



A Quick Look at the “Reinforcement Learning” course

A. LAZARIC (*SequeL Team @INRIA-Lille*)

Ecole Centrale - Option DAD

SequeL – INRIA Lille

Why

Why: Important Problems

Why: Important Problems

- ▶ Autonomous robotics



Why: Important Problems

- ▶ Autonomous robotics



- ▶ *Elder care*

Why: Important Problems

- ▶ Autonomous robotics



- ▶ *Elder care*
- ▶ *Exploration of unknown/dangerous environments*

Why: Important Problems

- ▶ Autonomous robotics



- ▶ *Elder care*
- ▶ *Exploration of unknown/dangerous environments*
- ▶ *Robotics for entertainment*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications



Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications



- ▶ *Trading execution algorithms*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications



- ▶ *Trading execution algorithms*
- ▶ *Portfolio management*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications



- ▶ *Trading execution algorithms*
- ▶ *Portfolio management*
- ▶ *Option pricing*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management



Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management



- ▶ *Energy grid integration*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management



- ▶ *Energy grid integration*
- ▶ *Maintenance scheduling*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management



- ▶ *Energy grid integration*
- ▶ *Maintenance scheduling*
- ▶ *Energy market regulation*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management



- ▶ *Energy grid integration*
- ▶ *Maintenance scheduling*
- ▶ *Energy market regulation*
- ▶ *Energy production management*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems

The image shows a Google search interface for the query "bird houses". The search bar contains "bird houses" and the search button is visible. Below the search bar, the results are displayed. The top section is labeled "Sponsored Links" and contains several advertisements for bird houses, including "Bird Houses" from Scotts.com, "Specialty Bird Houses" from birds-out-back.com, "Bird Houses at BestNest" from bestnest.com, "Learn More About Bird Houses" from JustBirdHouses.net, "Bird Houses" from birdhouses101.com, and "Bird Feeders, Bird Houses - The Backyard Bird Company". The bottom section is labeled "Organic Results" and contains several search results for bird houses, including "Bird Houses" from backyardbird.com, "Bird Houses" from lowes.com, "Bird Houses Sale" from OutdoorLivingShowroom.com, "High Quality Bird Houses" from backyardbird.com, and "Decorative Bird Houses" from BirdHouseStation.com. Two red arrows point to the "Sponsored Links" and "Organic Results" labels.

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems

The screenshot shows a Google search for "bird houses". The search bar contains "bird houses" and the search button is visible. Below the search bar, the results are displayed. The first result is a sponsored link for "Bird Houses" from Scotts.com, with a yellow background. A red arrow points to the word "bird houses" in the search bar, and another red arrow points to the word "bird houses" in the search results. The search results include several other links for bird houses, bird feeders, and birdhouses, with various descriptions and prices. The search results are displayed in a grid format with columns for sponsored links and organic search results.

- ▶ *Web advertising*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems

The screenshot shows a Google search for "bird houses". The search bar contains "bird houses" and the search button is visible. Below the search bar, the results are displayed. The first result is a sponsored link for "Bird Houses" from Scotts.com, with a red arrow pointing to the text "Sponsored Links". The second result is a sponsored link for "Specialty Bird Houses" from birds-out-back.com, also with a red arrow pointing to the text "Sponsored Links". The third result is a sponsored link for "Bird Houses at BestNest" from bestnest.com. Below these are several organic search results for bird houses, including "Learn More About Bird Houses", "Bird House", "Bird Houses and Bird Feeders for north american bird species", and "Bird Feeders, Bird Houses - The Backyard Bird Company". On the right side of the search results, there are several sponsored links for "Bird Houses", "Bird Houses Sale", "High Quality Bird Houses", and "Decorative Bird Houses". Two red arrows point to the text "Sponsored Links" above the first two sponsored links on the right.

- ▶ *Web advertising*
- ▶ *Product recommendation*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems

The screenshot shows a Google search for "bird houses". The search bar contains "bird houses" and the search button is visible. Below the search bar, the text "Results 1 - 10 of about 22,100,000 for bird houses (0.19)" is displayed. The results are categorized into "Sponsored Links" and "Organic Results". Two red arrows point to the "Sponsored Links" section, which includes several advertisements for bird houses and bird feeders. The organic results include links to various websites like "JustBirdHouses.net" and "The Backyard Bird Company".

- ▶ *Web advertising*
- ▶ *Product recommendation*
- ▶ *Date matching*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems
- ▶ Social applications



Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems
- ▶ Social applications



- ▶ *Bike sharing optimization*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems
- ▶ Social applications



- ▶ *Bike sharing optimization*
- ▶ *Election campaign*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems
- ▶ Social applications



- ▶ *Bike sharing optimization*
- ▶ *Election campaign*
- ▶ *ER service optimization*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems
- ▶ Social applications



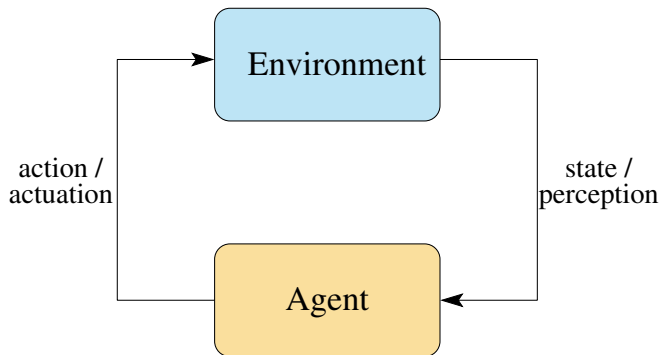
- ▶ *Bike sharing optimization*
- ▶ *Election campaign*
- ▶ *ER service optimization*
- ▶ *Resource distribution optimization*

Why: Important Problems

- ▶ Autonomous robotics
- ▶ Financial applications
- ▶ Energy management
- ▶ Recommender systems
- ▶ Social applications
- ▶ And many more...

What

What: Decision-Making under Uncertainty



How: Reinforcement Learning

Reinforcement learning is learning what to do – how to map situations to actions – so as to **maximize** a numerical reward signal. The learner is not told which actions to take, as in most forms of machine learning, but instead must discover which actions yield the most reward by **trying them** (**trial-and-error**). In the most interesting and challenging cases, actions may affect not only the immediate reward but also the **next situation** and, through that, all **subsequent rewards** (**delayed reward**).

*“An introduction to reinforcement learning”,
Sutton and Barto (1998).*

How: the Course

How: the Course



How: the Course



How: the Course



How: the Course



Google bird houses

Web Sites options... Results 1 - 16 of about 22,108,000 for **bird houses** (0.15)

Bird Houses
www.scotts.com - Scotts attracts colorful birds to your backyard!

Specialty Bird Houses
www.bird-out-back.com - Roosting Boxes, Purple Martins, Blue Chats.

Bird Houses at Backyard
www.backyard.com - Over 25 different houses in stock. Free shipping!

Learn More About Bird Houses
Bird House - JustBirdHouses.net learn more about blue bird houses and birdhouses, along with our blue bird house and purple martin bird houses.
www.purplebirdhouses.net - Contact - Order ->

Bird Houses
Bird Houses and Bird Feeders for earth american bird species.
www.birdhouses101.com - Contact - Order ->

Bird Feeders, Bird Houses - The Backyard Bird Company
Bird Feeders - The Backyard Bird Company has a variety of bird feeders and birdhouses, along with our blue bird house and purple martin bird houses.
www.backyardbird.com - Contact - Order ->

Bird Houses
Find All Types Of Bird Feeders And Houses At Lowest Prices Lowest Price
www.1.com ->

Bird Houses Sale
Authorized Dealer - New Designs - Low Price Guarantee - Free Shipping
www.OutdoorLivingShed.com ->

High Quality Bird Houses
Feeding boxes & decorative houses - 5-Star Service - Free Shipping \$75+
www.backyardbird.com

Decorative Bird Houses
Decorify Your Garden With Our Wooden Bird Houses at a Discount.
Bird-House-Station.com ->



How: the Course



Google bird houses

Web Sites options... Results 1 - 10 of about 22,108,000 for **bird houses** (0.15)

Bird Houses
www.scotts.com. Scats attracts colorful birds to your backyard!

Specialty Bird Houses
www.bird-out-back.com. Roosting Boxes, Purple Martins, Blue Chats.

Bird Houses at Barchart
www.barchart.com. Over 25 different houses in stock. Free shipping!

Learn More About Bird Houses
Bird House - JustBirdHouses.net learn more about blue bird houses and birdhouses, along with our blue bird house and purple martin bird houses.
www.purplebirdhouses.net. Cached - Details - >>

Bird Houses
Bird Houses and Bird Feeders for earth american bird species.
www.birdhousesof.com. Cached - Details - >>

Bird Feeders, Bird Houses - The Backyard Bird Company
Bird Feeders - The Backyard Bird Company has a variety of bird feeders and birdhouses, along with our blue bird house and purple martin bird houses.
www.backyardbird.com. Cached - Details - >>

Bird Houses
Sponsored Links
Find All Types Of Bird Feeders And Houses At Lowest Prices! Low Price Guarantee. Free Shipping.
www.outbacklivingstore.com. Get **Google**

Bird Houses Sale
Authorized Dealer - New Designs. Low Price Guarantee. Free Shipping.
www.outbacklivingstore.com. Get **Google**

High Quality Bird Houses
Feeding boxes & decorative houses. 5-Star Service. Free Shipping \$15+.
www.backyardbird.com

Decorative Bird Houses
Decorify Your Garden With Our Wonderful Bird Houses at a Discount Bird-House Station.com
Get **Google**

Velib' Mairie de Paris

La ville est plus belle à vélo

velib.paris.fr



How: the Course



Google bird houses

Web Sites options... Results 1 - 10 of about 22,108,000 for **bird houses** (0.15)

Bird Houses
www.scotts.com. Scats attracts colorful birds to your backyard!

Specialty Bird Houses
www.birds-out-back.com. Roosting Boxes, Purple Martins, Blue Chats.

Bird Houses at Backyard
www.backyard.com. Over 25 different houses in stock. Free shipping!

Learn More About Bird Houses
Bird House - JustBirdHouses.net learn more about blue bird houses and birdhouses, along with our blue bird house and purple martin bird houses.
www.purplebirdhouses.net - Cached - Similar - ?

Bird Houses
Bird Houses and Bird Feeders for earth american bird species.
www.birdhousesof.com - Cached - Similar - ?

Bird Feeders, Bird Houses - The Backyard Bird Company
Bird Feeders - The Backyard Bird Company has a variety of bird feeders and accept your bird's age and attract ability.
Bird Houses - Birdhouses - Decorative Bird Houses
www.backyardbird.com - Cached - Similar - ?

Bird Houses
Sponsored Links
Find All Types Of Bird Feeders And Houses At Lowest Prices Here!
www.1.com.com

Bird Houses Sale
Authorized Dealer - New Designs - Low Price Guarantee - Free Shipping
www.OutbackLivingShed.com
Google

High Quality Bird Houses
Feeding boxes & decorative houses - 5-Star Service - Free Shipping \$75+
www.backyardbird.com

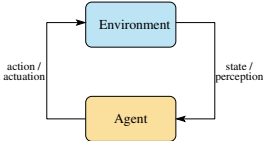
Decorative Bird Houses
Decorify Your Garden With Our Wooden Bird Houses at a Discount Bird-House-Station.com
Google

La ville est plus belle à vélo

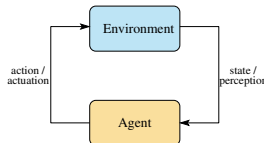
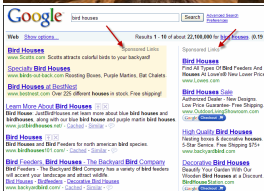
velib[®]

MAIRIE DE PARIS

velib.paris.fr



How: the Course



Formal and *rigorous* approach to the RL's way to decision-making under uncertainty

What: the Highlights of the Course

How do we formalize the agent-environment interaction?

What: the Highlights of the Course

How do we formalize the agent-environment interaction?

Markov Decision Process and Policy

A Markov decision process (MDP) is represented by the tuple $M = \langle X, A, r, p \rangle$ where X is the state space, A is the action space, $r : X \times A \rightarrow [0, B]$ is the reward function, p is the dynamics.

At time $t \in \mathbb{N}$ a *decision rule* $\pi_t : X \rightarrow A$ is a mapping from states to actions and a *policy* (strategy, plan) is a sequence of decision rules $\pi = (\pi_0, \pi_1, \pi_2, \dots)$.

The Bellman equations

$$V^\pi(x) = r(x, \pi(x)) + \gamma \sum_y p(y|x, \pi(x)) V^\pi(y),$$

$$V^*(x) = \max_{a \in A} \left[r(x, a) + \gamma \sum_y p(y|x, a) V^*(y) \right].$$

What: the Highlights of the Course

How do we solve an MDP?

What: the Highlights of the Course

How do we solve an MDP?

Dynamic Programming

Value Iteration

$$V_{k+1} = \mathcal{T}V_k$$

Policy Iteration

- ▶ *Evaluate*: given π_k compute V^{π_k} .
- ▶ *Improve*: given V^{π_k} compute $\pi_{k+1} = \text{greedy}(V^{\pi_k})$

What: the Highlights of the Course

How do we solve an MDP “online”?

What: the Highlights of the Course

How do we solve an MDP “online”?

Q-learning

Given a observed transition x, a, x', r update

$$Q_{k+1}(x, a) = (1 - \alpha)Q_k(x, a) + \alpha(r + \max_{a'} Q_k(x', a')).$$

What: the Highlights of the Course

How do we effectively trade-off exploration and exploitation?

What: the Highlights of the Course

How do we effectively trade-off exploration and exploitation?

Multi-arm Bandit

Given K arms we define the regret over n rounds of a bandit strategy as

$$R_n = \sum_{t=1}^n X_{i^*,t} - \sum_{t=1}^n X_{I_t,t}.$$

For the UCB strategy we can prove

$$R_n \leq \sum_{i \neq i^*} \frac{b^2}{\Delta_i} \log(n).$$

What: the Highlights of the Course

How do we solve a “huge” MDP?

What: the Highlights of the Course

How do we solve a “huge” MDP?

Approximate Dynamic Programming

Approximate Value Iteration

$$\hat{V}_{k+1} = \hat{\mathcal{T}}\hat{V}_k$$

Approximate Policy Iteration

- ▶ *Evaluate*: given π_k compute \hat{V}^{π_k} .
- ▶ *Improve*: given \hat{V}^{π_k} compute $\hat{\pi}_{k+1} \approx \text{greedy}(\hat{V}^{\pi_k})$

What: the Highlights of the Course

How “sample-efficient” are these algorithms?

What: the Highlights of the Course

How “sample-efficient” are these algorithms?

Sample Complexity of LSP1

$$\|V^{\pi_K} - V^*\|_{2,\rho} \leq \inf_{f \in \mathcal{F}} \|V^* - f\|_{2,\rho} + \frac{C_\rho}{1-\gamma} \sqrt{\frac{\log(1/\delta)}{n}}.$$

Who

Lectures and Practical Sessions

Alessandro LAZARIC

Sequel Team

INRIA-Lille Nord Europe

alessandro.lazaric@inria.fr

researchers.lille.inria.fr/~lazaric/

When/What/Where

See planning on the website.

Evaluation

- ▶ To be defined (probably homework+review project at the end of the course)

Reinforcement Learning

The Inria logo is displayed in a white rounded square with a teal border. The word "Inria" is written in a red, cursive script font.

Inria

Alessandro Lazaric

alessandro.lazaric@inria.fr

sequel.lille.inria.fr