Reinforcement Learning

Aldo Faisal with contributions
by Ed Johns and Paul Bilokon

Imperial College London

July 2021 – Version 7.01

Contents

Our first half of the course is an introduction to Reinforcement Learning (RL)

1. Mathematical Foundations
2. Markov Decision Process (much more than a Markov Process)
3. Dynamic Programming (not the way you know it)
4. Monte-Carlo Learning
5. Temporal Difference Learning
6. Function Approximation Methods (Deep RL, Policy Gradients)
7. Reinforcement Learning Outlook

Acknowledgements

The lecture notes for this course are based on material from colleagues' books or lecture notes by Peter Dayan, Rich Sutton, Andrew Barto, David Silver, Zoubin Ghahramani, Sergey Levine, and many others, as well as older versions of my own courses (MLNC 2009-2015, CO424H, 2015-2018).
We especially would like to thank the following people for their input and suggestions

- Manon Flageat
- Athanasios Vlontzos
- Paul Festor
- Luke Dickens
- Marc Deisenroth
- Luchen Li
- Ali Shafti

and the feedback of many excellent students at Imperial College who took or take this course.

Teaching team

This course wouldn't be possible without the efforts of our teaching team—the dedicated teaching scholars

- Manon Flageat (manon.flageat18@imperial.ac.uk)
- Athanasios Vlontzos (athanasios.vlontzos14@imperial.ac.uk)

and the graduate teaching assistants:

- Xiaoxiao Cheng
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- Luca Grillotti
- Max Grogan
- Pierre Guilleminot
- Shubham Jain
- Anirudh Kulkarni
- Bryan Lim
- Marcus Panchal
- Arnaud Robert
- Pakorn Uttayopas
- Pierre E. Valassakis
- Filippo Valdettaro
- Vitalis Vosylius
- Nat Wannawas

Admin: Assessment

- Course structured in Lectures, Q&A and Computer Labs. Content and learning occurs in all of them, they may be complementary to each other (i.e you will learn things in one that you do not learn in the other explicitly).
- Entire module: 25% Coursework 1, 25% Coursework 2, 50% exam.
- In Computer Labs you can work on Lab Assignments and Coursework.
- Initially more weight on lectures to get us up to speed, then less lectures more labs.
- We want to use Teams for the lab work and EdStem for all Q&A and support where possible.

Admin: Teaching

Course has two parts taught by

1. Dr Paul Bilokon (Part 1)
   - Students watch 1 hour of pre-recorded lecture on their own
   - Q&A (over Teams) Thursday 9-9:30am
   - Interactive computer labs (over Teams) Thursday 9:30-11am
2. Prof Aldo Faisal (Part 2)
   - Students watch 1 hour of pre-recorded lecture on their own
   - Q&A (over Teams) Thursday 9-9:30am
   - Interactive computer labs (over Teams) Thursday 9:30-11am

Admin stuff

- We want to use Teams for the lab work and EdStem for all Q&A and support where possible.
- The college expects that students invest time outside the course and invest about 1 hour per hour of course in their own time, plan your calendar accordingly.
- Labs and Courseworks may have programming tasks – we expect you to know how to program (i.e. you should be able to pick up by now on your own an unknown programming language as you go along).

Ed (Ed Stem)

- We are using Ed Discussion for class Q&A.
- This is the best place to ask questions about the course, whether curricular or administrative.
- You will get faster answers here from staff and peers than through email.
- Here are some tips:
  - Search before you post;
  - Heart questions and answers you find useful;
  - Answer questions you feel confident answering;
  - Share interesting course related content with staff and peers.
- For more information on Ed Discussion, you can refer to the Quick Start Guide:
  `https://edstem.org/quickstart/ed-discussion.pdf`

How we will use Ed I

- To encourage student engagement in Ed we will leave questions for 2 working days so that other students have the opportunity to answer.
- Coursework related questions are fielded on Ed up to two days before the coursework deadline, so that the answer will become available in time for submission.
- We cannot provide answers to question that directly solve part of the coursework.
- We will accept exam related questions up to 9am the day before the exam, and answer them by 6pm on the day before the exam.
- We cannot provide answers to questions that directly solve exam-style or coursework-style question (so as to systematically explore all possible questions)

How we will use Ed II

- General questions will be fielded by GTAs from Monday to Friday during normal working hours.

Interactive computer labs I

- We will use Microsoft Teams, you should have been added to a teams called "Reinforcement Learning" as a live video based session.
- You will work in small groups of 5-10 students ("Breakout rooms") where you can work together on your lab assignments and coursework.
- Our over 20 Graduate Teaching Assistants (GTAs) and the lecturers will be moving through all the breakout rooms to directly engage with questions and support for each small group.

Text books

- Richard Sutton and Andrew Barto (2018, new edition) "Reinforcement Learning: An Introduction", MIT Press. Available online and in the library. There is also a great new version 2.0 you can find on their homepage with a slightly different notation).
- Csaba Szepesvari (2010) "Algorithms for Reinforcement Learning", Morgan Claypool. Available online.
- Mathematics background: Marc P. Deisenroth, A. Aldo Faisal & Cheng Soon Ong (2020) "Mathematics for Machine Learning", Cambridge University Press, available freely on the web https://mml-book.com

Outline I

Section overview

Motivation

Artificial Intelligence I

Definition (Artificial Intelligence)

Artificial Intelligence is a question: How do we build systems that solve tasks for which humans need intelligence?

Definition (Machine Learning)

Machine Learning is the contemporary answer to the AI question: Methods, algorithms and data structures that **learn** to solve such tasks from data.

Artificial Intelligence II

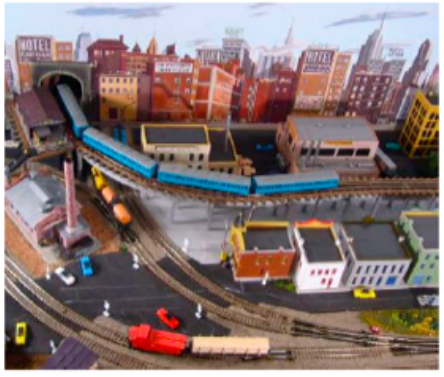
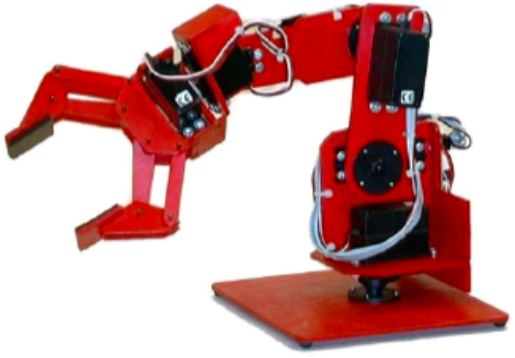
Definition (Big Data)

Big Data encompasses methods to handle and understand large data sets, and is composed of Data Science (how to analyse the world in a data-driven manner) and Data Engineering (how to collect, store, process, clean, maintain large data).

- AI means often an intelligent system that embodies an entire practical solution (e.g. a self-driving car), while machine learning is more focussed on the algorithm (e.g. python code).
- Machine Learning puts the engineers efforts on building a system that learns to solve a problem, instead of engineering a system that solves a problem – for the first time in human history.

Uses of Reinforcement Learning

Reinforcement learning solves problems of control, i.e. choosing the "best"/optimal action at the right time.


Learning to control our body: Long history of high jump

Olympic control policies with

Gold medal reward: High-jump

Ethel Catherwood (Canada), 1928 gold medal

Cornelius Johnson (USA), 1936, gold medal

Dick Fosbury (USA), 1968, gold medal

History of success in reinforcement learning:

- Backgammon (Tesauro, 1994)
- Inventory Management (Van Roy, Bertsekas, Lee & Tsitsiklis, 1996)
- RoboCup Soccer (e.g. Stone & Veloso, 1999)
- Helicopter drone control (e.g. Ng, 2003, Abbeel & Ng, 2006)
- Few-shot learning of pendulum swing up (Deisenroth et al, 2011)
- Playing Atari video games - from pixels to joystick command (DeepMind, 2015)
- Grand-master level Go playing (DeepMind, 2016)
- AI Clinician (Komorowski et Faisal, 2018)
- Solving Rubik's cube with a robot hand (OpenAI, 2019)

Examples: Learning to play Go against human grand master

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日本語要約

Mastering the game of Go with deep neural networks and tree search

David Silver, Aja Huang, Chris J. Maddison, Arthur Guez, Laurent Sifre, George van den Driessche, Julian Schrittwieser, Ioannis Antonoglou, Veda Panneershelvam, Marc Lanctot, Sander Dieleman, Dominik Grewe, John Nham, Nal Kalchbrenner, Ilya Sutskever, Timothy Lillicrap, Madeleine Leach, Koray Kavukcuoglu, Thore Graepel & Demis Hassabis

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Nature **529**, 484–489 (28 January 2016) | doi:10.1038/nature16961
Received 11 November 2015 | Accepted 05 January 2016 | Published online 27 January 2016

Abstract

The game of Go has long been viewed as the most challenging of classic games for artificial intelligence owing to its enormous search space and the difficulty of evaluating board positions and moves. Here we introduce a new approach to computer Go that uses 'value networks' to evaluate board positions and 'policy networks' to select moves. These deep neural networks are trained by a novel combination of supervised learning from human expert games, and reinforcement learning from games of self-play. Without any lookahead search, the neural

Reinforcement Learning Framework

- Agent interacts with environment to gain knowledge
- Explores and receives rewards
- Actions change the state of the environment
- Choose actions to maximize long-term reward

AI & Machine Learning @ Imperial I

The Cross-Faculty Network in Artificial Intelligence (or simply @ImperialAI) is the central hub for AI at Imperial College. We have over 200 Faculty members and over 800 PostDoc and PhD students members. The networks is open to all students at Imperial and we form London's and the UK's largest academic AI community.

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- Aldo is its current Speaker elected by its academics, i.e. that he answers if somebody 'calls' Imperial about AI.

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  - Announcements to go out over AI Talks.