Reinforcement Learning

M.Sc. in AI & Robotics

Roberto Capobianco

SAPIENZA
UNIVERSITÀ DI ROMA

About Me

Name: Roberto Capobianco

Current Positions: External Professor @ Sapienza | Senior Research Scientist @ Sony AI

Research Interests: Reinforcement Learning, Explainable AI, Robot Learning, Knowledge Representation (https://krlgroup.github.io)

Hobbies: Playing drums, drawing, hiking

About your ‘Corso di Laurea’

Coordinator: Prof. Massimo Mecella

Google Classroom:
https://classroom.google.com/c/NDAxOTU1NTQ0Mjc4?cjc=y2ae7sp

Useful for news, general information and upcoming seminars (including a *welcome* seminar soon)

About the Course

Teaching Assistants: Michela Proietti, Andrea Fanti

Google Classroom: link (or code kbrncgq)

Schedule:

- Wed 12:00 - 14:00 (theory), Room 201, Building D, Viale Regina Elena 295
- Friday 11:00 - 15:00 (theory + practical), Room 201, Building D, Viale Regina Elena 295

Covered Topics: Sequential Decision Making, Dynamic Programming, Linear Quadratic Regulators, Model-Free Reinforcement Learning, Model-Based Reinforcement Learning, Deep Reinforcement Learning, Exploration in RL, Multi-Agent RL

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Math-Heavy Course

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Math-Heavy Course

$$
\begin{aligned}
Q^{\pi^{t+1}}(s,a) - Q^{\pi^t}(s,a) &= \gamma \mathbb{E}_{s' \sim P(s,a)} \left[Q^{\pi^{t+1}}(s', \pi^{t+1}(s')) - Q^{\pi^t}(s', \pi^t(s')) \right] \\
&= \gamma \mathbb{E}_{s' \sim P(s,a)} \left[Q^{\pi^{t+1}}(s', \pi^{t+1}(s')) - Q^{\pi^t}(s', \pi^{t+1}(s')) + Q^{\pi^t}(s', \pi^{t+1}(s')) - Q^{\pi^t}(s', \pi^t(s')) \right] \\
&\geq \gamma \mathbb{E}_{s' \sim P(s,a)} \left[Q^{\pi^{t+1}}(s', \pi^{t+1}(s')) - Q^{\pi^t}(s', \pi^{t+1}(s')) \right] \geq \ldots, \geq -\gamma^{\infty}/(1-\gamma) = 0
\end{aligned}
$$

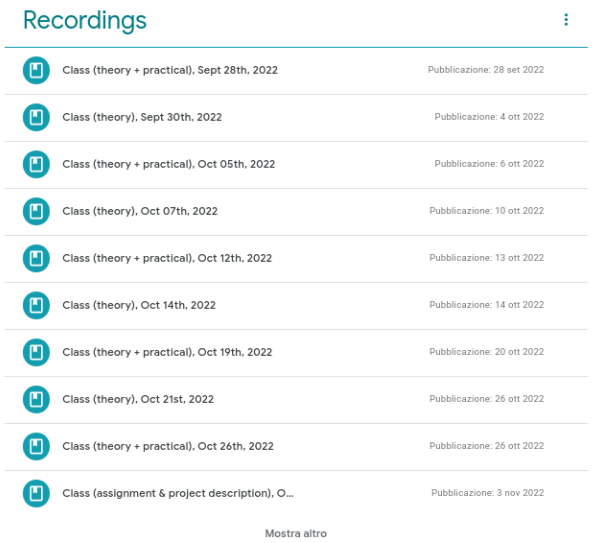
$$
\begin{aligned}
\nabla_\theta J(\theta) &= \nabla_\theta \sum_\tau P(\tau;\theta) R(\tau) \\
&= \sum_\tau \nabla_\theta P(\tau;\theta) R(\tau) \\
&= \sum_\tau \frac{P(\tau;\theta)}{P(\tau;\theta)} \nabla_\theta P(\tau;\theta) R(\tau) \\
&= \sum_\tau P(\tau;\theta) \frac{\nabla_\theta P(\tau;\theta)}{P(\tau;\theta)} R(\tau) \\
&= \sum_\tau P(\tau;\theta) \nabla_\theta \log P(\tau;\theta) R(\tau)
\end{aligned}
$$

$$
\begin{aligned}
&\| V^t(s) - V^\pi(s) \| \leq \gamma^t \| V^0 - V^\pi \| \\
&\forall s, \left| V^{t+1}(s) - V^\pi(s) \right| \\
&= \left| r(s,\pi(s)) + \gamma \mathbb{E}_{s' \sim P(\cdot|s,\pi(s))} V^t(s') - \left(r(s,\pi(s)) + \gamma \mathbb{E}_{s' \sim P(\cdot|s,\pi(s))} V^\pi(s') \right) \right| \\
&= \gamma \left| \mathbb{E}_{s' \sim P(\cdot|s,\pi(s))} V^t(s') - \mathbb{E}_{s' \sim P(\cdot|s,\pi(s))} V^\pi(s') \right| \\
&\leq \gamma \mathbb{E}_{s' \sim P(\cdot|s,\pi(s))} \left| V^t(s') - V^\pi(s') \right| \\
&\leq \gamma \left\| V^t - V^\pi \right\|_\infty
\end{aligned}
$$

About the Course

Zoom & Streaming:

Zoom Information:
This year, classes won't be streamed or recorded. However, all the slides, assigments, practicals and recorded material from last year is already available on the Classroom web-page. New material that is covered this year will not be recorded.



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About the Course

Exam:

Grading
The exam will be composed by 3 assignments (or a written exam) plus a final project for a total of 95% of the maximum score (which is 30 cum laude - or 33 - according to the Italian system). The missing 5% can be obtained through the attendance bonus or through a valid contribution to the course repository, to be agreed with the TAs.

Grade breakdown

- Assignments (3 homeworks: 15% each) or written exam 45% ;
- Final project 50%;
- Attendance bonus or repository contribution 5%.

Assignment rules

Students may discuss assignments, but each student must code up and write up their solutions independently. Students must also indicate on each homework the names of the colleagues they collaborated with and what online resources they used.

Late days policy
Assignments must be submitted by the posted due date. However, we recognize that students may face unusual circumstances and require some flexibility during the semester. For this reason, each student will have a total of 6 free late (calendar) days to use as (s)he prefers, that are counted and tracked at the granularity of days: e.g., 3 hours late is one late day. If an assignment is submitted beyond the late-day budget, the student will receive a 33.33% penalty per day over budget (up to zero). Late days can only be used for assignments, not for the project.

Participation/extra effort bonus
We encourage participation including asking/answering questions in lectures. For this reason, active participation in class will be tracked and considered in the final score. Similarly, contributions to the code repository of the course will be considered, previous agreement with the TAs.

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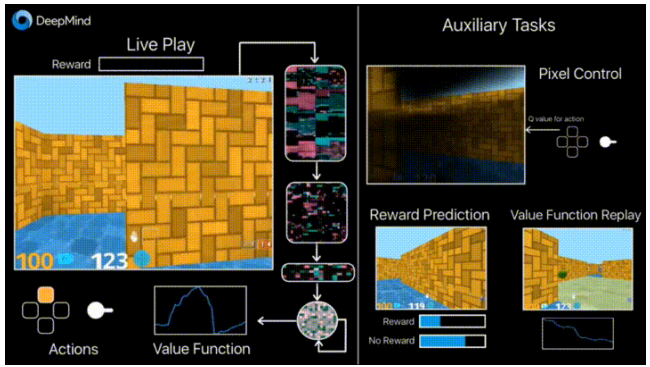
5 meaningful questions/answers to my questions

Reinforcement Learning

- Problem of interest in psychology, AI, neuroscience, etc.
- (Trending) research field
- Set of algorithms and approaches

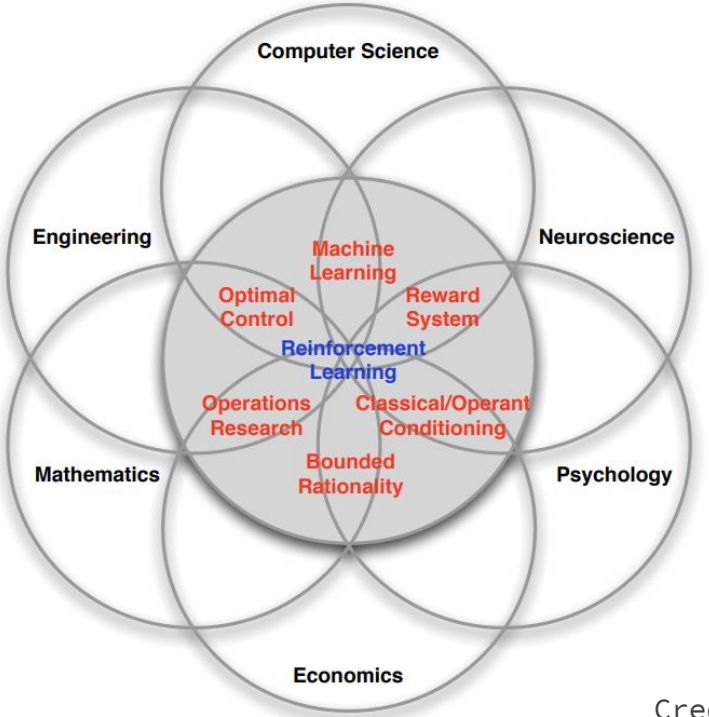


Reinforcement Learning

Reinforcement Learning benefits from fruitful interactions with other scientific disciplines

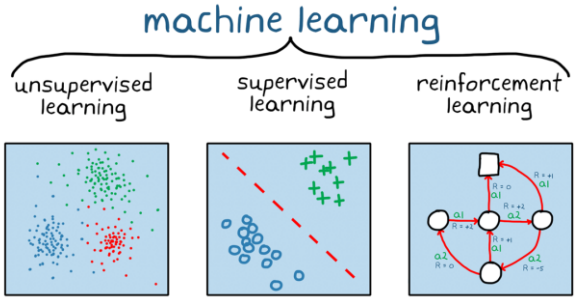
- General machine learning
- Use of function approximators to address the curse-of-dimensionality
- Work towards simple general principles for AI
- Psychology
- Neuroscience

Reinforcement Learning



Credits: David Silver

Reinforcement Learning



Credits: MathWorks

Reinforcement Learning is not:

- Supervised learning (learning from a training set of labeled examples)
  - Important but not adequate for interaction
  - Impractical to obtain correct and representative examples of desired behavior
- Unsupervised learning (finding structure hidden in unlabeled data)
  - RL uses a reward signal
  - Useful but does not solve the problem

Characteristics of Reinforcement Learning

Reinforcement Learning is learning what to do to **maximize a numerical reward signal**

- Learner must discover which actions yield the most reward by trying them
- Actions might affect not only immediate reward, but also subsequent ones

- Trial-and-error
- Delayed rewards

Characteristics of Reinforcement Learning

Agent has to:

- **Exploit** what it has already been experienced to obtain a reward
- **Explore** in order to make better action selections in the future

Challenges:

- Exploration-exploitation trade-off (both have to be achieved)
- On stochastic tasks, each action must be tried many times (to correctly estimate expected reward)
- Considers whole problem of a goal-directed agent (not subproblems)
- Significant uncertainty about the environment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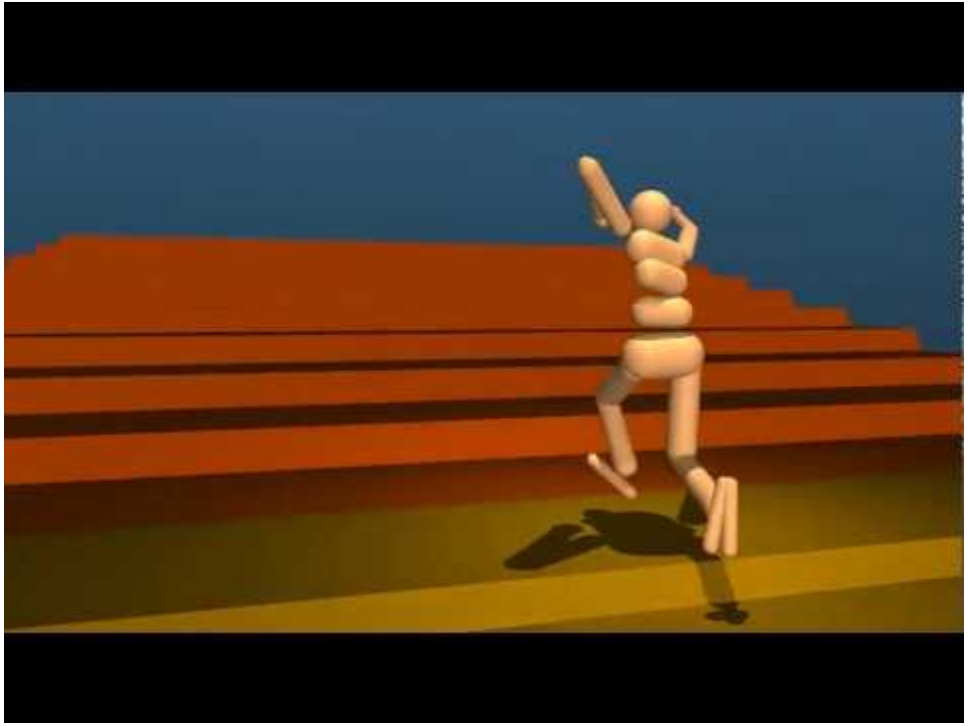

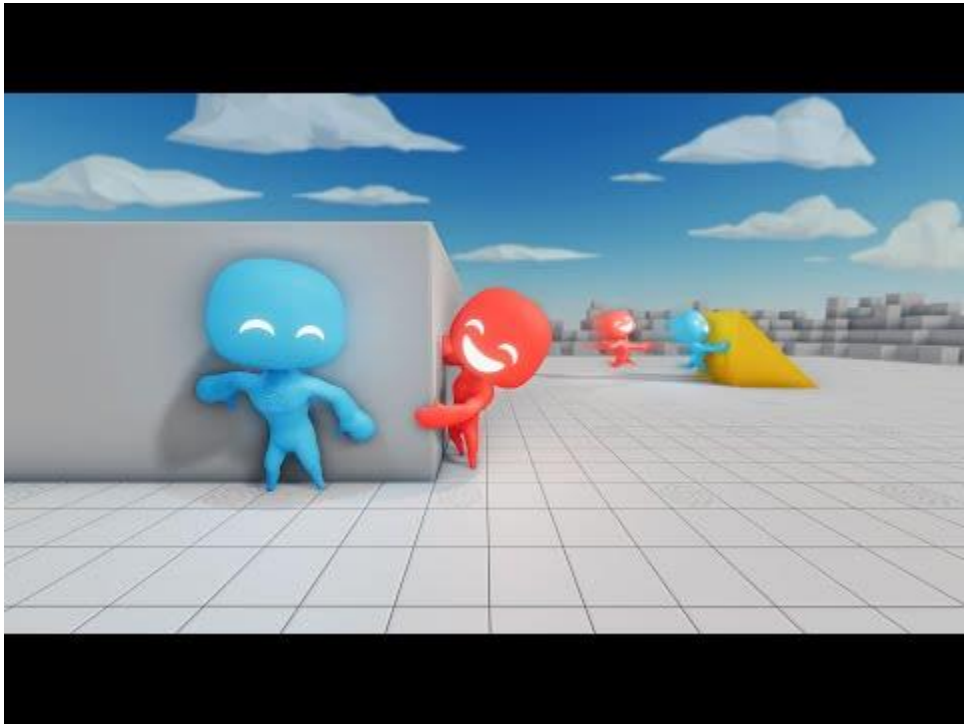

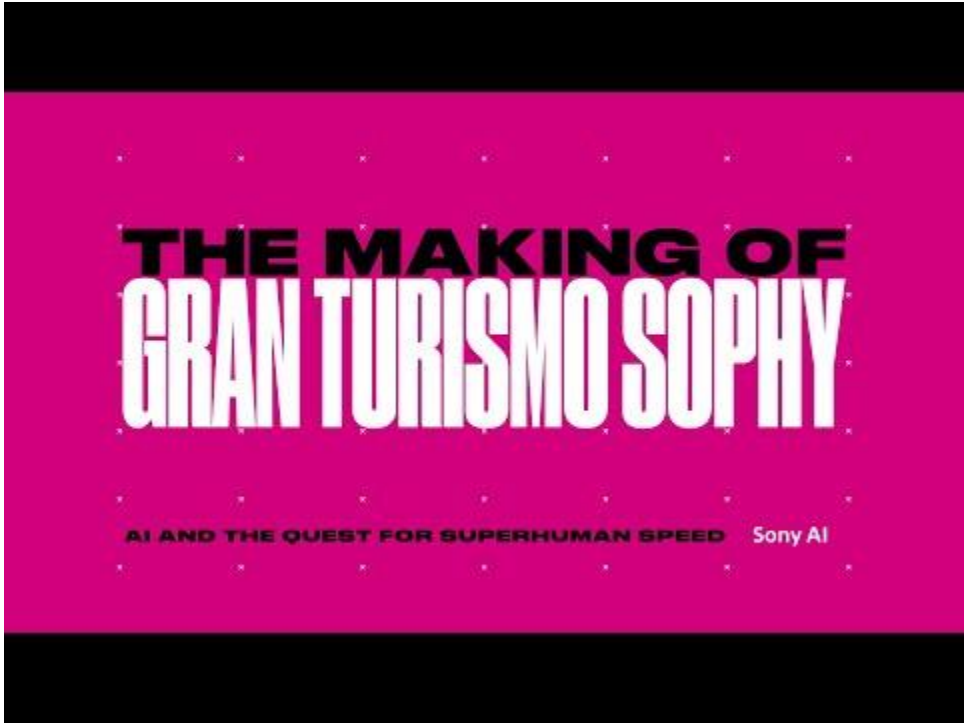
THE MAKING OF
GRAN TURISMO SOPHY
AI AND THE QUEST FOR SUPERHUMAN SPEED
Sony AI

MARL Example

Pistonball, a cooperative environment from PettingZoo and its observation space