

Lecture 8: Introduction to Reinforcement Learning

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References

These slides are almost the exact copy of Practical RL course week 1 slides.
Special thanks to YSDA team for making them publicly available.

Original slides link: [week01_intro](#)

- From Supervised Learning to Reinforcement Learning
- Multi-armed bandits
- The Markov Decision Process
- Crossentropy method
 - Tabular crossentropy method
 - Approximate crossentropy method
- Practice

Supervised learning

Given:

- objects and answers

$$(x, y)$$

- algorithm family

$$a_\theta(x) \rightarrow y$$

- loss function

$$L(y, a_\theta(x))$$

Find:

$$\theta' \leftarrow \operatorname{argmin}_\theta L(y, a_\theta(x))$$

Supervised learning

Given:

- objects and answers
- algorithm family
- loss function

$$\begin{aligned} & (x, y) \\ & \text{[banner,page], ctr} \\ & a_\theta(x) \rightarrow y \\ & \text{linear / tree / NN} \\ & L(y, a_\theta(x)) \\ & \text{MSE, crossentropy} \end{aligned}$$

Find:

$$\theta' \leftarrow \operatorname{argmin}_\theta L(y, a_\theta(x))$$

Supervised learning

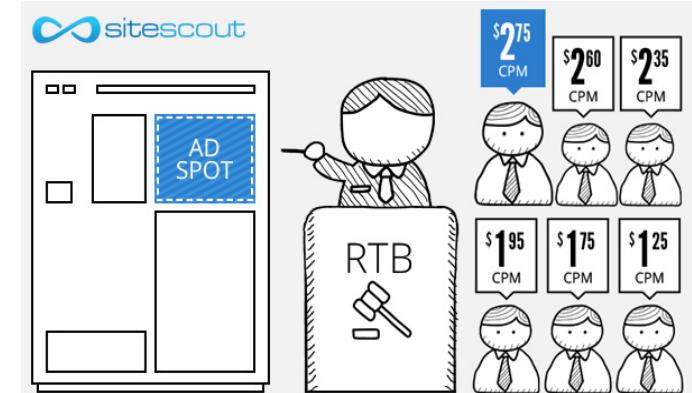
Great... except if we have no reference answers

Online Ads

Great... except if we have no reference answers

We have:

- YouTube at your disposal
- Live data stream
(banner & video features, #clicked)
- (insert your favorite ML toolkit)



We want:

- Learn to pick relevant ads

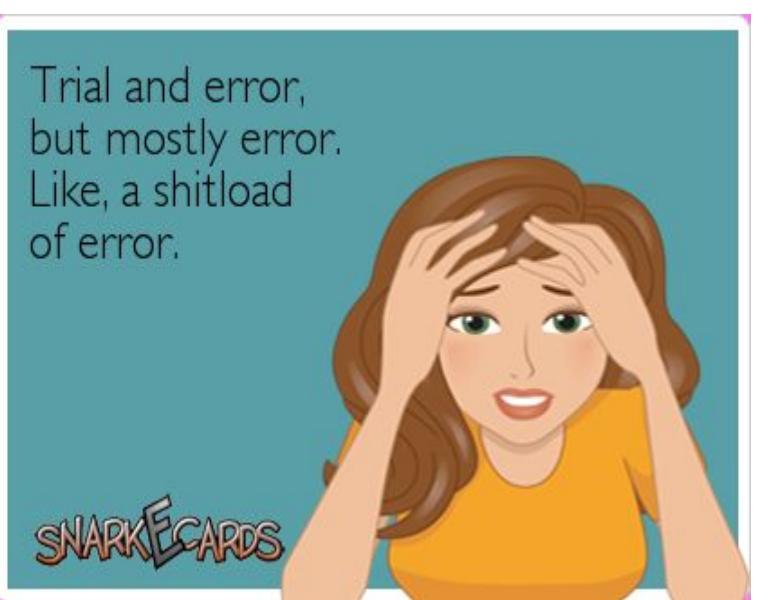


Ideas?

Duct tape approach

Common idea:

- Initialize with naïve solution
- Get data by trial and error and error and error and error and error
- Learn (situation) → (optimal action)
- Repeat



Giant Death Robot (GDR)

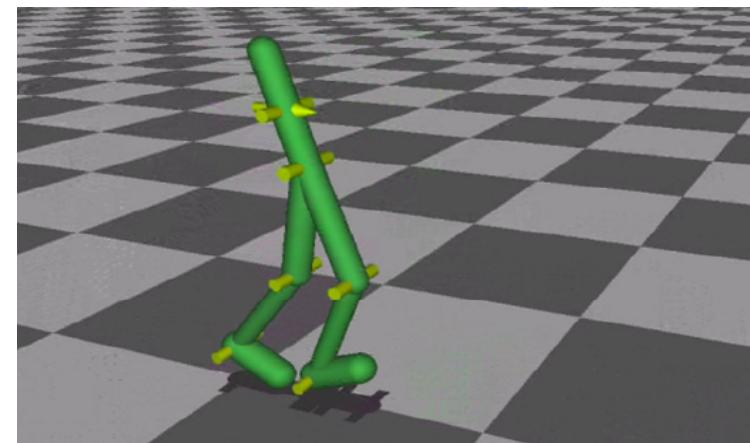
Great... except if we have no reference answers

We have:

- Evil humanoid robot
- A lot of spare parts
to repair it :)

We want:

- ~~Enslave humanity~~
- Learn to walk forward

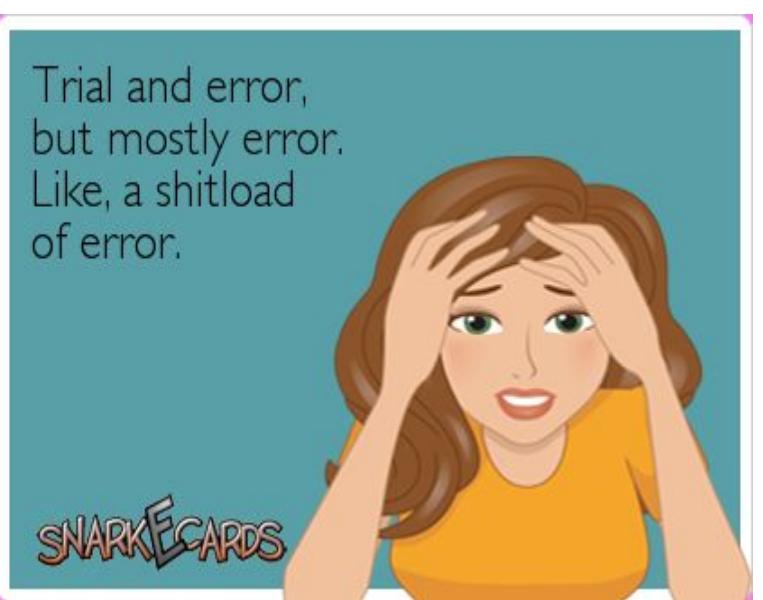


Ideas?

Duct tape approach (again)

Common idea:

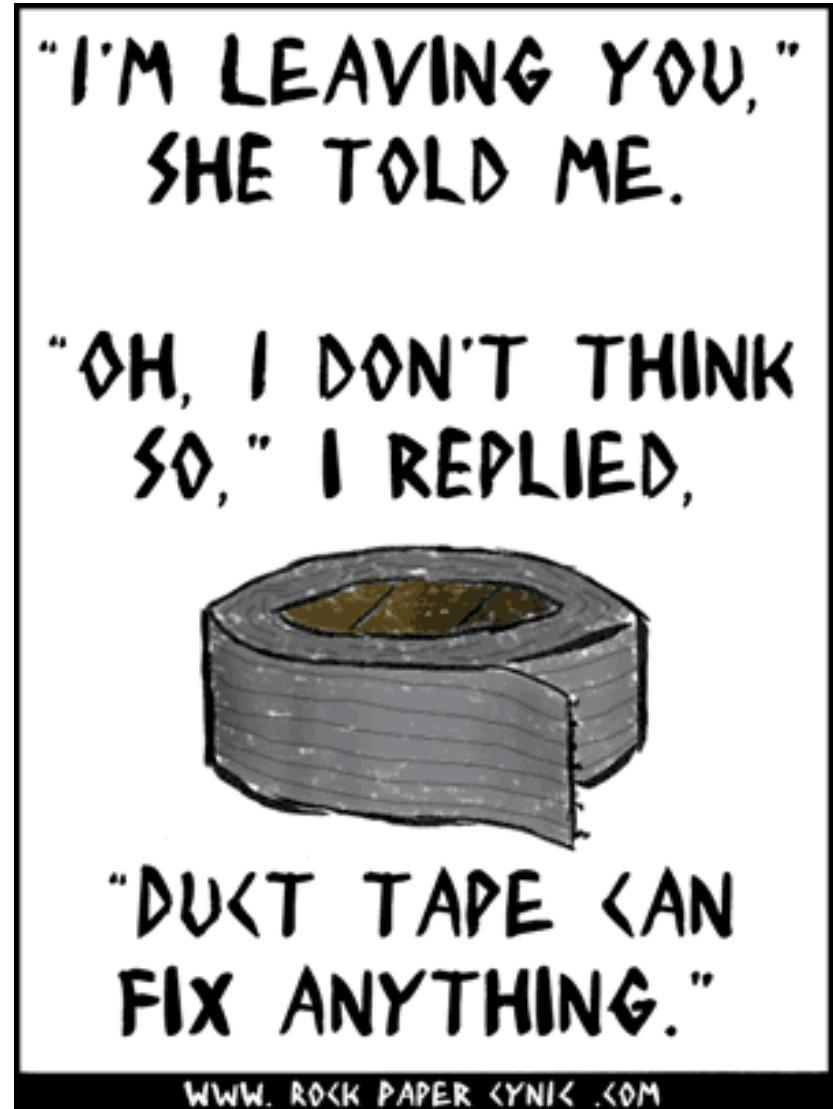
- Initialize with naïve solution
- Get data by trial and error and error and error and error and error
- Learn (situation) → (optimal action)
- Repeat



Trial and error,
but mostly error.
Like, a shitload
of error.

SNARKYCARDS

Duct tape approach



Problems

Problem 1:

- What exactly does the “optimal action” mean?

Extract as much
money as you can
right now

vs

Make user happy
so that he would
visit you again

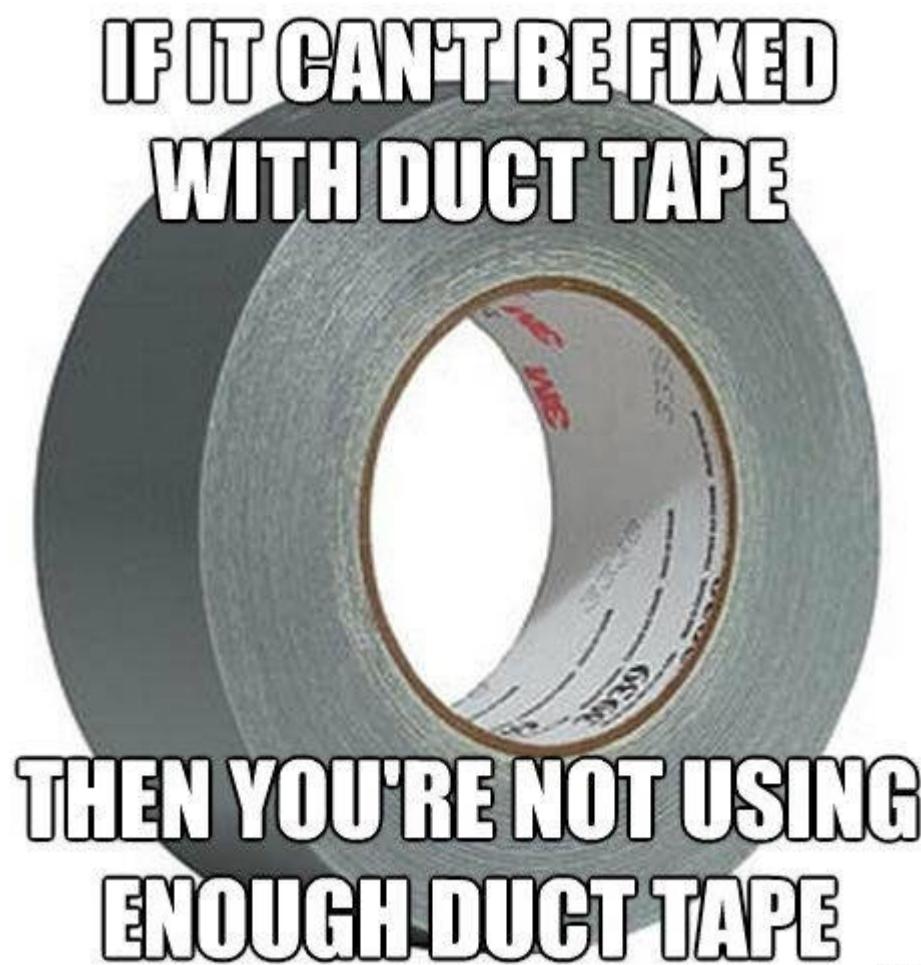
Problems

Problem 2:

- If you always follow the “current optimal” strategy, you may never discover something better.
- If you show the same banner to 100% users, you will never learn how other ads affect them.

Ideas?

Duct tape approach



zipmeme

Reinforcement learning

STAND BACK



**I'M GOING TO TRY
SCIENCE**

What is: bandit



Examples:

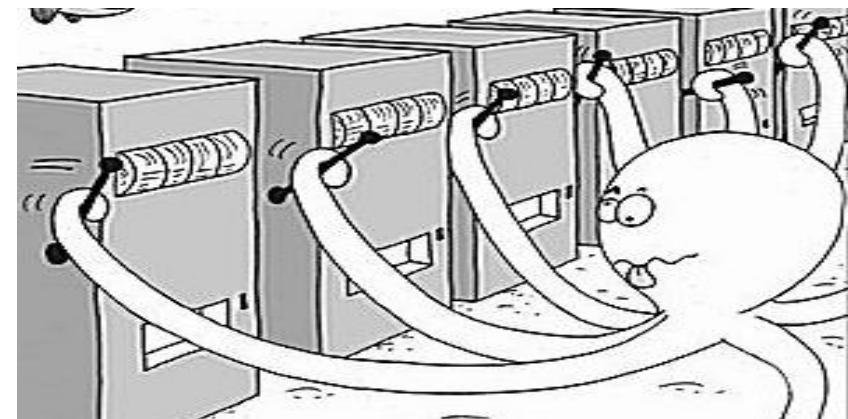
- banner ads (RTB)
- recommendations
- medical treatment

What is: bandit



Examples:

- banner ads (RTB)
- recommendations
- medical treatment



What is: bandit

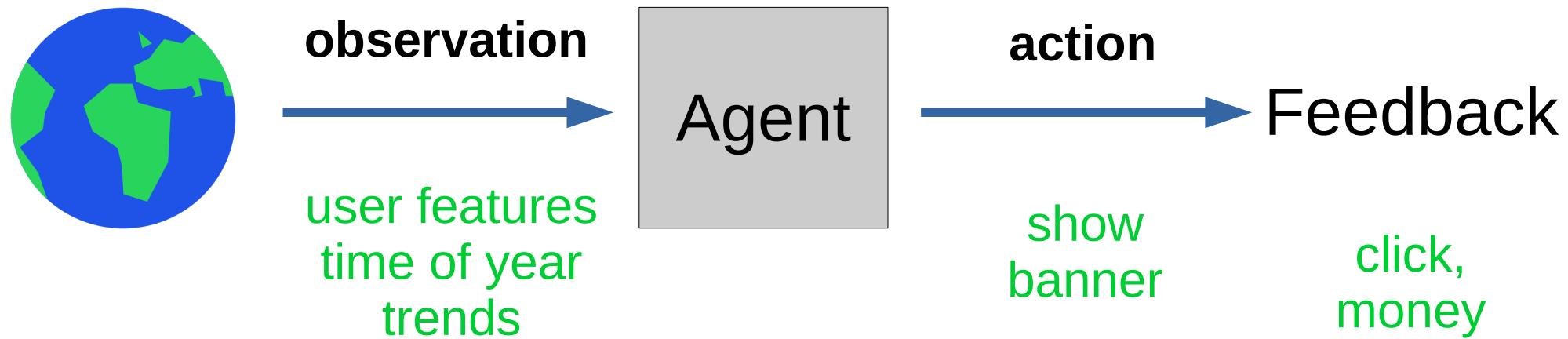


Examples:

- banner ads (RTB)
- recommendations
- medical treatment

Q: what's observation, action and feedback in the banner ads problem?

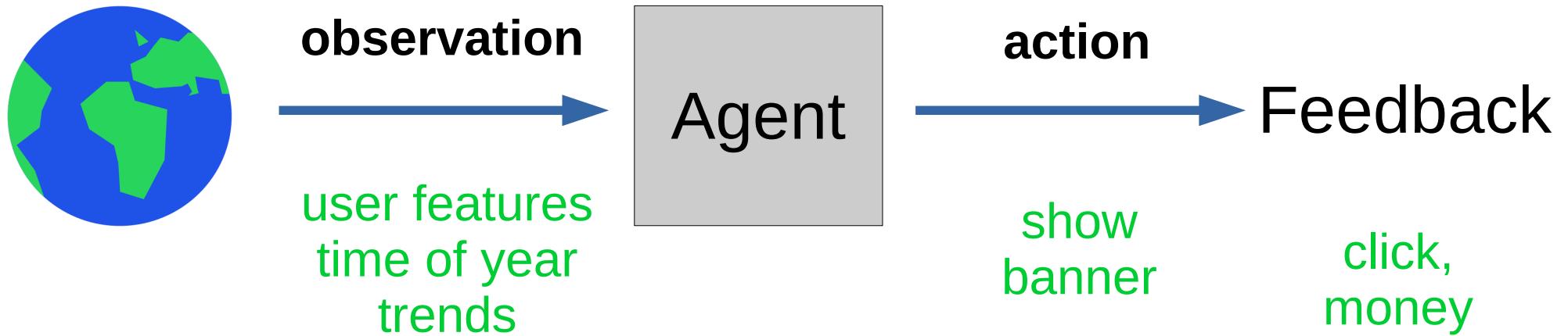
What is: bandit



Examples:

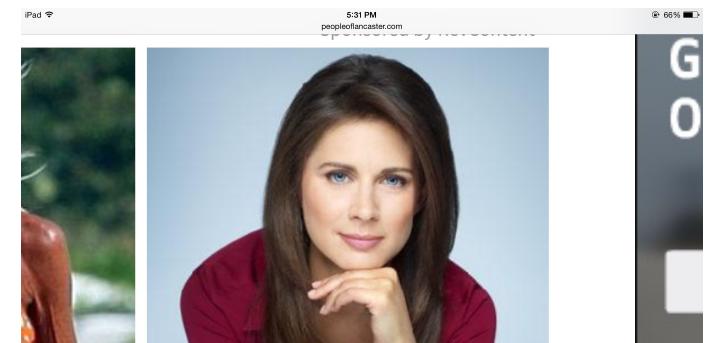
- banner ads (RTB)
- recommendations
- medical treatment

What is: bandit



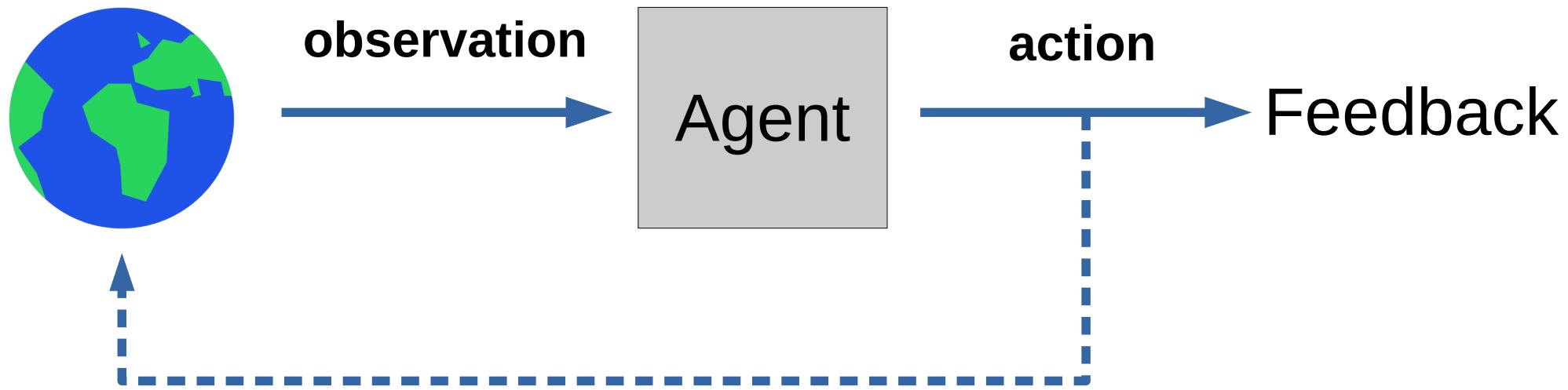
Q: You're Yandex/Google/Youtube.
There's a kind of banners that would have great click rates: the “clickbait”.

Is it a good idea to show clickbait?



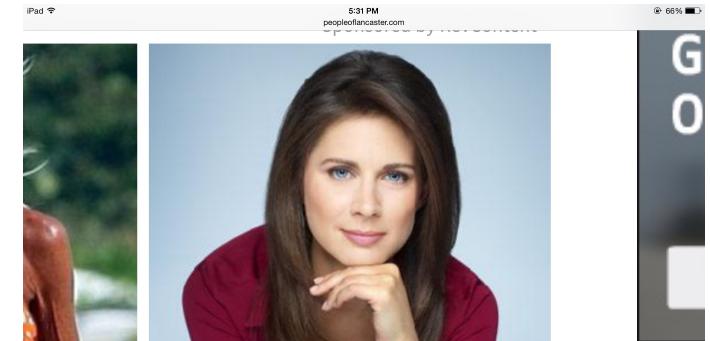
Who 23 Celebrities You Would Never Guess Are Actually Black
Age 0

What is: bandit



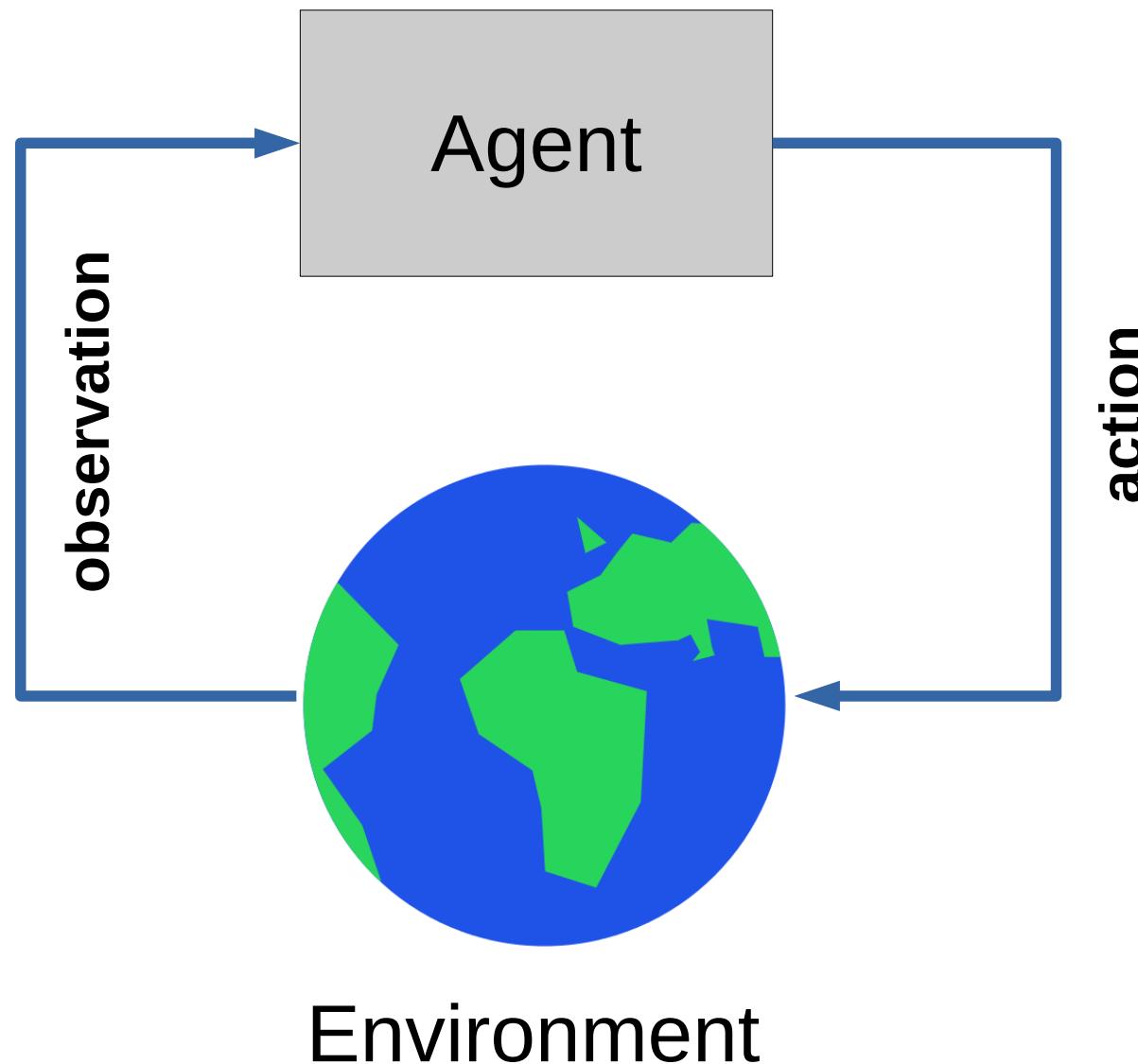
Q: You're Yandex/Google/Youtube.
There's a kind of banners that would have great click rates: the “clickbait”.

Is it a good idea to show clickbait?
No, no one will trust you after that!

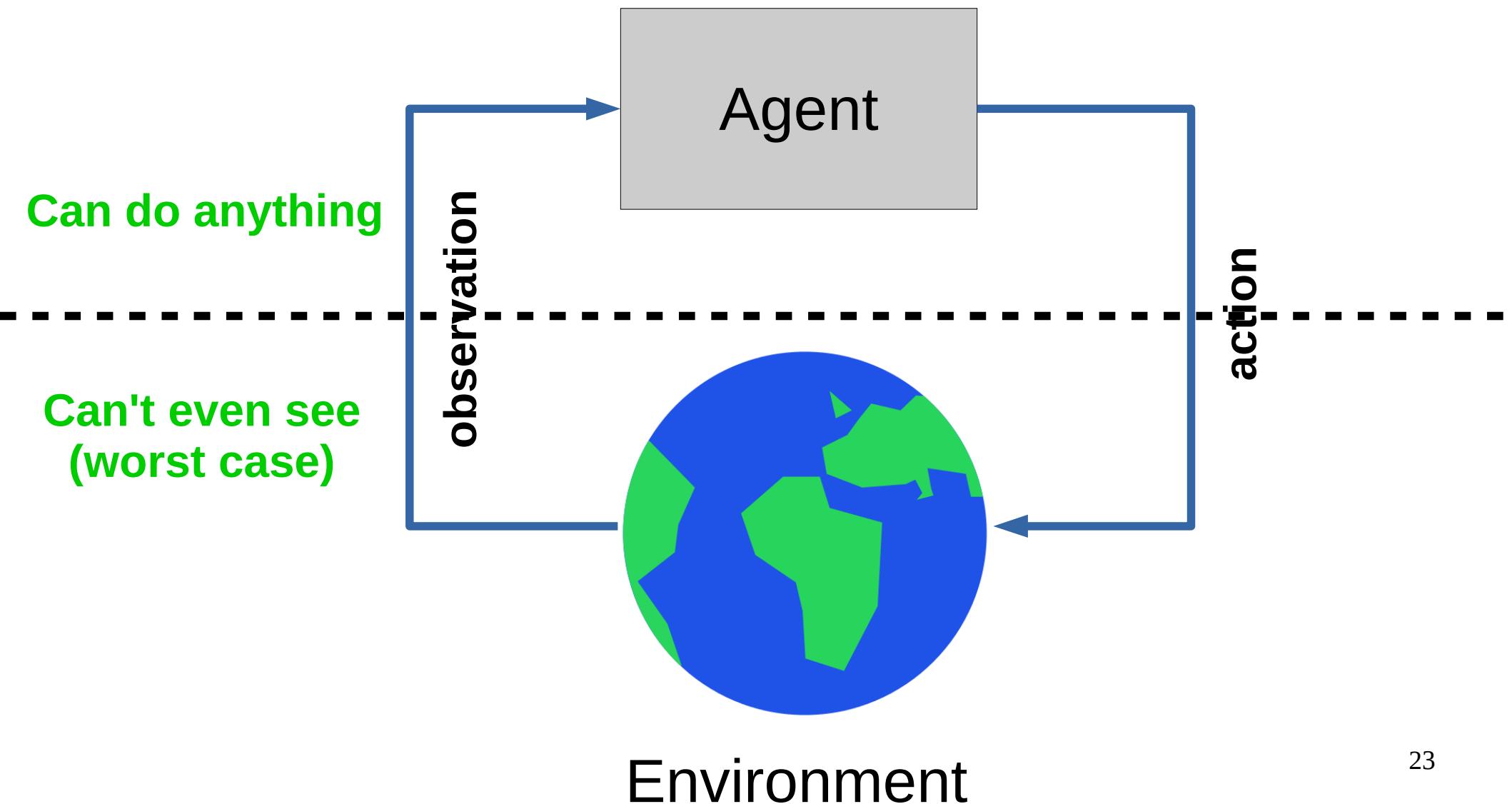


Who 23 Celebrities You Would Never Guess Are Actually Black
Age

What is: decision process

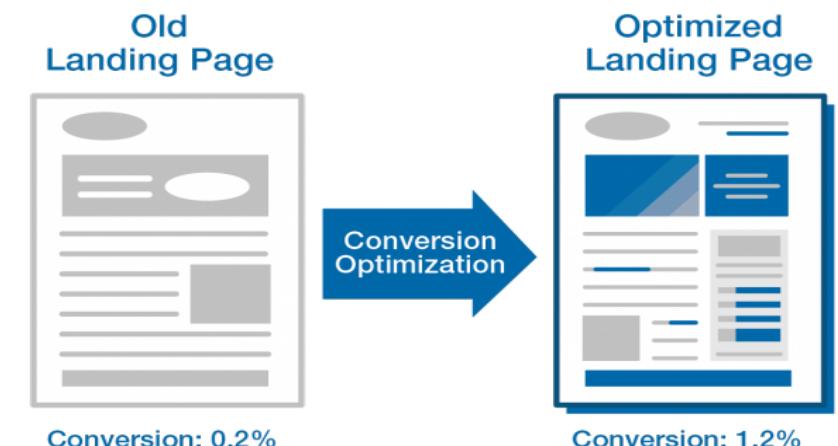
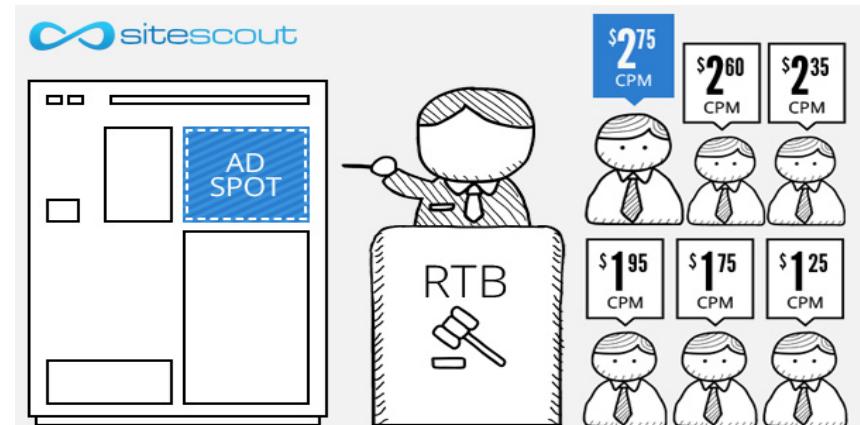


What is: decision process



Reality check: web

- **Cases:**
 - Pick ads to maximize profit
 - Design landing page to maximize user retention
 - Recommend movies to users
 - Find pages relevant to queries
- **Example**
 - Observation – user features
 - Action – show banner #i
 - Feedback – did user click?

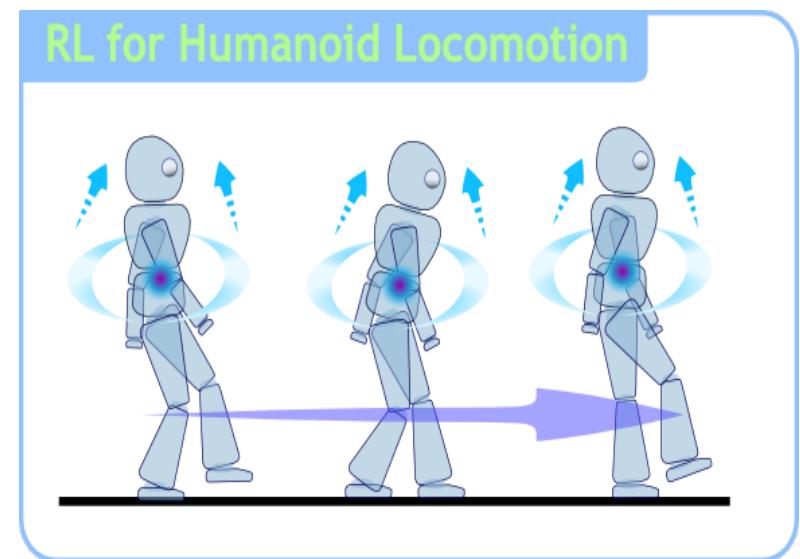


Reality check: dynamic systems

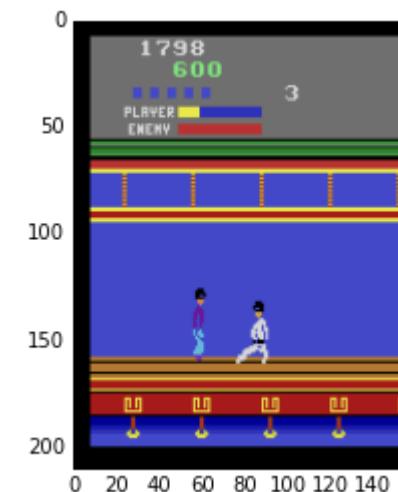
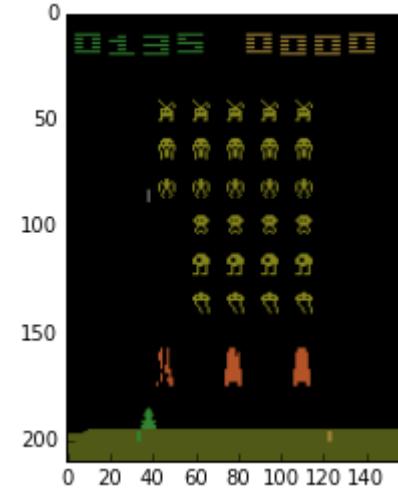
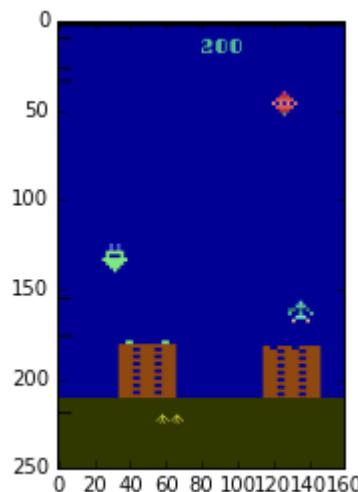


Reality check: dynamic systems

- **Cases:**
 - Robots
 - Self-driving vehicles
 - Pilot assistant
 - More robots!
- **Example**
 - Observation: sensor feed
 - Action: voltage sent to motors
 - Feedback: how far did it move forward before falling

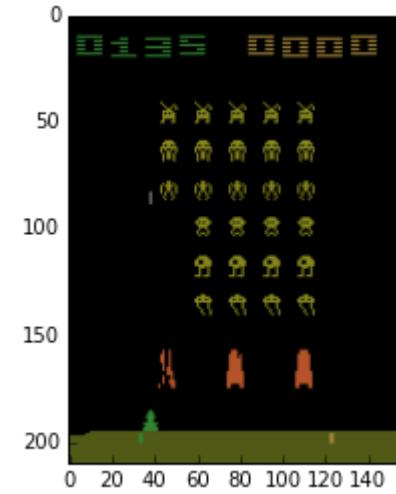
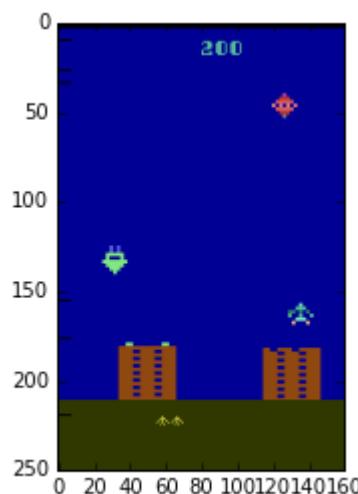


Reality check: videogames



- Q: What are observations, actions and feedback?

Reality check: videogames



- Q: What are observations, actions and feedback?

Other use cases

- Personalized medical treatment



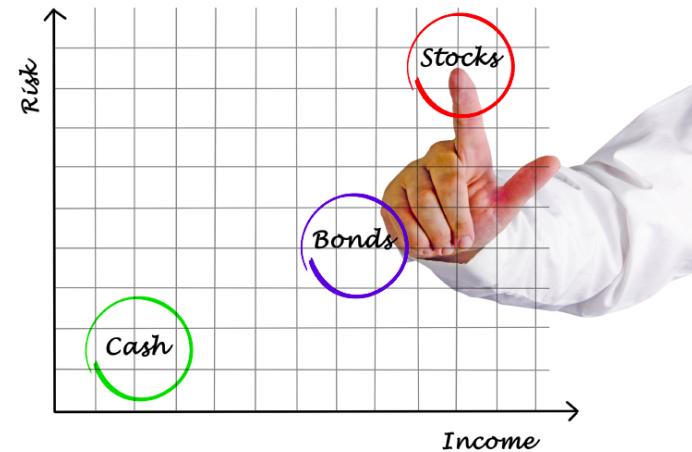
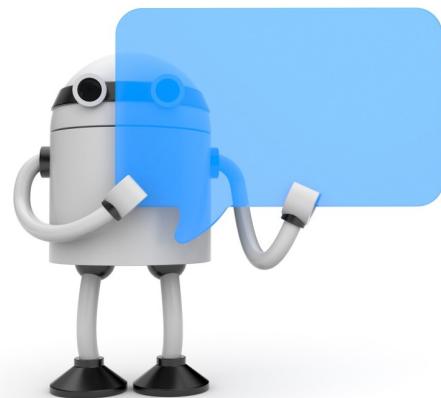
- Even more games (Go, chess, etc)



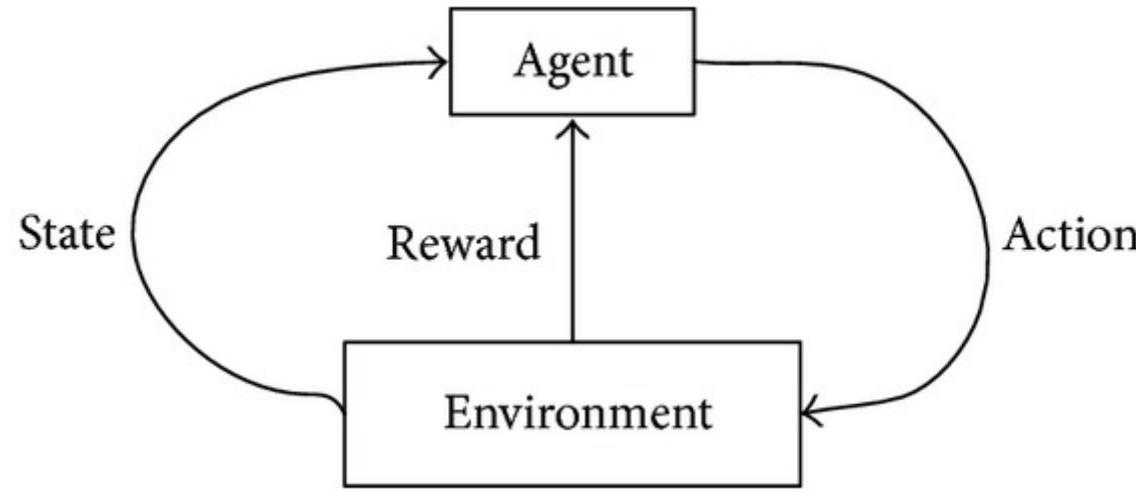
- Q: What are observations, actions and feedback?

Other use cases

- Conversation systems
 - learning to make user happy
- Quantitative finance
 - portfolio management
- Deep learning
 - optimizing non-differentiable loss
 - finding optimal architecture



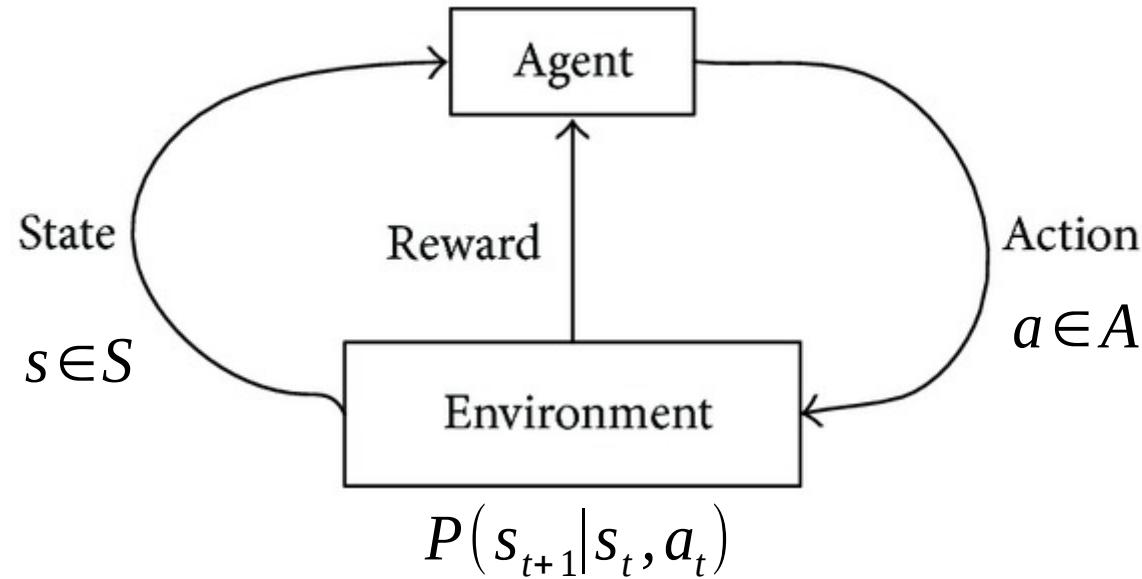
The MDP formalism



Markov Decision Process

- Environment states: $s \in S$
- Agent actions: $a \in A$
- Rewards $r \in \mathbb{R}$
- Dynamics: $P(s_{t+1} | s_t, a_t)$

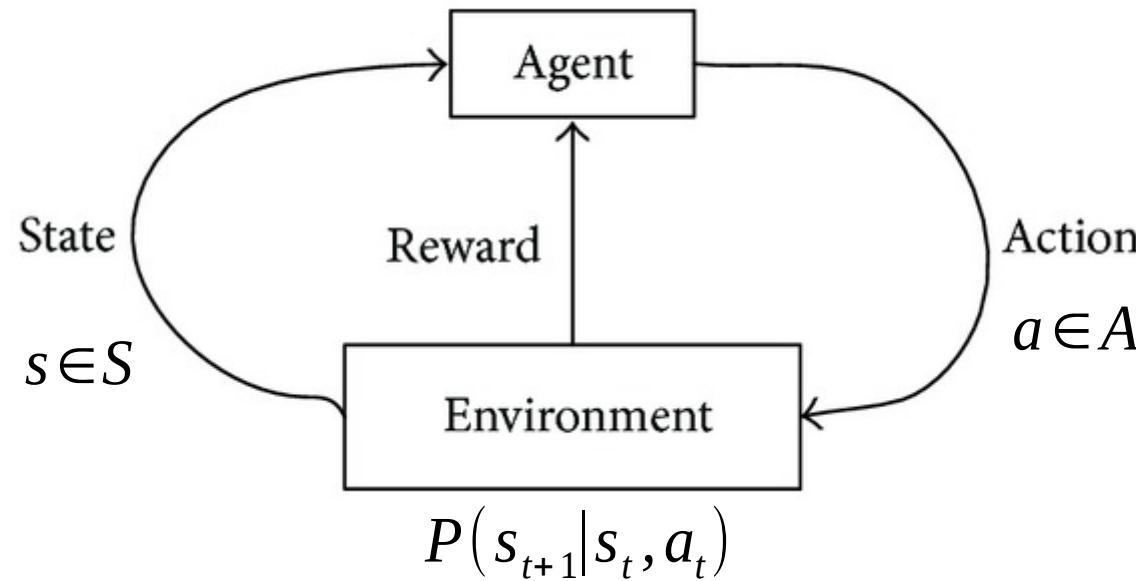
The MDP formalism



Markov Decision Process
Markov assumption

$$P(s_{t+1}|s_t, a_t, s_{t-1}, a_{t-1}) = P(s_{t+1}|s_t, a_t)$$

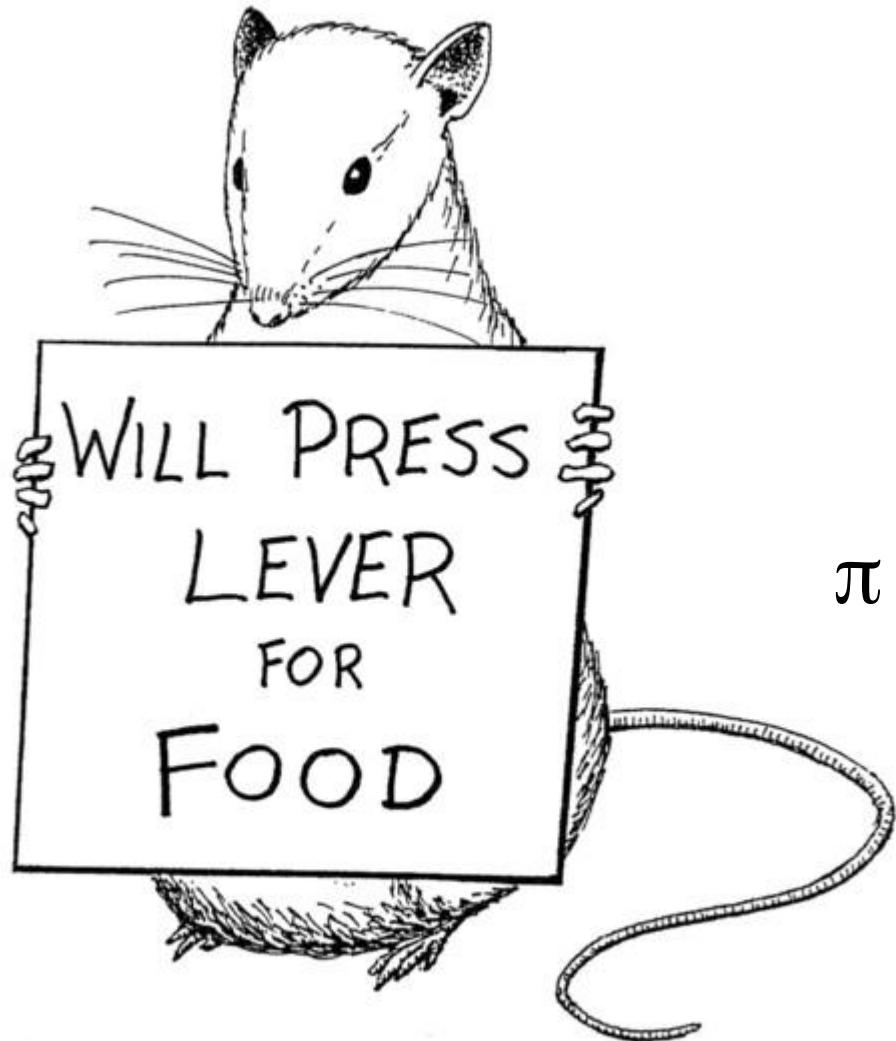
The MDP formalism



Markov Decision Process
Markov assumption

$$P(s_{t+1}|s_t, a_t, s_{t-1}, a_{t-1}) = P(s_{t+1}|s_t, a_t)$$

Total reward



Total reward for session:

$$R = \sum_t r_t$$

Agent's policy:

$$\pi(a|s) = P(\text{take action } a \text{ in state } s)$$

Problem: find policy with highest reward:

$$\pi(a|s) : E_{\pi}[R] \rightarrow \max$$

Objective

The easy way:

$E_{\pi} R$ is an expected sum of rewards
that agent with policy π earns per session

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$E_{\pi} R$ is an expected sum of rewards
that agent with policy π earns per session

The hard way:

$$E \quad E \quad E \quad \dots \quad E \quad [r_0 + r_1 + r_2 + \dots + r_T]$$
$$s_0 \sim p(s_0), a_0 \sim \pi(a|s_0), s_1, r_0 \sim P(s', r | s, a) \quad s_T, r_T \sim P(s', r | s_{T-1}, a_{t-1})$$

How do we solve it?

General idea:

Play a few sessions

Update your policy

Repeat

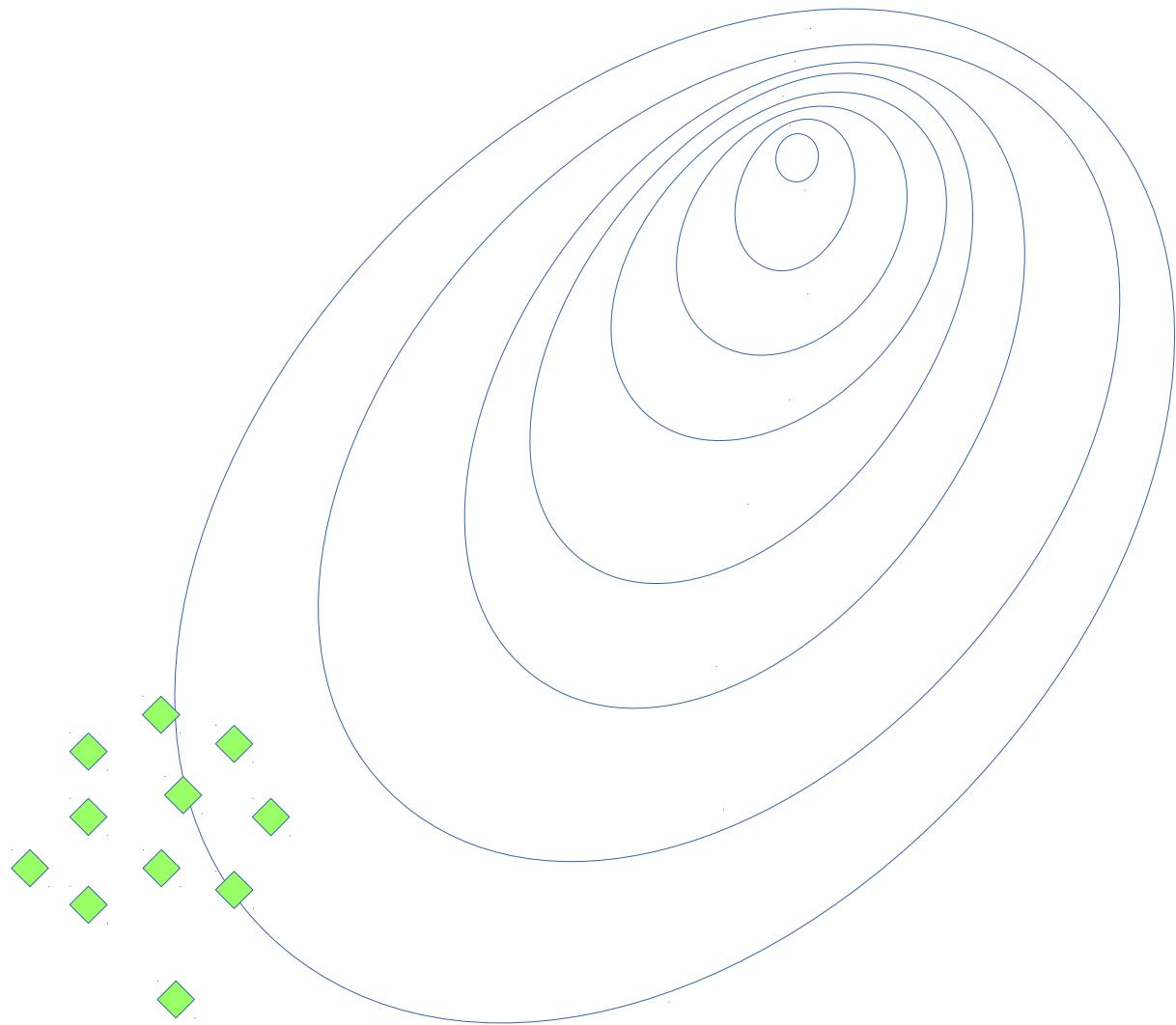
Crossentropy method

Initialize policy

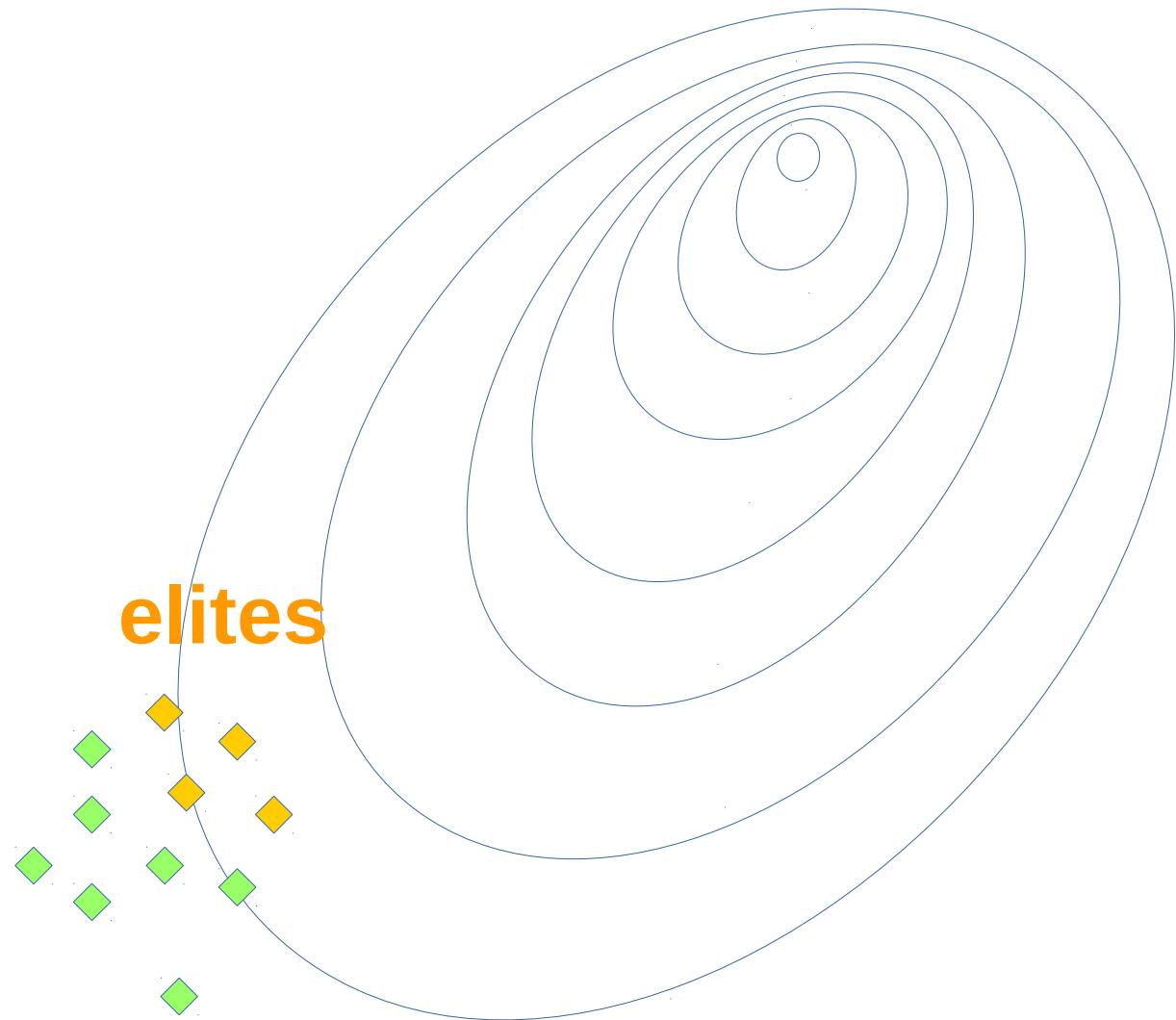
Repeat:

- Sample $N[100]$ sessions
- Pick $M[25]$ best sessions, called **elite** sessions
- Change policy so that it prioritizes actions from elite sessions

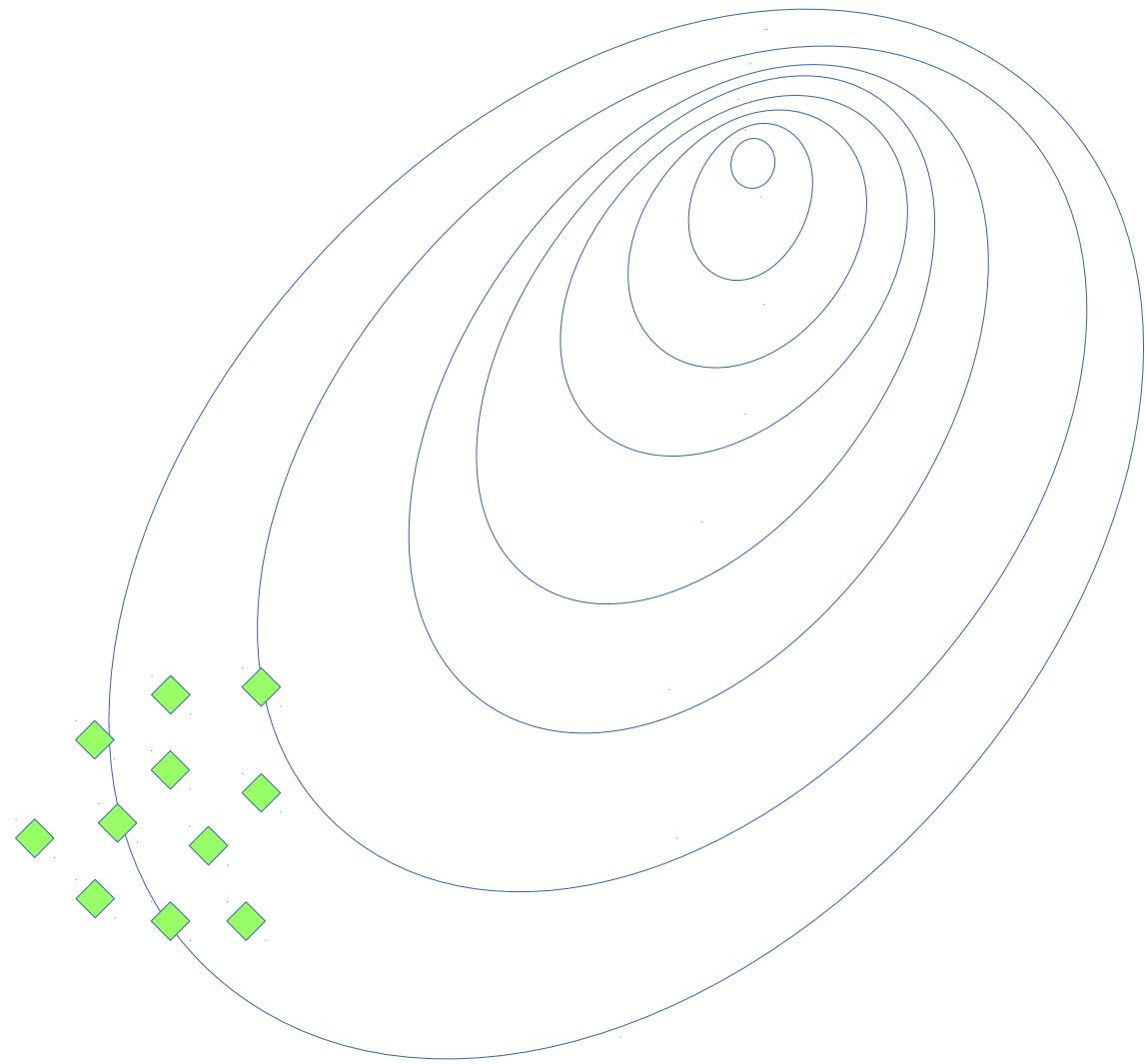
Step-by-step view



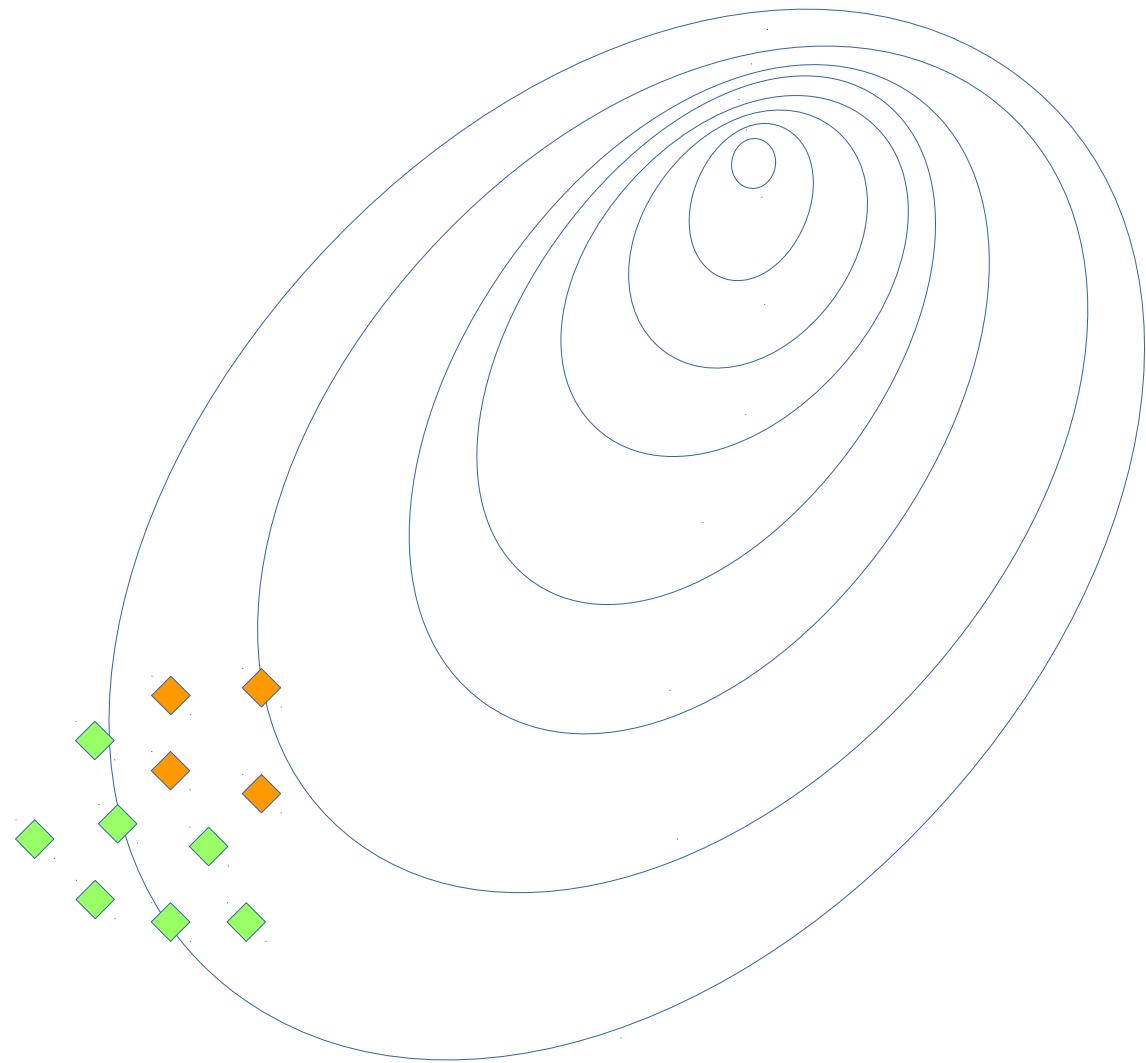
Step-by-step view



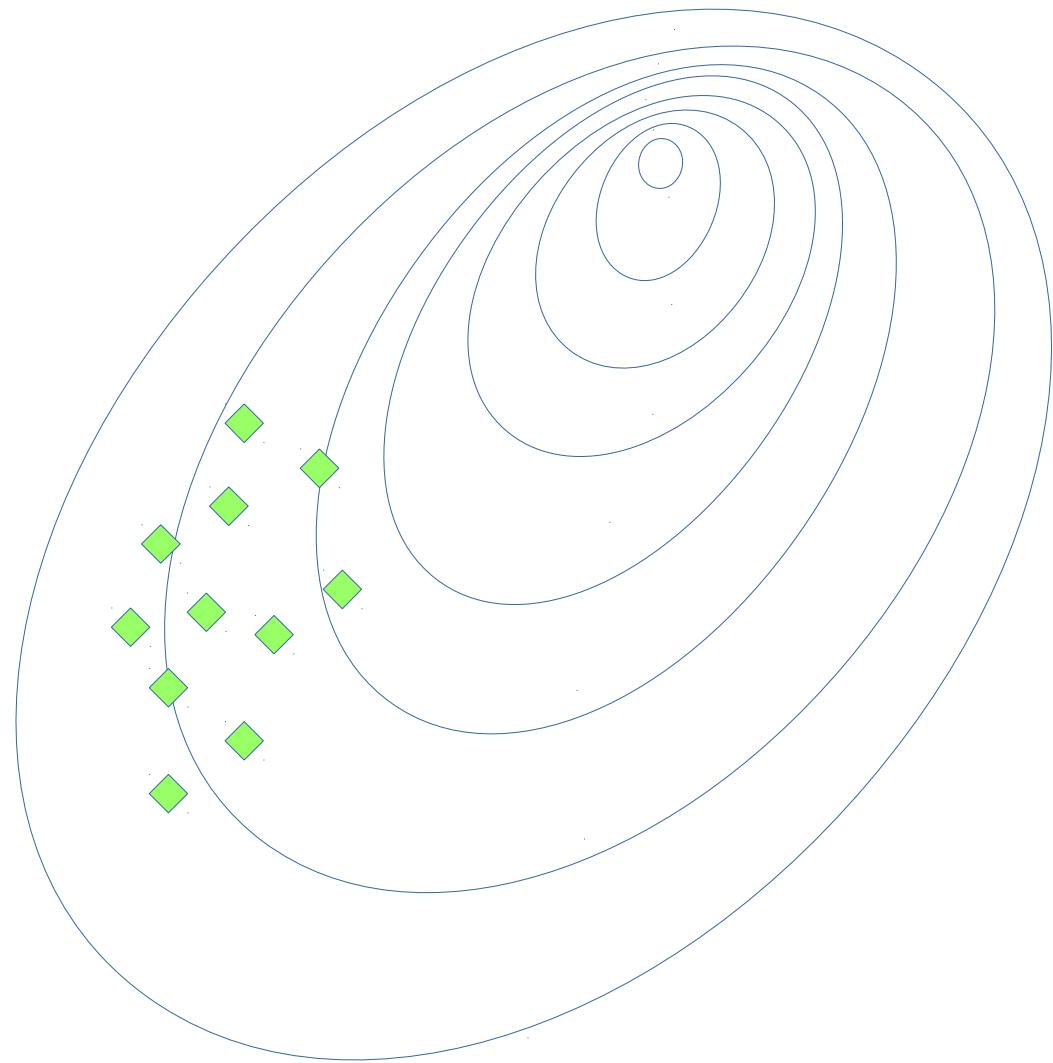
Step-by-step view



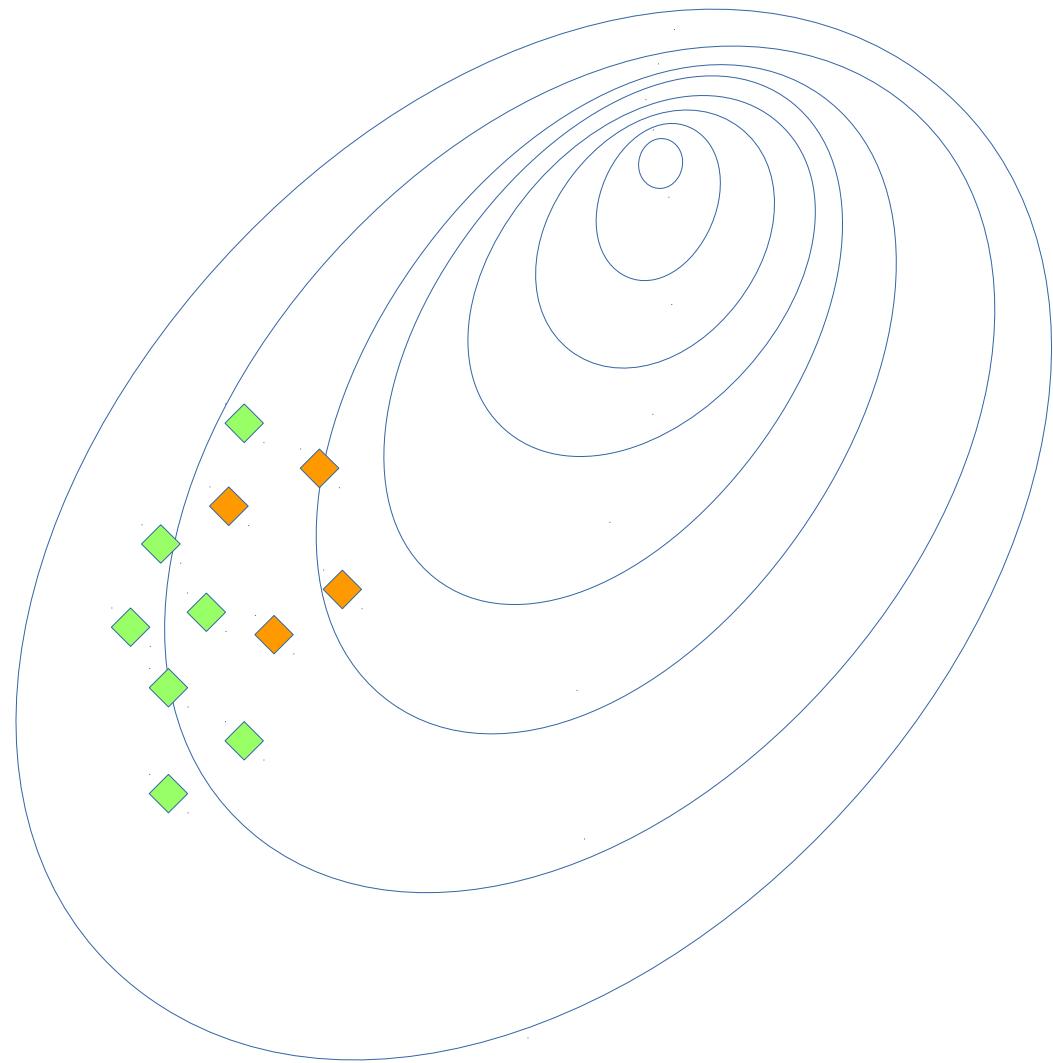
Step-by-step view



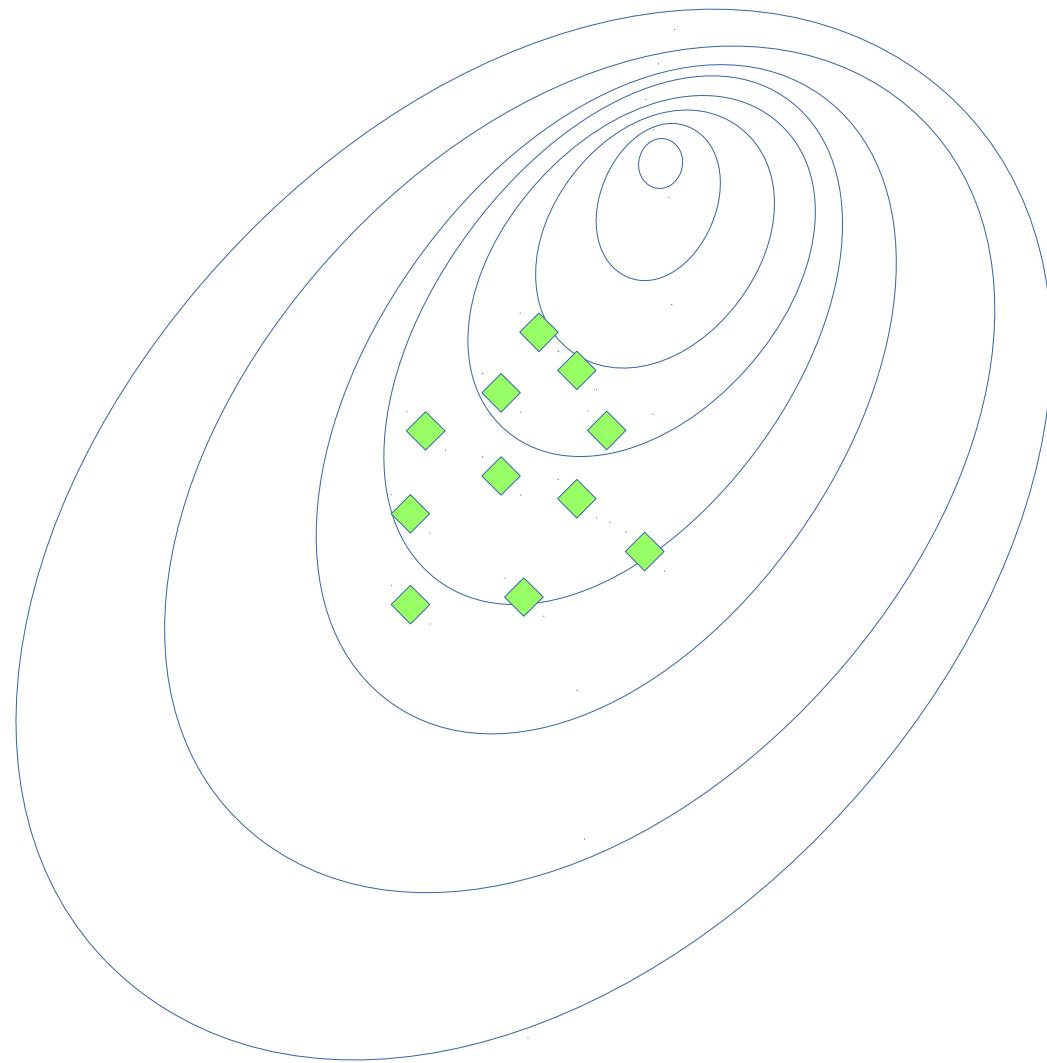
Step-by-step view



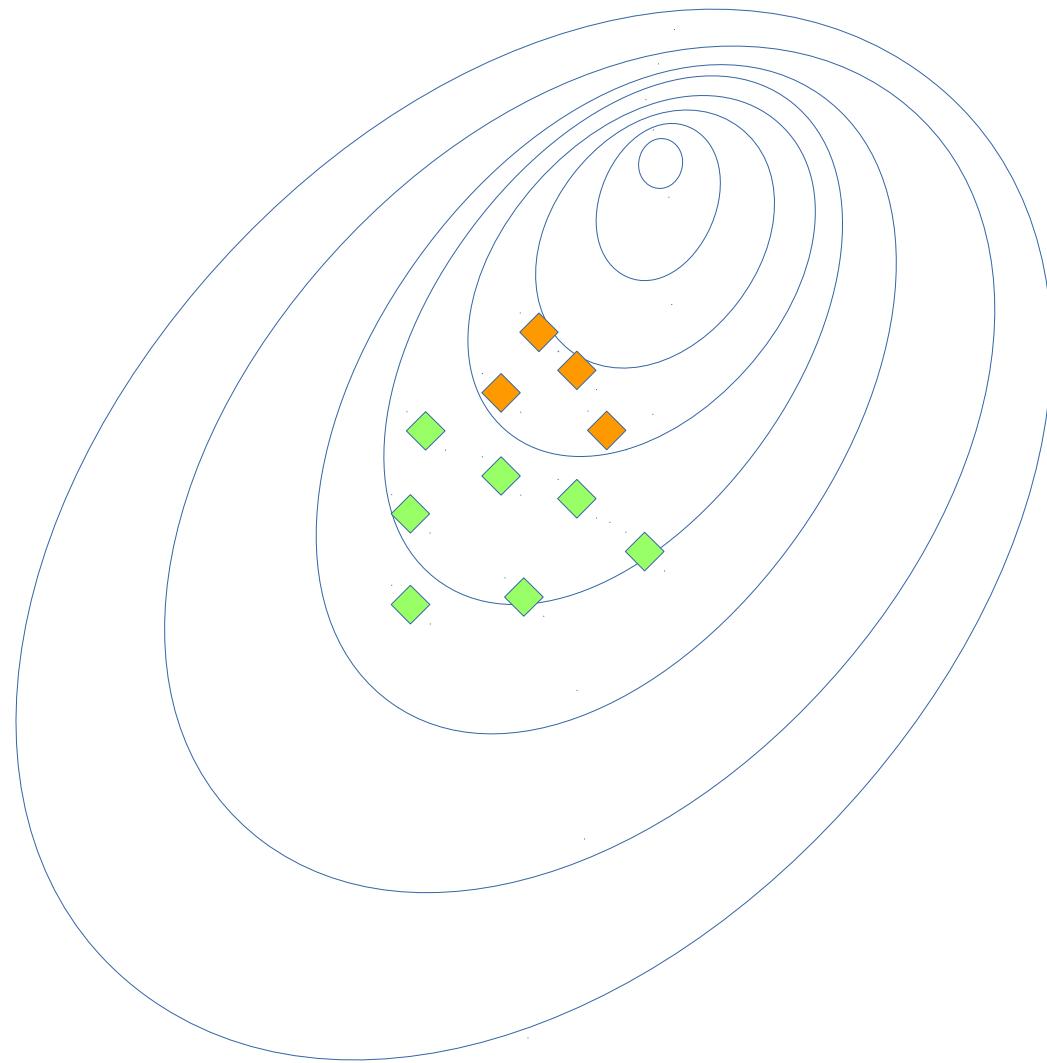
Step-by-step view



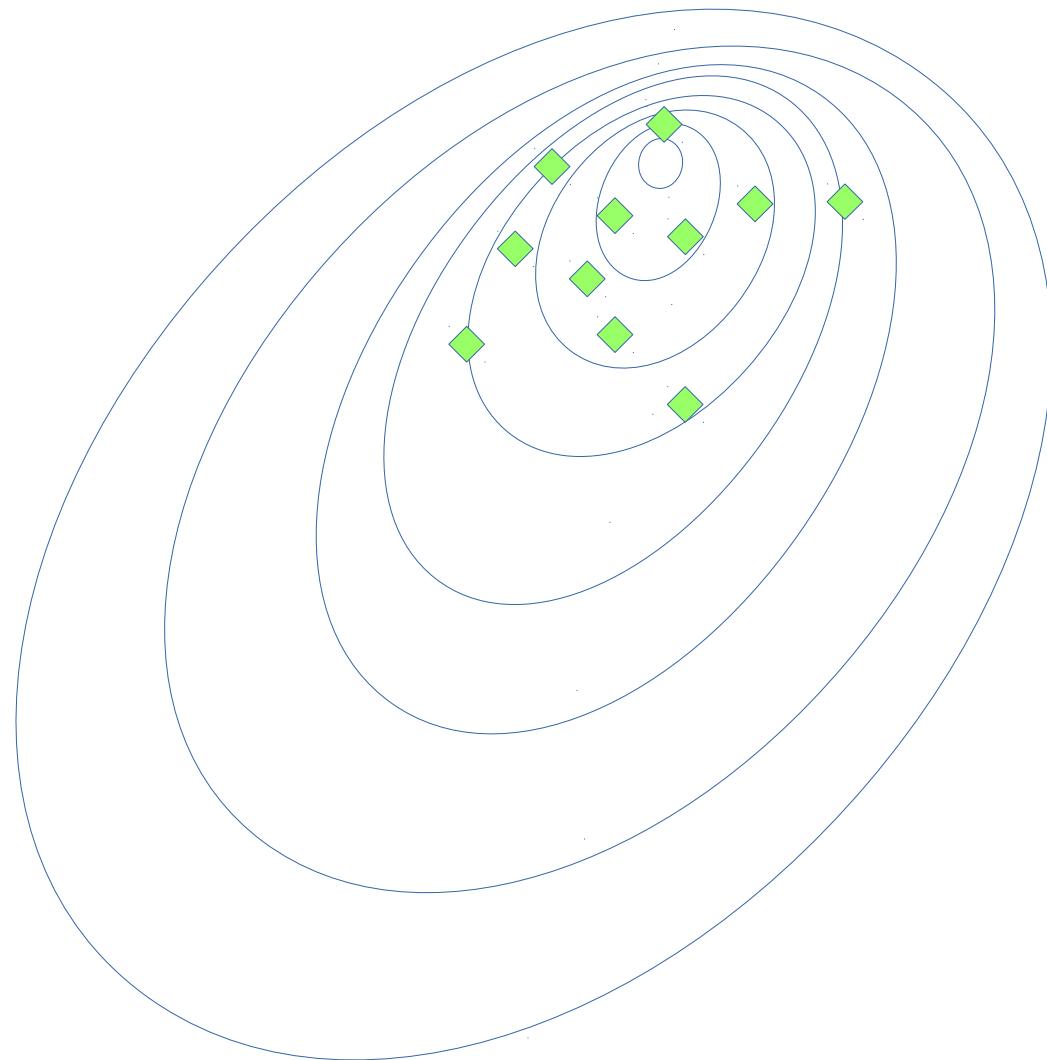
Step-by-step view



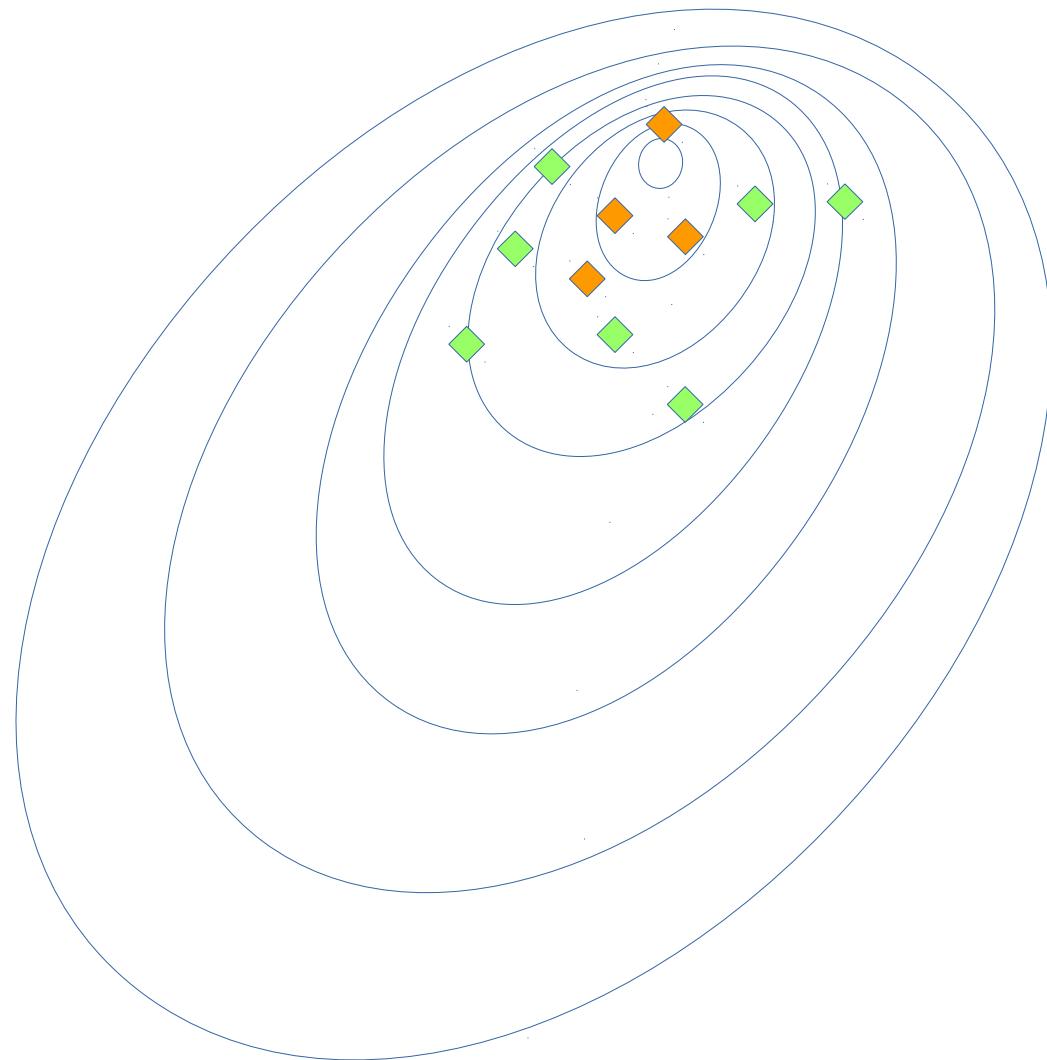
Step-by-step view



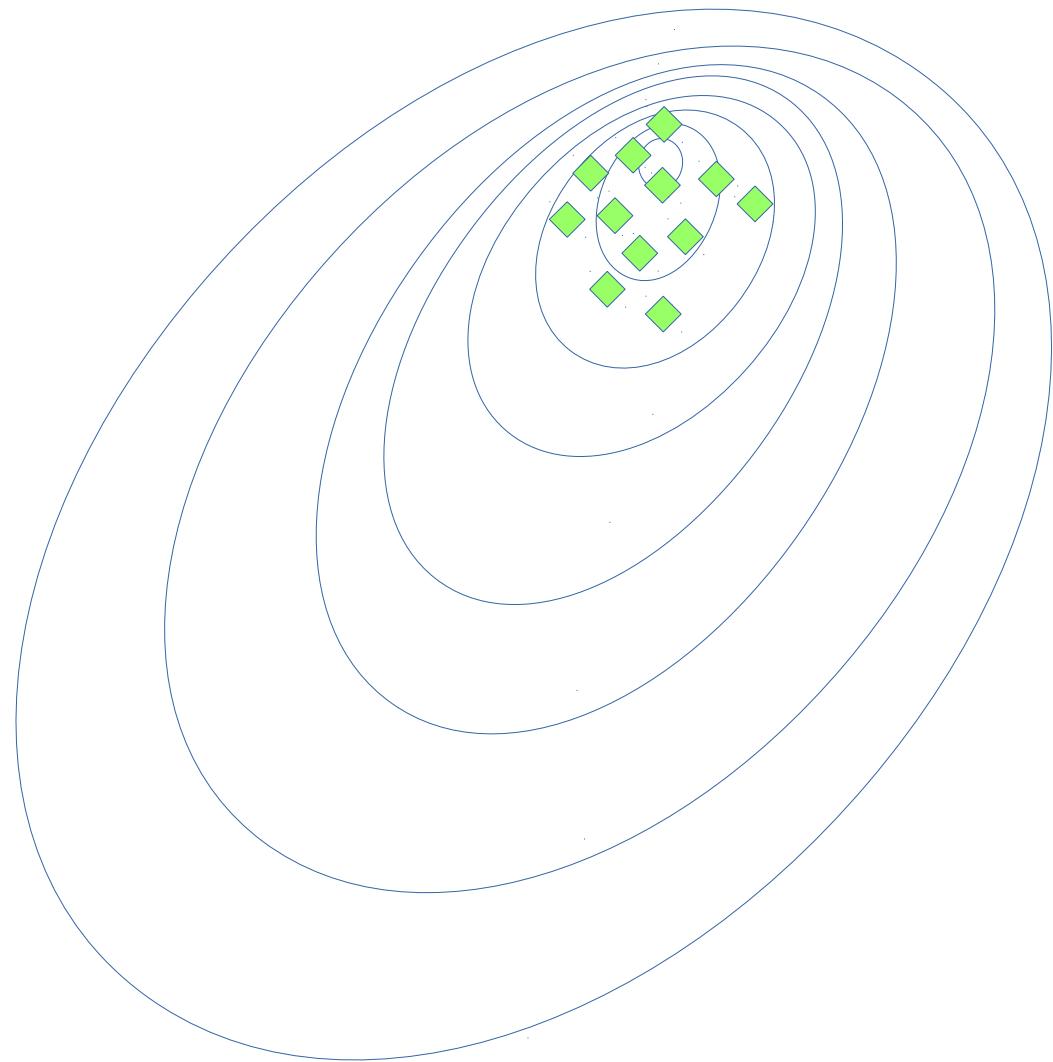
Step-by-step view



Step-by-step view



Step-by-step view



Tabular crossentropy method

- Policy is a matrix

$$\pi(a|s) = A_{s,a}$$

- Sample N games with that policy
- Get M best sessions (elites)

$$Elite = [(s_0, a_0), (s_1, a_1), (s_2, a_2), \dots, (s_k, a_k)]$$

Tabular crossentropy method

- Policy is a matrix

$$\pi(a|s) = A_{s,a}$$

- Sample N games with that policy
- Take M best sessions (elites)
- Aggregate by states

$$\pi(a|s) = \frac{\sum_{s_t, a_t \in Elite} [s_t = s][a_t = a]}{\sum_{s_t, a_t \in Elite} [s_t = s]}$$

Tabular crossentropy method

- Policy is a matrix

$$\pi(a|s) = A_{s,a}$$

- Sample N games with that policy
- Take M best sessions (elite)
- Aggregate by states

$$\pi(a|s) = \frac{\text{took } a \text{ at } s}{\text{was at } s}$$

In M best games

Grim reality

If your environment has infinite/large state space



Approximate crossentropy method

- Policy is approximated
 - Neural network predicts $\pi_w(a|s)$ given s
 - Linear model / Random Forest / ...

Can't set $\pi(a|s)$ explicitly

All state-action pairs from M best sessions

$$Elite = [(s_0, a_0), (s_1, a_1), (s_2, a_2), \dots, (s_k, a_k)]$$

Approximate crossentropy method

Neural network predicts $\pi_W(a|s)$ given s

All state-action pairs from M best sessions

$$Elite = [(s_0, a_0), (s_1, a_1), (s_2, a_2), \dots, (s_k, a_k)]$$

Maximize likelihood of actions in “best” games

$$\pi = \operatorname{argmax}_{\pi} \sum_{s_i, a_i \in Elite} \log \pi(a_i | s_i)$$

Approximate crossentropy method

- Initialize NN weights $W_0 \leftarrow \text{random}$
- Loop:
 - Sample N sessions
 - $\text{Elite} = [(s_0, a_0), (s_1, a_1), (s_2, a_2), \dots, (s_k, a_k)]$
 - $W_{i+1} = W_i + \alpha \nabla [\sum_{s_i, a_i \in \text{Elite}} \log \pi_{W_i}(a_i | s_i)]$

Approximate crossentropy method

- Initialize NN weights **nn = MLPClassifier(...)**
- Loop:
 - Sample N sessions
 - $Elite = [(s_0, a_0), (s_1, a_1), (s_2, a_2), \dots, (s_k, a_k)]$
 - **nn.fit(elite_states,elite_actions)**

Continuous action spaces

- Continuous state space
- Model $\pi_W(a|s) = N(\mu(s), \sigma^2)$
 - Mu(s) is neural network output
 - Sigma is a parameter or yet another network output
- Loop:
 - Sample N sessions
 - elite = take M best sessions and concatenate
 - $W_{i+1} = W_i + \alpha \nabla \left[\sum_{s_i, a_i \in Elite} \log \pi_{W_i}(a_i | s_i) \right]$

What changed?

Approximate crossentropy method

- Initialize NN weights **nn = MLPRegressor(...)**
- Loop:
 - Sample N sessions
 - $Elite = [(s_0, a_0), (s_1, a_1), (s_2, a_2), \dots, (s_k, a_k)]$
 - **nn.fit(elite_states,elite_actions)**

Almost nothing!

Tricks

- Remember sessions from 3-5 past iterations
 - Threshold and use all of them when training
 - May converge slower if env is easy to solve.
- Regularize with entropy
 - to prevent premature convergence.
- Parallelize sampling
- Use RNNs if partially-observable (later)





**Q: How is RL different
from supervised learning?**

What-what learning?

Supervised learning

- Learning to approximate reference answers
- Needs correct answers
- Model does not affect the input data

Reinforcement learning

- Learning optimal strategy by trial and error
- Needs feedback on agent's own actions
- Agent can affect it's own observations



What-what learning?

Unsupervised learning

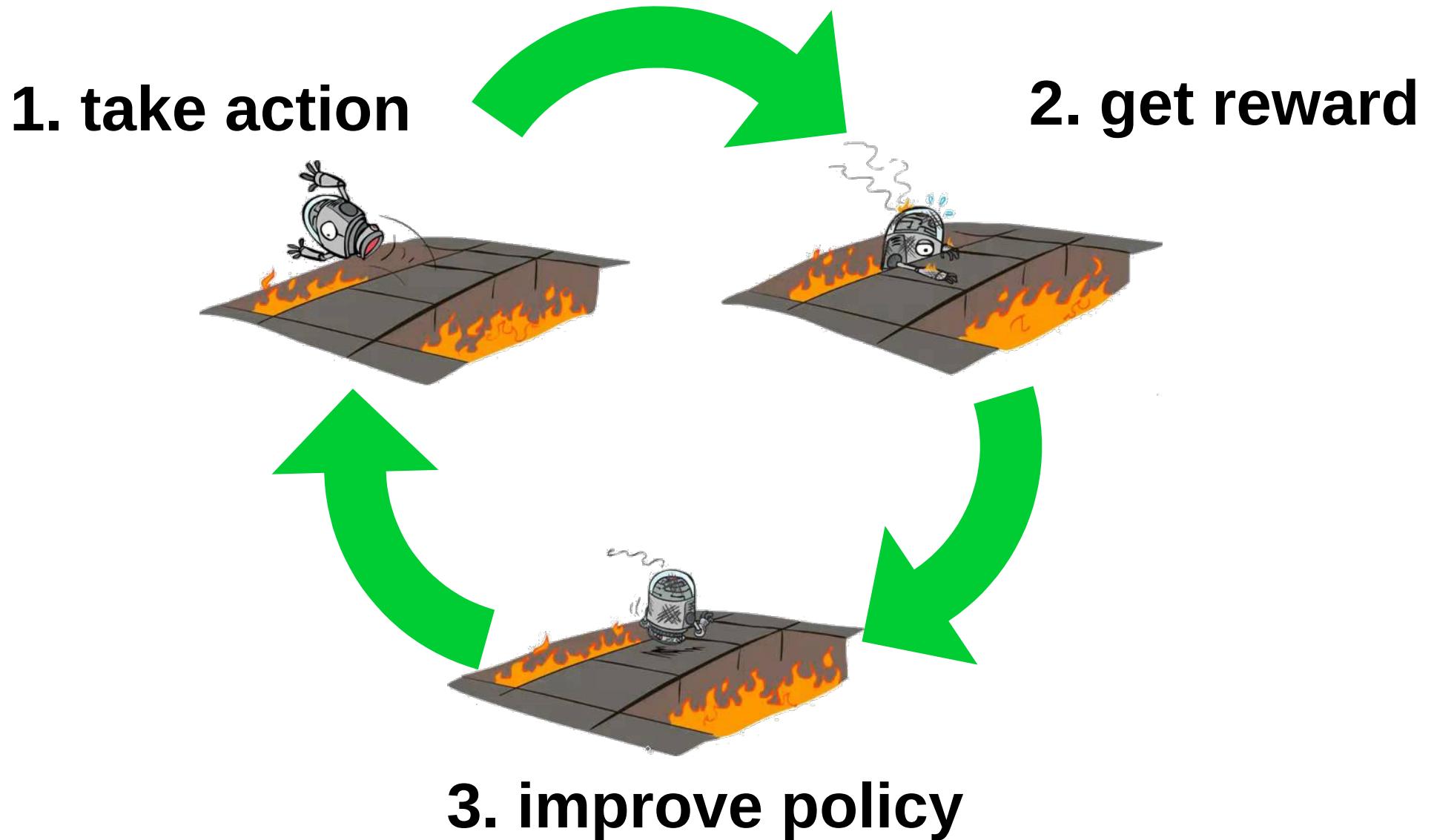
- Learning underlying data structure
- No feedback required
- Model does not affect the input data

Reinforcement learning

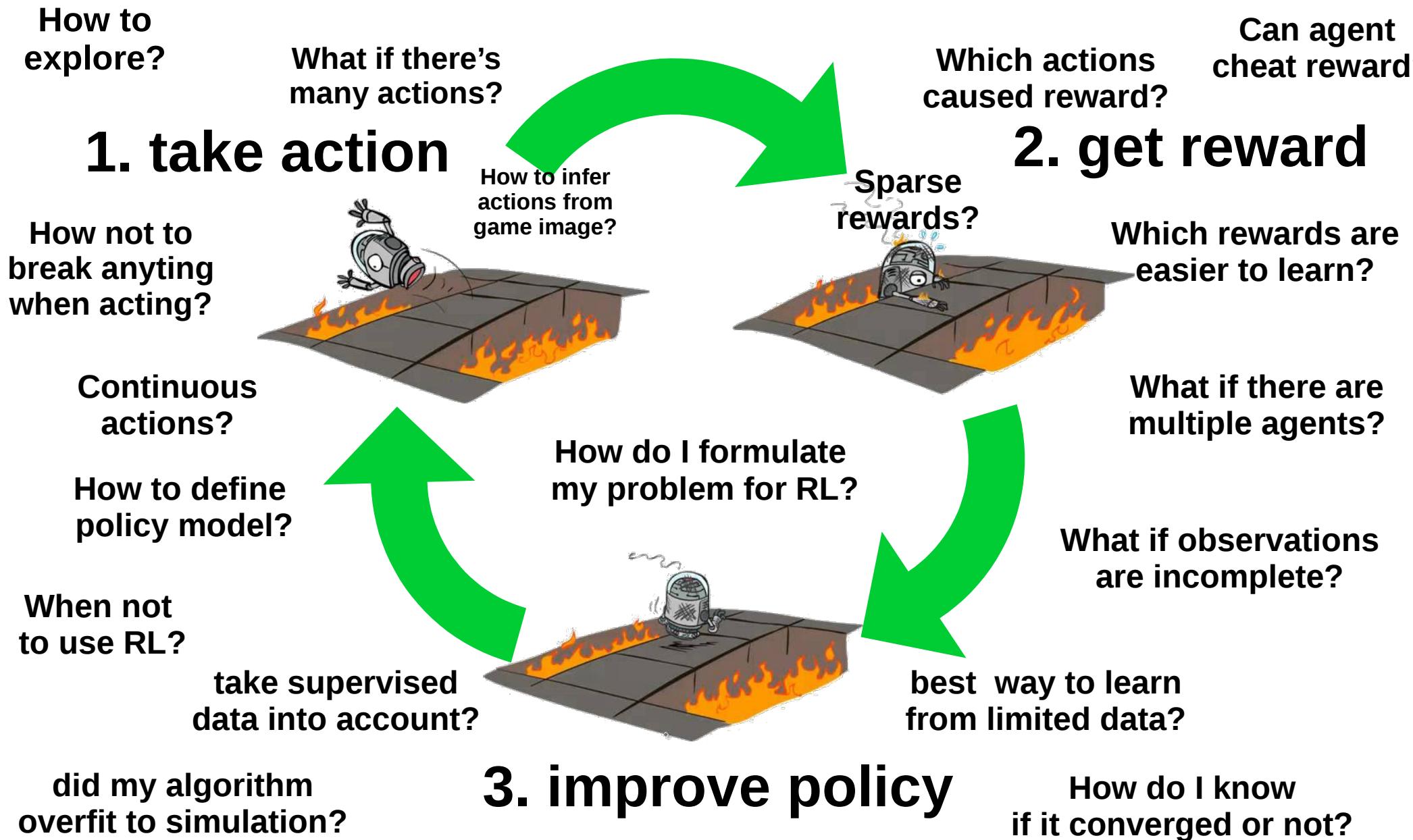
- Learning optimal strategy by trial and error
- Needs feedback on agent's own actions
- Agent can affect its own observations



Reinforcement learning is easy!



Reinforcement learning is challenging!



- RL is different both from Supervised and Unsupervised learning
- Remember the Markov assumptions
- Try to think in terms of distributions
- The crossentropy method is simple and still very powerful approach