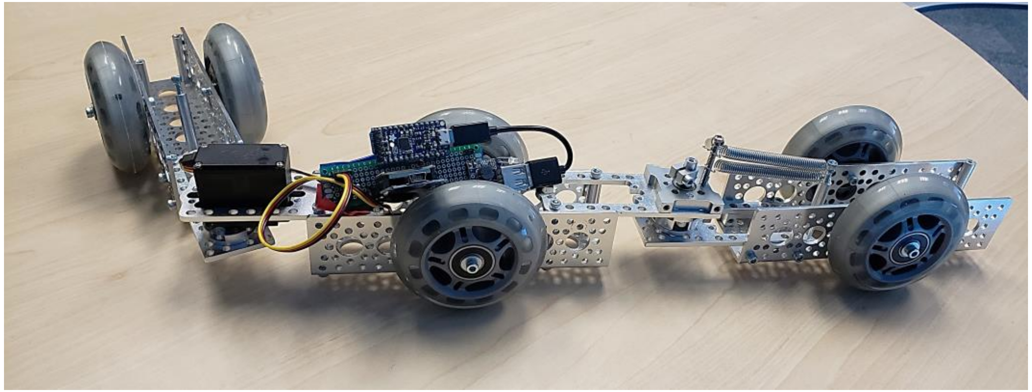
COMS W4733: Computational Aspects of Robotics

Lecture 1: Course Logistics and Introduction



Instructor: Tony Dear

Today

- Course logistics
- What does the field of robotics entail?
- What topics will we cover in this course?

Course Staff

- Instructor: Tony Dear <tony.dear@columbia.edu>
  - Office hours in 618 CEPSR, time TBD

- Instructional assistants:
  - Bryan Li <b.li@columbia.edu> (head TA)
  - Matthew Chan <mac2474@columbia.edu>
  - Jiaheng Hu <jh3916@columbia.edu>
  - Yuxiang Liu <yl3996@columbia.edu>

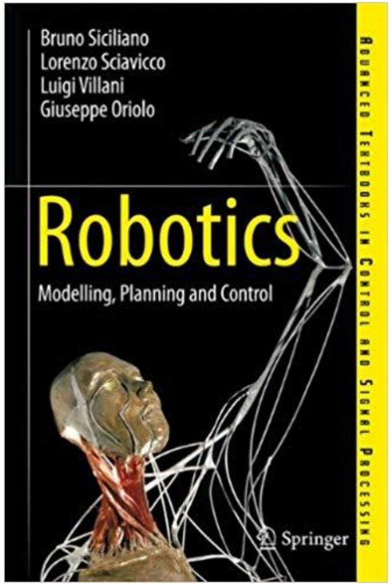
- Office hours in 122 Mudd, times TBD

Lectures and Notes

- MW 4:10pm – 5:25pm in 633 Mudd
- Mix of slides and blackboard; your best bet is to attend all lectures

- Recommended textbook readings
- Siciliano, Sciavicco, Villani, Oriolo (SSVO)
- *Robotics: Modelling, Planning, and Control*

- Additional notes or readings posted as appropriate



Online Resources

- Courseworks / Canvas
  - Master site—links to all resources, Campuswire, Gradescope
- Campuswire: Discussion forum for all course-related questions
  - Make all questions public if possible, and help each other out!
  - Only urgent or private logistical questions thru email
- Gradescope: Submission of homework assignments
  - We'll also track grades here until the end of the semester
  - Make sure your name matches Canvas

Assessments

Homework (x3)	30%
Midterm	25%
Case studies (x3)	45%

- First half of course: Fundamental ideas in manipulator/mobile robotics

- **Homeworks** consist of written and programming combination of problems
- Latter mostly done in Python and/or ROS
- **Midterm** just before spring break marks halfway point

Papers / Case Studies

- Robotics is a booming research field—state of the art and new results published in technical papers every day
- Whether in academia or industry, reading and analyzing research papers are necessary skills for finding the latest results
- Also important for deeper study of other technical fields

- Second half of this course: we will cover more advanced robotics topics
- Supplemented by several **seminal research papers** in the field
- Learn how to read and understand them; assignments will ask you to analyze them from different angles and implement ideas

Academic Integrity and Collaboration

- Collaboration encouraged!
  - In class (polling), Campuswire, and on assignments
  - Discuss assignments, but **submit your own writeups**
  - **Acknowledge all collaborators**

- Any suspicion of passing off other work, either that of your peers or other (online) sources, as your own will be investigated immediately.

What should I take away from this course?

- Recommended prereq: Previous course in AI, ML, and related areas
  - Mathematical maturity with probability and linear algebra, programming experience

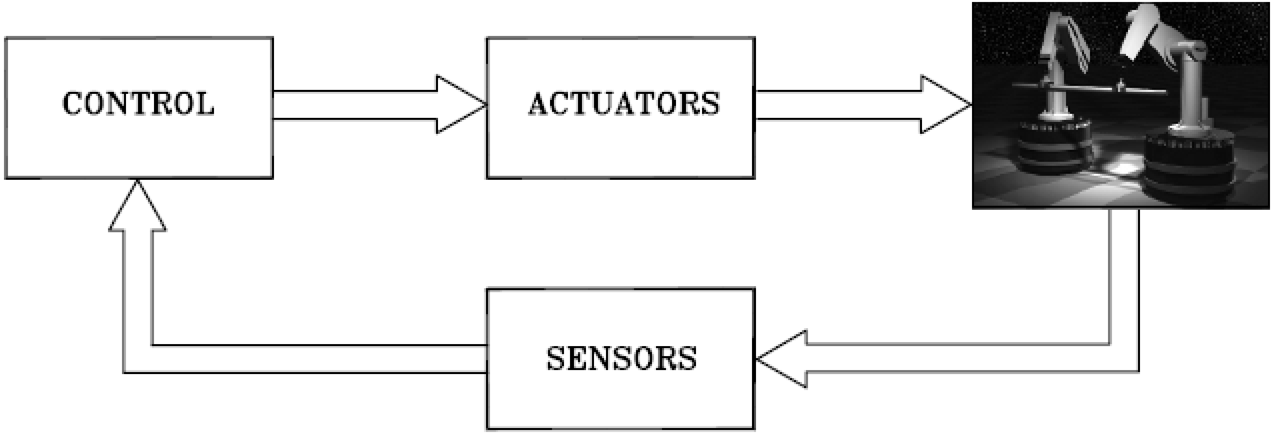
- Goal #1: Be able to read and analyze technical research papers

- Goal #2: Learn the fundamental problems of modern robotics as they relate to computer scientists and their roles in solving them

- Goal #3: Strengthen underlying knowledge in mathematics and algorithms

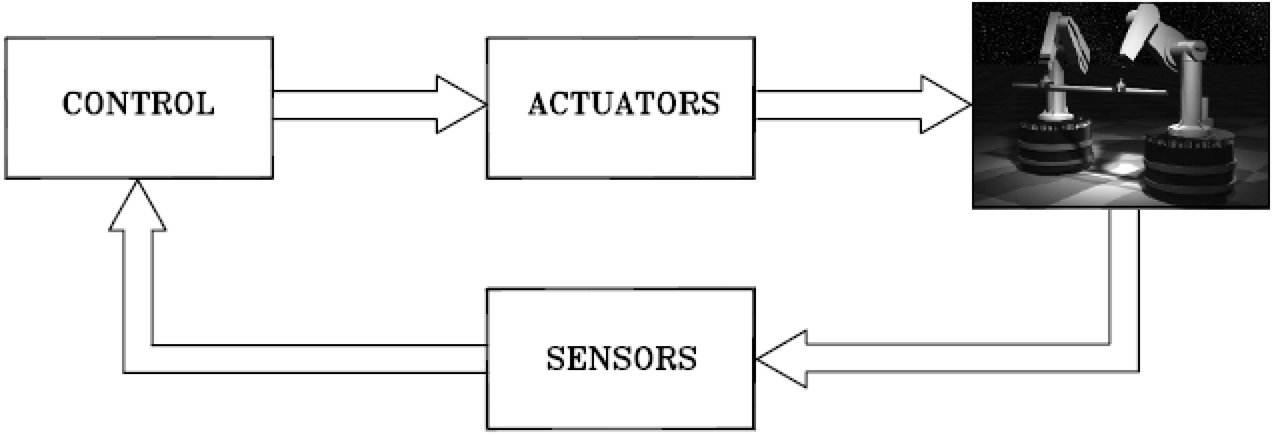
What is robotics?

- *Robota*: Czech for useful and forced labor
- Philosophically, any mechanism that can enrich **human** lives by assisting us
- Modern understanding:



What is robotics?

- Roboticists are concerned with some sort of *intelligent connection* between perception and action embedded into a *mechanical system*
- Interdisciplinary field with mechanics, control, computer science, electronics

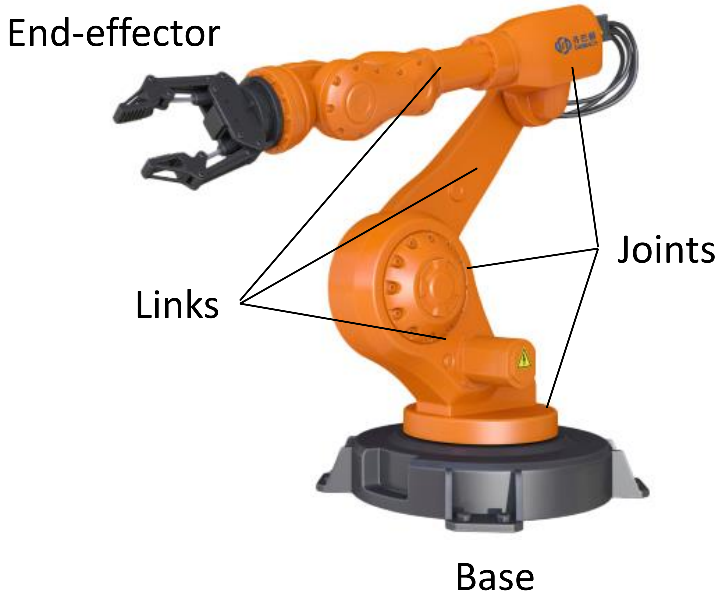


Manipulator Robots

- **Manipulators** are heavily used in many industrial settings

- Usually stationary, taking the form of an *open kinematic chain* between a **base** and an **end-effector**

- Often concerned with these robots' *degrees of freedom*

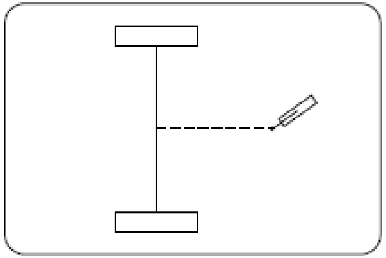
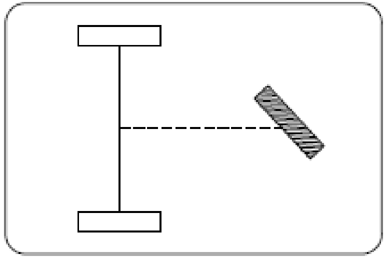
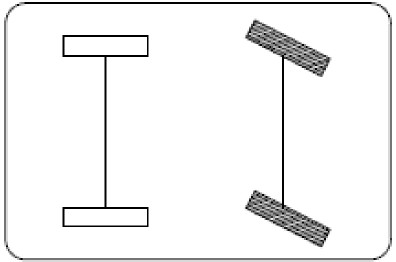


Manipulator Robots

- Lots of development in 1950s-1970s: PUMA arm, Stanford arm, SCARA arm…
- Lot of use in industry for pick-and-place, assembly operations
- Very useful for menial and repetitive labor

Mobile Robots

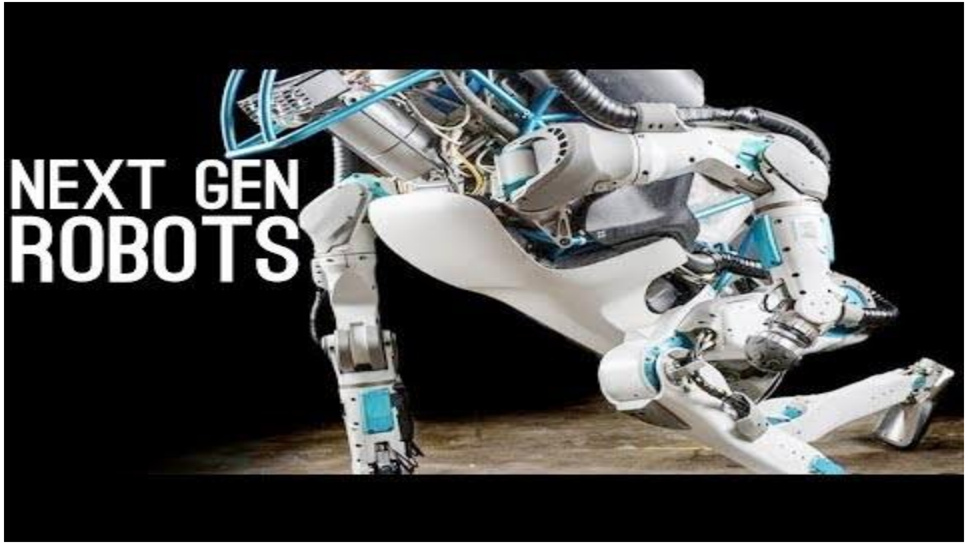
- Robots that *move*, most commonly with wheels or legs
- Different types of wheels and wheel placements lead to vastly different capabilities and limitations
  - Ex: Differential-drive, tricycle, Ackermann drive, omnidirectional

- With legs, often have to consider how to synchronize periodic ground contact to generate stable and efficient gaits

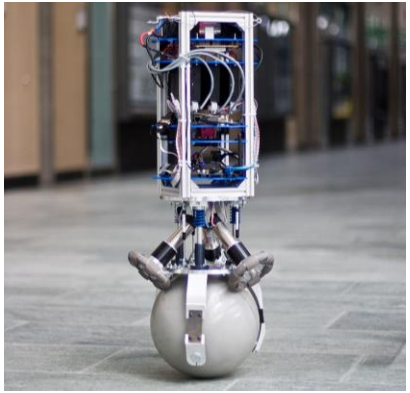
Mobile Robots

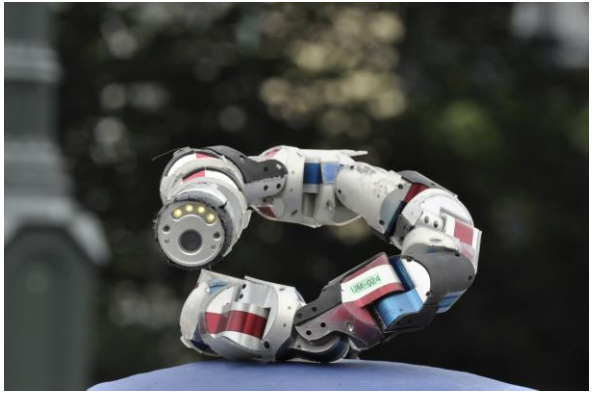
- Legged robots often take inspiration from *biology*
- Not only bipeds (humans), but also quadrupeds and hexapods (insects)

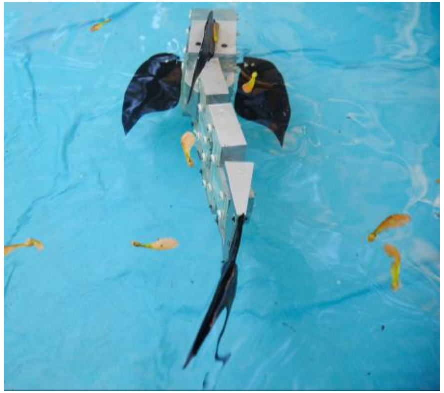


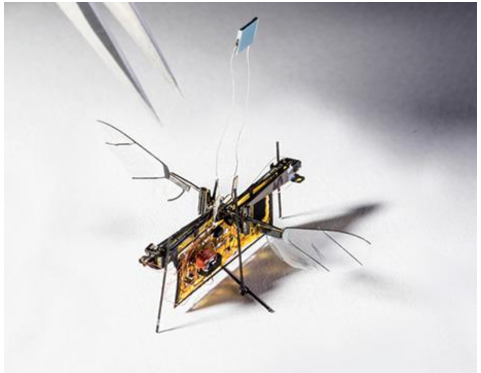
Other Classes of Robots

- Ballbots
- Snake robots
- Swimming robots
- Flying robots









Applications: Field Robotics

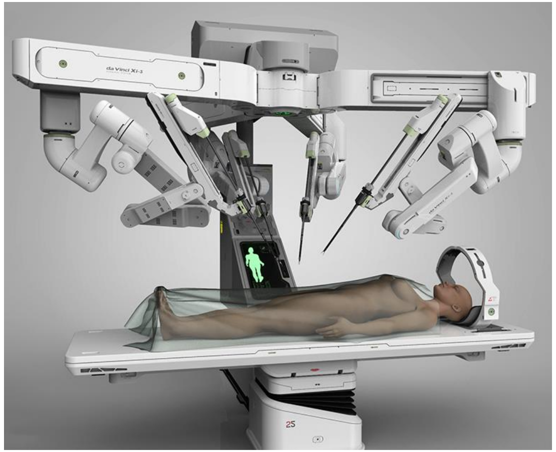
- Space exploration
  - Mars rovers

- Disaster recovery
  - Search and rescue

- Reconnaissance

Applications: Service/Personal Robotics

- Autonomous cars
- Minimally invasive surgery
- Home assistance



Course Outline

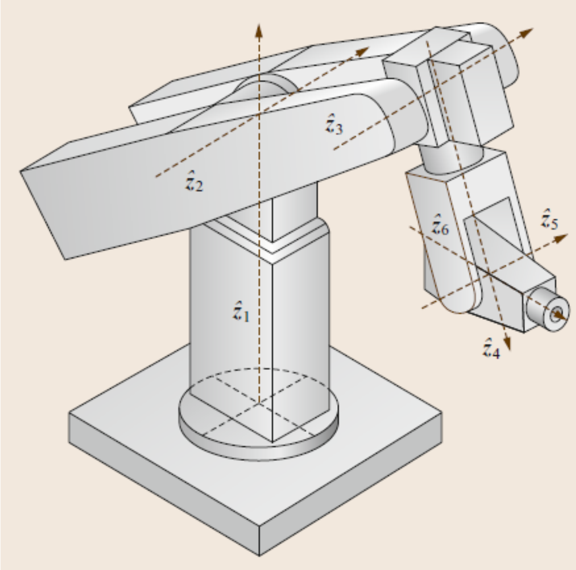
- Robot kinematics
- Mobile robots, bug algorithms, and motion control

- Motion planning algorithms
- State estimation
- Computer vision
- Robot learning

Robot Kinematics

- Particularly with manipulators, need to characterize positioning and orienting of our robots
- Mathematical tools: Rotation matrices, homogeneous transforms

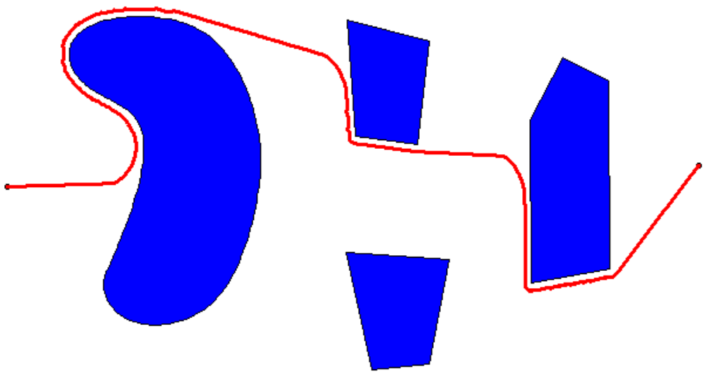
- Relationships between joint and whole arm configurations and velocities
- Jacobian mapping to determine properties such as singularities and redundancy



Mobile Robots and Bug Algorithms

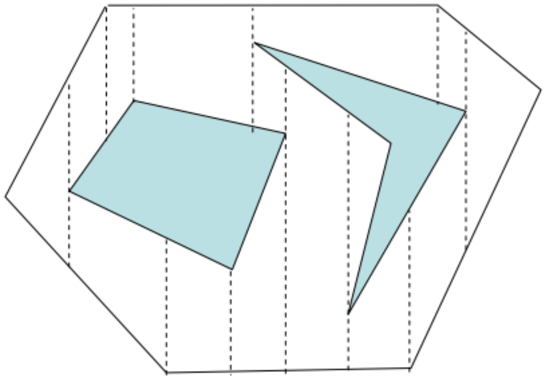
- Wheeled robots modeled based on *nonholonomic constraints*
- Problem is now locomotion instead of manipulation

- Point-to-point path/trajectory planning
  - How are trajectories represented?
- How much knowledge does the robot have?
  - Global vs local planning



Motion Planning

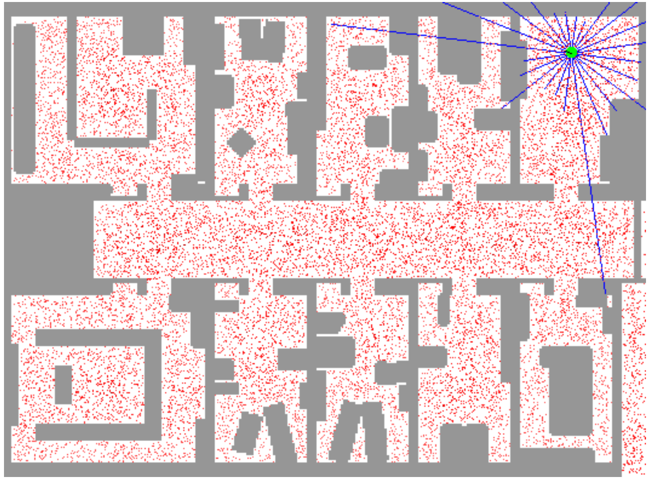
- Real robots are not actually bugs!
- They have structure, constraints, limitations
  - How do we plan to account for them?
  - How to deal with obstacles in the world?



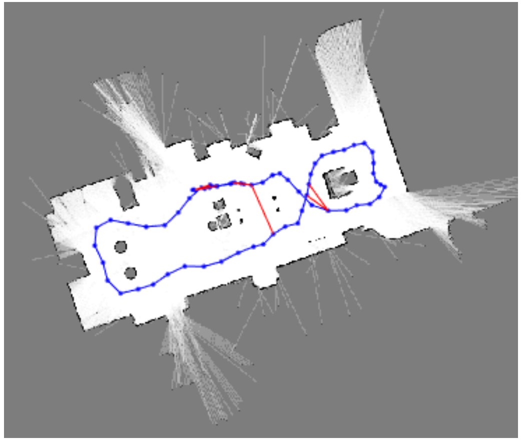
- Cell decomposition
- Graph-based methods
- Potential fields
- Probabilistic planning

State Estimation

- Lots of uncertainty in the real world
- How does a robot know where it is or what configuration it is in?
- How do we incorporate noisy measurements?



- Particle filters
- Kalman filters
- Localization—SLAM



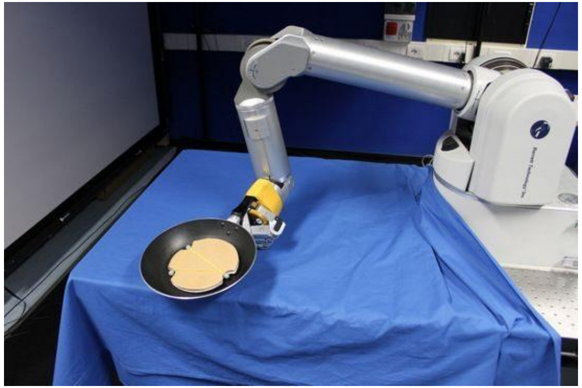
Computer Vision

- Vision is a basic percept for many robots
- How do we process images into features and numerical information?
  - Edge detection, segmentation
- How do we combine multiple images?

- Pose estimation—measuring correspondences
- Visual servoing
  - Combining visual feedback with control

Robot Learning

- How can robots adapt to new environments?
- What problems can learning help with?



- Model learning for control
- Reinforcement learning for planning
- Learning from demonstration
- Dealing with data

For Next Class…

- Make sure to sign up on Gradescope and Campuswire
- Acquire textbook, start on readings
  - Review matrix algebra if needed (Appendix A)

- Next 3 weeks: Manipulator kinematics
- HW 1 out next week

References

- Siciliano, Sciavicco, Villani, Oriolo. *Robotics: Modelling, Planning, and Control*

- Geku Automation: Snooker robot (https://www.youtube.com/watch?v=nH08-JQwsZQ)
- ColdFusion robot compilation: Atlas, Spot Mini, Handle, Asimo, da Vinci, Ocean Onee, SOFI, Open Cat (https://www.youtube.com/watch?v=8vIT2da6N_o)
- Science Channel: Curiosity rover (https://www.youtube.com/watch?v=nQ365jzwk5w)
- CNN: Search and rescue robots (https://www.youtube.com/watch?v=FrgEbx6esYE)

- ETH Zurich Rezero BallBot
- CMU Biorobotics Snakebot
- UW RoboFly
- UC Berkeley PR2 laundry-folding robot
- Intuitive Surgical da Vinci surgical robot