236609 - AI and Robotics

Lesson 1: Introduction

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Winter 2024-5

The Taub Faculty of Computer Science
Technion - Israel Institute of Technology

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Introduction

A little bit about me

- I am a member of the Taub Computer Science Faculty at the Technion.
- I lead the Collaborative AI and Robotics (CLAIR) lab
- My research focuses on multi-agent AI and multi-robot systems.
- My work offers novel approaches to increasing the capabilities of AI agents via the **design** of the environments in which they are intended to act.
- My email: `sarahk@cs.technion.ac.il`

Acknowledgements

This course is based and inspired by two courses:

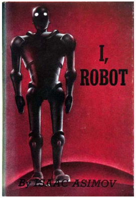
- Autonomous Robot Systems (CS189) I took at Harvard by Radhika Nagpal (now at Princeton) *https://www.radhikanagpal.org/*
- Multi Robot Systems by amanda prorok from Cambridge University *https://www.youtube.com/playlist?list=PLaTKfS3-bDpDyOwrxLcQRGxY9XJw33ANo*

What is a robot ?

The word ’Robot’ was coined by a Czech playwright named Karel Capek in his 1921 play “Rossum’s Universal Robots”

Rabota = menial work

The word “Robotics” believed to be coined by Isaac Asimov



Definitions?

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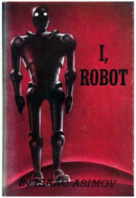

Definitions?

- **Definition:** A **robot** is an autonomous system that exists in the **physical** world, can sense its environment, and can act on it to achieve some goals.
- **Definition:** An **autonomous robot** acts based upon its decisions, and is not controlled by a human.

Why Study Robotics ?

Figure 1: Yesterday’s robots

Why Study Robotics ?

Figure 2: Way in the future robots

Why Study Robotics ?

Figure 3: Today's robots

Why Study Robotics ?

Figure 4: Today's robots

Why Study Robotics ?

Key Point:
Robots are quickly moving out of the ’factory’ and into the ’real-world’. Soon there will be robots for the masses, but we aren’t there yet...

Autonomy: Complex decision making in a complex world
Sensing, Thinking, Acting

A robot does not have to be a single physical object : Any combination of sensors and actuators can be thought of as a robot (smart home, factory, ...)

Why Study Robotics at the Technion?

Figure 5: Some of the Technion's robotics researchers

Consider attending the Technion's Robotics Seminar (TRS) on Tuesdays. *`https://tasp.technion.ac.il/news-events/`*

Work done at the CLAIR lab

A Brief History of Robotics

Robotics emerged from the influences of:

- Control Theory: the mathematics of controlling machines.
  - Develop algorithms governing to drive the system to a desired state, while minimizing delay, maximizing stability, etc.
  - In robotics,feedback control used sensors and making adjustments to keep the measured variable within a set range
- Cybernetics: the study of control and communication in biological systems and machines
- Artificial Intelligence: the mechanisms for planning and reasoning;

A Brief History of Robotics

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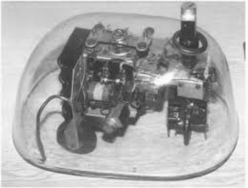
- **Cybernetics:** the study of control and communication in biological systems and machines
    - Integration of sensing, action, and the environment
- **Artificial Intelligence:** the mechanisms for planning and reasoning;
    - The study of intelligent agents, which refers to any system that perceives its environment and takes actions that maximize its chance of achieving its goals
    - The original focus was on creating machines that think like humans (i.e., that pass the Turing test) - today the focus has changed.

The First Robot

- Grey Walter (1910-1977) - a neurophysiologist and cyberneticist who created in the 1940s simple robots based on reflexes (before AI existed) - bio-mimetic machines.
- The **Tortoise** robot:
    - tricycle-like design (one motor per wheel)
    - one photocell: one bump sensor
    - rechargeable battery
    - analog circuit and vacuum tubes connecting sensors with wheels
- Behaviors:
    - find light / head towards light / back away from light
    - turn and push to avoid obsacles recharge battery
- Control: reactive, with prioritized reflexes
- First example of 'artificial life': Tortoises now shown in museums around the world



https://youtu.be/lLULRlmXkKo

Artificial Intelligence

- Originate in 1956 at a workshop at Dartmouth University, USA: **Dartmouth Summer Research Project on Artificial Intelligence**
- Some of the researchers present: Marvin Minsky, John McCarthy, Allan Newell, Herbert Simin, Claude Shannon, John Nash, etc..

Artificial Intelligence

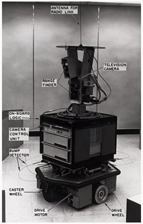
- Outcome of meeting - what we need for AI is:
  - Internal models of the world
  - Search through possible solutions
  - Planning and reasoning to solve problems
  - Symbolic representations of information
  - Hierarchical system organization
  - Sequential program execution

" We propose that a 2 month, 10 man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College. "

— Nathaniel Rochester, 1955

Shakey: the First intelligent robot

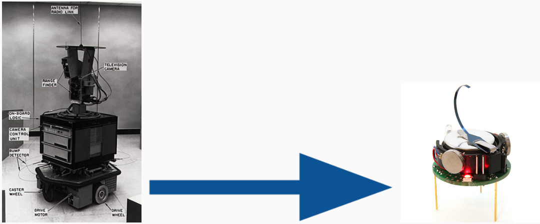
- Built in the 1960s at the Stanford Research Institute (SRI)
- The robot had
  - Camera and contact sensors
  - Application of AI techniques to vision algorithms
  - Lived in a simple black and white world
  - The robot shook when trying to execute its navigation plans.
- Reasoning:
  - Planning with STRIPS
  - Programming with LISP



https://www.youtube.com/watch?v=7bsEN8mwUB8&t=21s

A New Paradigm: Behavior Based Robotics

- Robots developed based on classical AI techniques in the 1970s and 1980s thought to be **too hard** and **too slow**.
- 1980s robotics enters a new phase:
  - reactive control
  - hybrid control
  - behavior-based control
- In stark contrast to purely **deliberative** control



Behavior Based Robotics

A new wave in AI in the 80s-90s

- Spearheaded by Rodney Brooks (MIT) and later Ronald Akin (Georgia Tech)
- Stepping away from complex AI, deliberative planning (e.g., a chess playing computer) to the basics of intelligence.
- How? By realizing that organisms in nature follow simple sets of **reactive rules** giving rise to **reactive behaviors**

Which behavior-based robot do we all know ?

Behavior Based Robotics

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Behavior Based Robotics

Behavior-based architectures had a huge impact on collective intelligence and swarm robotics

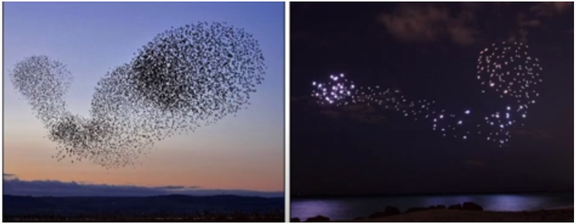


Figure 6: Starlings

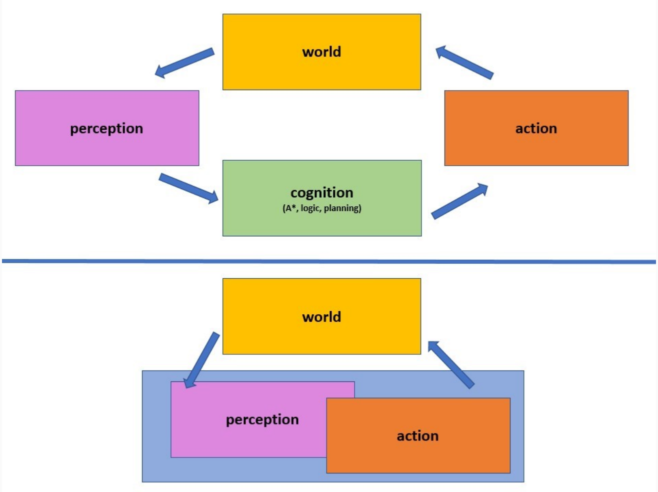
https://youtu.be/0bRocfcPhHU?t=255

Cognitive robotics

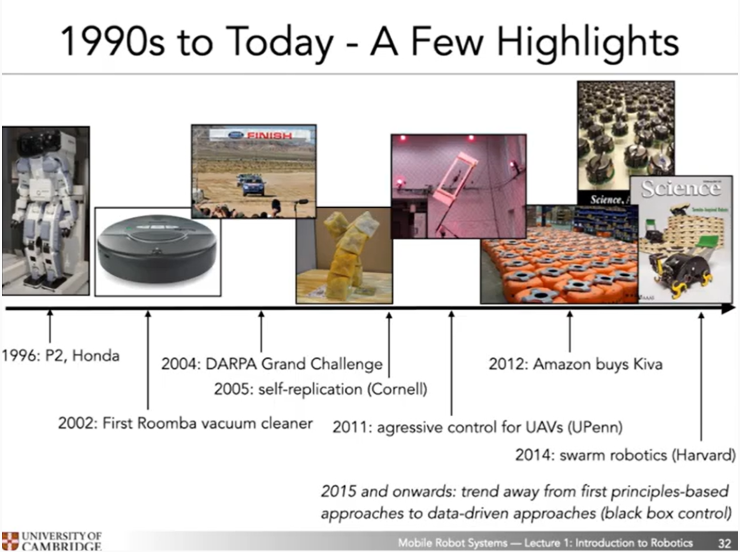
- A subfield of robotics concerned with endowing a robot with intelligent behavior by providing it with a processing architecture that will allow it to learn and reason about how to behave in response to complex goals in a complex world.
- Needs to
  - monitor itself for potential problems (both observable and hidden)
  - schedule tasks in time
  - come up with novel plans to achieve desired goals over time
  - collaborate with other (autonomous) agents
  - deal with risk ...
- Typically controlled by a model-based AI program (models of the robot, the world, possible actions, other agents) - AI program reasons about the model to make decisions



Two streams of thought in robotics



Historical Overview



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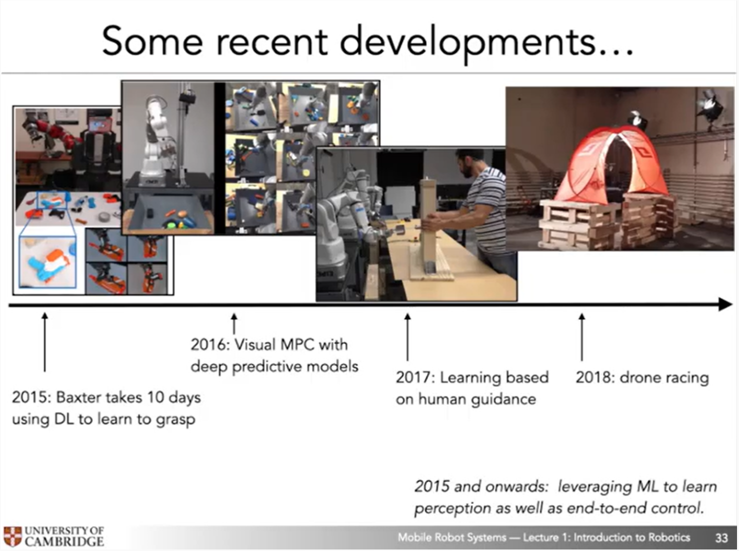


Autonomy

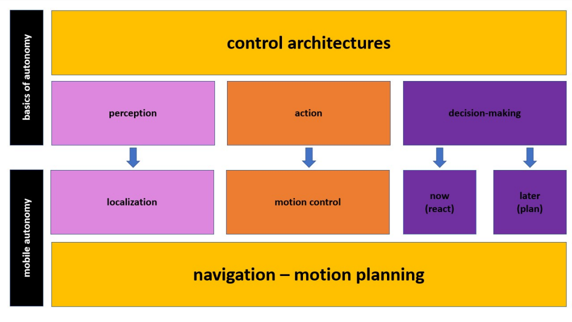
Autonomy

Challenges:

- How to model and perceive the world?
- How to process information and execute actions ?
- How to reason and plan in the face of uncertainty ?

The field of robotics provides methods that address each challenge and architectures that combine them.

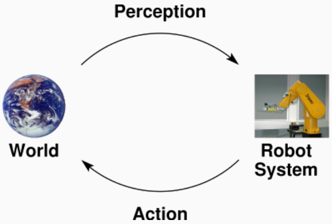
Autonomy - detailed perspective



Autonomy

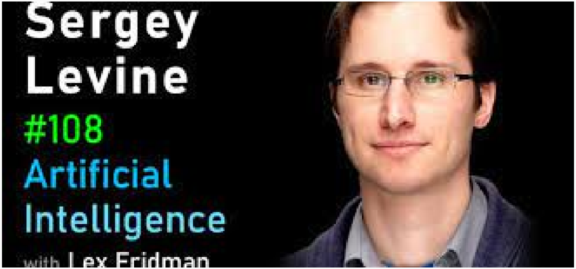
What does it mean to be autonomous ?

- Action (Actuation)
  - Locomotion: wheels (e.g., differential drives)
  - Manipulation: arms, grippers, etc.
- Perception (Sensors)
  - Proprioception (internal: IMU (inertial measurement unit), encoders , etc,)
  - Exteroception (external: cameras, scanners)
- Cognition (Control)
  - From reactive to proactive
  - From finite state machines to cognitive robotics



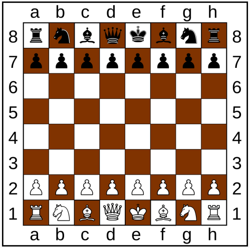
Single Robot Autonomy - Are we there yet ?

https://www.youtube.com/live/AtNGJeXTXu4?si=
90REz2DGfoH4F54Q



https://youtu.be/kxi-_TT_-Nc?t=164

Single Robot Autonomy - Are we there yet ?



https://youtu.be/QaCuEv_7lfs?t=19739

George Konidaris: ***https://cs.brown.edu/~gdk/***

Examples

1994 AAAI Mobile Robot Competition and Exhibition


Figure 1. The Participating Robots in the Competition.

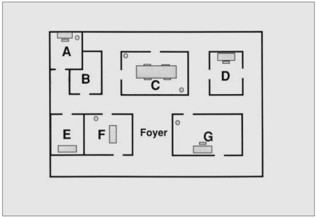
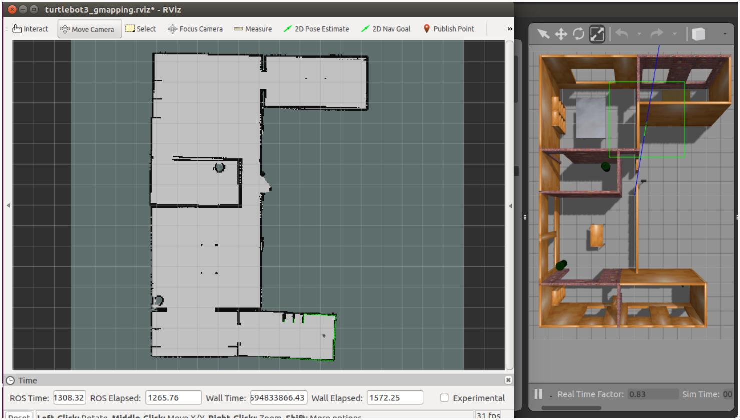


Figure 2. The Competition Arena.

- **Office Delivery**:
  navigate from one room to another within a large arena of offices, corridors, and foyers.
- **Office Cleanup**: the same arena was littered with cups, empty soda cans, and paper wads.
  - robots had to recognize and collect as many objects as possible in the allotted time and deposit them in near by trash bins.
  - several trials, with the main difference being the density of trash placed in the offices

https://doi.org/10.1609/aimag.v23i1.1603//
https://ojs.aaai.org//index.php/aimagazine/article/view/1130

Turtlebot3 SLAM



Search and Rescue

Manipulation

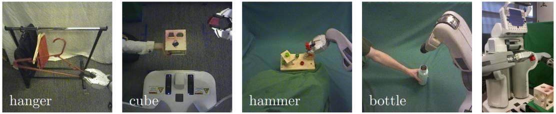
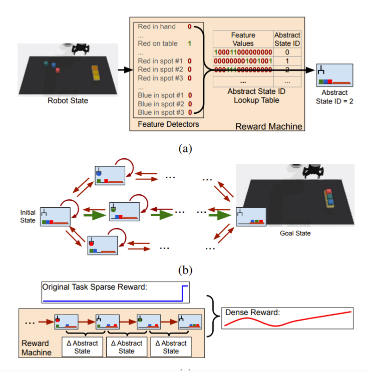
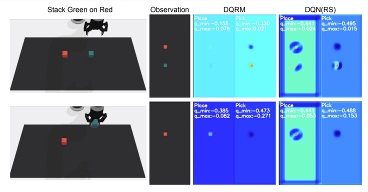


Figure 1: Our method learns visuomotor policies that directly use camera image observations (left) to set motor torques on a PR2 robot (right).

End-to-End Training of Deep Visuomotor Policies
Sergey Levine, Chelsea Finn, Trevor Darrell, Pieter Abbeel(2016)
https://jmlr.org/papers/volume17/15-522/15-522.pdf

Manipulation



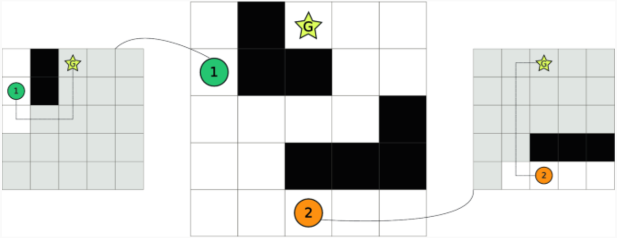


Reward Machines for Vision-Based Robotic Manipulation. Camacho et al. (2021)
https://ieeexplore.ieee.org/abstract/document/9561927

Cooking

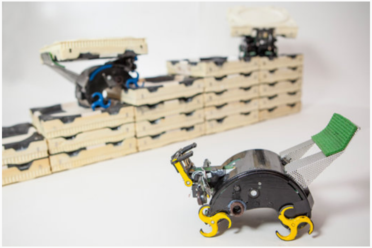
https://www.youtube.com/watch?v=JNOk1rylDpU
https://arxiv.org/abs/1802.08705
https://www.youtube.com/watch?v=5R-xL9YmdR0

Multi-Robot



Optimizing Multi-Robot Communication under Bandwidth Constraints - Marcotte et al. (2019) *https://april.eecs.umich.edu/media/pdfs/marcotte2019auro.pdf*

Multi-Robot



AI and Robotics: Safety

South Korea: Man crushed to death by robot that mistook him for a box The man was reportedly inspecting the mechanical arm when the accident happened.

Thursday 9 November 2023 06:09, UK

https://news.sky.com/story/south-korea-man-crushed-to-death-by-robot-that-mistook-him-for-a-box-13003635

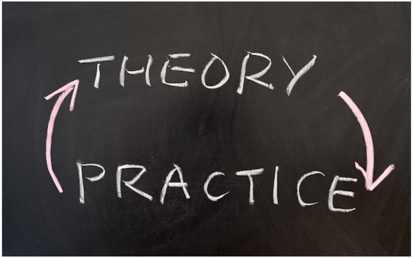
Course objectives

What is this class about ?

- From observations to decisions
- From low-level to high-level reasoning
- From single agent to multi-Agent
- From theory to practice to theory …

From theory to practice to theory ...

- **Theory:** we will learn about
  - single robot low to high level decision making:
    - **Automated planning**
    - **Reinforcement learning**
    - **Integrated task and motion planning**
  - multi-robot systems and multi-agent AI
- **Practice:** we will
  - implement the ideas we discuss
  - think about the limitations of the theory we learned about and of ways to extend it to support our applications



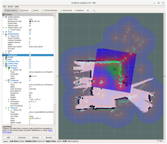
From single agent to multi-agent

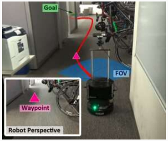
Robots (or any group of automated agents) can:

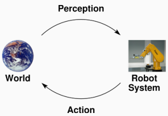
- **Collaborate** to achieve the same goal
- **Cooperate** by helping each other achieve their individual goals
- **Coordinate** their behavior in order not to interfere with each other's objectives
- **Compete** with each other

From low-level to high-level reasoning

- **Motion control** (e.g., feedback control)
- **Vision and perception** (e.g., RBG, motion based reasoning)
- **Behavior programming:** (e.g., State Machines, automated planning)
- **Navigation:** (e.g., localization, building maps, path planning)
- **Task Planning:** (e.g., pickup and delivery)
- **Multi-agent robotics**



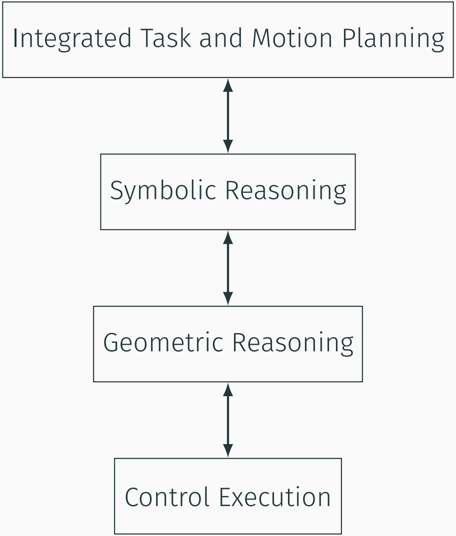




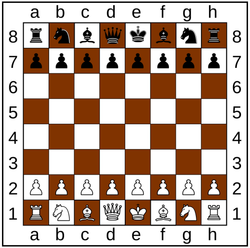
Focus on autonomy:
our robots must do all their **sensing-thinking-acting** on their own.

Our focus

Integrating Task Planning, motion Planning, and control.



Symbolic world vs. real world



Symbolic world vs. real world

Task planners can reason over very large sets of states by manipulating partial descriptions, while **motion (geometric)** planners operate on completely detailed specifications of world states.

A **task planner** could decide that the living room needs to be traversed, regardless of the detailed arrangement of its furniture.

Motion planners deal beautifully with geometry, but not with non-physical aspects of the domain; they can plan how to get to the phone but not decide that a phone call needs to be made.

After motion plan is computed, **control** methods are applied to execute and monitor the planned movements.

Course structure

Staff and schedule

- **Teaching:** Sarah Keren
  sarahk@cs.technion.ac.il
- **TA:** Ido Jacobi
  ido.jacobi@campus.technion.ac.il
- **Exercise Checking:** Shiran Peeran
  shiran96@campus.technion.ac.il
- **Schedule:**
  - Lesson: Wednesday: 14:30-16:30
  - Lab / tutorial: Monday 16:30-17:30
  - Reception Hours (via Zoom): Sunday 09:30-10:20.

Course Structure

- Weekly 2-hour class and a 1-hour hands-on lab and tutorial.
- In class we will cover the theory behind decision making for robotics.
- In the lab and in the home-work assignments, we will implement the ideas we learned about on simulated and real robots.
- We will have 3 projects:
  - A small scale assignment - task planning
  - Mid-term assignment - motion planning
  - Final project - integrated task and motion planning

Course Structure

- Attendance and participation are expected (really !)
- Work will be in single or pairs, according to your preferences. I encourage working in pairs. I will allow groups of 3, but the volume of the assignments will be adjusted accordingly.
- The assignments can be developed in the simulated environment, but will be also tested on the real robots.

Useful Links

- 3rd Summer School on Cognitive Robotics (2019): *https://sites.usc.edu/cognitive-robotics/schedule/*
- TASP - Technion Autonomous Systems Program *https://www.youtube.com/channel/UCaOlOHpGQc5Rza5bXzgLObw/featured*
- MIT Robotics seminar: *https://www.youtube.com/channel/UCK2tKzmSFFnpFhUXtRKjvnQ?app=desktop*

Summary

Summary:

- We motivated the study of robotics
- We highlighted the relationship between task planning, motion planning and control

What next ?

- Explore a robot's structure
- Examine different AI Approaches and their relevance to robotics