Algorithmic Human-Robot Interaction

Course Overview

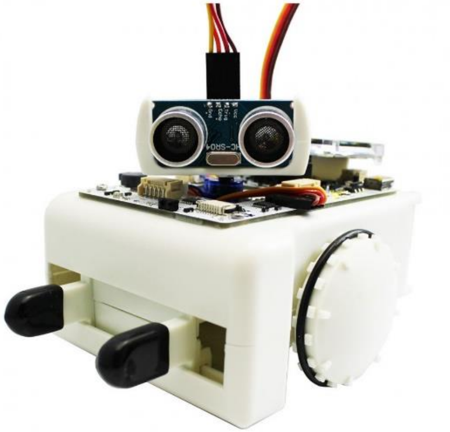
CSCI 7000

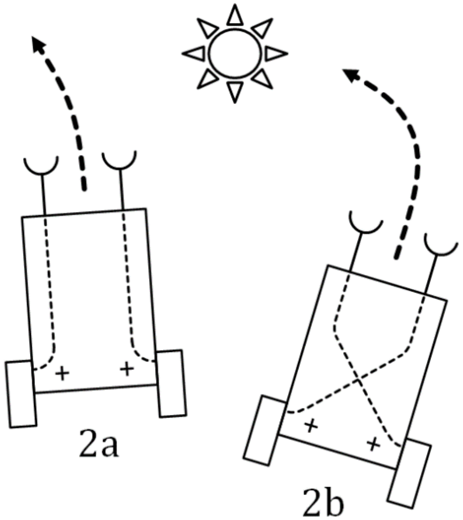
Prof. Brad Hayes

Computer Science Department

University of Colorado Boulder

What is a robot?





Robot

A machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer.

Robotics is the science and technology behind the design, manufacturing and application of robots.

Robot

A robot is a system which exists in the physical world and autonomously senses its environment and acts in it (USC)

Robotics is the science and technology behind the design, manufacturing and application of robots.

The First Commercial Robot

What’s missing from this video?

Sensing/Perception

- No tactile sensing
- No visual sensing

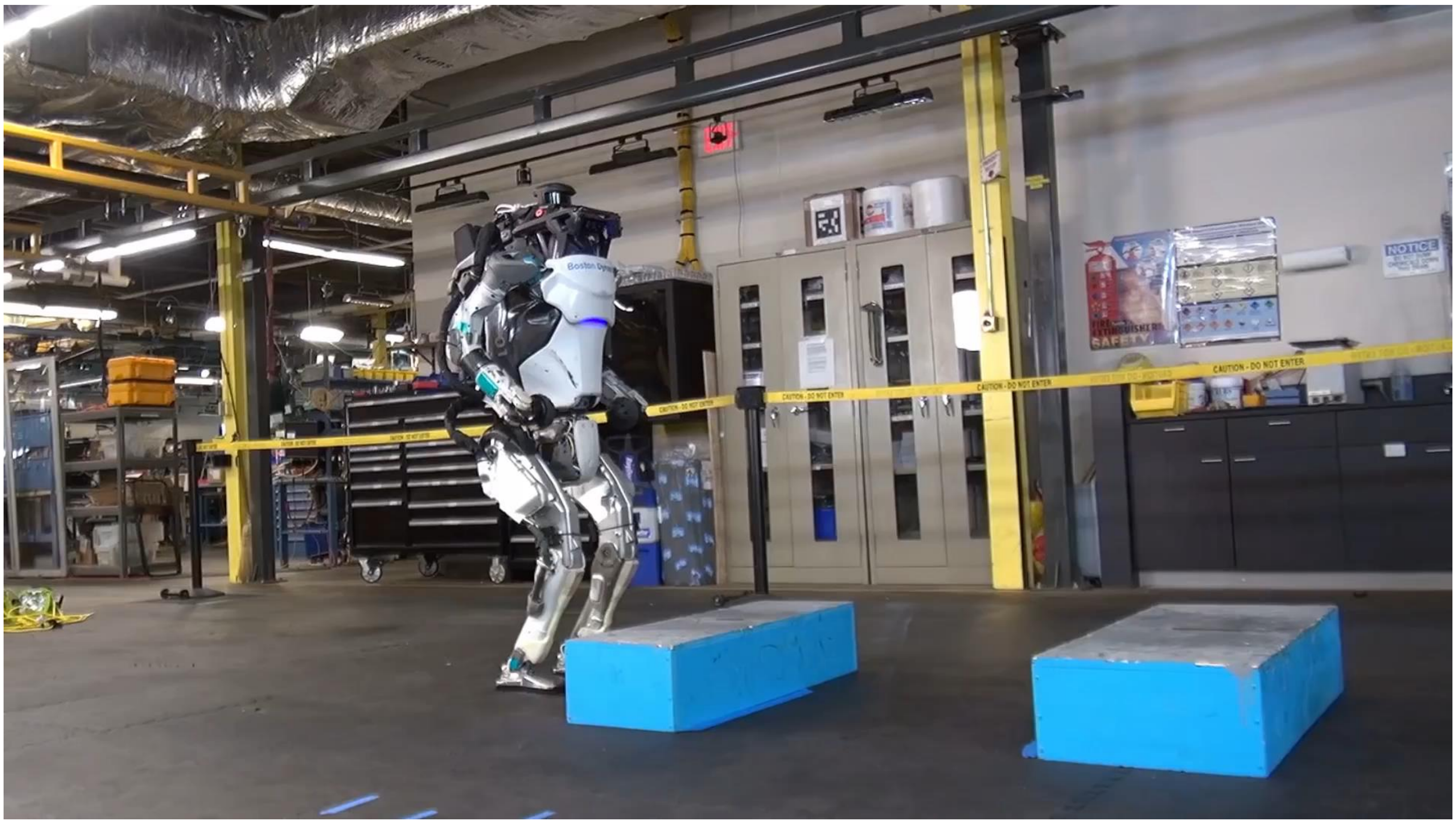
Safety systems

- No force cut-off
- No human awareness

Task understanding

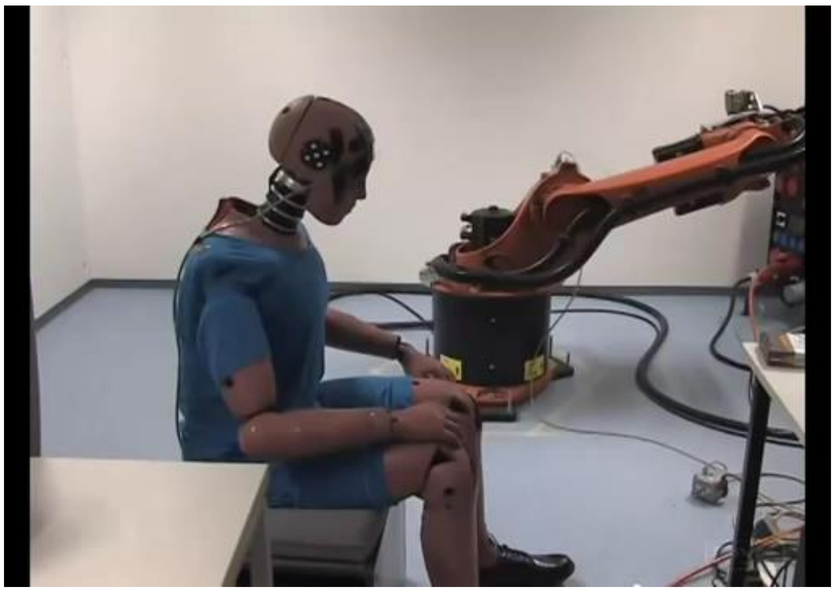
- Simple keyframing – no task comprehension!

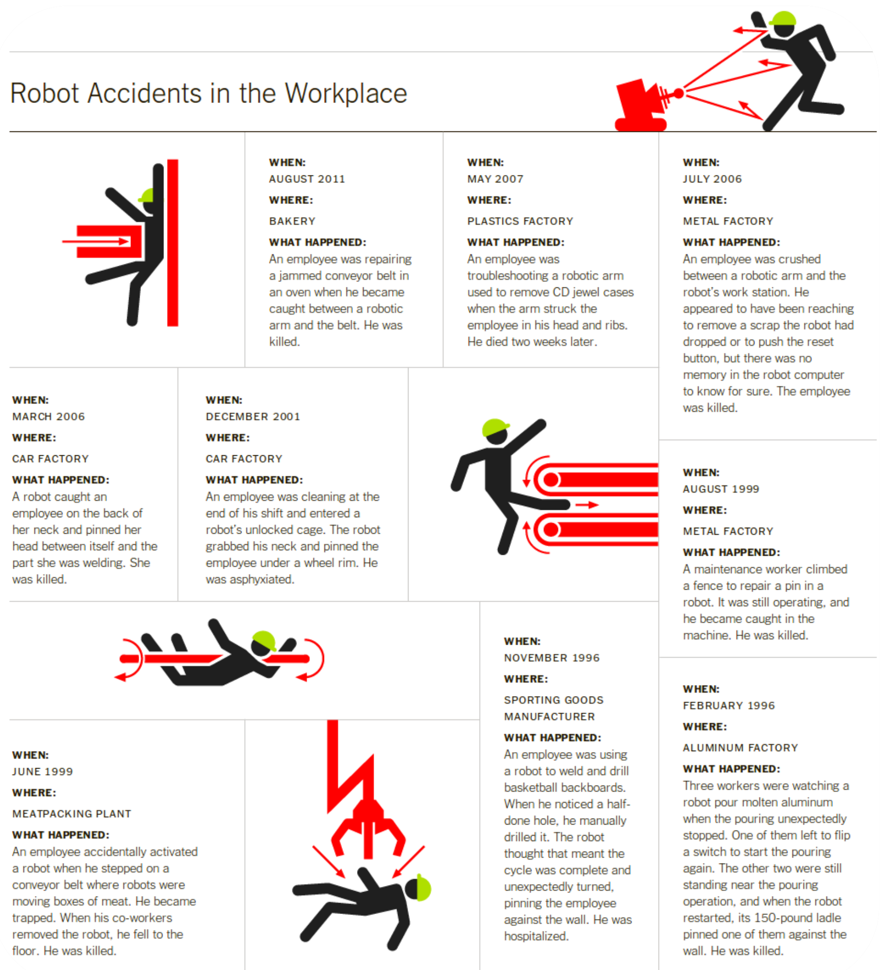
Robotics



What is Human-Robot Interaction?

Physical Human-Robot Interaction





Robot Accidents in the Workplace

WHEN: AUGUST 2011
WHERE: BAKERY
WHAT HAPPENED: An employee was repairing a jammed conveyor belt in an oven when he became caught between a robotic arm and the belt. He was killed.

WHEN: MAY 2007
WHERE: PLASTICS FACTORY
WHAT HAPPENED: An employee was troubleshooting a robotic arm used to remove CD jewel cases when the arm struck the employee in his head and ribs. He died two weeks later.

WHEN: JULY 2006
WHERE: METAL FACTORY
WHAT HAPPENED: An employee was crushed between a robotic arm and the robot's work station. He appeared to have been reaching to remove a scrap the robot had dropped or to push the reset button, but there was no memory in the robot computer to know for sure. The employee was killed.

WHEN: MARCH 2006
WHERE: CAR FACTORY
WHAT HAPPENED: A robot caught an employee on the back of her neck and pinned her head between itself and the part she was welding. She was killed.

WHEN: DECEMBER 2001
WHERE: CAR FACTORY
WHAT HAPPENED: An employee was cleaning at the end of his shift and entered a robot's unlocked cage. The robot grabbed his neck and pinned the employee under a wheel rim. He was asphyxiated.

WHEN: AUGUST 1999
WHERE: METAL FACTORY
WHAT HAPPENED: A maintenance worker climbed a fence to repair a pin in a robot. It was still operating, and he became caught in the machine. He was killed.

WHEN: NOVEMBER 1996
WHERE: SPORTING GOODS MANUFACTURER
WHAT HAPPENED: An employee was using a robot to weld and drill basketball backboards. When he noticed a half-done hole, he manually drilled it. The robot thought that meant the cycle was complete and unexpectedly turned, pinning the employee against the wall. He was hospitalized.

WHEN: JUNE 1999
WHERE: MEATPACKING PLANT
WHAT HAPPENED: An employee accidentally activated a robot when he stepped on a conveyor belt where robots were moving boxes of meat. He became trapped. When his co-workers removed the robot, he fell to the floor. He was killed.

WHEN: FEBRUARY 1996
WHERE: ALUMINUM FACTORY
WHAT HAPPENED: Three workers were watching a robot pour molten aluminum when the pouring unexpectedly stopped. One of them left to flip a switch to start the pouring again. The other two were still standing near the pouring operation, and when the robot restarted, its 150-pound ladle pinned one of them against the wall. He was killed.

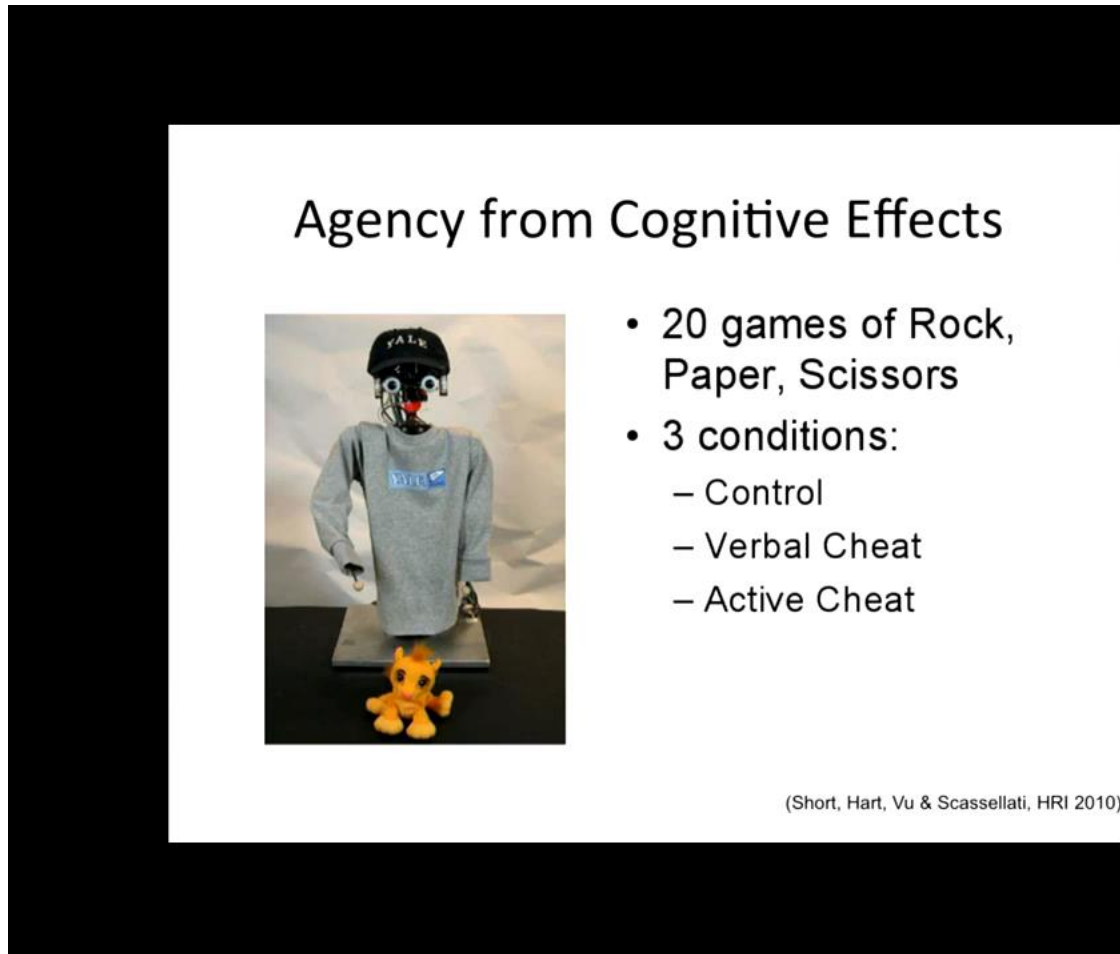
Physical Human-Robot Interaction

Physical Human-Robot Interaction

Social Human-Robot Interaction

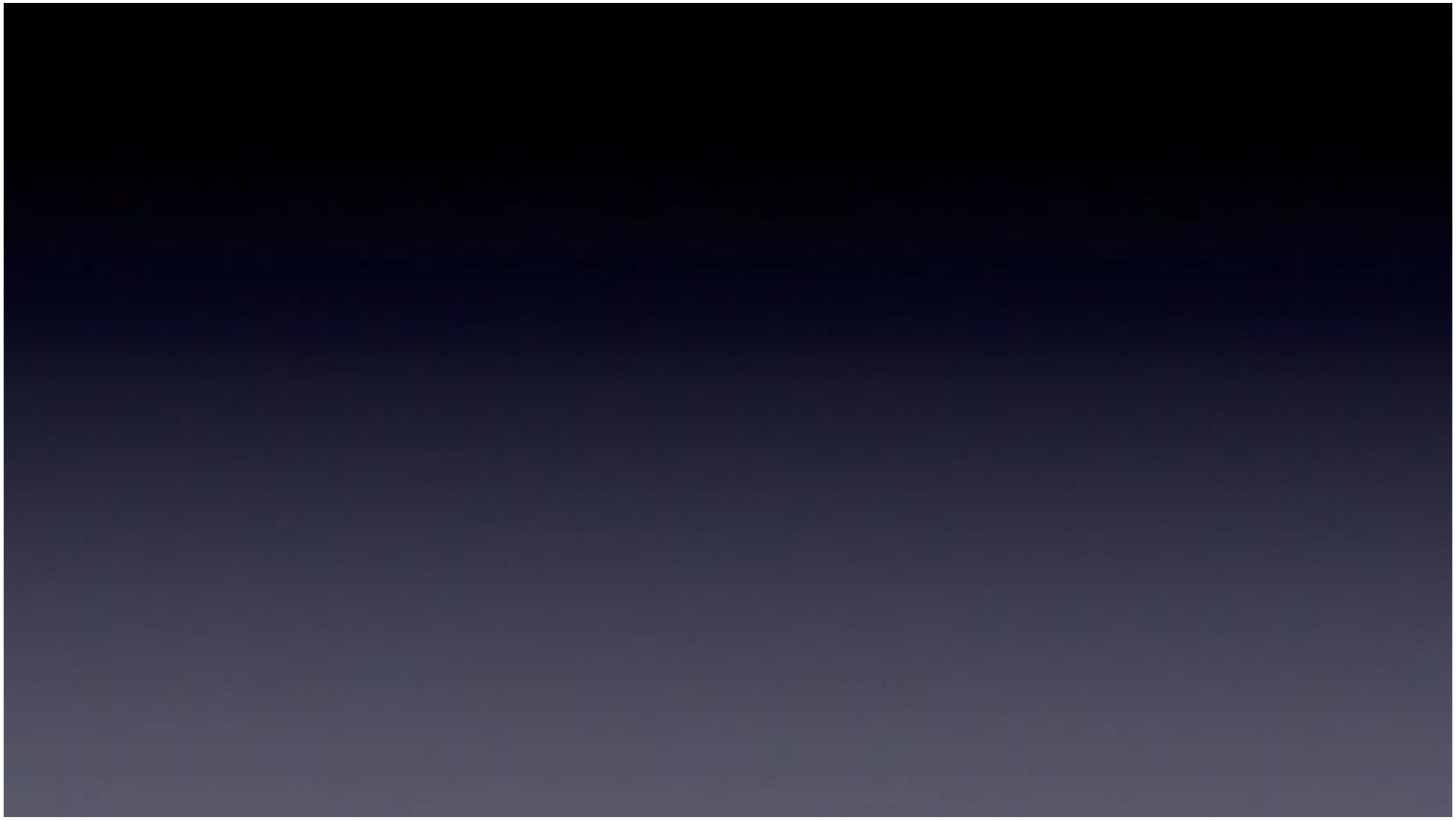
Social Human-Robot Interaction

Fig. 2. The humanoid robot, Nico.



Algorithmic Human-Robot Interaction

Algorithmic Human-Robot Interaction



Algorithmic Human-Robot Interaction

Human Robot Interaction (HRI)

A field of study involving the design, characterization, and evaluation of robotic systems for use by or with humans.

Emphasis on **how an interaction should work**, rather than algorithms or generalization

Algorithmic HRI

Algorithms, models, and frameworks that enable robots to autonomously generate behavior to achieve useful tasks while interacting, coordinating, coexisting, or assisting humans

Emphasis on interaction, but also

focused on autonomy and generalization

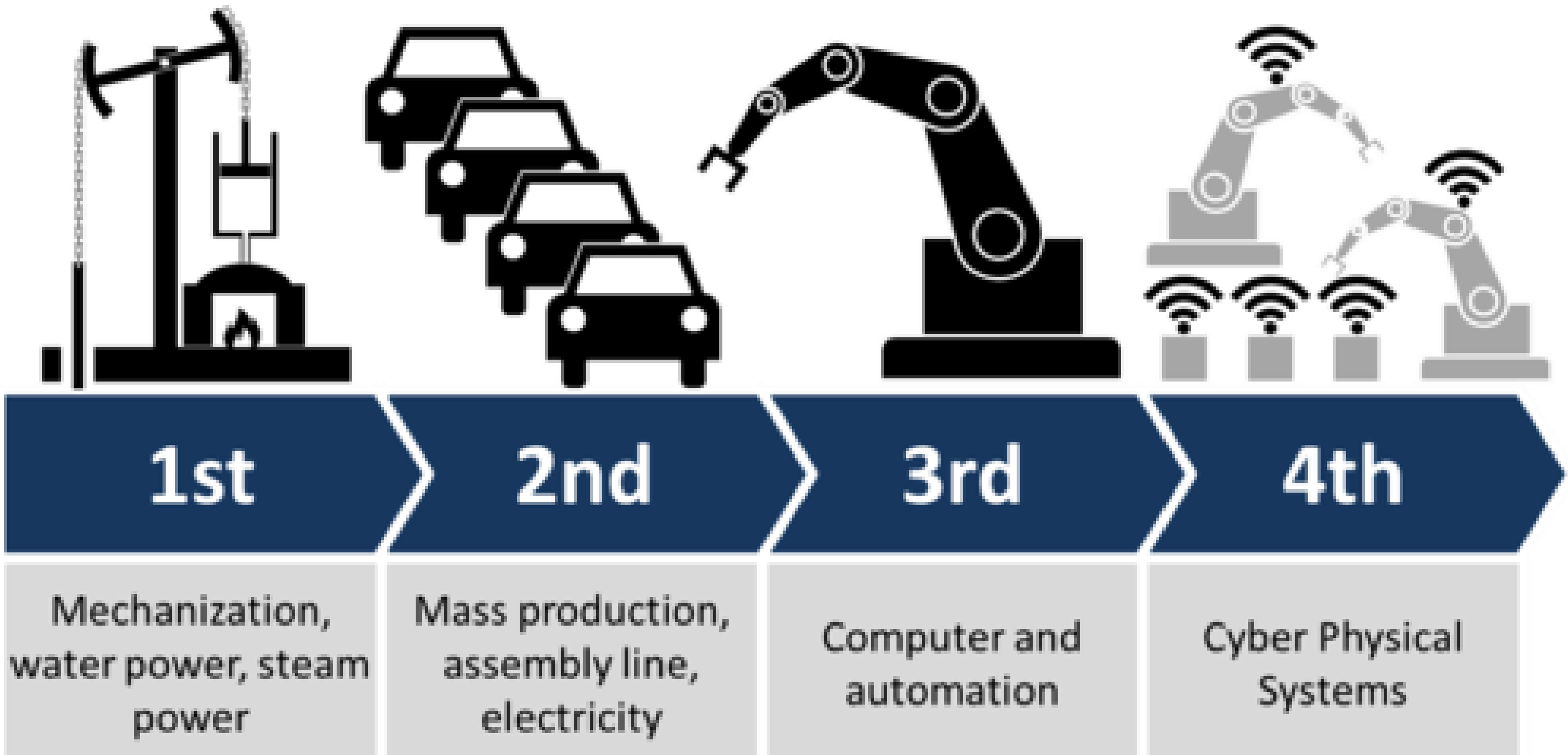
HRI $\subset$ Computer Science

- Path planning
- Optimization
- Mapping
- Localization
- Manipulation
- Reinforcement Learning
- Optimal Control
- Computer Vision
- Natural Language Processing
- …

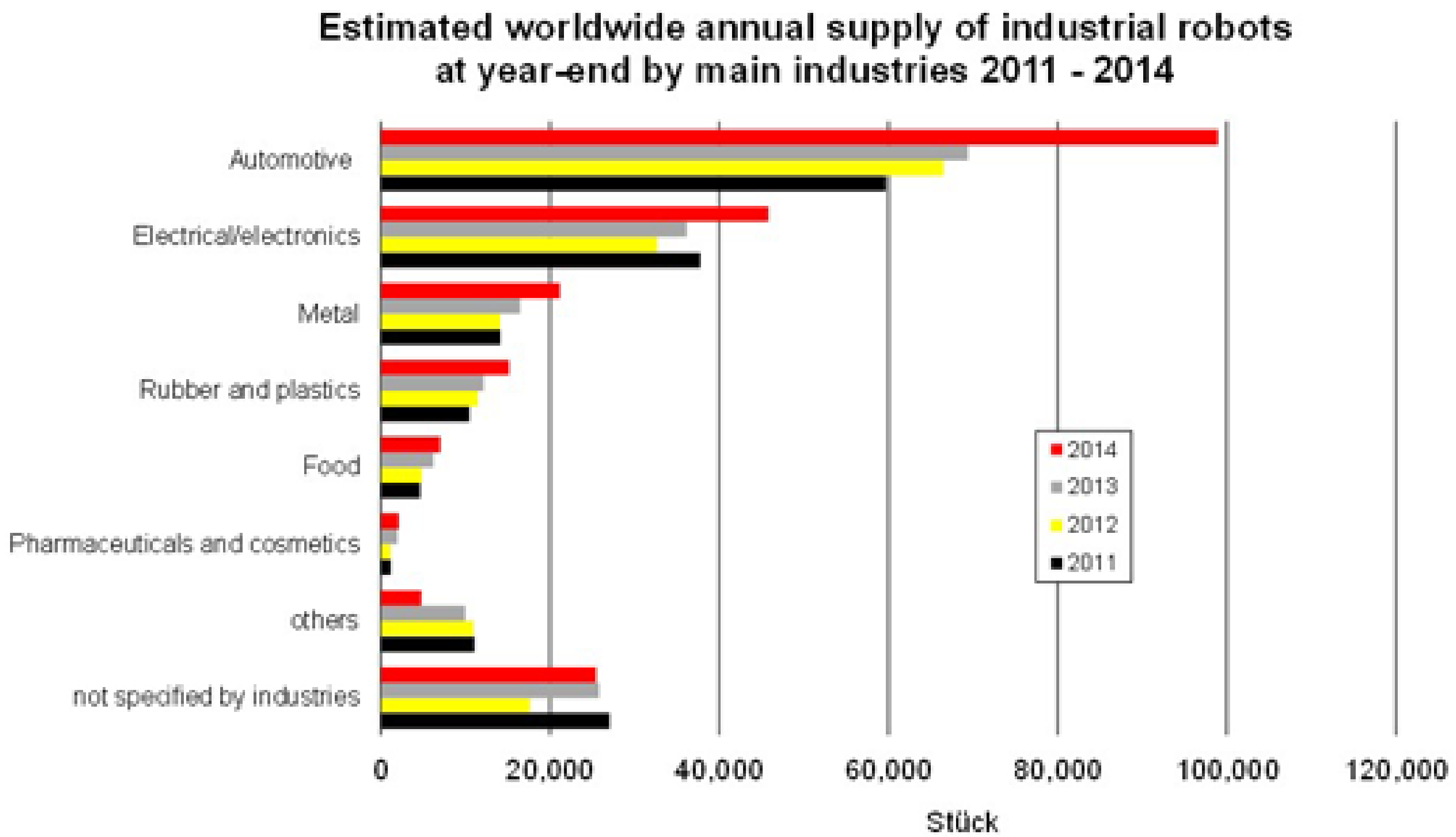
Industry 4.0

Industry 4.0

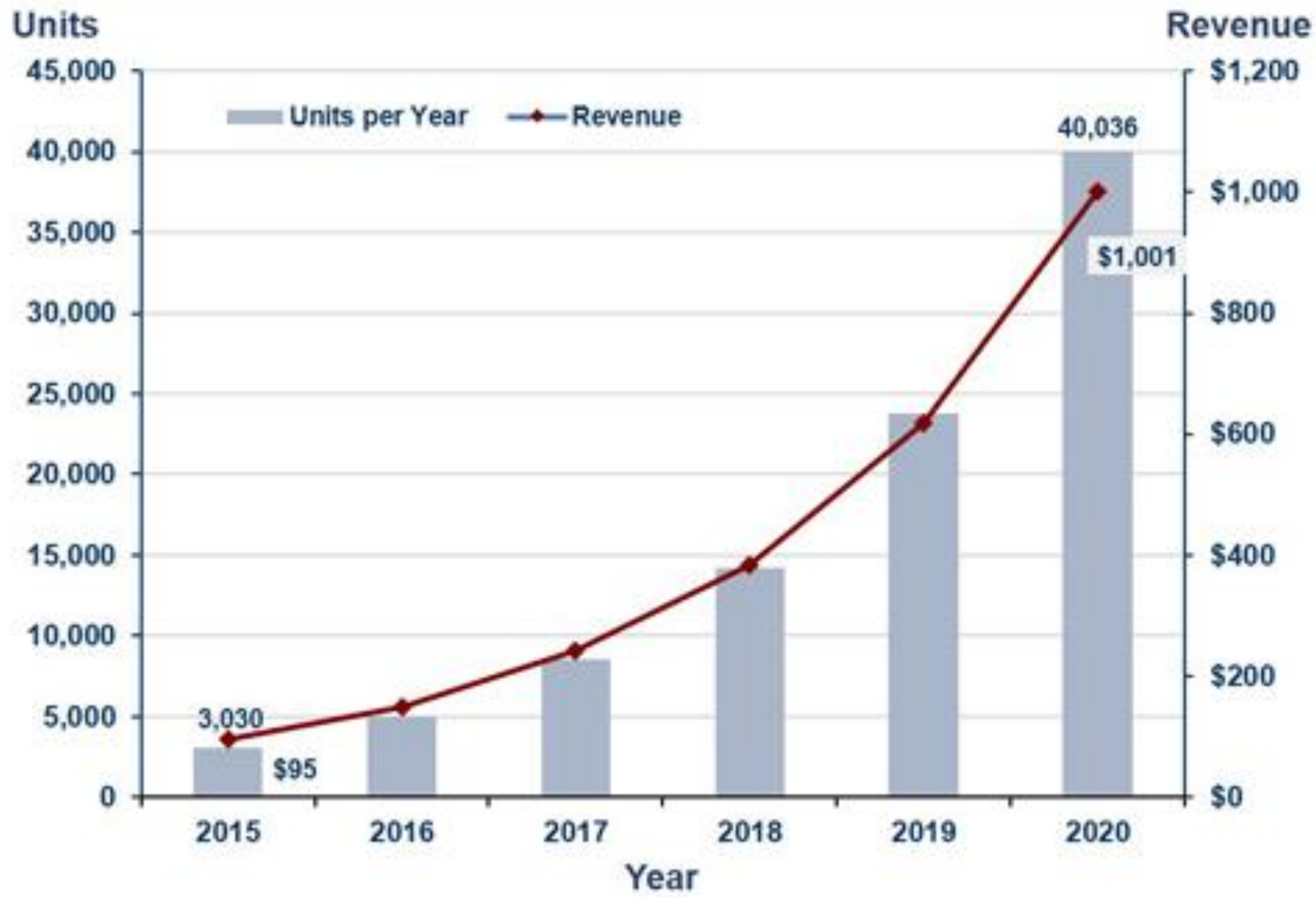
Where are all the robots?



Main drivers: automotive and electronics



Source: IFR World Robotics 2015



Collaborative robot sales projected to exceed $1 billion by 2020.
(Courtesy of ABI Research)

Introductions

Name

Student Information (Year / Program / etc.)

What interested you about this class?

Have you ever worked with any robots before? If so, which?

About Me

Brad Hayes, Assistant Professor

Collaborative AI and Robotics Laboratory (CAIRO Lab), Director

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Ph.D. Computer Science, 2015, Yale University

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http://www.bradhayes.info/

CAIRO
Collaborative AI and Robotics Laboratory

CAIRO Research Focus

Collaborative AI and Robotics Laboratory

Human-Robot Collaboration

- Modeling human behavior
- Computational models of cooperation
- Leveraging intentionality in robot behaviors
- Skill/Task learning from demonstration and language

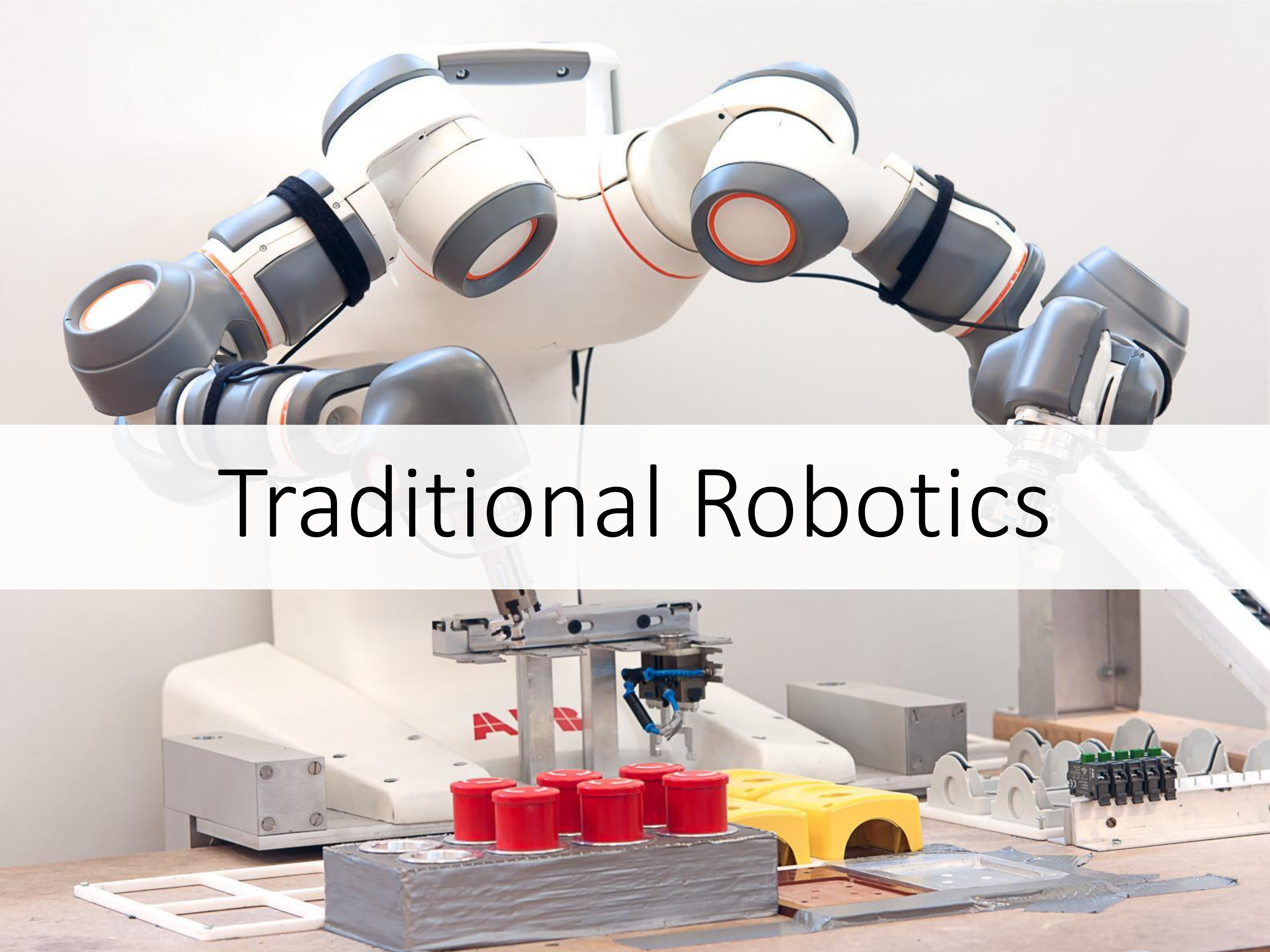
Explainable AI / Interpretable Machine Learning

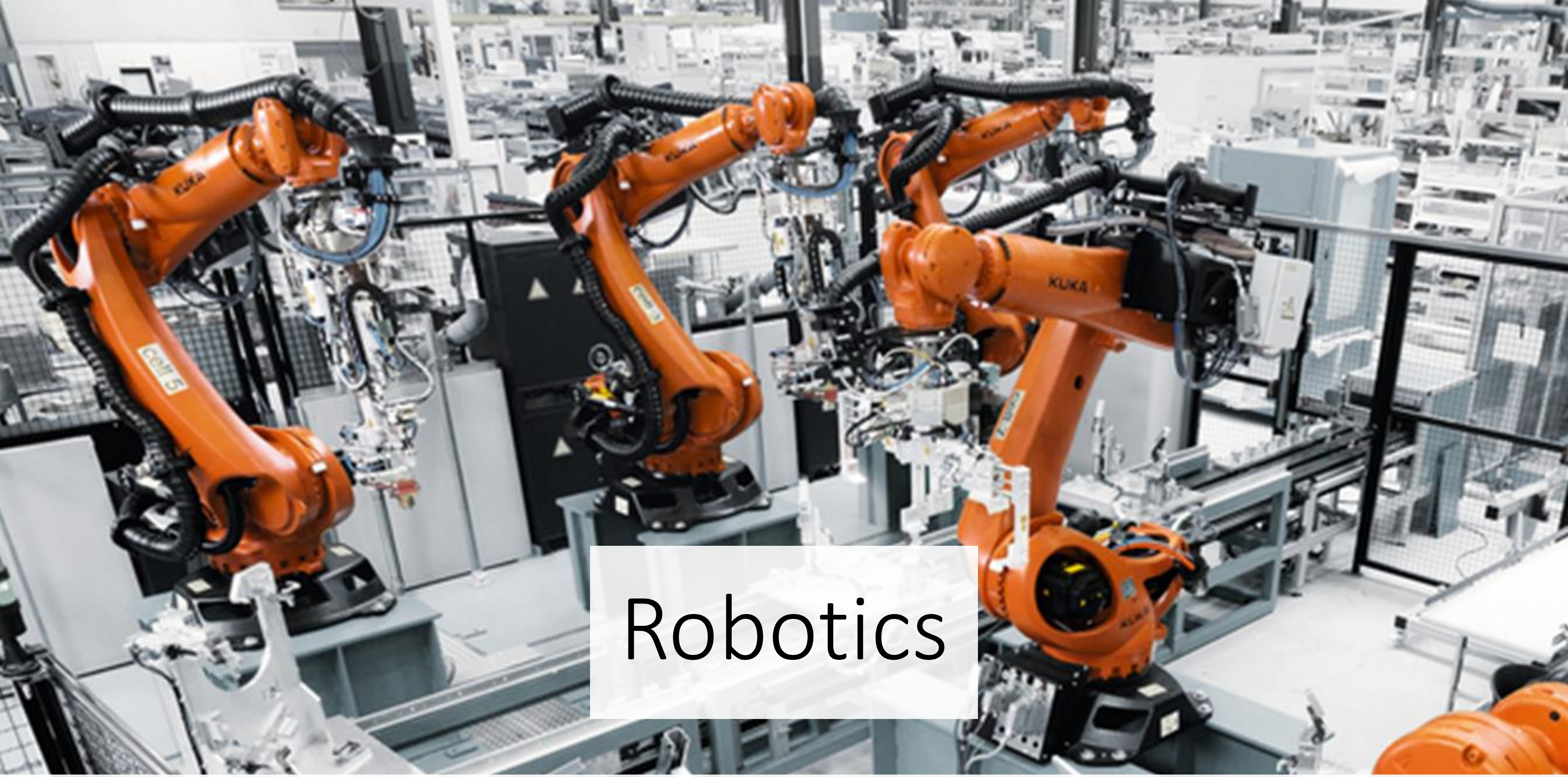
- Enable intelligent systems to explain their reasoning
- Empower novice humans to understand systems' rationale

Life-long Learning / Transfer Learning

- Giving robots the ability to draw from past experiences to inform current behaviors.

Traditional Robotics





Robotics

Algorithms that enable robots to autonomously generate behavior to achieve useful tasks

Emphasis remains on *function* and *generalization*

Traditional Robotics

Perception / State estimation

- How can we correctly register objects of interest?
- What is the state of the world?

Motion planning / control

- How can we manipulate the objects without breaking them?
- How can I manipulate objects subject to my own physical constraints?

Physics model

- What effects do my actions have on the physical world?

Task Planning

- When do I perform particular actions? In what order?

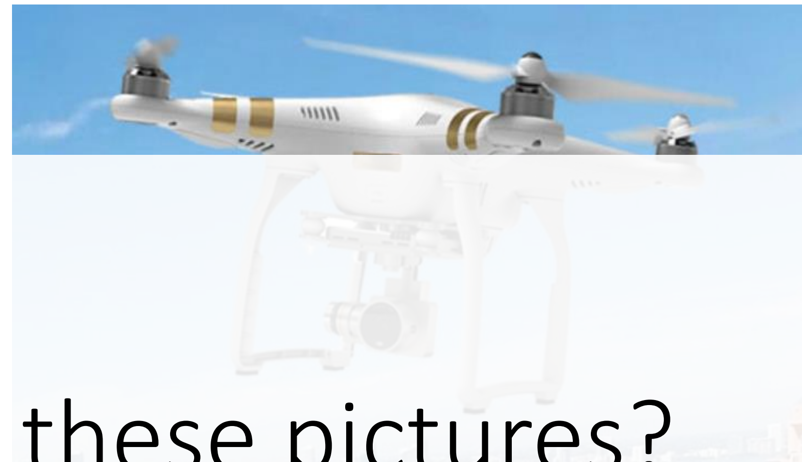
Learning

- How can I use experience to inform my action selection?

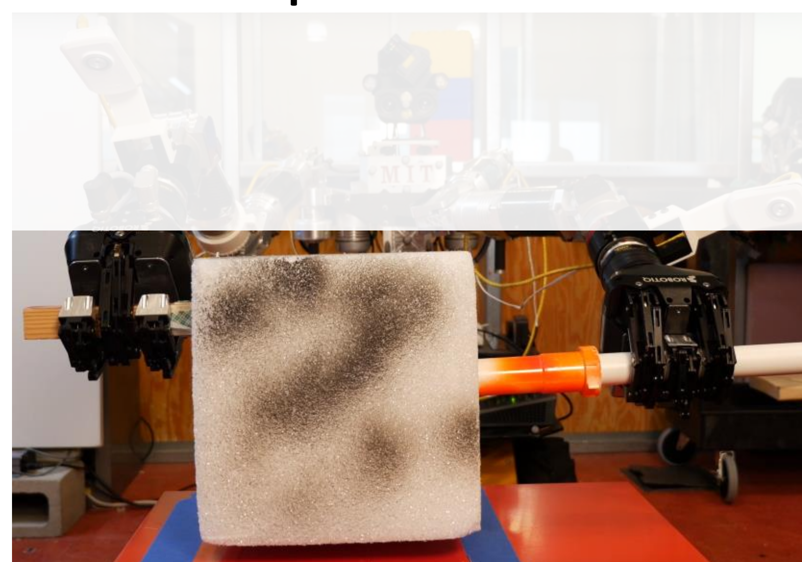
Consider a robot clearing a table…

- Perception / State estimation
- Motion planning / control
- Physics model
- Task Planning
- Learning

Autonomy is Inevitable



What's missing from these pictures?



Interactive Autonomy is Inevitable

“Traditional Robotics” isn’t enough

- Humans are non-stationary data sources
- Humans are not just obstacles, they’re critical components of a continuous decision-making process
- Actions change not only the physical world **but additionally** what people think and do.
- Requires coordination with non-mechanical agents!

Interactive Autonomy is Happening

- Perception/State Estimation
  - Human intent prediction and motion anticipation (beyond skeleton tracking)
- Physics model
  - Requires human reaction/behavior model too
- Motion planning
  - Real-time adaptation (to human motion), predictability (to move in an expected way), legibility (to signal intent)
- Task Planning
  - Collaborative planning to avoid role collision
- Learning
  - Leveraging interaction partners as training sources (Learning from Demonstration)

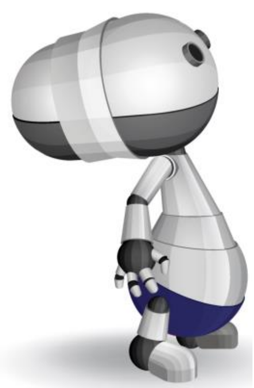
Why HRI?

- Design guidance and validation
  - How do I build a system to accomplish something?
- System evaluation
  - How do I know I’ve built something that works?
- Psychology
  - How can I characterize how my system affects human behavior?
- Societal Impact
  - How can I best develop a system to positively affect work, collaboration, or relationships?

Robot Decision Support

Course Content

We will study fundamental topics in robotics and psychology/cognitive science with the objective of introducing robustness to human interaction to the former and automation to the latter.



Course Content

- Motion
  - Motion Planning
  - Trajectory Optimization
  - Human-aware Motion Planning
- Learning from Demonstration
  - Keyframing / Kinesthetic Teaching
  - Imitation Learning
  - Social Scaffolding
- Intent
  - Human motion modeling
  - Shared Autonomy
  - Non-verbal Behaviors (Gaze, Deictic Gesture)
- Coordination
  - Theory of mind
  - Task Modeling
- Verbal Communication
  - Requesting assistance
  - Synchronizing Mental Models

Course Format

Paper Presentations:

- Each lecture with assigned reading will include two student presentations per paper-

  1 PRO (15-20 min) and 1 CON (5-10 min)

- Presentations can be done either via whiteboard or PowerPoint but are expected to be of high quality

Quizzes:

- A short quiz will be administered at the start of lecture to test high level knowledge and conceptual understanding for assigned readings. They will be graded +, ✓, or -.

Final Project:

- A semester long team-based research effort tackling an unsolved problem in Algorithmic HRI

Final Projects

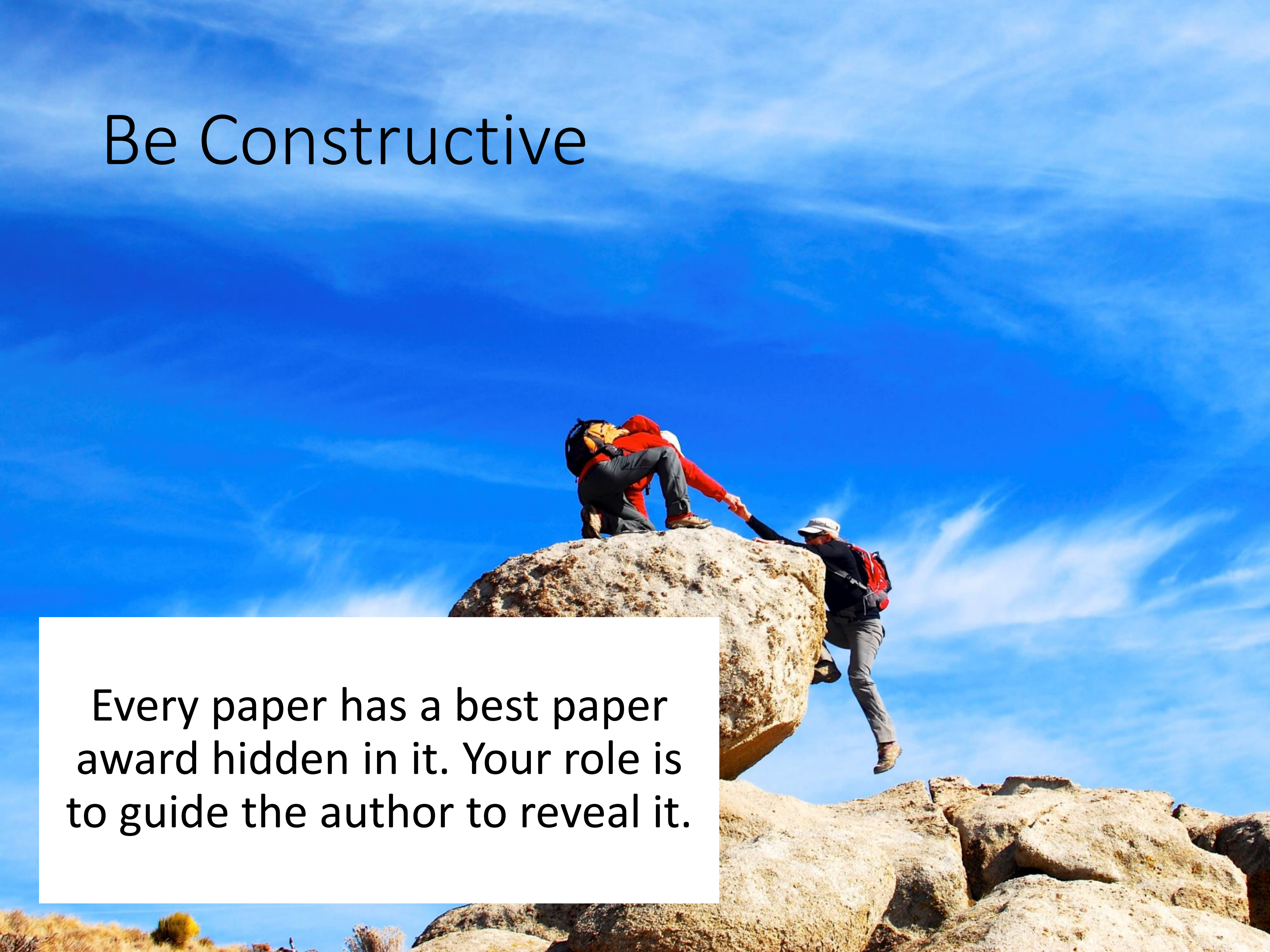
Final projects will culminate in a research paper suitable for publication at the workshop or symposium level, such as the AI-HRI Symposium at the AAAI Fall Symposium Series (AAAI-FSS)

Reviewing Papers

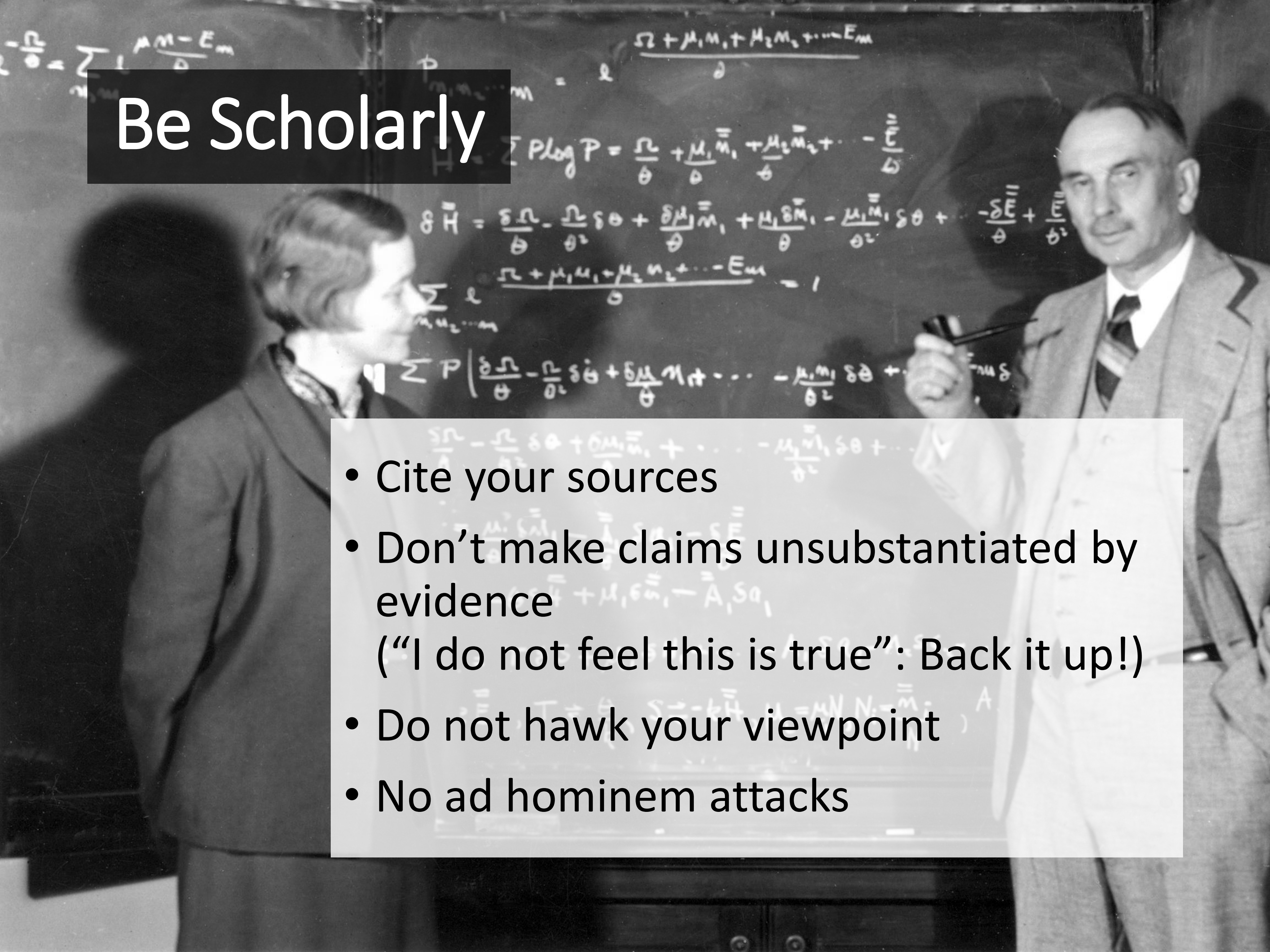
Be Compassionate

Invert your position and ask yourself how you'd feel if you received your review. If it makes your blood boil, take a break, and revise your review.

Be Constructive



Every paper has a best paper award hidden in it. Your role is to guide the author to reveal it.



Be Scholarly

- Cite your sources
- Don’t make claims unsubstantiated by evidence
  (“I do not feel this is true”: Back it up!)
- Do not hawk your viewpoint
- No ad hominem attacks

Re-Express

You should attempt to re-express your target's position so clearly, vividly, and fairly that your target says,

"Thanks, I wish I'd thought of putting it that way."

-Daniel Dennett

Summary

- Re-express target's position clearly, vividly, and fairly
- List any points of agreements
- Mention anything you have learned from the target
- Professionally introduce rebuttal or critique

Presenting Papers

- Identify key insights
- Identify corner cases
- Identify scaling issues
- Identify unrealistic application constraints
- Avoid being procedural

Presenting a Paper

1. Bigger picture
2. Motivation
3. Problem Statement
4. Why is this hard
5. Key insight
6. Details
7. Results
8. Broader picture
9. Restate the key insight that addressed the problem

Expected Background

CS Foundations

- Programming (Python or C++)
- Networking
- Systems-building

Presentation and Written Skills

- LaTeX

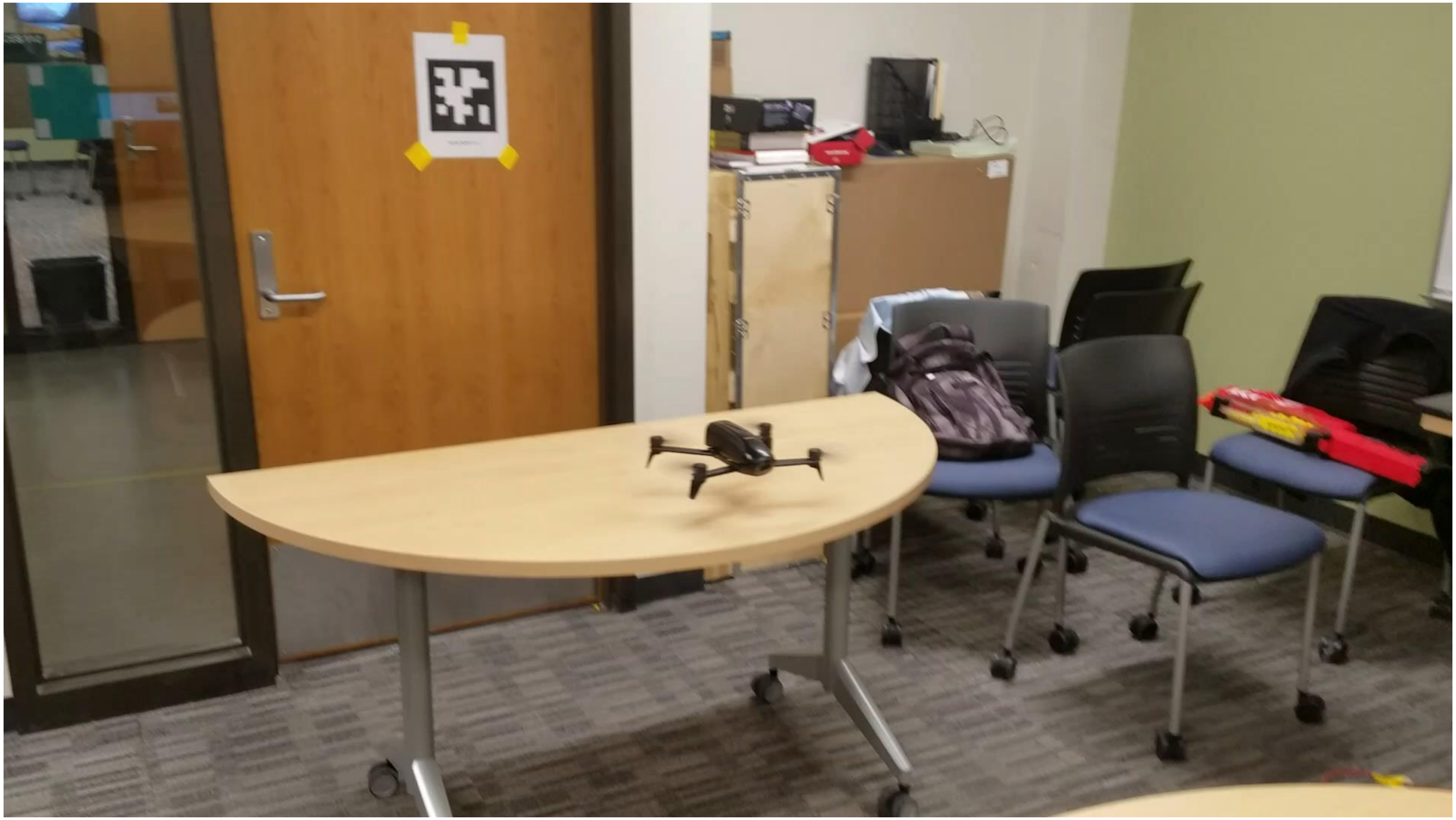
Bonus Skills

- Debugging (e.g., pdb or gdb)
- Artificial Intelligence / Machine Learning

Things You Will Know Afterwards

- Robot Operating System
- Control on a real robot platform
- Probabilistic Motion Planning
- Task Planning
- Interaction Design
- Experimental Design / User Study Analysis
- Applied Artificial Intelligence and Machine Learning
  - Modeling
  - Active Learning
  - Learning from Demonstration

Robotics is Hard,
Nobody knows everything



Class Schedule

Course Website:

Moodle Link Forthcoming

Slides posted after each lecture

Location:

KOBL 235

Time:

5:00pm – 6:15pm

Office Hours:

By Appointment (ECES 128)

Grading

Class Participation – 10%

Attend regularly, engage in discussions!

Paper Presentations – 30%

Make presentations worth your peers’ time!

Quizzes – 20%

Do the reading, and this will be easy!

Final Project – 40%

This is why you’re taking the course, make it count!

First Reading Assignment

Computational Human-Robot Interaction

http://guyhoffman.com/publications/ThomazHoffmanCakmak16.pdf

Survey of recent papers in the field:

Serve as inspiration for final projects

Catalyst for choosing special topics to cover