Teaching controller synthesis using AI and formal methods

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Based on the
Formal Methods for System Design
course of Mickaël Randour

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Talk overview

We use **STORM** in the context of **student projects**.

Goal

Synthesise well-performing controllers in Markov decision processes.

- The course is an **optional Master's course**.
- It is available to **computer science** and **mathematics** students.

Main context

This project is a part of a **two-semester course**.

Structure of the course

Semester 1:

- **Theoretical course**
  - Transition systems, bisimulation, simulation.
  - LTL and CTL model checking of transition systems.
  - **Markov chains** and PCTL model checking.
  - **Reactive LTL synthesis via two-player zero-sum games on graphs**.
- Presentations of model checking tools

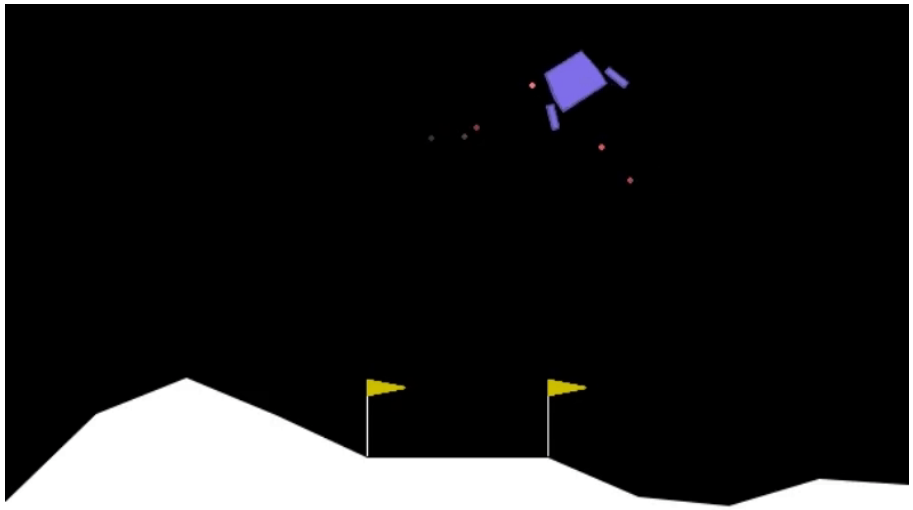
Semester 2:

- **Project**
- Presentations of advanced works

Framework

Goal of the project

Synthesise controllers for **Gymnasium environments** through **formal methods** (e.g., with STORM) and **reinforcement learning**.



Philosophy of the project

Organisation of the project

Unlike traditional projects in Belgium, we coach and direct the students through **regular meetings** throughout the semester.

- Students are grouped together into **two to four groups**.
- Everyone can view the **code of the other groups**.
- Students start the project with limited background regarding **Markov decision processes (MDPs)** and **reinforcement learning**.

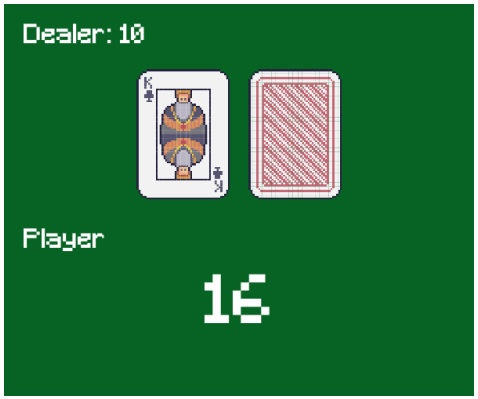
Medium for meetings

Students present their work via **Jupyter notebooks**.

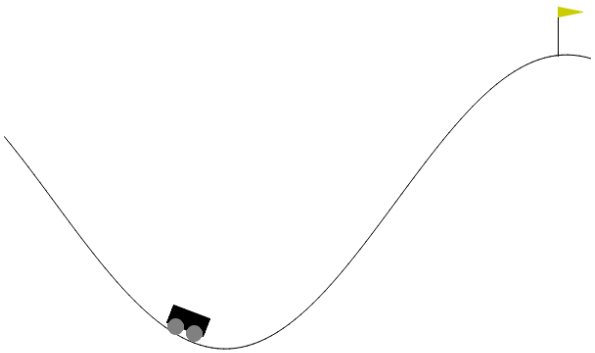
Typical progression

1. Simple finite environment

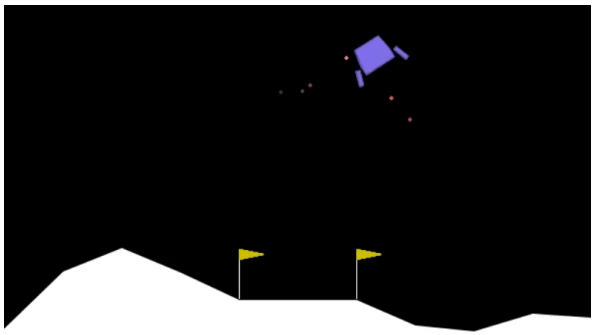
2. More complex finite environment



3. Low-dimensional infinite environment



4. High-dimensional infinite environment



Challenges faced by students

Students face several **challenges**:

- **modelling** Gymnasium environments as MDPs;
- familiarising themselves with **new techniques**, e.g, Q-learning and discretisation approaches;
- **extracting** and using **strategies**;
- **evaluating strategies**;
- determining relevant **experiments** and **presenting** results.

Our expectations

We expect the students to be able to **understand** and be able to **explain** the techniques and models they use throughout the project.

STORM

Typical usage of STORM in the project

Synthesis of optimal strategies in finite MDPs for:

- reachability specifications;
- step-bounded reachability specifications;
- total-reward specifications.

Verification of induced Markov chains for controllers obtained via reinforcement learning.

In some cases, students may use **more advanced models** and algorithms, e.g., partially observable Markov decision processes.

Feedback

What do students think about this project?

- The project is **interesting** and helps in preparing **presentations**.
- Students find that the workload is heavy.

Thank you for your attention!

References I

All images are screenshots of Gymnasium environment graphical interfaces.