Passive Reinforcement Learning

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Introduction to Artificial Intelligence

Notation Review

- Recall the Bellman Equation:

$$U(s) = R(s) + \gamma \max_{a \in A(s)} \sum_{s'} P(s'|s,a)U(s')$$

alternate version

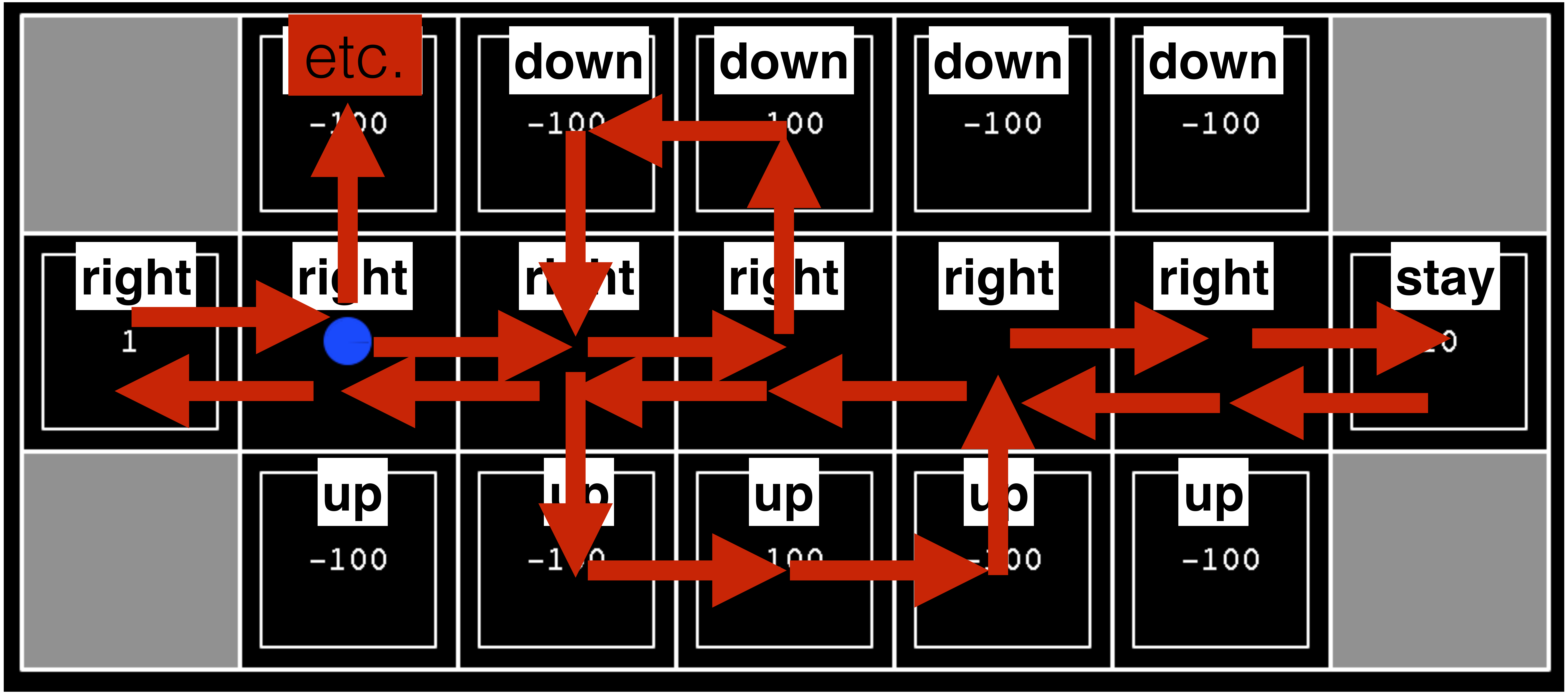
$$U(s) = \max_{a \in A(s)} R(s,a) + \gamma \sum_{s'} P(s'|s,a)U(s')$$

$$\pi^*(s) = \arg\max_{a \in A(s)} \sum_{s'} P(s'|s,a)U(s')$$

Value Iteration Drawbacks

- Computes utility for every state
- Needs exact transition model
- Needs to fully observe state
- Needs to know exact reward for each state in advance

Slippery Bridge

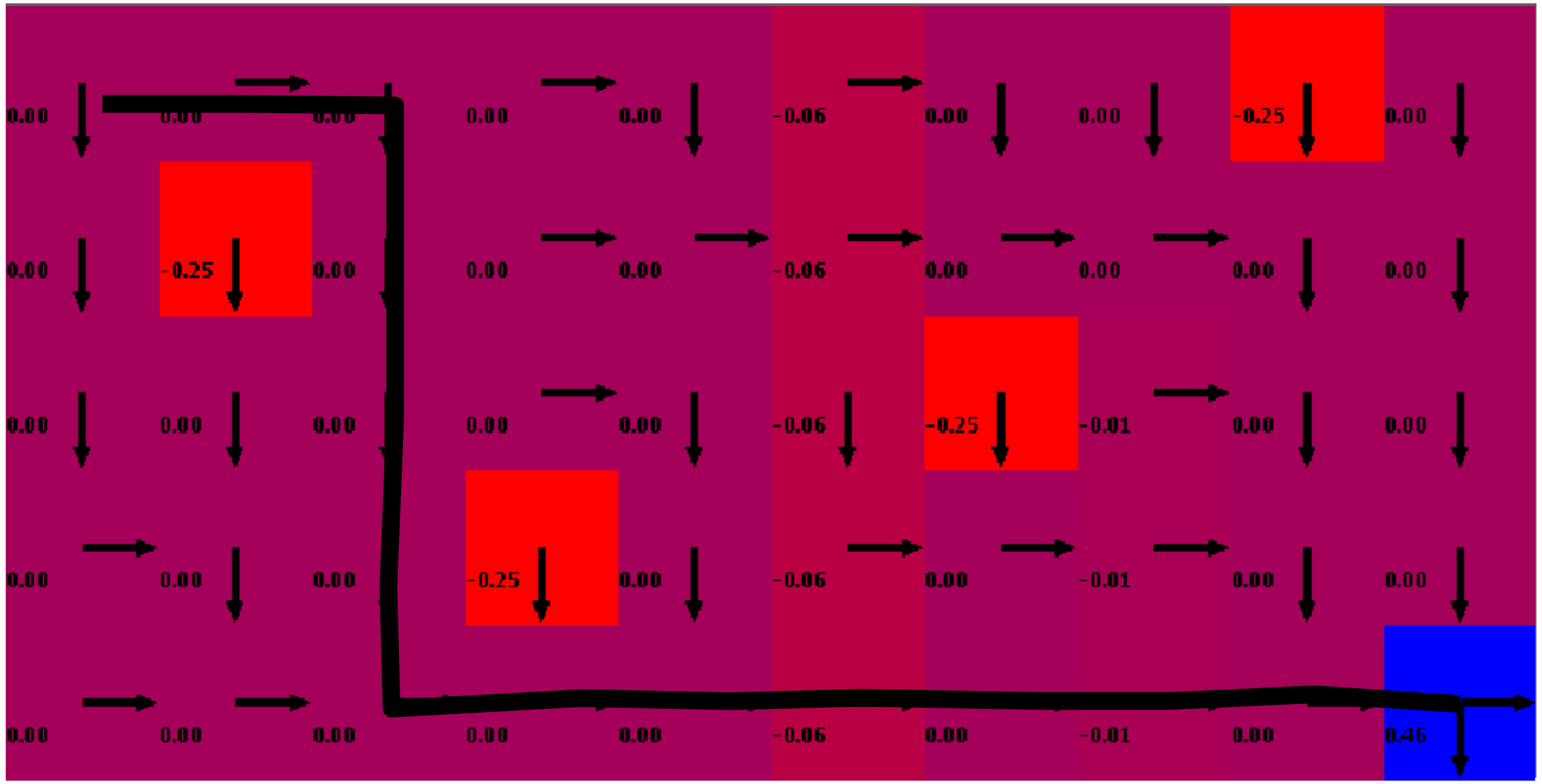


	Value Iteration	Passive Learning	Active Learning
States and rewards	Observes all states and rewards in environment	Observes only states (and rewards) visited by agent	Observes only states (and rewards) visited by agent
Transitions	Observes all action-transition probabilities	Observes only transitions that occur from chosen actions	Observes only transitions that occur from chosen actions
Decisions	N/A	Learning algorithm does not choose actions	Learning algorithm chooses actions

Detour Slide: Inverse Reinforcement Learning

Slide by Prof. Michael Littman

Maximum Likelihood IRL



Gradient ascent through reward parameters on likelihood function (Babes, Marivate, Littman & Subramanian 11).

Passive Learning

- Recordings of agent running fixed policy
- Observe states, rewards, actions
- Three passive learning methods:
  - Direct utility estimation
  - Adaptive dynamic programming (ADP)
  - Temporal-difference (TD) learning

Passive Learning

- Learn U^{π} from observed recordings
  - May learn $Pr(s' \mid s, a)$
- What is the benefit of learning U^{π}?
- Can we act intelligently given U^{π} and $Pr(s' \mid s, a)$?

Direct Utility Estimation

$$U(s) = R(s) + \gamma \max_{a \in A(s)} \sum_{s'} P(s'|s, a) U(s')$$

$$U^{\pi}(s) = R(s) + \gamma \sum_{s'} P(s'|s, \pi(s)) U^{\pi}(s')$$

future reward of state assuming we use this policy

Direct utility estimation: use observed rewards and future rewards to estimate U (i.e., take average of samples from data)

	t=1	2	3	4	5	6	7	8	9	10	…	…	T
State	A	B	C	A	D	D	E	E	F	G			E
Action	up	up	down	up	right	right	left	up	down	down	…	…	up
Reward	10	-30	1	10	-2	-2	100	100	90	80	…	…	100

	t=1	2	3	4	5	6	7	8	9	10	…	…	T
State	**A**	B	C	**A**	D	D	E	E	F	G			E
Action	**up**	up	down	**up**	right	right	left	up	down	down	…	…	up
Reward	**10**	-30	1	**10**	-2	-2	100	100	90	80	…	…	100

A

10	-30	1	10	-2	-2	100	100	90	80	…	…	100
			10	-2	-2	100	100	90	80	…	…	100

	t=1	2	3	4	5	6	7	8	9	10	…	…	T
State	A	**B**	C	A	D	D	E	E	F	G			E
Action	up	**up**	down	up	right	right	left	up	down	down	…	…	up
Reward	10	**-30**	1	10	-2	-2	100	100	90	80	…	…	100

A

10	-30	1	10	-2	-2	100	100	90	80	…	…	100

10	-2	-2	100	100	90	80	…	…	100

B

-30	1	10	-2	-2	100	100	90	80	…	…	100

	t=1	2	3	4	5	6	7	8	9	10	…	…	T
State	A	B	C	A	**D**	**D**	E	E	F	G			E
Action	up	up	down	up	**right**	**right**	left	up	down	down	…	…	up
Reward	10	-30	1	10	**-2**	**-2**	100	100	90	80	…	…	100

A

10	-30	1	10	-2	-2	100	100	90	80	…	…	100

10	-2	-2	100	100	90	80	…	…	100

B

-30	1	10	-2	-2	100	100	90	80	…	…	100

…

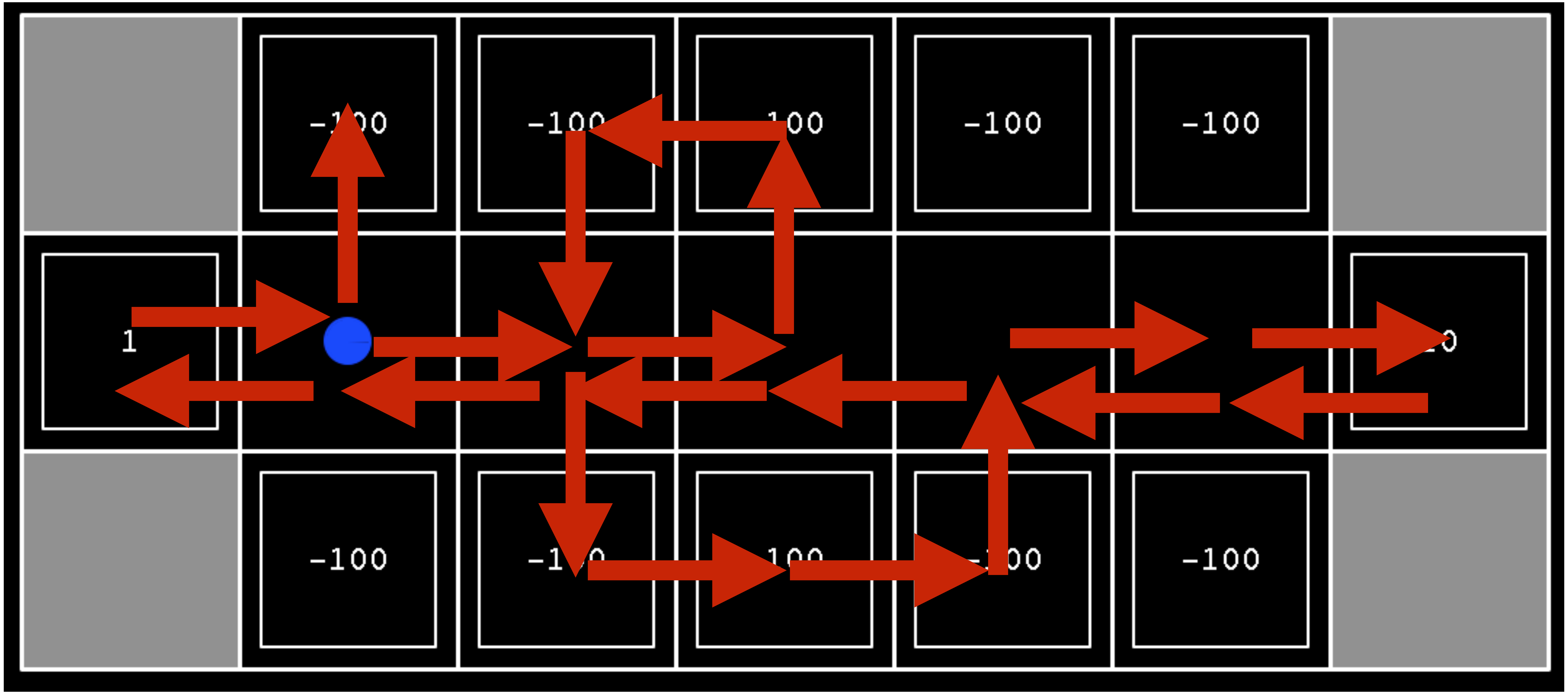
D

-2	**-2**	100	100	90	80	…	…	100

-2	100	100	90	80	…	…	100

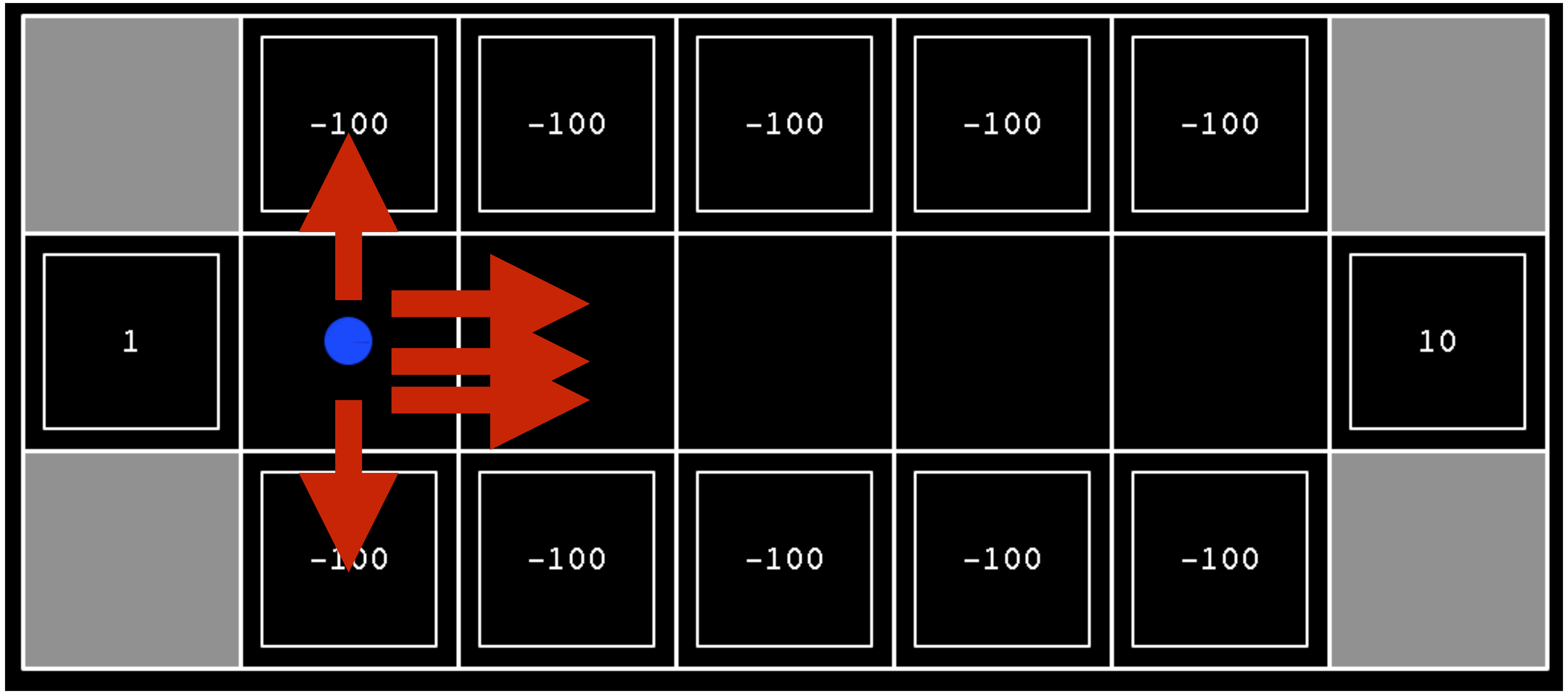
Adaptive Dynamic Programming

- Run value iteration using rewards and estimated transition probabilities



Adaptive Dynamic Programming

- Run value iteration using rewards and estimated transition probabilities



Action	Result
RIGHT	UP
RIGHT	RIGHT
RIGHT	RIGHT
RIGHT	DOWN
RIGHT	RIGHT

Adaptive Dynamic Programming

- Run value iteration using rewards and estimated transition probabilities

(Estimate of) Estimate of

$$U_{i+1}(s) \leftarrow \boxed{R(s)} + \gamma \max_{a \in A(s)} \sum_{s'} \boxed{P(s'|s,a)} U_i(s')$$

Temporal-Difference Learning

$$U^\pi(s) = R(s) + \gamma \sum_{s'} P(s'|s,\pi(s))U^\pi(s')$$

$$U^\pi(s) = R(s) + \gamma \mathrm{E}_{s'}[U^\pi(s')]$$

$$U^\pi(s) = \mathrm{E}_{s'}[R(s) + \gamma U^\pi(s')]$$

learning rate parameter

current estimate of utility

$$U^\pi(s) \leftarrow U^\pi(s) + \alpha(R(s) + \gamma U^\pi(s') - U^\pi(s))$$

“observed utility”

Temporal-Difference Learning

$$U^\pi(s) \leftarrow U^\pi(s) + \alpha(\boxed{R(s) + \gamma U^\pi(s')} - \boxed{U^\pi(s)})$$

Run each time we transition from state **s** to **s'**

Converges slower than ADP, but much simpler update.

Leads to famous q-learning algorithm

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