Reinforcement Learning

Building a Complete RL System

Slides by
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.7 February 2025

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informatics

Lecture Outline

- What is Gymnasium?
- How to implement your own environment?
- How to implement a RL algorithm?
- How to evaluate your results?
- Demonstration

Gymnasium

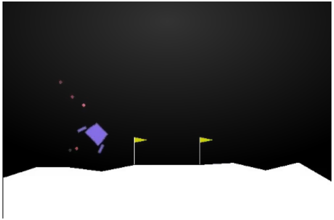
What is Gymnasium? (Towers et al., 2023)

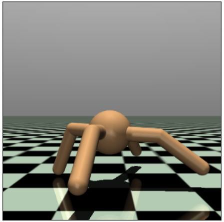
- Open source interface for sequential decision processes
- A fork of OpenAI Gym which was originally developed by OpenAI Research Lab (Brockman et al., 2016)
- Currently maintained by the Farama Foundation
- Collection of RL environments
- Standardised interface for RL environments

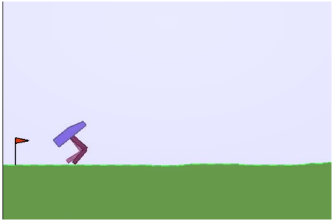
Can be installed with

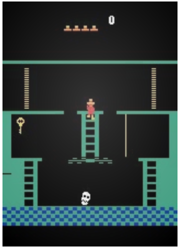
```
pip install gymnasium
```

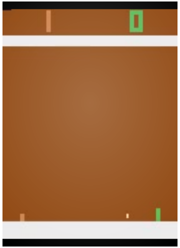
Lots of Interesting Environments! (Towers et al., 2023)



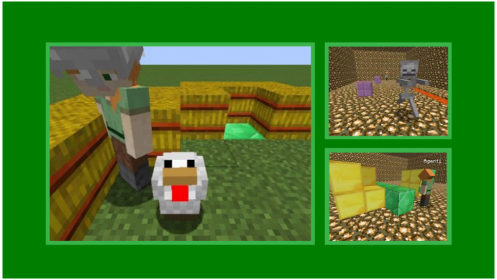








And many more... (Vinyals et al., 2017; Johnson et al., 2016; Kauten, 2018)



Gym Interface

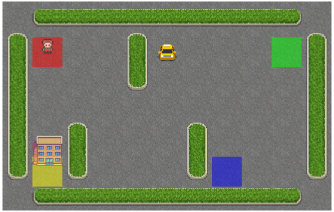
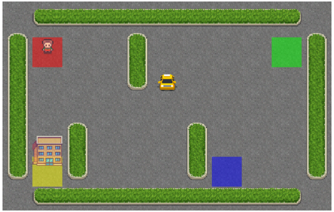
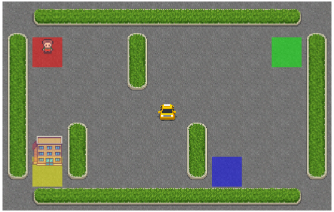
- `gym.make(<env_name>, render_mode=...)` $\longrightarrow$ gym environment
  Create a gym environment
- `env.reset()` $\longrightarrow$ observation, info
  Resets environment for a new episode
- `env.step(action)` $\longrightarrow$ observation, reward, terminated, truncated, info
  Take an action and observe new information
- `env.render()`
  Render a visualisation of the current environmental state
- `env.close()`
  Close created environment

Gym Example Snippet

Gym control flow

```
env = gym.make('Taxi-v3', render_mode='human')
obs, info = env.reset()
done = False
while not done:
    action = agent.choose_action(obs)
    next_obs, reward, terminated, truncated, info = env.step(action)
    done = terminated or truncated
    obs = next_obs
env.close()
```

Example: Taxi-v3 Environment

- Gridworld with 5×5 map
- Four designated pick-up and drop-off locations (Red, Green, Yellow and Blue)

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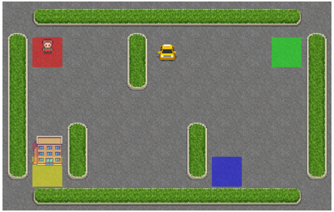
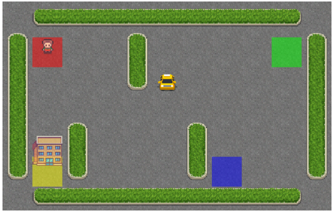
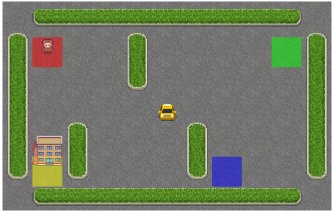

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- Observations $\in [0, 499]$ including taxi row and col, pass. and dest. index

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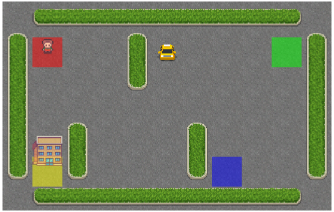 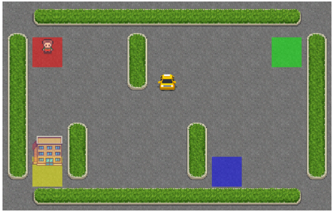 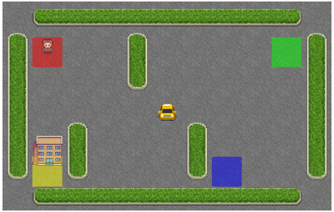

- Gridworld with 5×5 map
- Four designated pick-up and drop-off locations (Red, Green, Yellow and Blue)
- Observations $\in [0, 499]$ including taxi row and col, pass. and dest. index
- Actions: [`South`, `North`, `East`, `West`, `Pick`, `Drop`]

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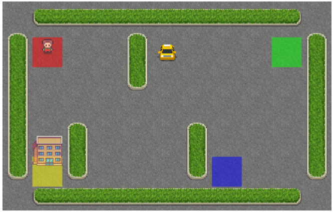
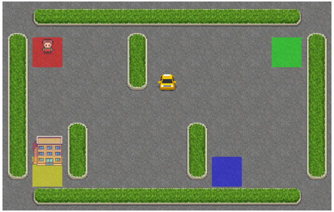
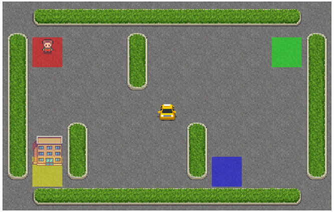
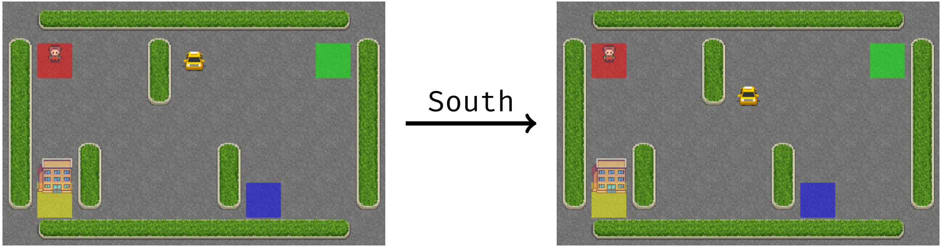
  

- Goal: Pickup passenger and drop it off at destination
- Reward: $+20$ for successful delivery, -1 at each timestep, -10 for illegal move
- Challenge: navigate gridworld

Taxi Environment Step I



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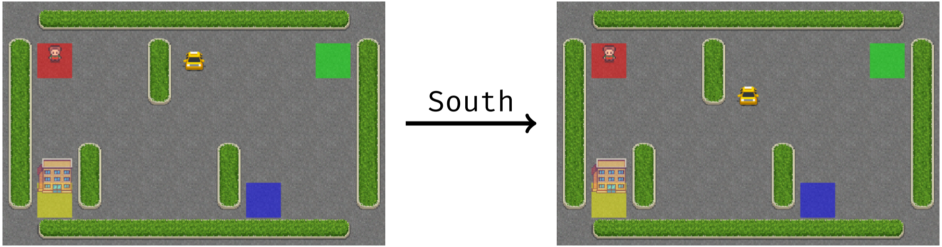
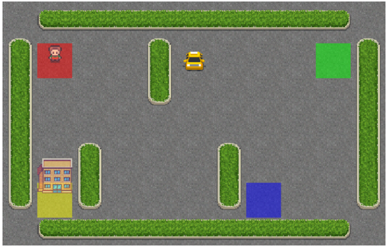


$\texttt{nobs, r, term, trunc, \_} = \texttt{env.step(a)}$:

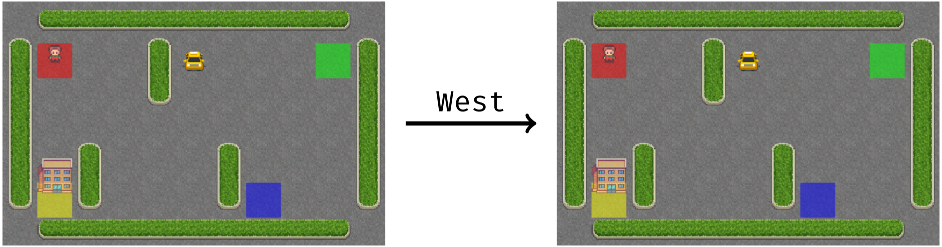
$\texttt{o} = 42 \xrightarrow{\texttt{a}=0\ \text{(South)}} \langle \texttt{nobs} = 142,\ \texttt{r} = -1,\ \texttt{term} = \texttt{False},\ \texttt{trunc} = \texttt{False} \rangle$

Taxi Environment Step II



West →

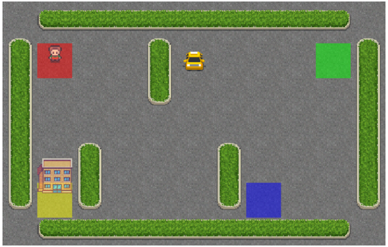
Taxi Environment Step II



$\texttt{nobs, r, term, trunc, \_} = \texttt{env.step(a)}$:

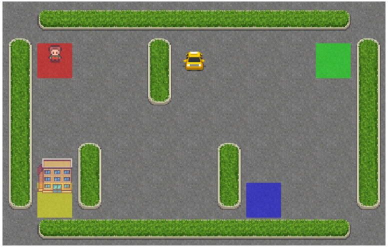
$$\texttt{o} = 45 \xrightarrow{\texttt{a}=3\ \texttt{(West)}} \langle \texttt{nobs} = 45,\ \texttt{r} = -1,\ \texttt{term} = \texttt{False},\ \texttt{trunc} = \texttt{False} \rangle$$

Taxi Environment Step III

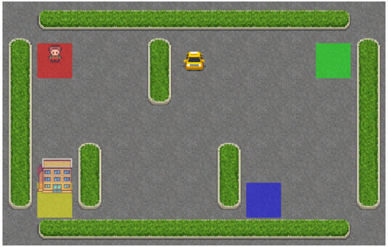


Pick/ Drop

Taxi Environment Step III



Pick/ Drop $\longrightarrow$



$$\texttt{nobs, r, term, trunc, \_} = \texttt{env.step(a)}:$$

$$\texttt{o} = 45 \xrightarrow{\texttt{a}=4/5\ \texttt{(Pick/ Drop)}} \langle \texttt{nobs} = 45,\ \texttt{r} = -10,\ \texttt{term} = \texttt{False},\ \texttt{trunc} = \texttt{False} \rangle$$

Implement your RL Agent

Recap: SARSA

On-Policy TD Control: Sarsa

$\longrightarrow$ learn q_π and improve π while following π

Updates: $Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha \left[R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t)\right]$

Exploration: ϵ-greedy policy π

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Exploration: ϵ-greedy policy π

```
Initialize Q(s,a), ∀s ∈ S, a ∈ A(s), arbitrarily, and Q(terminal-state, ·) = 0
Repeat (for each episode):
    Initialize S
    Choose A from S using policy derived from Q (e.g., ε-greedy)
    Repeat (for each step of episode):
        Take action A, observe R, S'
        Choose A' from S' using policy derived from Q (e.g., ε-greedy)
        Q(S,A) ← Q(S,A) + α[R + γQ(S',A') − Q(S,A)]
        S ← S'; A ← A';
    until S is terminal
```

SARSA Agent Class Structure

- **`__init__`** Initialise agent and Q-table as dictionary mapping `(obs, act) -> q-val`
- **`act`**: ϵ-greedy policy
- **`learn`**: Update Q-table given new experience

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

- **`schedule_hyperparameters`**: Update hyperparameters given training progress

And now in Code ... act

Epsilon-greedy Action Selection

```
def act(self, obs):
    act_vals = [self.q_table[(obs, act)] for act in range(self.
   n_acts)]
    max_val = max(act_vals)
    max_acts = [idx for idx, act_val in enumerate(act_vals) if
   act_val == max_val]

    if random.random() < self.epsilon:
        return random.randint(0, self.n_acts - 1)
    else:
        return random.choice(max_acts)
```

And now in Code ... learn

SARSA Q-Update

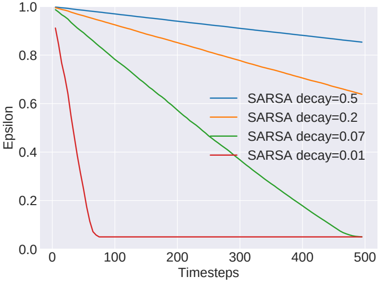
```
def learn(self, obs, action, reward, n_obs, n_action, done):
    target_value = reward + self.gamma * (1 - done) * self.
  q_table[(n_obs, n_action)]
    self.q_table[(obs, action)] += self.alpha * (
        target_value - self.q_table[(obs, action)]
    )
    return self.q_table[(obs, action)]
```

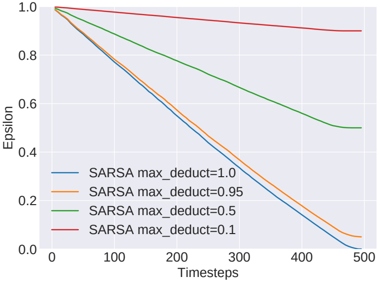
$$Q(S_t, A_t) \leftarrow Q(S_t, A_t) + \alpha \left[R_{t+1} + \gamma Q(S_{t+1}, A_{t+1}) - Q(S_t, A_t) \right]$$

And now in Code ... schedule_hyperparameters

SARSA ϵ-Scheduling

```
def schedule_hyperparameters(self, timestep, max_timestep):
    max_deduct, decay = 0.95, 0.07
    self.epsilon = 1.0 - (min(1.0, timestep/(decay *
 max_timestep))) * max_deduct
```





Evaluate your Results

Why do We Evaluate in the First Place?

- It gives our approach credibility
- Empirical evaluation is no proof, but can give strong indication about the strengths and limitations of an approach (when done right!)

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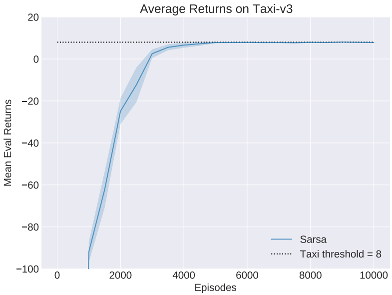
How to do it *right*?

What to Evaluate?

Evaluation Returns

- Plot mean returns over multiple runs
- Visualise standard deviation or confidence interval



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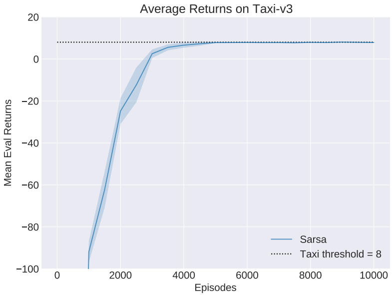

Which returns do we plot?

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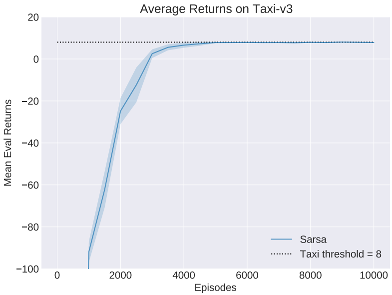
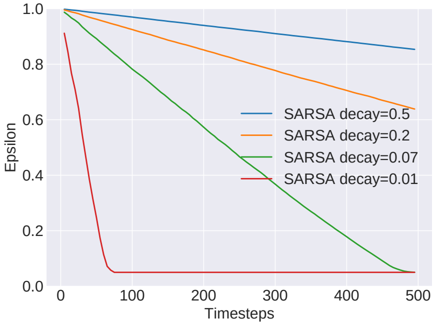


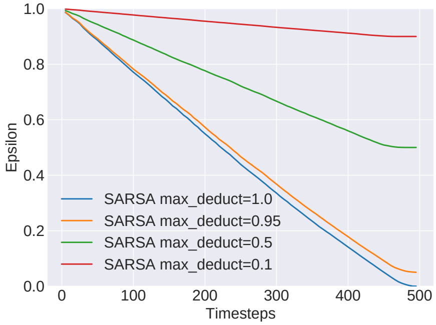
Which returns do we plot?

- Execute multiple evaluation runs with $\epsilon = 0$ at fixed intervals
- Evaluation does not involve any learning!

Hyperparameters

- Track hyperparameters, here ϵ-decay
- Try various values in a grid- or random-search and find good configuration





SARSA Gridsearch over Learning Rate α for Taxi-v3

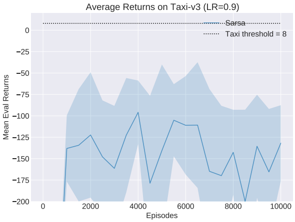


Figure 1: $\alpha = 0.9$

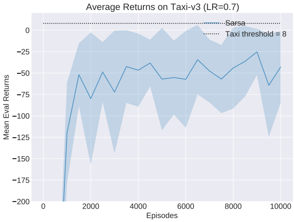


Figure 3: $\alpha = 0.7$

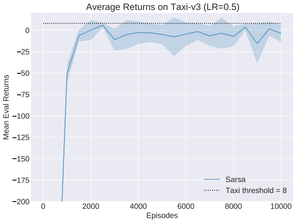


Figure 5: $\alpha = 0.5$

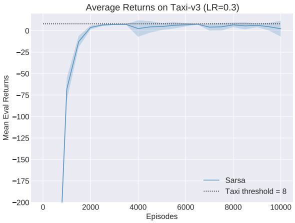


Figure 2: $\alpha = 0.3$

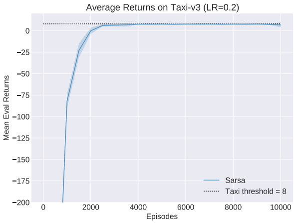


Figure 4: $\alpha = 0.2$

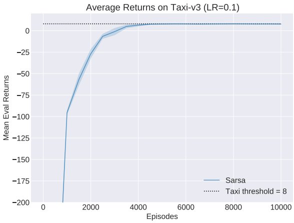


Figure 6: $\alpha = 0.1$

SARSA Learning Rate α Gridsearch Overview

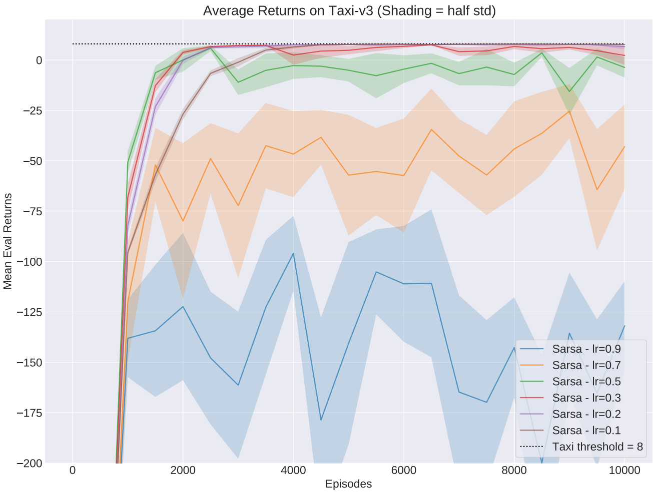


Figure 7: Gridsearch overview over learning rate α with half standard deviation as shading

Common Pitfalls (1)

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- It’s not enough to make it work once!
- Meaningful evaluation achieves consistent performance over multiple randomised runs
- Most RL algorithms have random components (e.g. ϵ-greedy policies)

Common Pifalls (2) (Henderson, 2018; Colas et al., 2019)

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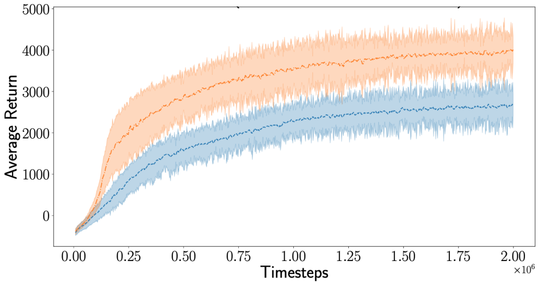

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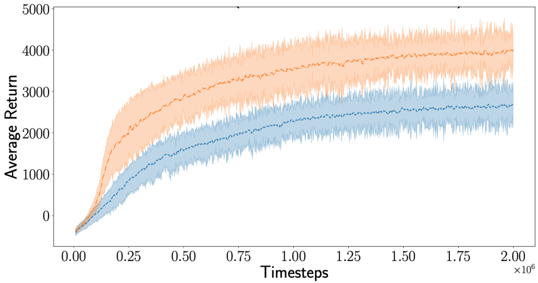

Which one is better?

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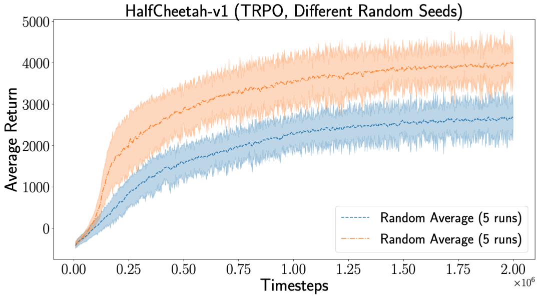

Which one is better? It's actually the same method!

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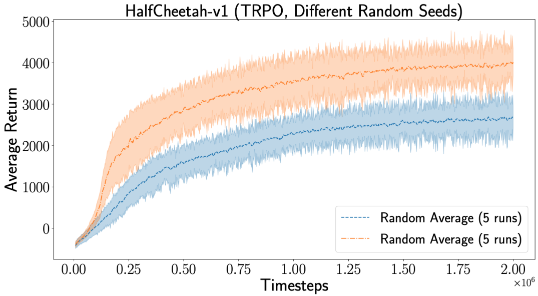

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Apparently, it's not enough! $\longrightarrow$ Statistical hypothesis testing (Colas et al., 2019) and effective statistical evaluation (Agarwal et al., 2021)

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- Reproducibility is key for meaningful research

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Rein in the four horsemen of irreproducibility

Dorothy Bishop describes how threats to reproducibility, recognized but unaddressed for decades, might finally be brought under control.

Dorothy Bishop

Demonstration

All code is available at `https://github.com/uoe-agents/Building-a-Complete-RL-System_Demonstration`

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Reading ii

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Any questions about this lecture or the demonstration?