Reinforcement Learning with Ray RLlib

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RAY

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https://research.ibm.com/blog/what-is-accelerated-discovery

https://time.com/6249784/quantum-computing-revolution/

01 Feb 2022 Explainer 10 minute read

What's next in computing: The era of accelerated discovery

To meet the growing challenges of an ever-shifting world, the ways we have discovered new ideas in the past won't cut it moving forward. A convergence of computing revolutions taking place right now will help accelerate the rate of scientific discovery like nothing before.

erated discovery aim to develop, validate, and incubate technologies that accelerate the
the scientific method, harnessing the capabilities of AI, hybrid cloud, and quantum computing. We
-edge technologies, working together, to address society's greatest challenges — to find novel
als able to help us fight challenges from pandemics to climate change and so much more.

Quantum Computers Could Solve Countless Problems—And Create a Lot of New Ones

Outline

- Why Reinforcement Learning?
- Ray RLlib
  - Aside: Why Ray?
- More Reinforcement Learning Concepts and Challenges
- Reinforcement Learning for Recommendations
- To Learn More...

https://www.youtube.com/watch?v=Lu56xVIZ40M

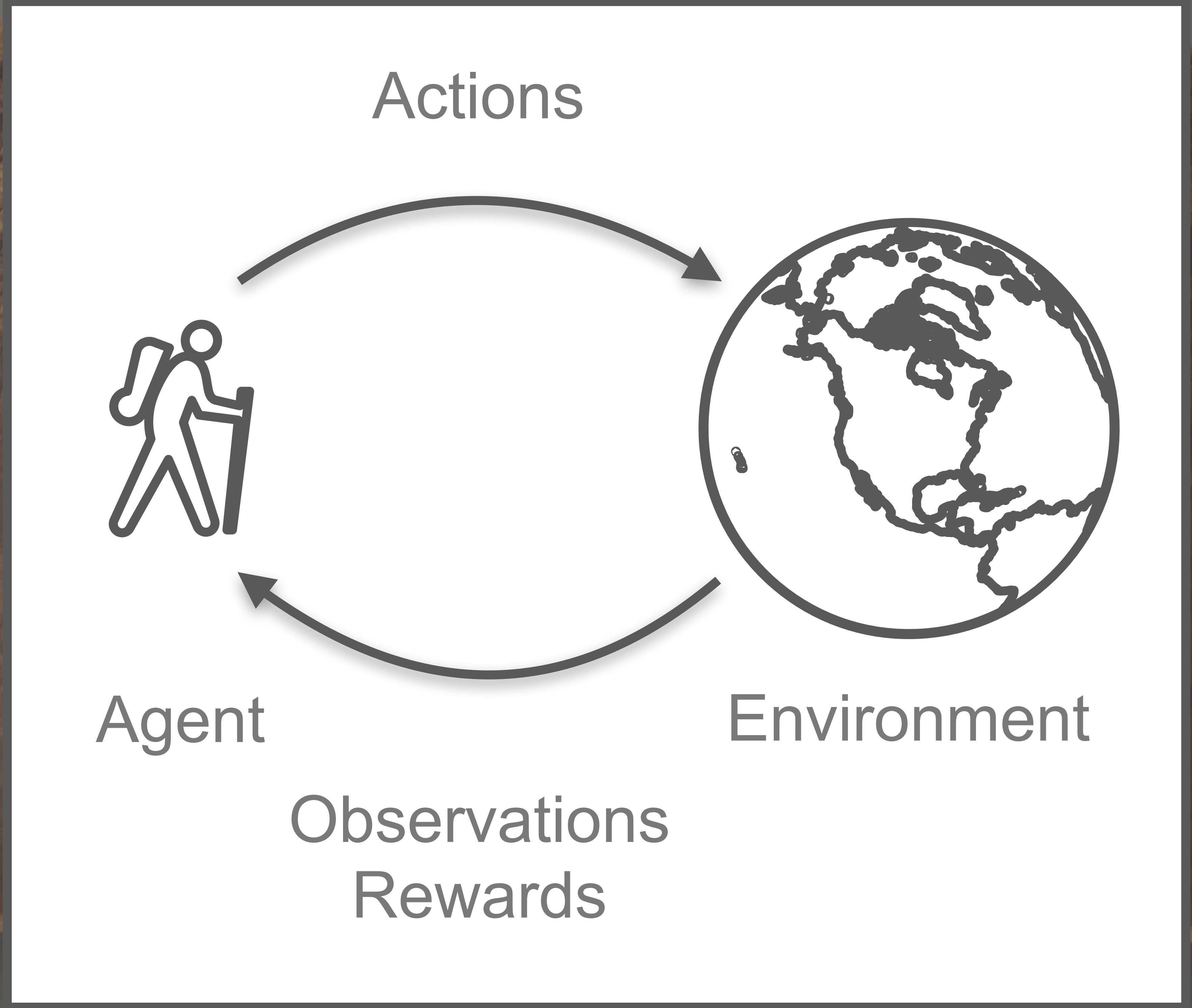
Why Reinforcement Learning?


TWO MINUTE
PAPERS
WITH KÁROLY ZSOLNAI-FEHÉR

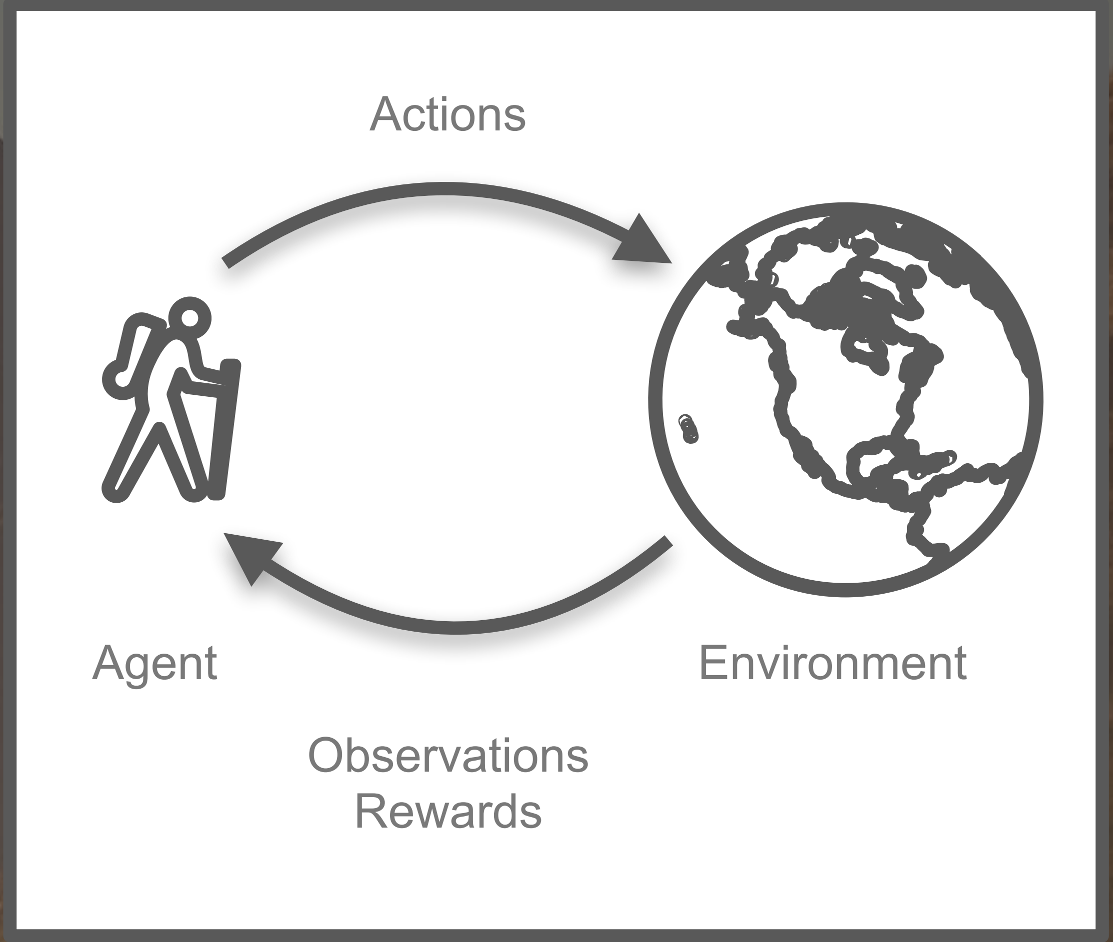
The Agent choses an Action, then Observes any changes to the Environment and a Reward received, if any.

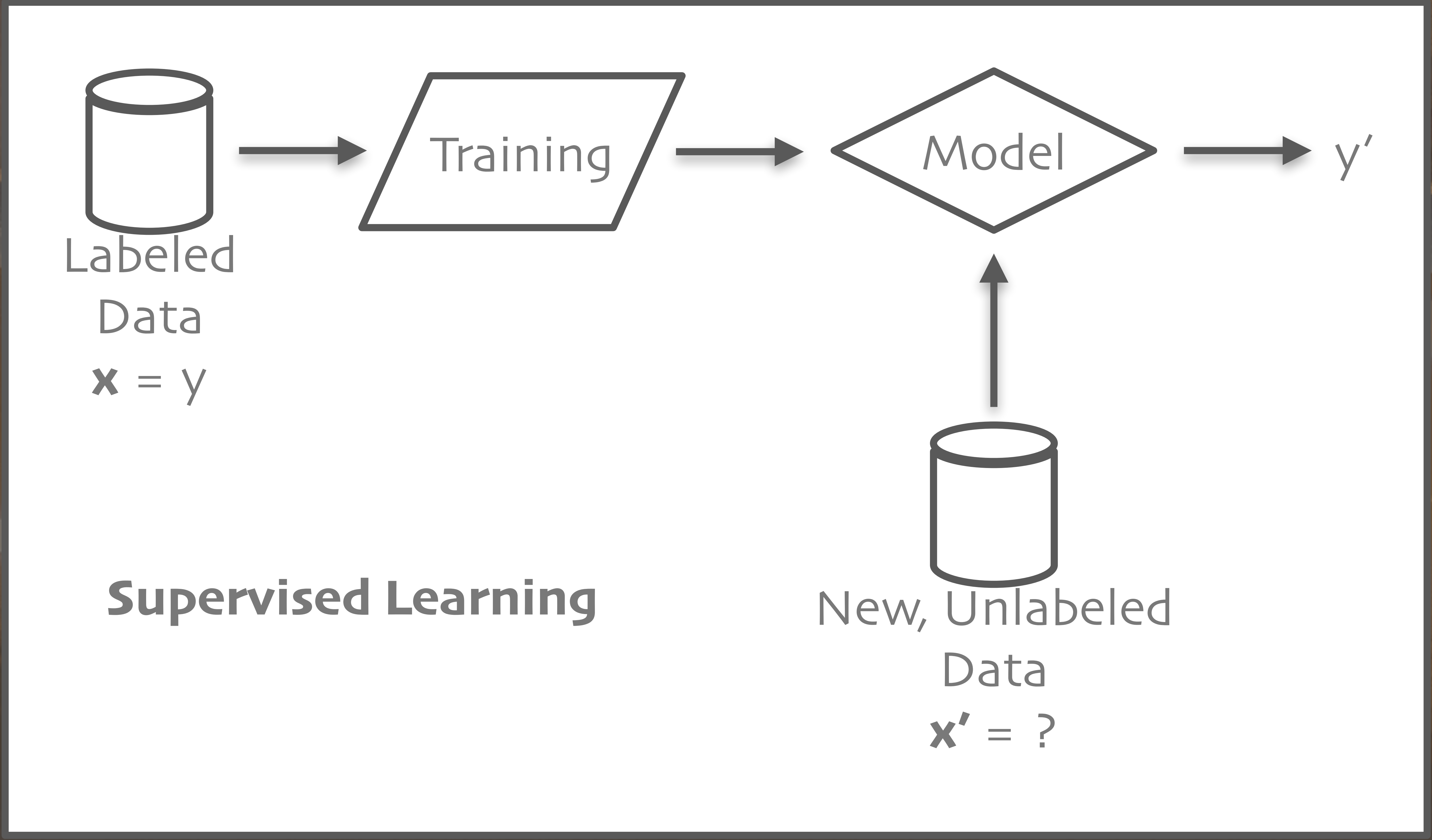
Through repeated steps like this, the Agent learns a Policy for maximizing the cumulative Reward.

Each sequence is an Episode. It takes many Episodes to learn a good Policy.

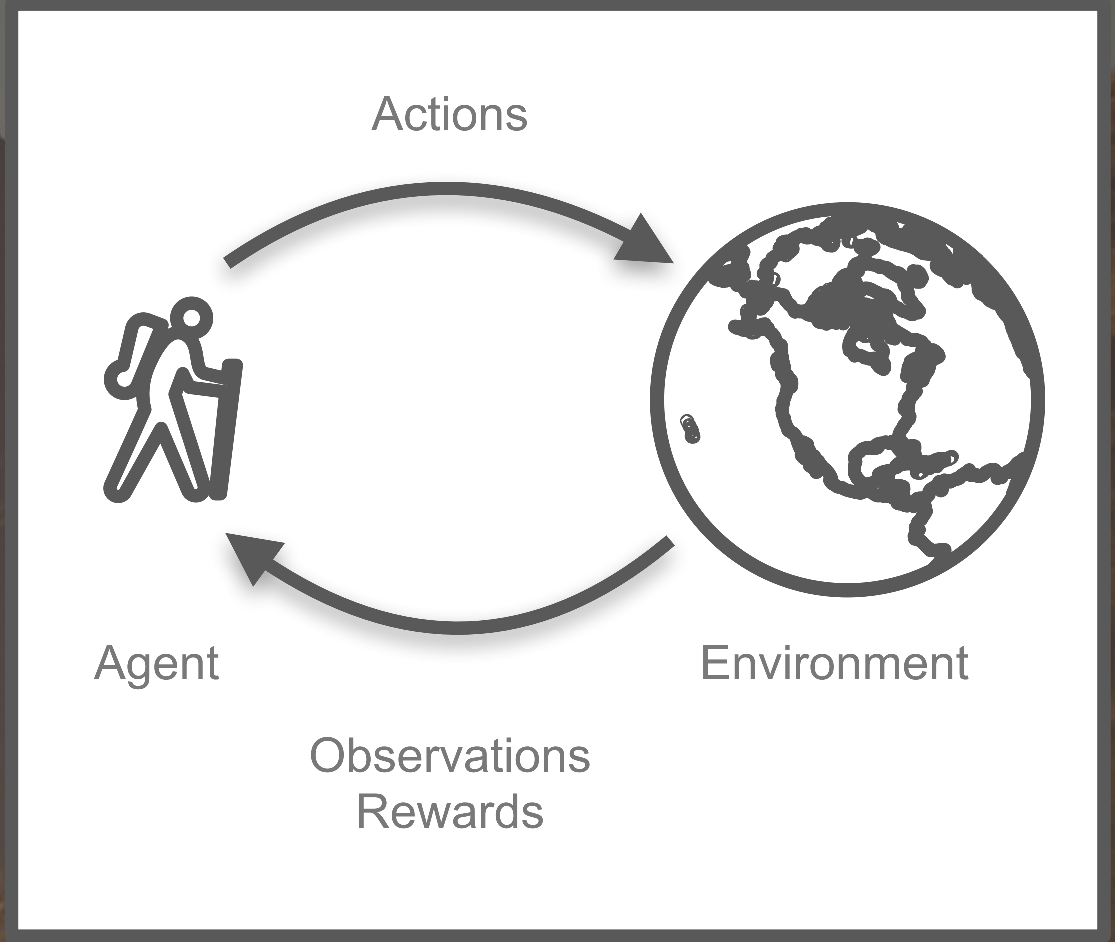


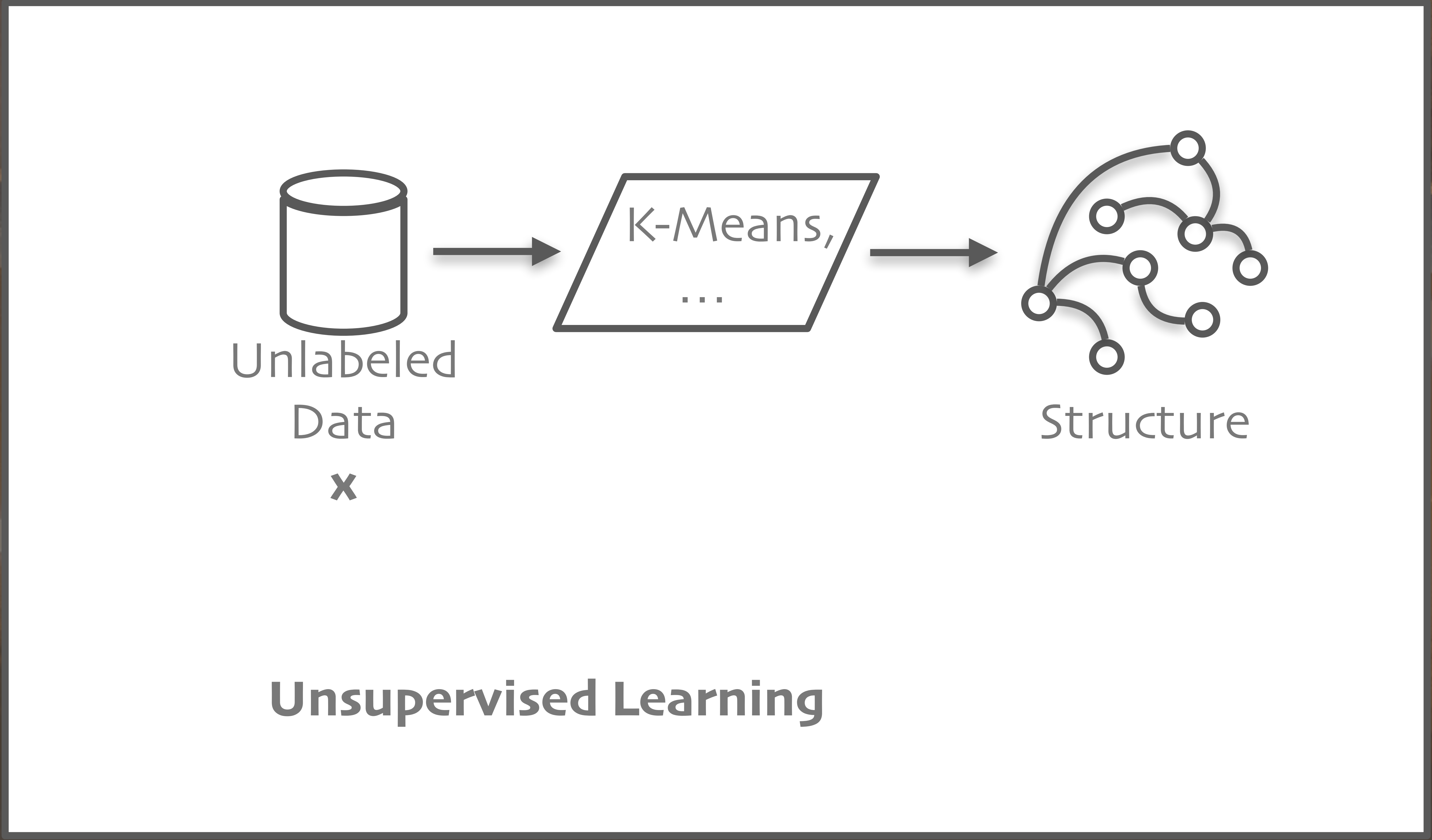
Compared to Supervised Learning





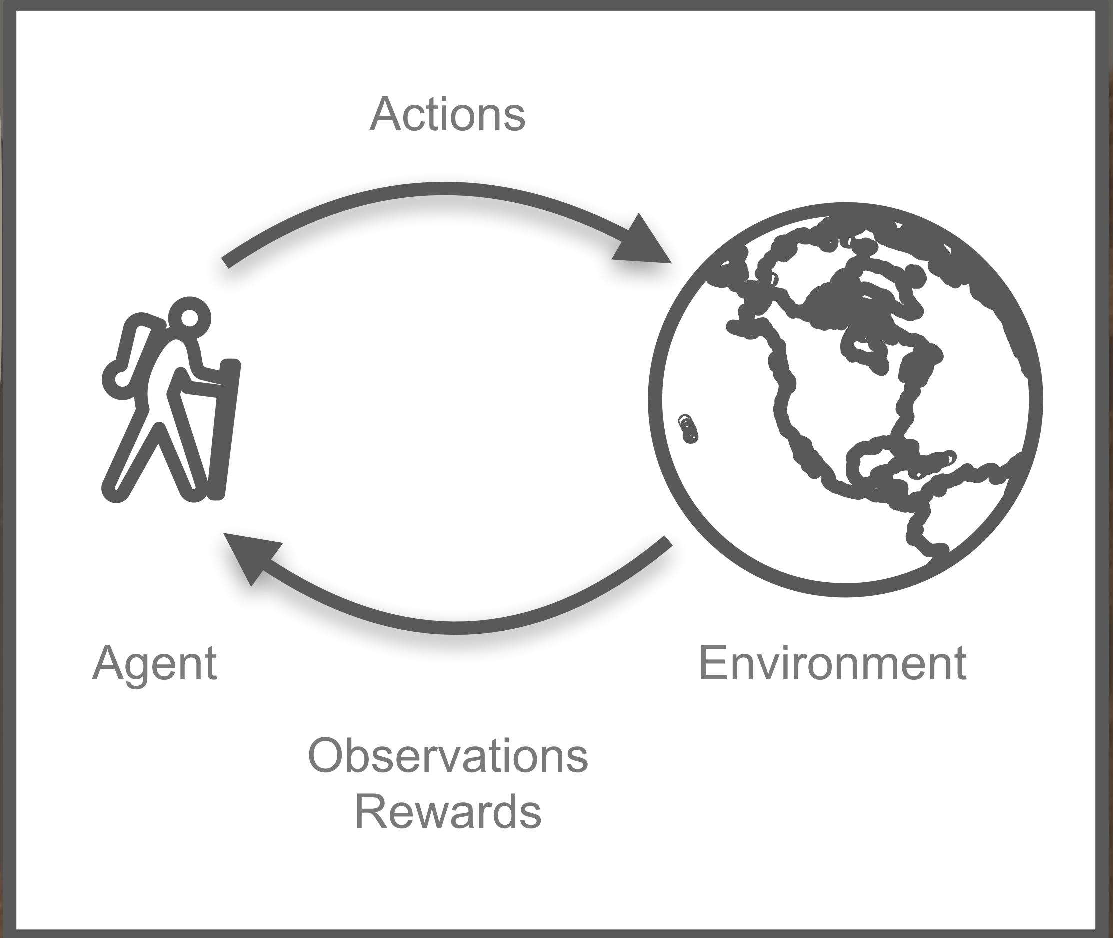
Compared to Unsupervised Learning



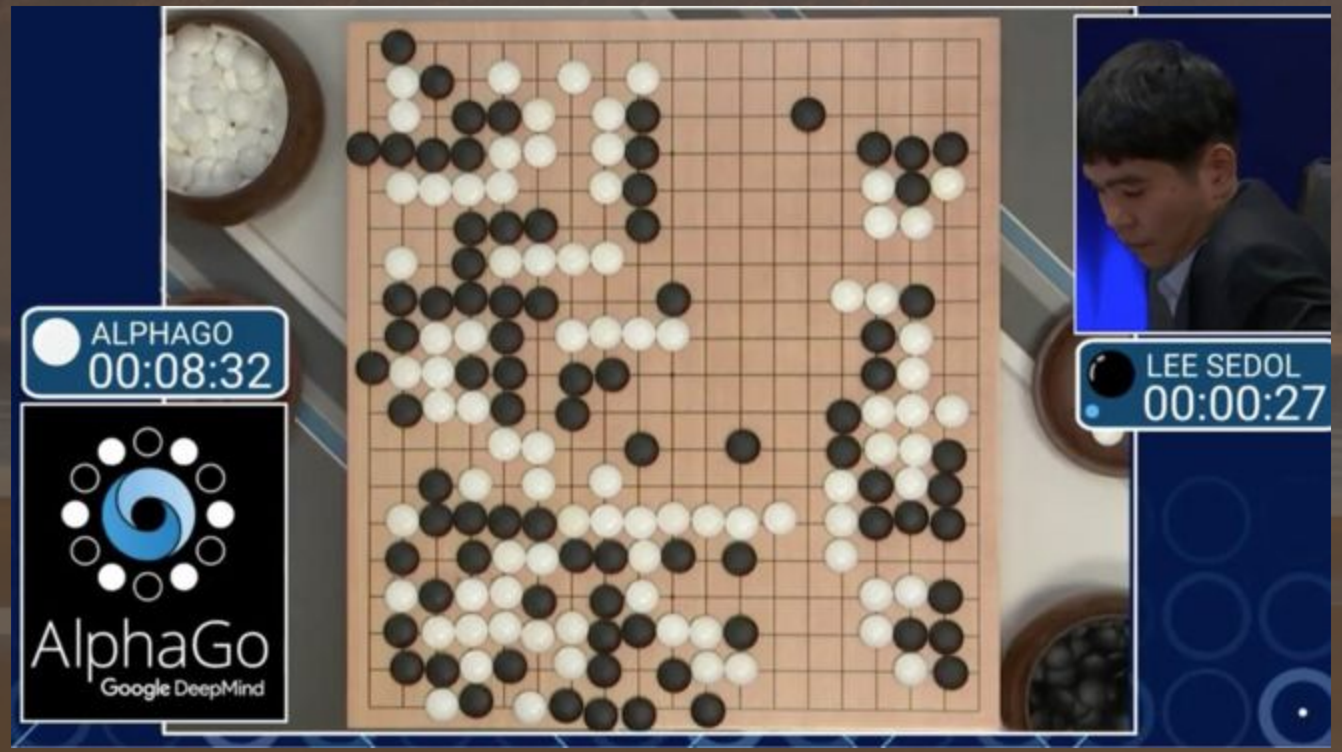


RL Applications

AlphaGo, Atari, OpenAI Gym/ Gymnasium, …

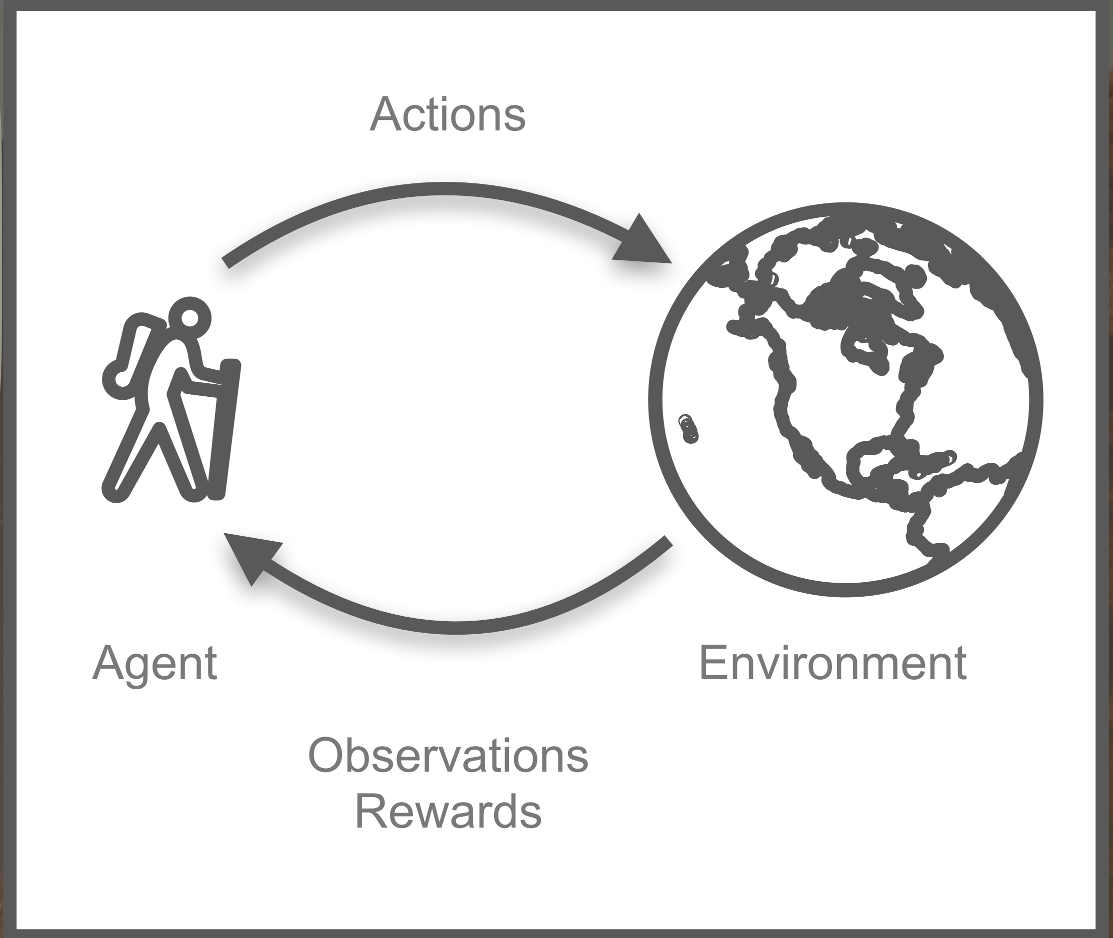


- Games
- Robotics, Autonomous Vehicles
- Industrial Processes
- System Optimization
- Advertising, Recommendations
- Finance



RL Applications

Autonomous vehicles, N-pedal robots, pick and place robots, …



Games

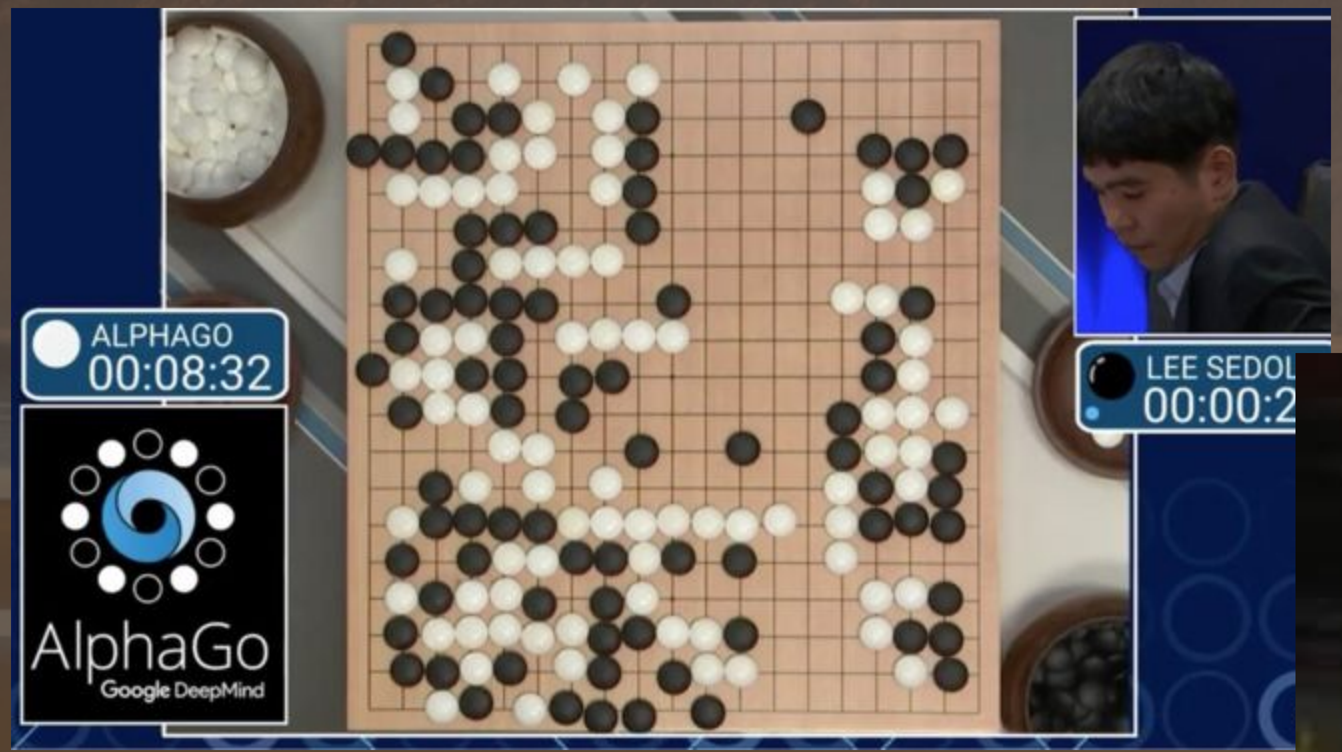
Robotics, Autonomous Vehicles

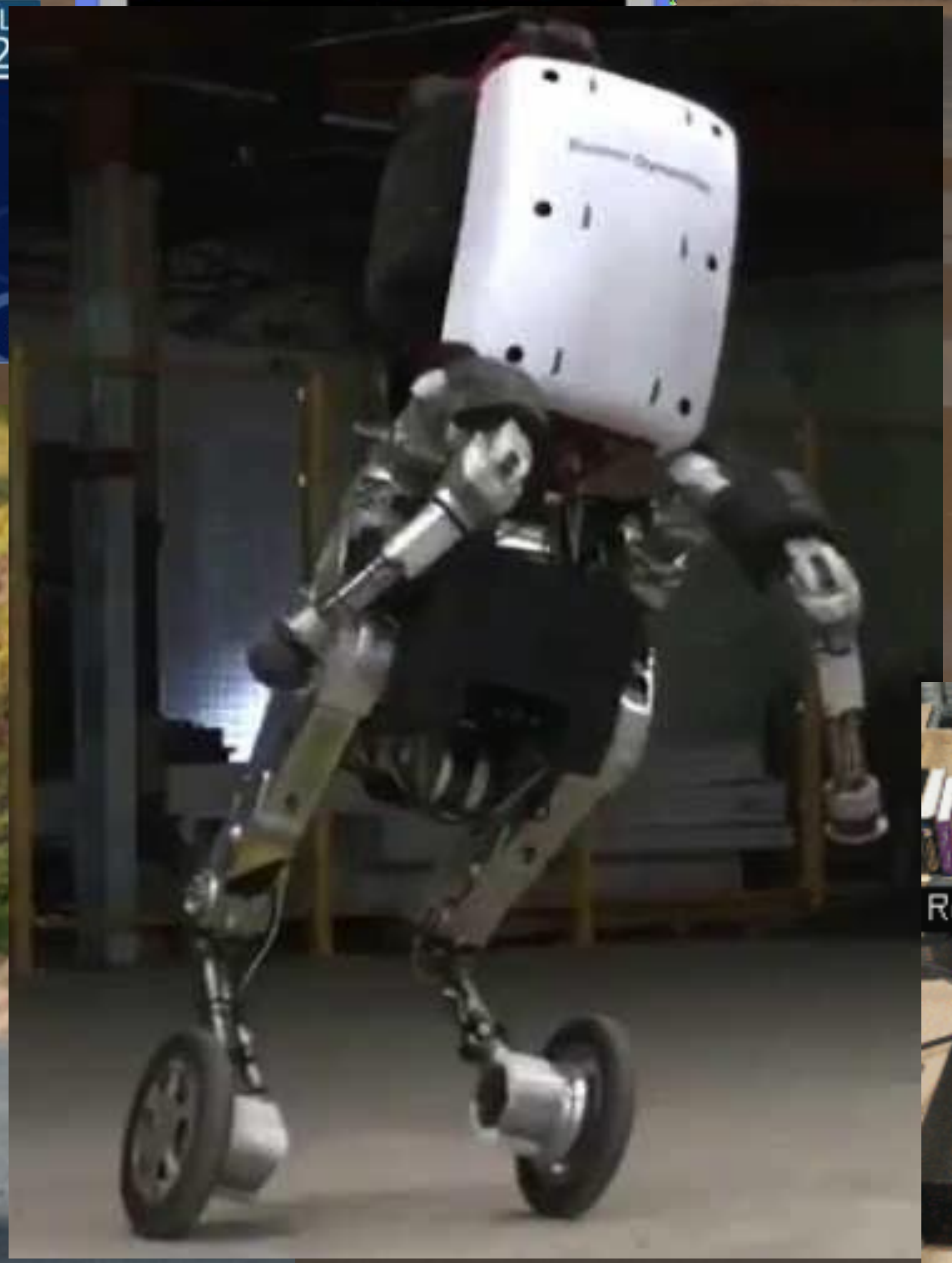
Industrial Processes

System Optimization

Advertising, Recommendations

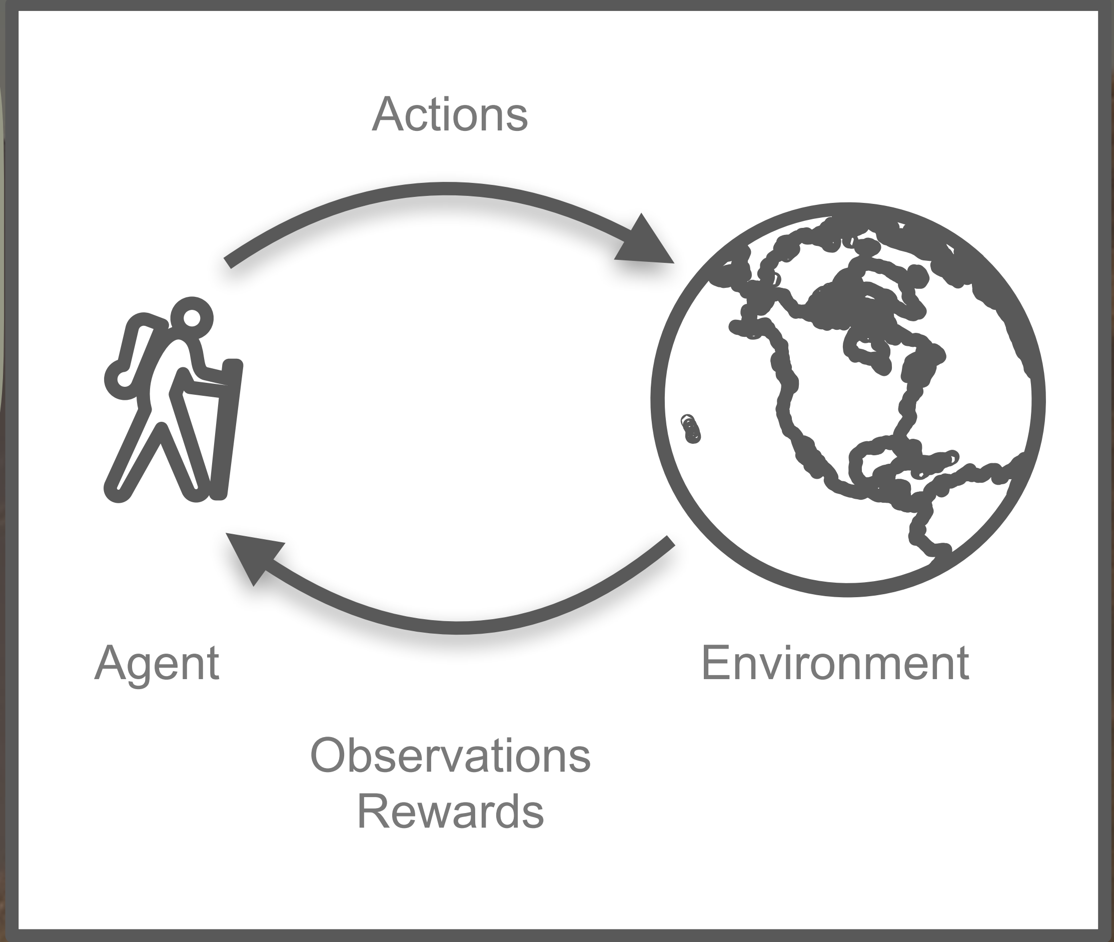
Finance





RL Applications

Assembly lines, warehouse and delivery routing, …



Games

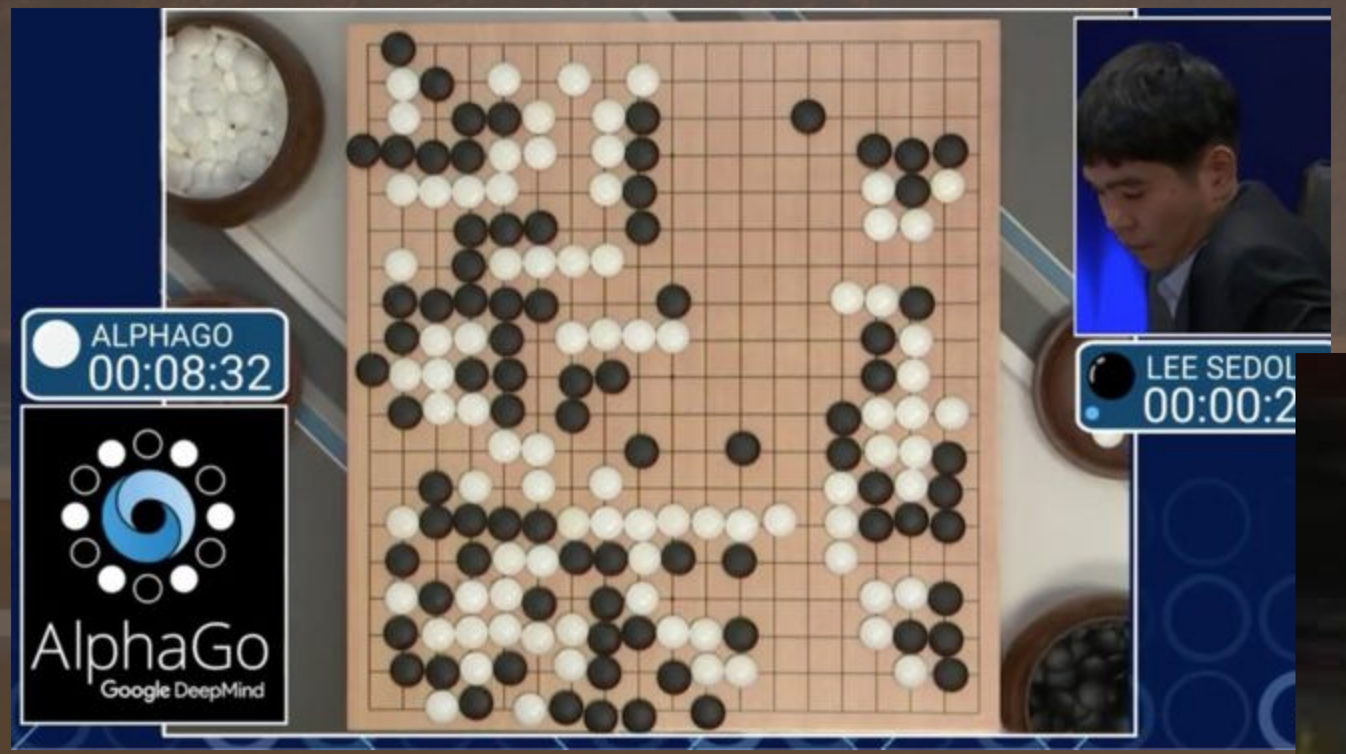
Robotics, Autonomous Vehicles

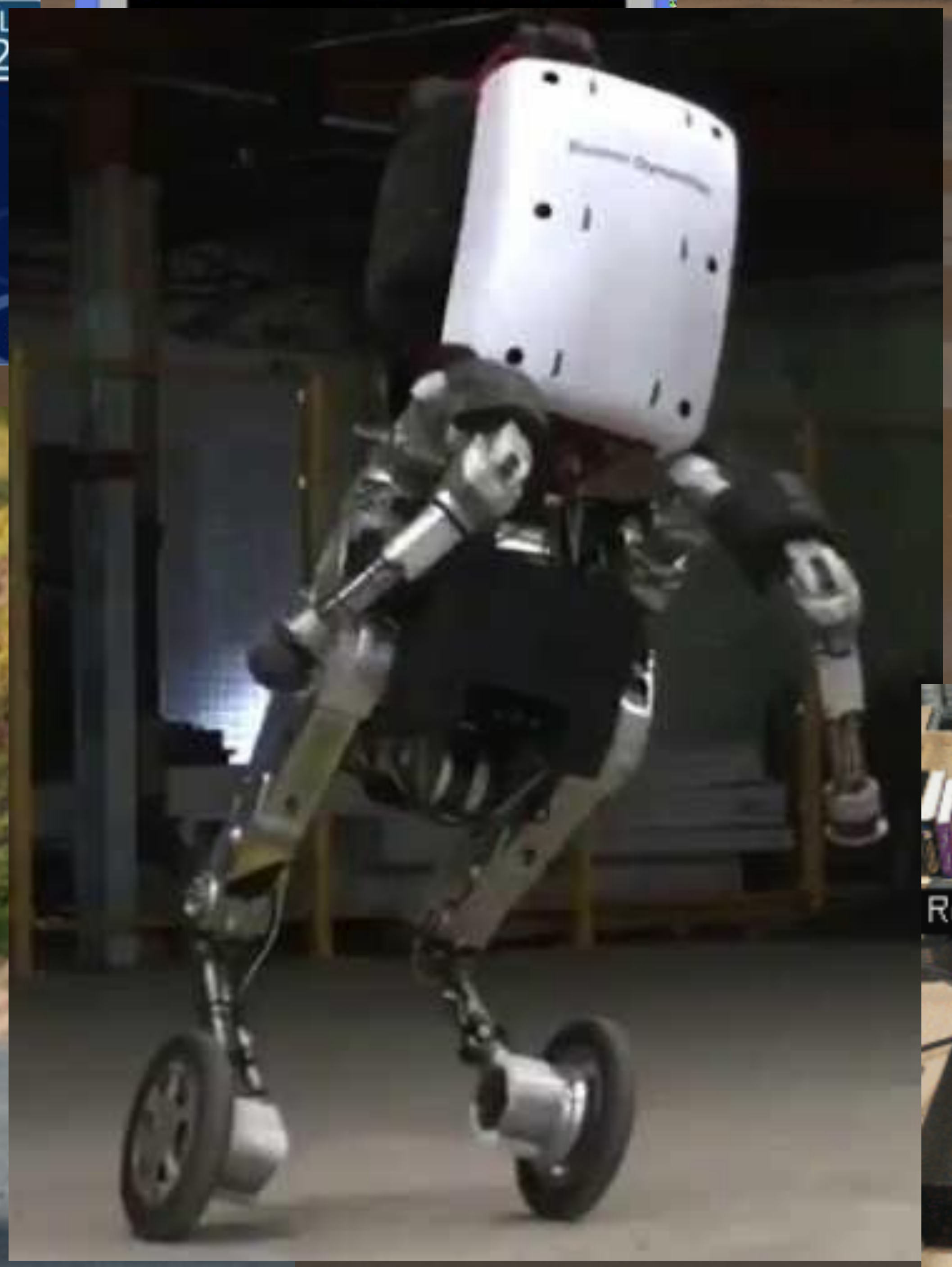
Industrial Processes

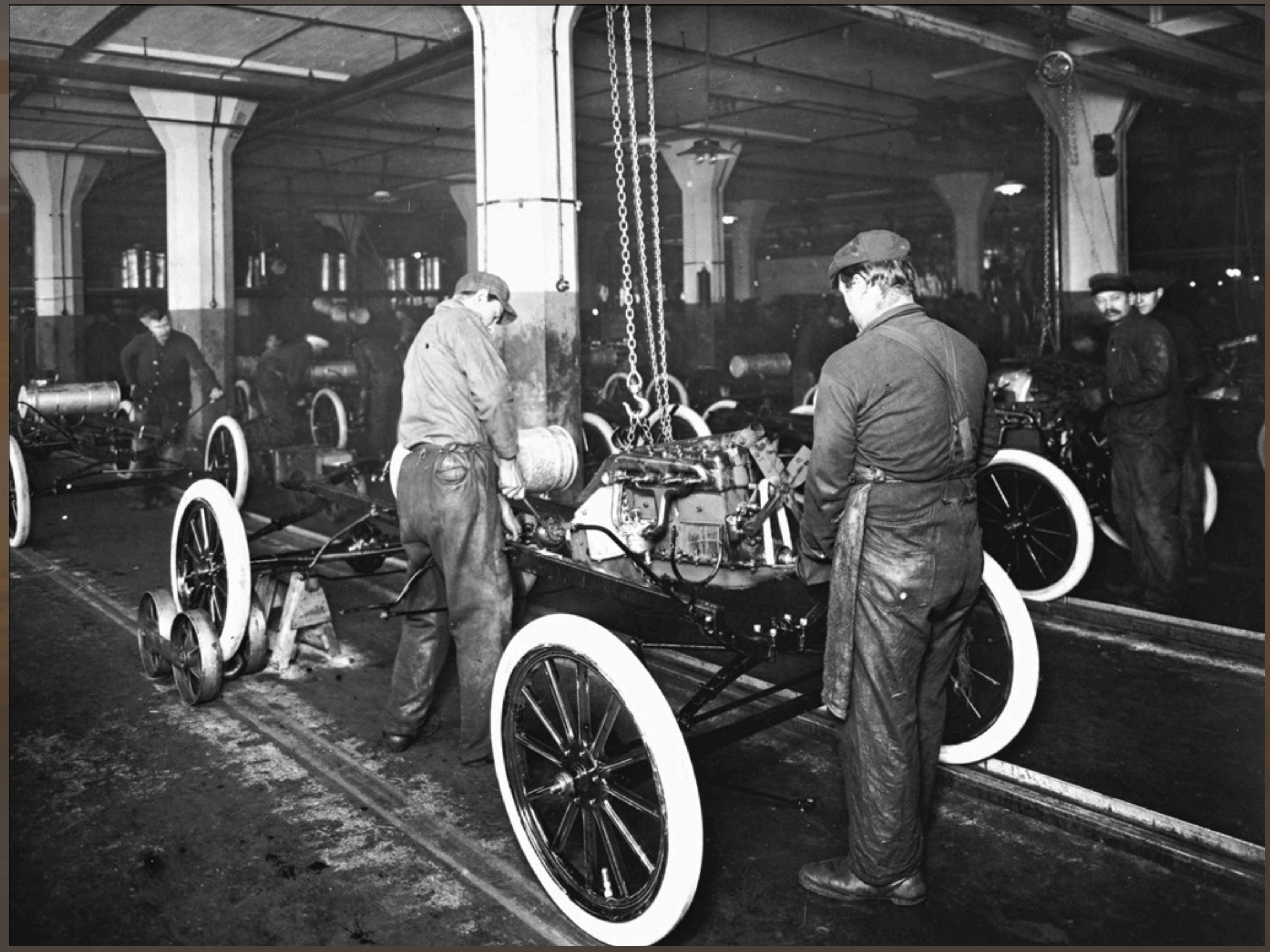
System Optimization

Advertising, Recommendations

Finance

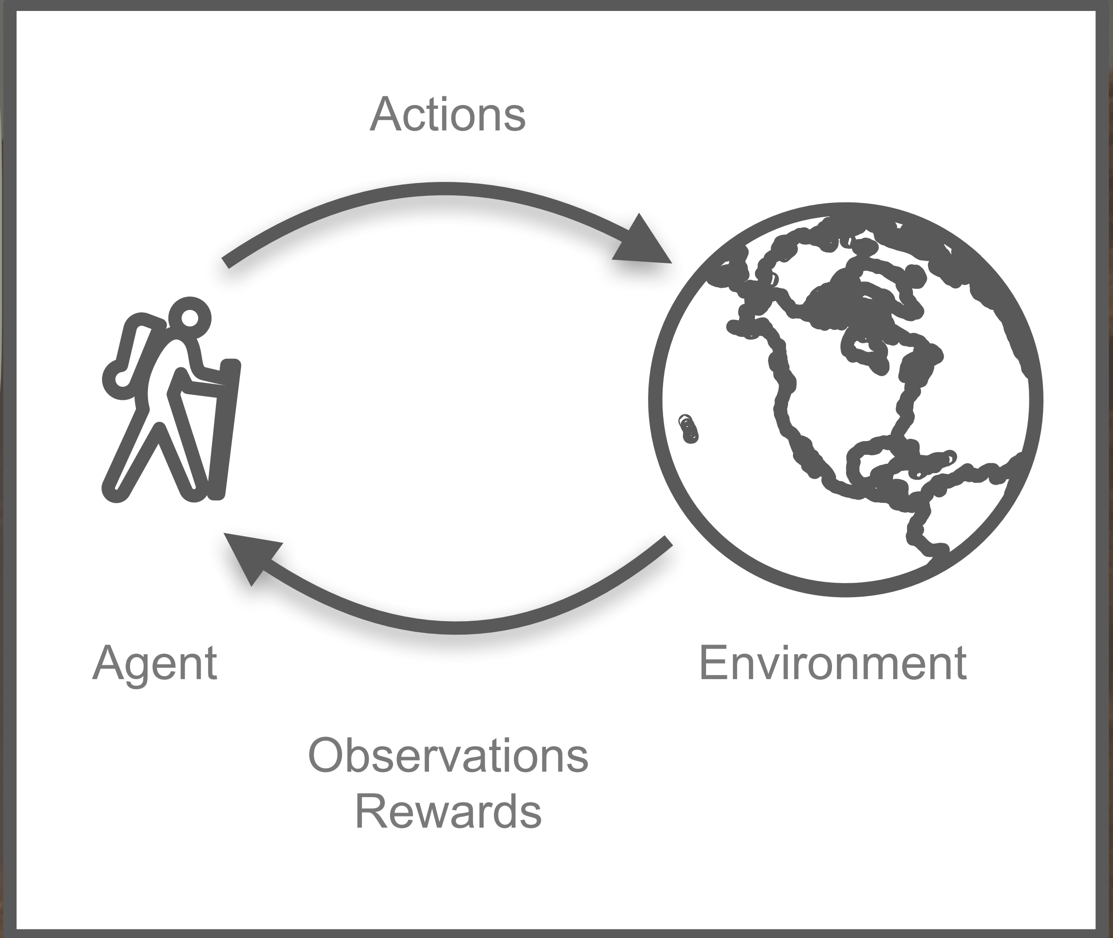






RL Applications

HVAC optimization, networks, business processes, …



Games

Robotics, Autonomous Vehicles

Industrial Processes

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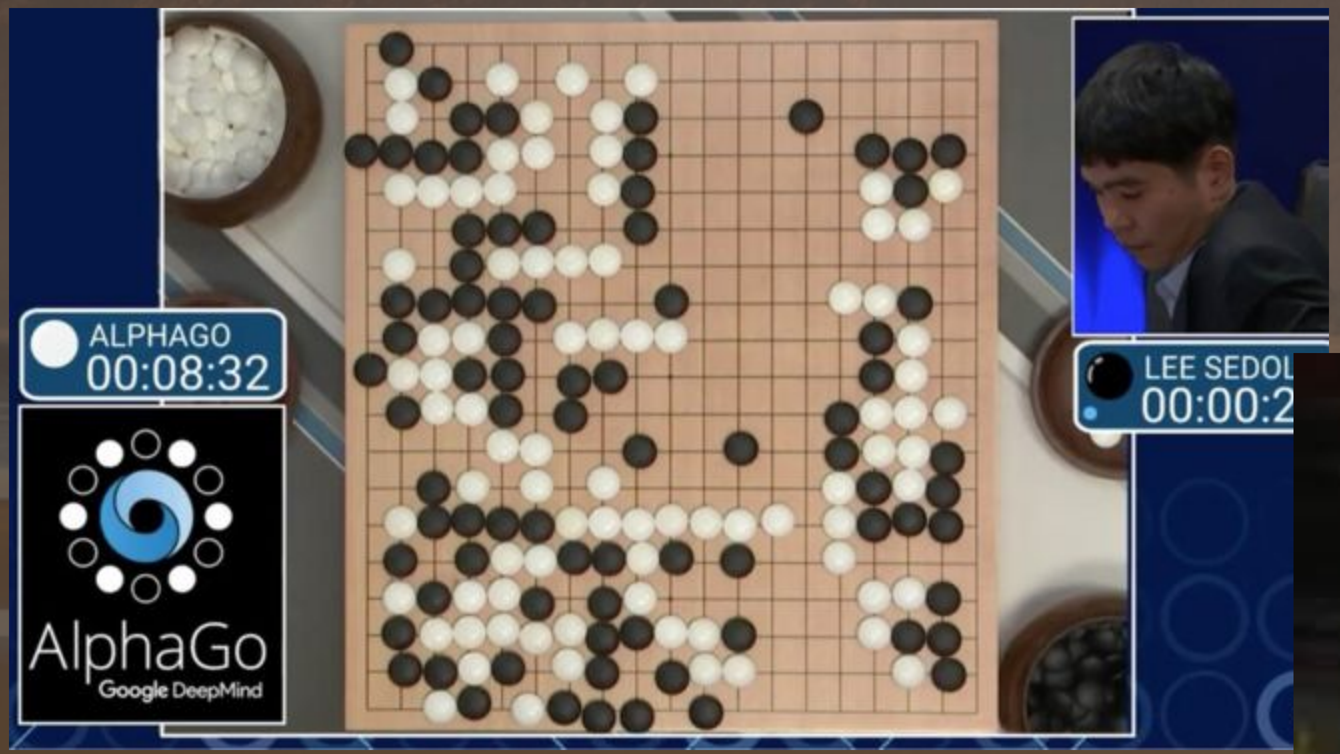
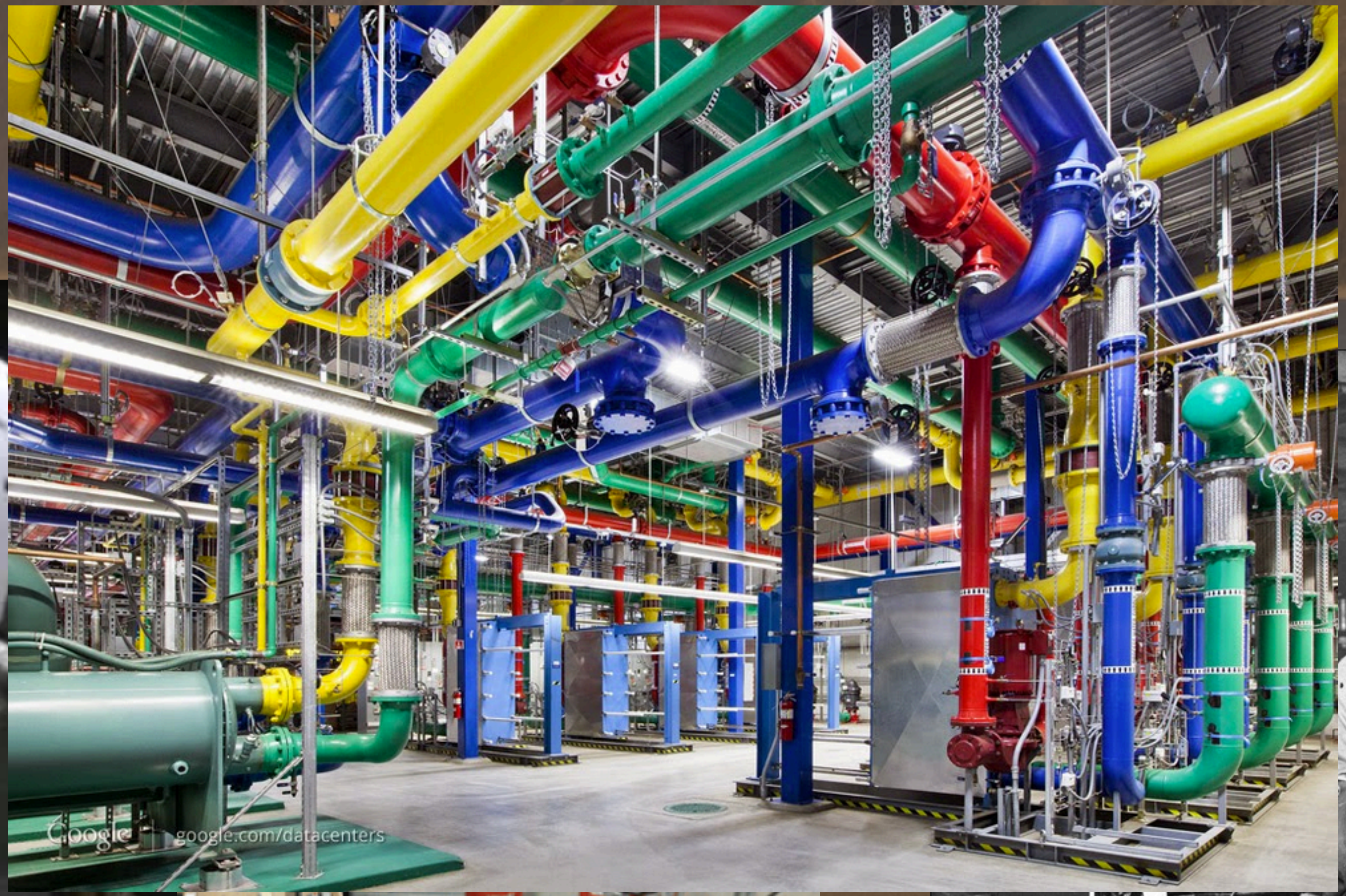
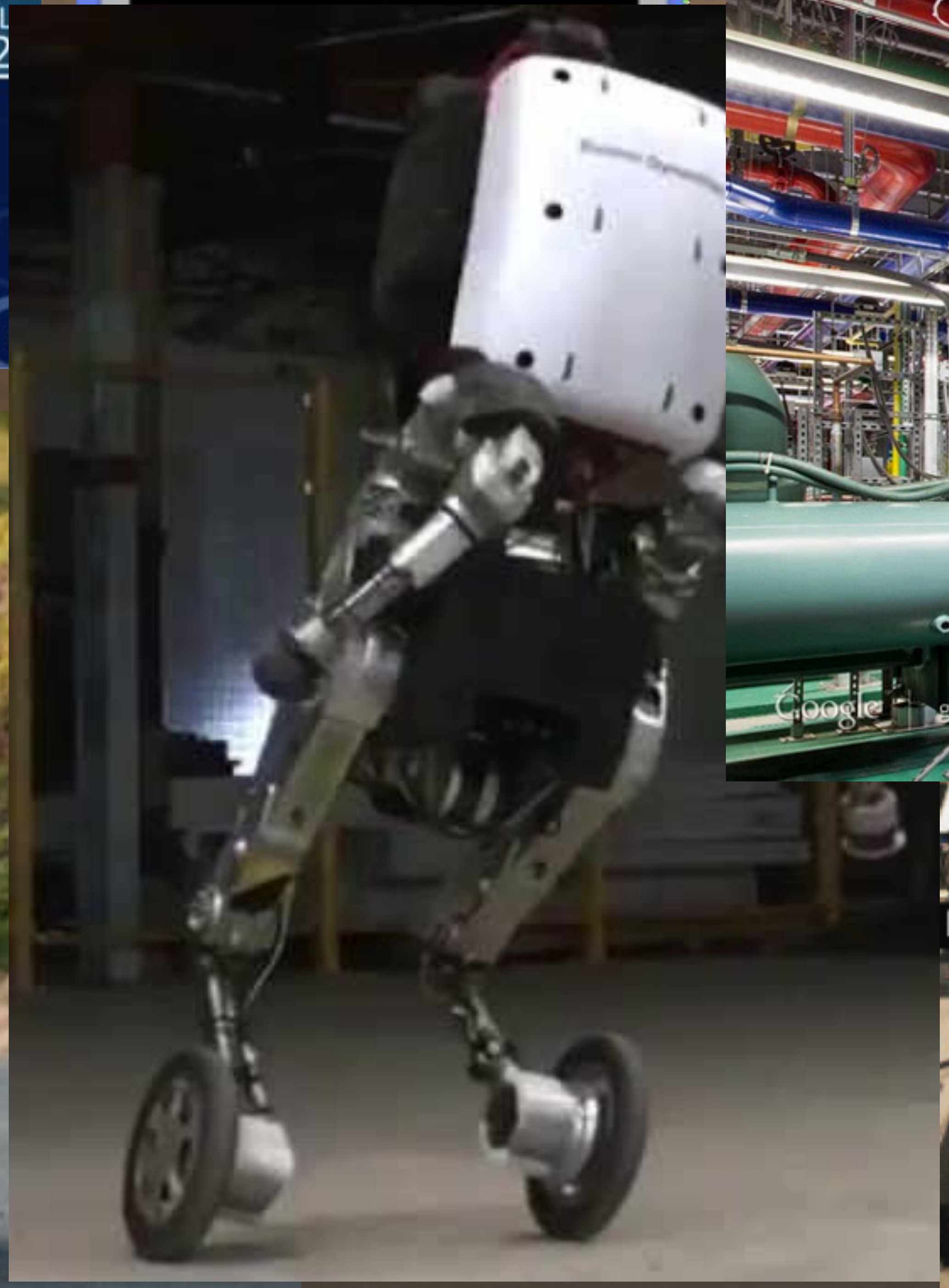
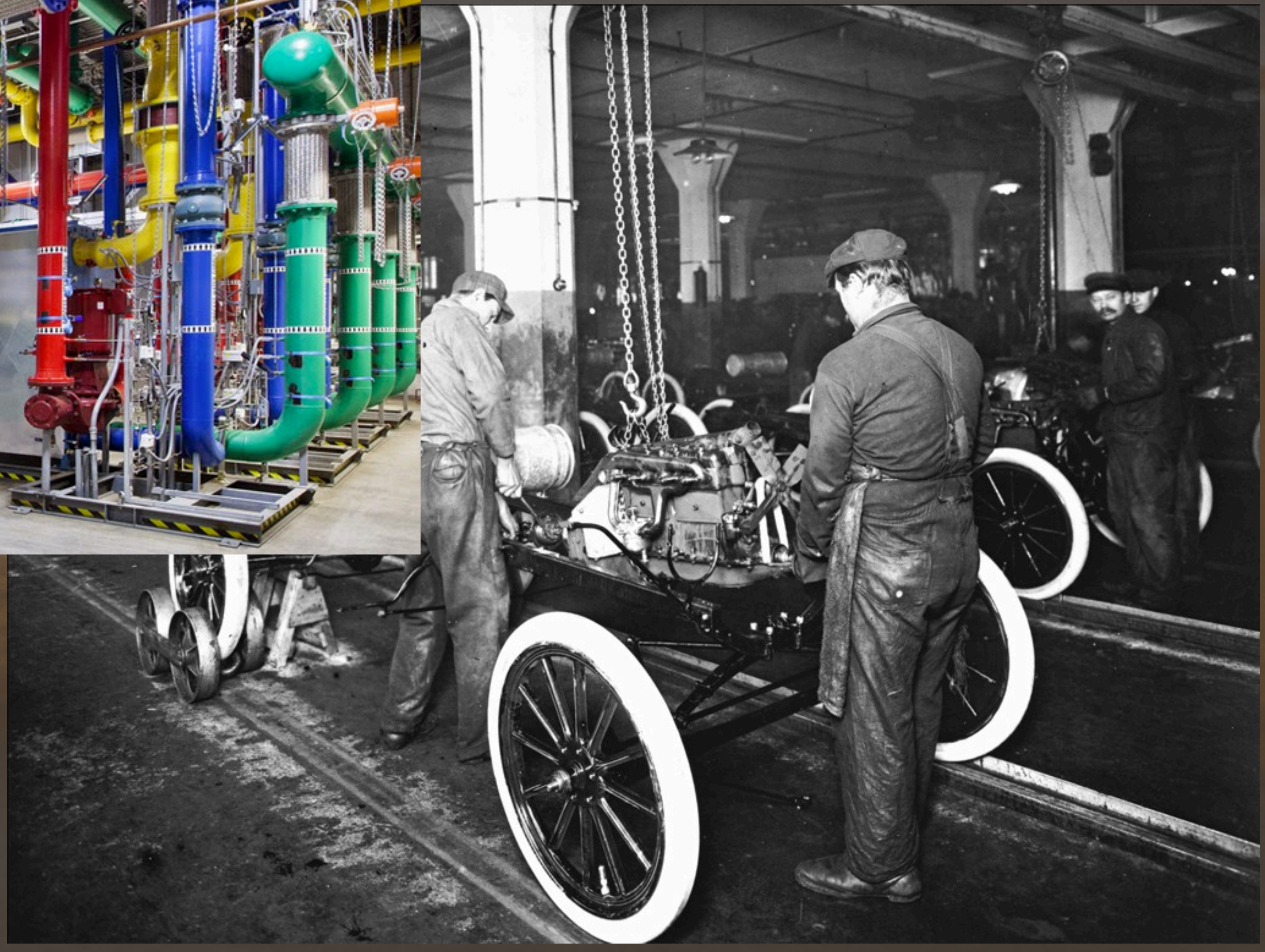
Finance





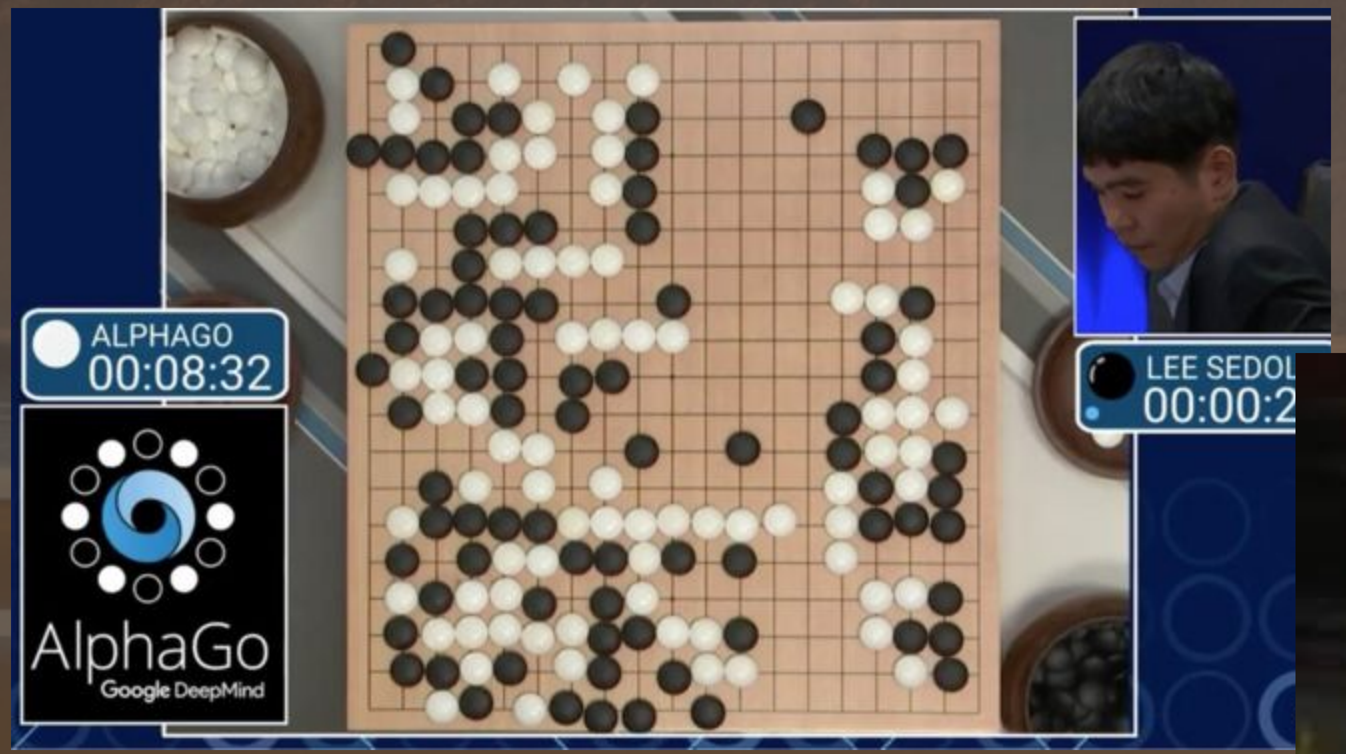


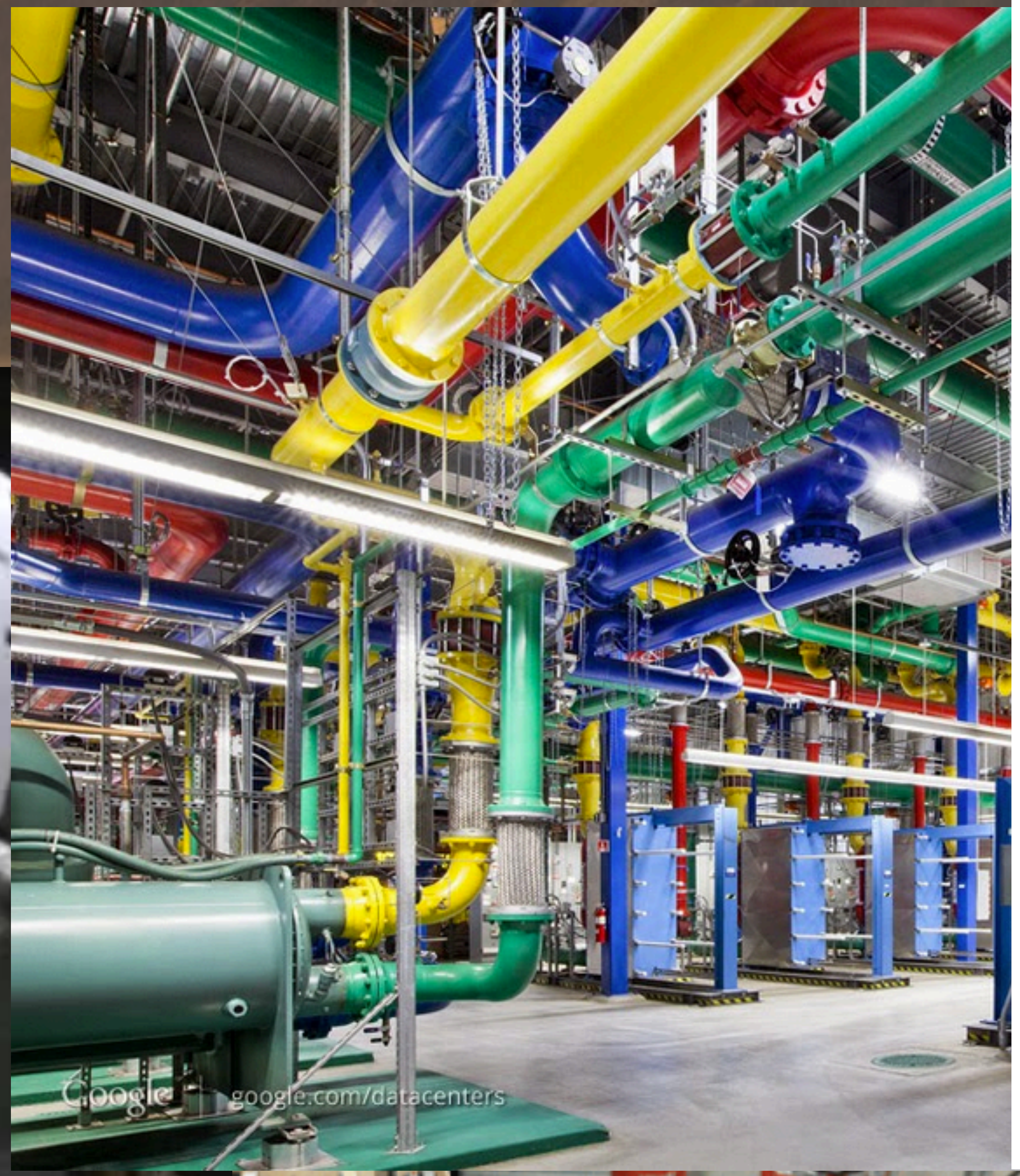


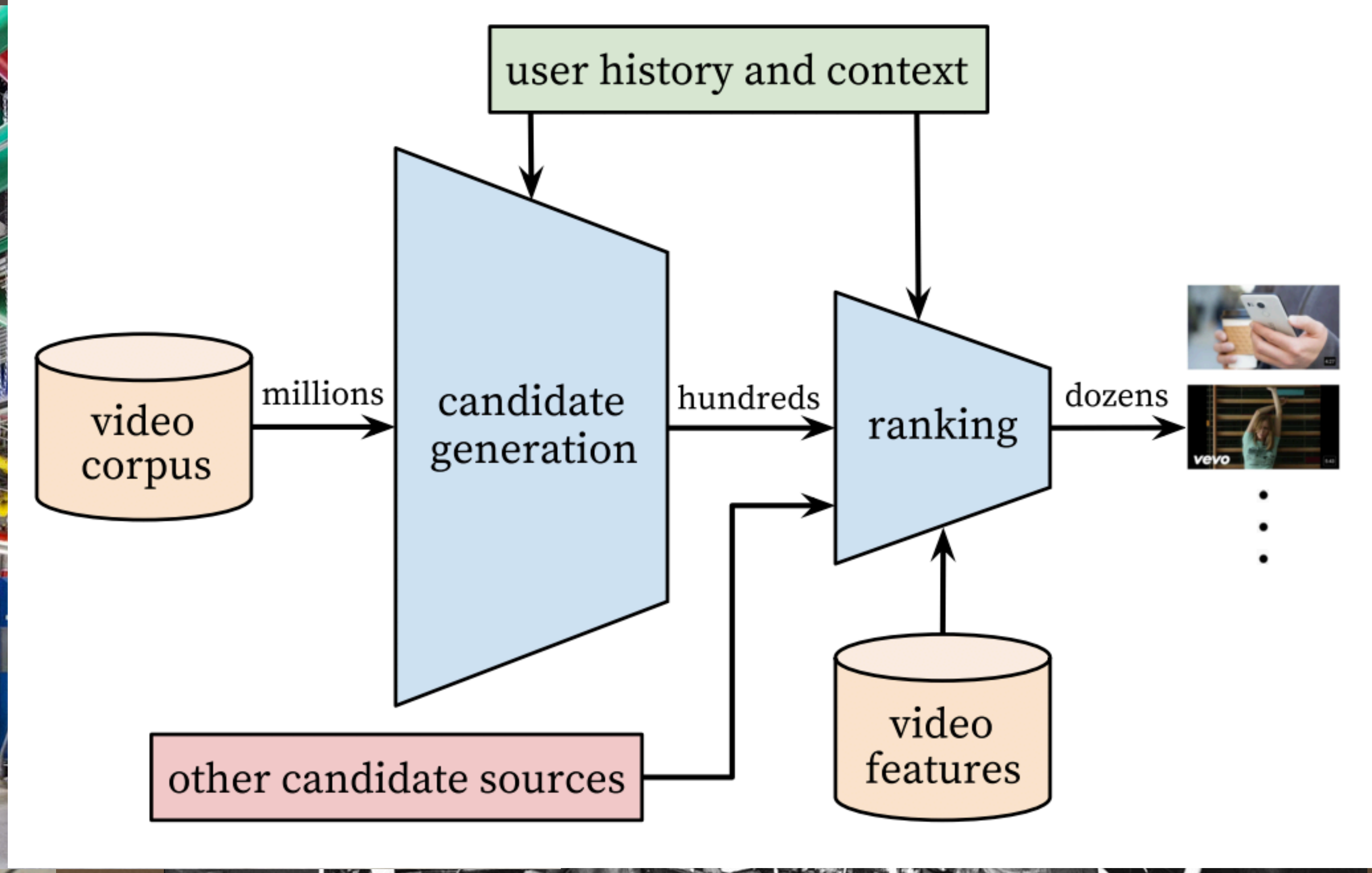
RL Applications

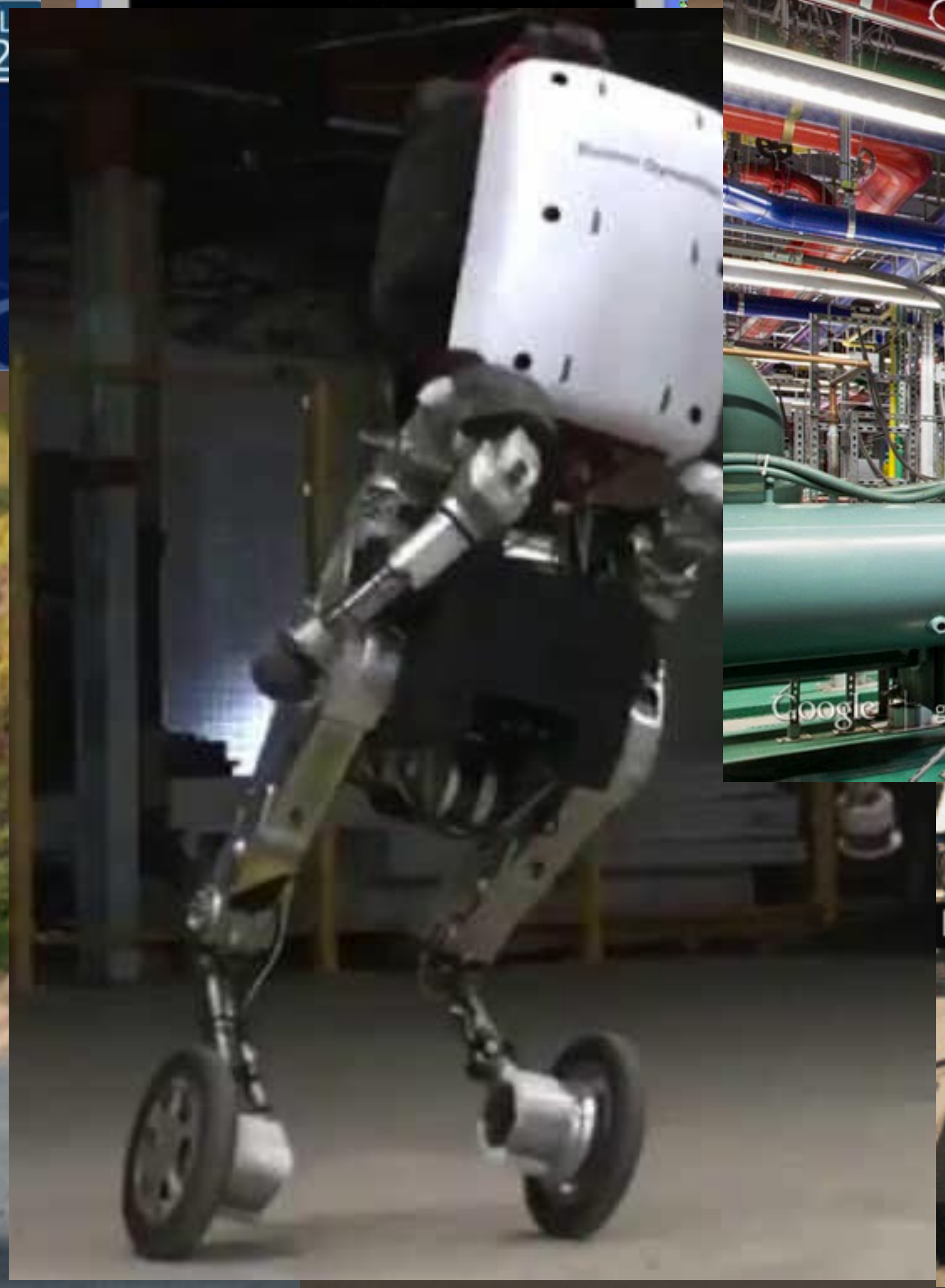
Better recommendations, ad placements, …

Games | Robotics, Autonomous Vehicles | Industrial Processes | System Optimization | Advertising, Recommendations | Finance









RL Applications

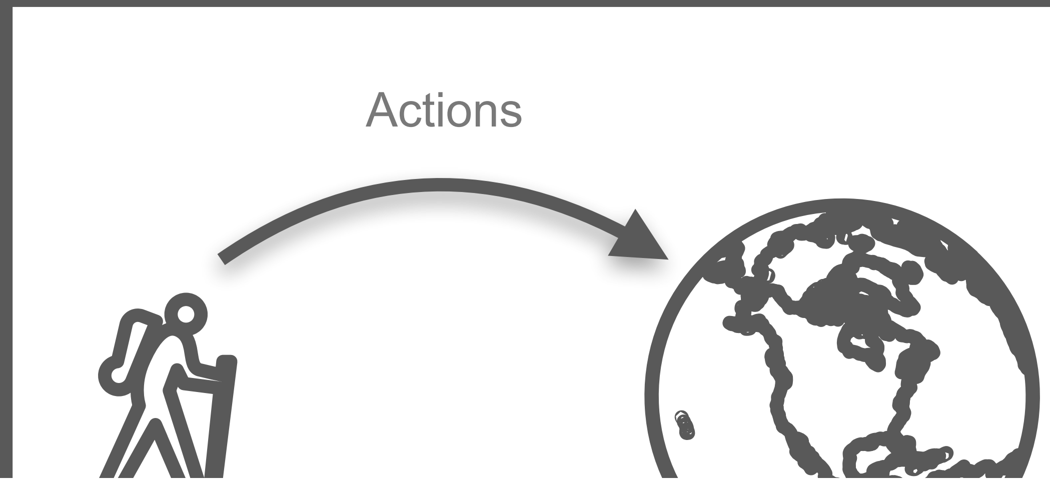
Market trends, timing of trades, …

Games | Robotics, Autonomous Vehicles | Industrial Processes | System Optimization | Advertising, Recommendations | Finance

RL Applications

ChatGPT!

https://openai.com/blog/chatgpt/



https://openai.com/blog/chatgpt/

Introducing ChatGPT research release Try↗ Learn more ›

OpenAI

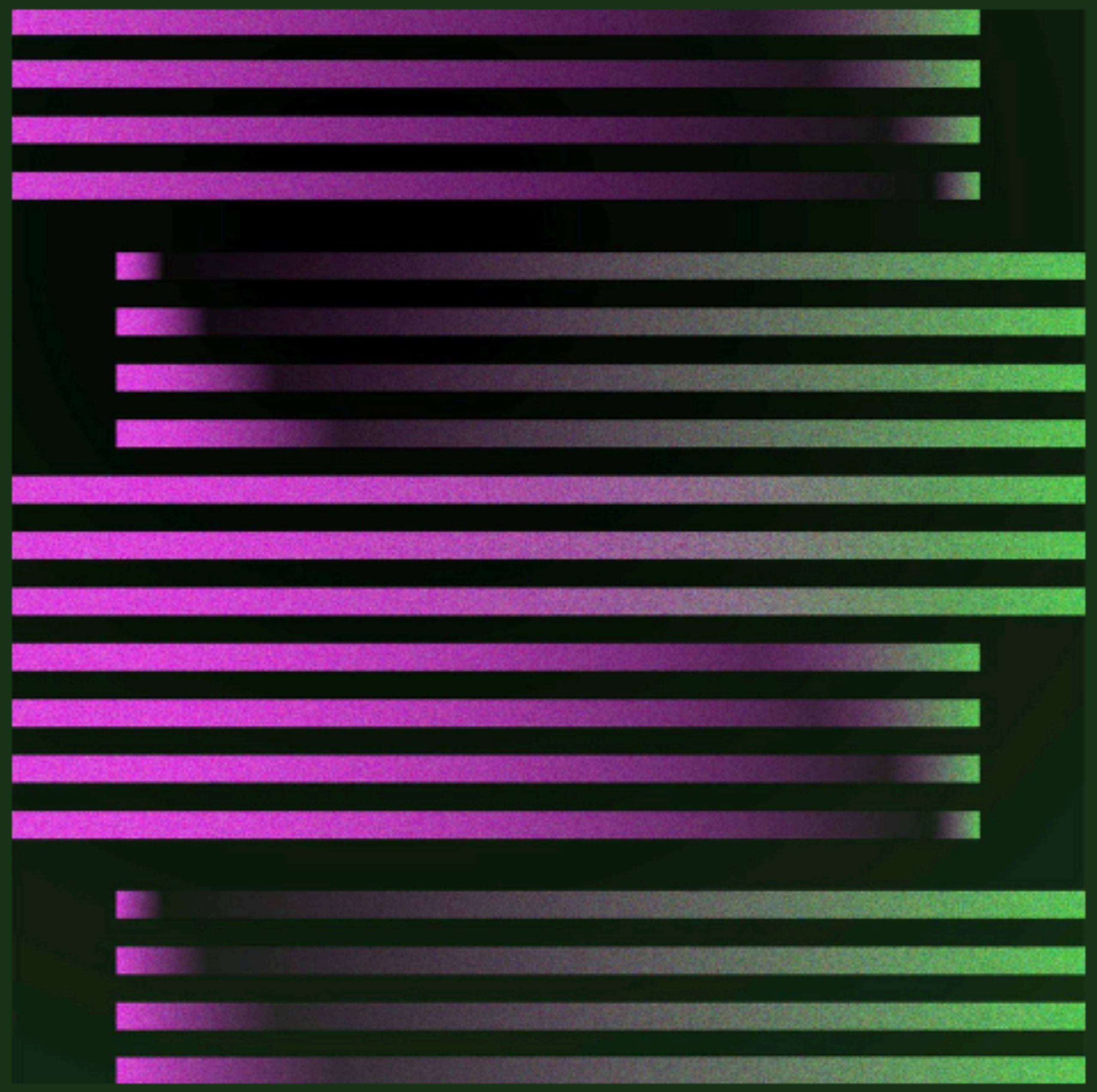
API RESEARCH BLOG ABOUT

ChatGPT: Optimizing Language Models for Dialogue

We've trained a model called ChatGPT which interacts in a conversational way. The dialogue format makes it possible for ChatGPT to answer followup questions, admit its mistakes, challenge incorrect premises, and reject inappropriate requests. ChatGPT is a sibling model to InstructGPT, which is trained to follow an instruction in a prompt and provide a detailed response.

TRY CHATGPT ↗

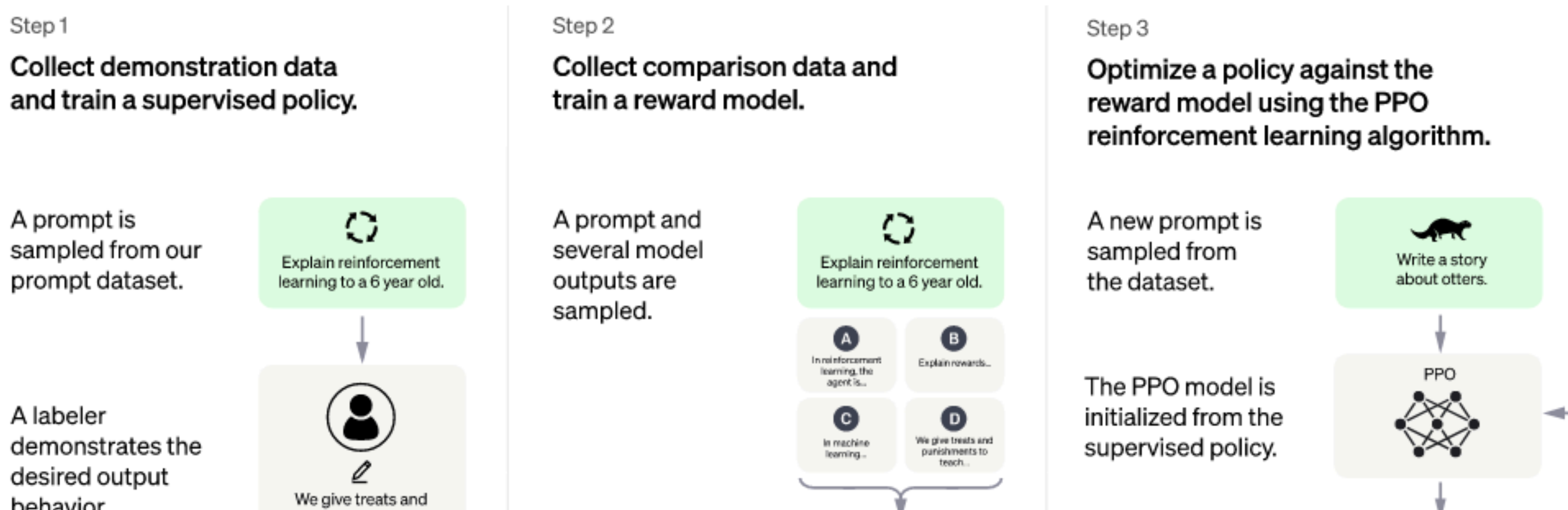
November 30, 2022
13 minute read



Methods

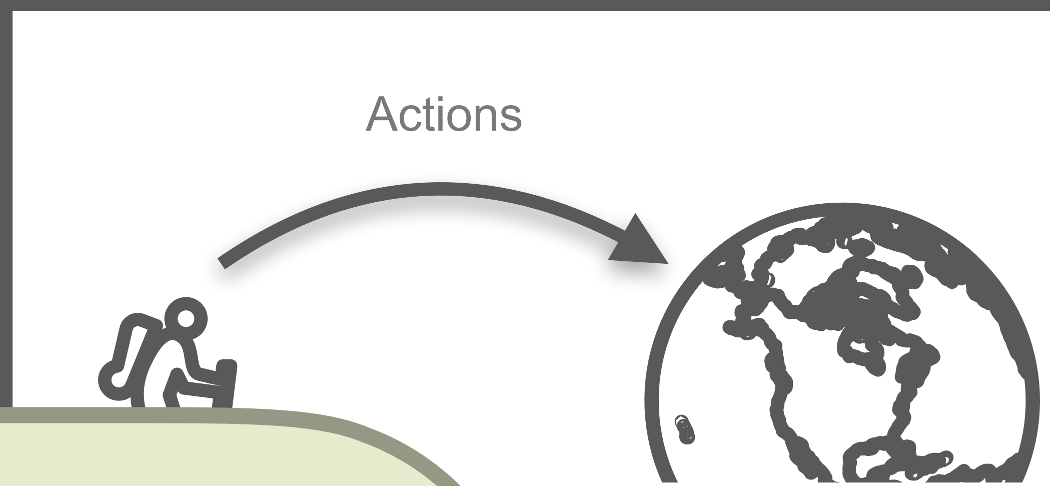
We trained this model using Reinforcement Learning from Human Feedback (RLHF), using the same methods as InstructGPT, but with slight differences in the data collection setup. We trained an initial model using supervised fine-tuning: human AI trainers provided conversations in which they played both sides—the user and an AI assistant. We gave the trainers access to model-written suggestions to help them compose their responses. We mixed this new dialogue dataset with the InstructGPT dataset, which we transformed into a dialogue format.

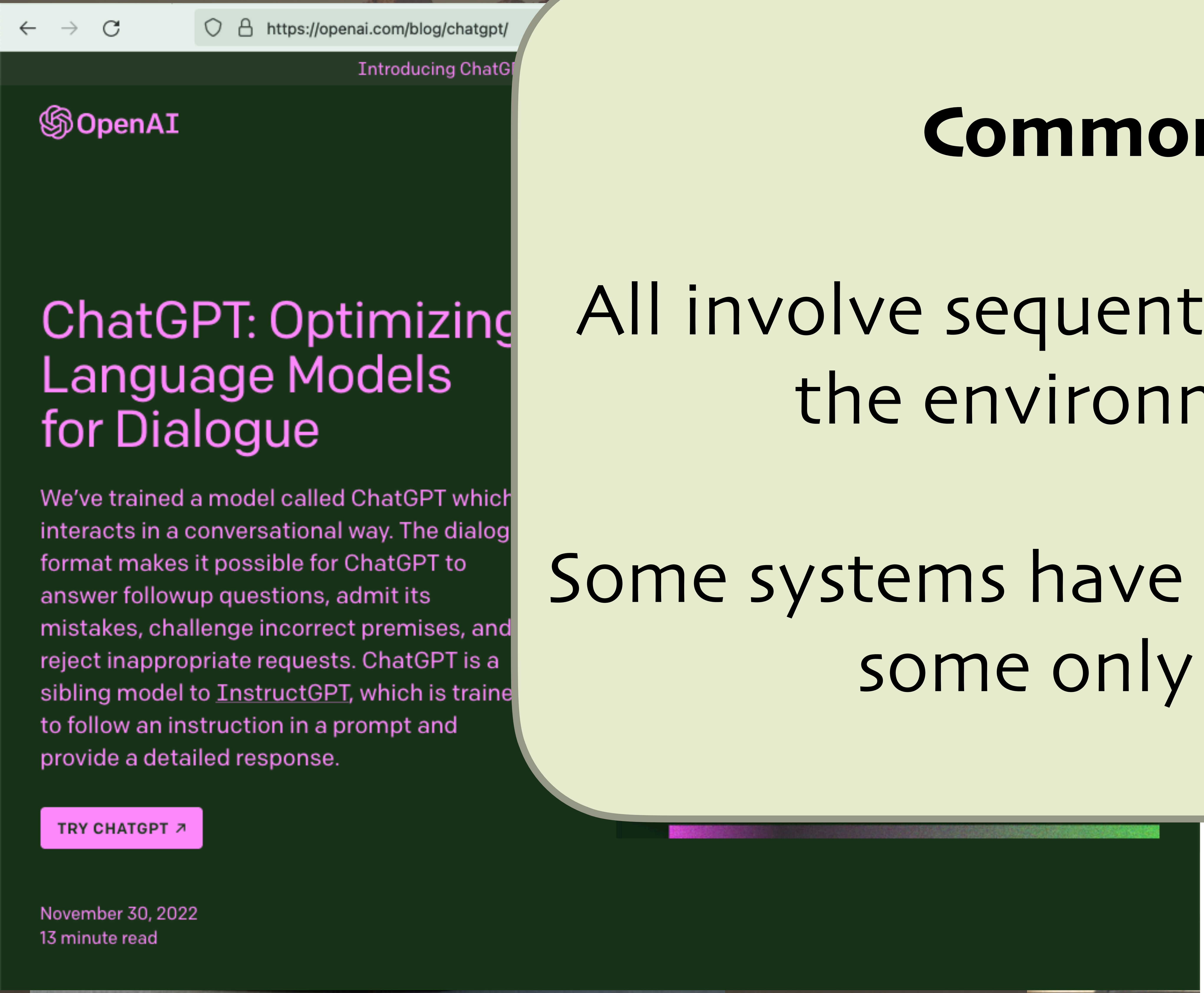
To create a reward model for reinforcement learning, we needed to collect comparison data, which consisted of two or more model responses ranked by quality. To collect this data, we took conversations that AI trainers had with the chatbot. We randomly selected a model-written message, sampled several alternative completions, and had AI trainers rank them. Using these reward models, we can fine-tune the model using Proximal Policy Optimization. We performed several iterations of this process.



RL Applications

ChatGPT!
https://openai.com/blog/chatgpt/

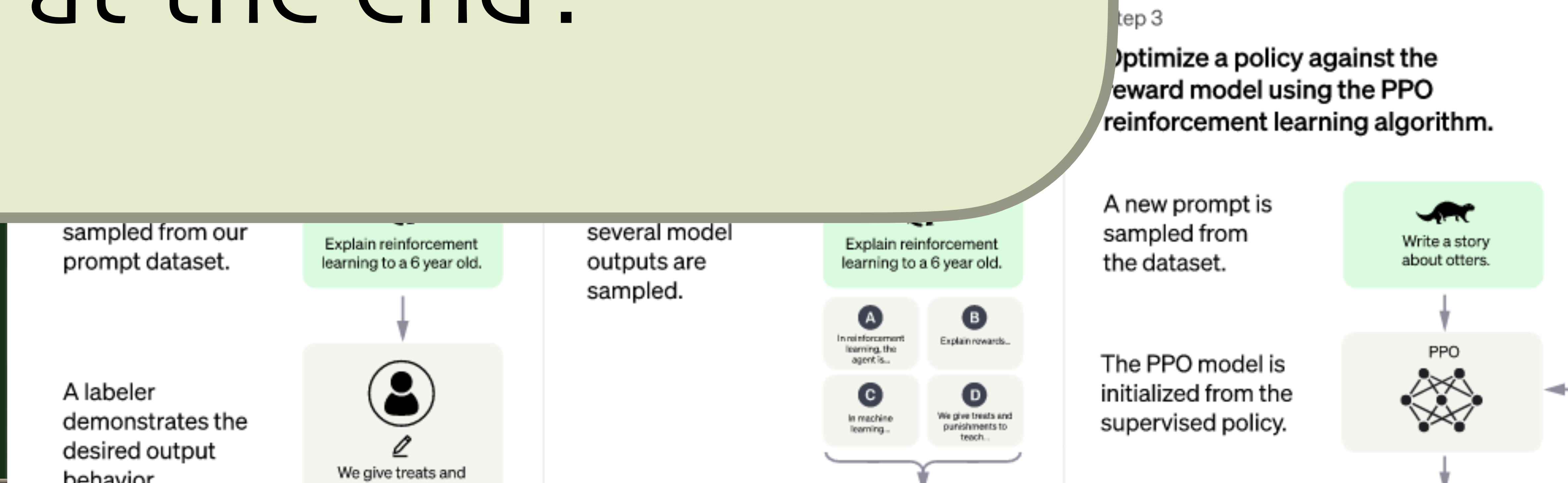




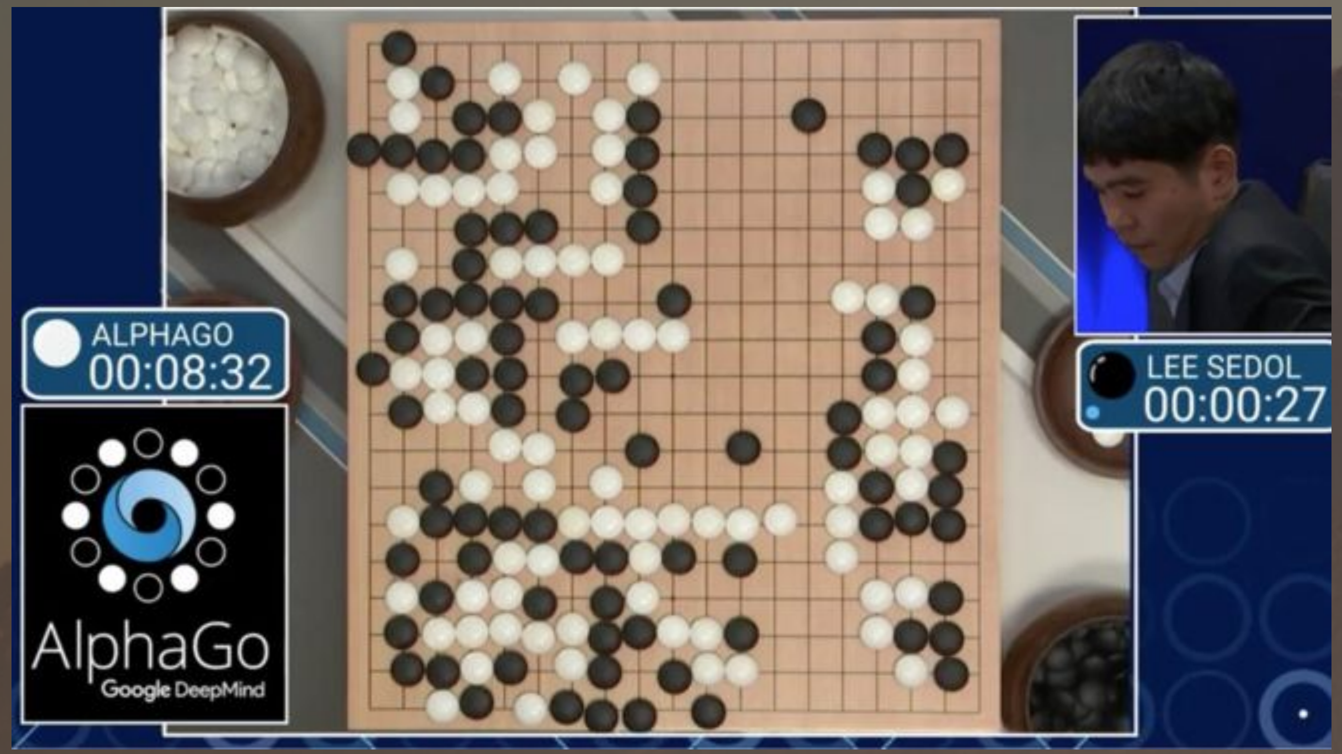
Common Theme:

All involve sequential, evolving state in the environment + agent.

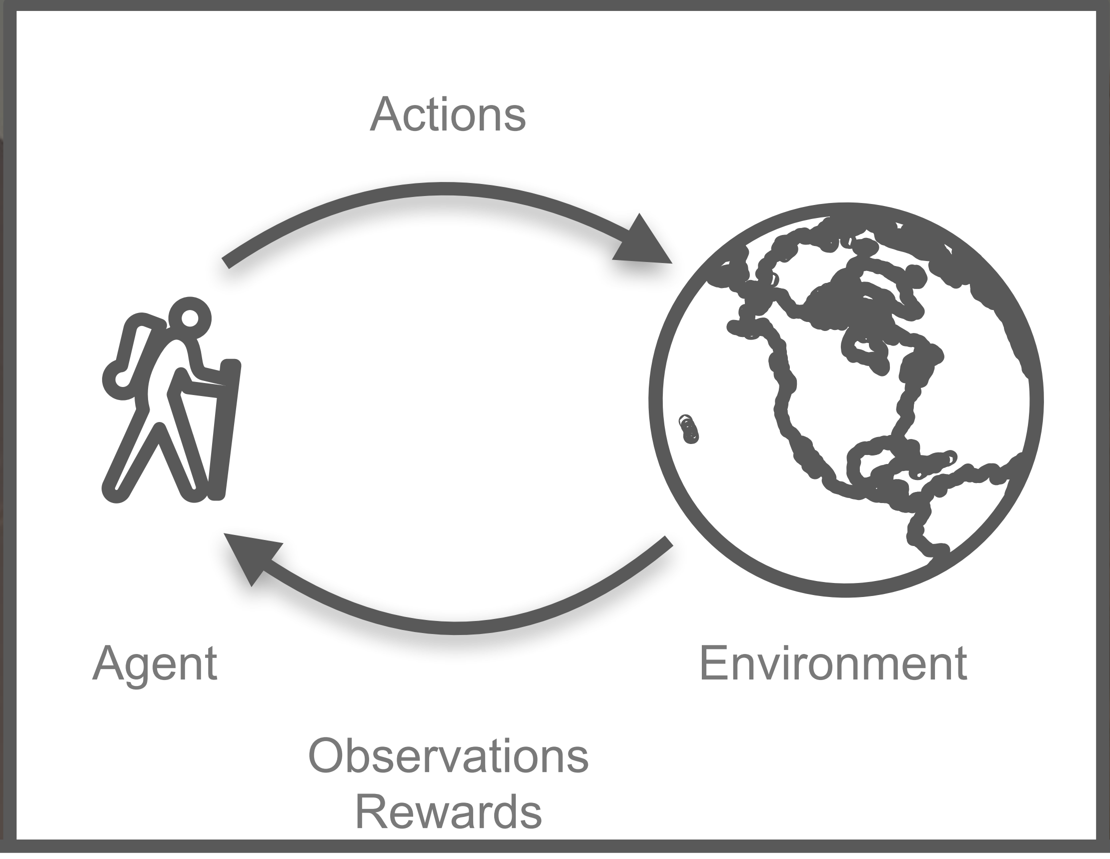
Some systems have rewards at each step, some only at the end!



AlphaGo example

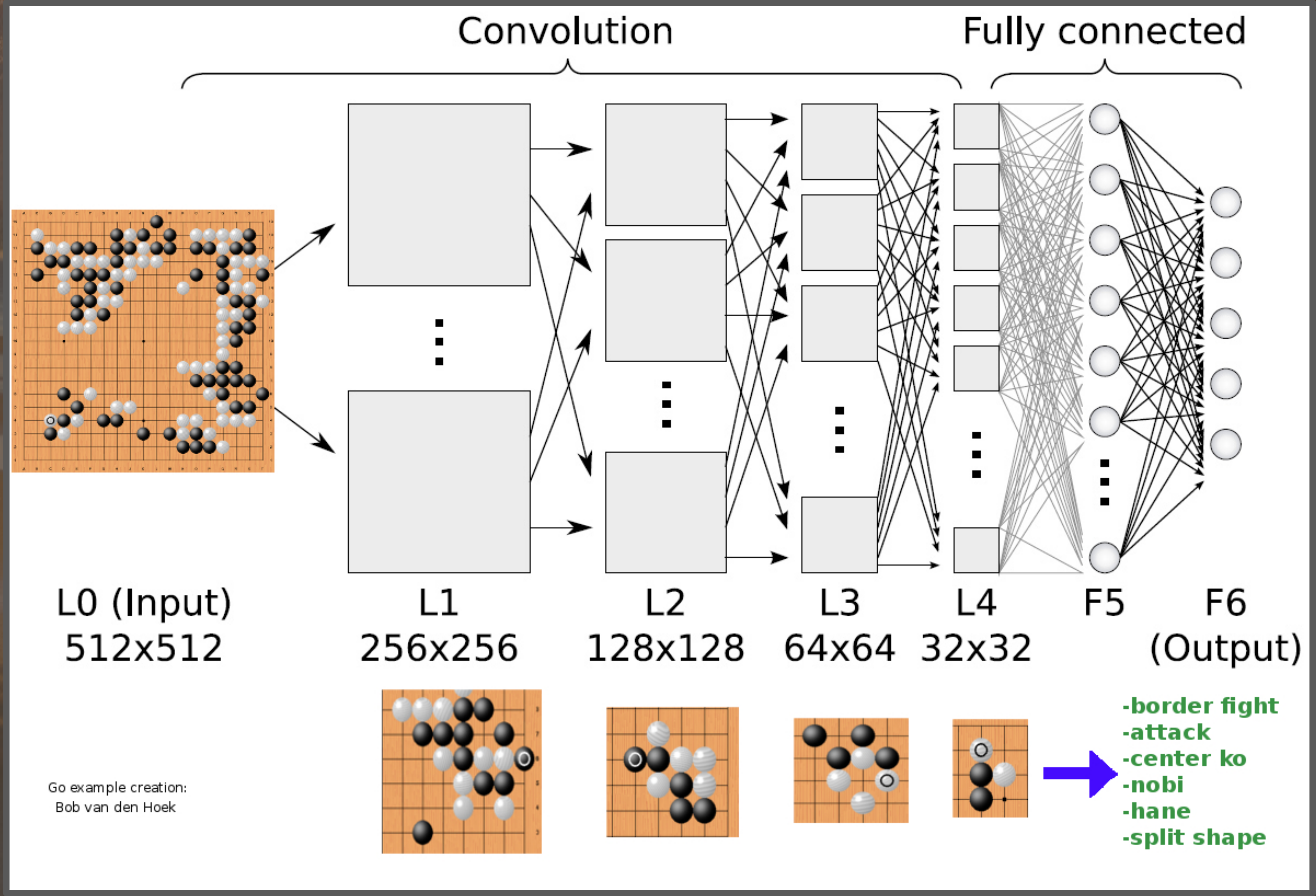


Deep Reinforcement Learning



AlphaGo (Silver et al. 2016)

- **Observations**:
  - board state
- **Actions**:
  - where to place the stones
- **Rewards**:
  - 1 if you win
  - 0 otherwise




Ray RLlib

RLlib: Industry-Grade Reinforcement Learning

RLlib is an open-source library for reinforcement learning (RL), offering support for production-level, highly distributed RL workloads while maintaining unified and simple APIs for a large variety of industry applications. Whether you would like to train your agents in a **multi-agent** setup, purely from **offline** (historic) datasets, or using **externally connected simulators**, RLlib offers a simple solution for each of your decision making needs.

If you either have your problem coded (in python) as an RL environment or own lots of pre-recorded, historic behavioral data to learn from, you will be up and running in only a few days.

RLlib is already used in production by industry leaders in many different verticals, such as climate control, industrial control, manufacturing and logistics, finance, gaming, automobile, robotics, boat design, and many others.

RLlib in 60 seconds

It only takes a few steps to get your first RLlib workload up and running on your laptop.

RLlib does not automatically install a deep-learning framework, but supports **TensorFlow** (both 1.x with static-graph and 2.x with eager mode) as well as **PyTorch**. Depending on your needs, make sure to install either TensorFlow or PyTorch (or both, as shown below):

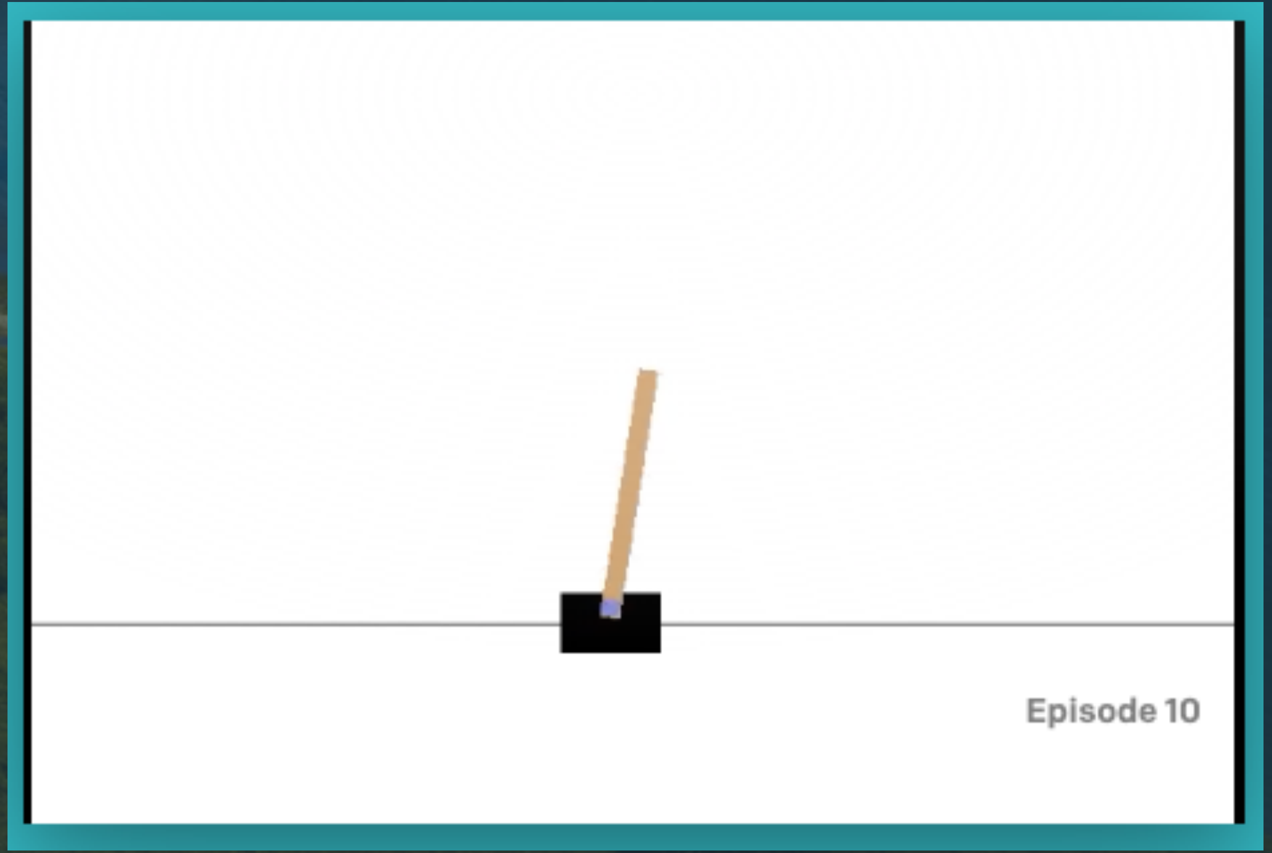
rllib.io


To Try It Out...

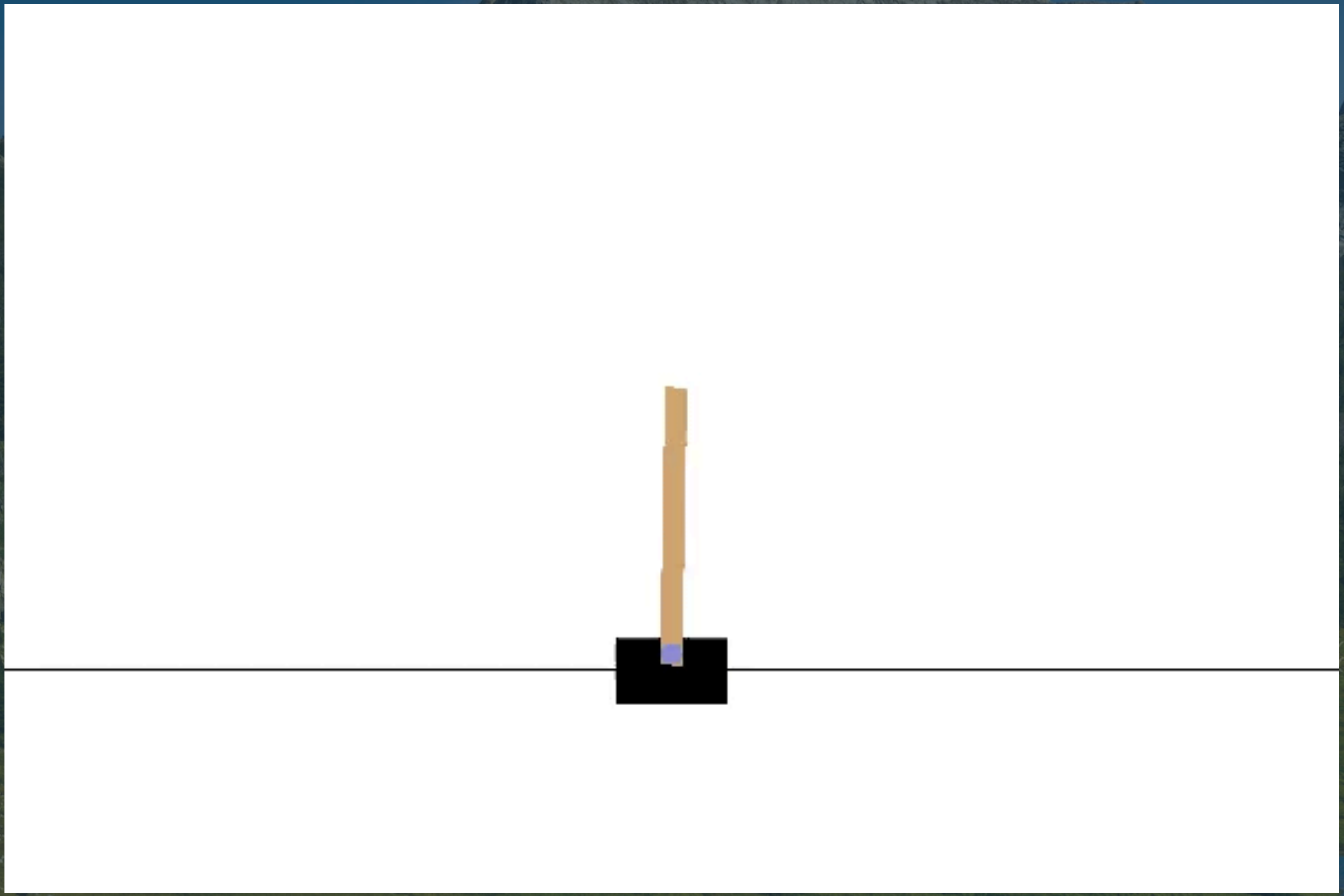
```
# Install what we need:
$ pip install "ray[rllib]" tensorflow \
  tensorflow-probability pygame

# Train CartPole using DQN, stop after 100 iterations:
# At end, will print the next command to run:
$ rllib train --algo DQN --env 'CartPole-v1' \
  --stop '{"training_iteration": 100}'

# Run CartPole and see how well it goes:
$ rllib evaluate /path/to/checkpoint --algo DQN
```

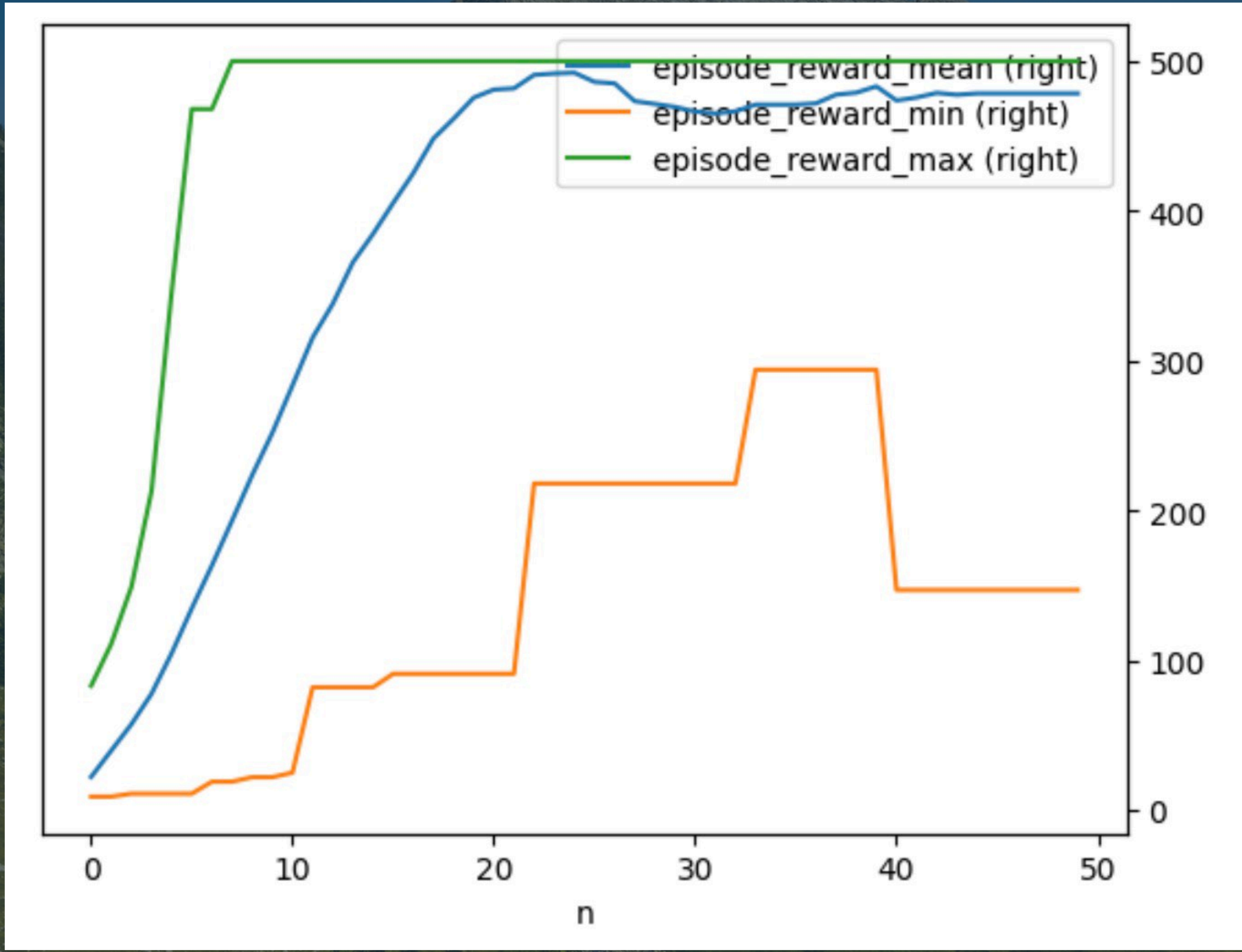


To Try It Out...



Example episode after training.

To Try It Out...



Training n=50 episodes with PPO. Max score is 500. Note that the average actually dips above 20 episodes. Probably overfitting?

To Try It Out...

RLlib Takeaways

- Rich set of RL algorithms
  - ... and features for building your own.
- Integrated with OpenAI Gym/Gymnasium
  - ... and you can build your own environments.
- Integrated with PyTorch and TensorFlow.
- Excellent performance... from Ray!

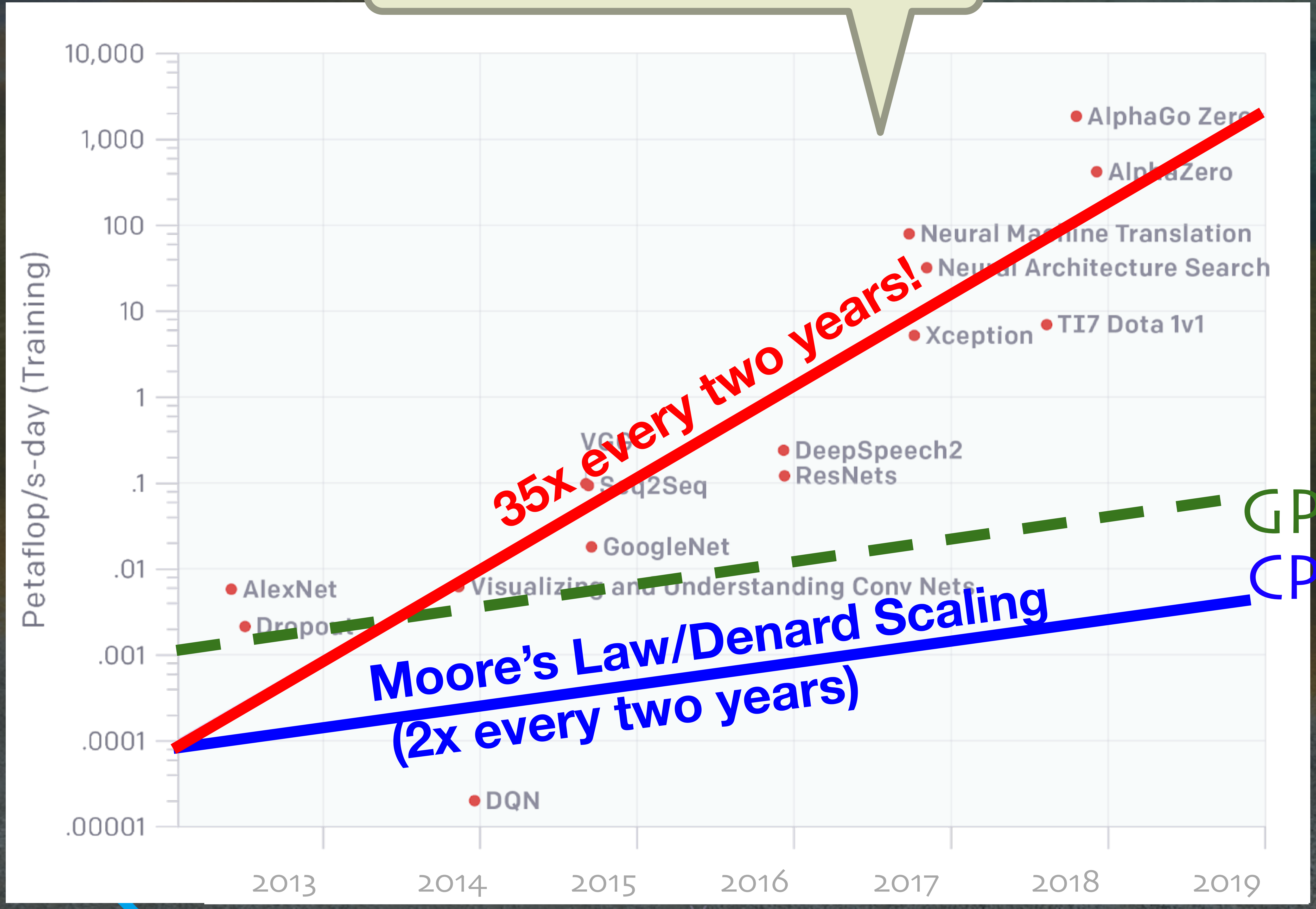
Aside: Why Ray??

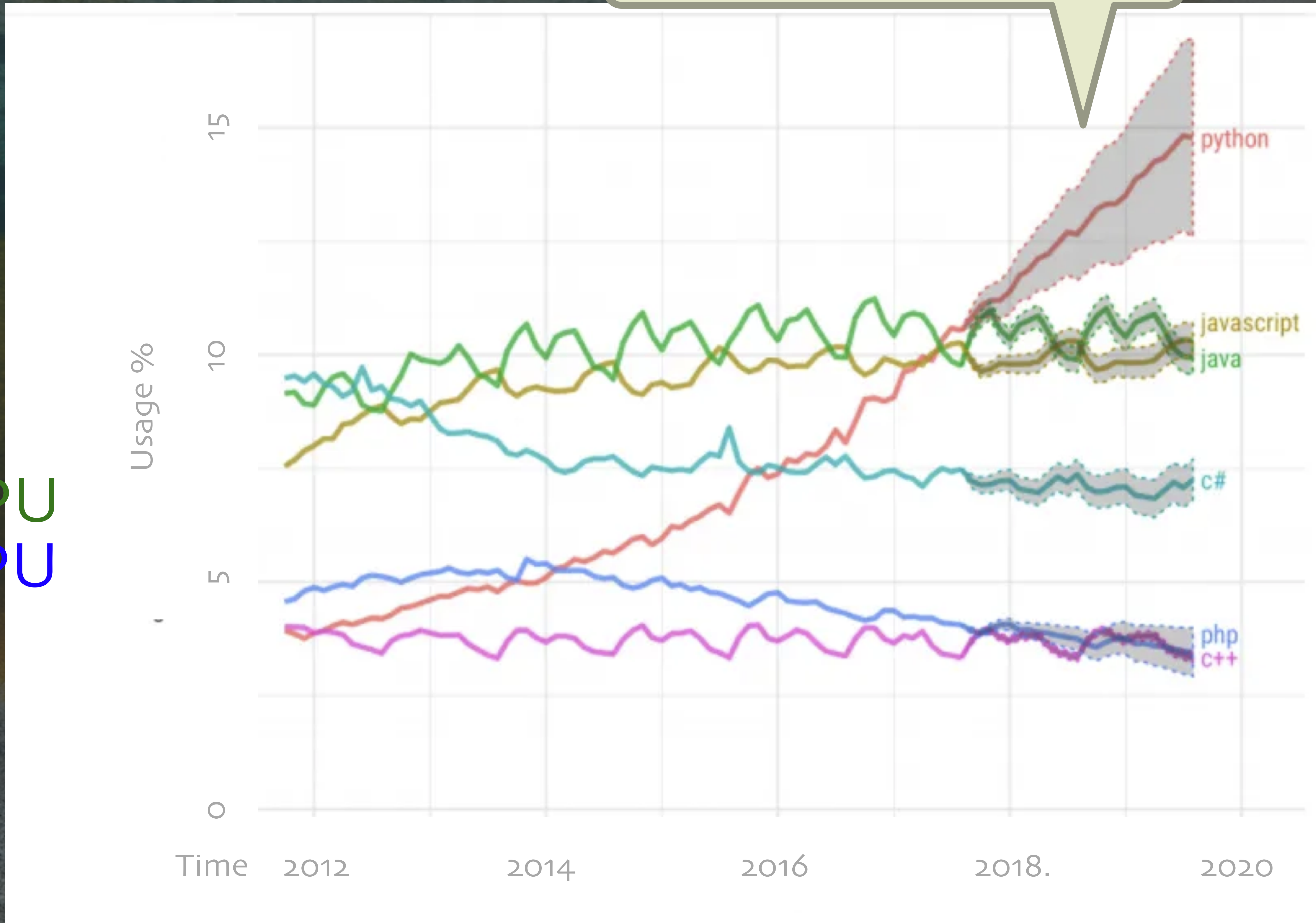
To Major Trends

Model sizes and therefore compute requirements outstripping Moore's Law

Hence, there is a pressing need for a robust, easy to use Python-centric distributed computing system

Python growth driven by ML/AI and other data science workloads





https://openai.com/blog/ai-and-compute/

The Data & ML Landscape Today

All require distributed implementations to scale

ETL	Streaming	HPO Tuning	Training	Simulation	Model Serving
Apache Spark, hadoop	Apache Spark, Flink, kafka	SIGOPT, talos AUTONOMY	Horovod, PyTorch, scikit learn	MPI, akka, Orleans	Clipper

The Ray Vision: Sharing a Common Framework

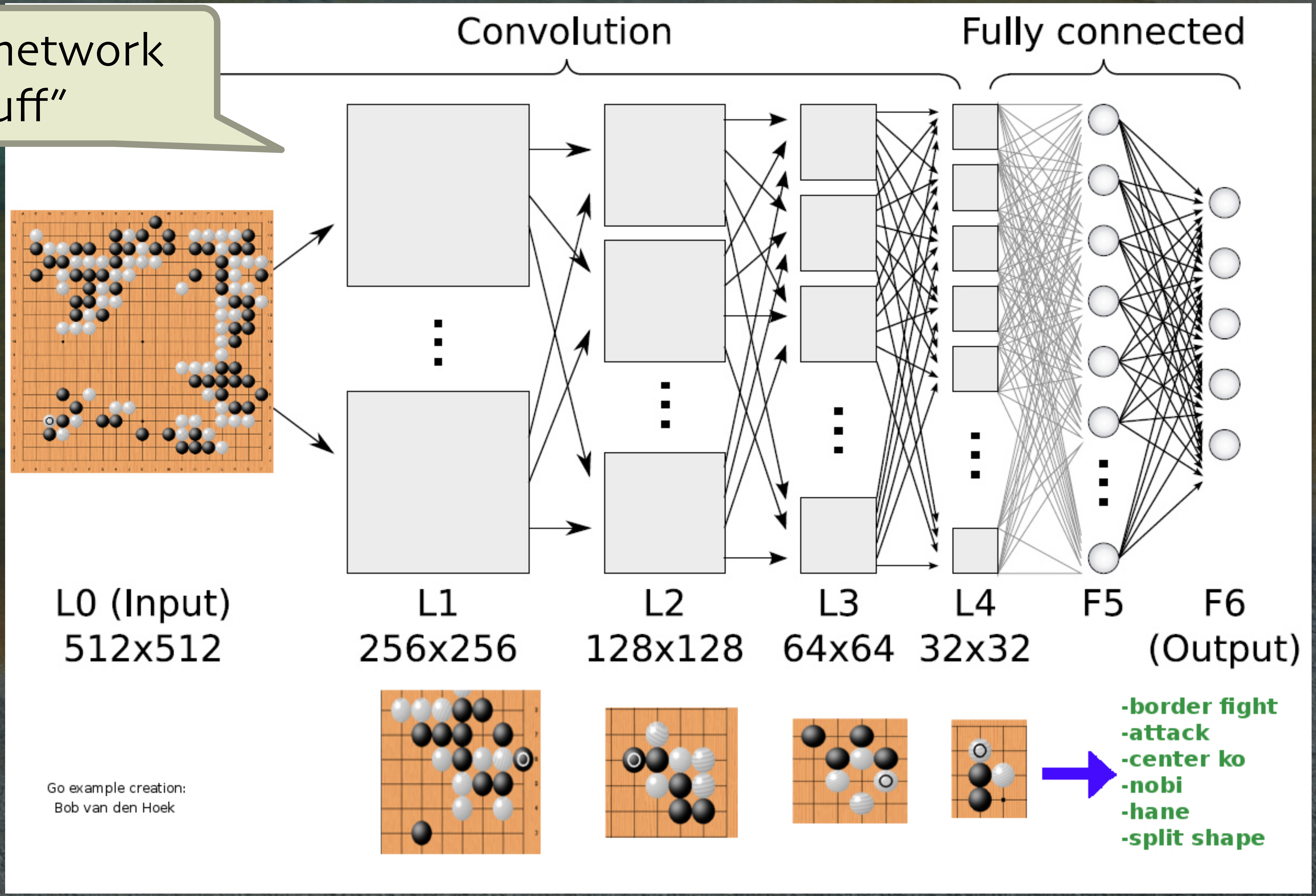
Domain-specific libraries for each subsystem

Plus a growing list of 3rd-party libraries

Diverse Compute Requirements Motivated Creation of Ray!

And repeated play, over and over again, to train for achieving the best reward

Neural network "stuff"



Simulator (game engine, robot sim, factory floor sim…)

Complex agent?

More Reinforcement Learning Concepts and Challenges

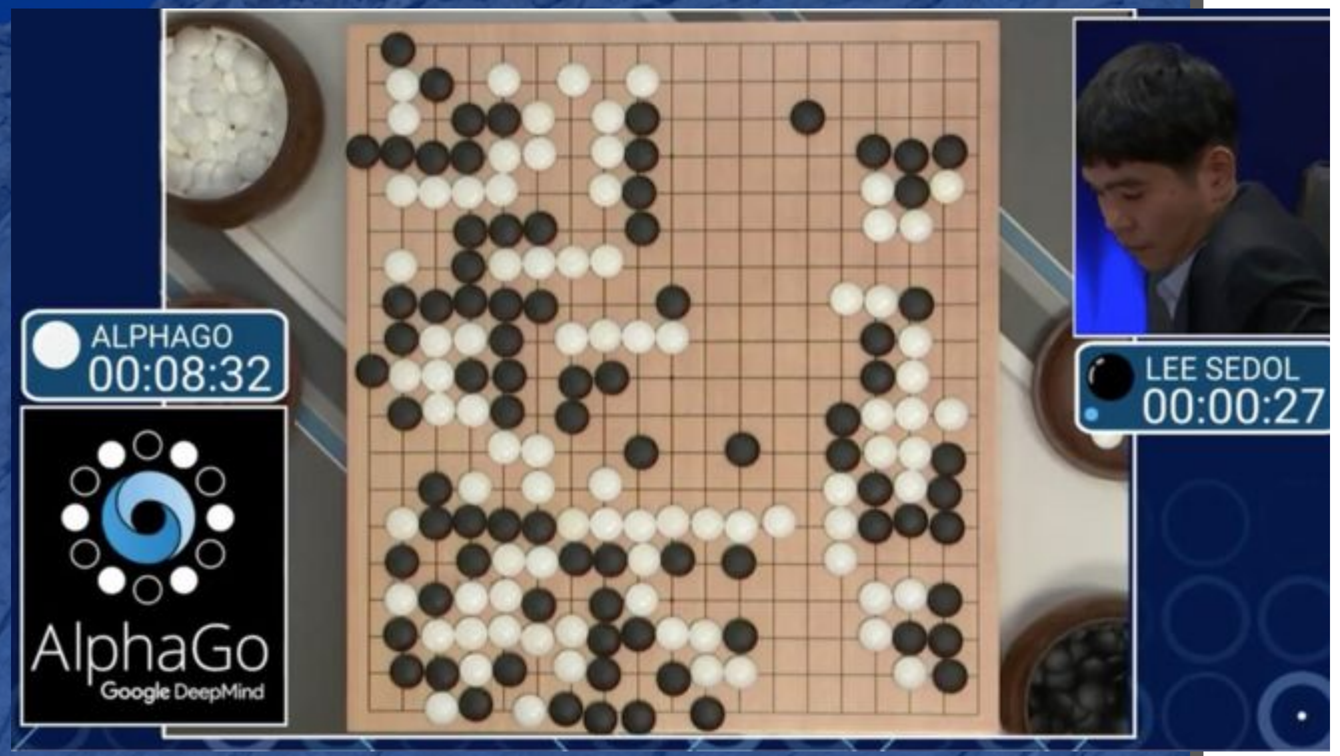
Exploitation vs. Exploration

What if the agent finds an action with a good short-term reward? Should it keep exploiting it?

Or, should it explore other actions, in case even better options exist?

The "Exploitation vs. Exploration Tradeoff"

What Makes a Good Reward?



Games often only provide a reward at the end of the episode - win or lose.

What about intermediate rewards?

Crafting rewards is hard. Intermediate rewards can lead to greedy optimization and local optima rather than the desired global optima - the cumulative reward.

Environments and Offline RL

What if you want to train a system for optimizing a chemical plant?

You can't let a naïve policy drive your plant while it learns!! The plant might be too complex to simulate, too. The higher the stakes, the greater the fidelity required.

However, since the environment "generates" data in normal RL, what about using historical data, instead?

Offline RL works with historical data instead of interacting with the environment.

Reinforcement Learning for Recommendations and Ad Placements

Preferences Change...

- You bought a toilet brush.
    - Do you want to keep seeing ads for toilet brushes?
- You've watched five action movies in a row.
    - Do you want to watch a sixth action movie or maybe something else for a change?

Preferences Change...

- How have your interests changed because of:
  - the weather
  - the economy
  - local, national, or world affairs
  - ???

RL for recommendations/ads helps with evolving preferences.

Considerations

- RL is less able to scale to large state spaces (e.g., all available movies catalog items).
- Traditional supervised learning methods are more scalable.

Real recommendation and ad systems must combine approaches; use RL once a subset of the state space is identified using a “classic” supervised learning approach.

Considerations

- A simulator is used to model real user behavior. (Training with real users doesn't scale well, etc.)

Or use offline RL with historical data about user behavior!

Considerations

- What is the reward? Some combination of user happiness measures?
- Could be very specific to the sub-genre of entertainment or product category.

Reward calculation balances mixed preferences & tradeoffs as they evolve in response to use actions.

To Learn More…

- rllib.io & ray.io
- Anyscale RL & RLlib course:
  https://applied-rl-course.netlify.app/en
- More resources in the extra slides!

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Extra Material

To Learn More…

- Courses
  - Hugging Face RL course https://huggingface.co/deep-rl-course/
  - Delta Academy https://delta-academy.xyz/
  - Fast Deep RL https://courses.dibya.online/p/fastdeeprl
  - Coursera RL Specialization from U of A https://www.coursera.org/specializations/reinforcement-learning
  - Udacity RL coursehttps://www.udacity.com/course/reinforcement-learning--ud600
- Video lectures
  - David Silver's lectures https://www.davidsilver.uk/teaching/
  - Sergey Levine's lectures http://rail.eecs.berkeley.edu/deeprlcourse/
- Books
  - Sutton & Barto http://incompleteideas.net/book/the-book-2nd.html (considered the definitive RL book)
  - Deep RL Hands-On https://www.packtpub.com/product/deep-reinforcement-learning-hands-on-second-edition/9781838826994
- Other
  - Spinning Up https://spinningup.openai.com/en/latest/ (a well-known resource for RL)

https://twitter.com/hardmaru/status/1597950795361660928

Another example of why RL;
how else are you going to train your new puppy?


More about RLlib

Architecture of RLlib

Some Algorithms in RLlib

- High-throughput architectures
  - Distributed Prioritized Experience Replay (Ape-X)
  - Importance Weighted Actor-Learner Architecture (IMPALA)
  - Asynchronous Proximal Policy Optimization (APPO)

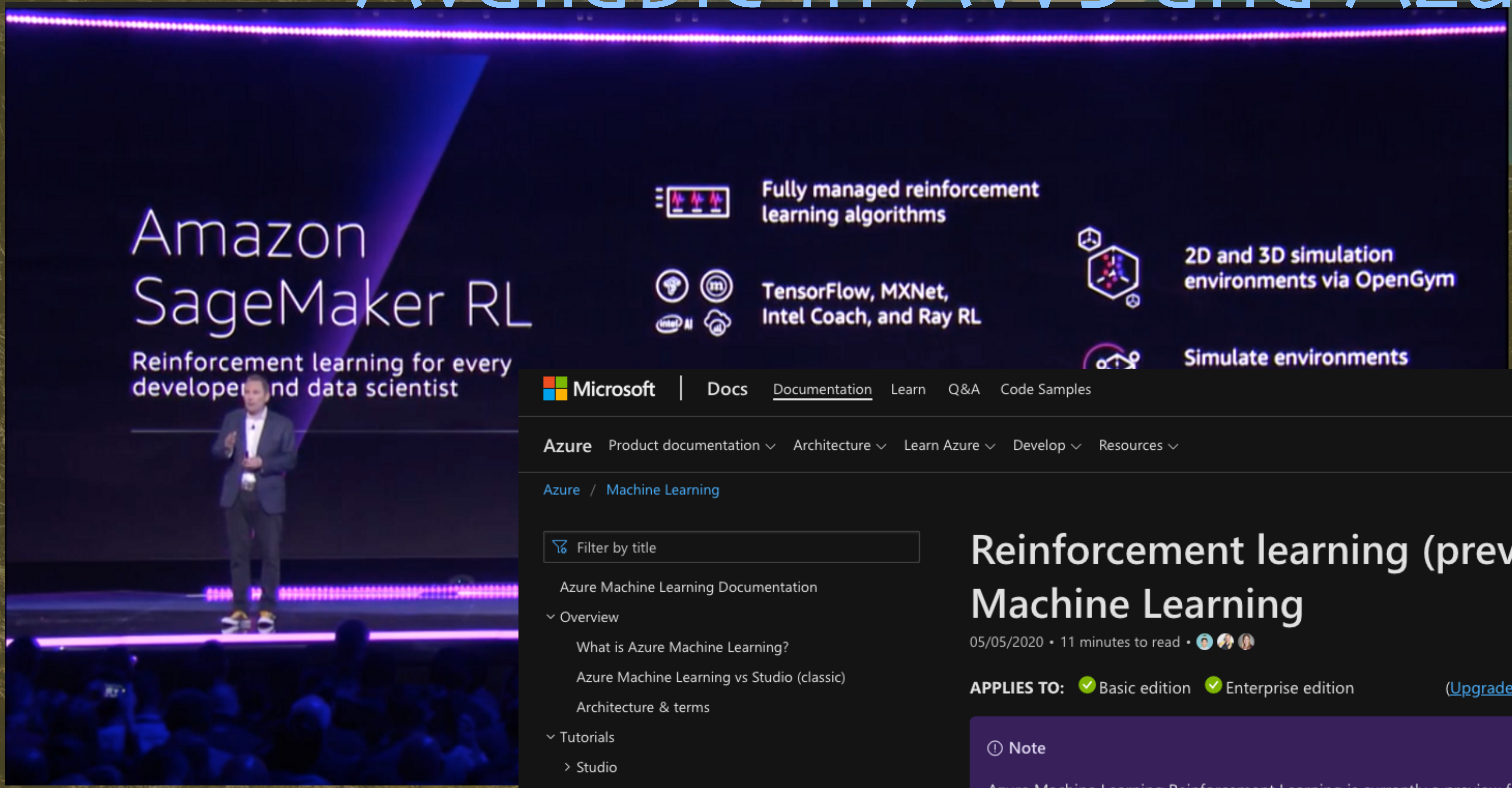
- Gradient-based
  - Soft Actor-Critic (SAC)
  - Advantage Actor-Critic (A2C, A3C)
  - Deep Deterministic Policy Gradients (DDPG, TD3)
  - Deep Q Networks (DQN, Rainbow, Parametric DQN)
  - Policy Gradients
  - Proximal Policy Optimization (PPO)

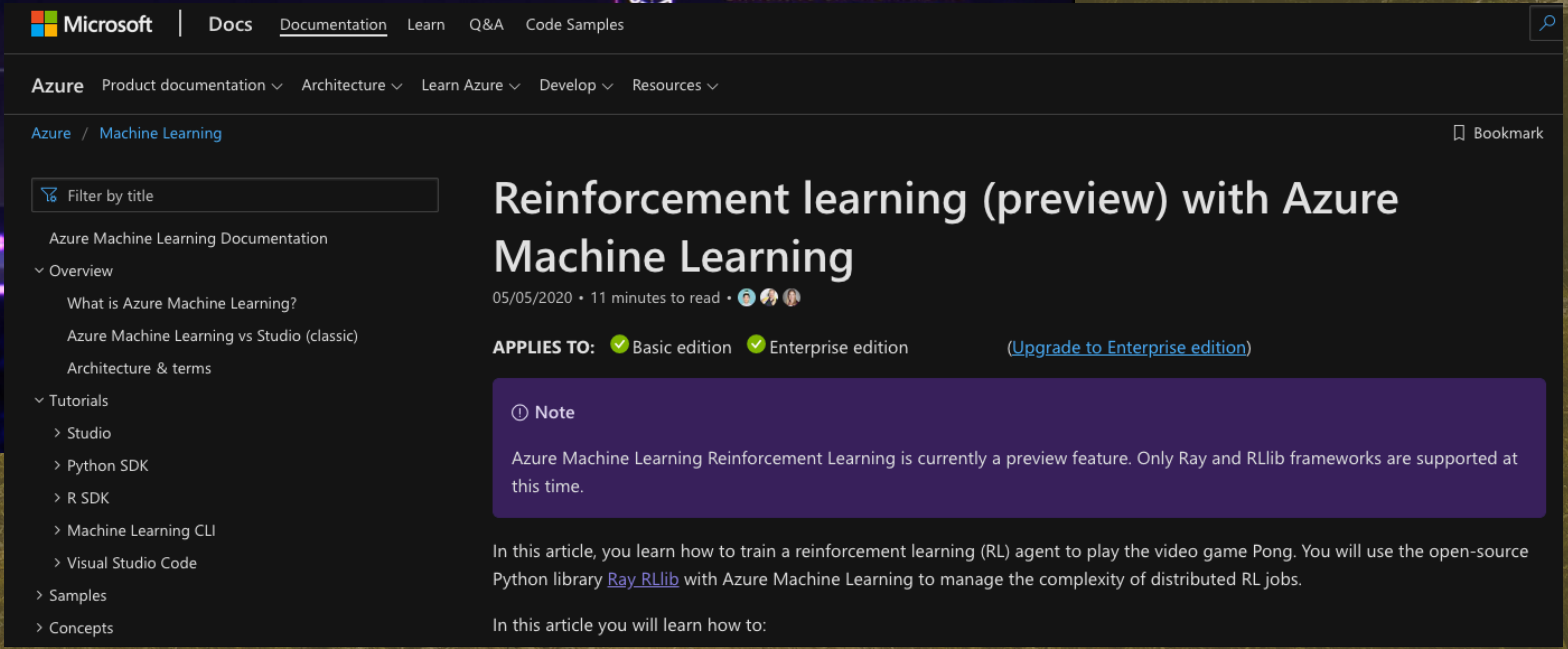
- gradient-free
  - Augmented Random Search (ARS)
  - Evolution Strategies

- Multi-agent specific
  - QMIX Monotonic Value Factorisation (QMIX, VDN, IQN)

- Offline
  - Advantage Re-Weighted Imitation Learning (MARWIL)

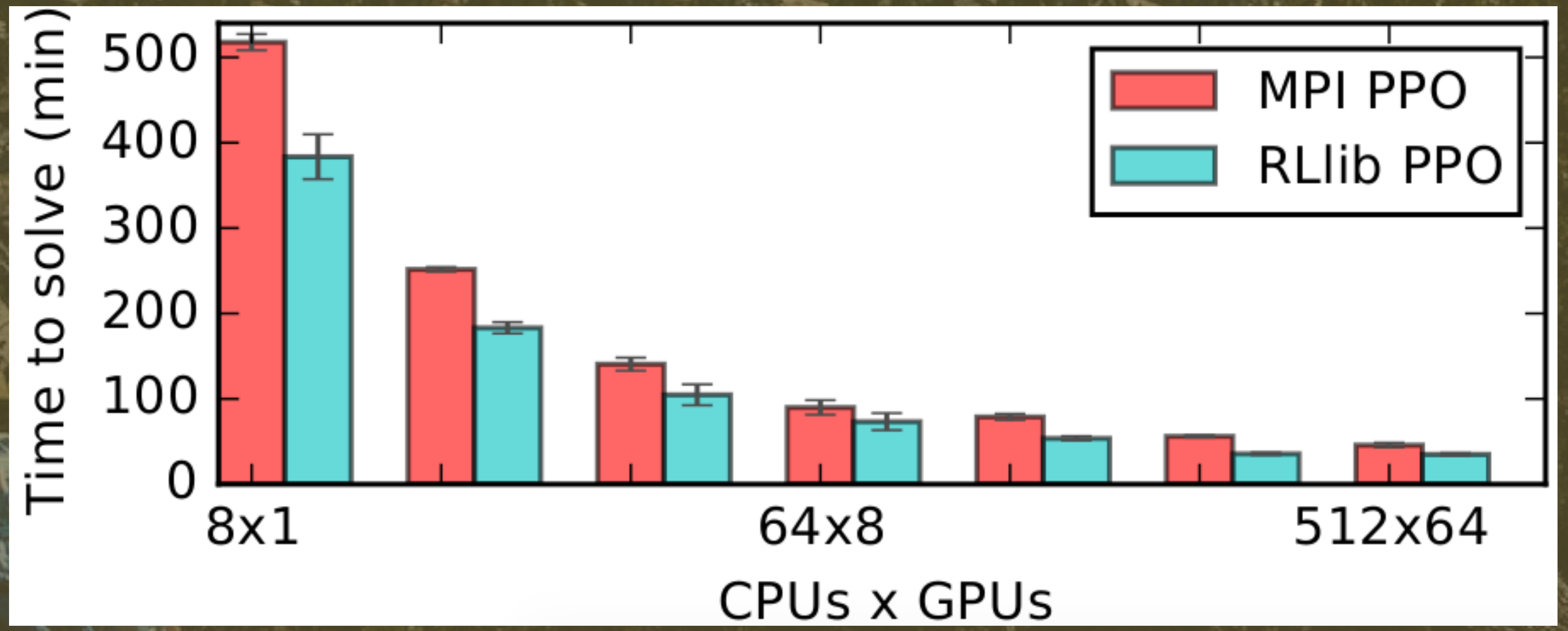
Available in AWS and Azure



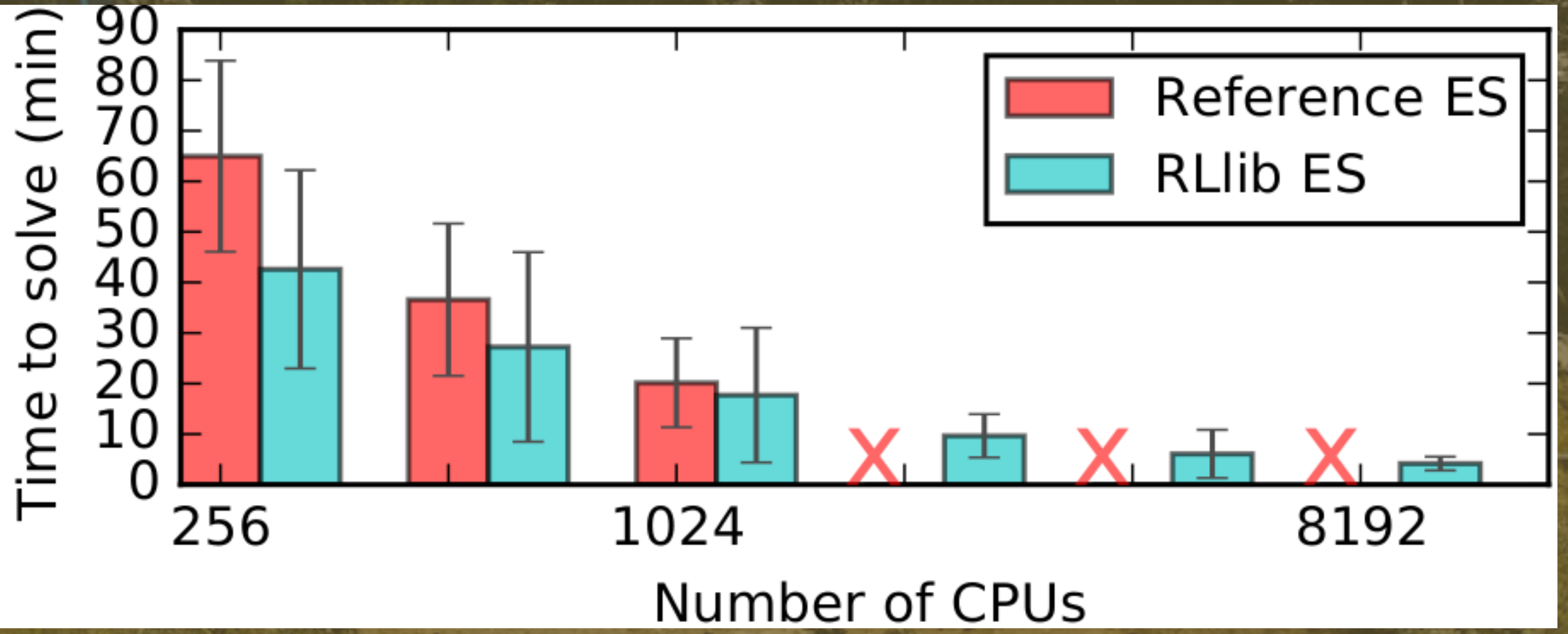


Excellent Performance vs. "Hand-tuned" Implementations

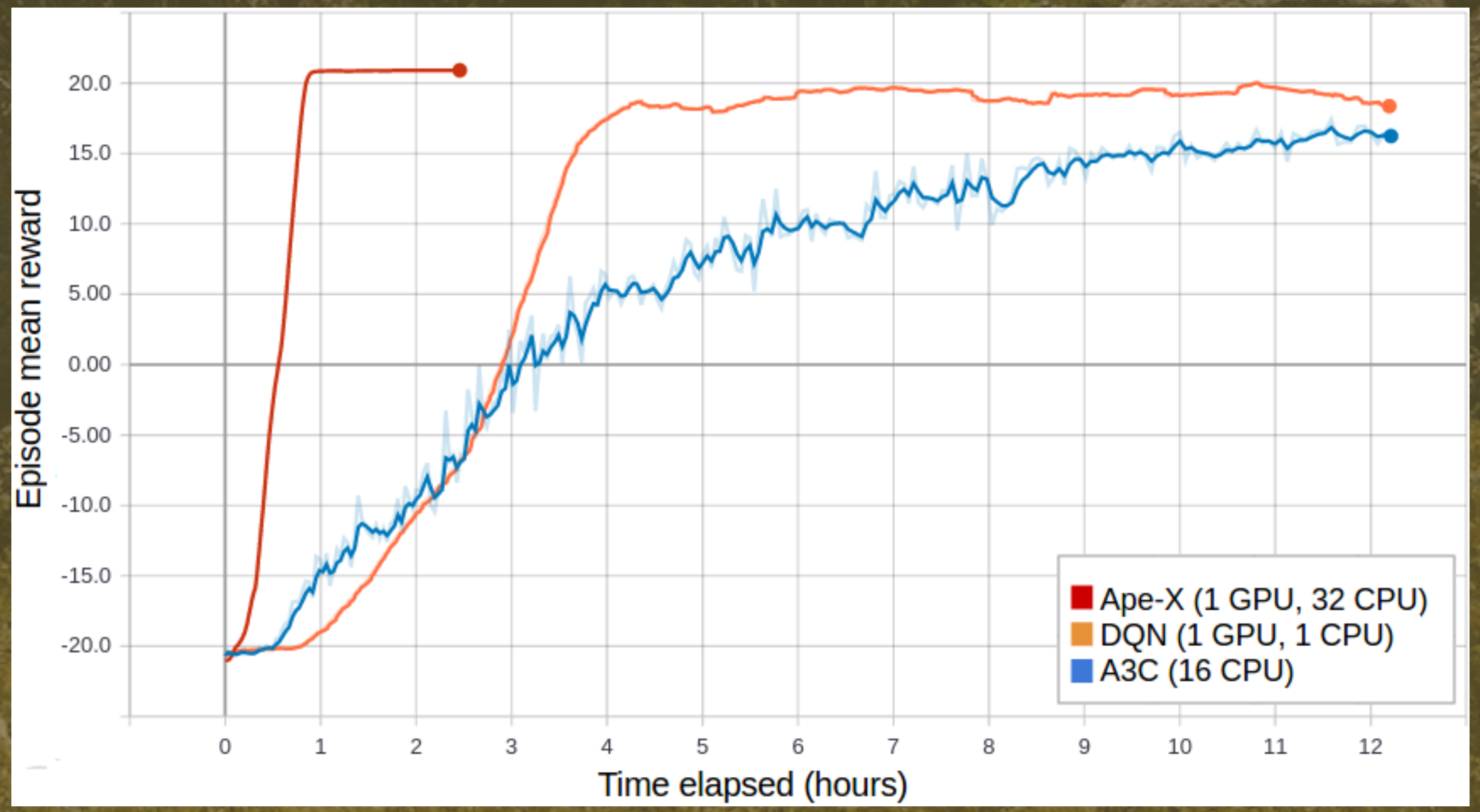
Distributed PPO



Evolution Strategies



Ape-X Distributed DQN, DDPG



Quick Intro to the Ray API

API - Designed to Be Intuitive and Concise

```python
def make_array(…):
    a = … # Construct a NumPy array
    return a


def add_arrays(a, b):
    return np.add(a, b)
```

The Python you already know…

API - Designed to Be Intuitive and Concise

Functions -> Tasks

```python
@ray.remote
def make_array(…):
    a = … # Construct a NumPy array
    return a

@ray.remote
def add_arrays(a, b):
    return np.add(a, b)
```

For completeness, add these first

```python
import ray
import numpy as np
ray.init()
```

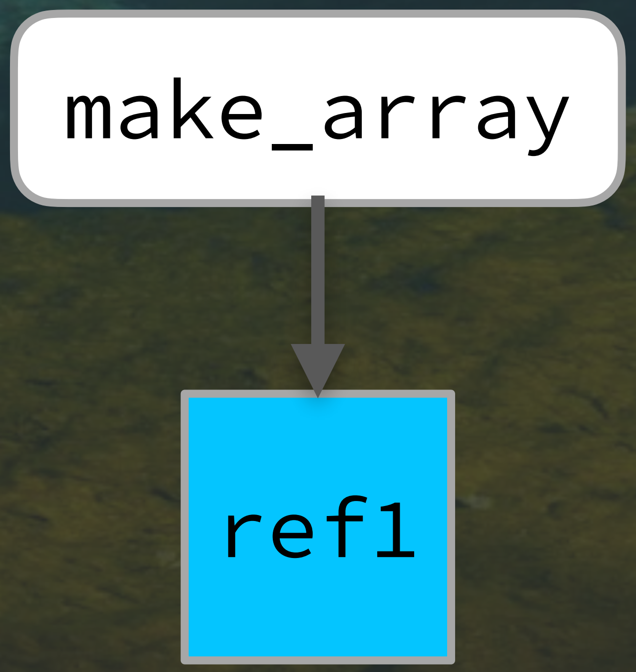
Now these functions are remote “tasks"

API - Designed to Be Intuitive and Concise

```python
@ray.remote
def make_array(…):
    a = … # Construct a NumPy array
    return a

@ray.remote
def add_arrays(a, b):
    return np.add(a, b)

ref1 = make_array.remote(…)
```



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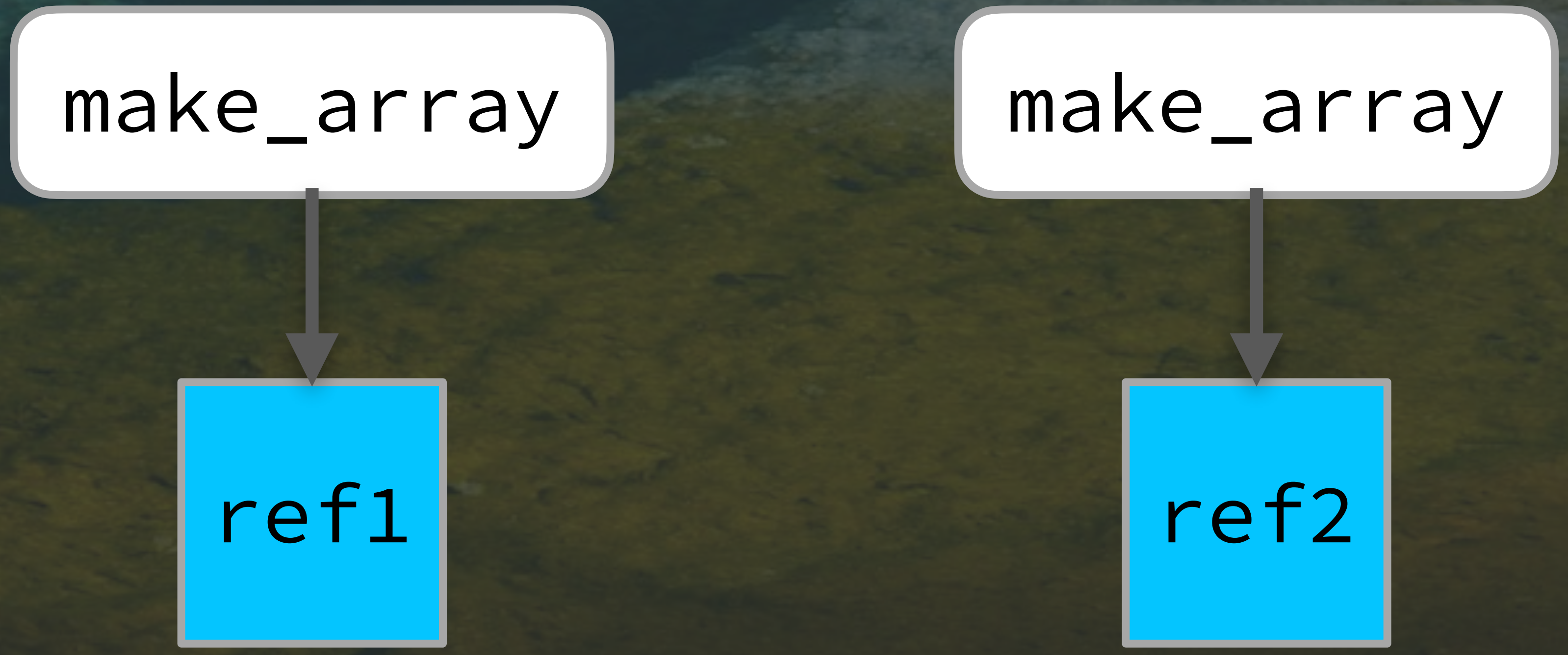
ref1 = make_array.remote(…)
ref2 = make_array.remote(…)
```



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ref3 = add_arrays.remote(ref1, ref2)
```
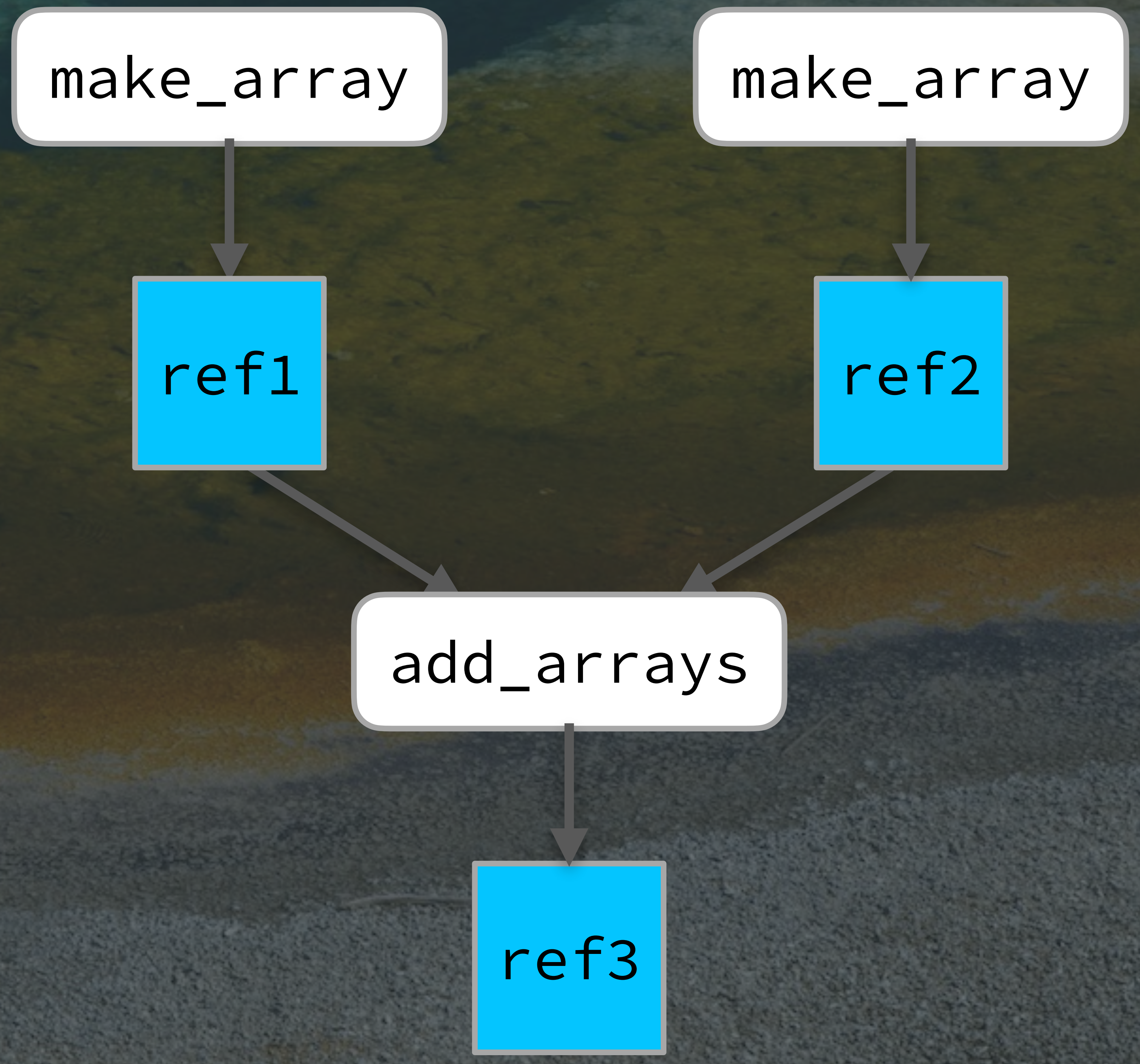
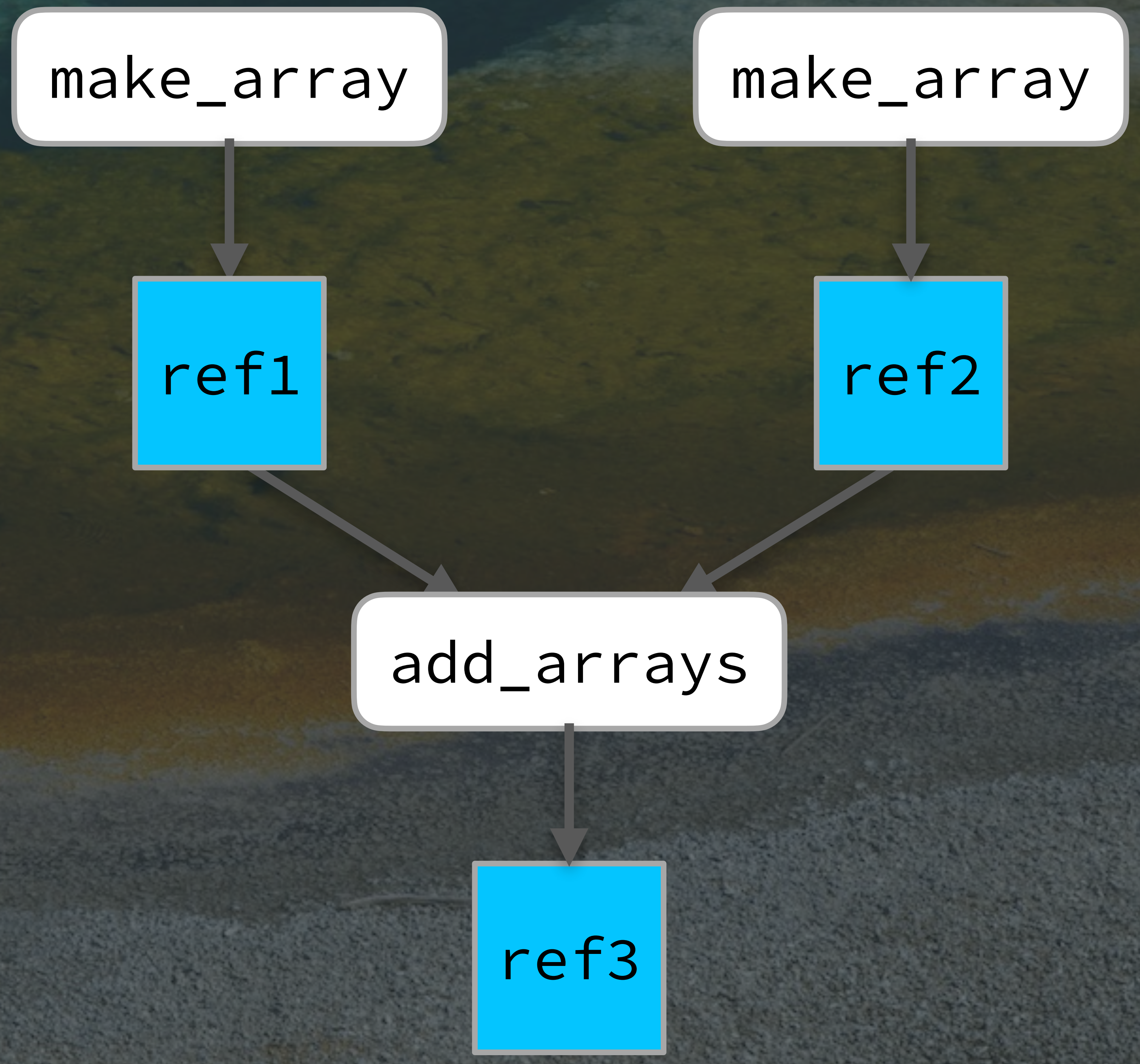



API - Designed to Be Intuitive and Concise

```
@ray.remote
def make_array(…):
    a = … # Construct a NumPy array
    return a

@ray.remote
def add_arrays(a, b):
    return np.add(a, b)

ref1 = make_array.remote(…)
ref2 = make_array.remote(…)
ref3 = add_arrays.remote(ref1, ref2)
ray.get(ref3)
```

Ray handles extracting the arrays from the object refs

Ray handles sequencing of async dependencies



API - Designed to Be Intuitive and Concise

What about distributed state?

```python
@ray.remote
def make_array(…):
    a = … # Construct a NumPy array
    return a

@ray.remote
def add_arrays(a, b):
    return np.add(a, b)

ref1 = make_array.remote(…)
ref2 = make_array.remote(…)
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```

API - Designed to Be Intuitive and Concise

Functions -> Tasks

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ref3 = add_arrays.remote(ref1, ref2)
ray.get(ref3)
```

Classes -> Actors

```
class Counter(object):
    def __init__(self):
        self.value = 0
    def increment(self):
        self.value += 1
        return self.value
```

The Python classes you love…

API - Designed to Be Intuitive and Concise

Functions -> Tasks

```
@ray.remote
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ray.get(ref3)
```

Classes -> Actors

```
@ray.remote
class Counter(object):
    def __init__(self):
        self.value = 0
    def increment(self):
        self.value += 1
        return self.value
    def get_count(self):
       return self.value
```

… now a remote "actor"

You need a "getter" method to read the state.

API - Designed to Be Intuitive and Concise

Functions -> Tasks

```python
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```

Classes -> Actors

```python
@ray.remote
class Counter(object):
    def __init__(self):
        self.value = 0
    def increment(self):
        self.value += 1
        return self.value
    def get_count(self):
       return self.value

c = Counter.remote()
ref4 = c.increment.remote()
ref5 = c.increment.remote()
ray.get([ref4, ref5]) # [1, 2]
```

API - Designed to Be Intuitive and Concise

Functions -> Tasks

```python
@ray.remote
def make_array(…):
    a = … # Construct a NumPy array
    return a

@ray.remote
def add_arrays(a, b):
    return np.add(a, b)

ref1 = make_array.remote(…)
ref2 = make_array.remote(…)
ref3 = add_arrays.remote(ref1, ref2)
ray.get(ref3)
```

Classes -> Actors

Optional configuration specifications

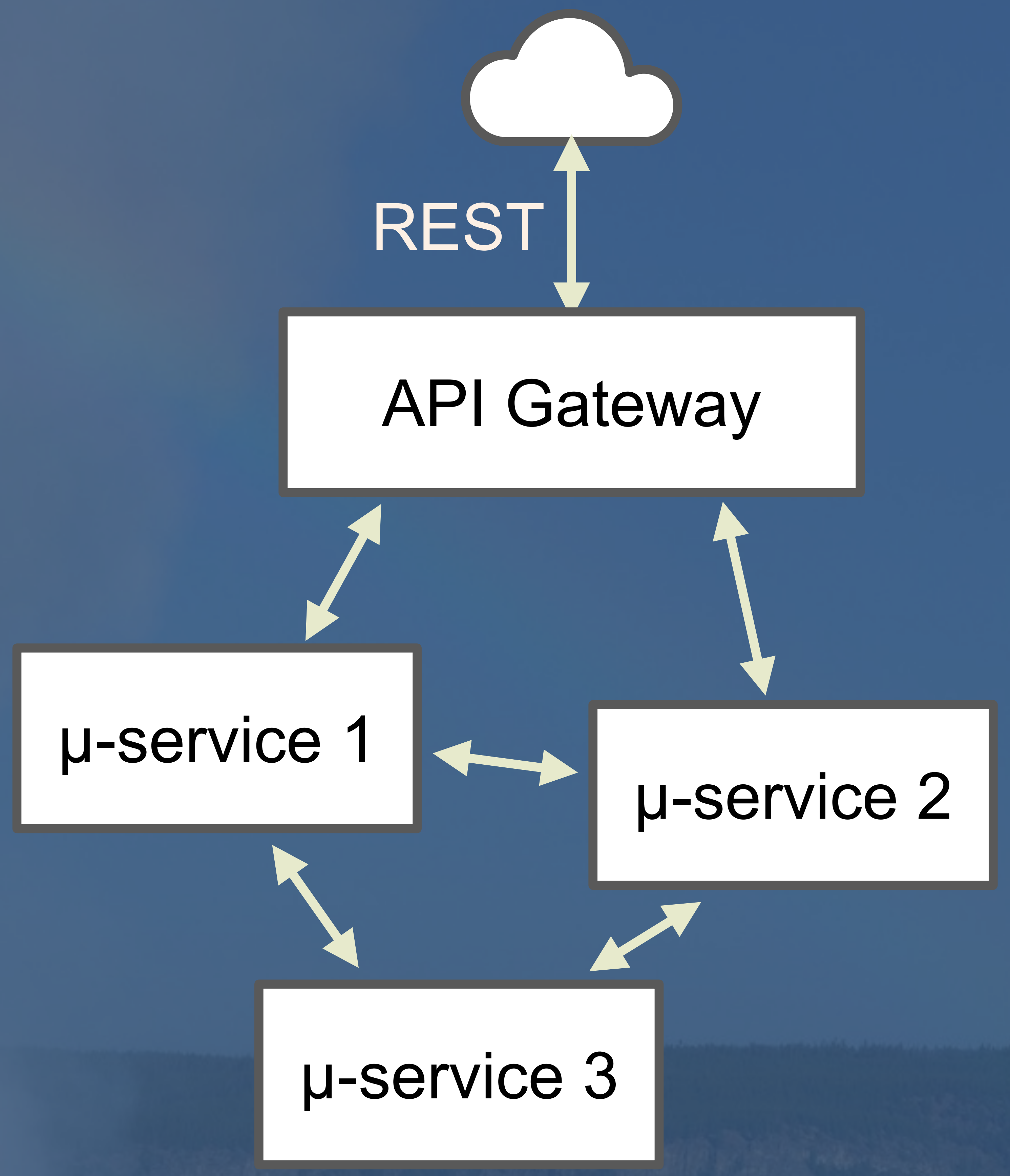
```python
@ray.remote(num_gpus=1)
class Counter(object):
    def __init__(self):
        self.value = 0
    def increment(self):
        self.value += 1
        return self.value
    def get_count(self):
       return self.value

c = Counter.remote()
ref4 = c.increment.remote()
ref5 = c.increment.remote()
ray.get([ref4, ref5]) # [1, 2]
```

Other Uses of Ray: Microservices

What Are Microservices?

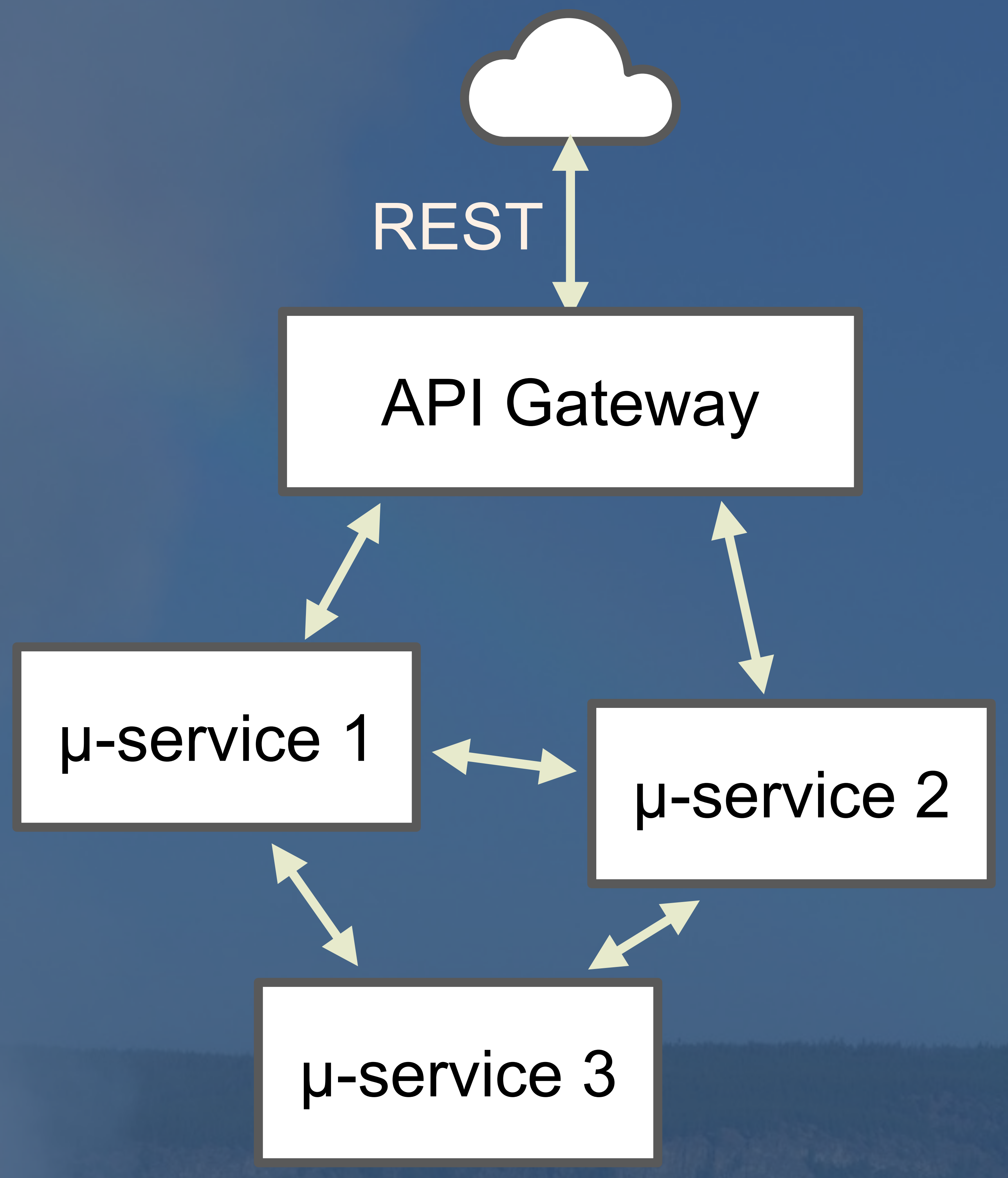
- They partition the domain
  - Conway's Law - Embraced
  - Separate responsibilities
- Separate management



What Are Microservices?

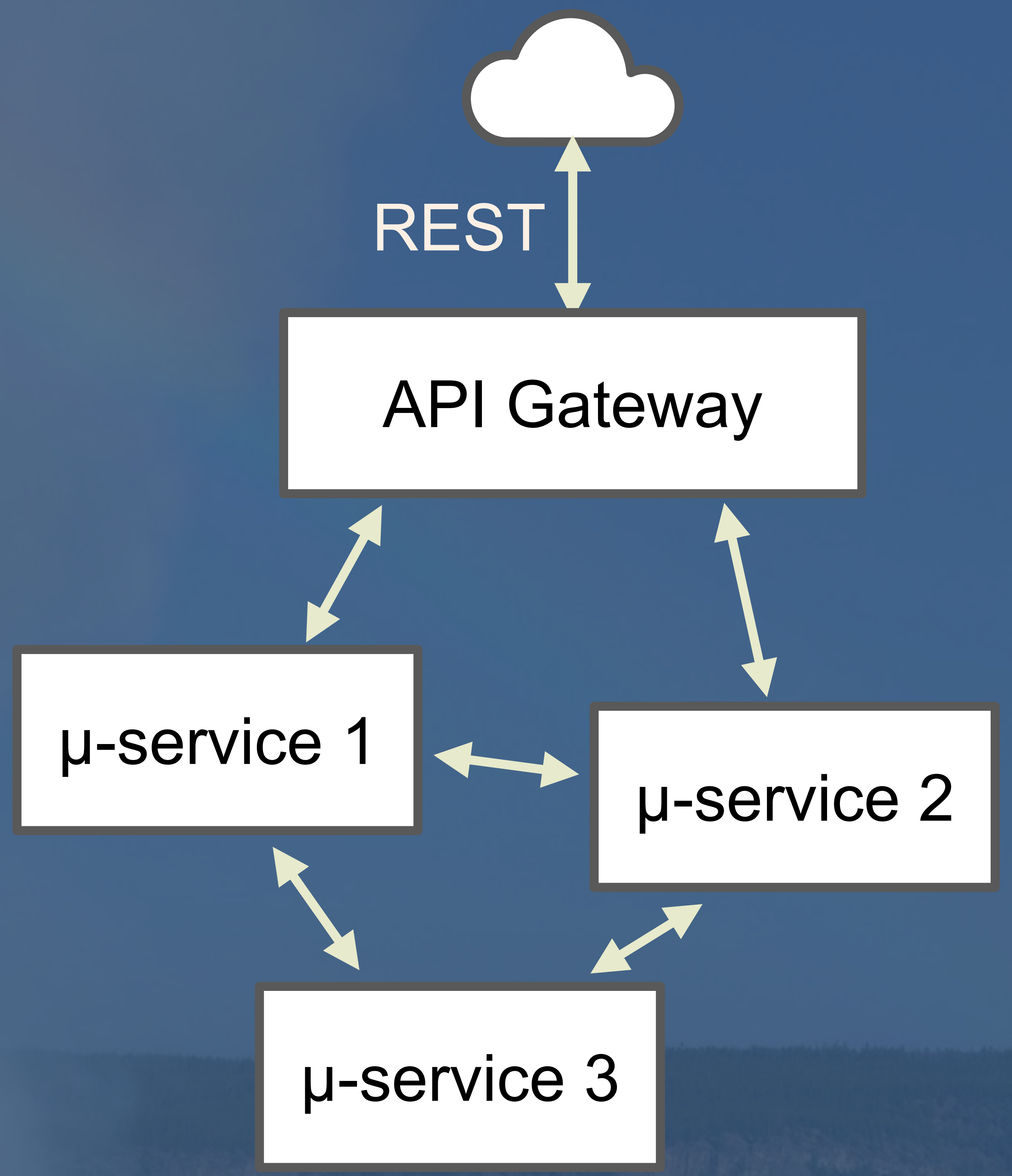
- They partition the domain
  - Conway's Law - Embraced
  - Separate responsibilities
- Separate management

What we mostly care about for today’s talk, the “Ops in DevOps”



Conway's Law - Embraced

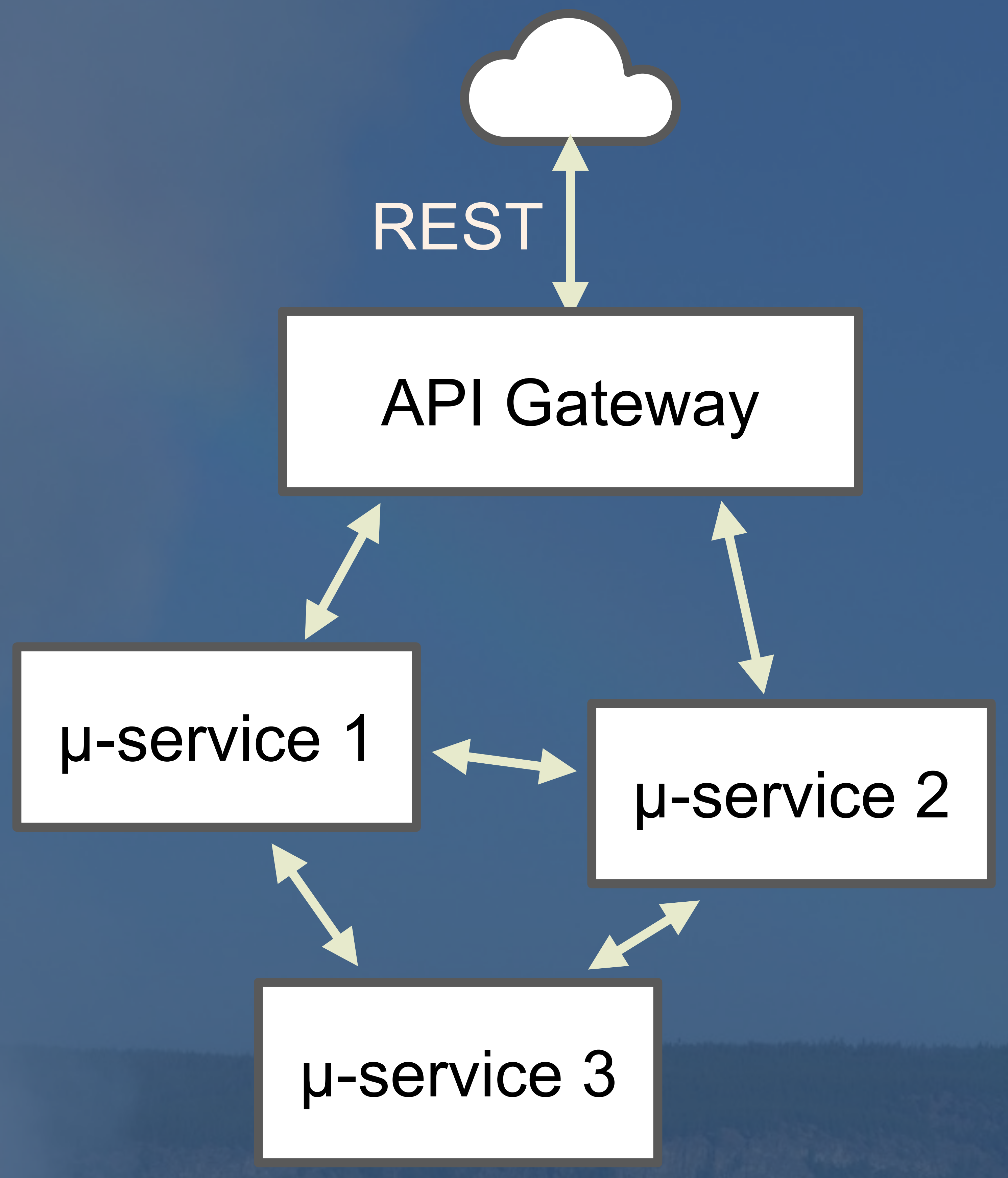
- "Any organization that designs a system will produce a design whose structure is a copy of the organization's communication structure"
- Let each team own and manage the services for its part of the domain



en.wikipedia.org/wiki/Conway's_law

Separate Responsibilities

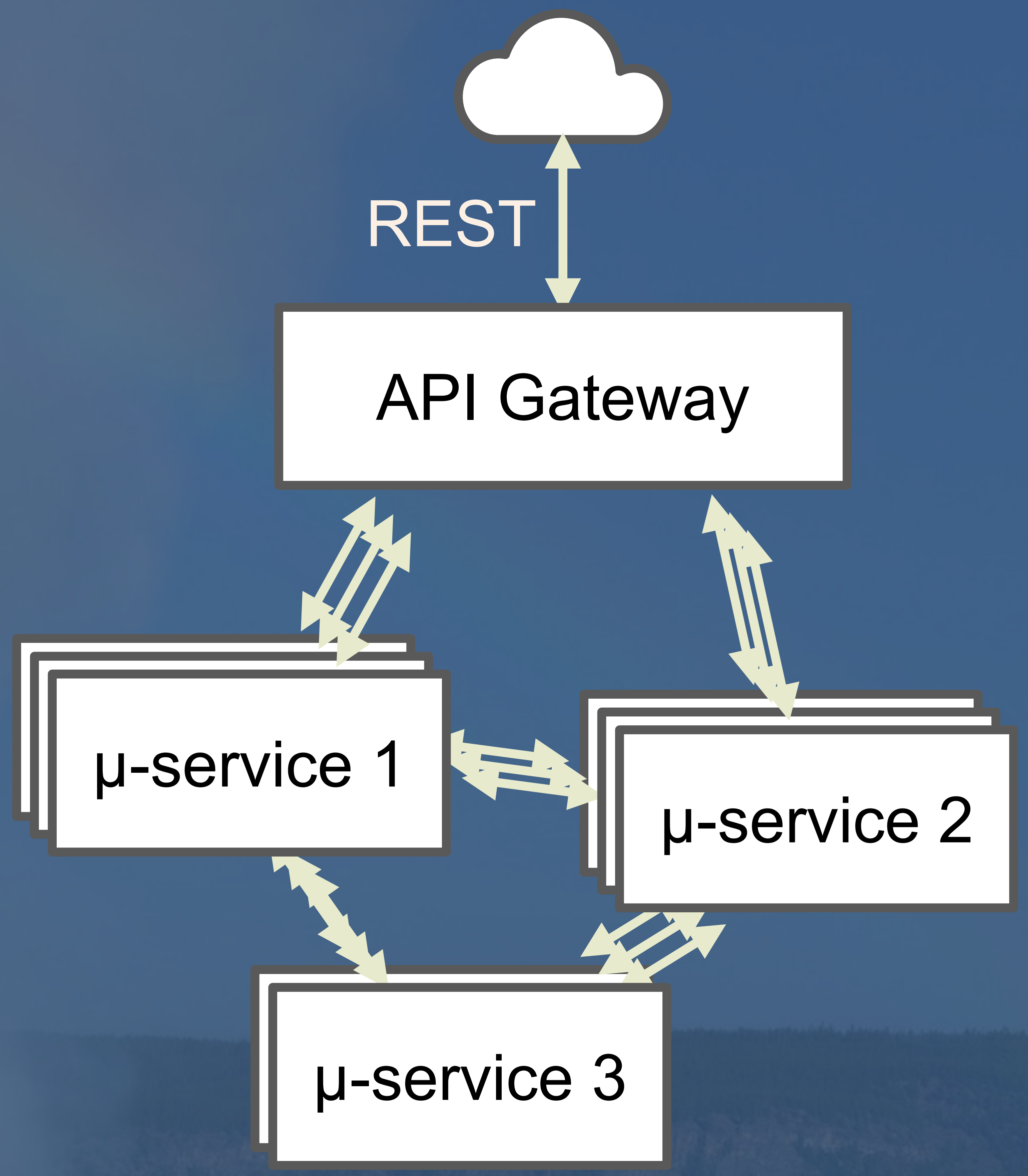
- Each microservice does "one thing", a single responsibility with minimal coupling to the other microservices
- (Like, hopefully, the teams are organized, too…)



wikipedia.org/wiki/Single-responsibility_principle

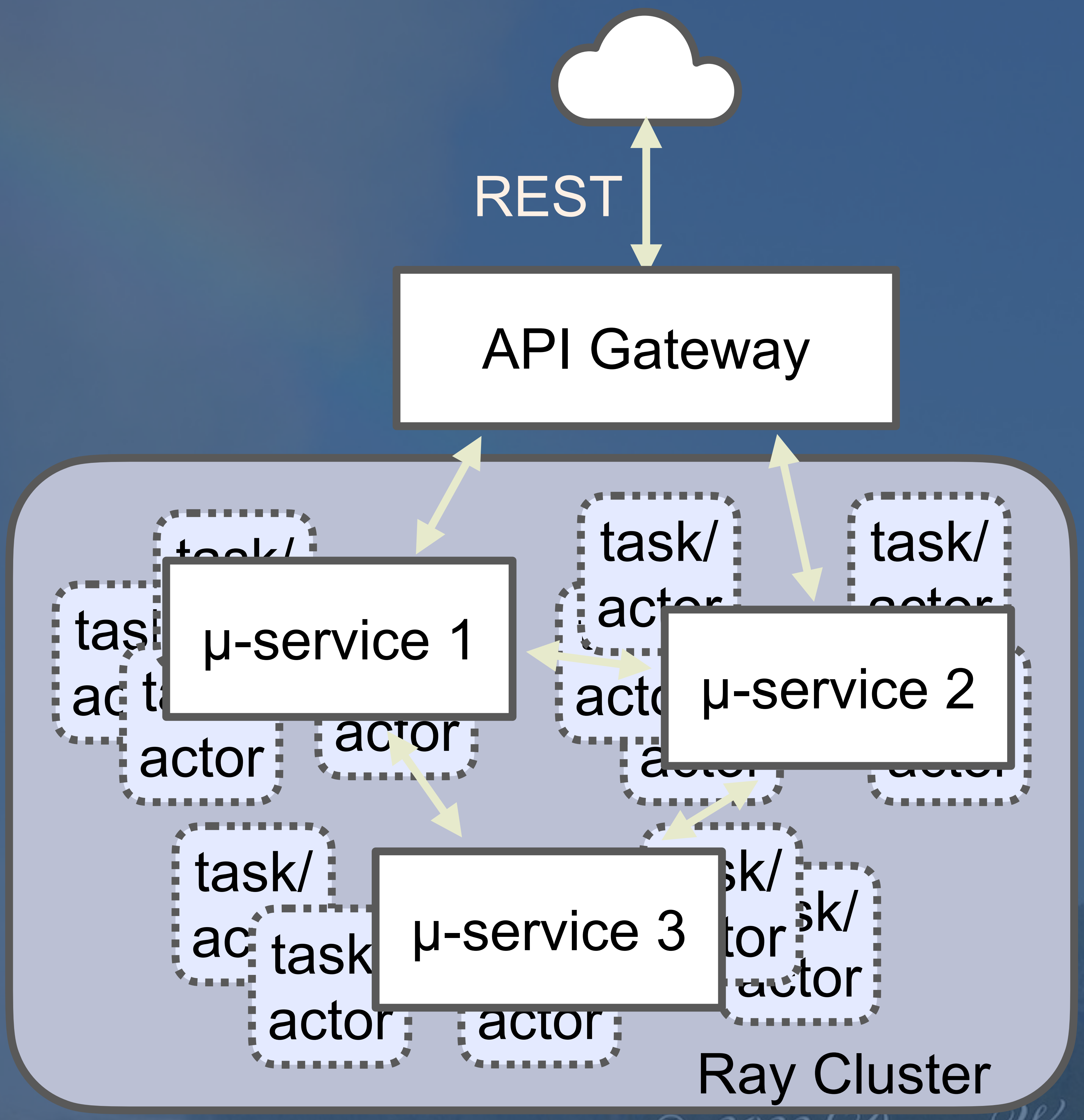
Separate Management

- Each team manages its own instances
- Each microservice has a different number of instances for scalability and resiliency
- But they have to be managed **explicitly**



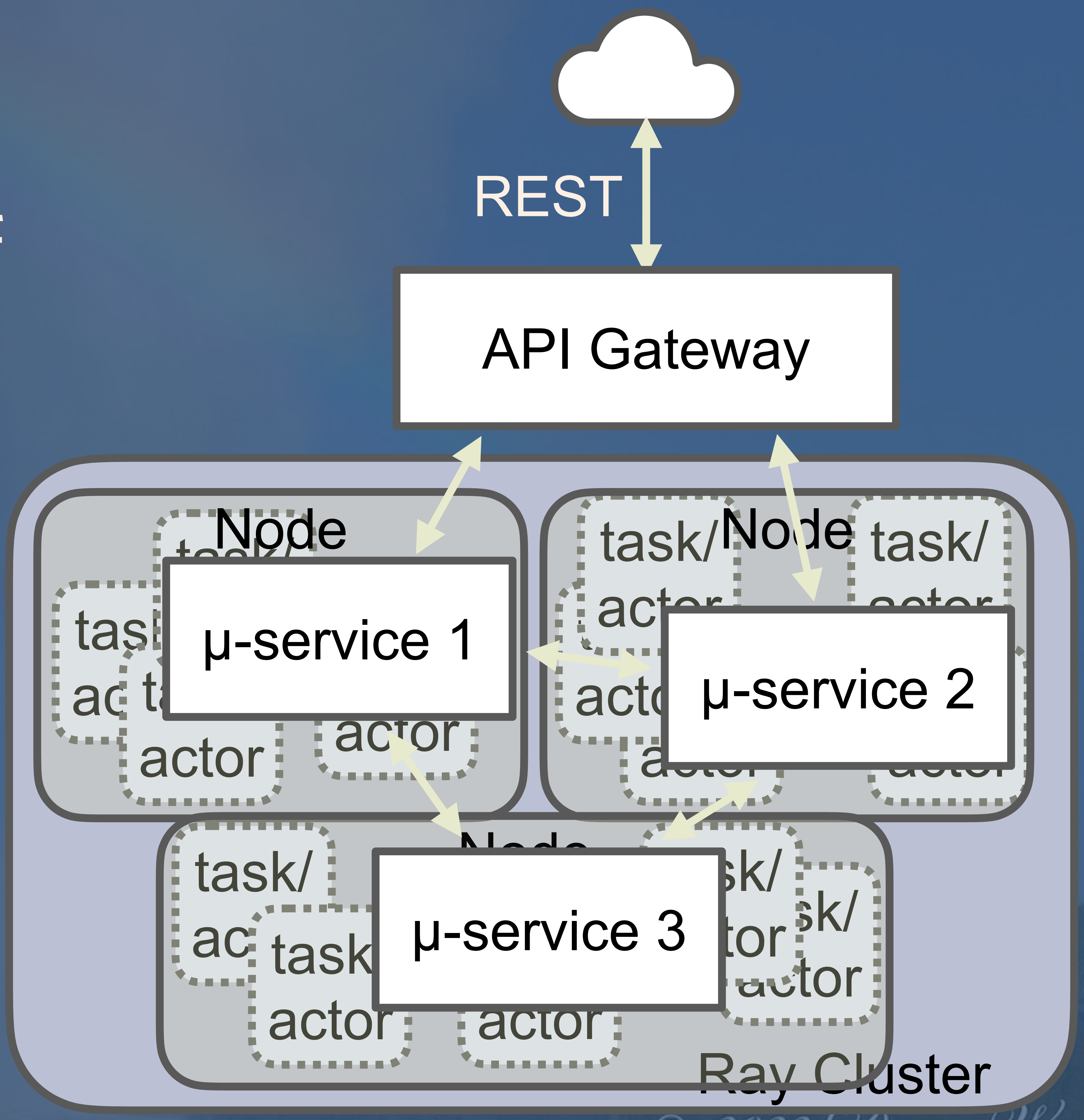
Management - Simplified

- With Ray, you have one “logical” instance to manage and Ray does the cluster-wide scaling for you.



What about Kubernetes (and others…)?

- Ray scaling is very fine grained.
- It operates within the “nodes” of coarse-grained managers
  - Containers, pods, VMs, or physical machines



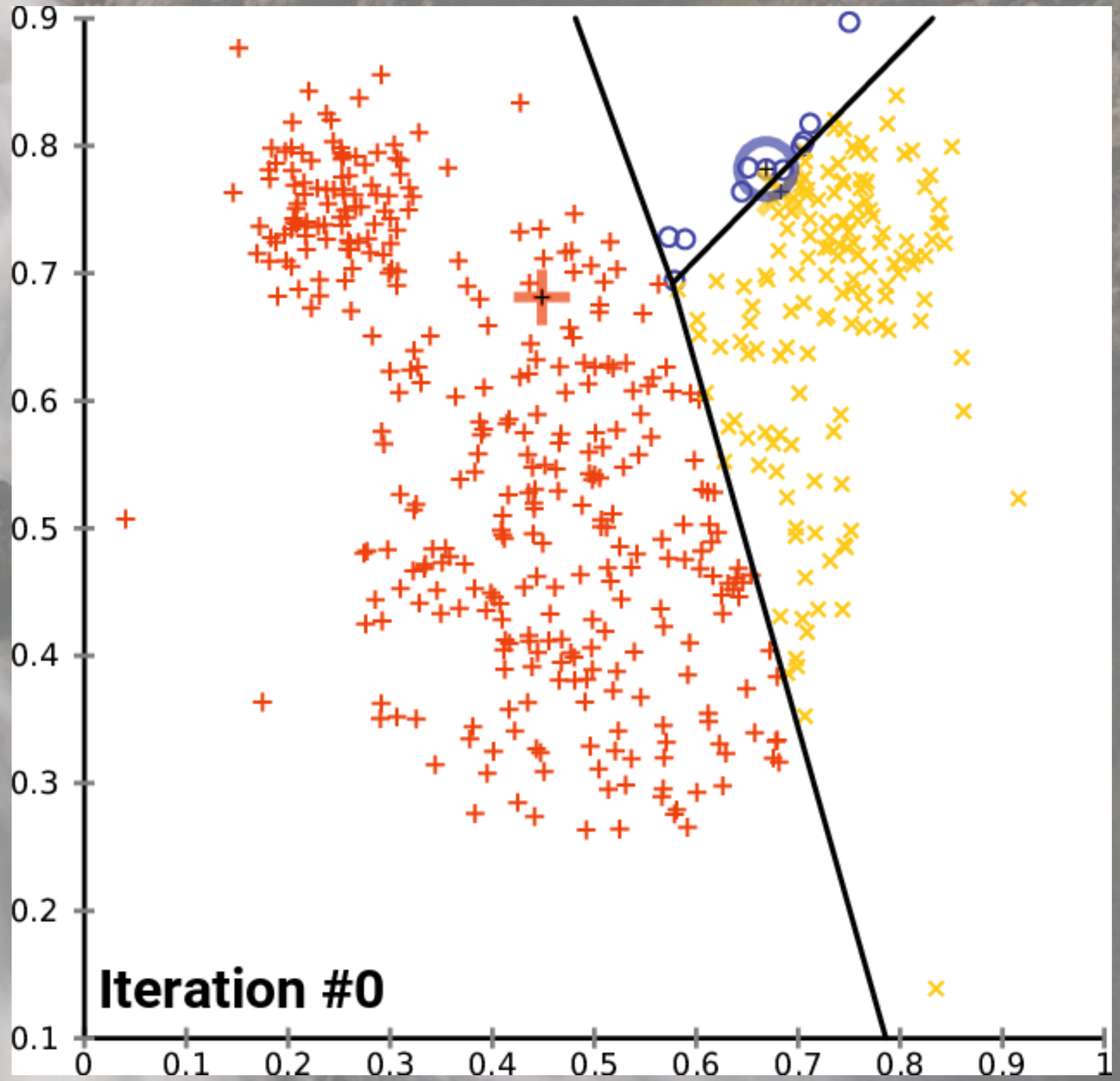
Hyper Parameter Tuning with Ray Tune

Hyperparameter Tuning - Ray Tune

What Is Hyperparameter Tuning?

Trivial example:

- What's the best value for "k" in k-means??
  - k is a "hyperparameter"
    - The resulting clusters are defined by "parameters"

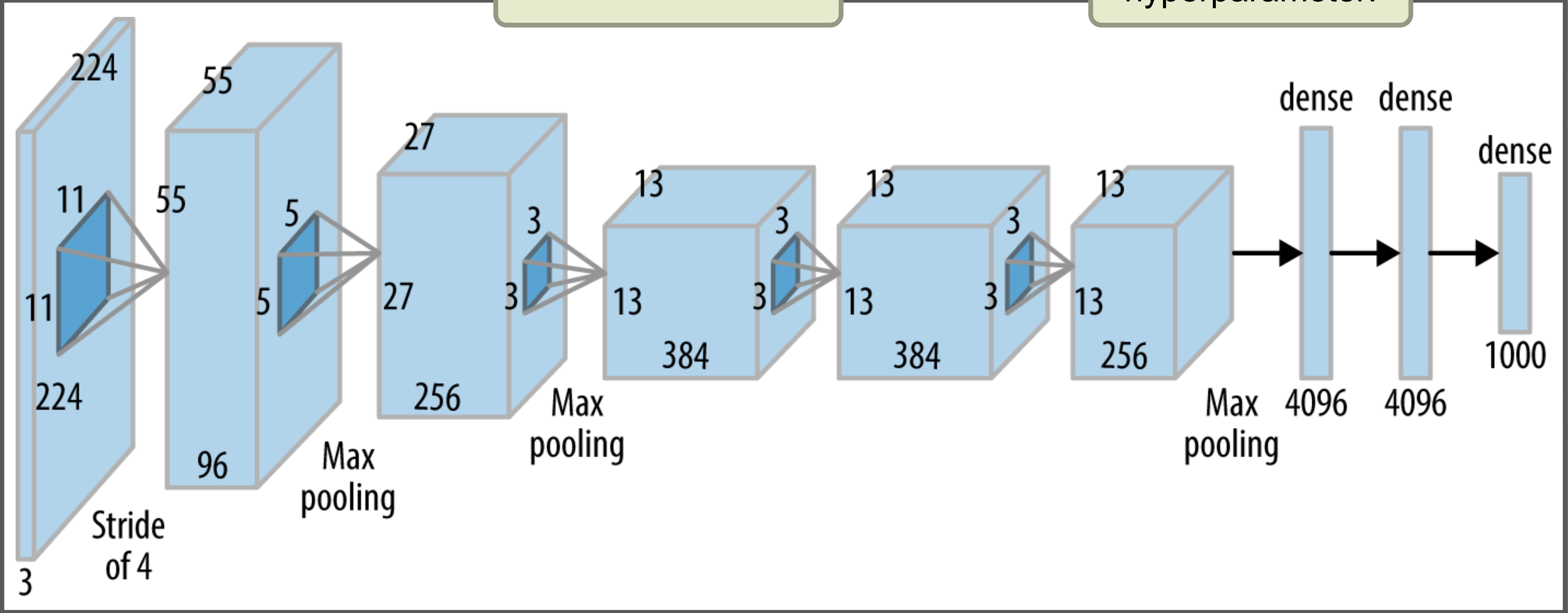


credit: https://commons.wikimedia.org/wiki/File:K-means_convergence.gif

Nontrivial Example - Neural Networks

How many layers?
What kinds of layers?

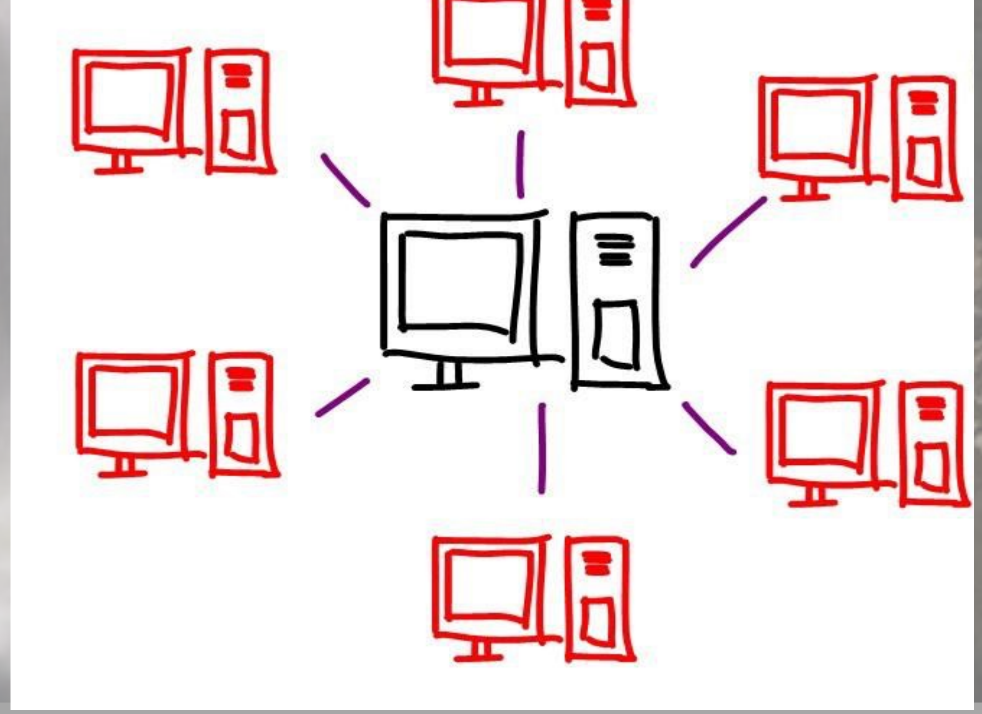
Every number shown is a hyperparameter!



Tune is Built with Deep Learning as a Priority

Resource Aware Scheduling

Seamless Distributed Execution



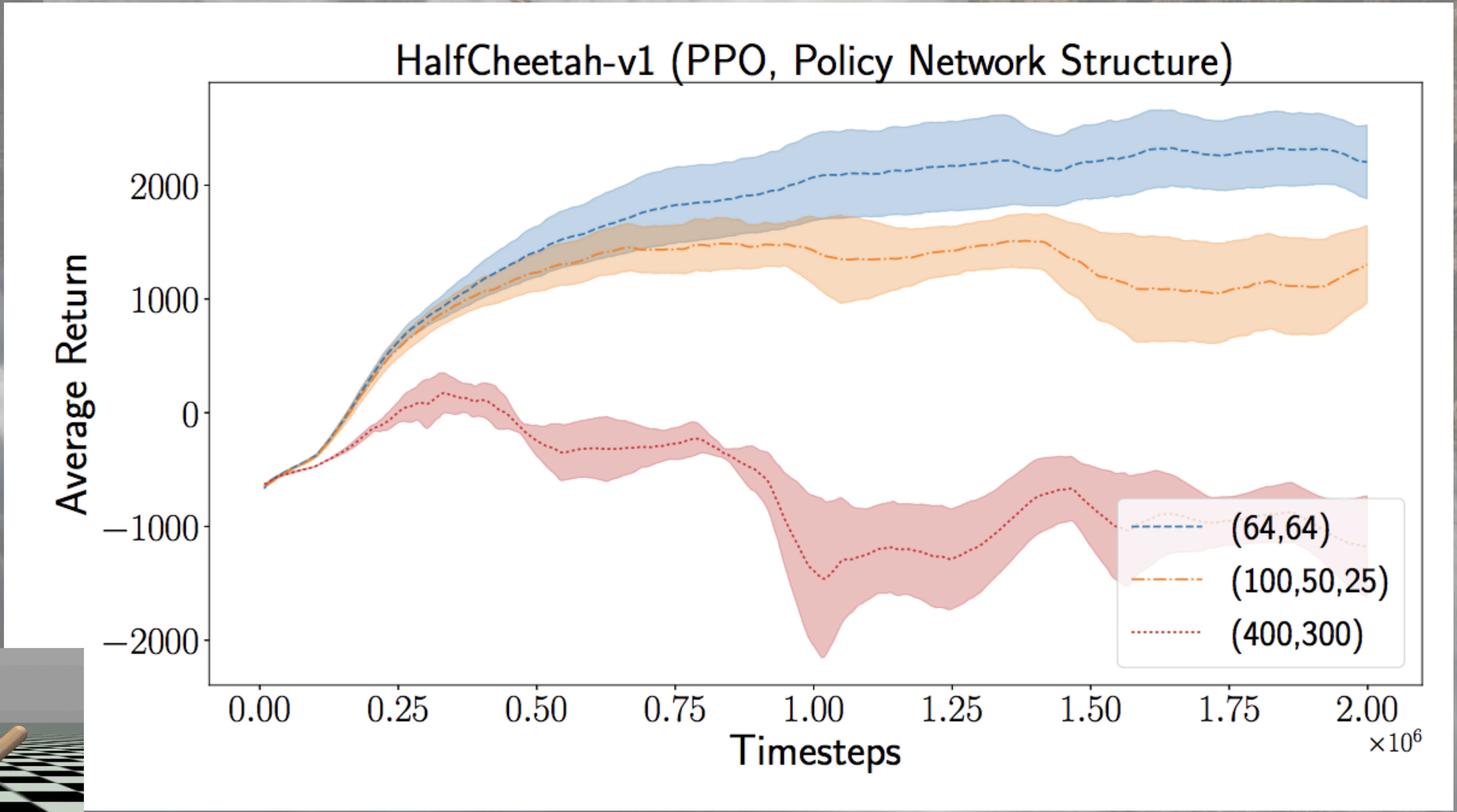
Simple API for new algorithms

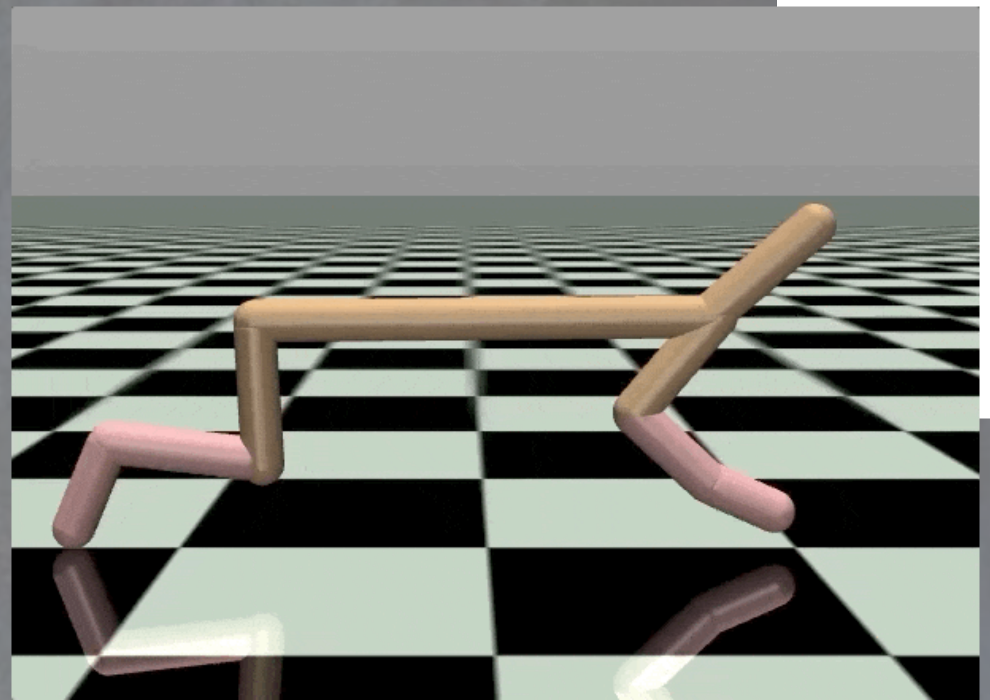
```python
class TrialScheduler:
    def on_result(self, trial, result): ...
    def choose_trial_to_run(self): ...
```

Framework Agnostic

tune.io

Hyperparameters Are Important for Performance





Why We Need a Framework for Tuning Hyperparameters

We want the best model

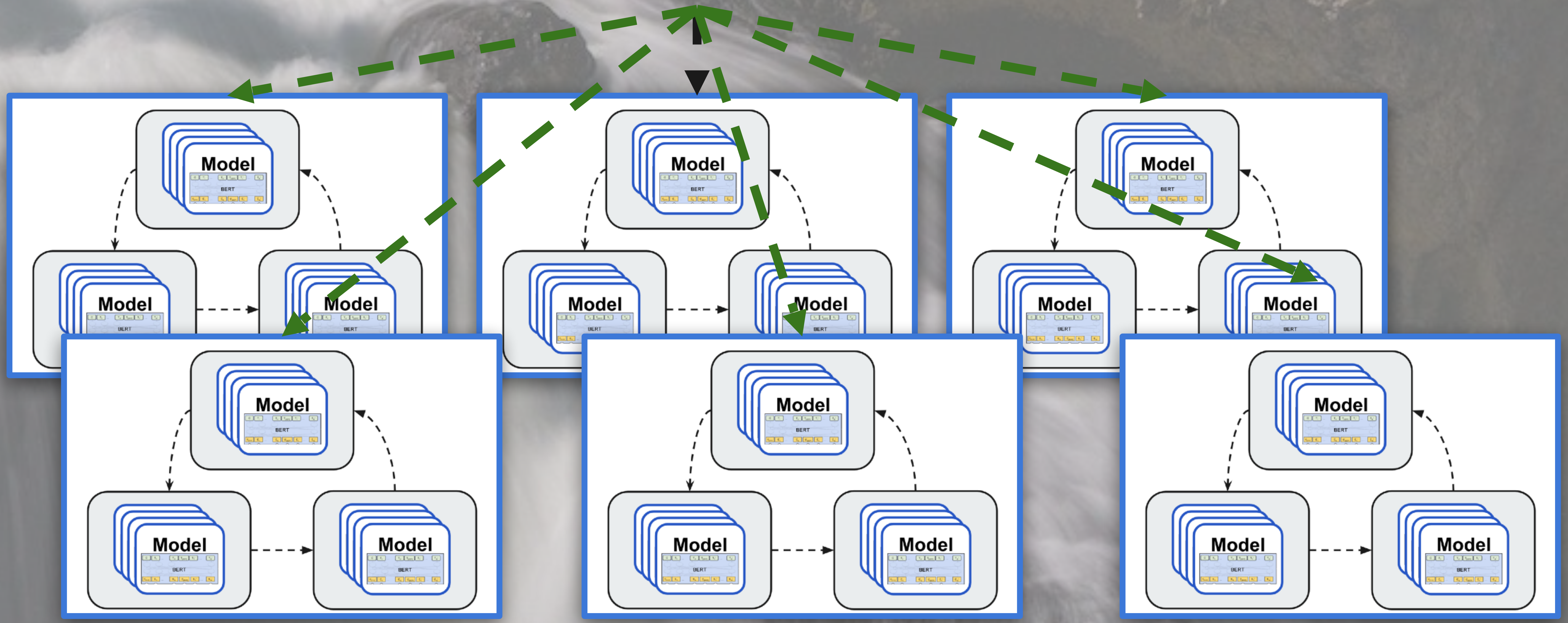
Resources are expensive

Model training is time-consuming

tune

Tuning + Distributed Training

```
tune.run(PytorchTrainable,
      config={
         "model_creator": PretrainBERT,
         "data_creator": create_data_loader,
         "use_gpu": True,
         "num_replicas": 8,
         "lr": tune.uniform(0.001, 0.1)
      },
      num_samples=100,
      search_alg=BayesianOptimization()
)
```



Native Integration with TensorBoard HParams