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# Deep Reinforcement Learning

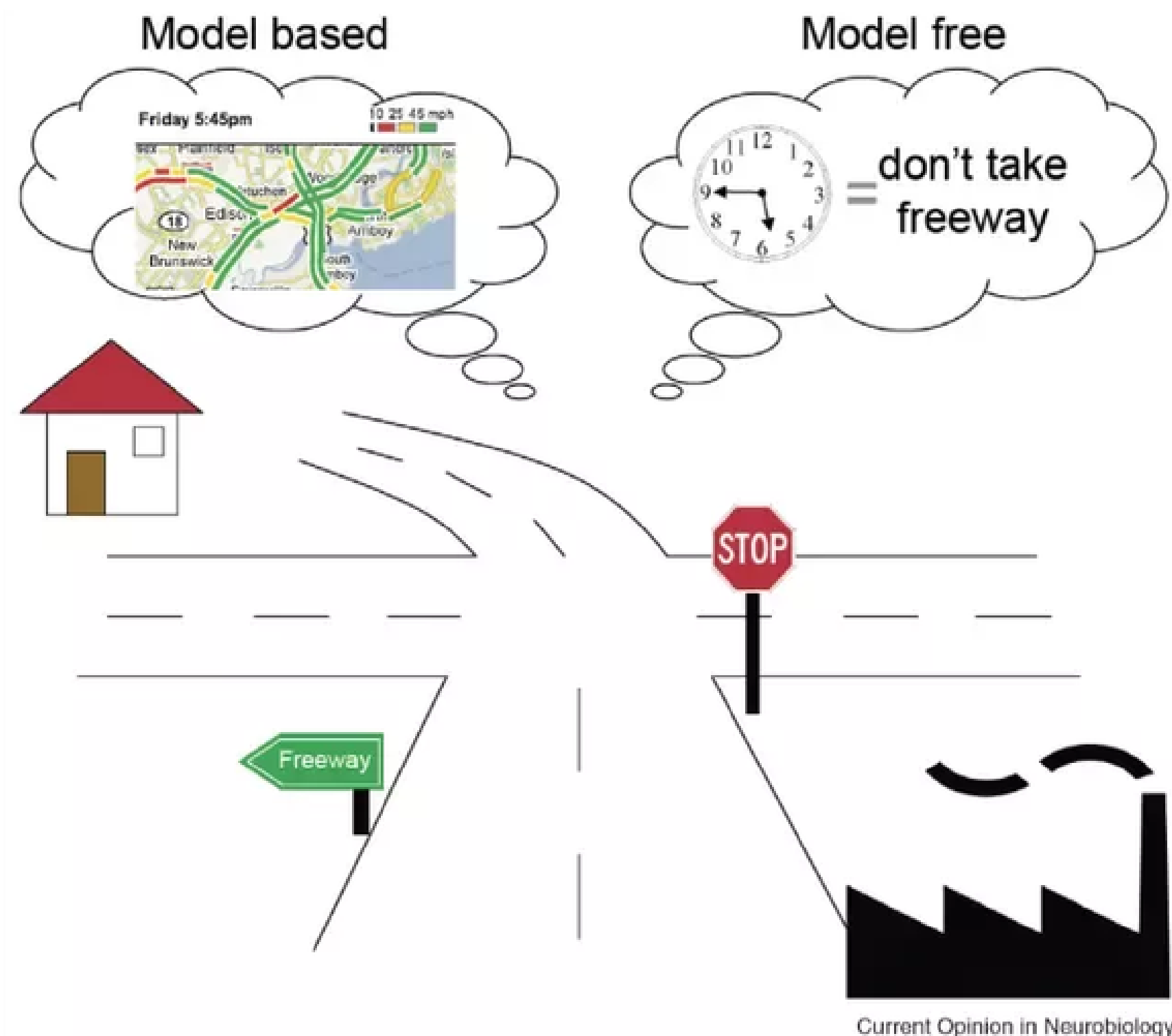
Model-based RL

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# 1 - Model-based RL

# Model-free vs. model-based RL



- In **model-free RL** (MF) methods, we do not need to know anything about the dynamics of the environment to start learning a policy:

$$p(s_{t+1}|s_t, a_t) \quad r(s_t, a_t, s_{t+1})$$

- We just sample transitions  $(s, a, r, s')$  and update Q-values or a policy network.
- The main advantage is that the agent does not need to “think” when acting: just select the action with highest Q-value (**reflexive behavior**).
- The other advantage is that you can use MF methods on **any** MDP: you do not need to know anything about them.

Source: Dayan P, Niv Y. (2008). Reinforcement learning: The Good, The Bad and The Ugly. Current Opinion in Neurobiology, Cognitive neuroscience 18:185–196. doi:10.1016/j.conb.2008.08.003

- But MF methods are very slow (sample complexity): as they make no assumption, they have to learn everything by trial-and-error from scratch.



# Model-free vs. model-based RL

- If you had a **model** of the environment, you could plan ahead (what would happen if I did that?) and speed up learning (do not explore stupid ideas): **model-based RL** (MB).
- In chess, players **plan** ahead the possible moves up to a certain horizon and evaluate moves based on their emulated consequences.
- In real-time strategy games, learning the environment (**world model**) is part of the strategy: you do not attack right away.

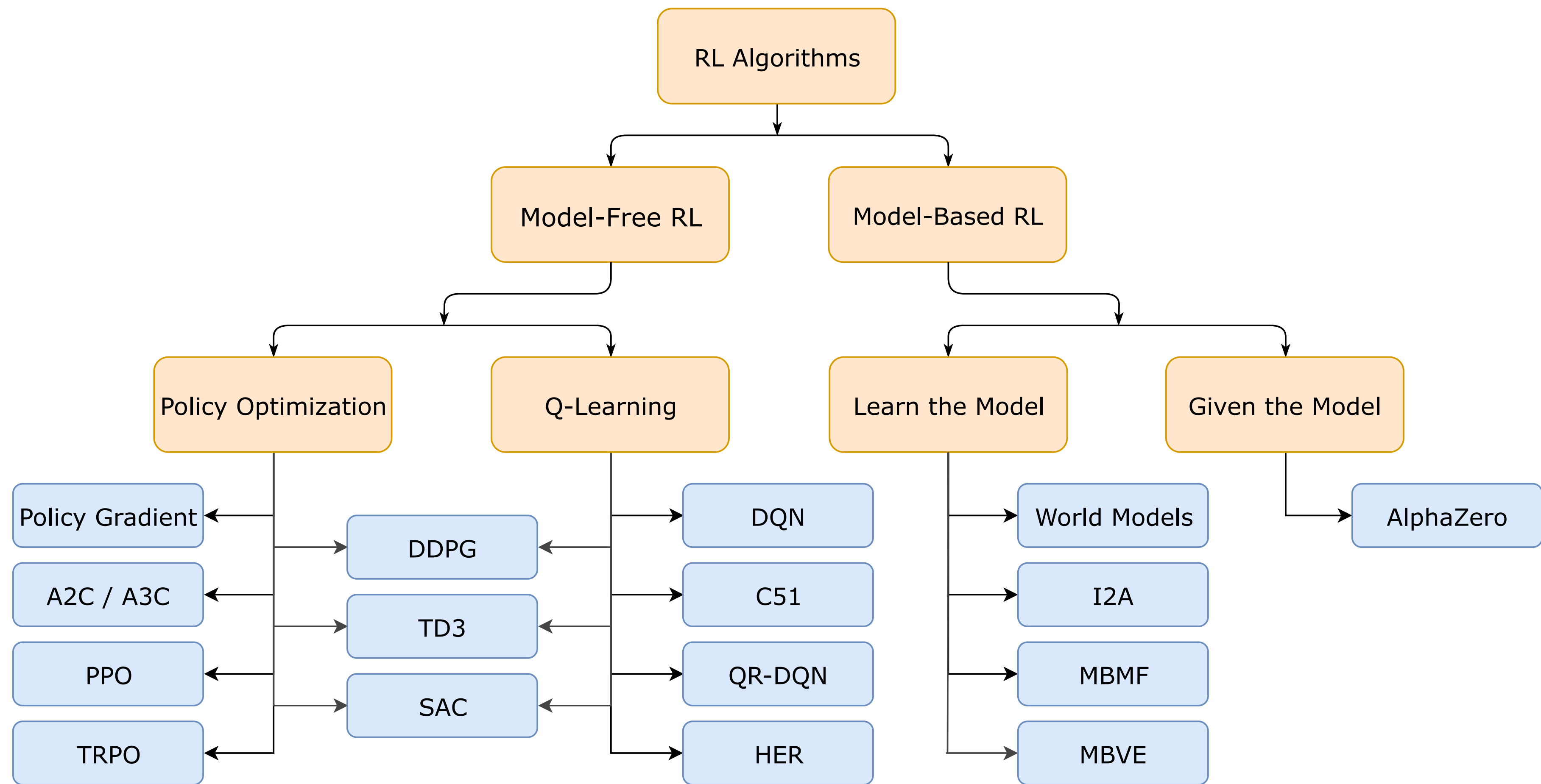


Source: <https://www.chess.com/article/view/announcing-the-chess-com-gif-maker>



Source: <https://towardsdatascience.com/model-based-reinforcement-learning-cb9e41ff1f0d>

# Two families of deep RL algorithms



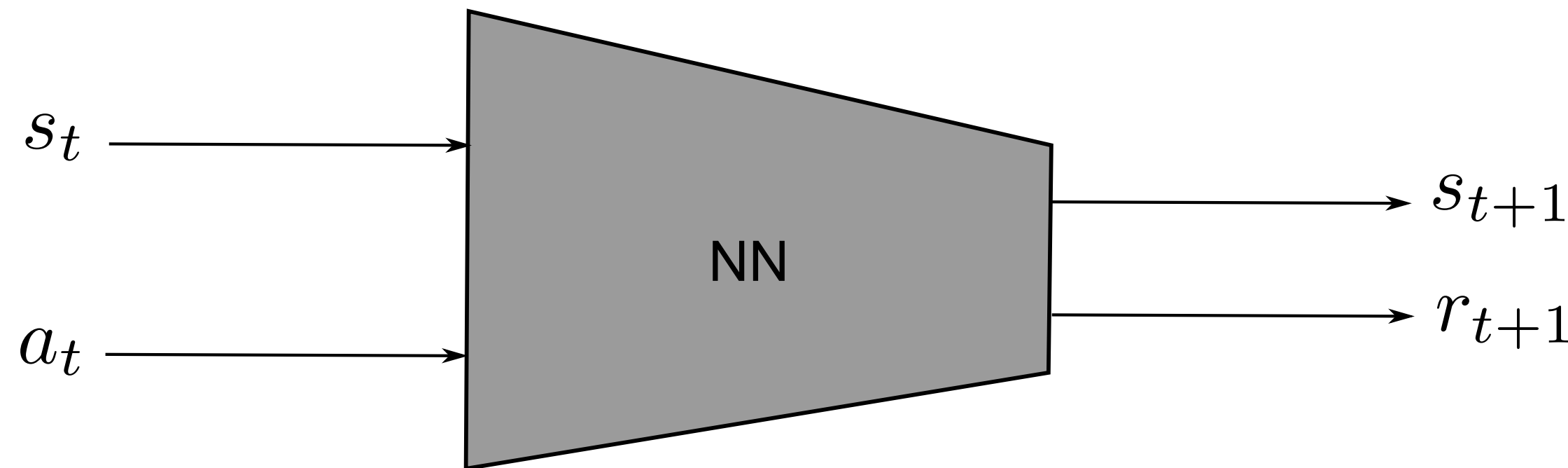
Source: <https://github.com/avillemin/RL-Personnal-Notebook>

## 2 - Model Predictive Control



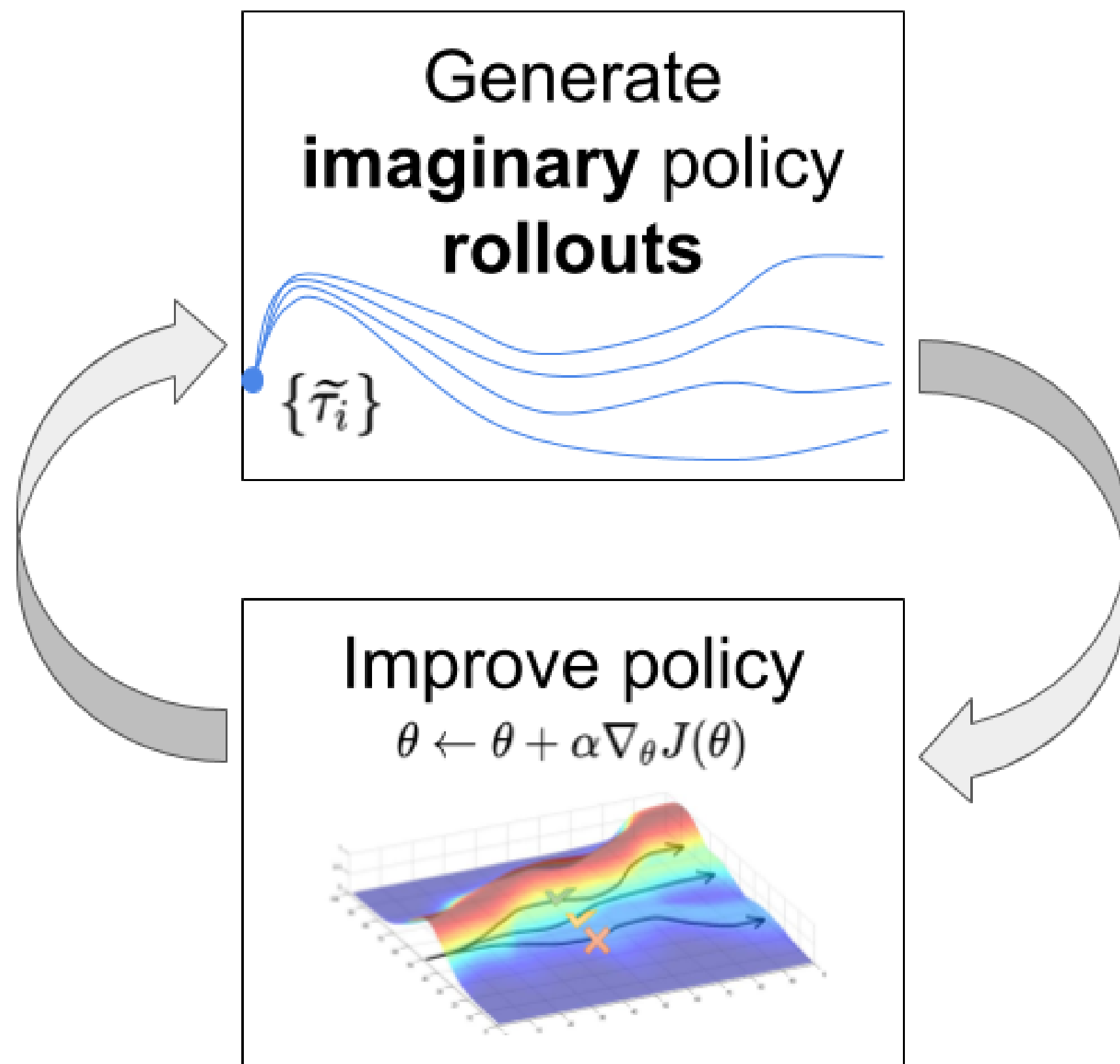
# Learning the world model

- Learning the world model is not complicated in theory.
- We just need to collect *enough* transitions  $s_t, a_t, s_{t+1}, r_{t+1}$  using a random agent (or during learning) and train a **supervised** model to predict the next state and reward.



- Such a model is called the **dynamics model**, the **transition model** or the **forward model**.
  - **What happens if I do that?**
- The model can be deterministic (use neural networks) or stochastic (use Gaussian Processes).
- Given an initial state  $s_0$  and a policy  $\pi$ , you can unroll the future using the local model.

# Learning from imaginary rollouts



- Once you have a good transition model, you can generate **rollouts**, i.e. imaginary trajectories / episodes using the model.

$$\tau = (s_o, a_o, r_1, s_1, a_1, \dots, s_T)$$

- You can then feed these trajectories to any model-free algorithm (value-based, policy-gradient) that will learn to maximize the returns.

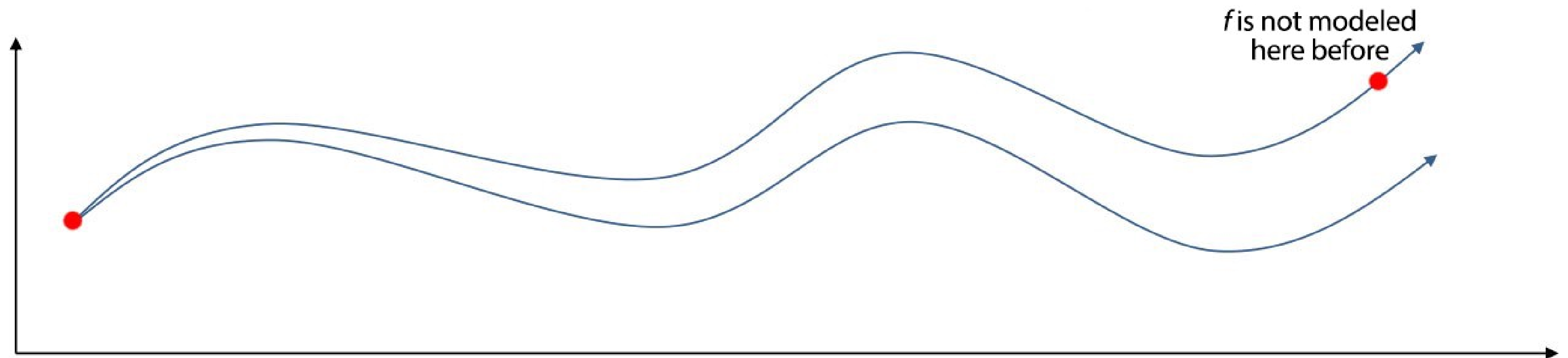
$$\mathcal{J}(\theta) = \mathbb{E}_{\tau} [R(\tau)]$$

- The only sample complexity is the one needed to train the model: the rest is **emulated**.
- Drawback: This can only work when the model is close to perfect, especially for long trajectories or probabilistic MDPs.



# Imperfect model

- For long horizons, the slightest imperfection in the model can accumulate (**drift**) and lead to completely wrong trajectories.

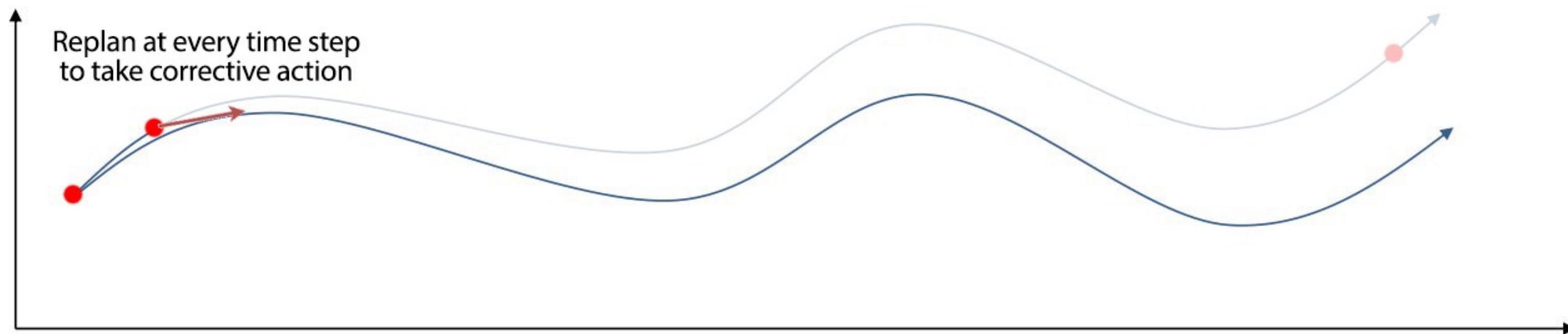


Source: [https://medium.com/@jonathan\\_hui/rl-model-based-reinforcement-learning-3c2b6f0aa323](https://medium.com/@jonathan_hui/rl-model-based-reinforcement-learning-3c2b6f0aa323)

- The emulated trajectory will have a biased return, the algorithm does not converge to the optimal policy.
- If you have a perfect model, you should not be using RL anyway, as classical control methods would be much faster (but see AlphaGo).

# MPC - Model Predictive Control

- The solution is to **replan** at each time step and execute only the first planned action **in the real environment**.



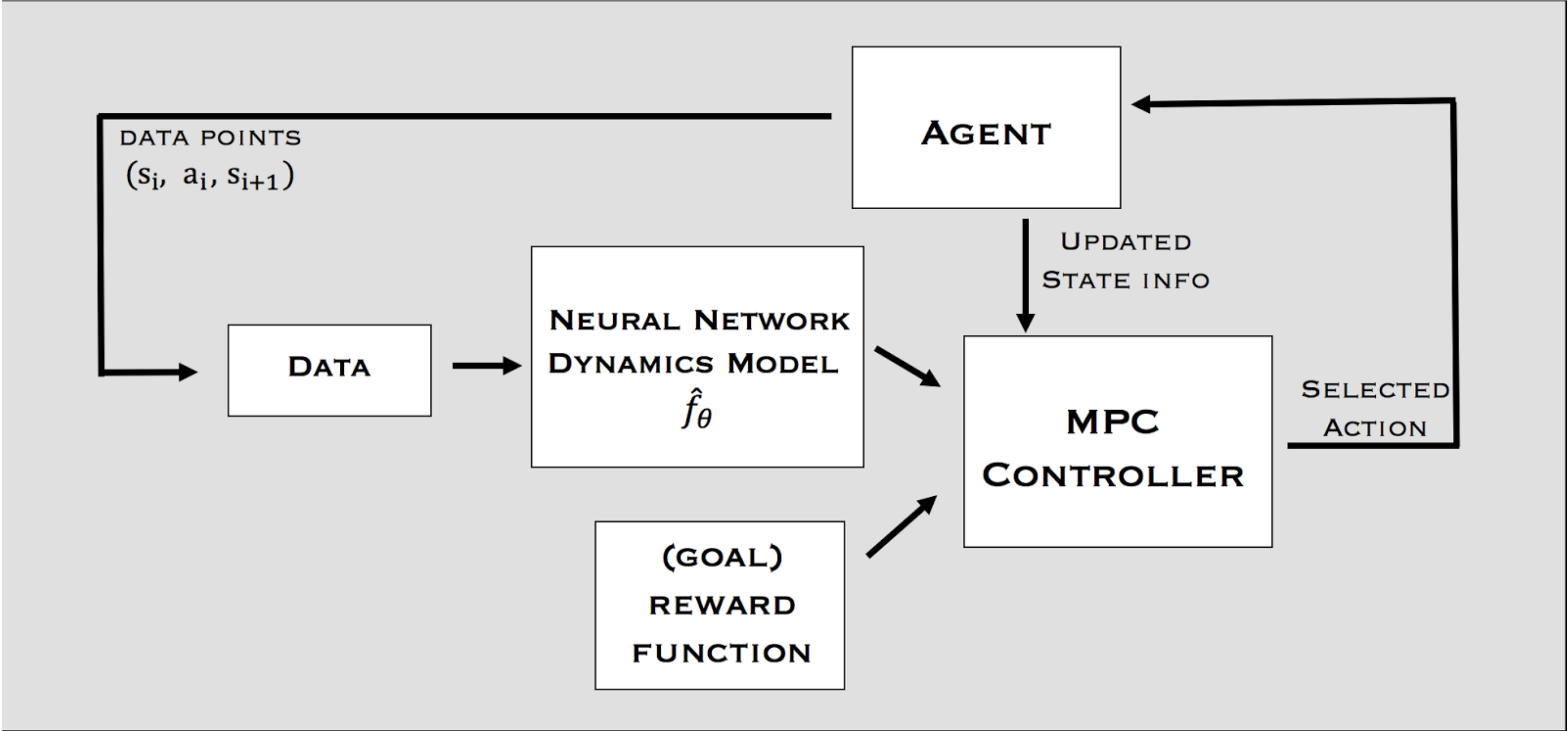
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- Model Predictive Control** iteratively plans complete trajectories, but only selects the first action.

- run base policy  $\pi_0(\mathbf{a}_t|\mathbf{s}_t)$  (e.g., random policy) to collect  $\mathcal{D} = \{(\mathbf{s}, \mathbf{a}, \mathbf{s}')_i\}$
  - learn dynamics model  $f(\mathbf{s}, \mathbf{a})$  to minimize  $\sum_i \|f(\mathbf{s}_i, \mathbf{a}_i) - \mathbf{s}'_i\|^2$
  - plan through  $f(\mathbf{s}, \mathbf{a})$  to choose actions
  - execute the first planned action, observe resulting state  $\mathbf{s}'$  (MPC)
  - append  $(\mathbf{s}, \mathbf{a}, \mathbf{s}')$  to dataset  $\mathcal{D}$
- every N steps

Source: [http://rail.eecs.berkeley.edu/deeprlcourse-fa17/f17docs/lecture\\_9\\_model\\_based\\_rl.pdf](http://rail.eecs.berkeley.edu/deeprlcourse-fa17/f17docs/lecture_9_model_based_rl.pdf)

# MPC - Model Predictive Control

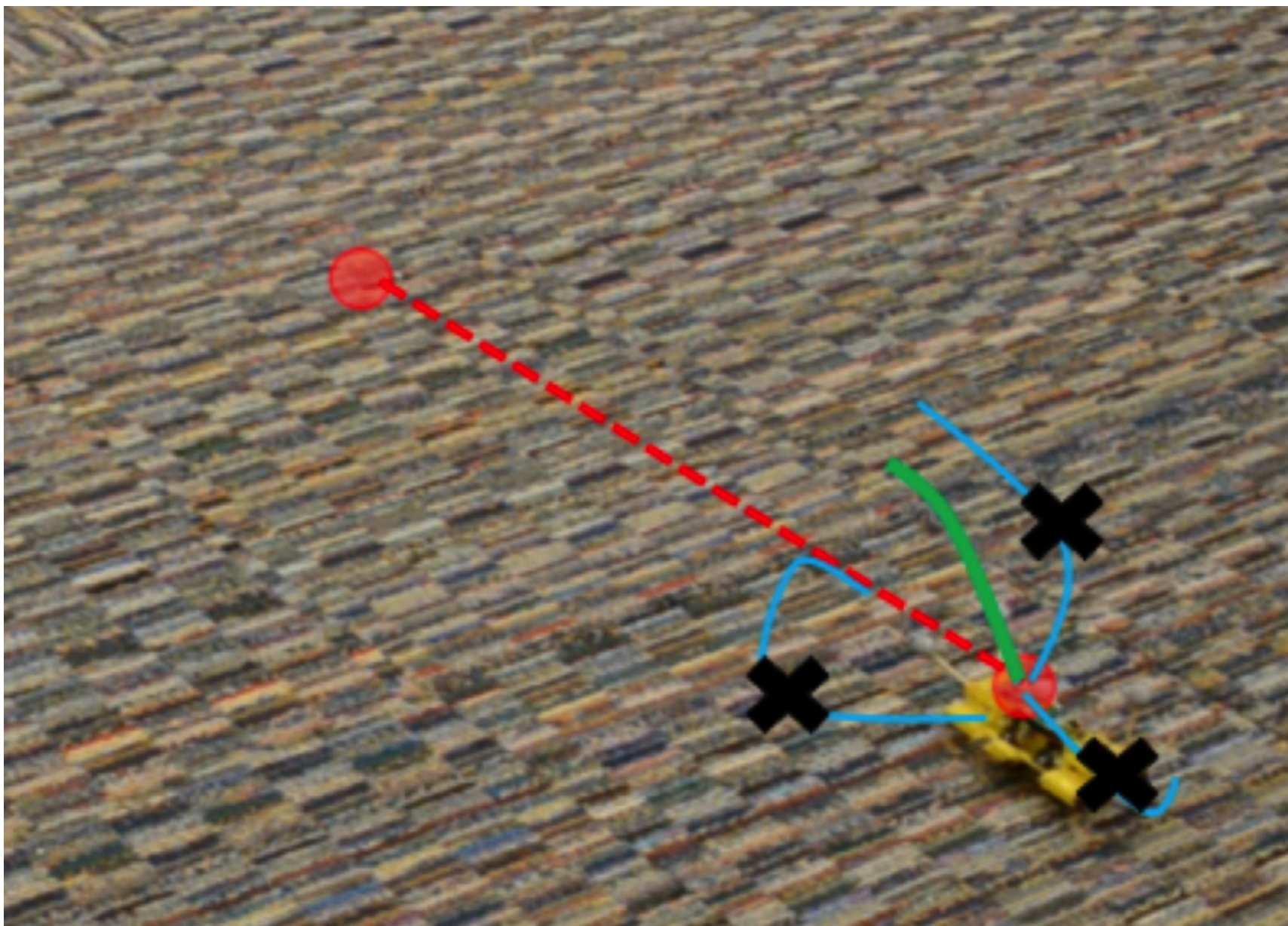




# MPC - Model Predictive Control

- The planner can actually be anything, it does not have to be a RL algorithm.
- For example, it can be iLQR (Iterative Linear Quadratic Regulator), a non-linear optimization method.

<https://jonathan-hui.medium.com/rl-lqr-ilqr-linear-quadratic-regulator-a5de5104c750>.

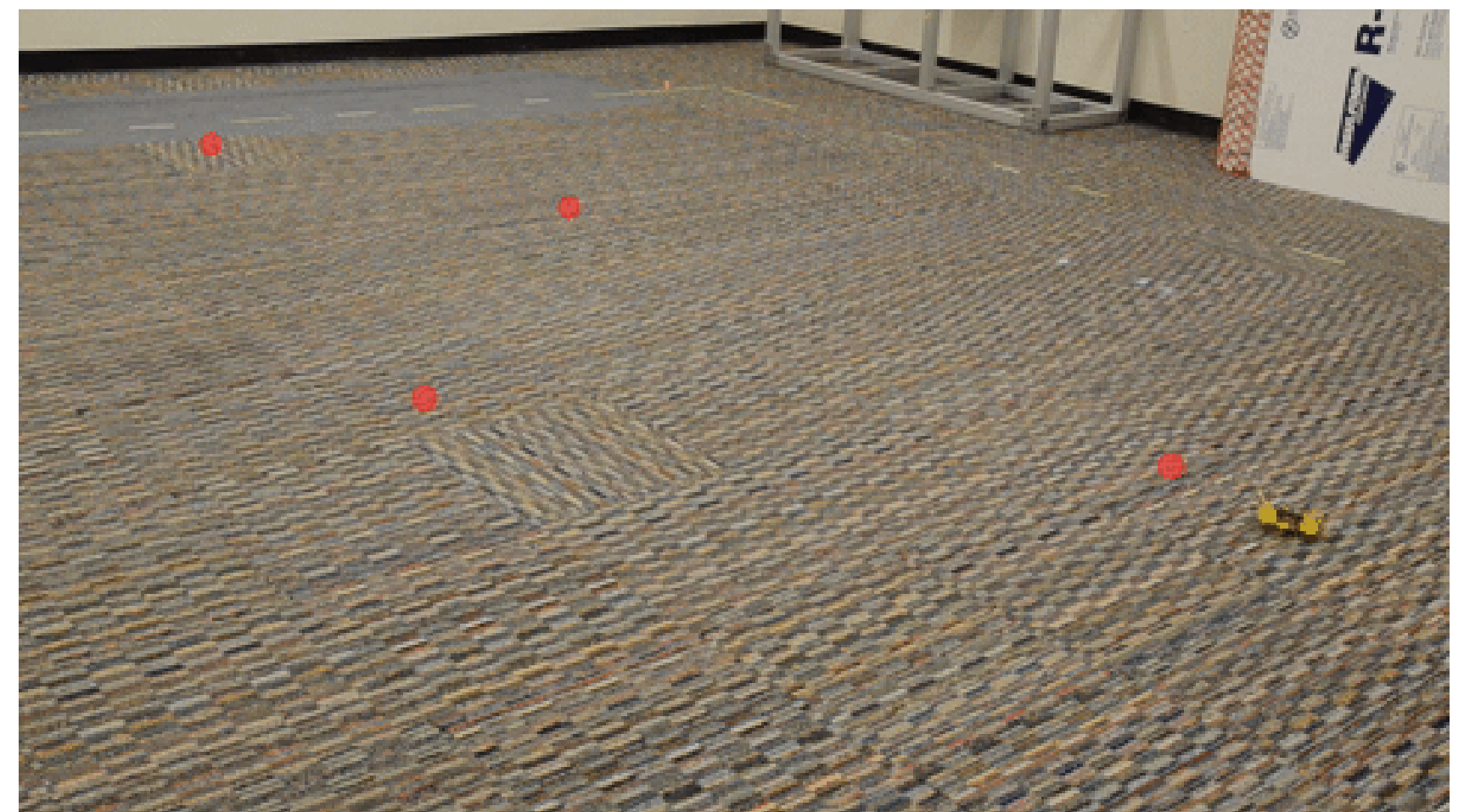
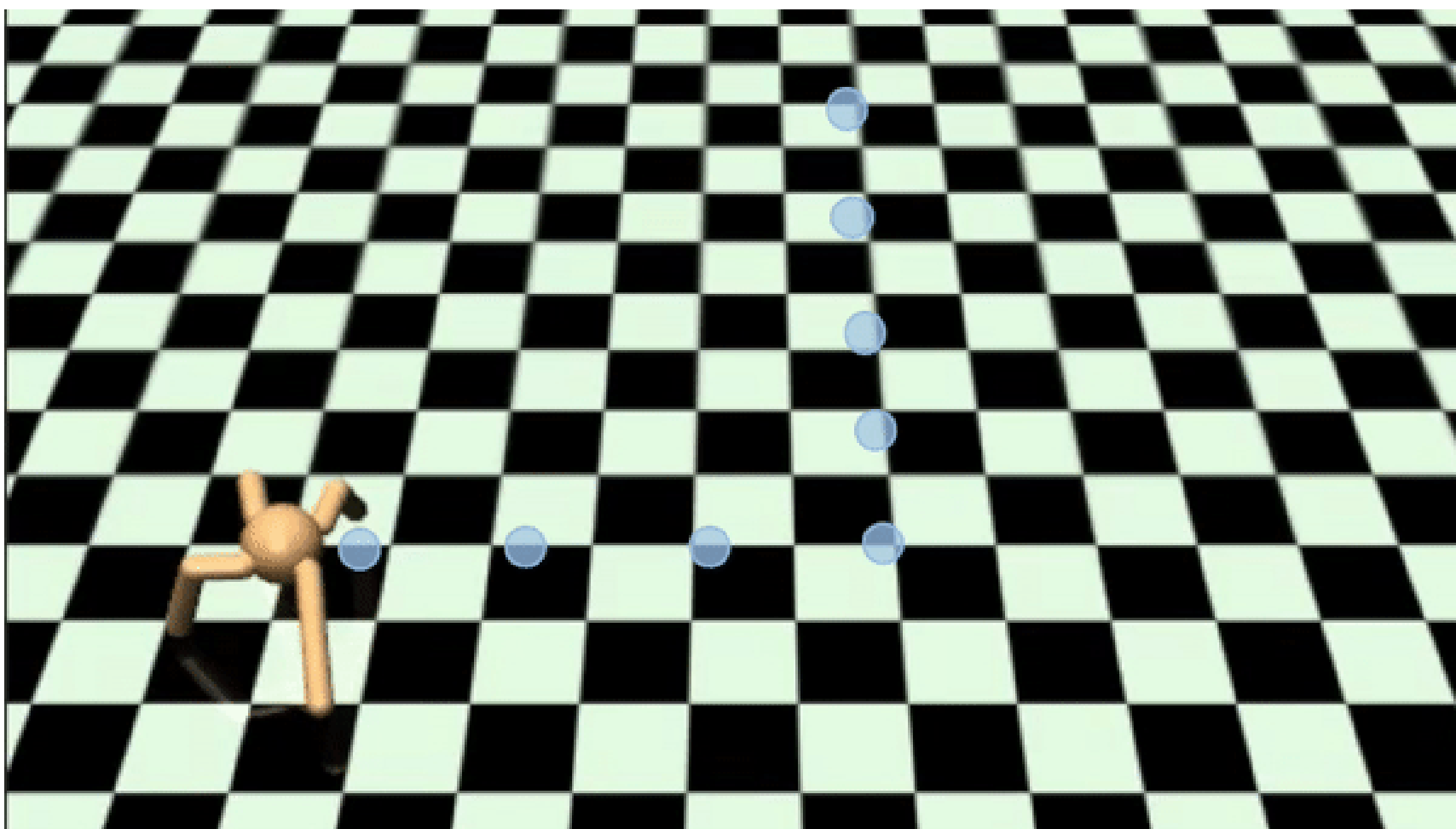


- Alternatively, one can use **random-sampling shooting**:
  1. in the current state, select a set of possible actions.
  2. generate rollouts with these actions and compute their returns using the model.
  3. select the action whose rollout has the highest return.

Source: <https://bair.berkeley.edu/blog/2017/11/30/model-based-rl/>

# MPC - Model Predictive Control

- The main advantage of MPC is that you can change the reward function (the **goal**) on the fly: what you learn is the model, but planning is just an optimization procedure.
- You can set intermediary goals to the agent very flexibly: no need for a well-defined reward function.
- Model imperfection is not a problem as you replan all the time. The model can adapt to changes in the environment (slippery terrain, simulation to real-world).

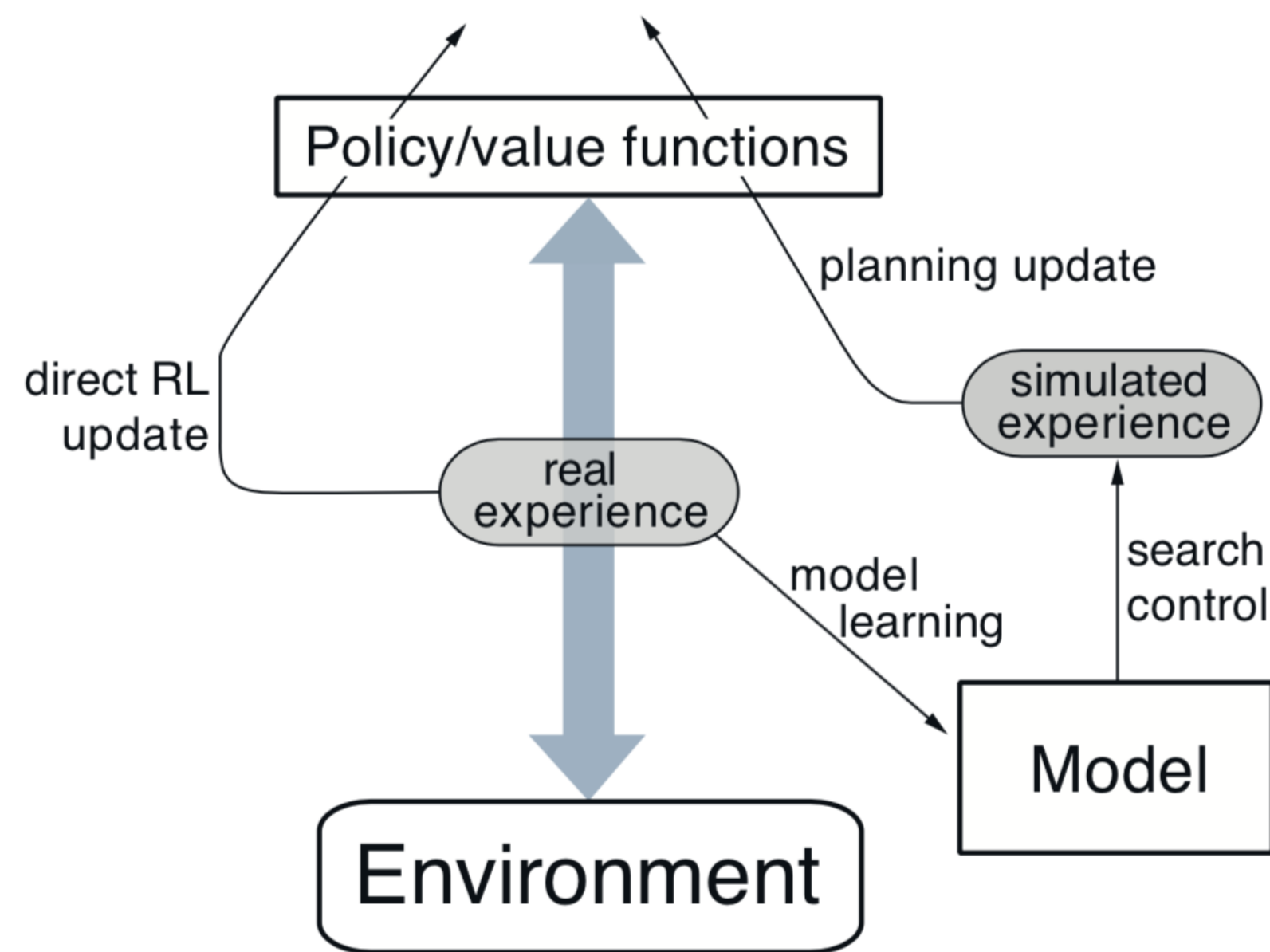


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# 3 - Dyna-Q

# Dyna-Q



Source: <https://towardsdatascience.com/reinforcement-learning-model-based-planning-methods-5e99cae0abb8>

- Another approach to MB RL is to **augment** MF methods with MB rollouts.
- The MF algorithm (e.g. Q-learning) learns from transitions  $(s, a, r, s')$  sampled either with:
  - **real experience**: interaction with the environment.
  - **simulated experience**: simulation by the model.
- If the simulated transitions are good enough, the MF algorithm can converge using much less **real transitions**, thereby reducing its **sample complexity**.

- The **Dyna-Q** algorithm is an extension of Q-learning to integrate a model  $M(s, a) = (s', r')$ .
- The model can be tabular or approximated with a NN.

# Dyna-Q

- Initialize values  $Q(s, a)$  and model  $M(s, a)$ .
- **for**  $t \in [0, T_{\text{total}}]$ :
  - Select  $a_t$  using  $Q$ , take it on the **real environment** and observe  $s_{t+1}$  and  $r_{t+1}$ .
  - Update the Q-value of the **real** action:

$$\Delta Q(s_t, a_t) = \alpha (r_{t+1} + \gamma \max_a Q(s_{t+1}, a) - Q(s_t, a_t))$$

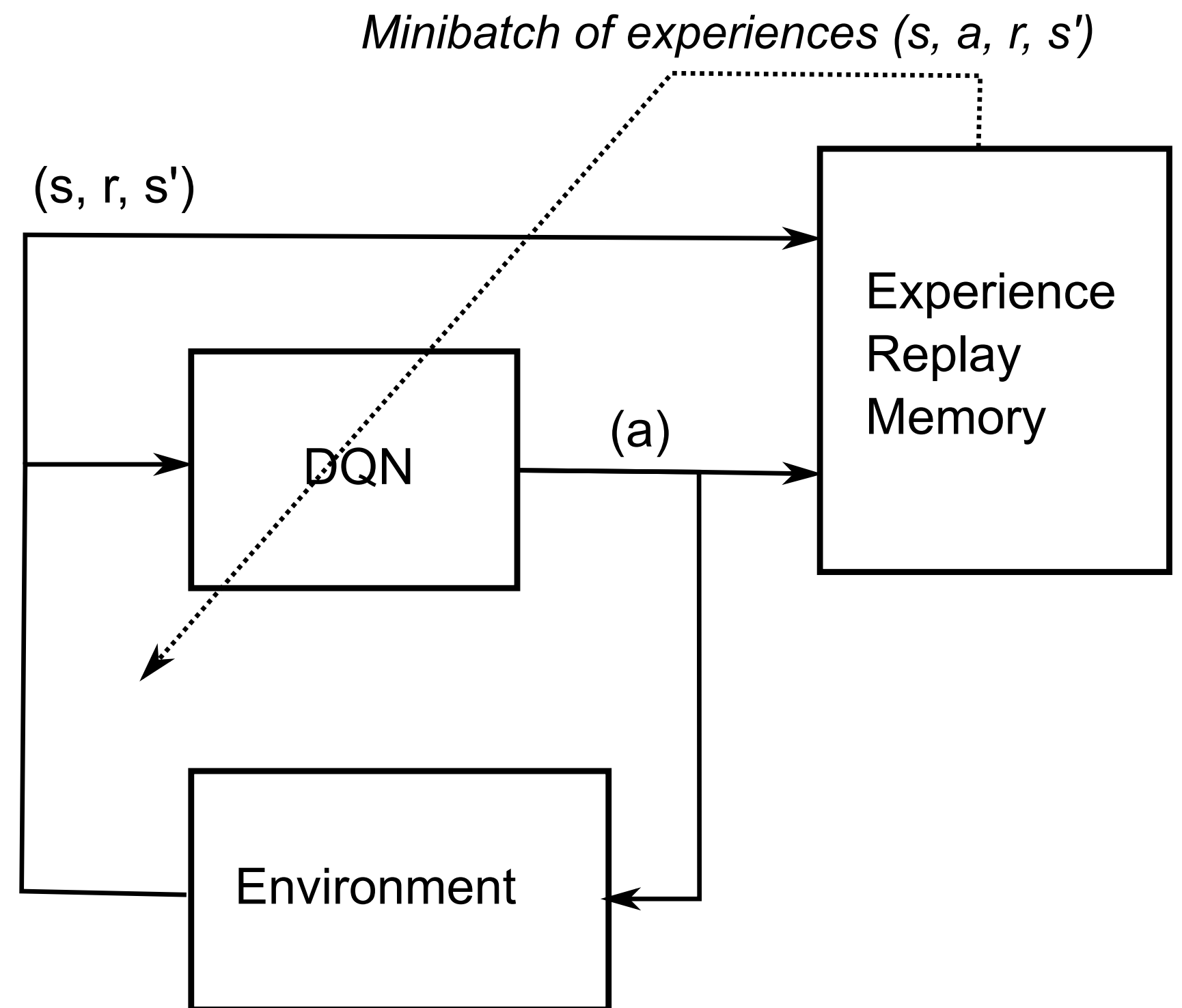
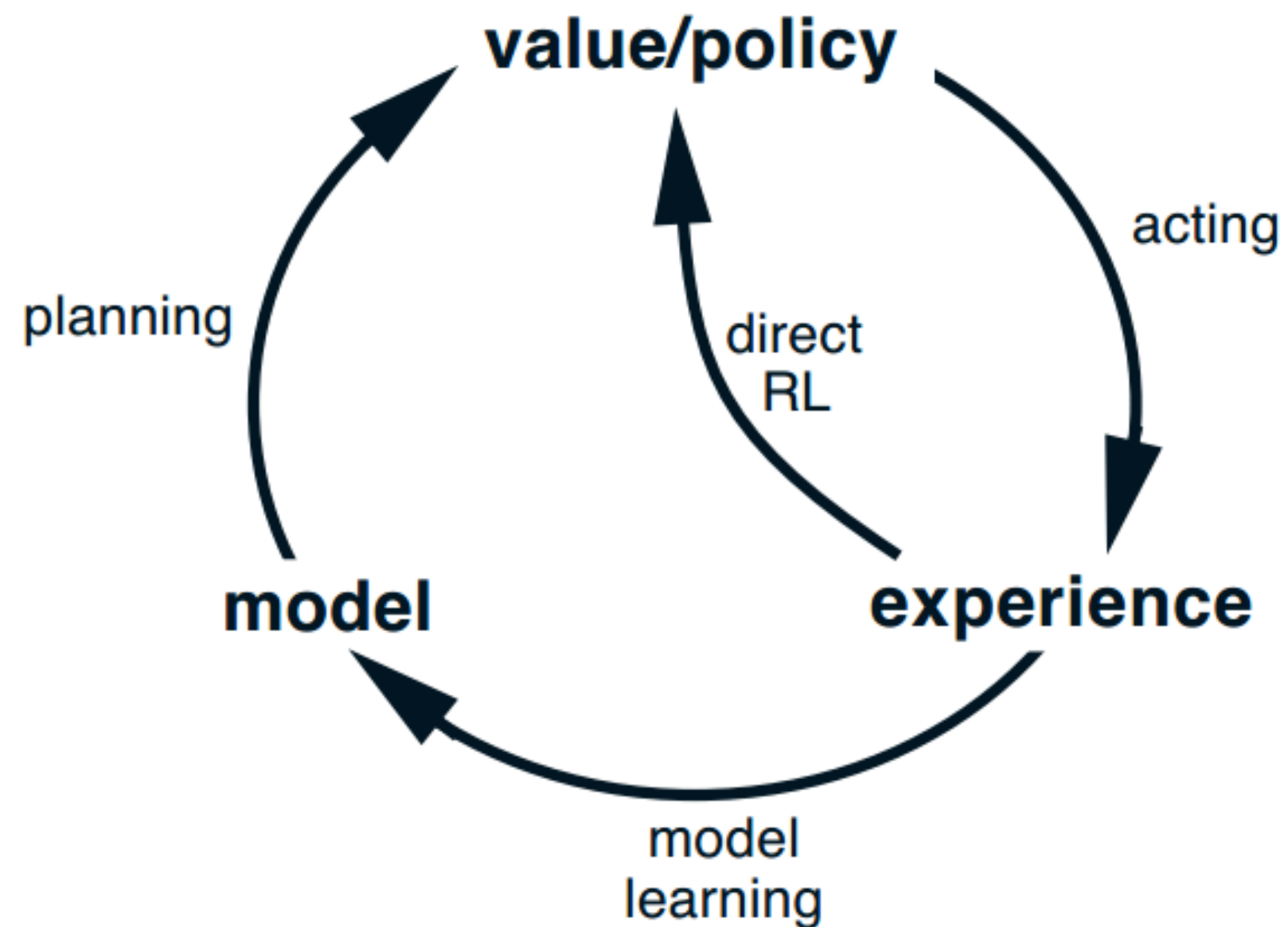
- Update the model:

$$M(s_t, a_t) \leftarrow (s_{t+1}, r_{t+1})$$

- **for**  $K$  steps:
  - Sample a state  $s_k$  from a list of visited states.
  - Select  $a_k$  using  $Q$ , predict  $s_{k+1}$  and  $r_{k+1}$  using the **model**  $M(s_k, a_k)$ .
  - Update the Q-value of the **imagined** action:

$$\Delta Q(s_k, a_k) = \alpha (r_{k+1} + \gamma \max_a Q(s_{k+1}, a) - Q(s_k, a_k))$$

# Dyna-Q



- It is interesting to notice that Dyna-Q is very similar to DQN and its **experience replay memory**.
- In DQN, the ERM stores **real transitions** generated in the past.
- In Dyna-Q, the model generates **imagined transitions** based on past real transitions.