

236609 - AI and Robotics

Lesson 1: Introduction

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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 ?

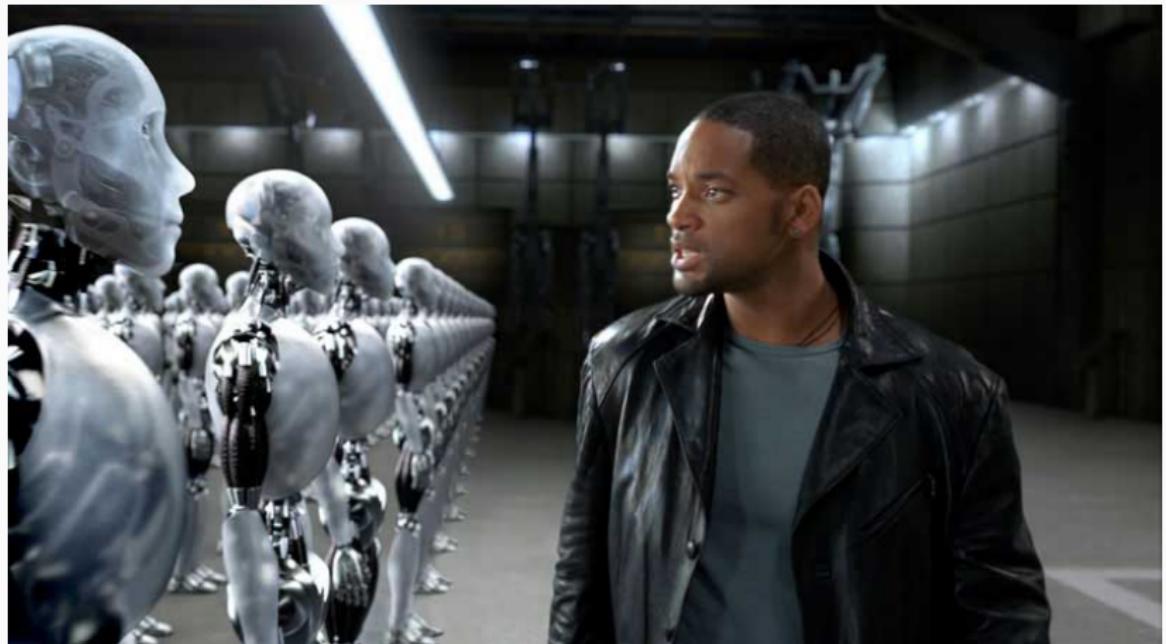


Figure 2: Way in the future robots

Why Study Robotics ?

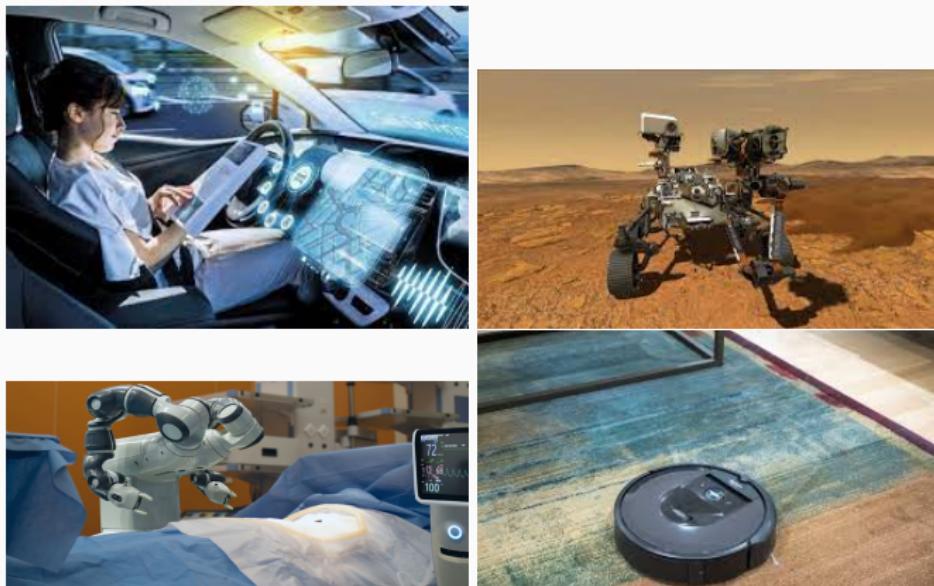


Figure 3: Today's robots

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;

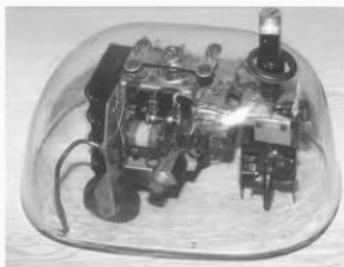
A Brief History of Robotics

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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 obstacles recharge battery
- Control: reactive, with prioritized reflexes
- First example of 'artificial life': Tortoises now shown in museums around the world



- 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 A. Simon, 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

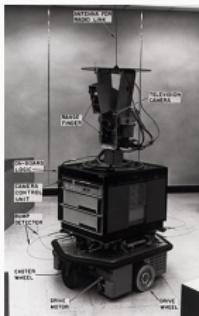


" We propose that a 2 month, 10 man study of artificial intelligence be carried out during the summer of 1956 at Dartmouth College. "

— Nathaniel Rochester, 1955

Shakey: the First intelligent robot

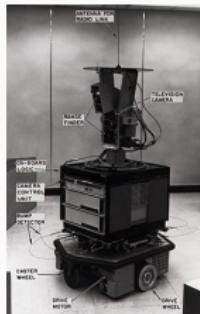
- Built in the 1960s at the Stanford Research Institute (SRI)
- The robot had
 - Camera and contact sensors
 - Application of AI techniques to vision algorithms
 - Lived in a simple black and white world
 - The robot shook when trying to execute its navigation plans.
- Reasoning:
 - Planning with STRIPS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

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Behavior Based Robotics

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



Figure 6: Starlings

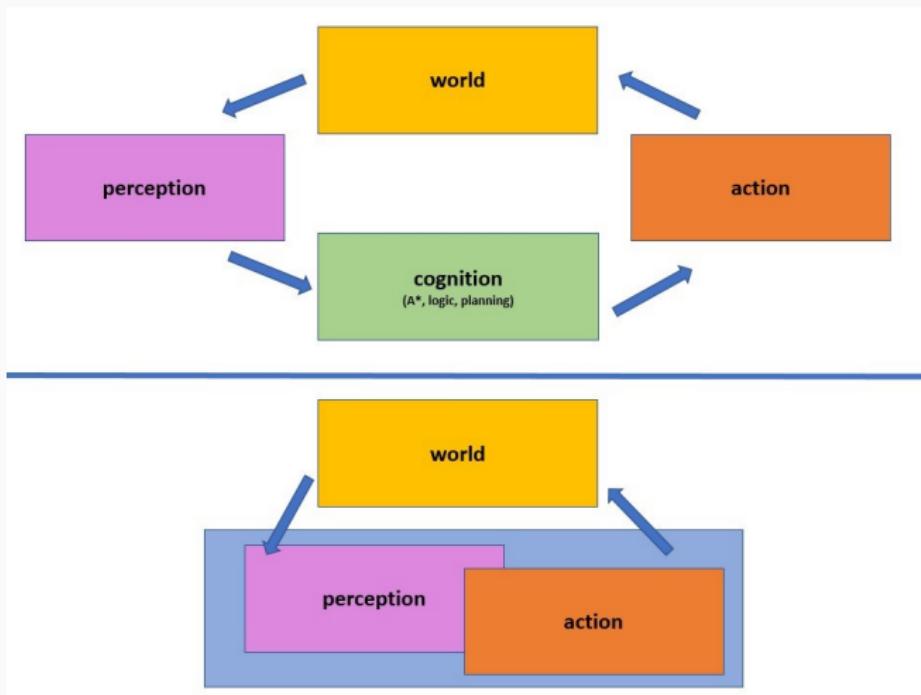
<https://youtu.be/0bRocfcPhHU?t=255>

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

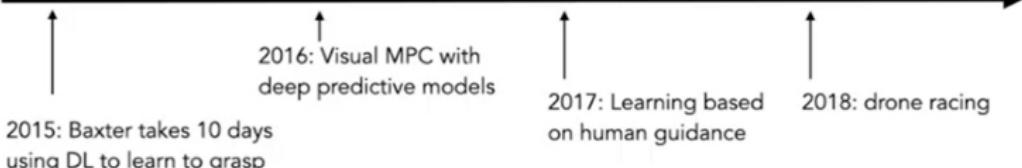


1990s to Today - A Few Highlights



2015 and onwards: trend away from first principles-based approaches to data-driven approaches (black box control)

Some recent developments...



2015 and onwards: leveraging ML to learn perception as well as end-to-end control.

Autonomy

Autonomy

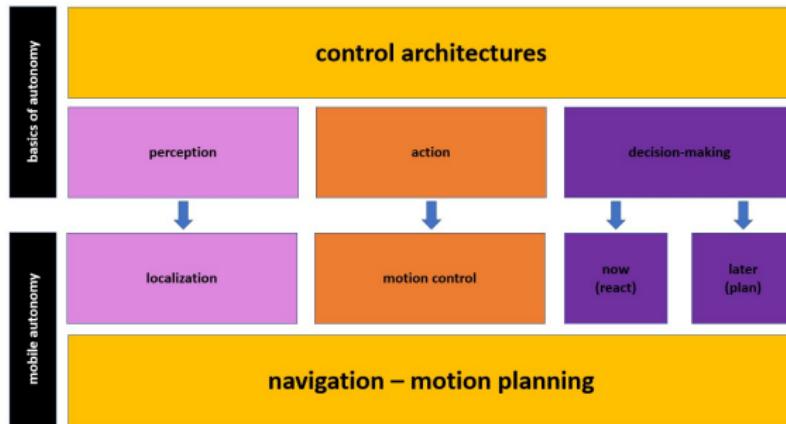


Challenges:

- 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.

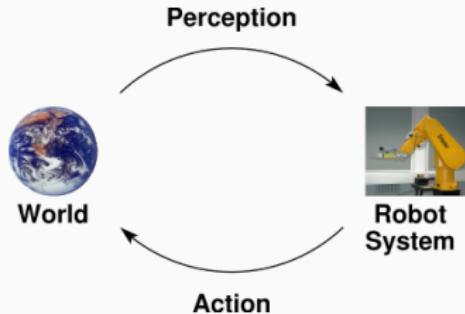
Autonomy - detailed perspective



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 ?



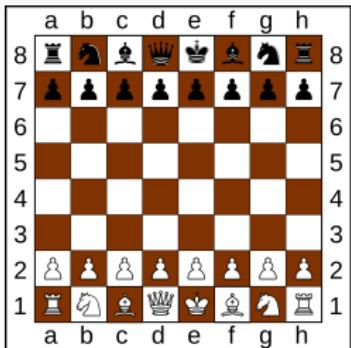
<https://www.youtube.com/live/AtNGJeXTXu4?si=90REz2DGfoH4F54Q>

Single Robot Autonomy - Are we there yet ?



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.

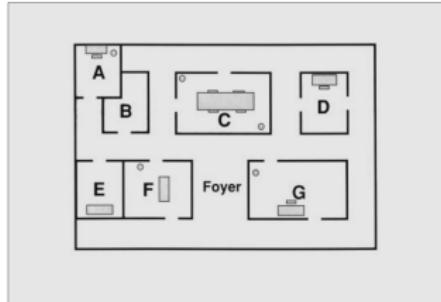


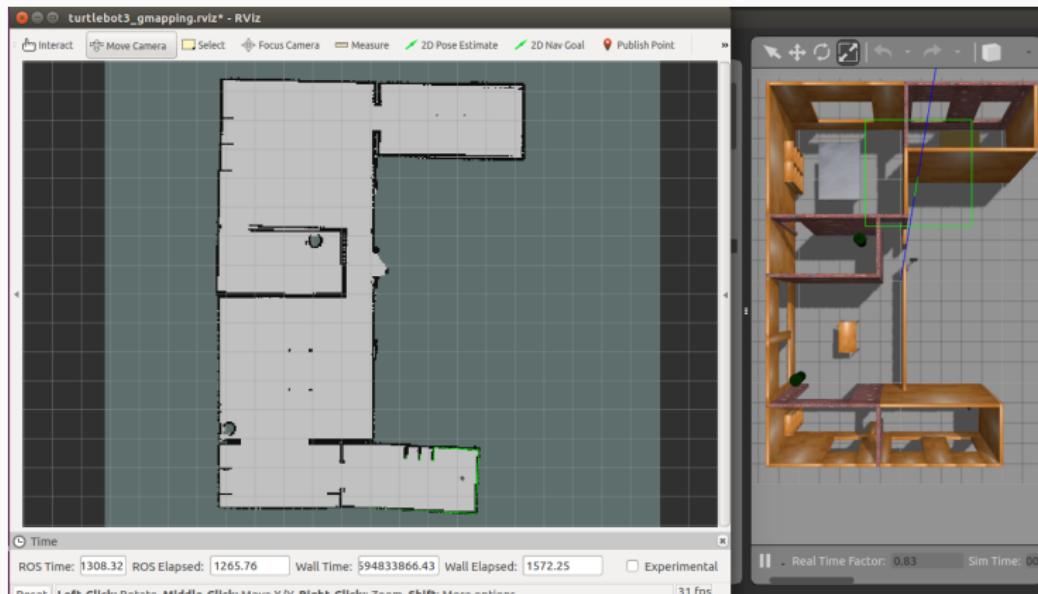
Figure 2. The Competition Arena.

- **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



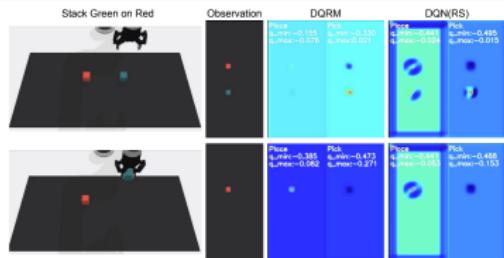
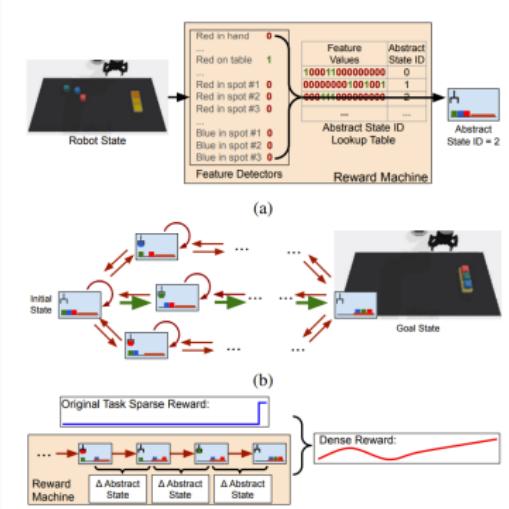
Figure 1: Our method learns visuomotor policies that directly use camera image observations (left) to set motor torques on a PR2 robot (right).

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

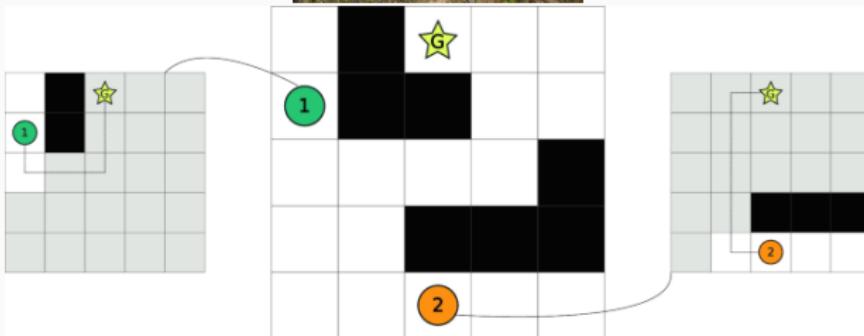


<https://www.youtube.com/watch?v=JN0k1rylDpU>

<https://arxiv.org/abs/1802.08705>

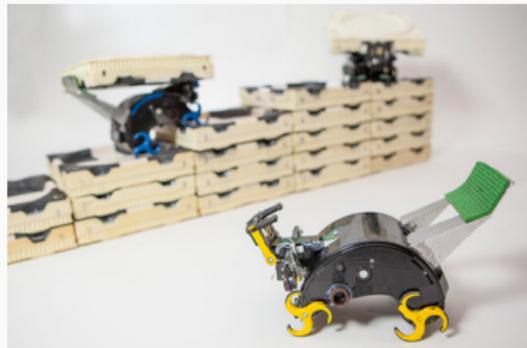
<https://www.youtube.com/watch?v=5R-xL9YmdR0>

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>

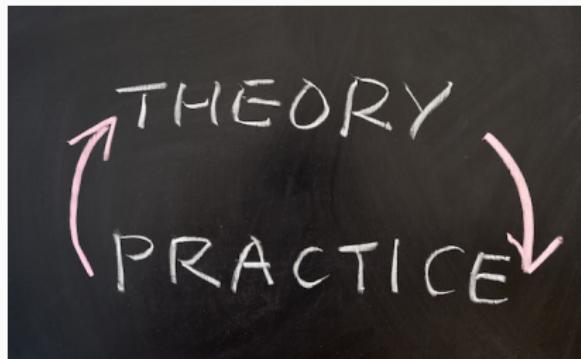
Course objectives

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

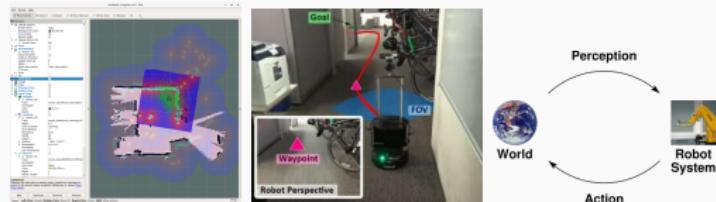
Robots (or any group of automated agents) can:

- **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., RGB, 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

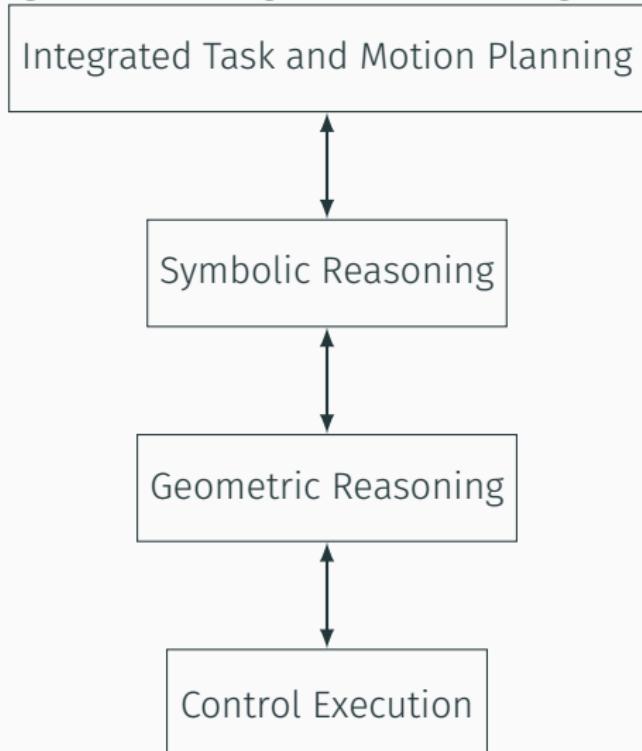


Focus on autonomy:

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

	a	b	c	d	e	f	g	h	
8	■	■	■	■	■	■	■	■	8
7	■	■	■	■	■	■	■	■	7
6	■	■	■	■	■	■	■	■	6
5	■	■	■	■	■	■	■	■	5
4	■	■	■	■	■	■	■	■	4
3	■	■	■	■	■	■	■	■	3
2	■	■	■	■	■	■	■	■	2
1	■	■	■	■	■	■	■	■	1
	a	b	c	d	e	f	g	h	



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 Peoran
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/*](https://sites.usc.edu/cognitive-robotics/schedule/)
- TASP - Technion Autonomous Systems Program
[*https://www.youtube.com/channel/UCaOlOHpGQc5Rza5bXzgLObw/featured*](https://www.youtube.com/channel/UCaOlOHpGQc5Rza5bXzgLObw/featured)
- MIT Robotics seminar: [*https://www.youtube.com/channel/UCK2tKzmSFFnpFhUXtRKjvnQ?app=desktop*](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

