exploration

GLIE - Greedy in the Limit with Infinite Exploration (GLIE) means that the behavior policies are required to become greedy (no exploration) in the limit of an online learning setting where the agent has gathered an infinite amount of experience



Algorithm 11: First-Visit Constant- α (GLIE) MC Control

Input: positive integer $num_episodes$, small positive fraction α , GLIE $\{\epsilon_i\}$

Output: policy π ($\approx \pi_*$ if $num_episodes$ is large enough)

Initialize Q arbitrarily (e.g., $Q(s, a) = 0$ for all $s \in \mathcal{S}$ and $a \in \mathcal{A}(s)$)

for $i \leftarrow 1$ **to** $num_episodes$ **do**

$\epsilon \leftarrow \epsilon_i$

$\pi \leftarrow \epsilon\text{-greedy}(Q)$

 Generate an episode $S_0, A_0, R_1, \dots, S_T$ using π

for $t \leftarrow 0$ **to** $T - 1$ **do**

if (S_t, A_t) is a first visit (with return G_t) **then**

$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha(G_t - Q(S_t, A_t))$

end

α Mean

end

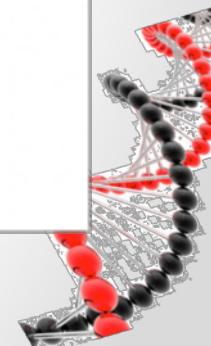
$\alpha = 0$, never learns

return π

$\alpha = 1$, never remembers !

$\alpha = \text{small, larger history, learns slowly}$

$\alpha = \text{large, focuses more on recent experience, but potentially difficult to converge}$





Hands On #2 – Monte Carlo

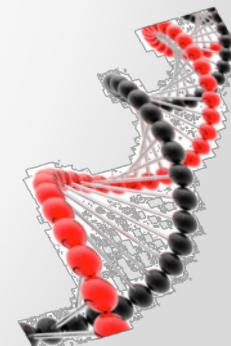
Goal:

- Implement Monte Carlo
- Explore different policies solving OpenAI Gym : FrozenLake

Steps:

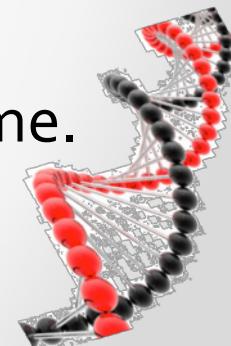
Notebook : Monte_Carlo_01.ipynb

1. Program Monte Carlo – 1st Visit or every visit
2. Run the code and understand how it all comes together
3. How is the exploration policy implemented ?
4. How do we finally get the learned policy from the agent ?
5. Does it correspond to our deterministic policy ?





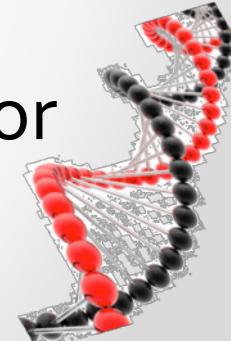
Points to Ponder

1. There are different ways of decaying ϵ
 - o Or we could just keep $\epsilon = 1$, making it uniformly random; but this won't work.
We will see some interesting results
 2. GLIE – decay ϵ as decreasing function of episodes
 3. Exponentially decay ϵ
 - o The ϵ decay is to incorporate the learning & make the action more deterministic
 4. We could use softmax & keep the policy constant i.e. weighted random.
 - o As it learns, its belief of the grid world changes and that shows up in the preferences
 5. After 1,000,000 episodes, it usually wins all the time.
 - o I had the $\epsilon_{\min} = 0.1$. Probably it should be reduced
- 



TD

- Temporal Difference Algorithm
- Motivation
 - [+] MC : Easy to understand
 - [+] MC : Low Bias
 - [-] MC : Requires full episodes
 - [-] MC : High Variance
 - [-] MC : Slow to converge
- So instead of waiting for a full episode, update the values after every step – TD(α) or every n steps – TD(λ)

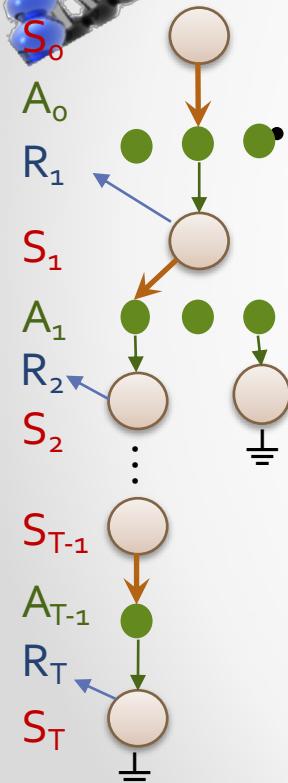




TD vs. MC

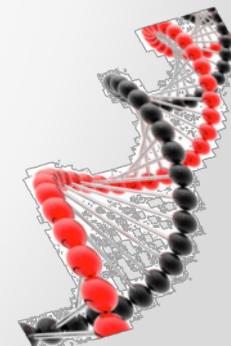
- MC : $Q(S_t, A_t) = Q(S_t, A_t) + \alpha(G_t) - Q(S_t, A_t)$

We observe from a full episode & update all

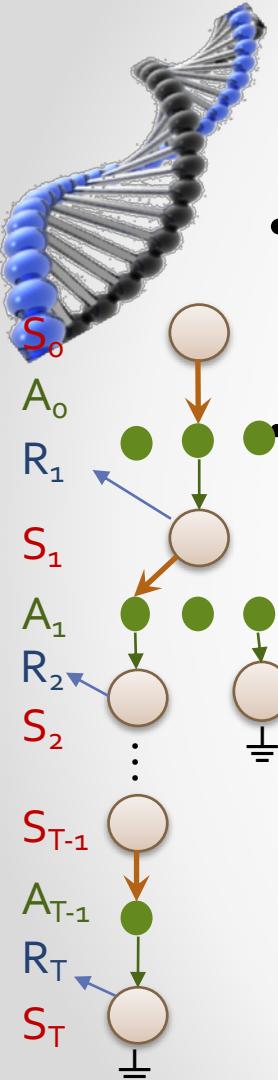


- $TD : Q(S_t, A_t) = Q(S_t, A_t) + \alpha (R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$

 - $TD Target$ TD Target = Alternate Estimate Current Estimate
 - $TD Error$ TD Error
 - At every timestep, so we have R_{t+1} not G_t
 - We bootstrap $Q(S_{t+1}, A_{t+1})$, but as we take more steps and more episodes it all converges
 - TD learns from incomplete episodes by bootstrapping
 - TD lends itself to function approximation
 - And scale to large state space
 - Remember, we must know S_{t+1} & select A_{t+1}
 - That is policy & more later

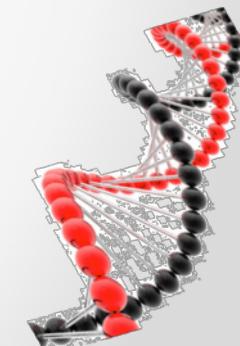
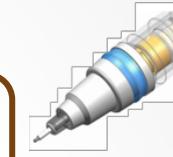


TD vs. MC



- MC :
$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha(G_t - Q(S_t, A_t))$$

We observe from a full episode & update all
- TD :
$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha(R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$$
 - \circ TD Target
 - \circ TD Error
 - \circ At every timestep, so we have R_{t+1} not G_t
 - \circ We bootstrap $Q(S_{t+1}, A_{t+1})$, but as we take more steps and more episodes it all converges
 - \circ TD learns from incomplete episodes by bootstrapping
 - \bullet And scale to large state space
 - \circ TD lends itself to function approximation
 - \bullet That is policy & more later
 - \circ Remember, we must know S_{t+1} & select A_{t+1}

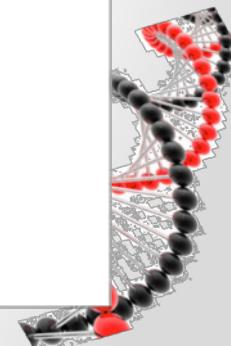




TD Intuition from Sutton Book/D.SLiver

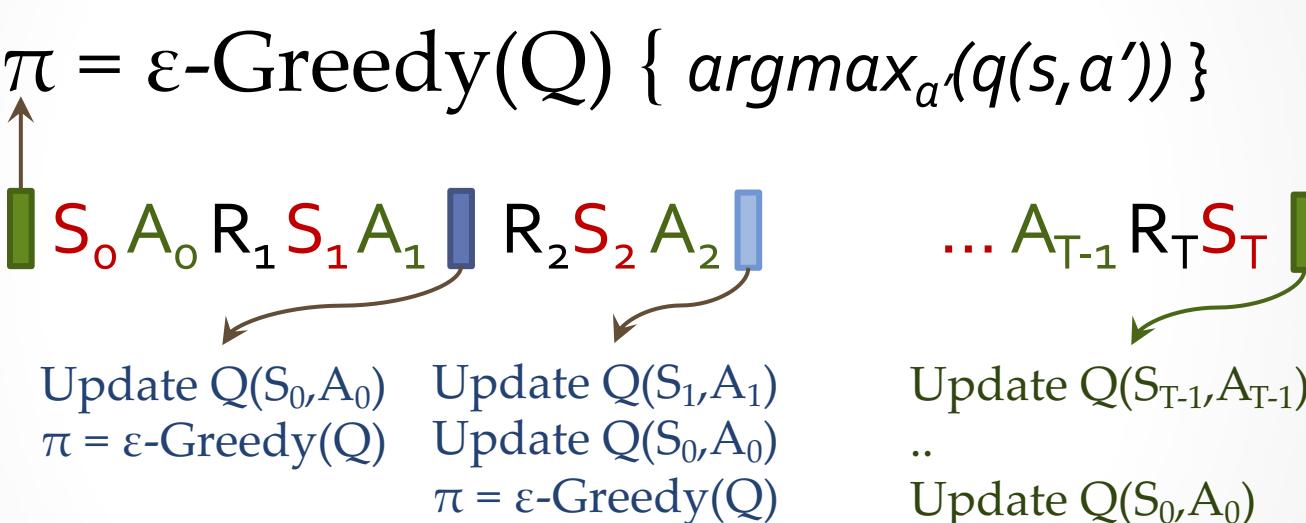
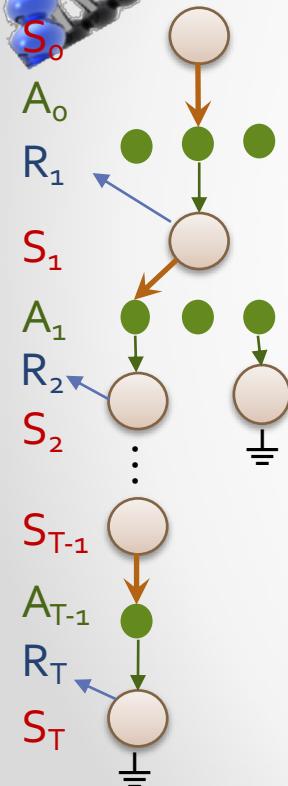
Driving Home Example

State	Elapsed Time (minutes)	Predicted Time to Go	Predicted Total Time
leaving office	0	30	30
reach car, raining	5	35	40
exit highway	20	15	35
behind truck	30	10	40
home street	40	3	43
arrive home	43	0	43



SARSA(0)

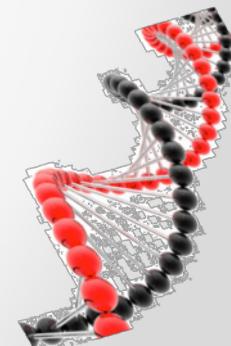
- Initialize $Q(s,a) \forall s \in \mathbb{S}, a \in \mathbb{A}$
- $\pi = \varepsilon\text{-Greedy}(Q) \{ \operatorname{argmax}_a(q(s,a')) \}$



Update Rule:

$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha(R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$$

A_{t+1} selected using $\varepsilon\text{-Greedy}(Q)$



Algorithm 13: Sarsa

Input: policy π , positive integer $num_episodes$, small positive fraction α , GLIE $\{\epsilon_i\}$

Output: value function Q ($\approx q_\pi$ if $num_episodes$ is large enough)

Initialize Q arbitrarily (e.g., $Q(s, a) = 0$ for all $s \in \mathcal{S}$ and $a \in \mathcal{A}(s)$, and $Q(terminal-state, \cdot) = 0$)

for $i \leftarrow 1$ **to** $num_episodes$ **do**

$\epsilon \leftarrow \epsilon_i$

 Observe S_0

 Choose action A_0 using policy derived from Q (e.g., ϵ -greedy)

$t \leftarrow 0$

repeat

 Take action A_t and observe R_{t+1}, S_{t+1}

 Choose action A_{t+1} using policy derived from Q (e.g., ϵ -greedy)

$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha(R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$

$t \leftarrow t + 1$

until S_t is terminal;

end

return Q



Q-Learning

SARSA Update Rule:

$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha (R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$$

$Q(S_{t+1}, A_{t+1})$: Selected using ϵ -Greedy(Q) for update

A_{t+1} : Selected using ϵ -Greedy(Q) for evaluation

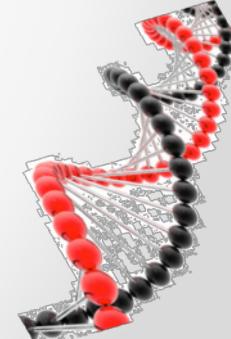
Q Learning Update Rule (SARSA_{max}):

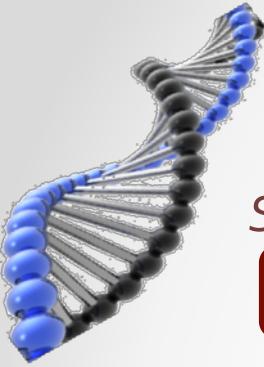
$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha (R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a) - Q(S_t, A_t))$$

$\max_{a \in \mathbb{A}} Q(S_{t+1}, a)$: Selected using Greedy(Q) for update

A_{t+1} : Selected using ϵ -Greedy(Q) for evaluation

- SARSA : Behavior = Target \mapsto On-Policy
- Q-Learning : Behavior \neq Target \mapsto Off-Policy
- *Learn Optimal policy while following exploratory policy*
- *Reuse data collected/Experience Replay/Prioritized Replay*





Q-Learning



SARSA Update Rule:

$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha (R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$$

$Q(S_{t+1}, A_{t+1})$: Selected using ϵ -Greedy(Q) for update

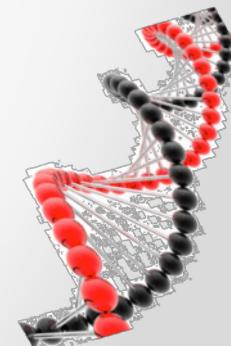
A_{t+1} : Selected using ϵ -Greedy(Q) for evaluation

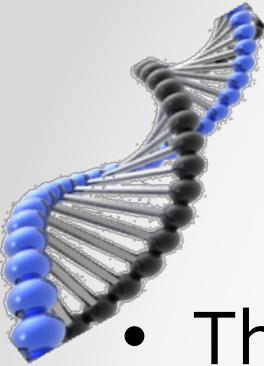
Q Learning Update Rule ($SARSA_{max}$):

$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha (R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a) - Q(S_t, A_t))$$

$\max_{a \in \mathbb{A}} Q(S_{t+1}, a)$: Selected using Greedy(Q) for update

A_{t+1} : Selected using ϵ -Greedy(Q) for evaluation

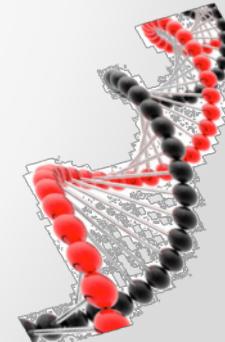
- SARSA : Behavior = Target \mapsto On-Policy
 - Q-Learning : Behavior \neq Target \mapsto Off-Policy
 - *Learn Optimal policy while following exploratory policy*
 - *Reuse data collected/Experience Replay/Prioritized Replay*
- 



Quiz



- This Algorithm implements TD(0)
 - What is ?
- Q-Learning in terms of SARSA
 - What is ?
- This algorithm learns the best exploratory policy
 - What is ?
- This algorithm learns the optimum policy
 - What is ?

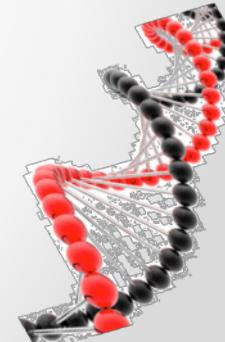




Quiz



- This Algorithm implements TD(0)
 - What is SARSA ?
- Q-Learning in terms of SARSA
 - What is $SARSA_{max}$?
- This algorithm learns the best exploratory policy
 - What is SARSA ?
- This algorithm learns the optimum policy
 - What is Q-Learning ?



Algorithm 14: Sarsamax (Q-Learning)

Input: policy π , positive integer num_episodes , small positive fraction α , GLIE $\{\epsilon_i\}$

Output: value function Q ($\approx q_\pi$ if num_episodes is large enough)

Initialize Q arbitrarily (e.g., $Q(s, a) = 0$ for all $s \in \mathcal{S}$ and $a \in \mathcal{A}(s)$, and $Q(\text{terminal-state}, \cdot) = 0$)

for $i \leftarrow 1$ **to** num_episodes **do**

$\epsilon \leftarrow \epsilon_i$

 Observe S_0

$t \leftarrow 0$

repeat

 Choose action A_t using policy derived from Q (e.g., ϵ -greedy)

 Take action A_t and observe R_{t+1}, S_{t+1}

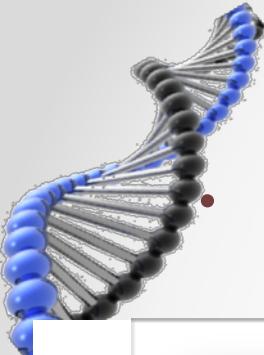
$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha(R_{t+1} + \gamma \max_a Q(S_{t+1}, a) - Q(S_t, A_t))$

$t \leftarrow t + 1$

until S_t is terminal;

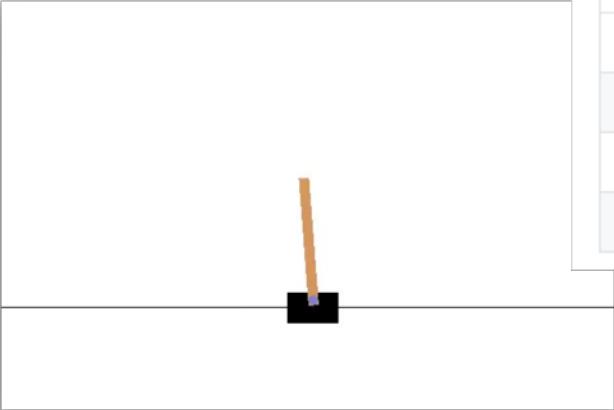
end

return Q



Introducing the CartPole

- Balance an Inverted Pendulum by applying force on the cart



Episode Termination

1. Pole Angle is more than $\pm 12^\circ$
2. Cart Position is more than ± 2.4 (center of the cart reaches the edge of the display)
3. Episode length is greater than 200

State: $\{x, \dot{x}, \theta, \dot{\theta}\}$

2 Discrete Actions: Apply force to cart left/right

Rewards: +1 for each step

Num	Observation	Min	Max
0	Cart Position	-2.4	2.4
1	Cart Velocity	-Inf	Inf
2	Pole Angle	$\sim -41.8^\circ$	$\sim 41.8^\circ$
3	Pole Velocity At Tip	-Inf	Inf

Num	Action
0	Push cart to the left
1	Push cart to the right

Solved after 211 episodes. Best 100-episode average reward was 195.27 ± 1.53. (CartPole-v0 is considered "solved" when the agent obtains an average reward of at least 195.0 over 100 consecutive episodes.)

Episodes to solve: 211 Total episodes: 500 Solved: ✓ Time to solve: 83s

[Download](#) [Tweet](#)

<https://gym.openai.com/envs/CartPole-v0/>
<https://github.com/openai/gym/wiki/CartPole-v0>

1

2

4

3



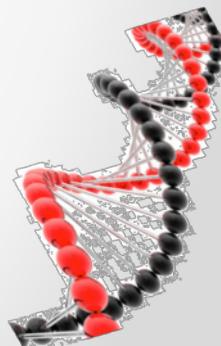
Hands On #4 – Q Learning

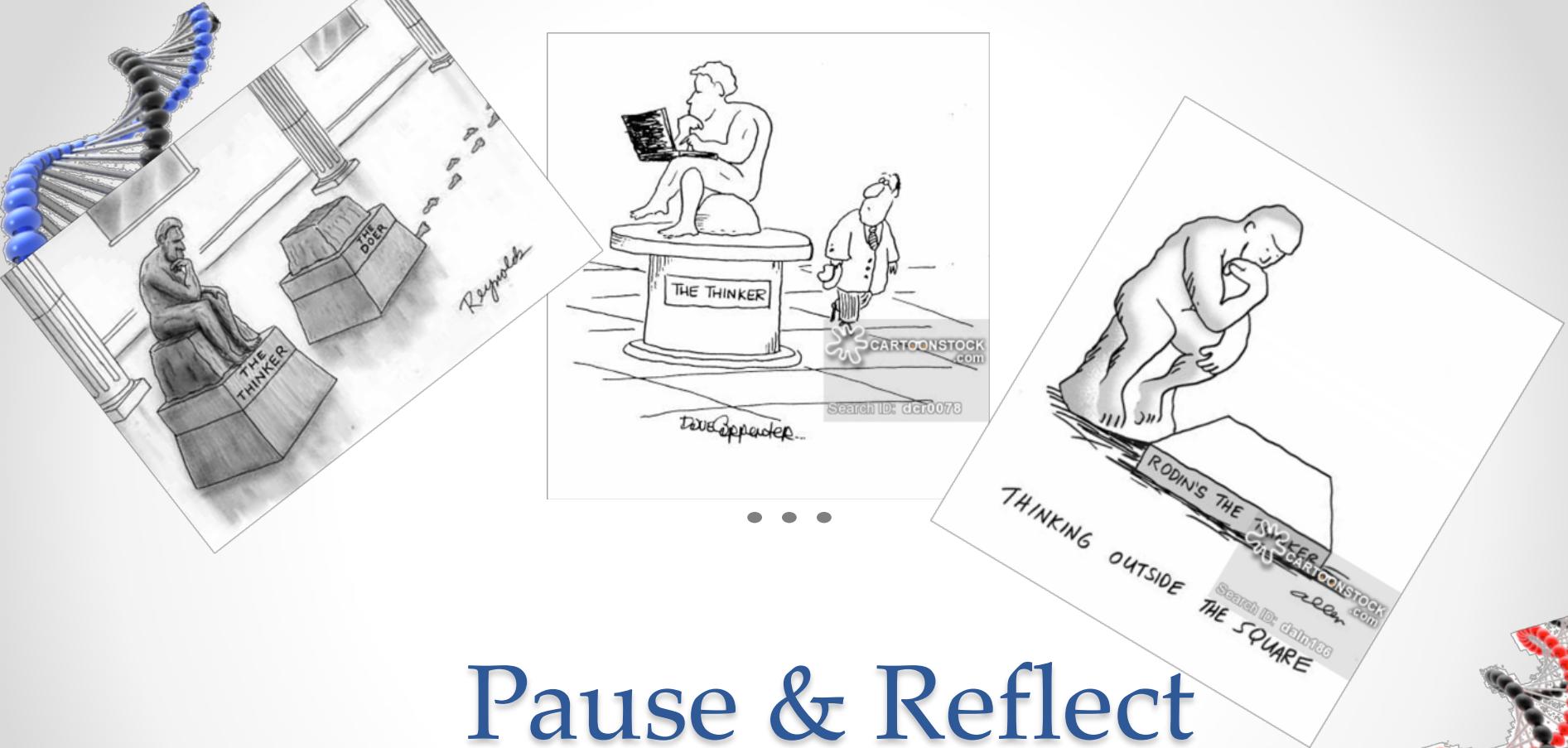
Goal:

- Introduce the CartPole Environment
 - *More complex, Continuous*
- Implement Q-Learning for digitized CartPole
 - *Later we will use function approximation & remove the requirement for digitization*

Steps:

1. Notebook : Q_Learning_01.ipynb
2. Get familiar with Cartpole environment
 - np.linspace() and np.digitize() for state space aggregation
3. Program Q Learning – 4 To Dos
4. Track & Plot Metrics to solve Cart Pole





Pause & Reflect

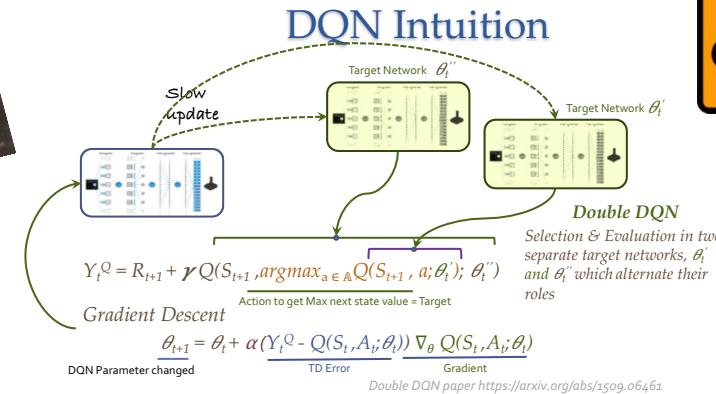


The Lab Continues Tomorrow 2:00-4:00

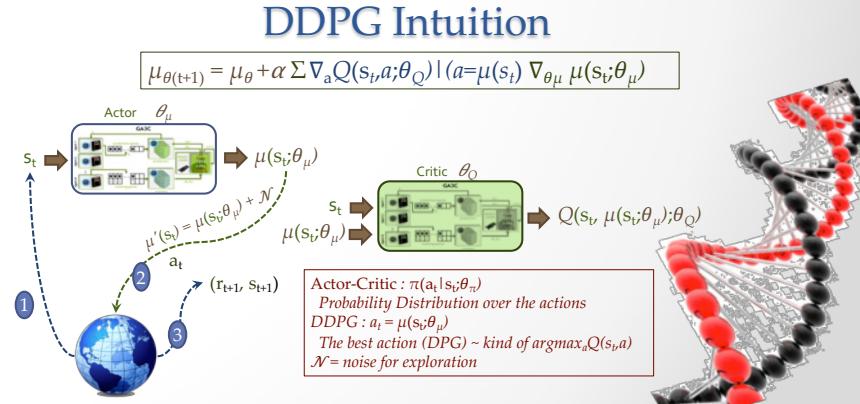
Down the DRL-Land

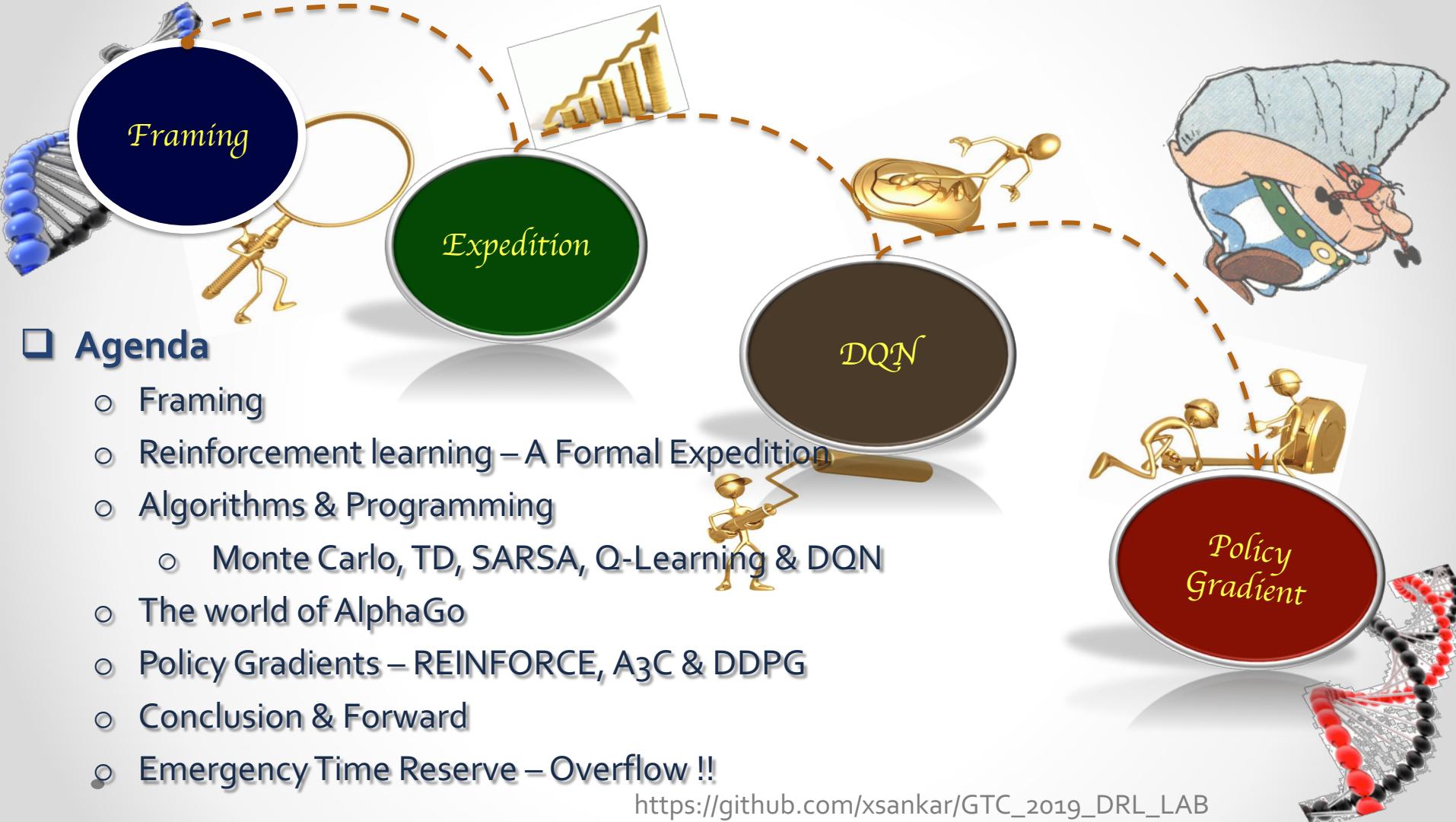


The world of α_{Go}



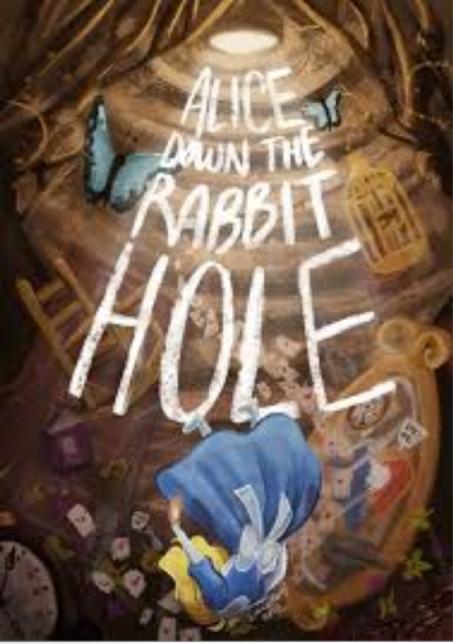
A detour – to DL machinery with *pytorch*



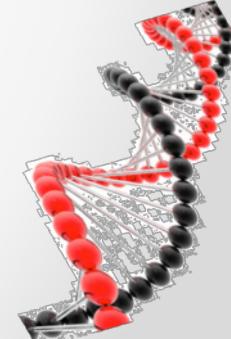


□ Agenda

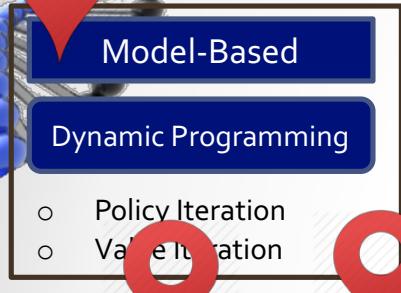
- Framing
- Reinforcement learning – A Formal Expedition
- Algorithms & Programming
 - Monte Carlo, TD, SARSA, Q-Learning & DQN
- The world of AlphaGo
- Policy Gradients – REINFORCE, A₃C & DDPG
- Conclusion & Forward
- Emergency Time Reserve – Overflow !!



Down the DRL-Land



RL Algorithm Taxonomy



Value Methods

SARSA

Q-Learning

Deep Q-Learning

- Fixed Q Targets
- Experience replay

- Double DQN
- Prioritized replay
- Dueling DQN

- Increase robustness*
- Reduce bias/variance*
- Sample efficiency*

RL \leftrightarrow DRL

Non-linear Function Approximation

- Hill Climbing
 - Steepest Hill Climbing
 - Cross-entropy
 - Evolution Strategies
- Random Restart
- Simulated Annealing
- Adaptive noise scaling

Policy Search

Policy Gradients

REINFORCE

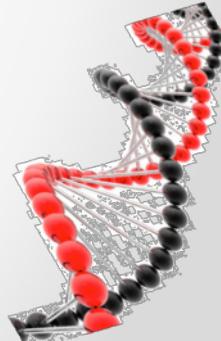
TRPO

PPO

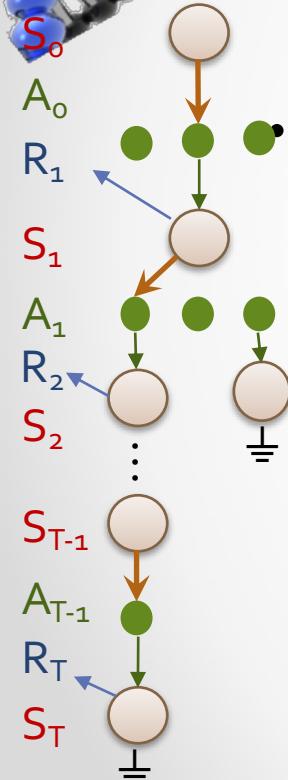
Actor-Critic

DDPG

- Why Policy Based ?
 - Simplicity
 - Stochastic Action Space
 - Rock-Paper-scissor
 - Continuous
 - Can output a # without exploring values in a continuous space
 - Aliased States



TD vs. MC



- MC : $Q(S_t, A_t) = Q(S_t, A_t) + \alpha(G_t - Q(S_t, A_t))$

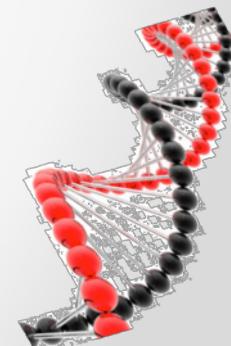
We observe from a full episode & update all

- TD : $Q(S_t, A_t) = Q(S_t, A_t) + \alpha(R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t))$

$\begin{array}{c} \text{TD Target} = \text{Alternate Estimate} \\ \text{Current Estimate} \end{array}$

TD Error

- TD Target
- TD Error
- At every timestep, so we have R_{t+1} not G_t
- We bootstrap $Q(S_{t+1}, A_{t+1})$, but as we take more steps and more episodes it all converges
- TD learns from incomplete episodes by bootstrapping
- TD lends itself to function approximation
 - And scale to large state space
- Remember, we must know S_{t+1} & select A_{t+1}
 - That is policy & more later



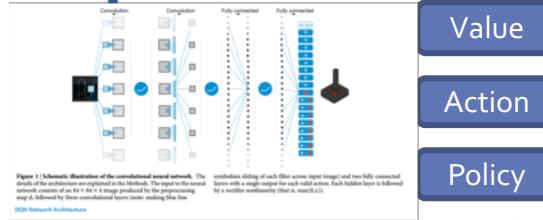


Deep Reinforcement Learning

- We have interesting algorithms, but they won't scale easily for large state spaces or for continuous state spaces
 - For example, GO has possibly 10^{170} states, more than the number of atoms in the observable universe (10^{80})
 - We want something that can sample and generalize; *that gets better with more data*
- Fortunately, Reinforcement Learning research has progressed so far that machines are able to win over Go world champions - 10 years ahead of the predicted timeframe !
 - Methodological breakthroughs in Deep Learning !!
- The latest DOTA 5 uses 120,000 CPUs & 256 GPUs to win over human players in a complex strategic game !



DeepRL Schematic



State

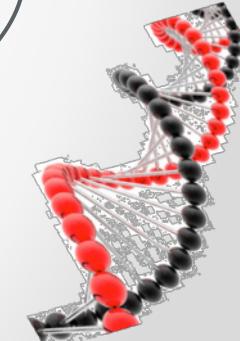
Reward

Agent

Actions

Environment

- We will first look at the simple mechanism
 - Replace our Q-Table with a function approximation ie a Neural Network, to make it work on the top of DL structures
 - Then we can get values, actions or even policies
 - Then we will look at extensions
 - And finally, we will see how these ideas scale to games with video frames, games like Go with huge state spaces and complex semantics



DQN Intuition

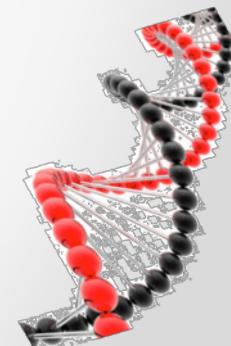
Q Learning Update Rule:

$$Q(S_t, A_t) = Q(S_t, A_t) + \alpha (R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a) - Q(S_t, A_t))$$

Deep Q Learning Update Rule:

$$Q(S_t, A_t; \theta_t) = Q(S_t, A_t; \theta_t) + \alpha (R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a; \theta_t) - Q(S_t, A_t; \theta_t))$$

Pl. note the direction
of the arrows



DQN Intuition

Deep Q Learning Update Rule:

$$Q(S_t, A_t; \theta_t) = Q(S_t, A_t; \theta_t) + \alpha (R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a; \theta_t) - Q(S_t, A_t; \theta_t))$$



$$Y_t = R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a; \theta_t)$$

Action to get Max next state value = Target

Gradient Descent

$$\theta_{t+1} = \theta_t + \alpha' \frac{(Y_t - Q(S_t, A_t; \theta_t))}{\text{TD Error}} \frac{\nabla_{\theta} Q(S_t, A_t; \theta_t)}{\text{Gradient}}$$

DQN Parameter changed

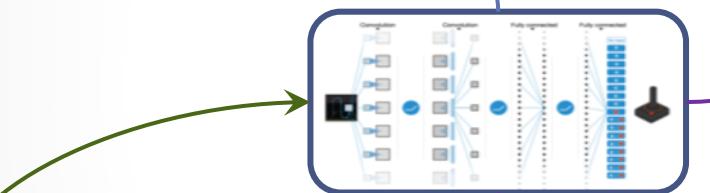
TD Error

Gradient

DQN Intuition

Deep Q Learning Update Rule:

$$Q(S_t, A_t; \theta_t) = Q(S_t, A_t; \theta_t) + \alpha (R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a; \theta_t) - Q(S_t, A_t; \theta_t))$$



$$Y_t = R_{t+1} + \gamma \max_{a \in \mathbb{A}} Q(S_{t+1}, a; \theta_t)$$

Action to get Max next state value = Target

Gradient Descent

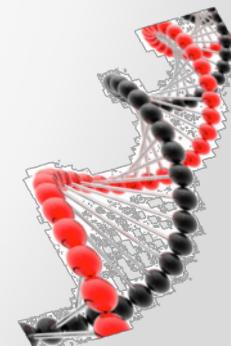
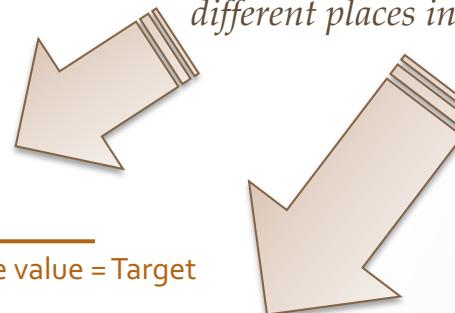
$$\theta_{t+1} = \theta_t - \alpha' \frac{(Y_t - Q(S_t, A_t; \theta_t))}{\text{TD Error}} \nabla_{\theta} Q(S_t, A_t; \theta_t)$$

DQN Parameter changed

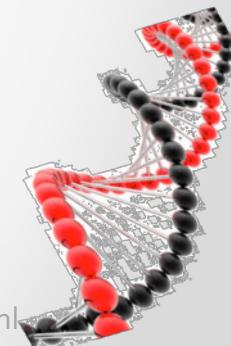
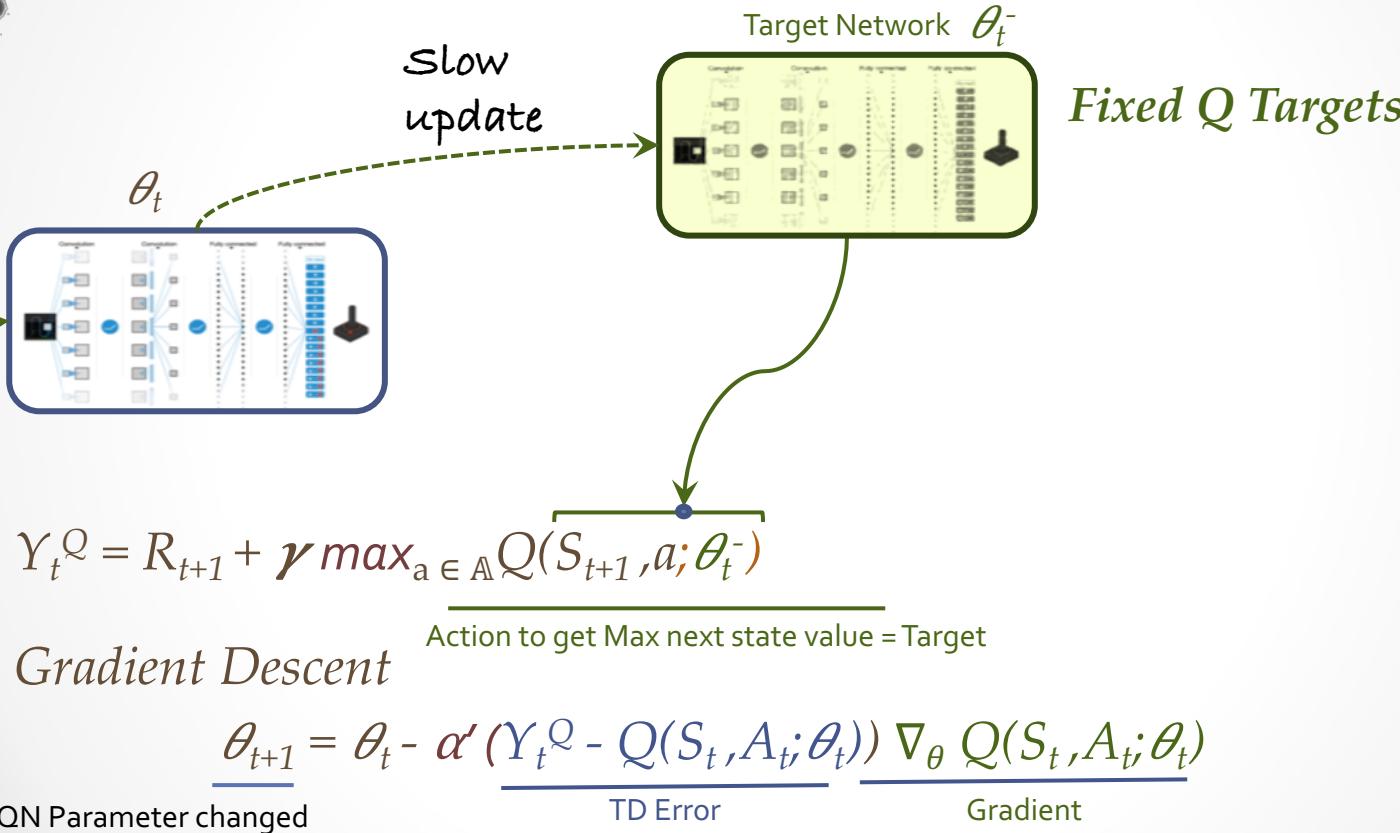
TD Error

Gradient

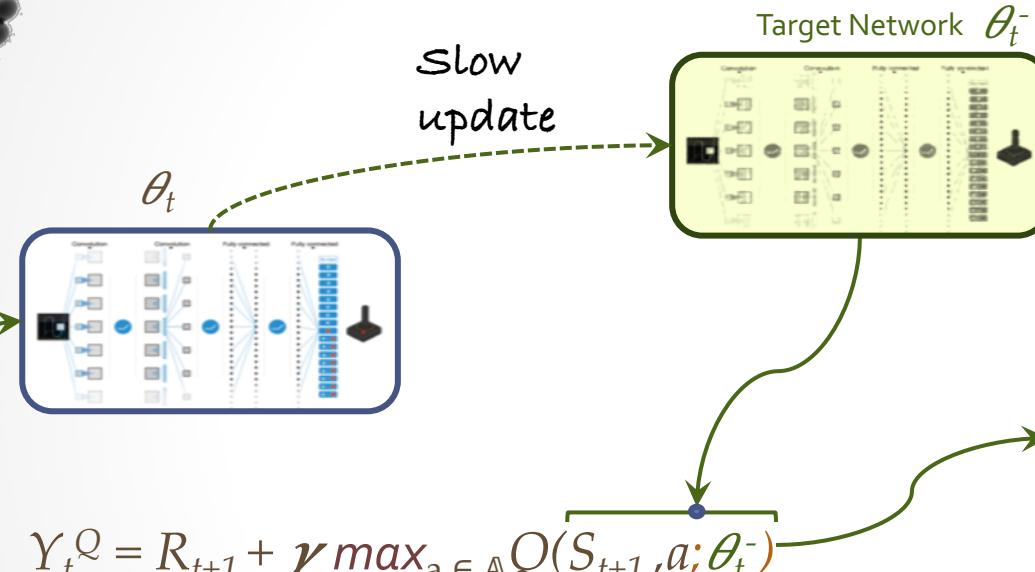
Constantly shifting values with the same parameters θ_t
“.. this approach can build large errors at different places in the state-action space ..”



DQN Intuition



DQN Intuition



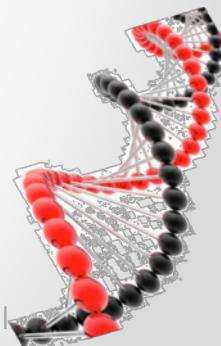
Gradient Descent

$$\underline{\theta_{t+1}} = \theta_t - \alpha' \frac{(Y_t^Q - Q(S_t, A_t; \theta_t))}{\text{TD Error}} \underline{\nabla_{\theta} Q(S_t, A_t; \theta_t)}$$

DQN Parameter changed

Fixed Q Targets

<https://arxiv.org/abs/1509.06461>
Over estimation (upward) Bias:
Over optimism w.r.t estimation errors - Selection & Evaluation with the same network θ_t^-
Solution : Double DQN



DQN Intuition



Slow update



Double DQN

Selection & Evaluation in two separate target networks, θ_t' and θ_t'' which alternate their roles

$$Y_t^Q = R_{t+1} + \gamma Q(S_{t+1}, \text{argmax}_{a \in \mathcal{A}} Q(S_{t+1}, a; \theta_t'); \theta_t'')$$

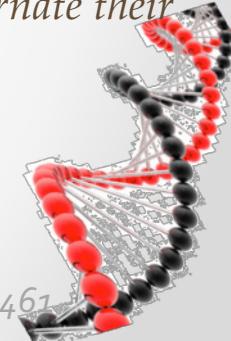
Action to get Max next state value = Target

Gradient Descent

$$\theta_{t+1} = \theta_t - \alpha' \frac{(Y_t^Q - Q(S_t, A_t; \theta_t))}{\text{TD Error}} \frac{\nabla_{\theta} Q(S_t, A_t; \theta_t)}{\text{Gradient}}$$

DQN Parameter changed

Double DQN paper <https://arxiv.org/abs/1509.06461>



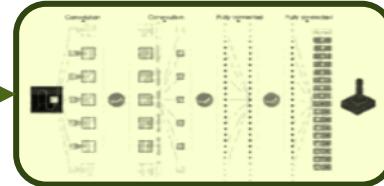
DQN Intuition



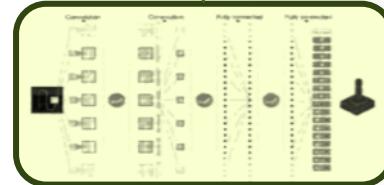
Slow update



Target Network θ_t''



Target Network θ_t'



Double DQN

Selection & Evaluation in two separate target networks, θ_t' and θ_t'' which alternate their roles

$$Y_t^Q = R_{t+1} + \gamma Q(S_{t+1}, \text{argmax}_{a \in \mathcal{A}} Q(S_{t+1}, a; \theta_t'); \theta_t'')$$

Action to get Max next state value = Target

Gradient Descent

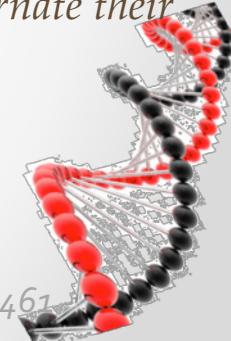
$$\theta_{t+1} = \theta_t - \alpha' (Y_t^Q - Q(S_t, A_t; \theta_t)) \nabla_{\theta} Q(S_t, A_t; \theta_t)$$

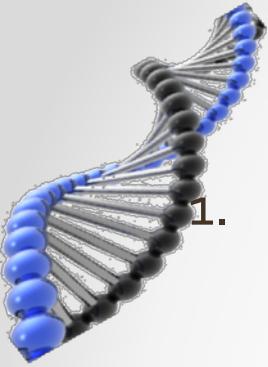
DQN Parameter changed

TD Error

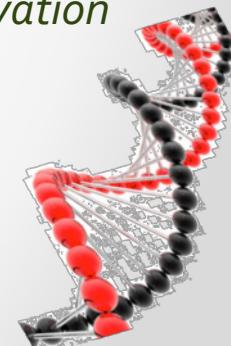
Gradient

Double DQN paper <https://arxiv.org/abs/1509.06461>





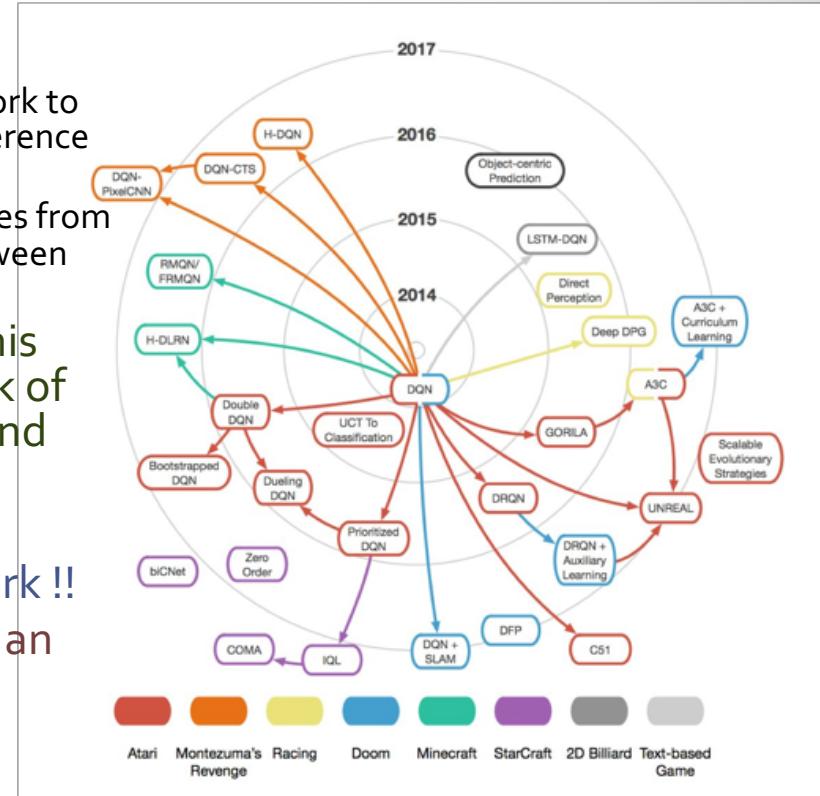
Experience Replay

1. Most optimization algorithms assume that the samples are independent & identically distributed(i.i.d).
 - Obviously, when the samples are generated from exploring sequentially in an environment this assumption no longer holds
 2. To make efficient use of hardware optimizations, it is essential to learn in minibatches, rather than online
- Solution : Experience Replay
 - Buffer the (s_t, a_t, r_t, s_{t+1}) tuple in a "*finite-sized circular cache*"
 - Sample a mini batch of appropriate size & train !
 - *"randomizes over the data, thereby removing correlations in the observation sequence and smoothing over changes in the data distribution"*
 - Decorrelate & Data efficiency
 - Prevent Catastrophic Forgetting
- 



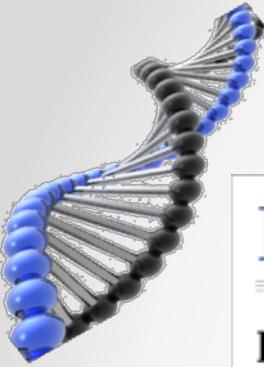
A word on the evolution

- DQN has two main innovations:
 1. The network is trained with a target Q network to give consistent targets during temporal difference backups
 2. The network is trained off-policy with samples from a replay buffer to minimize correlations between samples
- It looks a lot easier when we look from this side, but this is the result of a good chunk of research by David Silver, Volod, Dennis and team ...
- Am sure they spent tons of hours on mechanisms and schemes that didn't work !!
- And, I think, this work paved the way for an explosion of research and pragmatic applications based on Reinforcement Learning



<https://arxiv.org/abs/1708.07902>

<http://fzruniverse.life/2018/03/24/Modular-Architecture-for-Implementing-RL-Agent/>



Deep Q Networks

LETTER

doi:10.1038/nature14236

Human-level control through deep reinforcement learning

Volodymyr Mnih^{1*}, Koray Kavukcuoglu^{1*}, David Silver^{1*}, Andrei A. Rusu¹, Joel Veness¹, Marc G. Bellemare¹, Alex Graves¹, Martin Riedmiller¹, Andreas K. Fidjeland¹, Georg Ostrovski¹, Stig Petersen¹, Charles Beattie¹, Amir Sadik¹, Ioannis Antonoglou¹, Helen King¹, Dharshan Kumaran¹, Daan Wierstra¹, Shane Legg¹ & Demis Hassabis¹

- We tested this agent on the challenging domain of classic Atari 2600 games
- We demonstrate that the deep Q-network agent, receiving only the pixels and the game score as inputs, was able to achieve a professional human level across a set of 49 games
- *Same algorithm, network architecture and hyperparameters*



<https://storage.googleapis.com/deepmind-media/dqn/DQNNaturePaper.pdf>

https://eecs.wsu.edu/~taylorm/17_580/Yunshu_DQNpresentation_10102016.pdf

Input: the pixels and the game score
Output: Q action value function (from which we obtain a policy and select actions)

initialize replay memory D

initialize action-value function Q with random weight θ

initialize target action-value function \hat{Q} with weights $\theta^- = \theta$

for episode = 1 to M **do**

 initialize sequence $s_1 = \{x_1\}$ and preprocessed sequence $\phi_1 = \phi(s_1)$

for $t = 1$ to T **do**

 following ϵ -greedy policy, select $a_t = \begin{cases} \text{a random action} & \text{with probability } \epsilon \\ \arg \max_a Q(\phi(s_t), a; \theta) & \text{otherwise} \end{cases}$

 execute action a_t in emulator and observe reward r_t and image x_{t+1}

 set $s_{t+1} = s_t, a_t, x_{t+1}$ and preprocess $\phi_{t+1} = \phi(s_{t+1})$

 store transition $(\phi_t, a_t, r_t, \phi_{t+1})$ in D

 // experience replay

 sample random minibatch of transitions $(\phi_j, a_j, r_j, \phi_{j+1})$ from D

 set $y_j = \begin{cases} r_j & \text{if episode terminates at step } j + 1 \\ r_j + \gamma \max_{a'} \hat{Q}(\phi_{j+1}, a'; \theta^-) & \text{otherwise} \end{cases}$

 perform a gradient descent step on $(y_j - Q(\phi_j, a_j; \theta))^2$ w.r.t. the network parameter θ

 // periodic update of target network

 in every C steps, reset $\hat{Q} = Q$, i.e., set $\theta^- = \theta$

end

end

Sample

Learn

<https://arxiv.org/pdf/1810.06339.pdf>

Minh Paper : <https://arxiv.org/abs/1602.01783>

Algorithm 8: Deep Q-Network (DQN), adapted from Mnih et al. (2015)



UDACITY Explore ▾ Cata

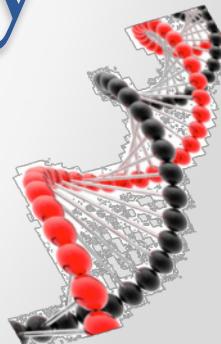
[Home](#) > [Catalog](#) > [Intro to Deep Learning with PyTorch](#)

FREE COURSE

Intro to Deep Learning
with PyTorch
by [facebook Artificial Intelligence](#)

Use PyTorch to implement your first deep neural network

A detour – to DL machinery
with *pytorch*



Introducing PYTORCH

Adam Paszke, Sam Gross, Soumith Chintala, Francisco Massa, Adam Lerer, James Bradbury, Gregory Chanan, Trevor Killeen, Zeming Lin, Natalia Gimelshein, Christian Sarofeen, Alban Desmaison, Andreas Kopf, Edward Yang, Zach Devito, Martin Raison, Alykhan Tejani, Sasank Chilamkurthy

• Origin <https://classroom.udacity.com/courses/ud188/>

- Started early, but matured at FAIR –
- Initially Soumith, Adam Paszke & Sam Gross
- slowly opened for “power users”
- Adopted by the “fun, long tail” (research) people, not the enterprise crowd ... so the core design is (more) research-friendly ... pythonic debugging capabilities
- But also is production-ready .. Function annotation ... IR export to C++ run-time or any other VM and so forth
- Hybrid frontend – parts of the model compiled – like the core RESNET, but leave the other parts not compiled
- JIT compiler – long term goal is to make the model faster leveraging hardware, optimizing fusing operations and so forth



- We exist!
- Launched Jan 2017
- An imperative programming model
- Eager evaluation (unlike Dynet which is lazy)
- Simplicity as a philosophy

- “Large part of pytorch live in C++
- Whatever user facing is in python ...”
- Giving it flexibility (“hackable”) and performance ...

PYTORCH

<http://pytorch.org>

Released Jan 2017

500,000+ downloads

2700+ community repos

17,200+ user posts

351 contributors

facebook



NVIDIA



ParisTech

Carnegie Mellon University

UNIVERSITE PARIS-Saclay, CURIE

Digital Reasoning

Stanford University

UNIVERSITY OF OXFORD

NYU

Inria

ENS

EPFL

Berkeley
UNIVERSITY OF CALIFORNIA

UBER



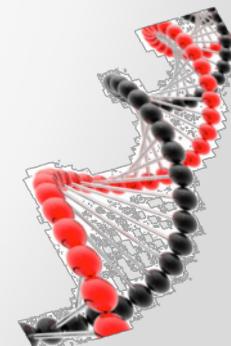
Code Review – pytorch DL Machinery

Goal:

- Get familiar with a basic pytorch neural network

Steps:

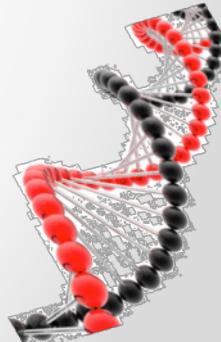
1. Define Network, loss & optimizer
2. Get Dataset - MNIST
3. Construct minibatch dataloader
4. Forward pass
5. Calculate error/loss
6. Do backprop
7. Update weights using Gradient Descent
8. Train & Test





pytorch DL Machinery

- Much simpler and easy to create a network
- Intuitive pythonic interface
- Things to keep in mind
 - Use with `torch.no_grad()` for inferencing
 - Disables autograd which is needed only for backpropagation
 - Use `model.eval()` for testing & inferencing
 - Disables dropout
 - Can enable dropout by `model.train()`
 - Do `optimizer.zero_grad()` to clear the gradient
 - To reset the accumulation of gradient – **very important !!**
 - Enabling GPU is easy and idiomatic
 - `device = torch.device("cuda" if torch.cuda.is_available() else "cpu")`
 - ..
 - `model.to(device)` **<- Move model to GPU**
 - ..
 - `inputs, labels = inputs.to(device), labels.to(device)` **<- Move data to GPU**
 - ..





Hands On #5 – Deep Q Learning

Goal:

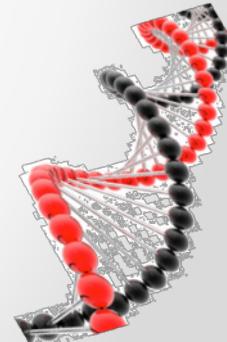
- Implement Deep Q-Learning for CartPole
 - No digitization
 - Handle continuous state

Steps:

1. Notebook : DQN_o1.ipynb
2. Understand the Deep Q Learning Code
3. Understand DNN implementation in pytorch
4. Metrics to solve Cart Pole
5. Plot Values
6. Answer the quiz in next page



“Confidence is recursive ! You have to come thru a few times to be certain and confident that you can beat it !”



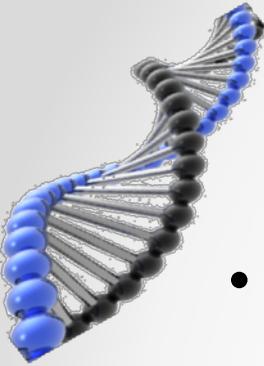


Quiz



- What is the DQN DNN topology ?
 -
- What is the input size ? Output size ?
 -
- How does the output translate to an action ?
 -
- How is the target network updated ?
 -
- Did it solve the environment ?
 -
- Can it be tuned to solve with lesser number of steps ?
 -

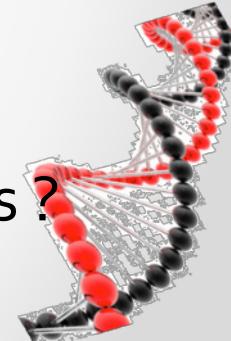


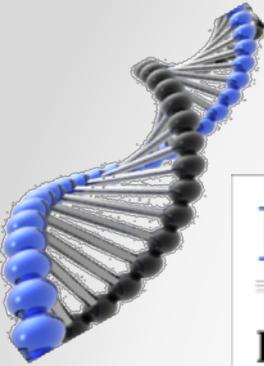


Quiz



- What is the DQN DNN topology ?
 - FC16-FC2
- What is the input size ? Output size ?
 - Input = 4 (state), output = 2 (actions) – *notice that we get all actions in one shot!*
- How does the output translate to an action ?
 - np.argmax(action_values,...)
- How is the target network updated ?
 - Soft_update with $\tau=0.001$
- Did it solve the environment ?
 - Yep, in ~ 3300 steps, with a particular set of hyperparameters
- Can it be tuned to solve with lesser number of steps ?
 - May be, probably, approximately definitely !





Deep Q Networks

LETTER

doi:10.1038/nature14236

Human-level control through deep reinforcement learning

Volodymyr Mnih^{1*}, Koray Kavukcuoglu^{1*}, David Silver^{1*}, Andrei A. Rusu¹, Joel Veness¹, Marc G. Bellemare¹, Alex Graves¹, Martin Riedmiller¹, Andreas K. Fidjeland¹, Georg Ostrovski¹, Stig Petersen¹, Charles Beattie¹, Amir Sadik¹, Ioannis Antonoglou¹, Helen King¹, Dharshan Kumaran¹, Daan Wierstra¹, Shane Legg¹ & Demis Hassabis¹

- Hyperparameters
 - Minibatch size = 32
 - Replay buffer = 1 Million
 - Agent history = 4 frames
 - Target Network update frequency = 10,000
 - ϵ = 1 to 0.1 ; linearly annealed in 1 million steps



<https://storage.googleapis.com/deepmind-media/dqn/DQNNaturePaper.pdf>
https://eecs.wsu.edu/~taylorm/17_580/Yunshu_DQNpresentation_10102016.pdf



Deep Q Learning - Extensions

Fixed Q Targets – improve stability with Target Networks

- “an iterative update that adjusts the action-values (Q) towards target values that are only periodically updated, thereby reducing correlations with the target”

- TD Error clipping to $[-1,1]$

- Experience replay

- “randomizes over the data, thereby removing correlations in the observation sequence and smoothing over changes in the data distribution”
- Decorrelate & Data efficiency
- Prevent Catastrophic Forgetting

- Prioritized replay

- Pay more attention to interesting experience
- Replying more often transitions from which there is more to learn

- Double DQN

- Dueling DQN

- Noisy nets - add parametric noises to network weights (we will see this later)

- Without ϵ -greedy - “Adding noise to a deep network is often equivalent or better than adding noise to an action like that in the ϵ -greedy method”

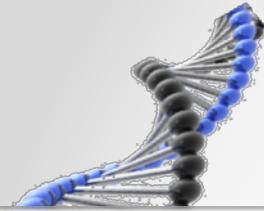
- Rainbow

- To address challenges robustness & stability
- Increase robustness, reduce bias/variance, sample efficiency
- The Integrated Agent – Rainbow !! <https://arxiv.org/abs/1710.02298>

- Another interesting paper : <https://medium.freecodecamp.org/improvements-in-deep-q-learning-dueling-double-dqn-prioritized-experience-replay-and-fixed-58b130cc5682>

- Homework : Can Rainbow solve Pong ? Breakout ?



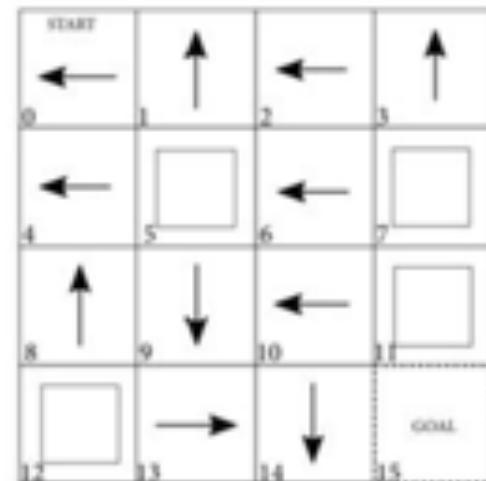


Hands On #6 – Skating slippery Frozen Lake with DQN

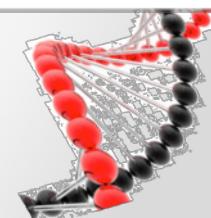
Yes, this is Frozen Lake's optimal policy!

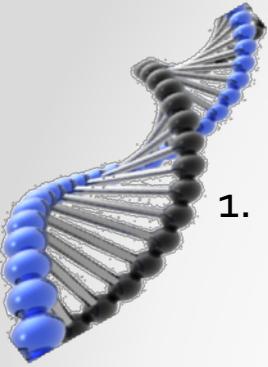
And I wish you at least question the validity of it. How is it possible that in state 14 the optimal action is to go DOWN? Shouldn't it be RIGHT?

Since the Frozen Lake environment stochasticity is so large, it makes it a great example to illustrate the difficulty of sequential decision making under uncertainty of action effects. The fact is, the RIGHT action would send us to state 10, 14 or 15 with equal probability. While DOWN would send us to state 13, 14 or 15. If you think about it, state 13 is preferred to 10 because we can only get to state 15 safely going LEFT in 10, DOWN in 9, RIGHT in 13 and DOWN in 14. On the other hand, going DOWN in state 14 keeps us only a few steps away from 15 regardless of where the environment sends us.

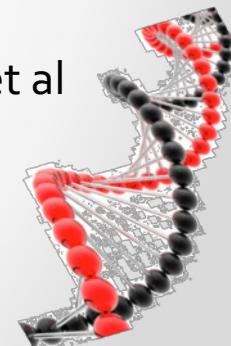


*Homework : See if DQN-Rainbow finds this policy
Compare with DDPG*



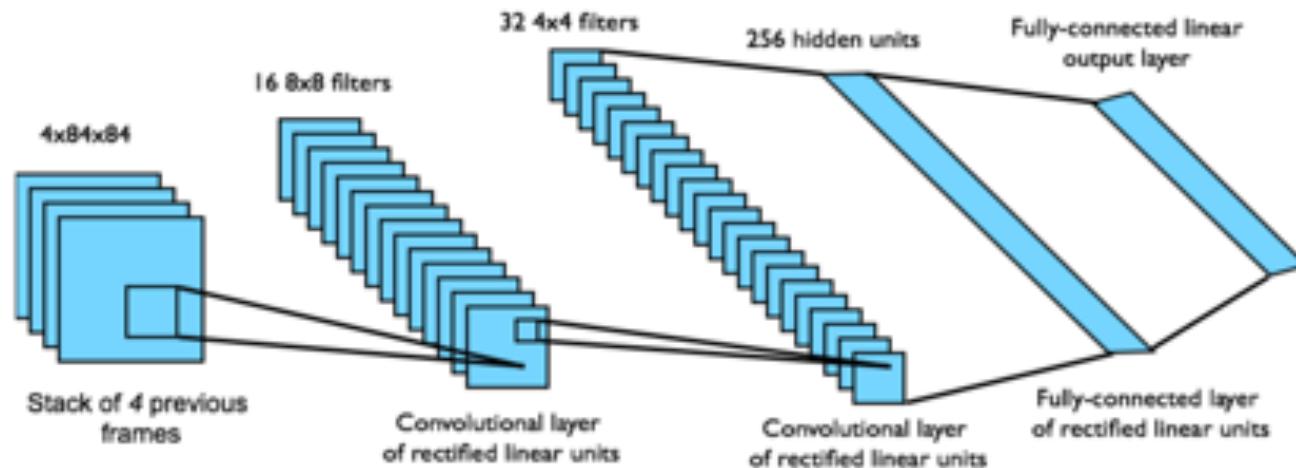


References

1. Human Level Control Through Deep Reinforcement Learning, Volodymyr Mnih et al <https://deepmind.com/research/publications/human-level-control-through-deep-reinforcement-learning/>
 - o *We demonstrate that the deep Q-network agent, receiving only the pixels and the game score as inputs, was able to surpass the performance of all previous algorithms and achieve a level comparable to that of a professional human games tester across a set of 49 games, using the same algorithm, network architecture and hyperparameters*
 2. Neural Fitted Q Iteration by Martin Riedmiller et al
 - o <https://qiita.com/Rowing0914/items/3d1b9a6ad4feoa53cf5b>
 3. Deep Reinforcement Learning with Double Q-learning by Hado van Hasselt, Arthur Guez, David Silver
 - o <https://arxiv.org/abs/1509.06461>
 4. Prioritized Experience Replay by Tom Schaul, John Quan, Ioannis Antonoglou, David Silver
 - o <https://arxiv.org/abs/1511.05952>
 5. A Brief Survey of Deep Reinforcement Learning by Kai Arulkumaran et al
 - o <https://arxiv.org/abs/1708.05866>
- 

DQN in Atari

- End-to-end learning of values $Q(s, a)$ from pixels s
- Input state s is stack of raw pixels from last 4 frames
- Output is $Q(s, a)$ for 18 joystick/button positions
- Reward is change in score for that step



Network architecture and hyperparameters fixed across all games

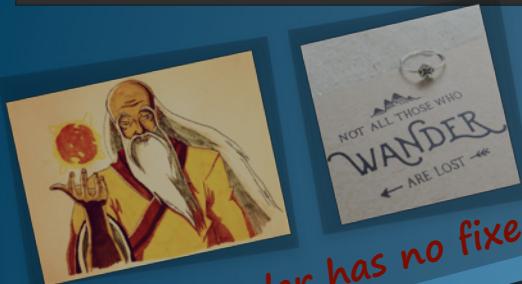


GPU TECHNOLOGY CONFERENCE

AGENDA ▾ ATTEND ▾ PRESENT ▾ EXHIBIT ▾ MORE ▾

SILICON VALLEY ▾

WORKSHOPS MARCH 17, 2019 | CONFERENCE MARCH 18-21, 2019



"A good traveler has no fixed plans and is not intent on arriving." - Lao Tzu

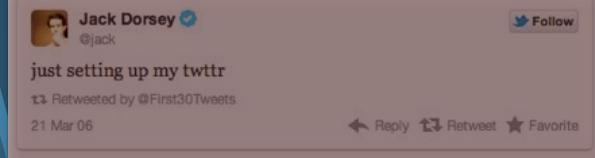
Demystifying Deep Reinforcement Learning – Part 2 : Policy Gradients

All observations are my own & do not represent my employer's or anyone else's

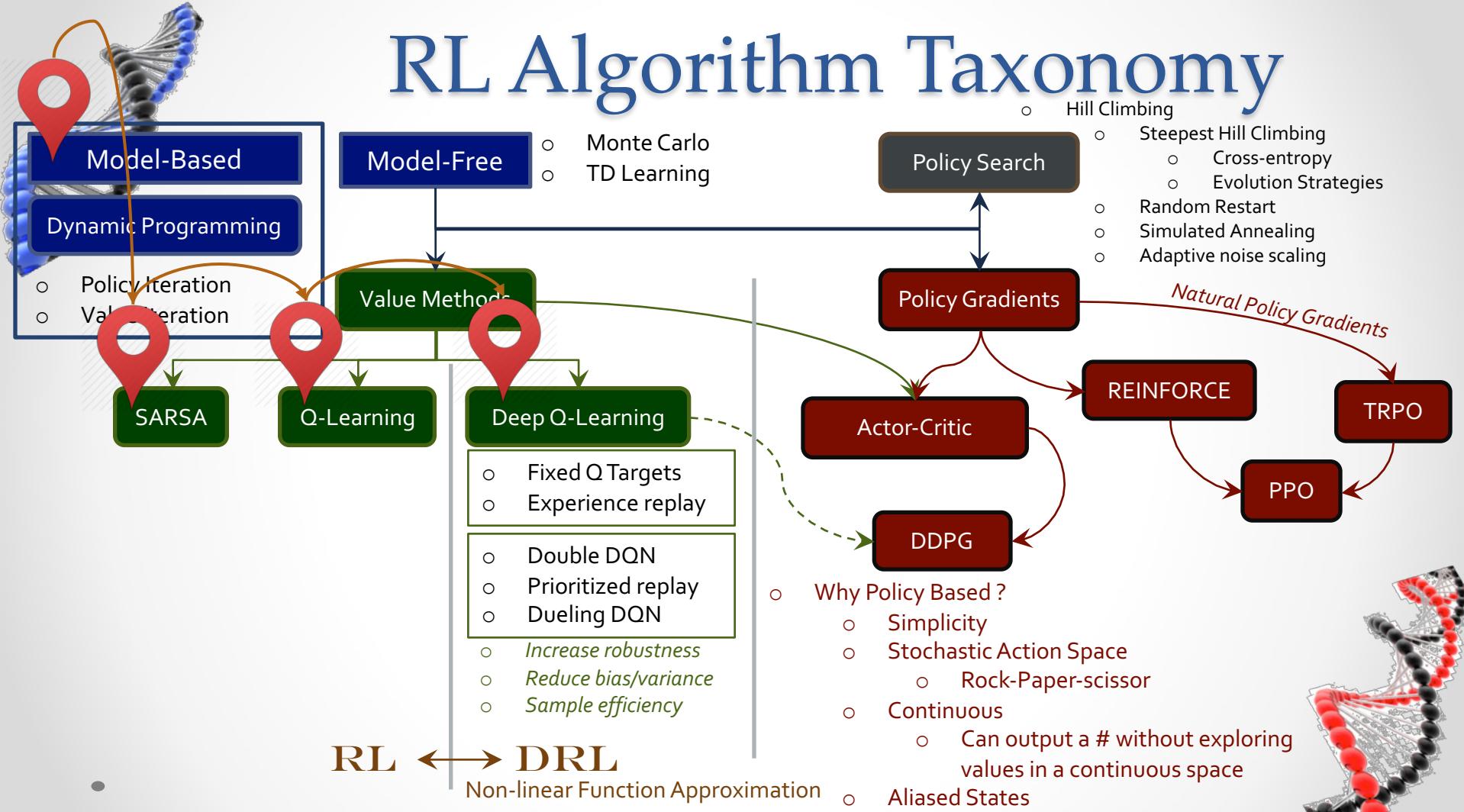
krishna sankar
@ksankar

“ I WOULD LIKE
TO DIE
ON MARS.
JUST NOT ON IMPACT ”

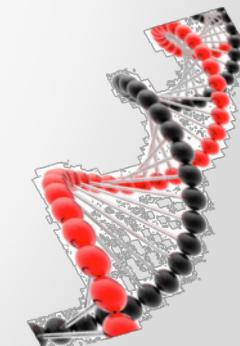
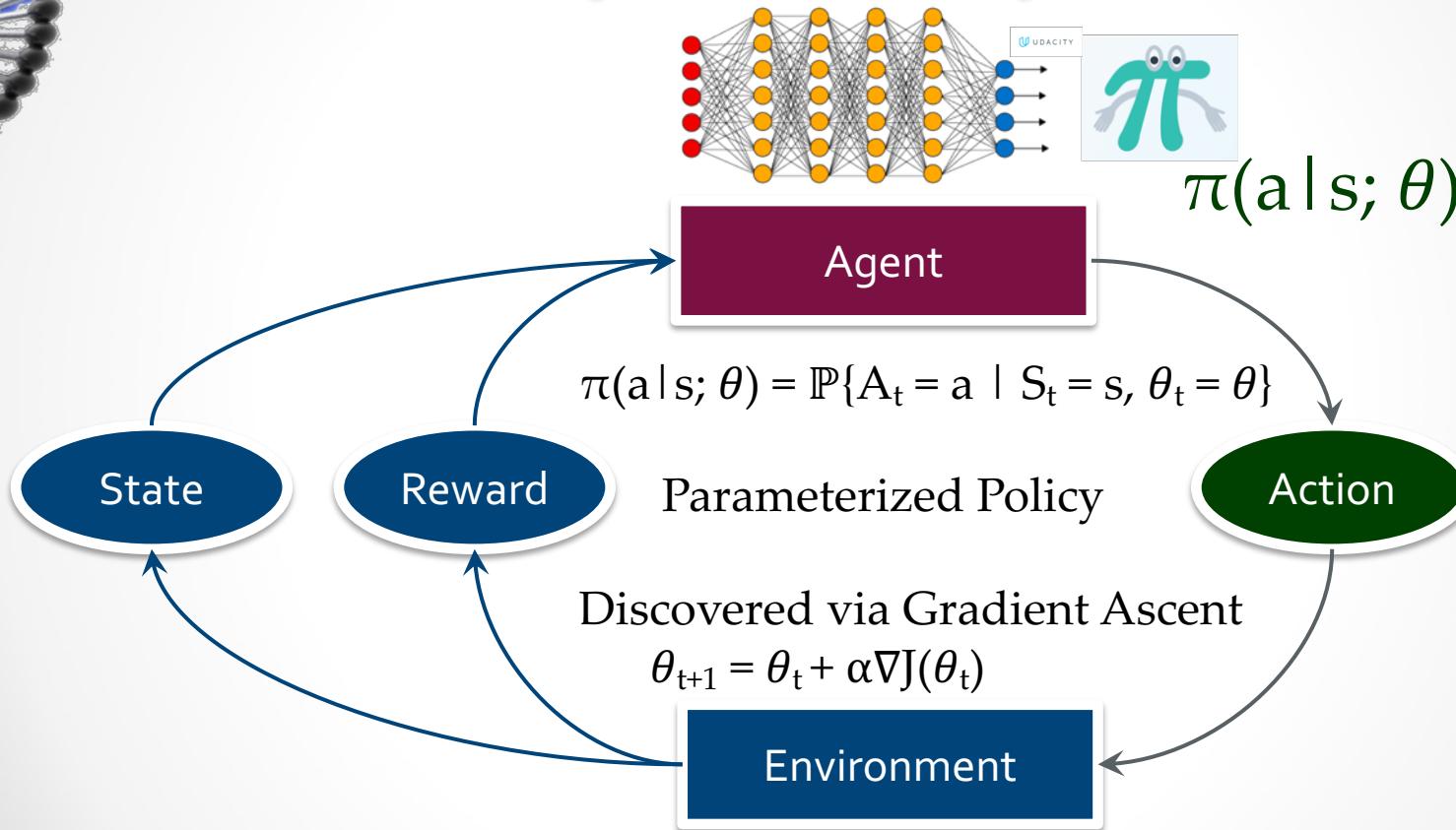
- ELON MUSK -



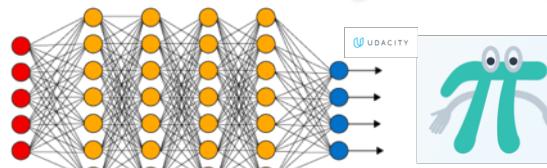
RL Algorithm Taxonomy



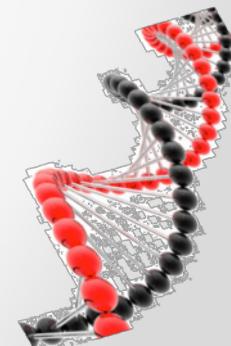
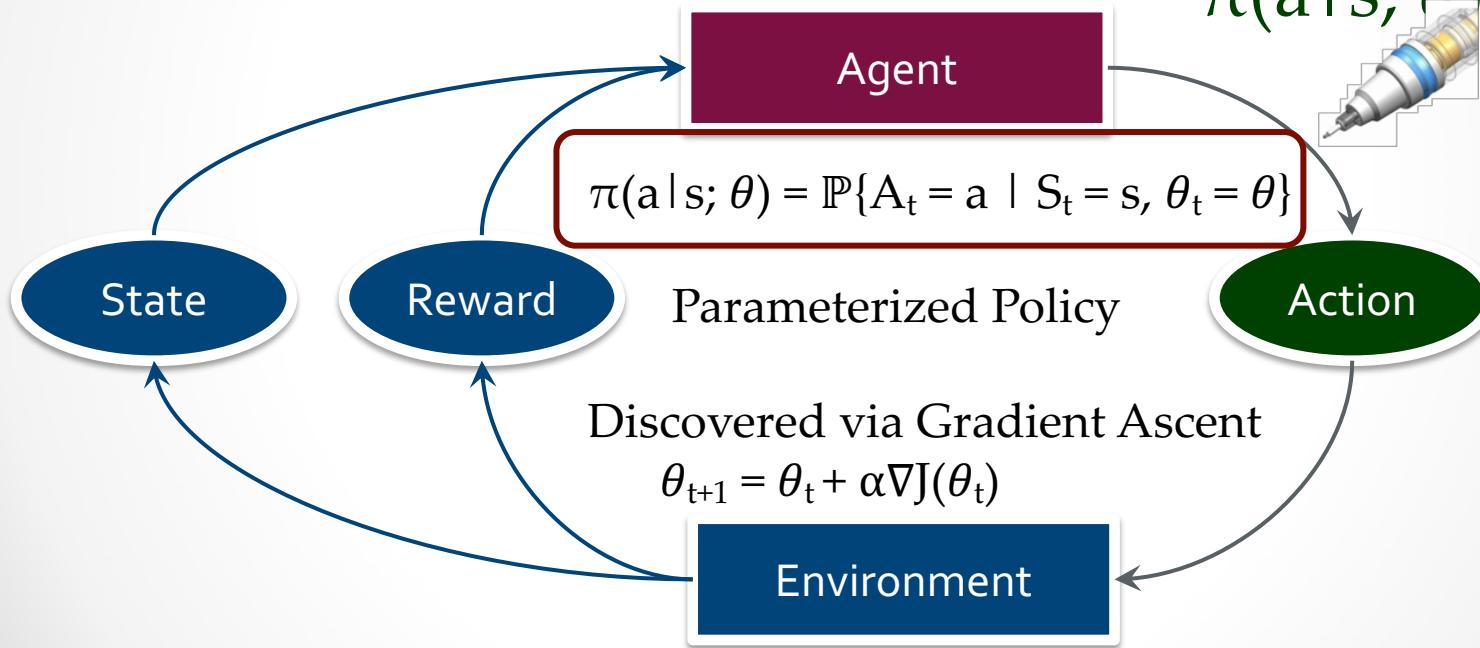
Policy in Policy Gradient



Policy in Policy Gradient



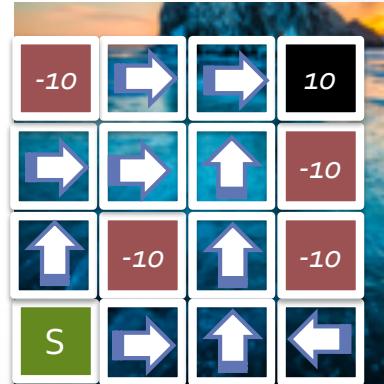
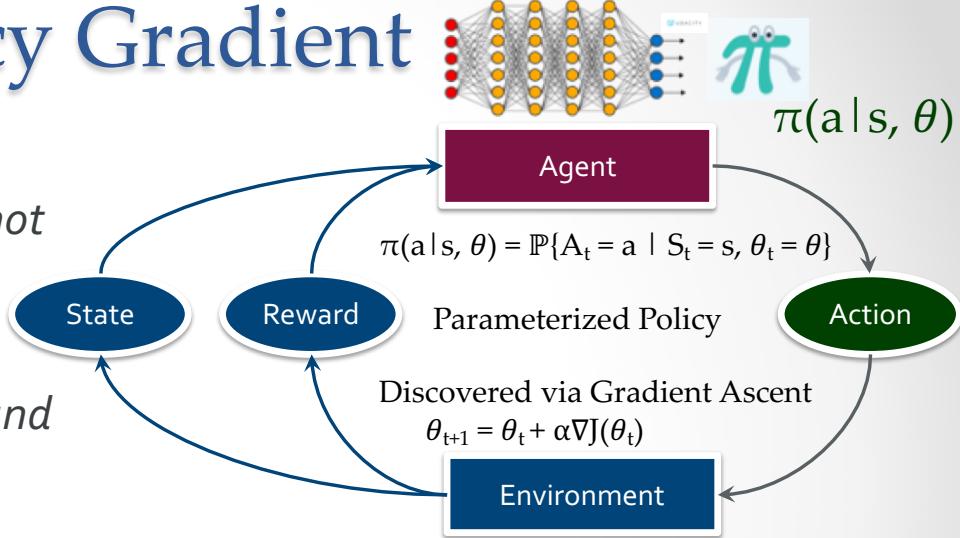
$$\pi(a|s; \theta)$$

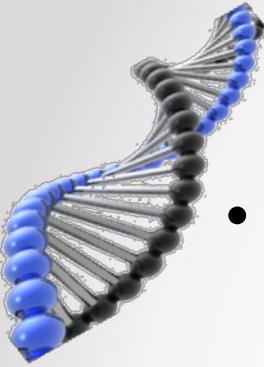




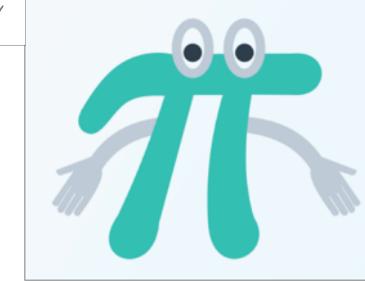
Policy in Policy Gradient

- All methods that follow this general schema we call policy gradient methods, whether or not they also learn an approximate value function.
- Methods that learn approximations to both policy and value functions are often called actor-critic methods
- Stochastic Policy $\pi(a|s; \theta) = \mathbb{P}\{a|s; \theta\}$
 - e.g. Softmax
 - Probability - A degree of belief (i.e. Credence), a subjective assessment of how much I can predict an event, given the knowledge I currently possess. Bayesian prior-ish !
- Deterministic Policy $\pi : s \mapsto a$
 - Our 1st exercise was a symbolic deterministic policy injecting domain knowledge

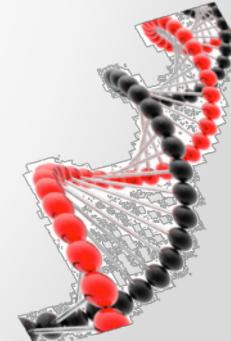


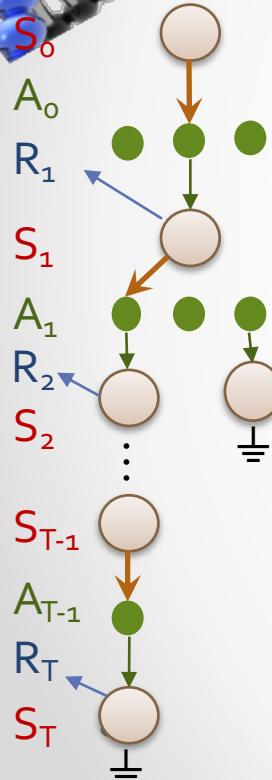


Policy Gradients

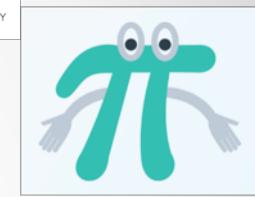


- Why Policy Gradients
 - Compact Representation
 - Better Convergence properties
 - Can handle Continuous space
 - Better for High Dimensional space
 - Stochastic Policies (rock-paper-scissor !)
 - Aliased States (Using uniform Stochastic Policy)
 - Simple
 - Enables the agent to devise robust strategies for navigating the environment directly (e.g. Left or Right)
- Challenges
 - Susceptible to converging to local minima
 - High Variance

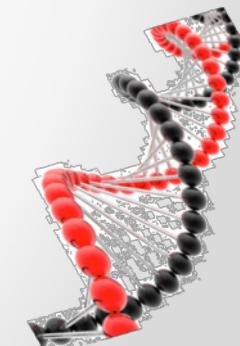


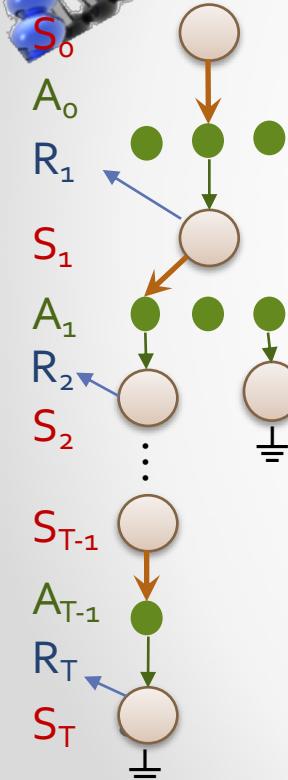


Policy Gradients - Nomenclature

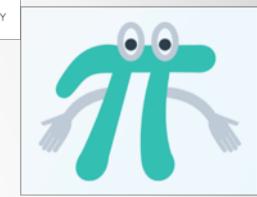


- Trajectory τ over a horizon H
 - $S_0 A_0 R_1 S_1 A_1 R_2 S_2 \dots A_{H-1} R_H S_H$
- Reward $R(\tau)$
 - $R(\tau) = \sum_{t=0 \text{ to } H} R(s_t, a_t)$
- Trajectory can be an episode ($H=T$), but doesn't dictate it





Policy Gradients - Nomenclature



- Trajectory τ over a horizon H

- $S_0 A_0 R_1 S_1 A_1 R_2 S_2 \dots A_{H-1} R_H S_H$

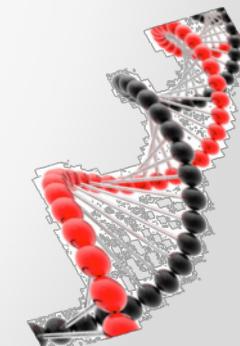


- Reward $R(\tau)$

- $$R(\tau) = \sum_{t=0 \text{ to } H} R(s_t, a_t)$$

This is the G_t we are used to.
Some literature calls it R_τ

- Trajectory can be an episode ($H=T$), but doesn't dictate it





Unrolling the Math

- Expected Return

$$U_{\theta} = \mathbb{E}[\sum_{t=0 \text{ to } \tau} R(s_t, a_t); \pi(\theta)] = \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau) \dots \text{some literature calls it } J_{\theta}$$

- Goal : Maximize J_{θ}

$$\max_{\theta}(U_{\theta}) = \max_{\theta} \{ \mathbb{E}[\sum_{t=0 \text{ to } \tau} R(s_t, a_t); \pi(\theta)] \} = \max_{\theta} \{ \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau) \}$$

- Likelyhood Ratio Method

- Forms the foundation for Policy Gradients, e.g. REINFORCE
- In essence, it means our policy makes some trajectories more likely to happen than others
 - With weighting those returns from those trajectories by the probability that they actually take place





Unrolling the Math



- Expected Return

$$U_{\theta} = \mathbb{E}[\sum_{t=0 \text{ to } \tau} R(s_t, a_t); \pi(\theta)] = \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau)$$

... some literature calls it J_{θ}

- Goal : Maximize J_{θ}

$$\max_{\theta}(U_{\theta}) = \max_{\theta} \{ \mathbb{E}[\sum_{t=0 \text{ to } \tau} R(s_t, a_t); \pi(\theta)] \} = \max_{\theta} \{ \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau) \}$$

- Likelyhood Ratio Method

- Forms the foundation for Policy Gradients, e.g. REINFORCE
- In essence, it means our policy makes some trajectories more likely to happen than others
 - With weighting those returns from those trajectories by the probability that they actually take place





Likelyhood Policy Gradient

$$\max_{\theta} U(\theta) = \max_{\theta} \{ \mathbb{E} [\sum_{t=0 \text{ to } T} R(s_t, a_t); \pi(\theta)] \} = \max_{\theta} \{ \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau) \}$$

Discovered via Gradient Ascent : $\theta_{t+1} = \theta_t + \alpha \nabla U(\theta_t)$

$$\nabla_{\theta} U(\theta) = \nabla_{\theta} \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau)$$

$$= \sum_{\tau} \nabla_{\theta} \mathbb{P}(\tau; \theta) R(\tau)$$

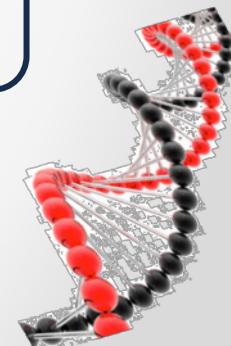
$$= \sum_{\tau} \frac{\mathbb{P}(\tau; \theta)}{\mathbb{P}(\tau; \theta)} \nabla_{\theta} \mathbb{P}(\tau; \theta) R(\tau)$$

$$= \sum_{\tau} \mathbb{P}(\tau; \theta) \frac{\nabla_{\theta} \mathbb{P}(\tau; \theta)}{\mathbb{P}(\tau; \theta)} R(\tau)$$

Def:

$$\nabla_x \log f(x) = \frac{\nabla_{\theta} f(x)}{f(x)}$$

$$\nabla_{\theta} U(\theta) = \sum_{\tau} \mathbb{P}(\tau; \theta) \nabla_{\theta} \log \mathbb{P}(\tau; \theta) R(\tau)$$





Likelyhood Policy Gradient

$$\max_{\theta} U(\theta) = \max_{\theta} \{ \mathbb{E} [\sum_{t=0 \text{ to } T} R(s_t, a_t); \pi(\theta)] \} = \max_{\theta} \{ \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau) \}$$

Discovered via Gradient Ascent : $\theta_{t+1} = \theta_t + \alpha \nabla U(\theta_t)$

$$\nabla_{\theta} U(\theta) = \nabla_{\theta} \sum_{\tau} \mathbb{P}(\tau; \theta) R(\tau)$$

$$= \sum_{\tau} \nabla_{\theta} \mathbb{P}(\tau; \theta) R(\tau)$$

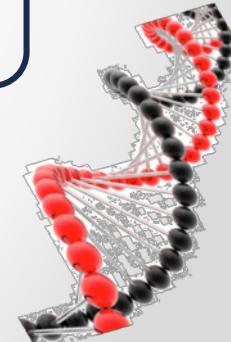
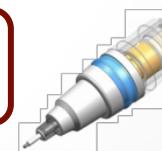
$$= \sum_{\tau} \frac{\mathbb{P}(\tau; \theta)}{\mathbb{P}(\tau; \theta)} \nabla_{\theta} \mathbb{P}(\tau; \theta) R(\tau)$$

$$= \sum_{\tau} \mathbb{P}(\tau; \theta) \frac{\nabla_{\theta} \mathbb{P}(\tau; \theta)}{\mathbb{P}(\tau; \theta)} R(\tau)$$

Def:

$$\nabla_x \log f(x) = \frac{\nabla_{\theta} f(x)}{f(x)}$$

$$\nabla_{\theta} U(\theta) = \sum_{\tau} \mathbb{P}(\tau; \theta) \nabla_{\theta} \log \mathbb{P}(\tau; \theta) R(\tau)$$





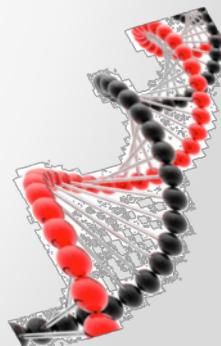
Likelyhood Policy Gradient

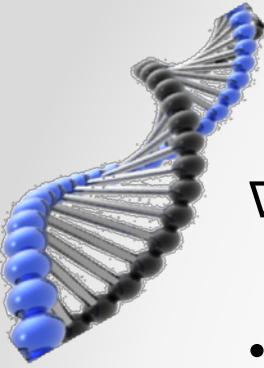
$$\nabla_{\theta} U(\theta) = \sum_{\tau} \mathbb{P}(\tau; \theta) \nabla_{\theta} \log \mathbb{P}(\tau; \theta) R(\tau)$$

Now we can perturb our parameter space θ and it will ascend or descend depending on $R(\tau)$

But we have 2 problems:

1. We don't have probabilities in terms of trajectories;
we have states and actions !
2. We assume infinite trajectories; not feasible for mere mortals
 - *Even though OpenAI 5 is using 120,000 CPUs and 256 GPUs,
learning the equivalent of 180 years of play per day !*



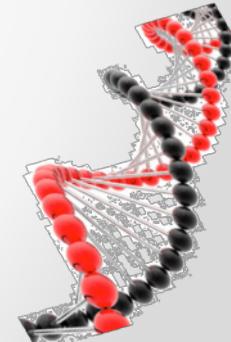


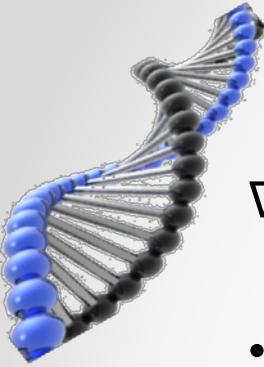
Unrolling the Math

$$\nabla_{\theta} U(\theta) = \sum_{\tau} \mathbb{P}(\tau; \theta) \nabla_{\theta} \log \mathbb{P}(\tau; \theta) R(\tau)$$

- Considering all possible trajectories is an impossible task.
- While in the math world, we can imagine as elegant as possible.
- ... But, down in the real world, we estimate empirically by sampling m trajectories(paths) under π_{θ} and average

$$\nabla_{\theta} U(\theta) \approx \frac{1}{m} \sum_{i=1 \text{ to } m} \nabla_{\theta} \log \mathbb{P}(\tau^i; \theta) R(\tau^i)$$



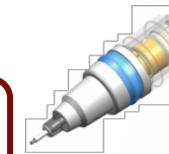


Unrolling the Math

$$\nabla_{\theta} U(\theta) = \sum_{\tau} \mathbb{P}(\tau; \theta) \nabla_{\theta} \log \mathbb{P}(\tau; \theta) R(\tau)$$

- Considering all possible trajectories is an impossible task.
- While in the math world, we can image as elegant as possible.
- ... But, down in the real world, we estimate empirically by sampling m trajectories(paths) under π_{θ} and average

$$\nabla_{\theta} U(\theta) \approx \frac{1}{m} \sum_{i=1 \text{ to } m} \nabla_{\theta} \log \mathbb{P}(\tau^i; \theta) R(\tau^i)$$





Decomposing trajectories to states & actions

$$\nabla_{\theta} U(\theta) = \frac{1}{m} \sum_{i=1 \text{ to } m} \nabla_{\theta} \log \mathbb{P}(\tau^i ; \theta) R(\tau^i)$$

- Let us reason about states and actions than probabilities of trajectories

$$\begin{aligned}\nabla_{\theta} \log \mathbb{P}(\tau ; \theta) &= \nabla_{\theta} \log [\prod_{t=0 \text{ to } T} \mathbb{P}(s_{t+1} | s_t, a_t) \pi(a_t | s_t, \theta)] \\ &= \nabla_{\theta} [\sum_{t=0 \text{ to } T} \log \mathbb{P}(s_{t+1} | s_t, a_t) + \sum_{t=0 \text{ to } T} \log \pi(a_t | s_t, \theta)] \\ &= \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \mathbb{P}(s_{t+1} | s_t, a_t) + \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \pi(a_t | s_t, \theta) \\ &= \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \pi(a_t | s_t, \theta) \dots \text{since } \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \mathbb{P}(s_{t+1} | s_t, a_t) = 0\end{aligned}$$

$$\nabla_{\theta} U(\theta) = \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) R(\tau^i)$$

... and this is the REINFORCE algorithm !

(<http://www-anw.cs.umass.edu/~barto/courses/cs687/williams92simple.pdf>)

Simple Statistical Gradient-Following Algorithms for
Connectionist Reinforcement Learning

Ronald J. Williams
College of Computer Science
Northeastern University
Boston, MA 02115

Appears in *Machine Learning*, 8, pp. 229-256, 1992.

Abstract

This article presents a general class of associative reinforcement learning algorithms for connectionist networks containing stochastic units. These algorithms, called REINFORCE algorithms, are shown to make weight adjustments in a direction that lies along the gradient of expected reinforcement in both immediate-reinforcement tasks and certain limited forms of





Decomposing trajectories to states & actions

$$\nabla_{\theta} U(\theta) = \frac{1}{m} \sum_{i=1 \text{ to } m} \nabla_{\theta} \log \mathbb{P}(\tau^i ; \theta) R(\tau^i)$$

- Let us reason about states and actions than probabilities of trajectories

$$\begin{aligned}\nabla_{\theta} \log \mathbb{P}(\tau ; \theta) &= \nabla_{\theta} \log [\prod_{t=0 \text{ to } T} \mathbb{P}(s_{t+1} | s_t, a_t) \pi(a_t | s_t, \theta)] \\ &= \nabla_{\theta} [\sum_{t=0 \text{ to } T} \log \mathbb{P}(s_{t+1} | s_t, a_t) + \sum_{t=0 \text{ to } T} \log \pi(a_t | s_t, \theta)] \\ &= \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \mathbb{P}(s_{t+1} | s_t, a_t) + \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \pi(a_t | s_t, \theta) \\ &= \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \pi(a_t | s_t, \theta) \dots \text{since } \nabla_{\theta} \sum_{t=0 \text{ to } T} \log \mathbb{P}(s_{t+1} | s_t, a_t) = 0\end{aligned}$$



$$\boxed{\nabla_{\theta} U(\theta) = \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) R(\tau^i)}$$

... and this is the REINFORCE algorithm !

(<http://www-anw.cs.umass.edu/~barto/courses/cs687/williams92simple.pdf>)

Simple Statistical Gradient-Following Algorithms for Connectionist Reinforcement Learning

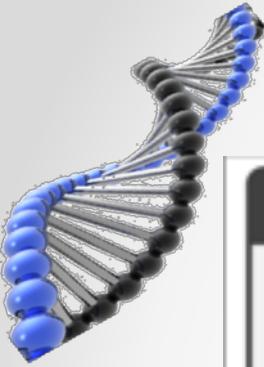
Ronald J. Williams
College of Computer Science
Northeastern University
Boston, MA 02115

Appears in *Machine Learning*, 8, pp. 229-256, 1992.

Abstract

This article presents a general class of associative reinforcement learning algorithms for connectionist networks containing stochastic units. These algorithms, called REINFORCE algorithms, are shown to make weight adjustments in a direction that lies along the gradient of expected reinforcement in both immediate-reinforcement tasks and certain limited forms of





REINFORCE = Monte Carlo PG

REINFORCE: Monte-Carlo Policy-Gradient Control (episodic) for π_* .

Input: a differentiable policy parameterization $\pi(a|s, \theta)$

Algorithm parameter: step size $\alpha > 0$

Initialize policy parameter $\theta \in \mathbb{R}^{d'}$ (e.g., to $\mathbf{0}$)

Loop forever (for each episode):

Generate an episode $S_0, A_0, R_1, \dots, S_{T-1}, A_{T-1}, R_T$, following $\pi(\cdot| \cdot, \theta)$

Loop for each step of the episode $t = 0, 1, \dots, T - 1$:

$$G \leftarrow \sum_{k=t+1}^T \gamma^{k-t-1} R_k \quad (G_t)$$
$$\theta \leftarrow \theta + \alpha \gamma^t G \nabla \ln \pi(A_t | S_t, \theta) \quad \alpha = 0.1 \text{ or } 0.2$$

*Discounted
return for
variance
reduction*

- Reinforce = MonteCarlo PG
 - i.e. full episode as Trajectory
 - *Just nudges the policy depending on the reward from a trajectory (could be a partial trajectory)*
- Low bias, but high variance
- REINFORCE Paper : <http://www-anw.cs.umass.edu/~barto/courses/cs687/williams92simple.pdf>





REINFORCE

1. Create initial policy π_θ
2. Act in the environment $a_t \sim \pi(s_t)$ for an episode storing states, actions, rewards: $s_0, a_0, r_0, \dots, s_T, a_T, r_T$
3. Compute return $R = \sum_{t=0}^T r_t$
4. Compute policy gradient $\nabla_\theta J(\theta) = \sum_{t=0}^T \nabla_\theta \log \pi_\theta(a_t|s_t) R$
5. Take a step in the direction of the gradient: $\theta = \theta + \alpha \nabla_\theta J(\theta)$
6. Repeat until convergence
 $\alpha = 0.1$ or 0.2

Input: policy $\pi(a|s, \theta)$, $\hat{v}(s, w)$

Parameters: step sizes, $\alpha > 0$, $\beta > 0$

Output: policy $\pi(a|s, \theta)$

initialize policy parameter θ and state-value weights w
for *true* do

generate an episode $s_0, a_0, r_1, \dots, s_{T-1}, a_{T-1}, r_T$, following $\pi(\cdot| \cdot, \theta)$

for each step t of episode $0, \dots, T-1$ do

$G_t \leftarrow$ return from step t

$\delta \leftarrow G_t - \hat{v}(s_t, w)$

$w \leftarrow w + \beta \delta \nabla_w \hat{v}(s_t, w)$

$\theta \leftarrow \theta + \alpha \gamma^t \delta \nabla_\theta \log \pi(a_t|s_t, \theta)$

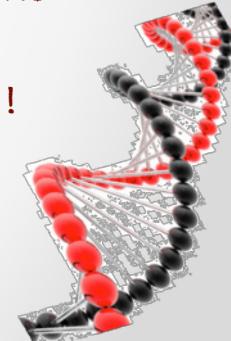
end

end

The algorithm from the
edx course is a lot
easier to understand !

Algorithm 6: REINFORCE with baseline (episodic), adapted from Sutton and Barto (2018)

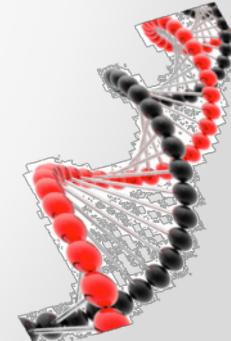
<https://arxiv.org/pdf/1810.06339.pdf>





Hands-On #10 : Balancing the Cart Pole w/ Policy Gradient (REINFORCE)

- Goal:
 - Implement Policy Gradient Network for CartPole
 - It is a lot simpler !!
- Steps:
 - Notebook : REINFORCE_o1.ipynb
 - Understand the REINFORCE code
 - Plot Values

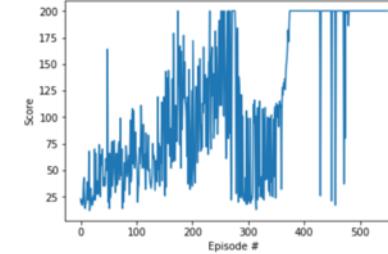




Implementation Lessons

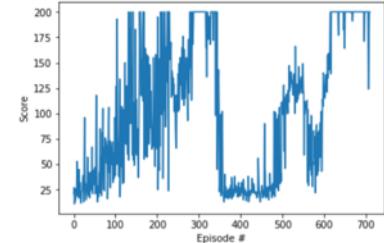
1. Very Simple
2. No digitization – neural network takes care of generalization
3. Solves the environment in less number of steps
4. It does oscillate a bit, but converges reasonably well

```
Episode 100    Average Score: 47.22
Episode 200    Average Score: 80.94
Episode 300    Average Score: 116.19
Episode 400    Average Score: 112.00
Episode 500    Average Score: 191.65
Environment solved in 450 episodes!      Average Score: 195.18
Elapsed : 0:00:23.645272
2019-01-12 11:47:30.619834
```

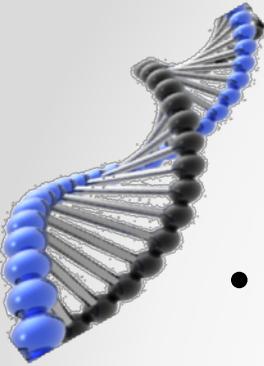


```
Max Score 200.000000 at 174
Percentile [25,50,75] : [ 51. 111. 200. ]
Variance : 4779.687
```

```
Episode 100    Average Score: 41.11
Episode 200    Average Score: 102.92
Episode 300    Average Score: 142.24
Episode 400    Average Score: 102.35
Episode 500    Average Score: 31.79
Episode 600    Average Score: 98.43
Episode 700    Average Score: 189.09
Environment solved in 610 episodes!      Average Score: 195.07
Elapsed : 0:00:22.520751
2019-02-08 13:10:04.801406
```



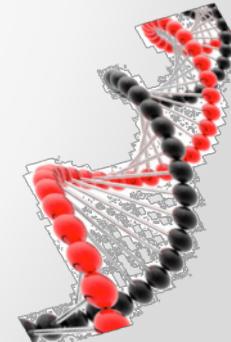
```
Max Score 200.000000 at 171
```

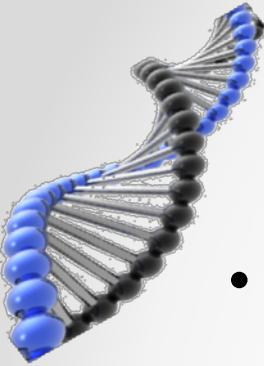


Quiz



- What is the DQN DNN topology ?
 -
- What is the input size ? Output size ?
 -
- What is the output of the network ?
 -
- How does the output translate to an action ?
 -
- Is the policy deterministic or stochastic ?
 -
- How do you characterize this w.r.t others ?
 -

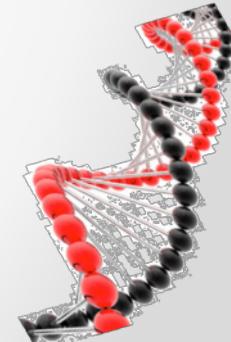




Quiz

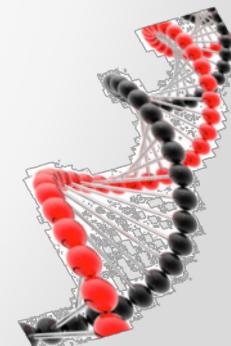
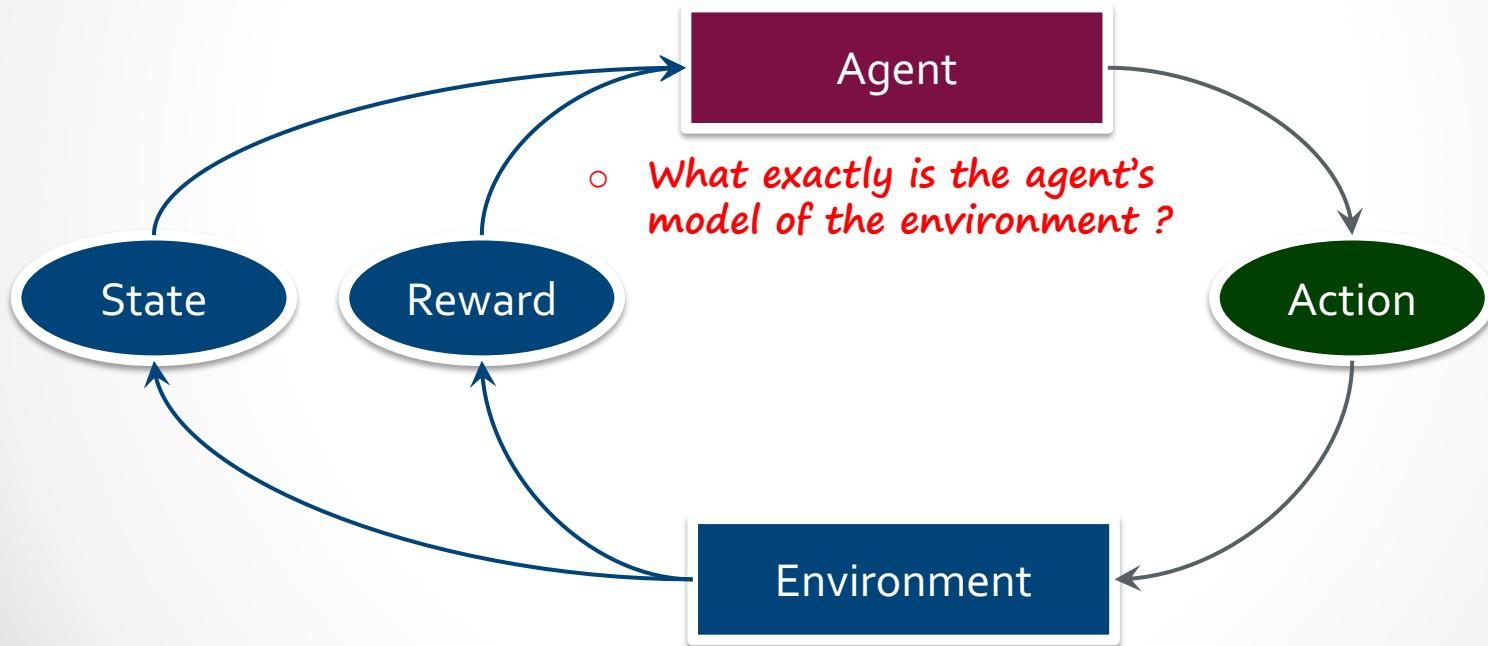
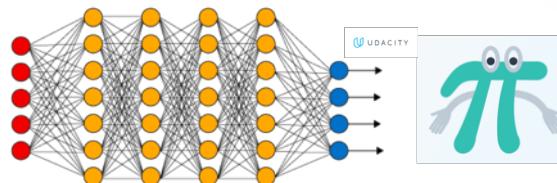


- What is the DQN DNN topology ?
 - FC16-FC2
- What is the input size ? Output size ?
 - Input = 4 (state), output = 2 (actions)
- What is the output of the network ?
 - softmax
- How does the output translate to an action ?
 - sample
- Is the policy deterministic or stochastic ?
 - Stochastic ! We get it as a part of the architecture !
- How do you characterize this w.r.t others ?
 - A better solution ! Probably the right solution for Cartpole.



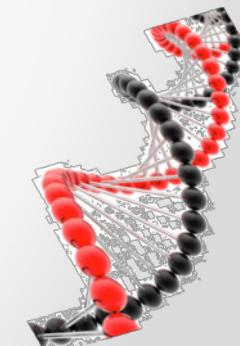
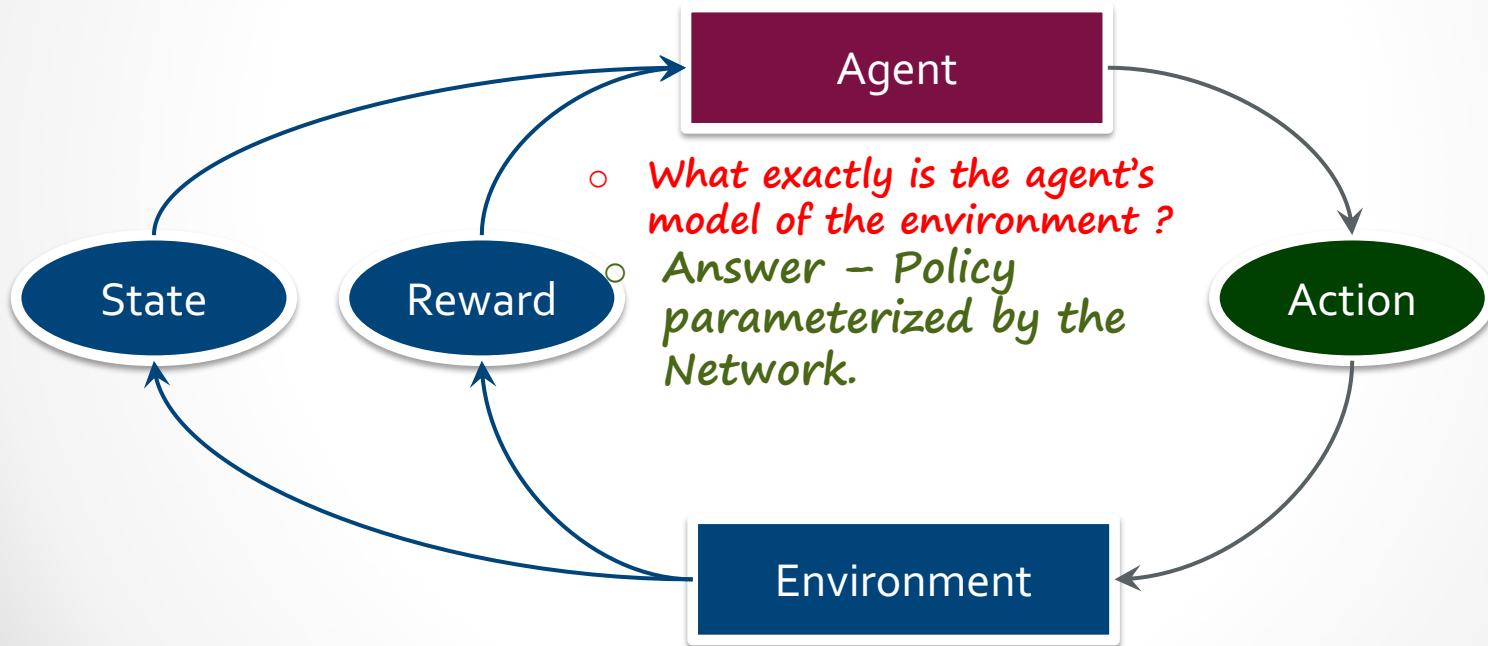
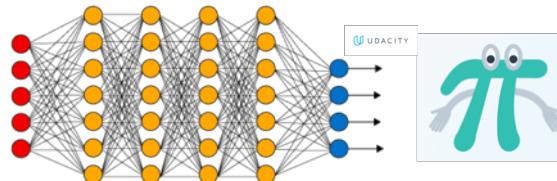


Quiz



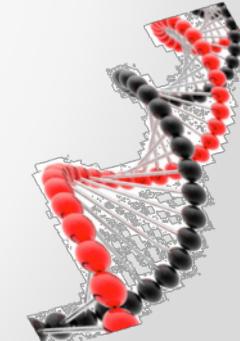
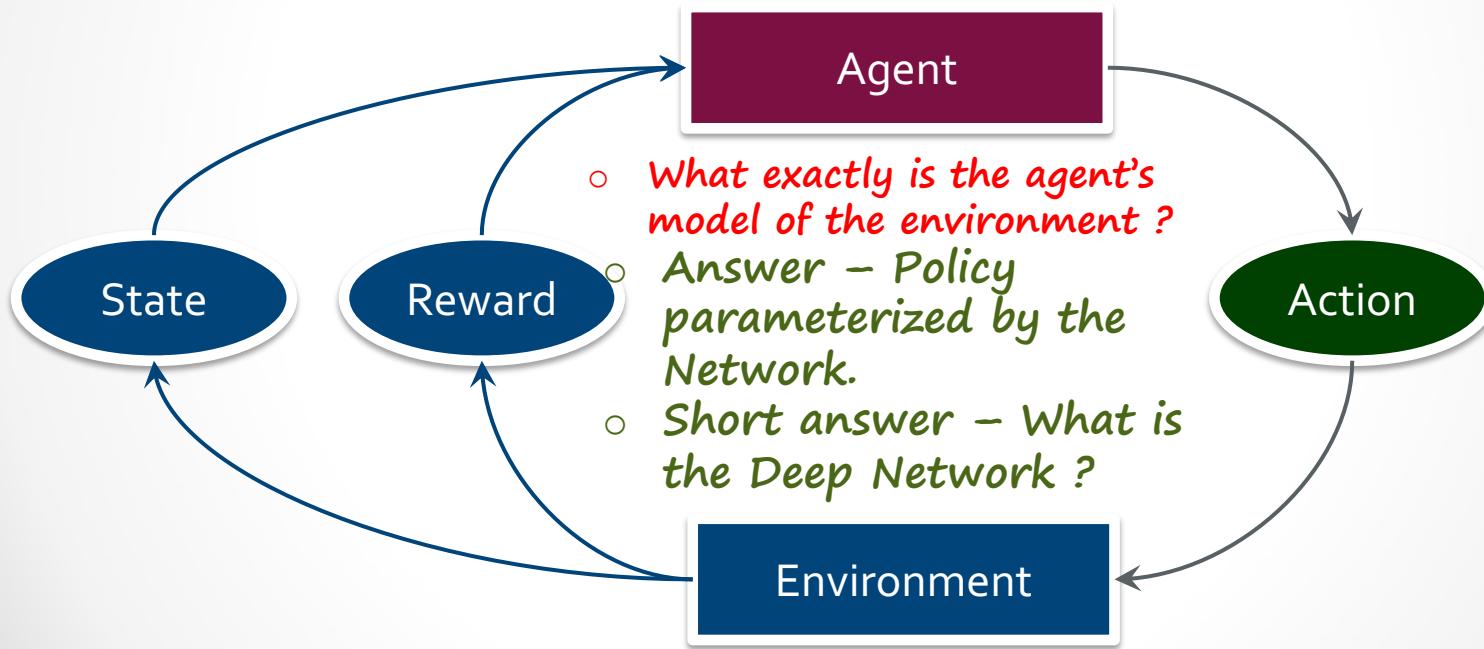
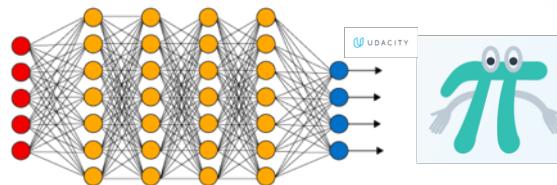


Quiz



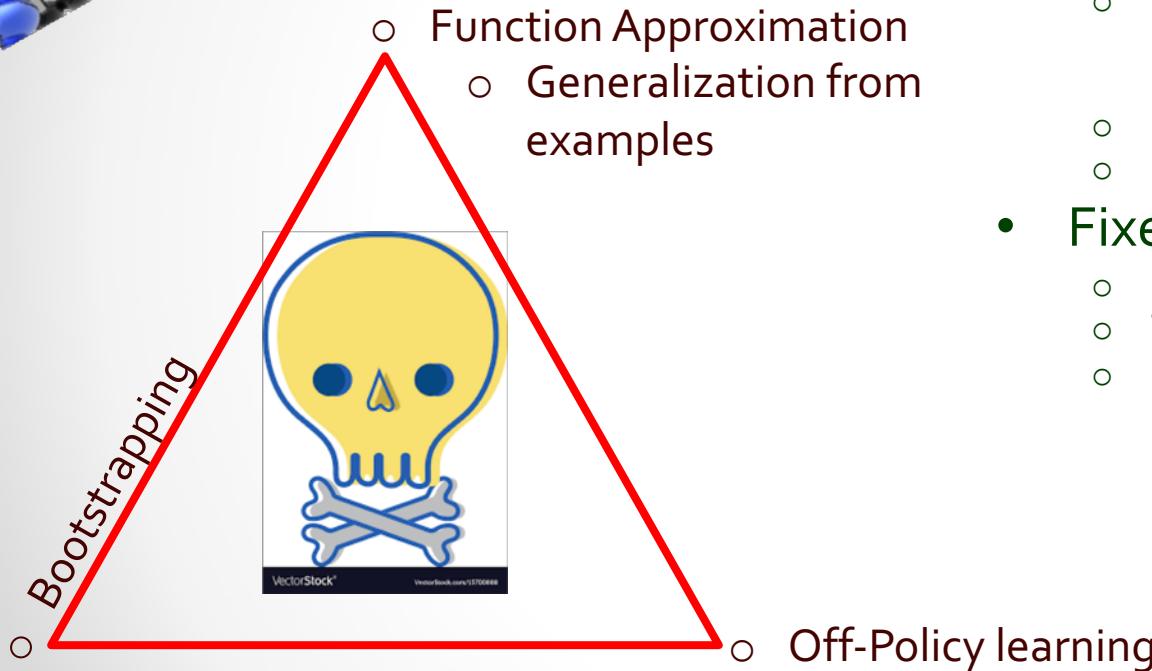


Quiz

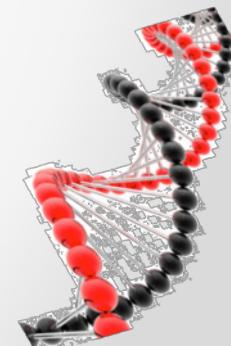


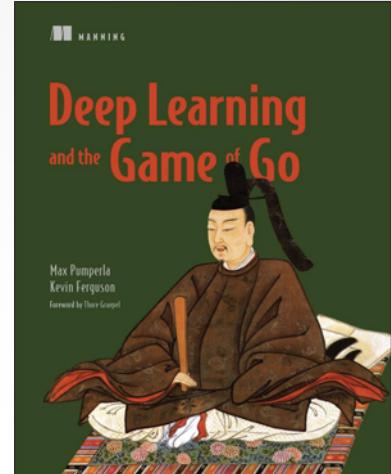
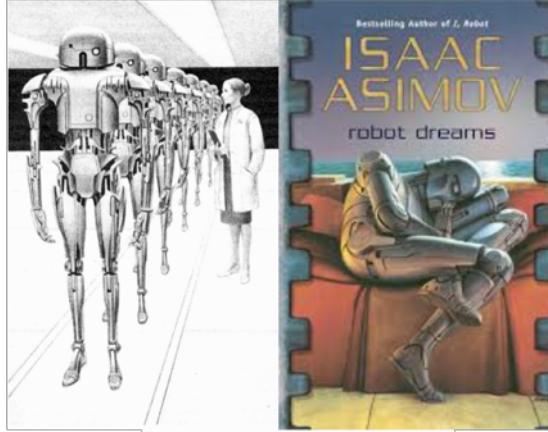


The Deadly Triad--Sutton



- REINFORCE
 - Unbiased, very noisy
 - We are sampling one out of millions of trajectories, for each iteration
 - Sample inefficient
 - Credit Assignment
- Fixes
 - Baseline
 - Temporal Structure
 - KL-Divergence Trust Region





Deep Learning: Sky's the Limit?

The generally accepted idea is that deep learning neural networks are as good as the data you feed them. In this blog, we review recent achievements of deep learning and address whether such systems are able to surpass and transcend the original learning material through self-learning, and ultimately can become – even better – than the data you feed them.

Wednesday, April 8, 2015

Part 2: AlphaGo under a Magnifying Glass (The historic match of deep learning AlphaGo vs. Lee Sedol) REVISED

[NL, Verse]

AlphaGo under a Magnifying Glass

Deep Learning program AlphaGo developed by the Google DeepMind team specifically to play Go was first demonstrated in London in 2015 by Demis Hassabis, Shane Legg and Mustafa Suleyman. The name *DeepMind* is to solve intelligence and it's made to move the world a better place (as a real advertisement slogan). DeepMind was at the time supported by the most brilliant AI entrepreneurs and investors who had a clear vision of the future, prior to being acquired by Google early 2014; their biggest European acquisition ever at \$400 million.

Deep Learning AlphaGo under a Magnifying Glass

Part 2: AlphaGo under a Magnifying Glass (The historic match of deep learning AlphaGo vs. Lee Sedol) REVISED

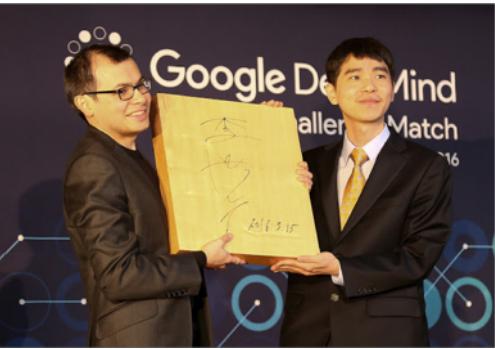



Bob van den Hout
Demis Hassabis


Mike van der Linde
Lee Sedol



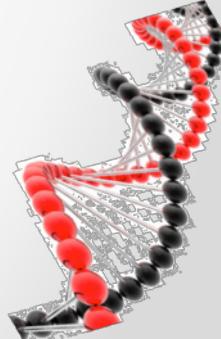
The world of α_{Go}



- AlphaGo AI program from Google's DeepMind defeated Go Champion
 - Lee Sedol (9-dan professional with 18 world titles)
- AlphaGo has the ability to look “globally” across a board—and find solutions that humans either have been trained not to play or would not consider.
 - This has huge potential for using AlphaGo-like technology to find solutions that humans don't necessarily see in other areas
- Search & Optimization
 - Policy Network with Values & search
 - “This ability of neural networks to bottle intuition / pattern recognition from one environment & apply to other contexts ”

GENERATIONAL GAP !

- Unlike IBM's Deep Blue, which defeated chess champion Garry Kasparov in 1997, AlphaGo was not programmed with decision trees, or equations on how to evaluate board positions, or with if-then rules
- AlphaGo learned how to play go essentially from self-play and from observing big professional games
 - During training, AlphaGo played a million go games against itself.

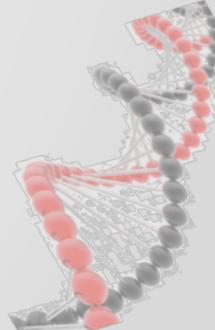




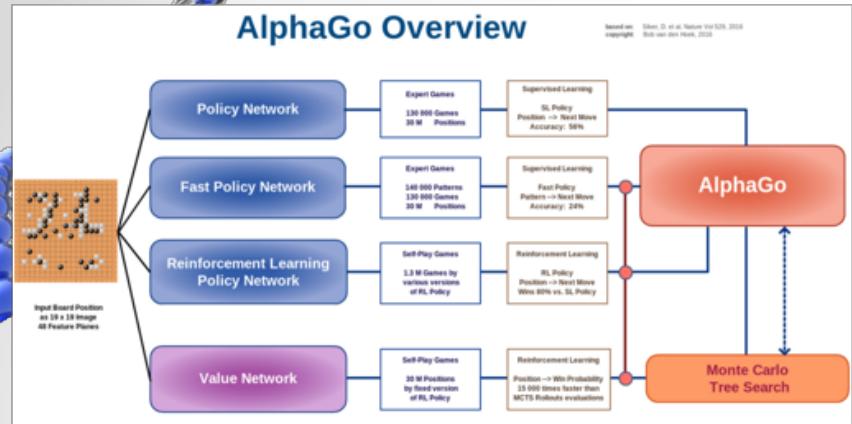
- AlphaGo AI program from Google's DeepMind defeated Go Champion
 - Lee Sedol (9-dan professional with 18 world titles)
- AlphaGo has the ability to look "globally" across a board—and find solutions that humans either have been trained not to play or would not consider.
 - This has huge potential for using AlphaGo-like technology to find solutions that humans don't necessarily see in other areas
- Search & Optimization
 - Policy Network with Values & search
 - "This ability of neural networks to bottle intuition / pattern recognition from one environment & apply to other contexts "

GENERATIONAL GAP !

- Unlike IBM's Deep Blue, which defeated chess champion Garry Kasparov in 1997, AlphaGo was not programmed with decision trees, or equations on how to evaluate board positions, or with if-then rules
- AlphaGo learned how to play go essentially from self-play and from observing big professional games
 - During training, AlphaGo played a million go games against itself



AlphaGo Overview



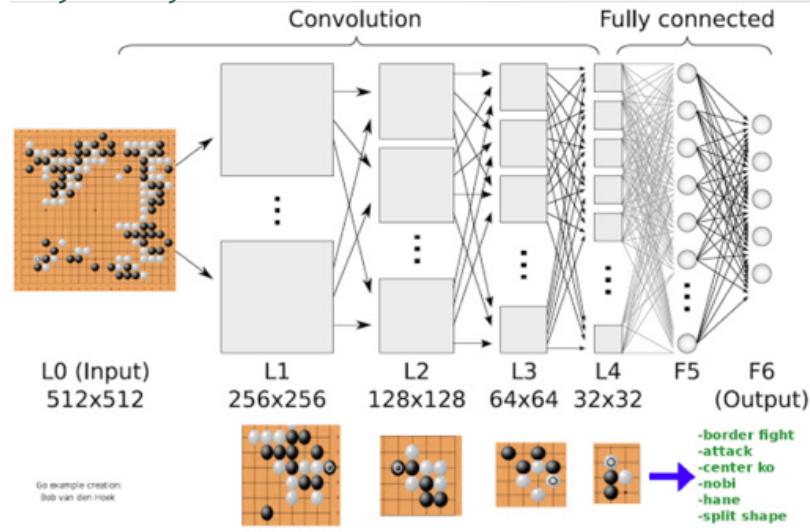
- It uses 4 networks :
- **Fast Rollout Policy Network (P-Network)** :It rolls out a quick plan for the game.
- **Supervised Learning Policy Network (SL-Network)** :The P-Network and the SL-Network are trained to predict human expert moves in a data set of positions.
- **Reinforcement Learning Policy Network (RL-Network)** :The RL Network is initialized as the SL policy network, and is then improved by policy gradient learning to maximize the outcome (that is, winning more games) against previous versions of the policy network. A new data set is generated by playing games of self-play with the RL policy network.
- **Value network** : a Value Network V is trained by regression to predict the expected outcome (that is, whether the current player wins) in positions from the self-play data set.

<https://medium.com/@arnabghosh93/deep-reinforcement-learning-driving-alpha-go-9881f1a90be4#.f462gnebl>

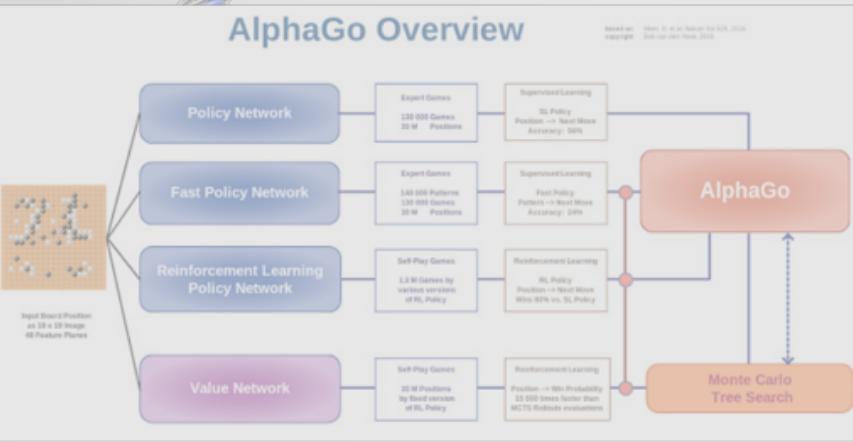
- AlphaGo is not a revolutionary breakthrough in itself, but rather a leading edge of an extremely important development

- **#AlphaGo** appeared to have a weakness in responding to unorthodox moves; Toward the end of the game, **#AlphaGo** played desperate moves similar to those of humans facing defeat ...

- Ultimately, the scary thing about the rise of intelligent machines is not that they could someday have a mind of their own, but they could someday have a mind that we humans – with all our flaws and complexity – design and build for them



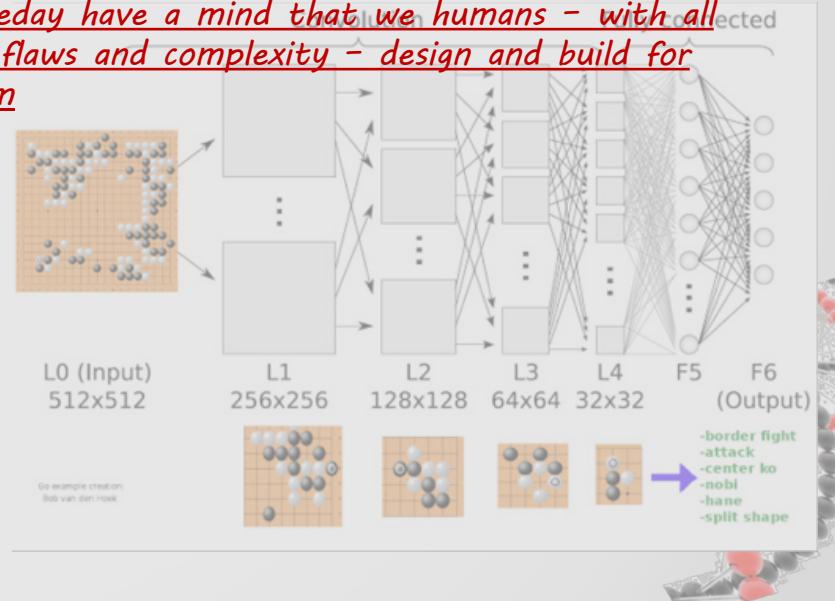
AlphaGo Overview



- It uses 4 networks :
- **Fast Rollout Policy Network (P-Network)** :It rolls out a quick plan for the game.
- **Supervised Learning Policy Network (SL-Network)** :The P-Network and the SL-Network are trained to predict human expert moves in a data set of positions.
- **Reinforcement Learning Policy Network (RL-Network)** :The RL Network is initialized as the SL policy network, and is then improved by policy gradient learning to maximize the outcome (that is, winning more games) against previous versions of the policy network. A new data set is generated by playing games of self-play with the RL policy network.
- **Value network** : a Value Network V is trained by regression to predict the expected outcome (that is, whether the current player wins) in positions from the self-play data set.

<https://medium.com/@arnabghosh93/deep-reinforcement-learning-driving-alpha-go-9881f1a90be4#f462gnebl>

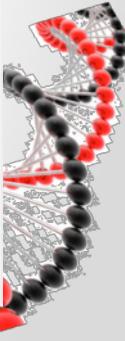
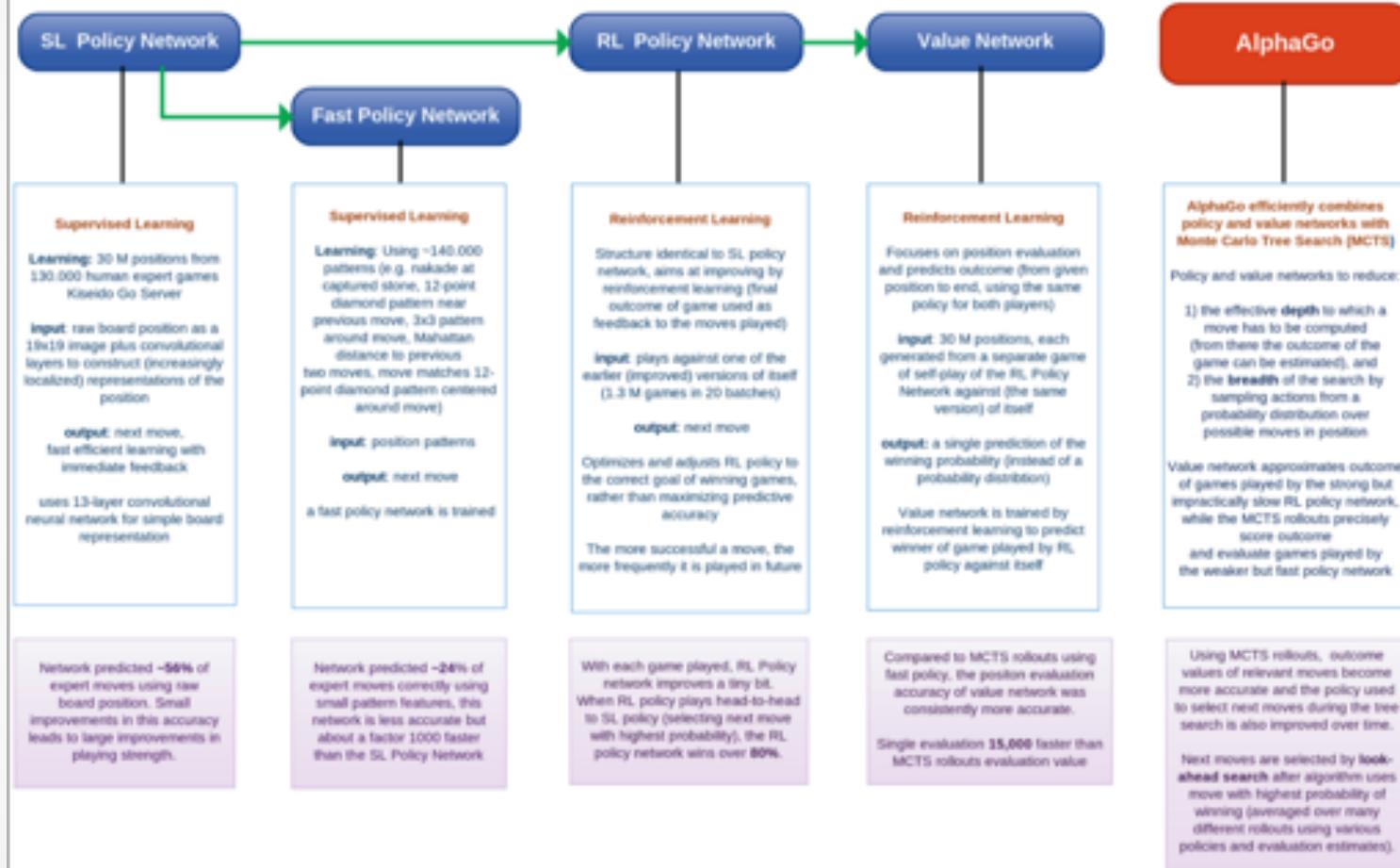
- AlphaGo is not a revolutionary breakthrough in itself, but rather a leading edge of an extremely important development
- #AlphaGo appeared to have a weakness in responding to unorthodox moves; Toward the end of the game, #AlphaGo played desperate moves similar to those of humans facing defeat ...
- Ultimately, the scary thing about the rise of intelligent machines is not that they could someday have a mind of their own, but they could someday have a mind that we humans - with all our flaws and complexity - design and build for them





AlphaGo in a Nutshell

based on: Silver, D. et al. Nature Vol. 529, 2016
copyright: Bob van den Hoek, 2016





ARTICLE

doi:10.1038/nature16961

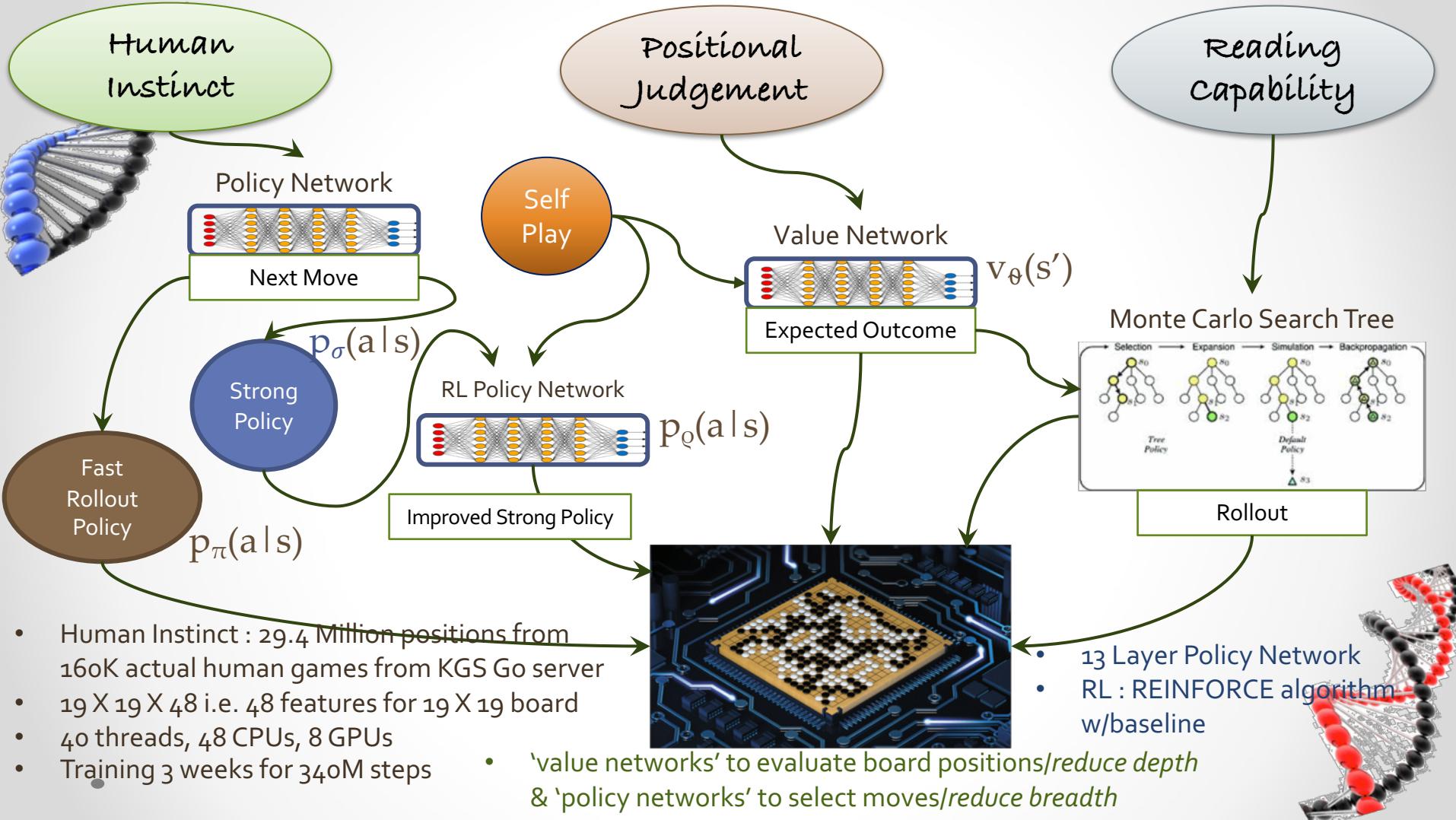
Mastering the game of Go with deep neural networks and tree search

David Silver^{1*}, Aja Huang^{1*}, Chris J. Maddison¹, Arthur Guez¹, Laurent Sifre¹, George van den Driessche¹, Julian Schrittwieser¹, Ioannis Antonoglou¹, Veda Panneershelvam¹, Marc Lanctot¹, Sander Dieleman¹, Dominik Grewe¹, John Nham², Nal Kalchbrenner¹, Ilya Sutskever², Timothy Lillicrap¹, Madeleine Leach¹, Koray Kavukcuoglu¹, Thore Graepel¹ & Demis Hassabis¹

- Combination of model-free and model-based approach
- Look ahead search using MCTS

<https://storage.googleapis.com/deepmind-media/alphago/AlphaGoNaturePaper.pdf>
<https://pdfs.semanticscholar.org/2088/c55ec3e52a8beg9cd933907020c70b281383.pdf>







- DQN can even book tickets !
- Given an instruction "Book a flight from WTK to LON on 21-Oct-2016", the DQN agent navigates through the web form and selects the cheapest flight

curriculum-DQN to book tickets !

LEARNING TO NAVIGATE THE WEB

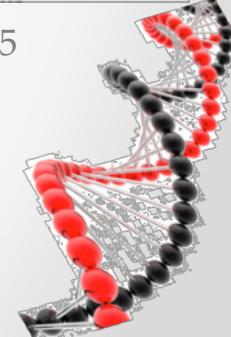
Izzeddin Gur, Ulrich Rueckert, Aleksandra Faust, Dilek Hakkani-Tur
Google AI
izzeddin@cs.ucsb.edu, {rueckert, faust}@google.com, dilek@ieee.org

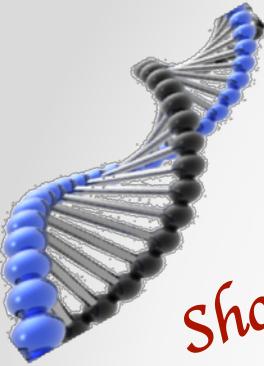
ABSTRACT

Learning in environments with large state and action spaces, and sparse rewards, can hinder a Reinforcement Learning (RL) agent's learning through trial-and-error. For instance, following natural language instructions on the Web (such as booking a flight ticket) leads to RL settings where input vocabulary and number of actionable elements on a page can grow very large. Even though recent approaches improve the success rate on relatively simple environments with the help of human demonstrations to guide the exploration, they still fail in environments where the set of possible instructions can reach millions. We approach the aforementioned problems from a different perspective and propose guided RL approaches that can generate unbounded amount of experience for an agent to learn from. Instead of learning from a complicated instruction with a large vocabulary, we decompose it into multiple sub-instructions and schedule a curriculum in which an agent is tasked with a gradually increasing subset of these relatively easier sub-instructions. In addition, when the expert demonstrations are not available, we propose a novel meta-learning framework that generates new instruc-

ss.LG] 21 Dec 2018

<https://arxiv.org/abs/1812.09195>





Will leave this section with 2 thoughts ...

Should we fear the machine's strengths and (try to) control them ?

[Update 3/6/16] An interesting post from [Tom Devenport](#) about Cognitive Computing.

- Good insights into what Cognitive Computing is, as a combination of [Intelligence\(Algorithms\)](#), [Inference\(Knowledge\)](#) and [Interface \(Visualization, Recommendation, Prediction,...\)](#)
- IMHO, Cognitive Computing is more than Analytics over unstructured data, it also has touches of AI in there.
- Reason being, Cognitive Computing understands humans – whether it is about buying patterns or the way different bodies reacts to drugs or the various forms of diseases or even the way humans work and interact
- And that knowledge is the difference between Analytics and Cognitive Computing !

“

I like Cognitive Computing as an important part of AI, probably that is where most of the applications are ... again understanding humans rather than being humans !

Is #AlphaGo's 3rd win a prelude of things to come ? "it played so well that it was almost scary"; "We're now convinced that AlphaGo is simply stronger than any known human Go player"; "Perhaps it's time for broader discussion about how human society will adapt to this emerging technology !!!" <https://goo.gl/htmOzR> show less



AlphaGo shows its true strength in 3rd victory against Lee Sedol

gogameguru.com • AlphaGo made history once again on Saturday, as the first computer program to defeat a top profes...

Or should we work with the machines - who understand us, rather than being us ?





Should we fear the machine's strengths and (try to) control them ?

[Update 3/6/16] An interesting post from a public report about Cognitive Computing.

- Cognitive Computing is a combination of Intelligence(Algorithms), Inference(Knowledge) and Integration, Optimization, Recommendation,...)
- IMHO, Cognitive Computing is more than Analytics of structured data, it also has touches of AI in there.
- Reason being, Cognitive Computing understands us better than we do. Whether it is about buying patterns or the way our bodies reacts to drugs or various forms of diseases or even the way humans work and interact
- And that knowledge is the difference between Cognitive Computing and Cognitive Computing !

I like Cognitive Computing because it is part of AI, probably that is where most of the applications are again understanding humans rather than being humans !

Will leave this section with 2 thoughts ...

Is #AlphaGo's 3rd win a prelude of things to come ? "it played so well that it was almost scary"; "We're now convinced that AlphaGo is simply stronger than any known human Go player"; "Perhaps it's time for broader discussion about how human society will adapt to this emerging technology !!!" <https://goo.gl/htmOzR> show less



AlphaGo shows its true strength in 3rd victory against Lee Sedol

gogameguru.com • AlphaGo made history once again on Saturday, as the first computer program to defeat a top profes...

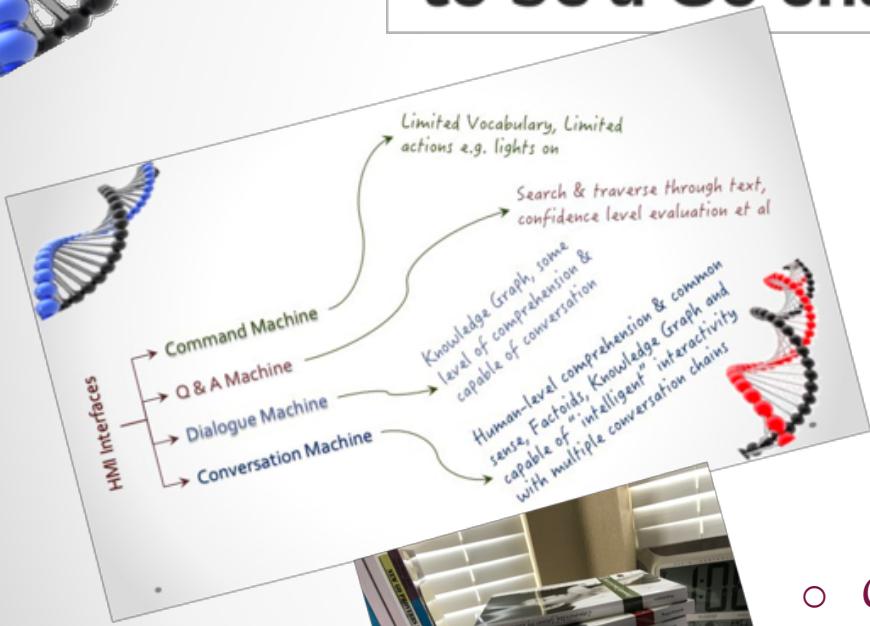
Or should we work with the machines - who understand us, rather than being us ?



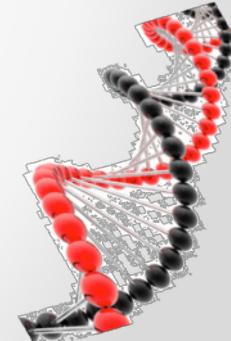


Ask not if AlphaZero can beat humans in Go—Ask if AlphaZero can teach humans to be a Go champion !!!

<https://goo.gl/vPzN9B>



- Can a program understand playstyles (e.g. Lee Sedol) & imitate ?
- Can it adapt to its student's level ?





Should we fear the
machine's strengths and
(try to) control them ?

[Update 3/6/16] An interesting post from Tom Devore on Cognitive Computing.

- Good insights into what Cognitive Computing is, as a combination of Intelligence(Algorithms), Information (Data) and Interface (User). Recommendation, Prediction,...)
- In fact, Cognitive Computing is Analytics over unstructured data, but also has touches of AI in there.
- Reason being, Cognitive Computing is all about understanding humans – whether it is about buying patterns or the way different people react to drugs or the various diseases or even the way humans work and interact.
- And that knowledge is the difference between Analytics and Cognitive Computing !

Self-awareness between
self & Task –
interesting paper from
Columbia
https://www.eurekalert.org/pub_releases/2019-01/cuso-asco12819.php

I like Cognitive Computing as an important part of AI, probably that is where most of the applications are – again understanding humans rather than being humans !

Will leave this section with 2 thoughts ...

Is #AlphaGo's 3rd win a prelude of things to come ? "it played so well that it was almost scary"; "We're now convinced that AlphaGo is simply stronger than any known human Go player"; "Perhaps it's time for broader discussion about how human society will adapt to this emerging technology !!!" <https://goo.gl/htmOzR> show less



AlphaGo shows its true strength in 3rd victory
against Lee Sedol

gogameguru.com • AlphaGo made history once again on Saturday, as the first computer program to defeat a top profes...

Or should we work with
the machines - who
understand us, rather
than being us ?





Should we fear the machine's strengths and (try to) control them ?

[Update 3/6/16] An interesting post from Tom Devenport about Cognitive Computing.

- Good insights into what Cognitive Computing is all about : a combination of Intelligence(Algorithms), Inference(Knowledge) and Visualization (Prediction,...)
- IMHO, Cognitive Computing is more than just AI. It also has touches of AI in there.
- Researchers are now exploring whether robots can model not just their own bodies, but also their own minds, whether robots can think about thinking"
- And the knowledge gap between Analytics and Cognitive Computing !

I like Cognitive Computing as an important part of AI, probably that is where most of the applications are again understanding humans rather than being humans !

Will leave this section with 2 thoughts ...

Is #AlphaGo's 3rd win a prelude of things to come ? "it played so well that it was almost scary"; "We're now convinced that AlphaGo is simply stronger than any known human Go player"; "Perhaps it's time for broader discussion about how human society will adapt to this emerging technology !!!" <https://goo.gl/htmOzR> show less

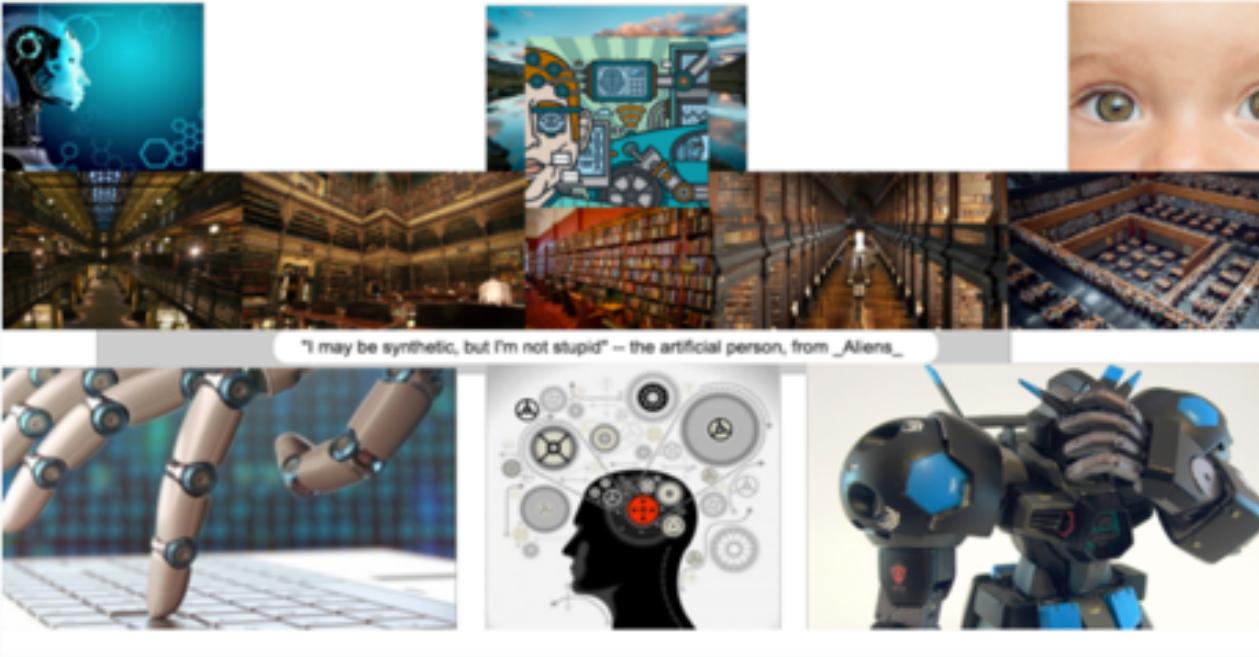


AlphaGo shows its true strength in 3rd victory against Lee Sedol

gogameguru.com • AlphaGo made history once again on Saturday, as the first computer program to defeat a top profes...

Or should we work with the machines - who understand us, rather than being us ?



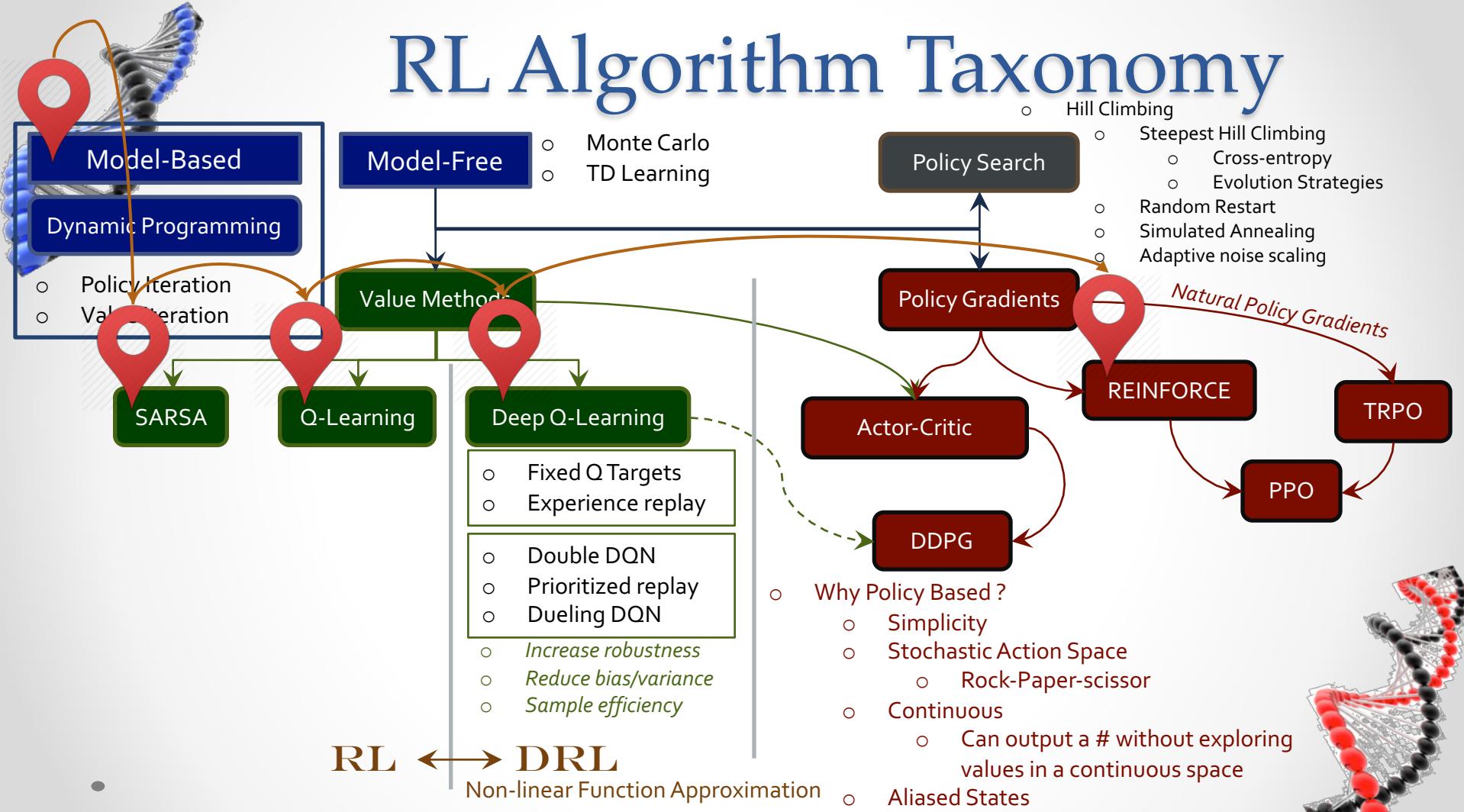


**WHAT WOULD YOU WANT AI TO DO, IF IT COULD DO WHATEVER YOU
WANTED IT TO DO ?**

<https://goo.gl/6pKvgY>



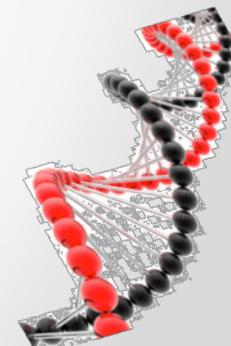
RL Algorithm Taxonomy

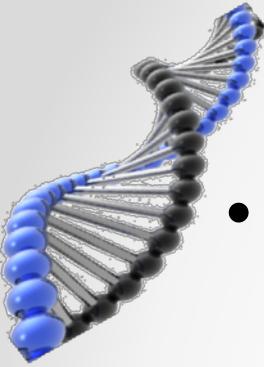




Back to the main feature ...

- REINFORCE
 - High variance
 - Difficult to converge
 - The dependence on $R(\tau^i)$
 - Pushes probabilities for all actions in that trajectory
 - Which is not fully meaningful
 - What if we have a better yardstick ?
 - i.e. better or worse than what you expect ?
 - i.e. compare with a baseline





Policy Gradients with a Baseline

- Bias and variance

- MonteCarlo has *low bias* – because it accumulates an estimate of reward from actual episodes
 - But because a state can participate in many different trajectories, there is the *high variance* of the cumulated rewards
- TD has *low variance*, because it works with a few steps, single step in many cases, instead of full rollout
 - But it has a *high bias* because it depends on estimates of estimates !

- Adding a TD baseline to REINFORCE reduces the variance

- Thus improves the convergence properties - results in better and consistent convergence
- And because of TD, speeds up learning as well !





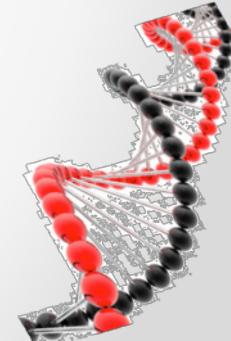
Reinforce with Baseline

$$\begin{aligned}\nabla_{\theta} U(\theta) &= \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) R(\tau^i) \\ &= \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) (R(\tau^i) - b)\end{aligned}$$

Many interesting choice for a baseline:

1. Average of all rewards so far i.e. $\mu\{R(\tau)\}$ – constant moving average
2. Optimal Baseline
3. Time dependent baseline
4. State dependent expected baseline i.e. $V_{\pi}(s)$

$$\nabla_{\theta} U(\theta) = \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) (R(\tau^i) - V_{\phi}(s_t))$$





Reinforce with Baseline

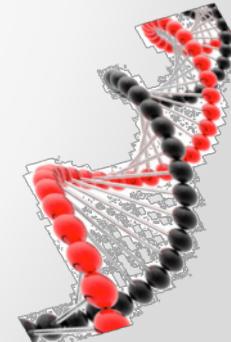
$$\begin{aligned}\nabla_{\theta} U(\theta) &= \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) R(\tau^i) \\ &= \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) (R(\tau^i) - b)\end{aligned}$$

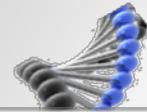
Many interesting choice for a baseline:

1. Average of all rewards so far i.e. $\mu\{R(\tau)\}$ – constant moving average
2. Optimal Baseline
3. Time dependent baseline
4. State dependent expected baseline i.e. $V_{\pi}(s)$



$$\nabla_{\theta} U(\theta) = \frac{1}{m} \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t, \theta) (R(\tau^i) - V_{\phi}(s_t))$$





REINFORCE with Baseline (episodic), for estimating $\pi_\theta \approx \pi_*$.

Input: a differentiable policy parameterization $\pi(a|s, \theta)$

Input: a differentiable state-value function parameterization $\hat{v}(s, w)$

Algorithm parameters: step sizes $\alpha^\theta > 0$, $\alpha^w > 0$

Initialize policy parameter $\theta \in \mathbb{R}^{d'}$ and state-value weights $w \in \mathbb{R}^d$ (e.g., to **0**)

Loop forever (for each episode):

Generate an episode $S_0, A_0, R_1, \dots, S_{T-1}, A_{T-1}, R_T$, following $\pi(\cdot| \cdot, \theta)$

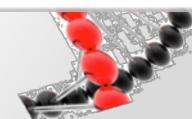
Loop for each step of the episode $t = 0, 1, \dots, T - 1$:

$$G \leftarrow \sum_{k=t+1}^T \gamma^{k-t-1} R_k \tag{G_t}$$

$$\delta \leftarrow G - \hat{v}(S_t, w)$$

$$w \leftarrow w + \alpha^w \delta \nabla \hat{v}(S_t, w)$$

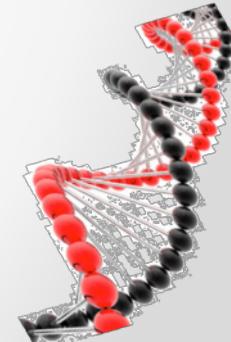
$$\theta \leftarrow \theta + \alpha^\theta \gamma^t \delta \nabla \ln \pi(A_t | S_t, \theta)$$





A Simpler Algorithm from edX

-
1. Initialize policy π_θ and value function V_ϕ
 2. For episode 1,2,...,n do:
 1. Collect trajectory τ by running current policy
 2. For each step in τ compute the discounted return $R_t = \sum_{t'=t}^T \gamma^{t'-t} r_{t'}$
 3. Re-fit the baseline minimizing $\|V_\phi(s_t) - R_t\|^2$ over all steps
 4. Update π_θ using gradient $\sum_{t=0}^T \nabla_\theta \log \pi_\theta(a_t | s_t) (R_t - V_\phi(s_t))$
-





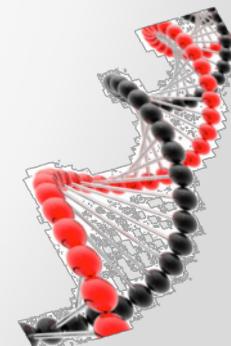
Morphing to A3C

- Would a better baseline reduce the variance for REINFORCE ? And generalize ?
 - Can we use a Neural Network to establish this baseline ?
 - Of course, Yes to both
 - A₃C & it's synchronous twin A₂C
 - And, ... if we use a TD-Critic, instead of a MonteCarlo baseline
 - Faster Learning than MC alone
 - Consistent Convergence than value based methods
 - And, we gain generalization
 - And that in essence leads us to A₃C & then to DDPG !
- 



Advantage

- Interestingly, R_t is nothing but $Q_\pi(s_t, a_t)$
 - So $R_t - V_\phi(s_t)$ becomes $Q_\pi(s_t, a_t) - V_\phi(s_t)$
 - Which says how much better the new state-action value is over the current value i.e. Advantage
 - $A(s_t, a_t) = Q_\pi(s_t, a_t) - V_\phi(s_t)$



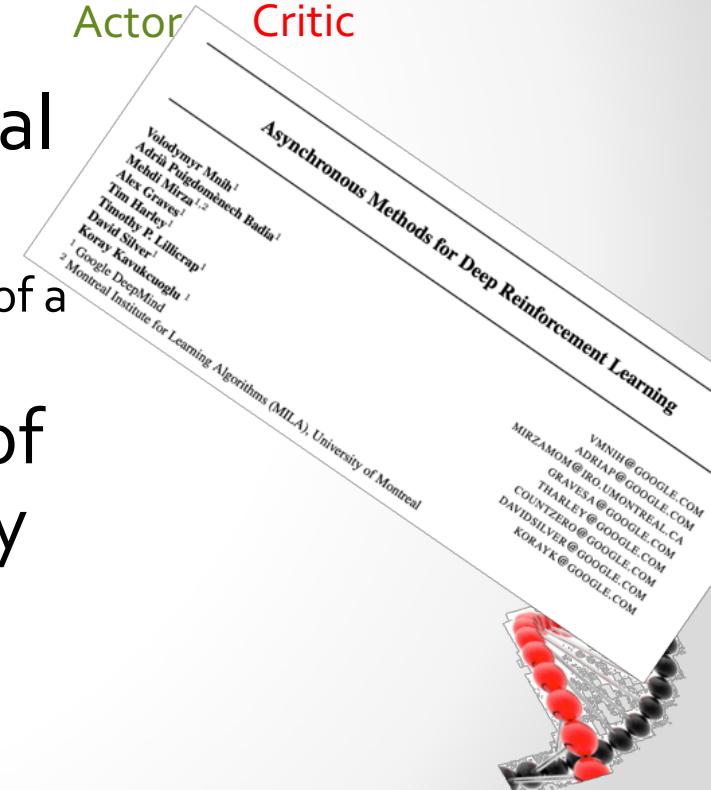


A Basic Actor-Critic Agent

$$\nabla_{\theta} U(\theta) = \sum_{i=1 \text{ to } m} \sum_{t=0 \text{ to } T} \nabla_{\theta} \log \pi(a_t | s_t; \theta) A_t$$

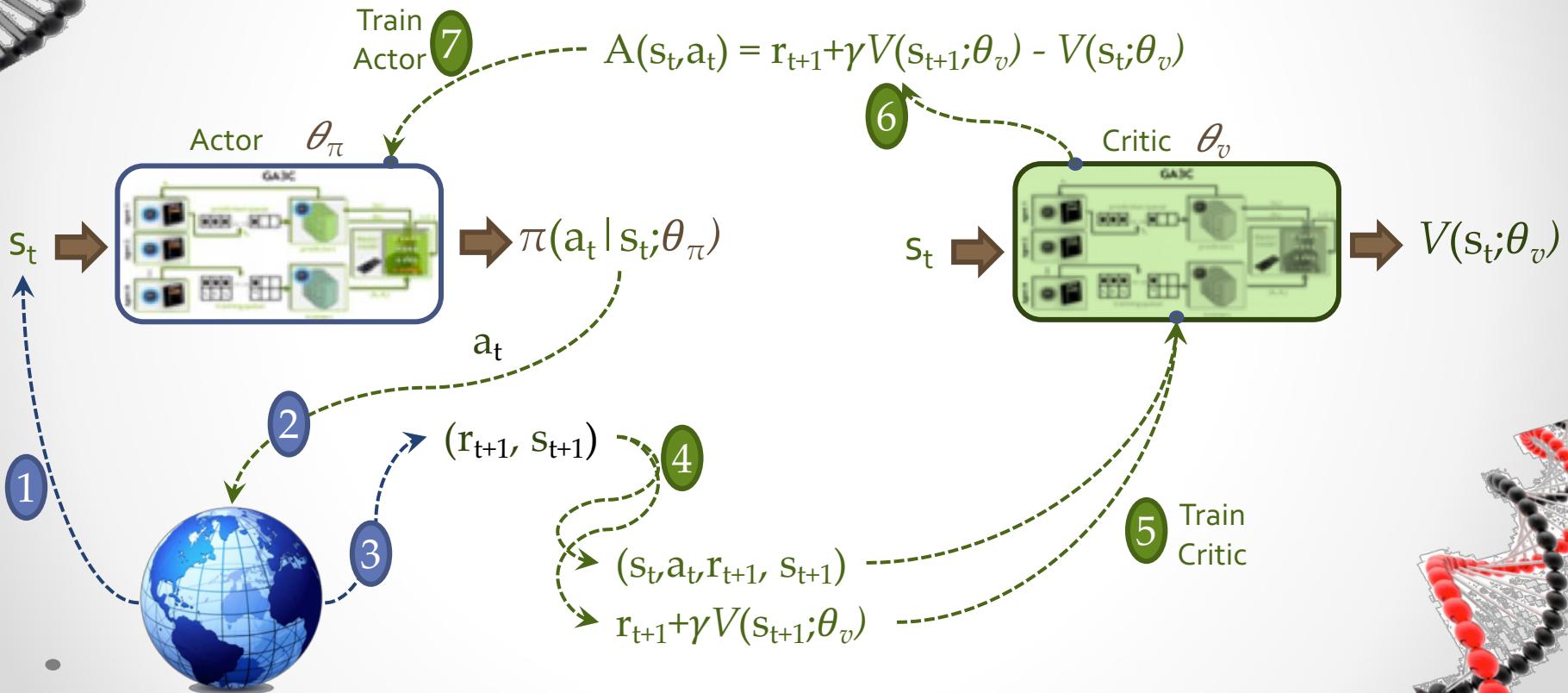
Actor Critic

- Function Approximation ie neural network for Actor and Critic
 - i.e. the Policy and the Predictor of Advantage of a policy using TD estimate
- Once you know the advantage of a policy, we can tweak the policy up or down
 - <https://arxiv.org/abs/1602.01783>



A3C Intuition

$$\pi_{\theta} = \pi_{\theta} + \alpha \sum \nabla \log \pi(a_t | s_t; \theta_{\pi}) (R(\tau) - V(s_t; \theta_v))$$



One-step Actor-Critic (episodic), for estimating $\pi_\theta \approx \pi_*$

Input: a differentiable policy parameterization $\pi(a|s, \theta)$

Input: a differentiable state-value function parameterization $\hat{v}(s, w)$

Parameters: step sizes $\alpha^\theta > 0$, $\alpha^w > 0$

Initialize policy parameter $\theta \in \mathbb{R}^{d'}$ and state-value weights $w \in \mathbb{R}^d$ (e.g., to $\mathbf{0}$)

Loop forever (for each episode):

 Initialize S (first state of episode)

$I \leftarrow 1$

 Loop while S is not terminal (for each time step):

$A \sim \pi(\cdot|S, \theta)$

 Take action A , observe S', R

$\delta \leftarrow R + \gamma \hat{v}(S', w) - \hat{v}(S, w)$ (if S' is terminal, then $\hat{v}(S', w) \doteq 0$)

$w \leftarrow w + \alpha^w \delta \nabla \hat{v}(S, w)$

$\theta \leftarrow \theta + \alpha^\theta I \delta \nabla \ln \pi(A|S, \theta)$

$I \leftarrow \gamma I$

$S \leftarrow S'$

Input: policy $\pi(a|s, \theta)$, $\hat{v}(s, w)$
Parameters: step sizes, $\alpha > 0$, $\beta > 0$
Output: policy $\pi(a|s, \theta)$

initialize policy parameter θ and state-value weights w

for *true* **do**

 initialize s , the first state of the episode

$I \leftarrow 1$

for s is not terminal **do**

$a \sim \pi(\cdot|s, \theta)$

 take action a , observe s', r

$\delta \leftarrow r + \gamma \hat{v}(s', w) - \hat{v}(s, w)$ (if s' is terminal, $\hat{v}(s', w) \doteq 0$)

$w \leftarrow w + \beta \delta \nabla_w \hat{v}(s_t, w)$

$\theta \leftarrow \theta + \alpha I \delta \nabla_\theta \log \pi(a_t|s_t, \theta)$

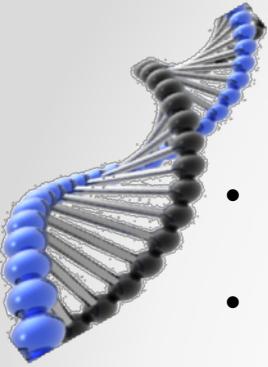
$I \leftarrow \gamma I$

$s \leftarrow s'$

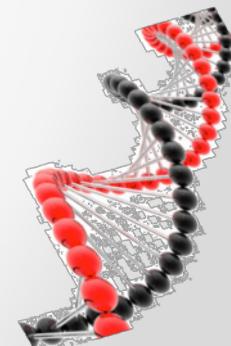
end

end

Algorithm 7: Actor-Critic (episodic), adapted from Sutton and Barto (2018)



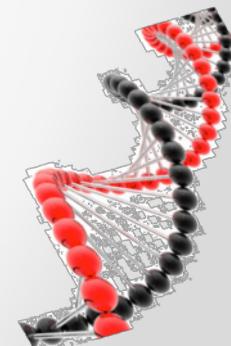
A3C

- A3C can share networks between the Actor and Critic.
 - But harder to train – so start with 2 networks, do hyperparameter and architecture tuning and then combine for performance
 - N-step bootstrapping TD(lambda) with lambda = n
 - More n, less bias while keeping variance under control
 - Usually 4-5 step bootstrapping are the best
 - Update last n steps
 - A3C doesn't use experience replay but gets diversity from parallel training ie running multiple agents to a common buffer
 - On or off policy ? On ! Stable and consistent convergence property !
 - Off policy often unstable and can diverge with nn
 - But there is work to make off-policy critic better
 - Q-Prop: Sample-Efficient Policy Gradient with An Off-Policy Critic <https://arxiv.org/abs/1611.02247>
 - A2C – Synchronous A3C !
 - Synchronous point, update network and update gradients of all agents
 - A3C CPU is Ok. A2C – better on a GPU
 - UC Berkeley Soft Actor Critic ! New development as of Jan'19
 - <https://bair.berkeley.edu/blog/2018/12/14/sac/>
- 

global shared parameter vectors θ and θ_v , thread-specific parameter vectors θ' and θ'_v
 global shared counter $T = 0, T_{max}$
 initialize step counter $t \leftarrow 1$
for $T \leq T_{max}$ **do**
 reset gradients, $d\theta \leftarrow 0$ and $d\theta_v \leftarrow 0$
 synchronize thread-specific parameters $\theta' = \theta$ and $\theta'_v = \theta_v$
 set $t_{start} = t$, get state s_t
 for s_t not terminal and $t - t_{start} \leq t_{max}$ **do**
 take a_t according to policy $\pi(a_t|s_t; \theta')$
 receive reward r_t and new state s_{t+1}
 $t \leftarrow t + 1, T \leftarrow T + 1$
 end
 $R = \begin{cases} 0 & \text{for terminal } s_t \\ V(s_t, \theta'_v) & \text{otherwise} \end{cases}$
 for $i \in \{t - 1, \dots, t_{start}\}$ **do**
 $R \leftarrow r_i + \gamma R$
 accumulate gradients wrt θ' : $d\theta \leftarrow d\theta + \nabla_{\theta'} \log \pi(a_i|s_i; \theta')(R - V(s_i; \theta'_v))$
 accumulate gradients wrt θ'_v : $d\theta_v \leftarrow d\theta_v + \nabla_{\theta'_v}(R - V(s_i; \theta'_v))^2$
 end
 update asynchronously θ using $d\theta$, and θ_v using $d\theta_v$
end

Algorithm 10: A3C, each actor-learner thread, based on Mnih et al. (2016)

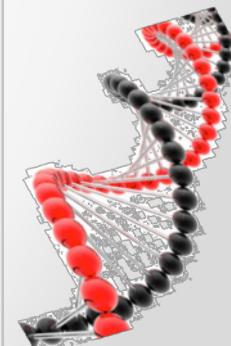
<https://arxiv.org/pdf/1810.06339.pdf>





Algorithm S2 Asynchronous n-step Q-learning - pseudocode for each actor-learner thread.

```
// Assume global shared parameter vector  $\theta$ .  
// Assume global shared target parameter vector  $\theta^-$ .  
// Assume global shared counter  $T = 0$ .  
Initialize thread step counter  $t \leftarrow 1$   
Initialize target network parameters  $\theta^- \leftarrow \theta$   
Initialize thread-specific parameters  $\theta' = \theta$   
Initialize network gradients  $d\theta \leftarrow 0$   
repeat  
    Clear gradients  $d\theta \leftarrow 0$   
    Synchronize thread-specific parameters  $\theta' = \theta$   
     $t_{start} = t$   
    Get state  $s_t$   
    repeat  
        Take action  $a_t$  according to the  $\epsilon$ -greedy policy based on  $Q(s_t, a; \theta')$   
        Receive reward  $r_t$  and new state  $s_{t+1}$   
         $t \leftarrow t + 1$   
         $T \leftarrow T + 1$   
    until terminal  $s_t$  or  $t - t_{start} == t_{max}$   
     $R = \begin{cases} 0 & \text{for terminal } s_t \\ \max_a Q(s_t, a; \theta^-) & \text{for non-terminal } s_t \end{cases}$   
    for  $i \in \{t - 1, \dots, t_{start}\}$  do  
         $R \leftarrow r_i + \gamma R$   
    Accumulate gradients wrt  $\theta'$ :  $d\theta \leftarrow d\theta + \frac{\partial(R - Q(s_i, a_i; \theta'))^2}{\partial \theta'}$   
    end for  
    Perform asynchronous update of  $\theta$  using  $d\theta$ .  
    if  $T \bmod I_{target} == 0$  then  
         $\theta^- \leftarrow \theta$   
    end if  
until  $T > T_{max}$ 
```



Algorithm S3 Asynchronous advantage actor-critic - pseudocode for each actor-learner thread.

// Assume global shared parameter vectors θ and θ_v , and global shared counter $T = 0$

// Assume thread-specific parameter vectors θ' and θ'_v

Initialize thread step counter $t \leftarrow 1$

repeat

 Reset gradients: $d\theta \leftarrow 0$ and $d\theta_v \leftarrow 0$.

 Synchronize thread-specific parameters $\theta' = \theta$ and $\theta'_v = \theta_v$

$t_{start} = t$

 Get state s_t

repeat

 Perform a_t according to policy $\pi(a_t | s_t; \theta')$

 Receive reward r_t and new state s_{t+1}

$t \leftarrow t + 1$

$T \leftarrow T + 1$

until terminal s_t **or** $t - t_{start} == t_{max}$

$R = \begin{cases} 0 & \text{for terminal } s_t \\ V(s_t, \theta'_v) & \text{for non-terminal } s_t // \text{Bootstrap from last state} \end{cases}$

for $i \in \{t - 1, \dots, t_{start}\}$ **do**

$R \leftarrow r_i + \gamma R$

 Accumulate gradients wrt θ' : $d\theta \leftarrow d\theta + \nabla_{\theta'} \log \pi(a_i | s_i; \theta') (R - V(s_i; \theta'_v))$

 Accumulate gradients wrt θ'_v : $d\theta_v \leftarrow d\theta_v + \partial (R - V(s_i; \theta'_v))^2 / \partial \theta'_v$

end for

 Perform asynchronous update of θ using $d\theta$ and of θ_v using $d\theta_v$.

until $T > T_{max}$



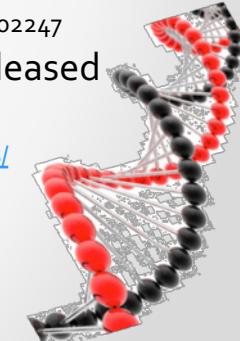
Evolution of Policy Gradients

DDPG

- Silver et al. released the DPG algorithm in 2014
 - <http://proceedings.mlr.press/v32/silver14.pdf>
- Lillicrap et al. iterated DPG with DDPG in 2015
 - <https://arxiv.org/abs/1509.02971>
- Ornstein–Uhlenbeck process
 - https://en.wikipedia.org/wiki/Ornstein–Uhlenbeck_process
- A3c vs DDPG
 - <https://yodahuang.github.io/articles/DDPG-vs-A2C/>

PPO

- In 2016, Schulman et al. released TRPO() and GAE algorithms(GAE on TRPO)
 - TRPO : <https://arxiv.org/abs/1502.05477>
 - GAE : <https://arxiv.org/abs/1506.02438>
- PPO (Proximal Policy Optimization Algorithms)
 - <https://arxiv.org/abs/1707.06347>
- Q-Prop: Sample-Efficient Policy Gradient with An Off-Policy Critic
 - Gu, Lillicrap, Levine : <https://arxiv.org/abs/1611.02247>
- Sergey Levine, Chelsea Finn, et al. released the GPS algorithm
 - Guided Policy Search <http://rll.berkeley.edu/gps/>





A3C vs DDPG

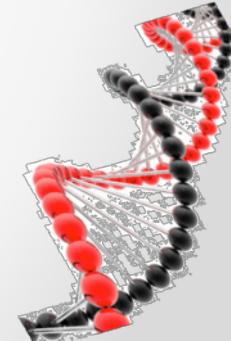
A3C

- Episode (~MC paradigm)
- On-line, on-policy
- Loss = loglikelihood
- Continuous action can be modelled as a Gaussian vector

DDPG

- TD() & TD(λ)
- Off-Policy
- Experience Replay
- Target network mix-in & blending via soft update
- Better for continuous state & action space

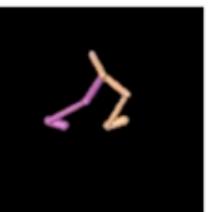
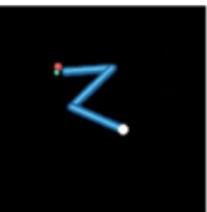
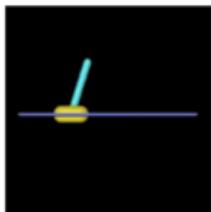
They both use the Actor-Critic design – approximately ! - finer semantics might differ





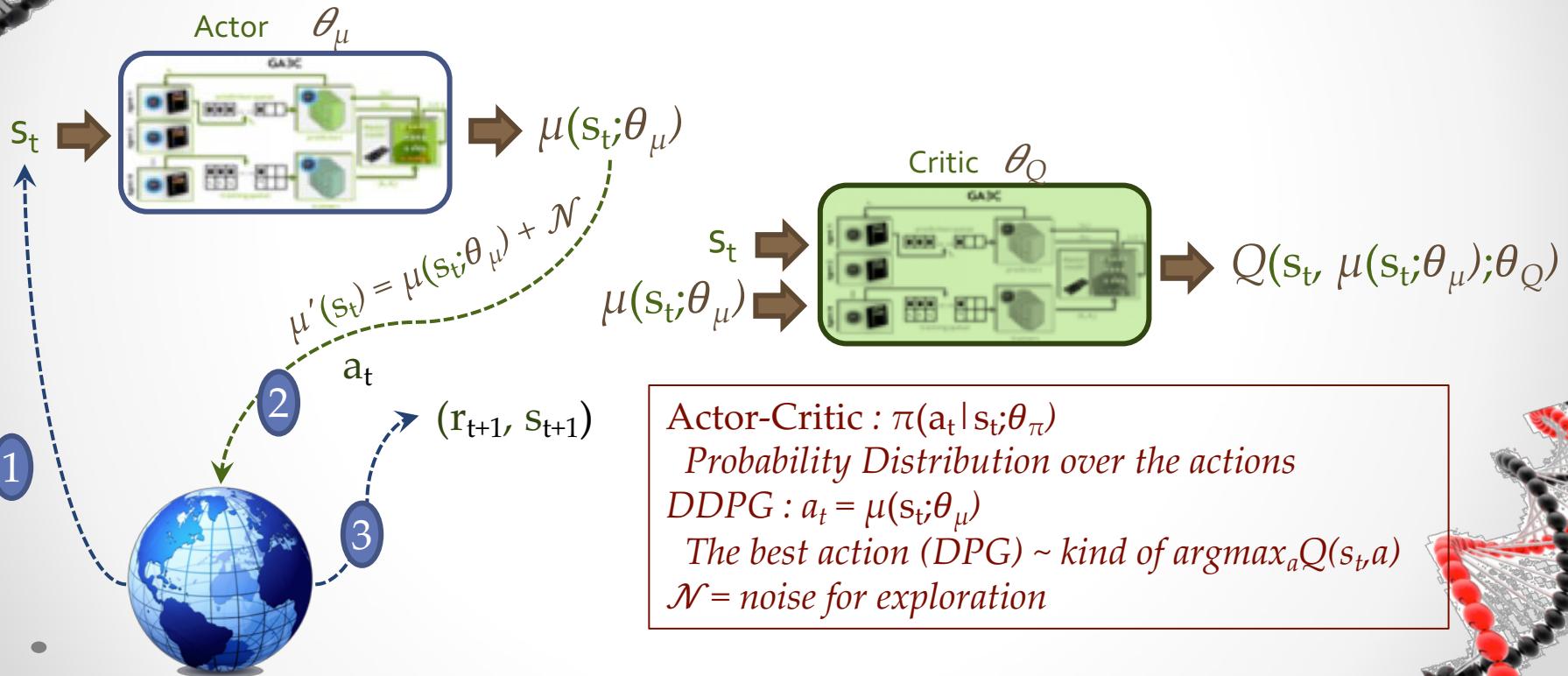
DDPG

- Paper <https://arxiv.org/abs/1509.02971>
- Deterministic Policy : $a_t = \mu(s_t | \theta^\mu)$
- Paper says it is actor-critic
 - Morales – it is more of an approx. DQN for continuous *action* space similar to NAF(<https://arxiv.org/abs/1603.00748>)
 - The critic is a maximizer not a baseline
- A key feature of the approach is its simplicity
 - *It requires only a straightforward actor-critic architecture and learning algorithm with very few “moving parts”, making it easy to implement and scale to more difficult problems and larger networks*



DDPG Intuition


$$\mu_{\theta(t+1)} = \mu_\theta + \alpha \sum \nabla_a Q(s_t, a; \theta_Q) | (a = \mu(s_t)) \nabla_{\theta_\mu} \mu(s_t; \theta_\mu)$$





Algorithm 1 DDPG algorithm

Randomly initialize critic network $Q(s, a|\theta^Q)$ and actor $\mu(s|\theta^\mu)$ with weights θ^Q and θ^μ .

Initialize target network Q' and μ' with weights $\theta^{Q'} \leftarrow \theta^Q, \theta^{\mu'} \leftarrow \theta^\mu$

Initialize replay buffer R

for episode = 1, M **do**

 Initialize a random process \mathcal{N} for action exploration

 Receive initial observation state s_1

for t = 1, T **do**

 Select action $a_t = \mu(s_t|\theta^\mu) + \mathcal{N}_t$ according to the current policy and exploration noise

 Execute action a_t and observe reward r_t and observe new state s_{t+1}

 Store transition (s_t, a_t, r_t, s_{t+1}) in R

 Sample a random minibatch of N transitions (s_i, a_i, r_i, s_{i+1}) from R] Experience Replay

 Set $y_i = r_i + \gamma Q'(s_{i+1}, \mu'(s_{i+1}|\theta^{\mu'})|\theta^{Q'})$

 Update critic by minimizing the loss: $L = \frac{1}{N} \sum_i (y_i - Q(s_i, a_i|\theta^Q))^2$

 Update the actor policy using the sampled policy gradient:

$$\nabla_{\theta^\mu} J \approx \frac{1}{N} \sum_i \nabla_a Q(s, a|\theta^Q)|_{s=s_i, a=\mu(s_i)} \nabla_{\theta^\mu} \mu(s|\theta^\mu)|_{s_i}$$

 Update the target networks:

$$\theta^{Q'} \leftarrow \tau \theta^Q + (1 - \tau) \theta^{Q'}$$

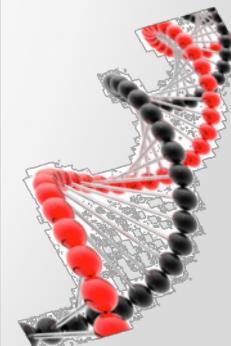
$$\theta^{\mu'} \leftarrow \tau \theta^\mu + (1 - \tau) \theta^{\mu'}$$

end for

end for

Sample
Env

Learn





Algorithm 1 Deep Deterministic Policy Gradient

1: Input: initial policy parameters θ , Q-function parameters ϕ , empty replay buffer \mathcal{D}
2: Set target parameters equal to main parameters $\theta_{\text{targ}} \leftarrow \theta$, $\phi_{\text{targ}} \leftarrow \phi$
3: **repeat**
4: Observe state s and select action $a = \text{clip}(\mu_\theta(s) + \epsilon, a_{\text{Low}}, a_{\text{High}})$, where $\epsilon \sim \mathcal{N}$
5: Execute a in the environment
6: Observe next state s' , reward r , and done signal d to indicate whether s' is terminal
7: Store (s, a, r, s', d) in replay buffer \mathcal{D}
8: If s' is terminal, reset environment state.
9: **if** it's time to update **then**
10: **for** however many updates **do**
11: Randomly sample a batch of transitions, $B = \{(s, a, r, s', d)\}$ from \mathcal{D}
12: Compute targets

$$y(r, s', d) = r + \gamma(1 - d)Q_{\phi_{\text{targ}}}(s', \mu_{\theta_{\text{targ}}}(s'))$$

13: Update Q-function by one step of gradient descent using

$$\nabla_\phi \frac{1}{|B|} \sum_{(s, a, r, s', d) \in B} (Q_\phi(s, a) - y(r, s', d))^2$$

14: Update policy by one step of gradient ascent using

$$\nabla_\theta \frac{1}{|B|} \sum_{s \in B} Q_\phi(s, \mu_\theta(s))$$

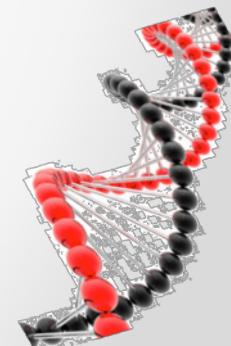
15: Update target networks with

$$\begin{aligned}\phi_{\text{targ}} &\leftarrow \rho\phi_{\text{targ}} + (1 - \rho)\phi \\ \theta_{\text{targ}} &\leftarrow \rho\theta_{\text{targ}} + (1 - \rho)\theta\end{aligned}$$

16: **end for**

17: **end if**

18: **until** convergence





Hands-On #11 : Balancing the Cart Pole w/ DDPG

- Goal:
 - Implement DDPG on the CartPole Environment
 - It is an overkill, but we will get a good understanding and also can compare against other algorithms
- Steps:
 - Program DDPG Algorithm
 - Run and Optimize
 - Plot Values, like we did in other exercises
- DDPG for discrete actions
 - DDPG for Discrete Action Domains
https://www.reddit.com/r/reinforcementlearning/comments/8k8bye/ddpg_for_discrete_action_domains/

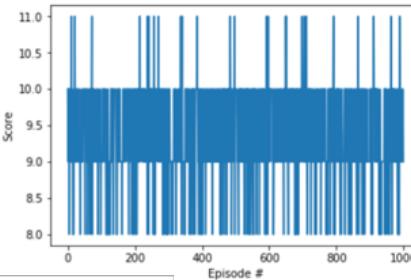




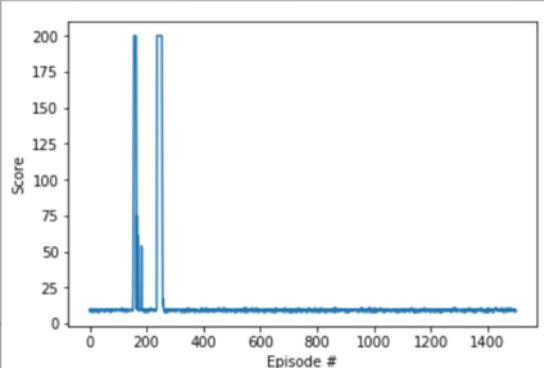
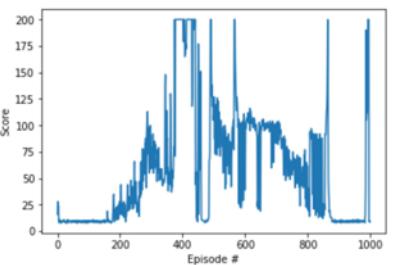
Bad Runs ..

- Just meanders around
- Doesn't go beyond a score of 11
- Or learns well
- Then unlearns

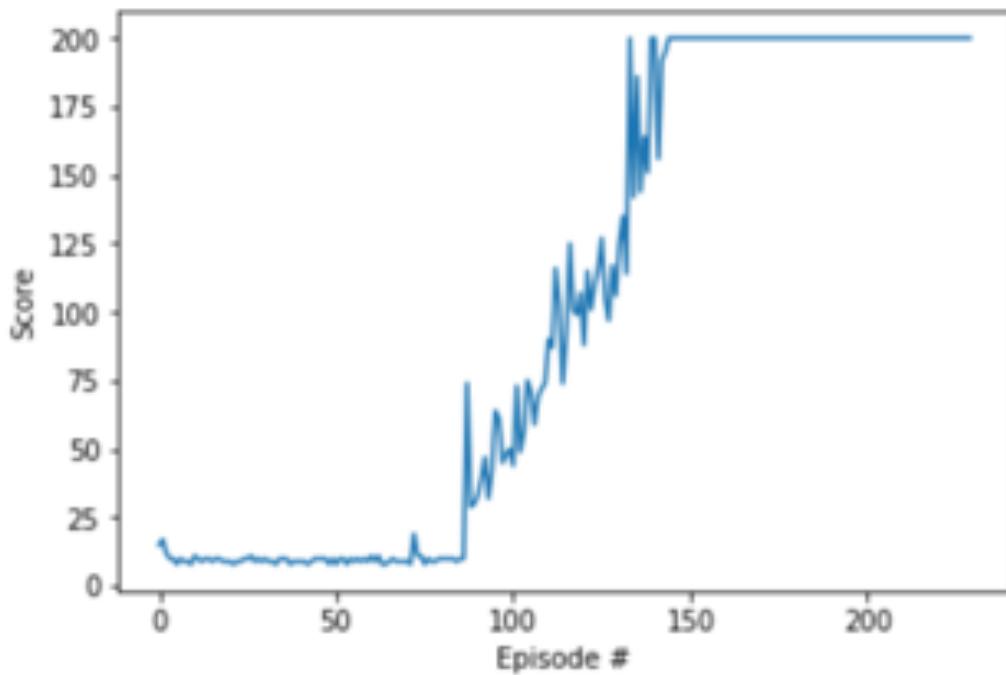
```
Episode 100    Average Score: 9.3131   Score:  9.00   Max_steps : 8
Episode 200    Average Score: 9.2929   Score: 10.00   Max_steps : 9
Episode 300    Average Score: 9.4242   Score:  8.00   Max_steps : 7
Episode 400    Average Score: 9.3232   Score: 10.00   Max_steps : 9
Episode 500    Average Score: 9.3333   Score: 10.00   Max_steps : 9
Episode 600    Average Score: 9.3333   Score:  9.00   Max_steps : 8
Episode 700    Average Score: 9.4343   Score: 10.00   Max_steps : 9
Episode 800    Average Score: 9.3838   Score: 10.00   Max_steps : 9
Episode 900    Average Score: 9.2929   Score: 10.00   Max_steps : 9
Episode 1000   Average Score: 9.2828   Score:  9.00   Max_steps : 8
Elapsed : 0:00:37.123424
2019-02-02 09:10:54.042185
```



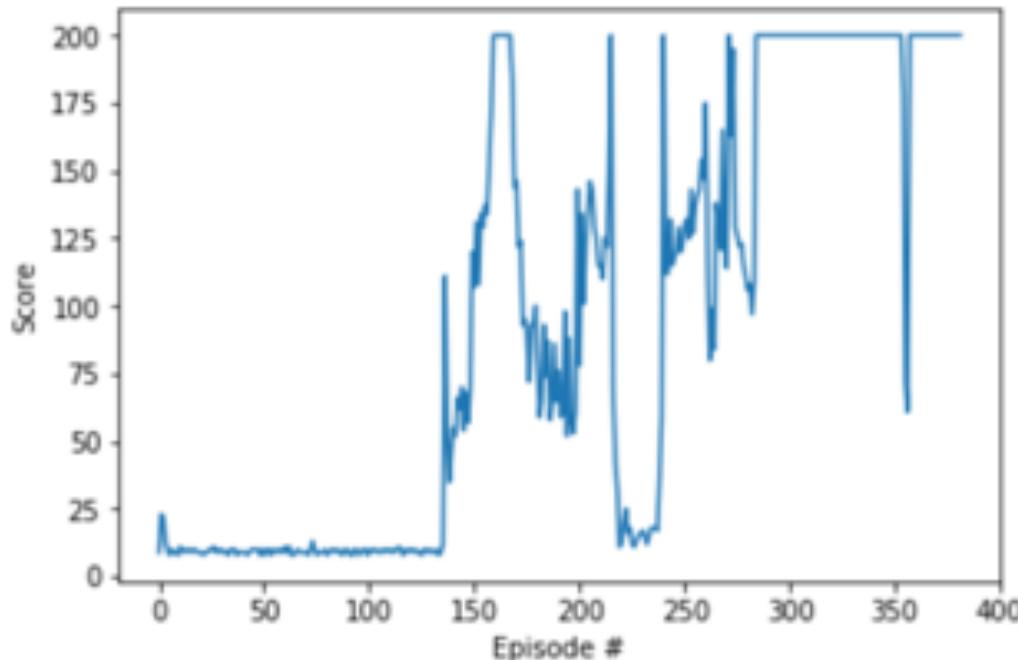
```
Episode 100    Average Score: 9.8080   Score:  8.00   Max_steps : 7
Episode 200    Average Score: 11.433   Score: 18.00   Max_steps : 17
Episode 300    Average Score: 42.622   Score: 59.00   Max_steps : 58
Episode 400    Average Score: 98.055   Score: 200.00  Max_steps : 199
Episode 500    Average Score: 113.16   Score: 110.00  Max_steps : 109
Episode 600    Average Score: 89.211   Score: 100.00  Max_steps : 99
Episode 700    Average Score: 94.122   Score: 85.00   Max_steps : 84
Episode 800    Average Score: 65.322   Score: 30.00   Max_steps : 29
Episode 900    Average Score: 44.555   Score: 10.00   Max_steps : 9
Episode 1000   Average Score: 24.555   Score:  9.00   Max_steps : 8
Elapsed : 0:03:46.871175
2019-02-02 09:18:48.363542
```



Episode 100 Average Score: 14.377 Score: 50.00 Max_steps : 49
Episode 200 Average Score: 162.22 Score: 200.00 Max_steps : 199
Episode 230 Average Score: 195.04 Score: 200.00 Max_steps : 199
Environment solved in 130 episodes! Average Score: 195.04
Elapsed : 0:01:16.801558
2019-02-08 12:59:29.923779



Episode 100 Average Score: 9.61 Score: 8.00 Max_steps : 79
Episode 200 Average Score: 71.03 Score: 143.00 Max_steps : 142
Episode 300 Average Score: 114.96 Score: 200.00 Max_steps : 199
Episode 382 Average Score: 195.17 Score: 200.00 Max_steps : 199
Environment solved in 282 episodes! Average Score: 195.17
Elapsed : 0:02:29.415469
2019-01-13 18:14:48.885969

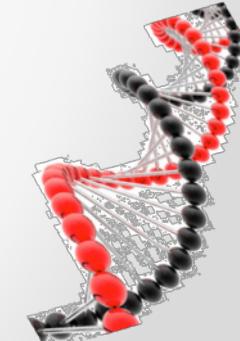
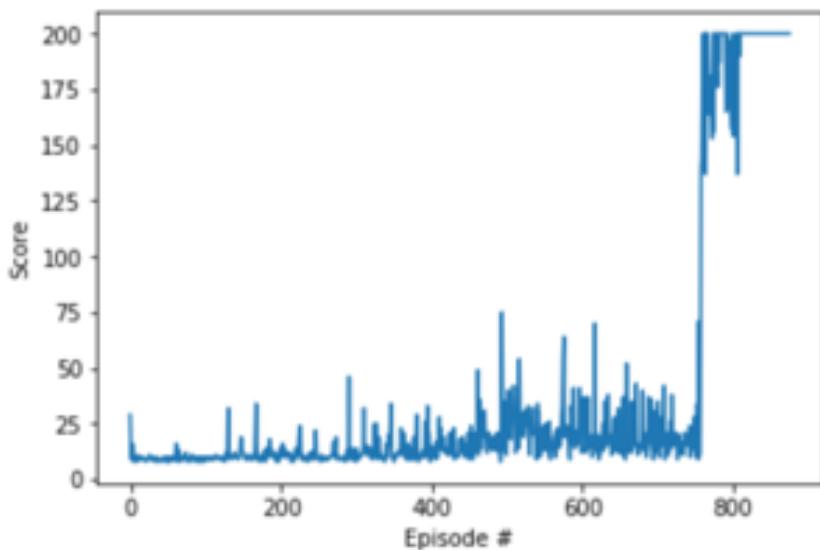


Perfect Test Score!

Episode : 1 Score : 200.00 Steps : 199
Episode : 2 Score : 200.00 Steps : 199
Episode : 3 Score : 200.00 Steps : 199
Episode : 4 Score : 200.00 Steps : 199
Episode : 5 Score : 200.00 Steps : 199
Episode : 6 Score : 200.00 Steps : 199
Episode : 7 Score : 200.00 Steps : 199
Episode : 8 Score : 200.00 Steps : 199
Episode : 9 Score : 200.00 Steps : 199
Episode : 10 Score : 200.00 Steps : 199
Mean of 10 episodes = 200.0
Elapsed : 0:00:00.517737
2019-01-13 18:18:07.700678



Episode 100	Average Score: 9.8282	Score: 8.00	Max_steps : 7
Episode 200	Average Score: 11.033	Score: 14.00	Max_steps : 13
Episode 300	Average Score: 11.300	Score: 8.00	Max_steps : 7
Episode 400	Average Score: 13.588	Score: 11.00	Max_steps : 10
Episode 500	Average Score: 16.977	Score: 11.00	Max_steps : 10
Episode 600	Average Score: 22.666	Score: 26.00	Max_steps : 25
Episode 700	Average Score: 20.444	Score: 12.00	Max_steps : 11
Episode 800	Average Score: 89.944	Score: 200.00	Max_steps : 199
Episode 875	Average Score: 195.33	Score: 200.00	Max_steps : 199
Environment solved in 775 episodes!	Average Score: 195.33		
Elapsed : 0:02:12.733915			
2019-01-18 09:19:16.580979			

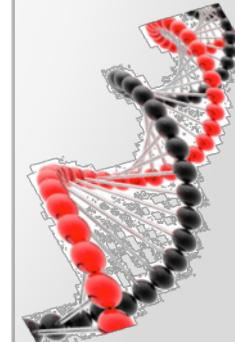
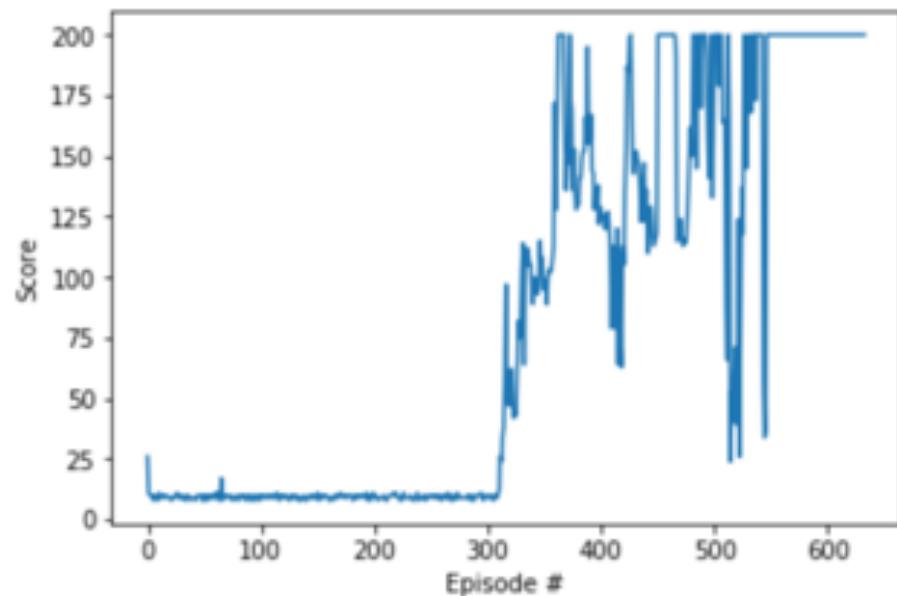


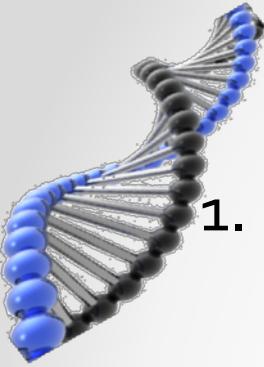


Episode 100	Average Score: 9.5858	Score: 8.00	Max_steps : 7
Episode 200	Average Score: 9.4444	Score: 11.00	Max_steps : 10
Episode 300	Average Score: 9.3535	Score: 10.00	Max_steps : 9
Episode 400	Average Score: 104.71	Score: 129.00	Max_steps : 128
Episode 500	Average Score: 149.30	Score: 170.00	Max_steps : 169
Episode 600	Average Score: 173.89	Score: 200.00	Max_steps : 199
Episode 633	Average Score: 195.01	Score: 200.00	Max_steps : 199
Environment solved in 533 episodes!		Average Score: 195.01	

Elapsed : 0:03:13.291465

2019-02-02 09:44:52.322328

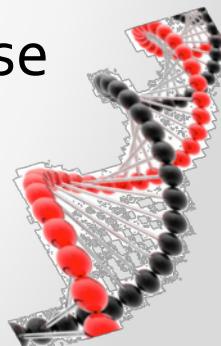


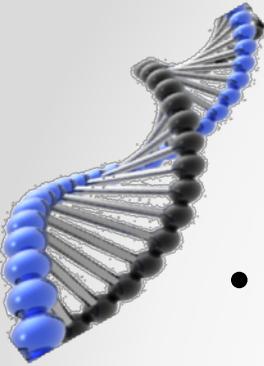


Lessons from Implementation

1. Ornstein-Uhlenbeck process for exploration noise !
 - o “.. Deterministic policy gradient might not explore the full state and action space”
 - o Need a noise process to encourage exploration : $a_t = \mu(s_t|\theta^\mu) + \mathcal{N}_t$
 - o “Generates temporally correlated exploration”
 - o “Exploration efficiency with inertia”
2. Unlearn & diverge / slow
 - o We can see what Lillicrap, Silver* et al refers to as “*instability in learning wherein progress on a problem is either destroyed by subsequent learning updates, or else learning is too slow to be practical*”
3. A good solution for the cartpole
4. Very sensitive to hyperparameters – may be because DDPG is an overkill for the cartpole
5. Remember to restart the Kernel between tries

*<https://arxiv.org/pdf/1509.02971.pdf>

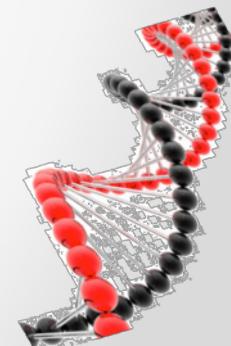




Quiz



- What is the DQN DNN topology ?
 -
- What is the input size ? Output size ?
 -
- What is the output of the actor network ?
 -
- How does the output translate to an action ?
 -
- Is the policy deterministic or stochastic ?
 -
- How do you characterize this w.r.t others ?
 -



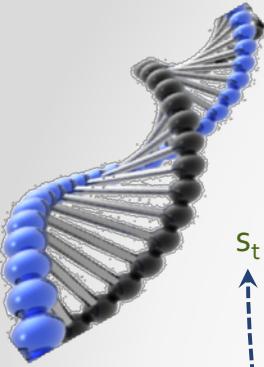


Quiz

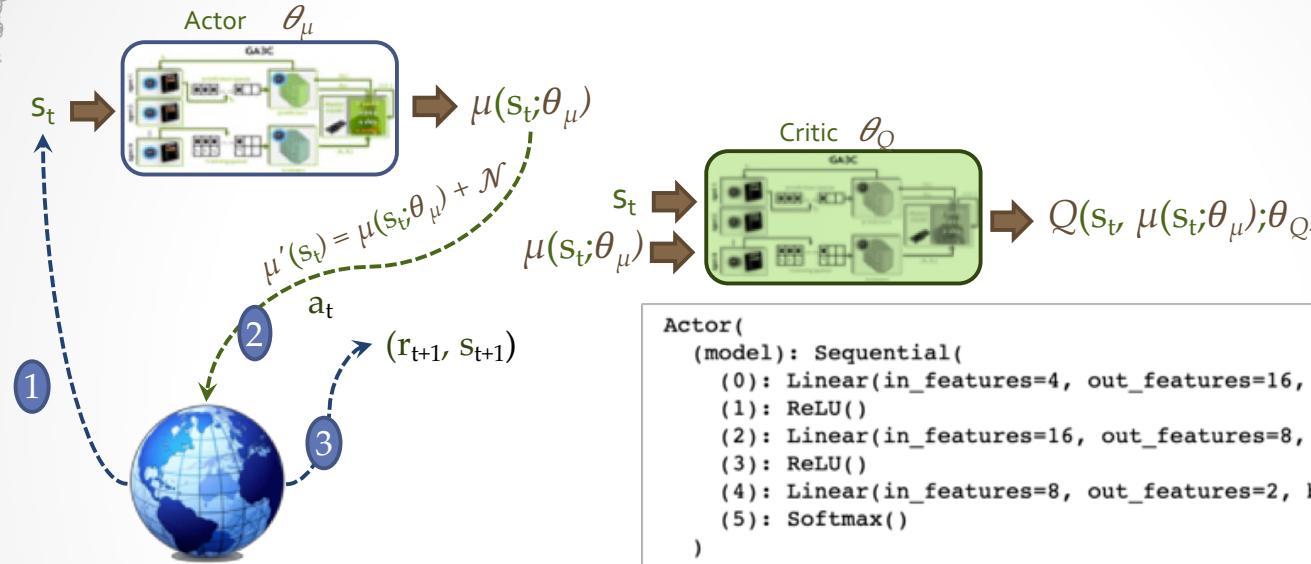


- What is the DQN DNN topology ?
 - FC16-FC8-FC2
- What is the input size ? Output size ?
 - Input = 4 (state), output = 2 (actions)
- What is the output of the actor network ?
 - softmax
- How does the output translate to an action ?
 - sample
- Is the policy deterministic or stochastic ?
 - Stochastic ! We get it as a part of the architecture !
- How do you characterize this w.r.t others ?
 - A good solution ! But sensitive to hyperparameters – probably an overkill



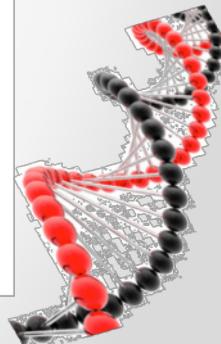


Notice the Critic Network

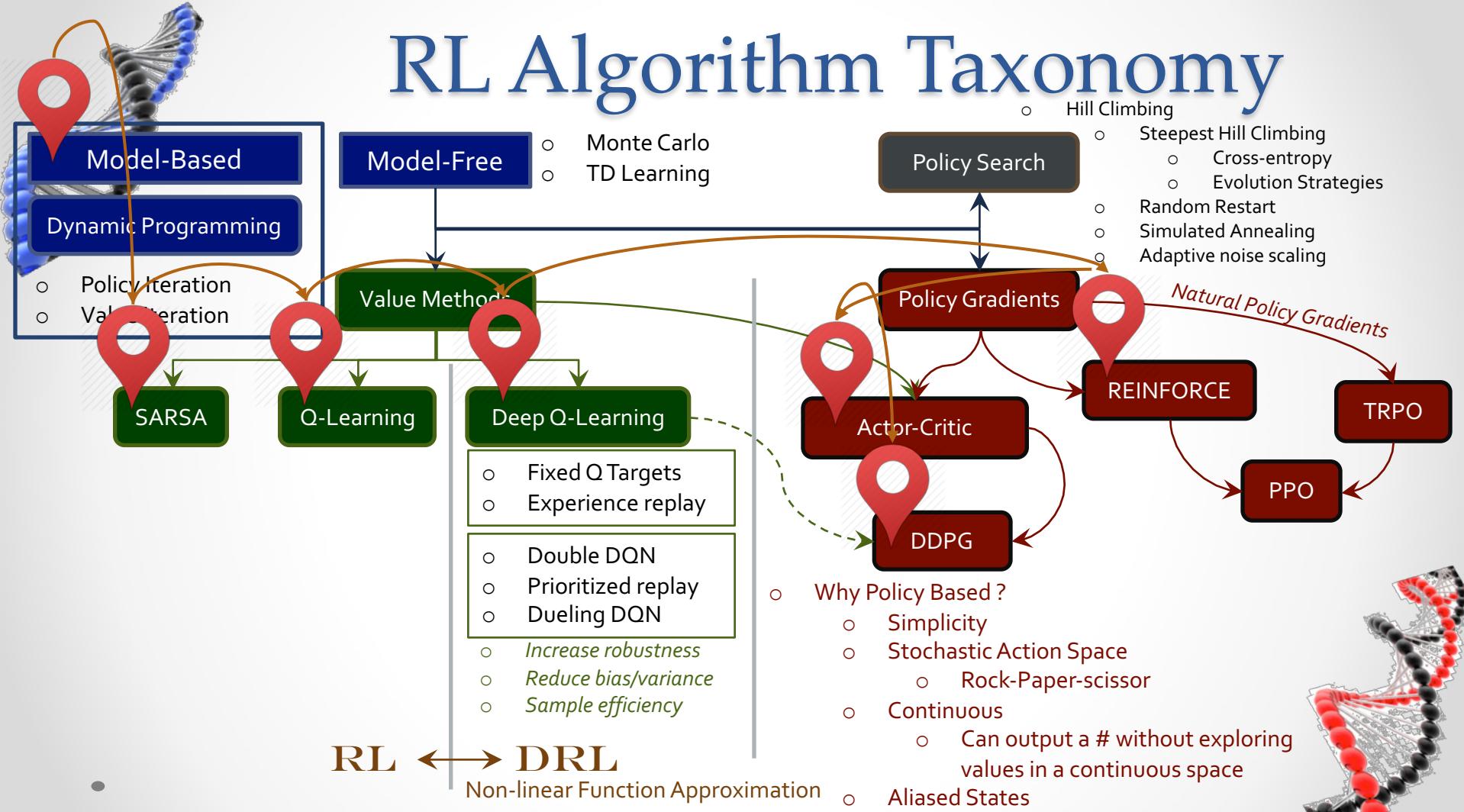


The actions are fed into the network after the FC16 layer

```
Actor(  
    (model): Sequential(  
        (0): Linear(in_features=4, out_features=16, bias=True)  
        (1): ReLU()  
        (2): Linear(in_features=16, out_features=8, bias=True)  
        (3): ReLU()  
        (4): Linear(in_features=8, out_features=2, bias=True)  
        (5): Softmax()  
    )  
)  
Critic(  
    (hc_1): Sequential(  
        (0): Linear(in_features=4, out_features=16, bias=True)  
        (1): ReLU()  
    )  
    (hc_2): Sequential(  
        (0): Linear(in_features=18, out_features=8, bias=True)  
        (1): ReLU()  
        (2): Linear(in_features=8, out_features=1, bias=True)  
    )  
)
```



RL Algorithm Taxonomy

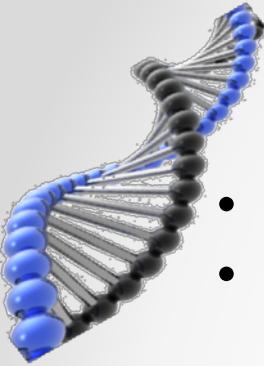




Natural Policy Gradients & Trust Region variants

- Policy Gradients tend to get stuck in local plateaus
- Natural Policy Gradients operate in a different space than the parameter space, the Fisher metric
 - Instead of following the usual steepest direction in the parameter space, NPG algorithms follow the steepest direction with respect to the Fisher metric
 - The caveat with natural gradients is that, in the case of neural networks and their large number of parameters, it is usually impractical to compute, invert, and store the Fisher information matrix
- Trust Region algorithms leverage the natural gradients
 - As a modification to the natural gradient method, policy optimization methods based on a trust region aim at improving the policy while changing it in a controlled way.



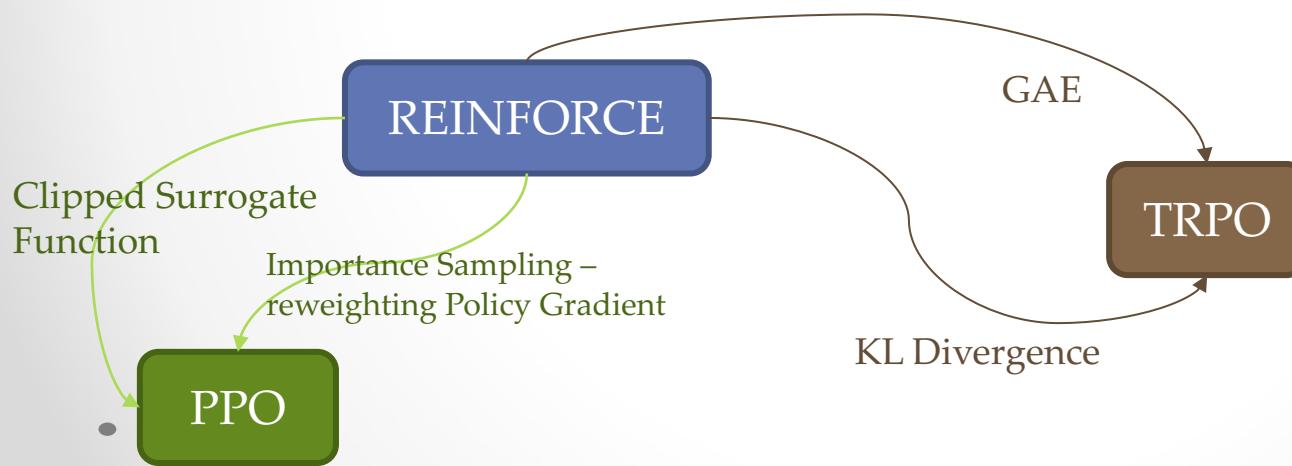


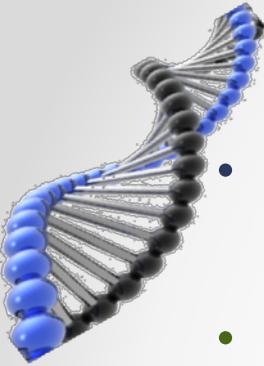
PPO & TRPO

- Another interesting set of ideas that have become mainstream
- *“PPO has become the default reinforcement learning algorithm at OpenAI because of its ease of use and good performance”*
 - <https://blog.openai.com/openai-baselines-ppo/>
 - PPO paper <https://arxiv.org/abs/1707.06347>
- TRPO
 - <https://spinningup.openai.com/en/latest/algorithms/trpo.html>

The image shows the OpenAI Spinning Up logo, which consists of a green hexagon with a white atom-like symbol inside, followed by the text "OpenAI Spinning Up". Below this, there is a dark sidebar with the following menu items:

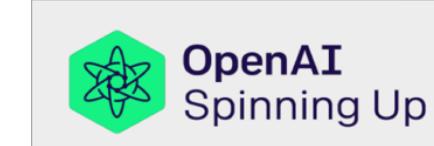
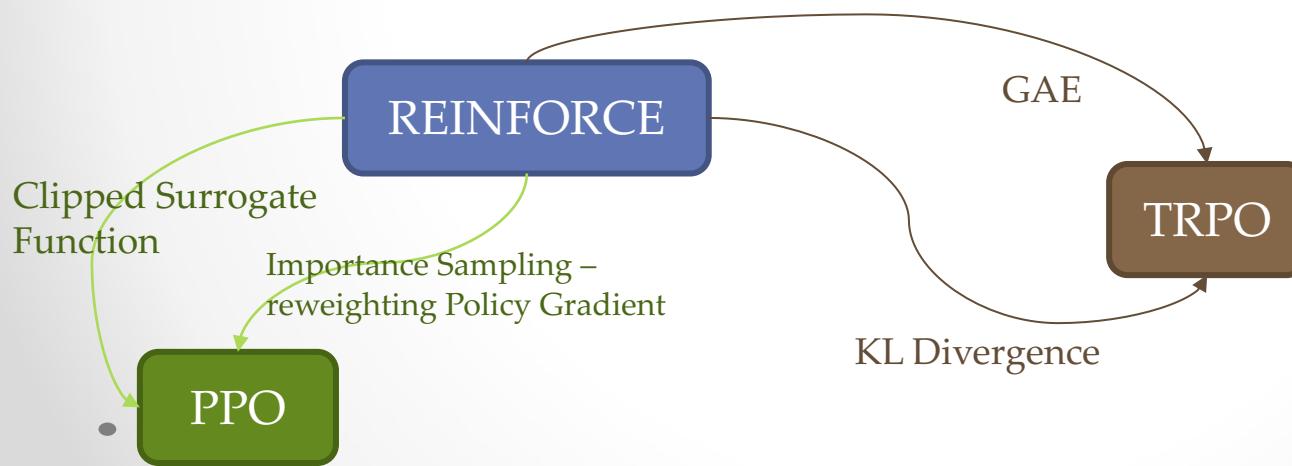
- ALGORITHMS DOCS
- Vanilla Policy Gradient
- Trust Region Policy Optimization
- Proximal Policy Optimization
- Deep Deterministic Policy Gradient
- Twin Delayed DDPG
- Soft Actor-Critic





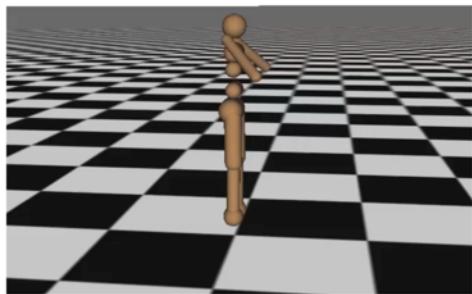
PPO & TRPO

- These constraint-based policy optimization methods focus on restricting the changes in a policy using mechanisms like the KL divergence between the action distributions
- TRPO uses constrained updates and advantage function estimation to perform the update, resulting in the reformulated optimization
- Proximal Policy Optimization (PPO) is a variant of the TRPO algorithm, which formulates the constraint as a penalty or a clipping objective, instead of using the KL constraint

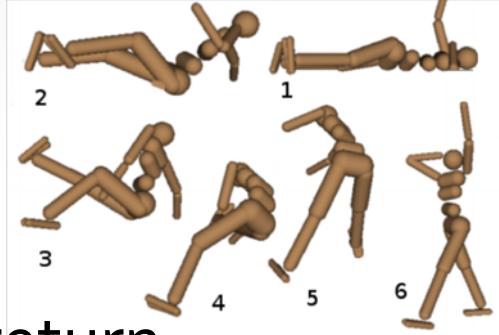


ALGORITHMS DOCS

- Vanilla Policy Gradient
- Trust Region Policy Optimization
- Proximal Policy Optimization
- Deep Deterministic Policy Gradient
- Twin Delayed DDPG
- Soft Actor-Critic



GAE



- GAE (is a mechanism) – mixture of lambda return.
Difficult to say which n is better
 - Combination of all n step weighted by exponentially decaying lambda
- High-Dimensional Continuous Control Using Generalized Advantage Estimation <https://arxiv.org/abs/1506.02438>
- Learning LocomoQon (TRPO + GAE)
 - Schulman, Moritz, Levine, Jordan, Abbeel, 2016

An interesting paper experiments with the agent's physical structure as a parameter
Reinforcement Learning for Improving Agent Design
• <https://arxiv.org/pdf/1810.03779.pdf>



Actor-Critic with A3C or GAE

- Policy Gradient + Generalized Advantage Estimation:

- Init π_{θ_0} $V_{\phi_0}^{\pi}$

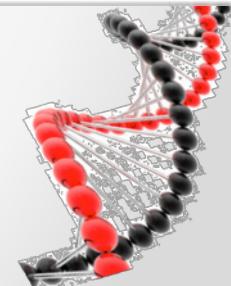
- Collect roll-outs $\{s, u, s', r\}$ and $\hat{Q}_i(s, u)$

- Update: $\phi_{i+1} \leftarrow \min_{\phi} \sum_{(s, u, s', r)} \|\hat{Q}_i(s, u) - V_{\phi}^{\pi}(s)\|_2^2 + \kappa \|\phi - \phi_i\|_2^2$

$$\theta_{i+1} \leftarrow \theta_i + \alpha \frac{1}{m} \sum_{k=1}^m \sum_{t=0}^{H-1} \nabla_{\theta} \log \pi_{\theta_i}(u_t^{(k)} | s_t^{(k)}) \left(\hat{Q}_i(s_t^{(k)}, u_t^{(k)}) - V_{\phi_i}^{\pi}(s_t^{(k)}) \right)$$

Async Advantage Actor Critic (A3C) [Mnih et al, 2016]

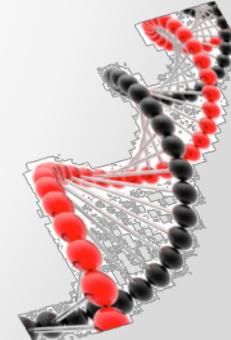
one of the above choices (e.g. k=5 step lookahead)





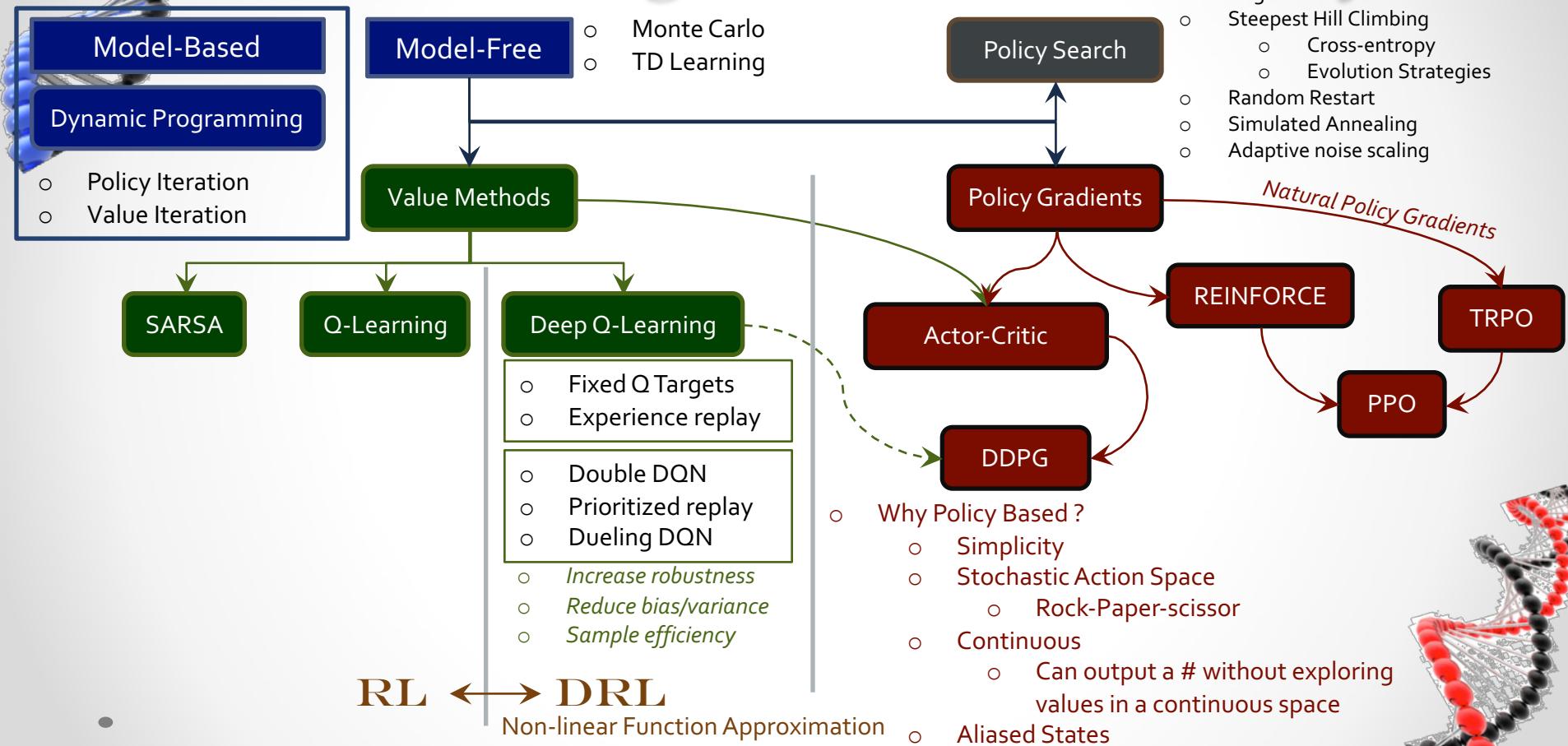
6. Conclusion

...





RL Algorithm Taxonomy

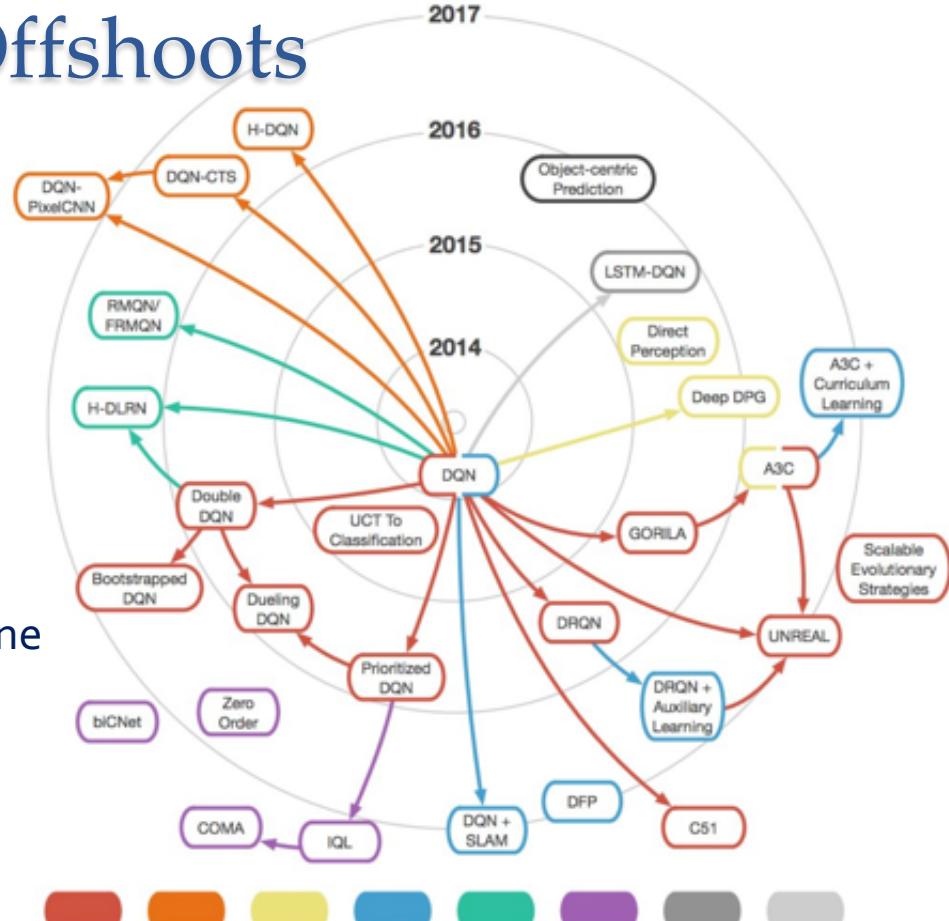




Influences & Offshoots



- My view is throw it all away and start again,...
- Max Planck said, 'Science progresses one funeral at a time'
- *The future depends on some graduate student who is deeply suspicious of everything I have said.*



<https://www.axios.com/artificial-intelligence-pioneer-says-we-need-to-start-over-1513305524-f619efbd-9dbo-4947-a9b2-7a4c310a28fe.html>

<https://arxiv.org/abs/1708.07902>



AlphaStar: Mastering the Real-Time Strategy Game StarCraft II

StarCraft, considered to be one of the most challenging Real-Time Strategy games and one of the longest-played esports of all time, has emerged by consensus as a "grand challenge" for AI research. Here, we introduce our StarCraft II program AlphaStar, the first Artificial Intelligence to defeat a top professional player.

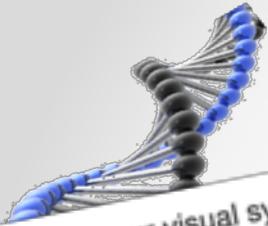


The AlphaStar team
10 hours ago

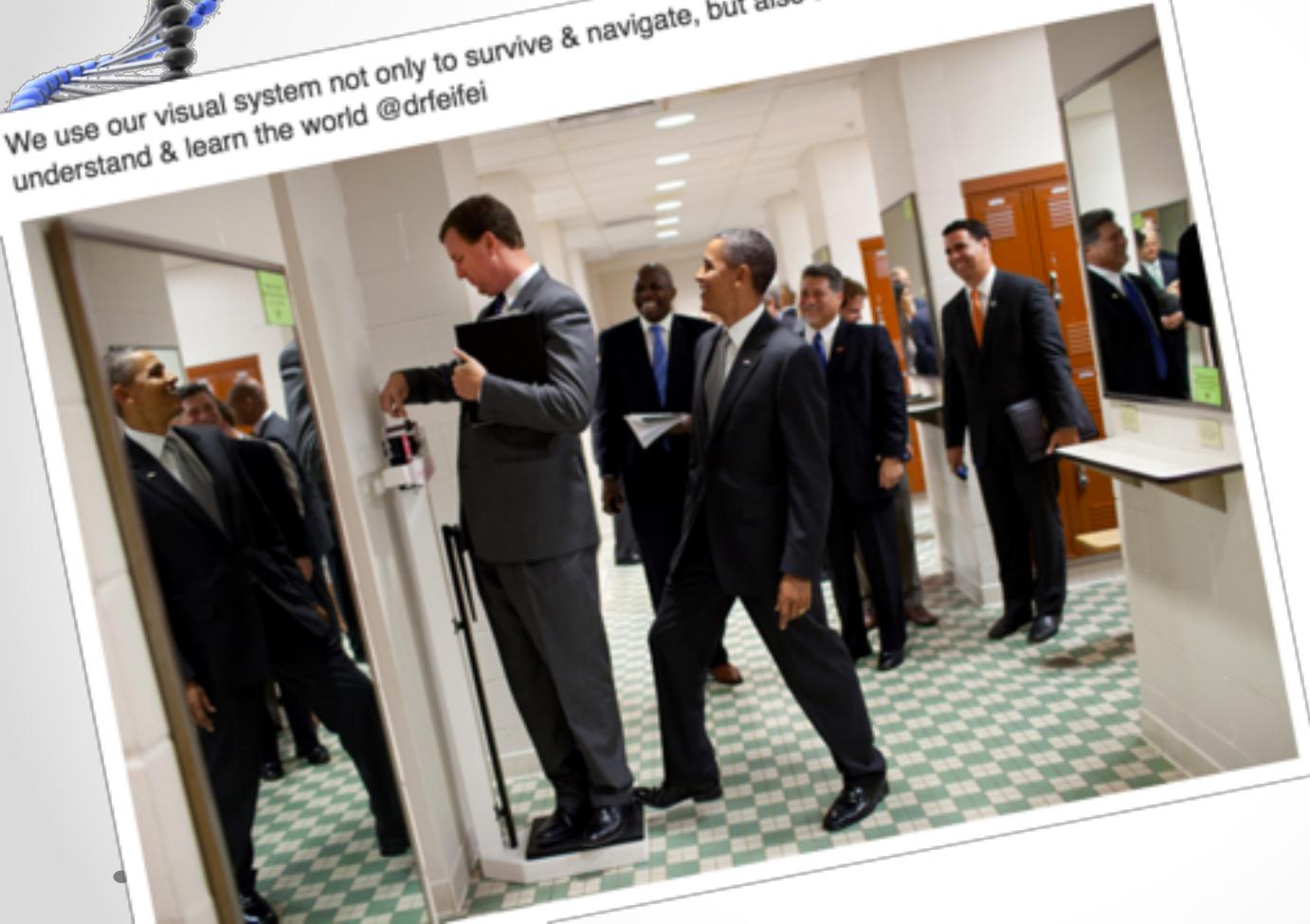


1. Game theory: StarCraft is a game where, just like rock-paper-scissors, there is no single best strategy. As such, an AI training process needs to continually explore and expand the frontiers of strategic knowledge.
2. Imperfect information: Unlike games like chess or Go where players see everything, crucial information is hidden from a StarCraft player and must be actively discovered by "scouting".
3. Long term planning: Like many real-world problems cause-and-effect is not instantaneous. Games can also take anywhere up to one hour to complete, meaning actions taken early in the game may not pay off for a long time.
4. Real time: Unlike traditional board games where players alternate turns between subsequent moves, StarCraft players must perform actions continually as the game clock progresses.
5. Large action space: Hundreds of different units and buildings must be controlled at once, in real-time, resulting in a combinatorial space of possibilities. On top of this, actions are hierarchical and can be modified and augmented. Our parameterization of the game has an average of approximately 10 to the 26 legal actions at every time-step.





We use our visual system not only to survive & navigate, but also to socialize, entertain, understand & learn the world @drleifei



Can a machine understand the nuances and humor in this picture ?

