Lecture 1: Introduction to Robotics
MAE 345/549

Anirudha Majumdar

Princeton

Sept. 6, 2022

PRINCETON UNIVERSITY

Mechanical and Aerospace Engineering

Agenda for today

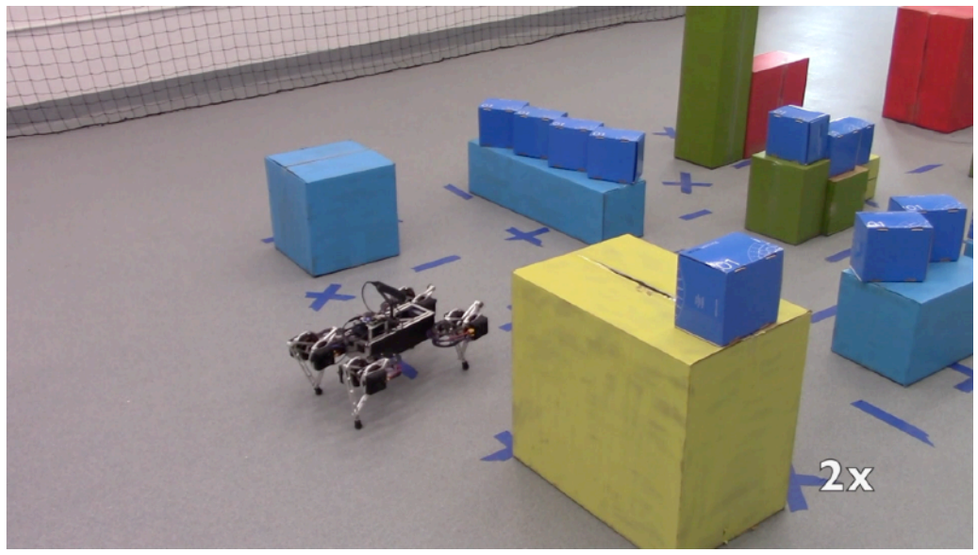
- Course logistics
- Motivation and introduction to course content
- Course plans, syllabus

A little bit about me

- Faculty in MAE and Associated Faculty in COS
- Visiting Researcher at Google Artificial Intelligence Lab @ Princeton
  - I spend ~1 day a week at the Google office
- My first name is difficult to pronounce!
  - I usually go by "Ani"

A little bit about me

- Research interests: Robotics
  - Controlling agile robots (e.g., UAVs, legged robots) with safety guarantees



IRoM Lab
Intelligent Robot Motion Lab

irom-lab.princeton.edu

Course logistics: AIs

Sasha Bodrova

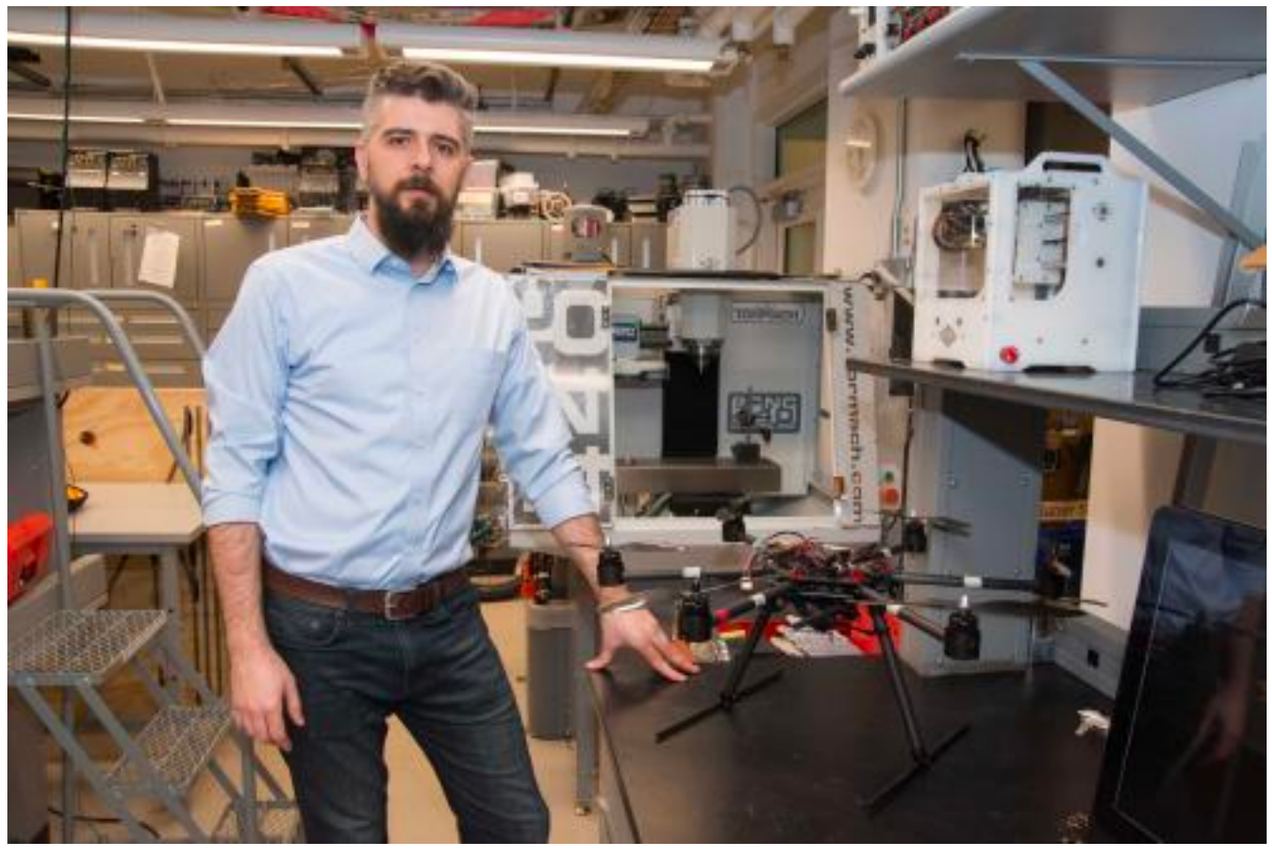
Eric Lepowsky

An-Ya Olson

Allen Ren

Nate Simon

Course logistics: support



Jon Prevost (MAE)

Course prerequisites

- Multivariable calculus (e.g., MAT 201 or 203)
- Linear algebra (e.g., MAT 202 or 204)
- Basic probability (e.g., ORF 309)
- Basic differential equations (e.g., MAE 305)
- Some programming experience (e.g., COS 126)
  - We will be using Python
  - Sasha will do an intro to Python (next week; not mandatory)

Course logistics: grading

- Problem Sets: 45% (assigned: Wed, due: Wed midnight)
  - Mixture of theory, coding, and hardware implementation
- Midterm Exam (Take-home): 25%
  - Early-November (see syllabus for tentative dates)
- Final Project: 30%

Course logistics: OHs

- Office hours: doodle poll

Course logistics: policies

- Collaboration is permitted (encouraged) on problem sets. But, you must turn in your own write-up, code, etc. (except for hardware portions).

- Write-ups should be clear/legible and explain all steps.

- Late policy: 10% deduction for every day of lateness (won't accept if more than week late).

- No collaboration on midterm exam (open notes, no internet).

- Regular attendance is strongly encouraged!

Course logistics: references

- No required textbooks
- References:
  - Nourbaksh and Siegwart, "Introduction to Autonomous Mobile Robots"

    https://pdfs.semanticscholar.org/4a37/fe05d825ae2554be2c0c90a19a39fe51c26b.pdf
  - Lavalle, "Planning Algorithms"

    http://planning.cs.uiuc.edu/
  - Thrun, Burgard, and Fox, "Probabilistic Robotics"

    https://docs.ufpr.br/~danielsantos/ProbabilisticRobotics.pdf

Other logistics

- Gradescope (through Canvas)
- Ed Discussion (through Canvas)

MAE 345 vs. MAE 549

- MAE 549 is the "grad track"
  - There are 12/12 students enrolled
  - MAE 549 students will have some extra problems on assignments (these will be clearly marked)

MAE 345/549: Introduction to Robotics

What is this course about?

What is a robot?

An embodied agent that can be programmed to perform physical tasks

Side note: asking this question is a good way to start a fight at a robotics conference

What is a robot?

- Other reasonable definitions:

- A machine — especially one programmable by a computer — capable of carrying out a complex series of actions *automatically* [Wikipedia/ dictionary definition]

- A reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks [Robotics Industries Association]

- An *autonomous* machine capable of sensing its environment, carrying out computations to make decisions, and performing actions in the real world [https://robots.ieee.org/learn/]

What is a robot?

- Ultimately, all proposed definitions have some issues
- Is this a robot?

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What is a robot?

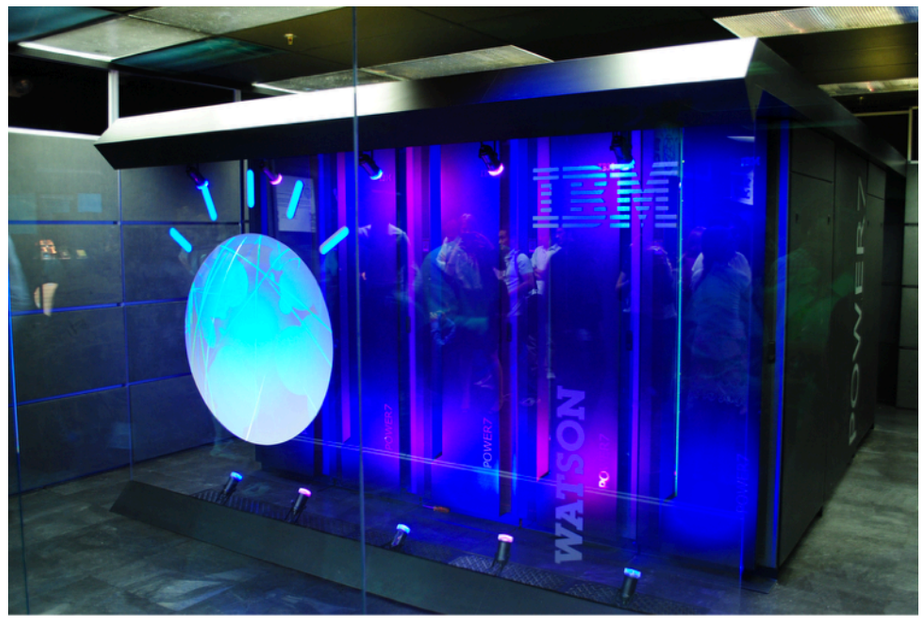
- Ultimately, all proposed definitions have some issues
- See these articles for a discussion of issues with definitions:

https://www.wired.com/story/what-is-a-robot/

https://robots.ieee.org/learn/

Robotics vs. Artificial Intelligence

- This is something most roboticists agree on



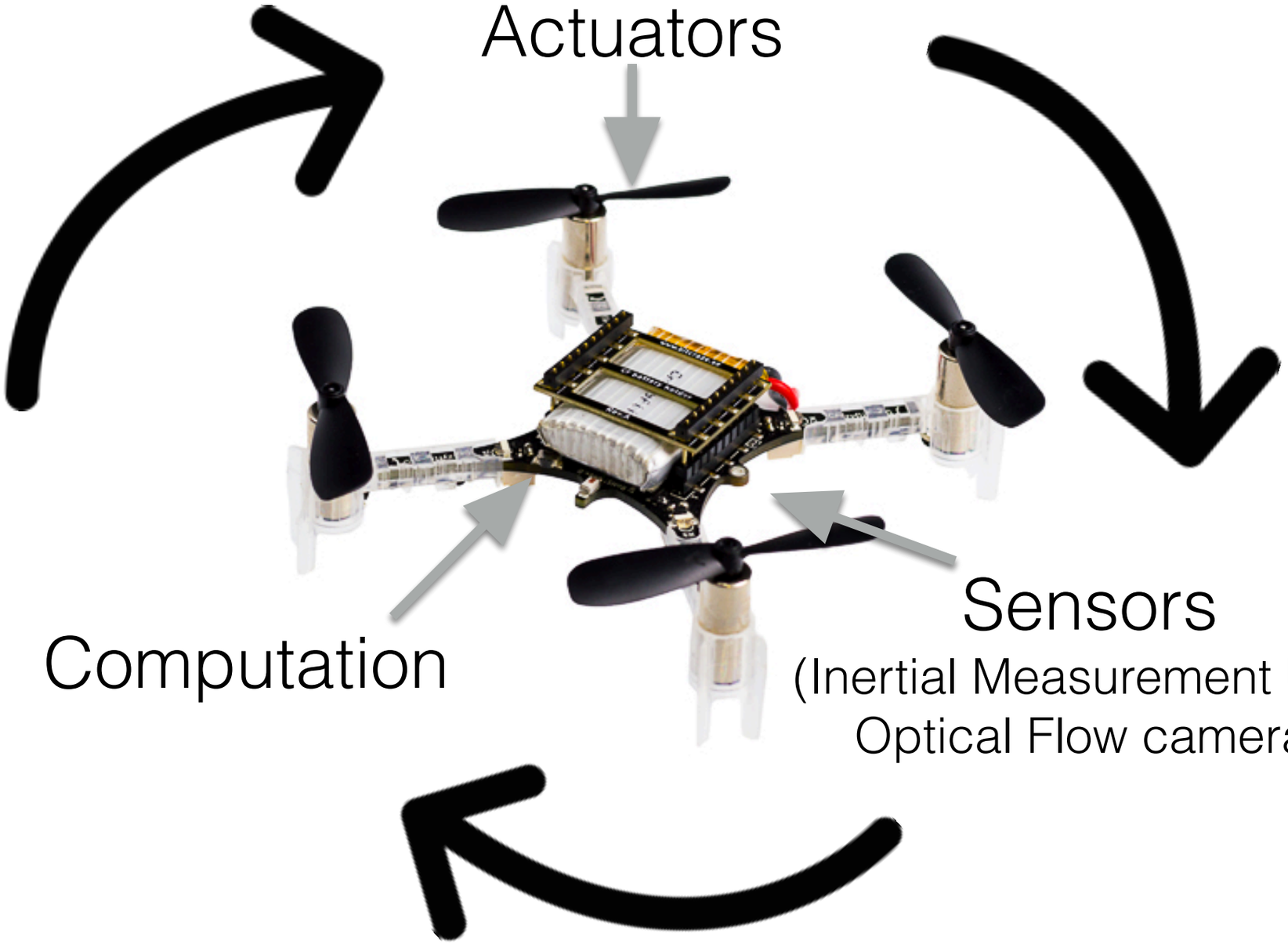
- A robot needs to be embodied
- Artificial Intelligence (AI) need not be embodied

Degrees of *roboticity*?

An embodied agent that can be programmed to perform physical tasks

- Lack of universally acceptable definition hints at some deep philosophical questions
- Could also be an indicator of the youth of the field
- Probably need to measure degree of "*roboticity*"
  - In terms of degree of embodiment, autonomy, complexity, programmability, …
  - But we don't have formal definitions for these concepts

Anatomy of a robotic system



“Sense-Think-Act”

A brief (pre-)history of robotics

- Greek mythology (Talos): ~1000BC
- Early automata: ~300BC - 100AD
- Leonardo da Vinci: ~1500s
- Descartes: ~1600s
- More complex automata: ~1700s
- Charles Babbage: ~1800s
- Karel Capek: 1920
- Unimate (George Devol, Joe Engelberger): ~1950s

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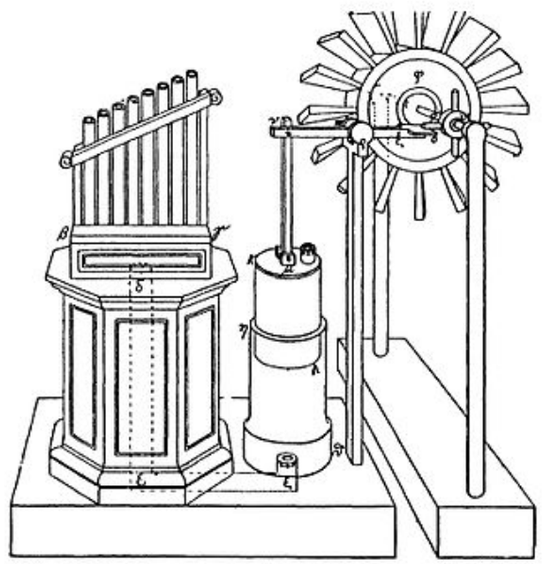

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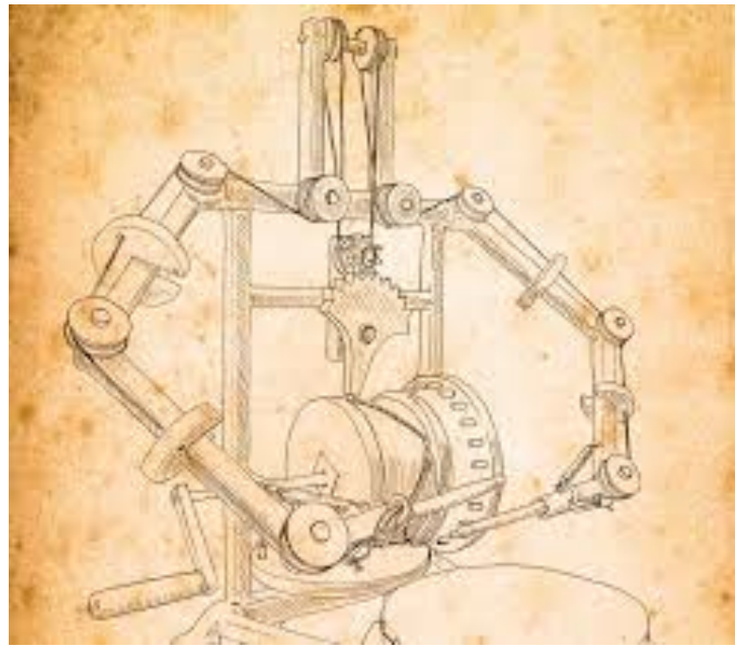

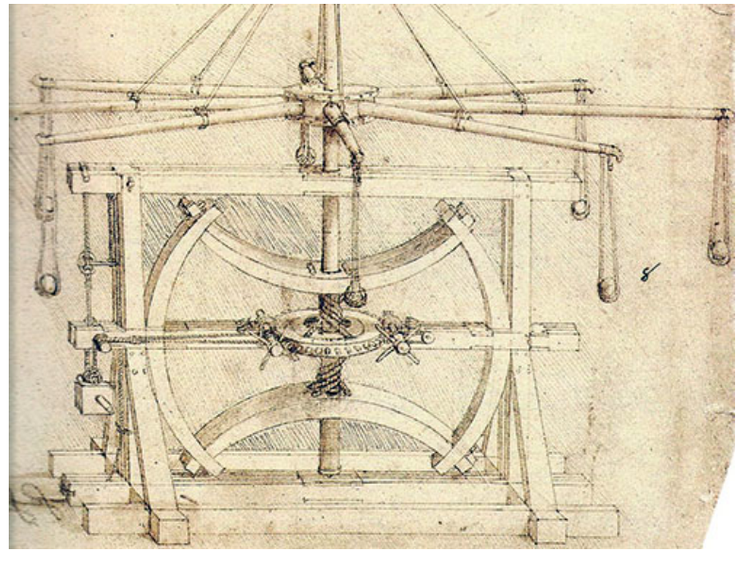

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Descartes: Animals as automata

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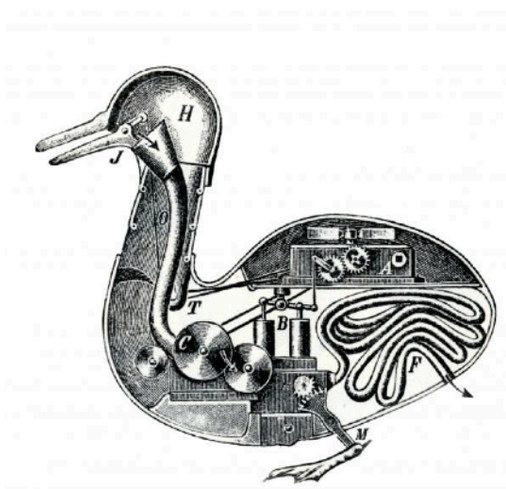

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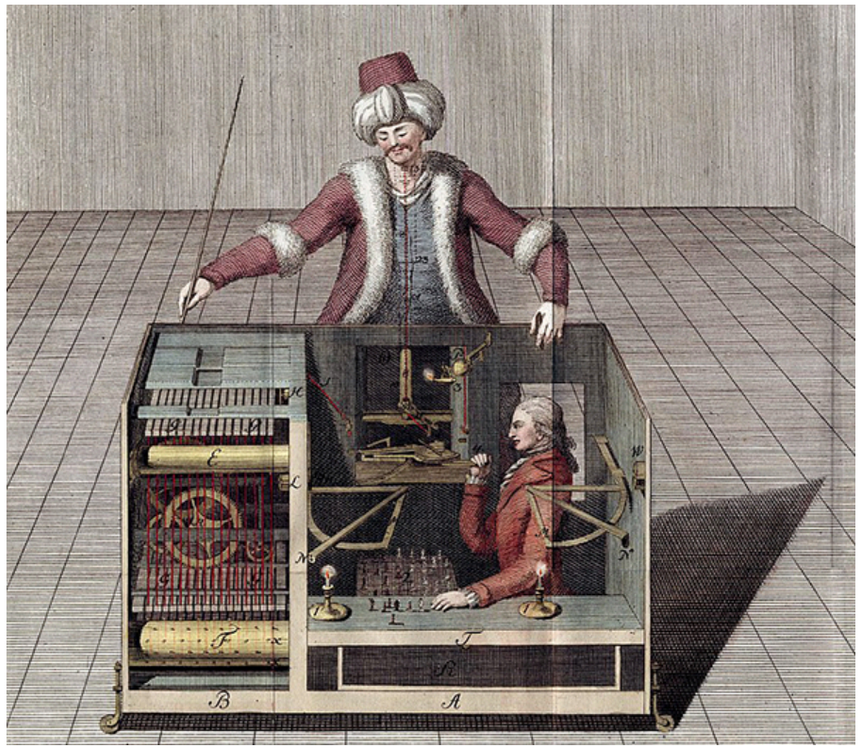

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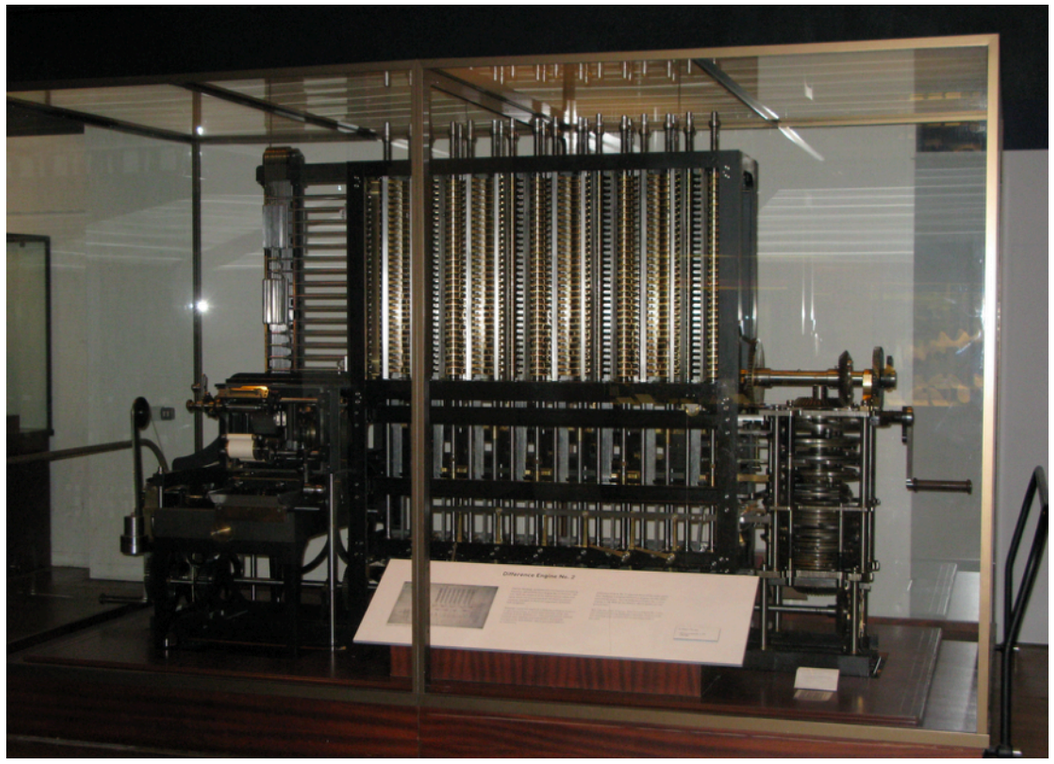

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Rossum's Universal Robots
This is where the word "robot" comes from
In Czech: "work", "labor"

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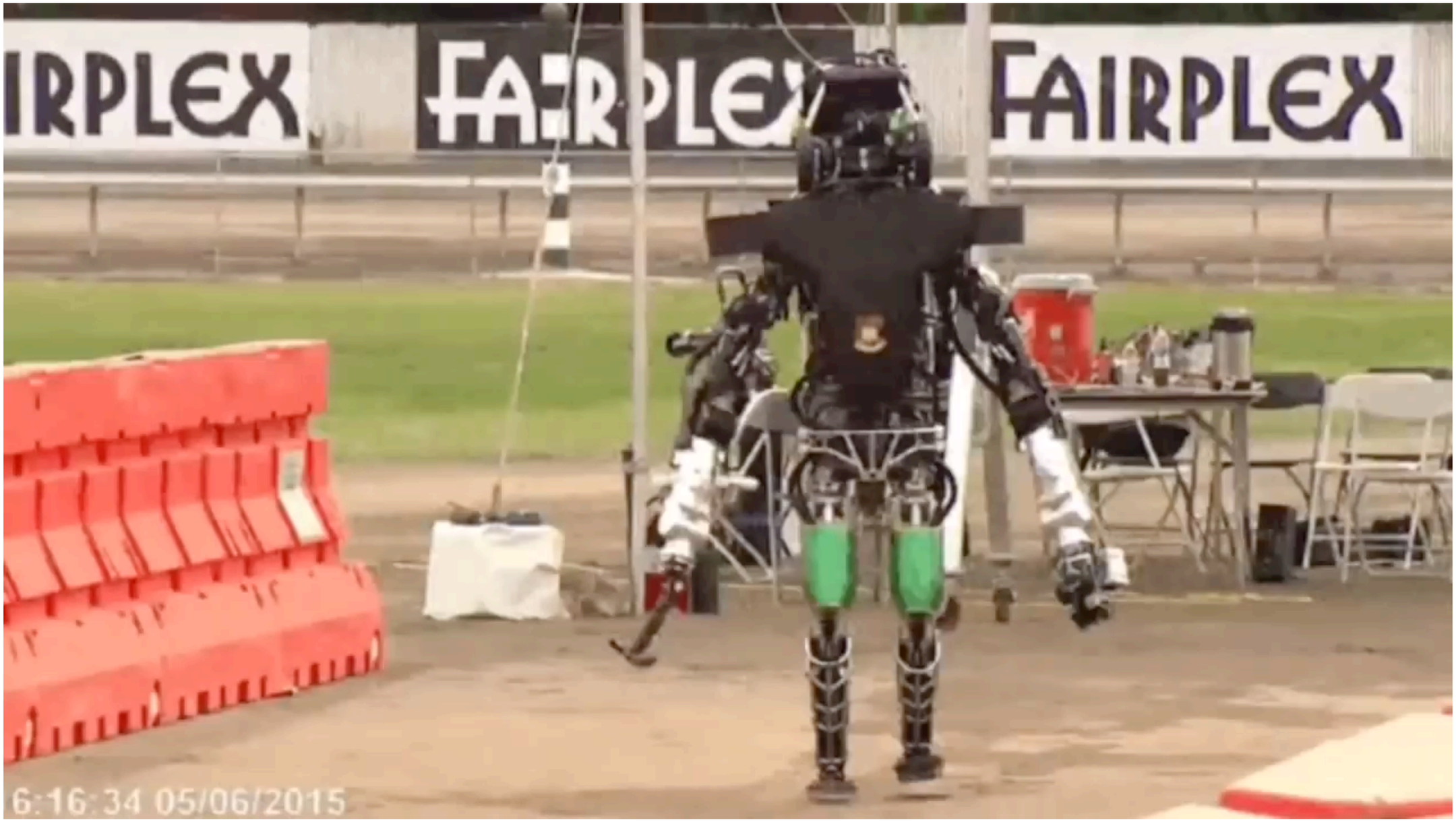
A brief history of robotics

- ~1960s - today: robotics has grown into its own academic discipline
- Huge amount of progress on theory, algorithms, and hardware

But still a **LONG** way to go!

Why is robotics hard?

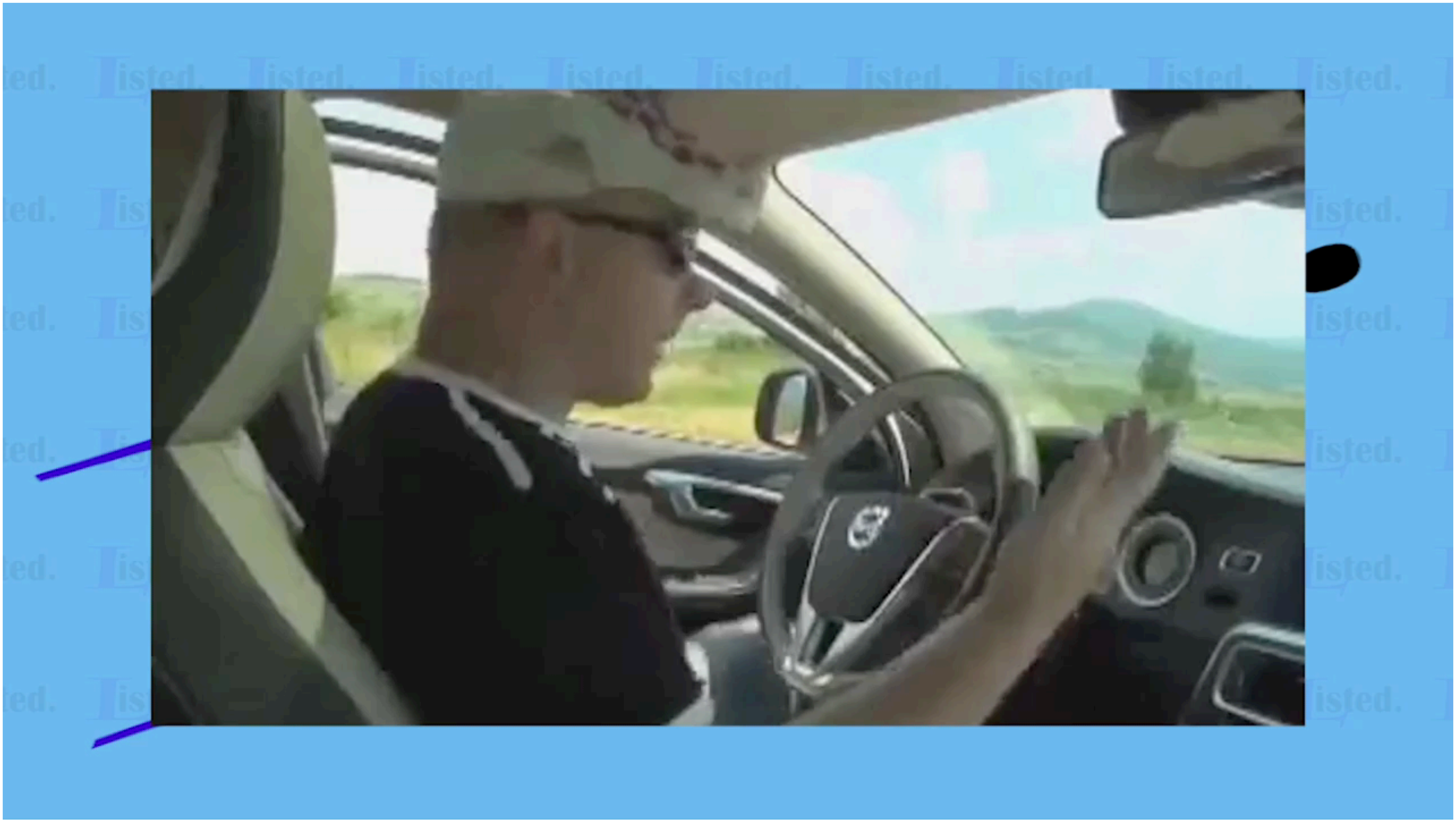


https://www.youtube.com/watch?v=g0TaYhjpOfo

Why is robotics hard?

https://www.youtube.com/watch?v=eTLMGjp-AIQ

Why is robotics hard?



https://www.youtube.com/watch?v=Ujk_5KD5G9o

Why is robotics hard?

Why is robotics hard?

- Uncertainty will be a recurring theme in the course

- Most challenges in robotics can be interpreted as the robot (or robot designer) facing uncertainty about something
  - Uncertainty in the dynamics of the robot
  - Uncertainty in the dynamics of the world
  - Uncertainty in the geometry of the world
  - Uncertainty in sensor measurements
  - Uncertainty in the user's intent
  - …

Why should you care about robotics?

- Important topic with massive interest from industry and government

GM Cruise raises $1.15B for self-driving cars

By Steve Crowe | May 7, 2019

An autonomous Chevrolet Bolt electric vehicle from GM Cruise.

Why should you care about robotics?

- Important topic with massive interest from industry and government

Zipline's new $190 million funding means it's the newest billion dollar contender in the game of drones

Jonathan Shieber @jshieber / 7:19 pm EDT • May 17, 2019

Comment

With a valuation of over $1 billion and $190 million in new financing, **Zipline** has become the latest contender

.com/author/jonathan-shieber/ game of drones.

Why should you care about robotics?

- Important topic with massive interest from industry and government

Global Agriculture Drones and Robots Market to Reach $23.06 Billion by 2028

BIS Research
Emerging Technology Market Intelligence

NEWS PROVIDED BY
BIS Research →
May 07, 2019, 08:30 ET

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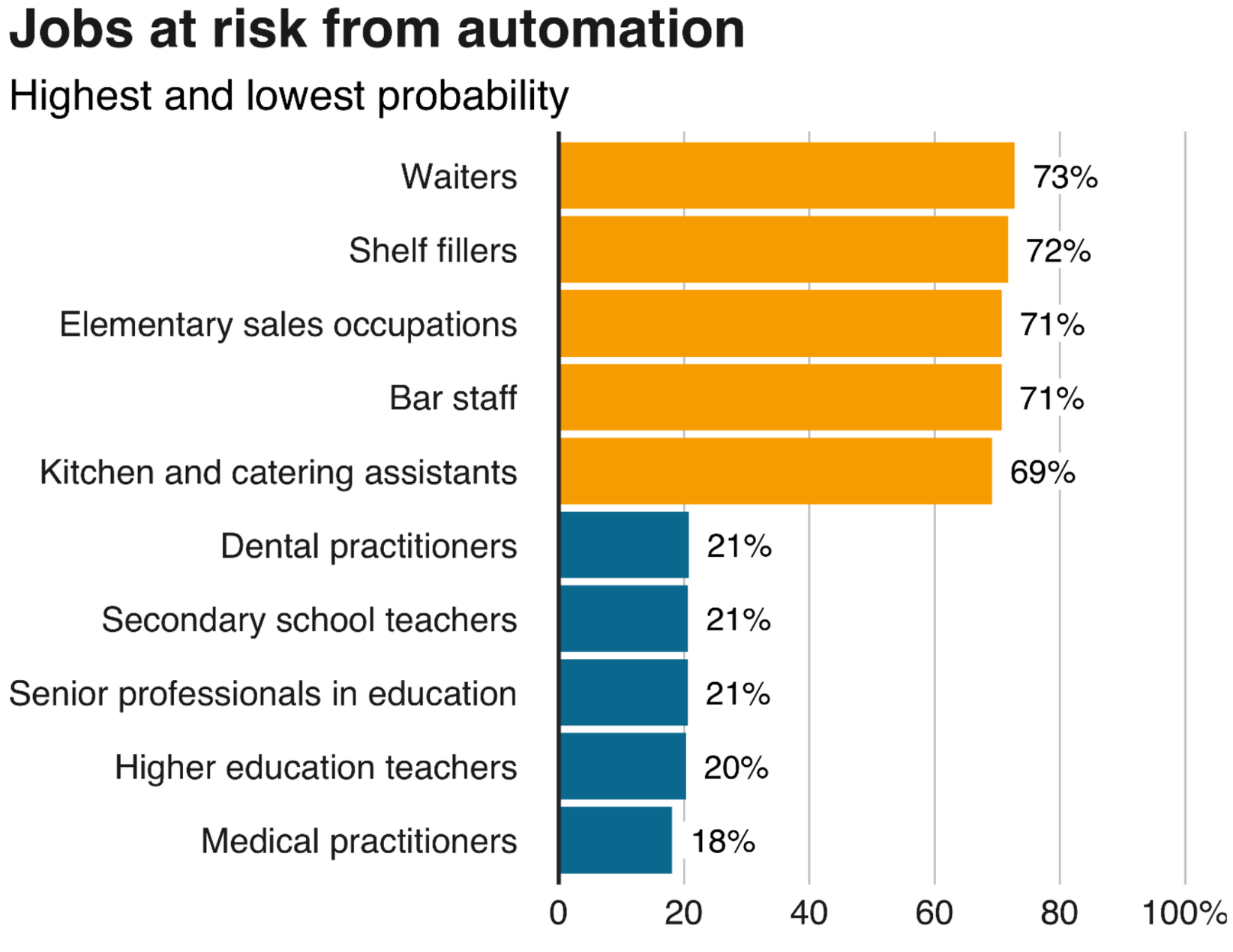
Why should you care about robotics?

- Important economic and social consequences



Why should you care about robotics?

- Lots of really fascinating technical challenges (many of which we'll discuss)
- Beautiful connections with many fields
  - AI, machine learning, control theory, computer vision, optimization, information theory, theoretical computer science, applied math, …
- Provides a lens on the really **BIG** questions
  - What is intelligence? What makes us human? What is consciousness? What is free will?
- It's really cool!!

How should we organize robotics?

- One option: by applications
  - e.g., aerial robotics, medical robotics, humanoid robotics, underwater robotics, etc.
- Another option: by concepts/techniques
  - Allows us to understand "core" ideas
  - Allows us to appreciate that many application domains share very similar challenges

Course plan: theory/algorithms

- Dynamics & Feedback control (~Lectures 2-5)
  - Equations of motion, feedback controllers, linear quadratic regulator
- Motion planning (~Lectures 6-9)
  - Discrete planning, planning in continuous spaces, trajectory optimization
- State estimation, localization, and mapping (~Lectures 10-15)
  - Bayes filtering, Kalman filtering, particle filtering
- Computer vision and Learning (~Lectures 16-22)
  - Camera models, optical flow, neural networks
- Broader topics in robotics (~Lectures 23-24)
  - Robotics and the law, ethics, policy, etc.

Course plan: hardware implementation

- Hardware implementation:
  - Best way to appreciate challenges
  - Nothing like seeing things work (or not) in practice!
- Will use Crazyflie 2.1 quadrotor to introduce concepts
  - Open source platform, small, light-weight, ideal for testing

Course plan: hardware implementation

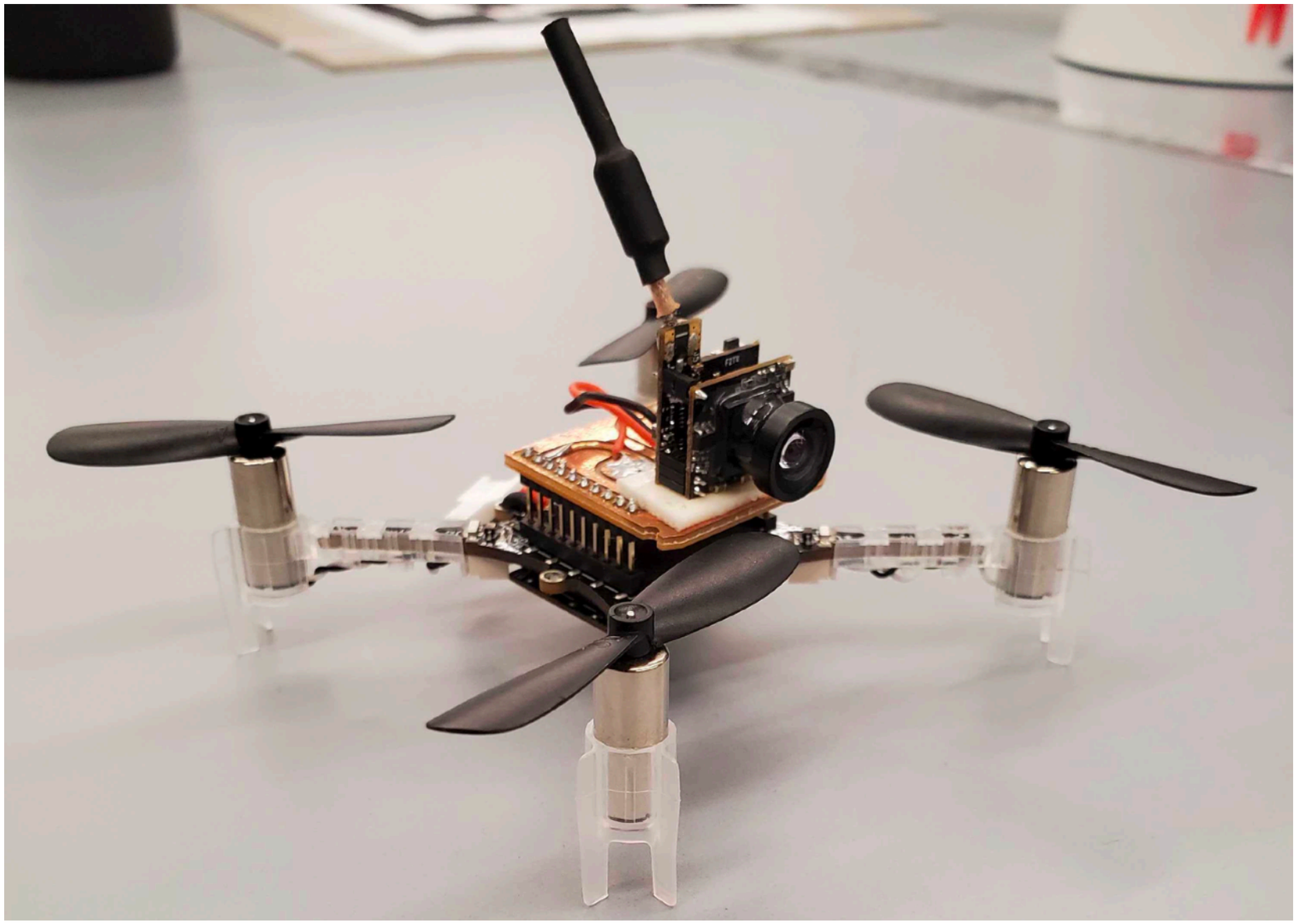
- Goal: make the drone navigate autonomously

Course plan: theory/algorithms

- Dynamics & Feedback control: **make drone hover**
  - Equations of motion, feedback controllers, linear quadratic regulator
- Motion planning: **find paths that will reach desired goal**
  - Discrete planning, planning in continuous spaces, trajectory optimization
- State estimation, localization, and mapping (won't implement on hardware)
  - Bayes filtering, Kalman filtering, particle filtering
- Computer vision and Learning: **optical flow and obstacle detection**
  - Camera models, optical flow, neural networks
- Broader topics in robotics
  - Robotics and the law, ethics, policy, etc.

Course plan: hardware implementation

- Final project: put pieces together to navigate autonomously



Course plan: hardware implementation

- Teams for hardware implementation portions of assignments
- Please form teams of **4** by next Wed **[Sept. 14th] and email course staff** (will hand out one drone per team in class on 9/15)
  - Can use Ed Discussion to facilitate team formation
  - Might be a good idea to have students from multiple majors in a team

Course plan: hardware implementation

- Logistics for hardware implementation
  - We have set up netted space in G105 and ACEE 012
  - General lab-safety training (if you haven't completed this)
    - https://ehs.princeton.edu/training
    - Online and in-person components (through EHS)
    - Needed to access lab

Course plan: comments

- Robotics borrows a lot of ideas and techniques from many different fields: control theory, computer vision, machine learning, optimization, …

- Tried to focus course on topics that are "quintessentially robotics", but can't avoid other topics altogether (e.g., control, computer vision)

  - May feel like "survey" at some points, but the goal is to introduce you to major concepts in robotics

  - Different parts may feel more or less challenging depending on your major

Course plan: comments

- Many topics we won't cover or do justice to:
  - Inverse kinematics, grasping and manipulation, hardware design, algorithms for walking/running, …
  - Robotics and X
    - X = ethics
    - X = the law
    - X = the economy
    - etc.

Course plan: comments

- Things will not be perfect
- Need help from you!
  - Feedback, suggestions, patience :)

Course plan: theory/algorithms

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  - Equations of motion, feedback controllers, linear quadratic regulator
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