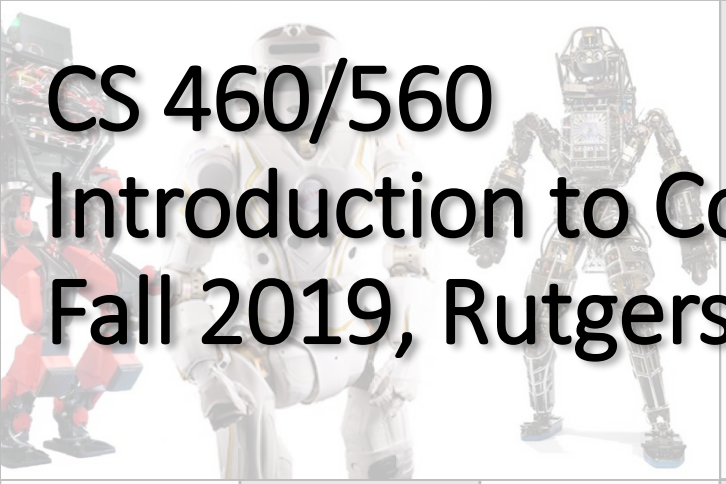
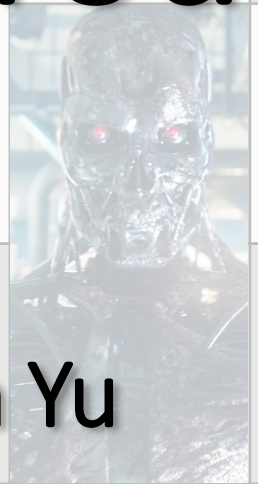
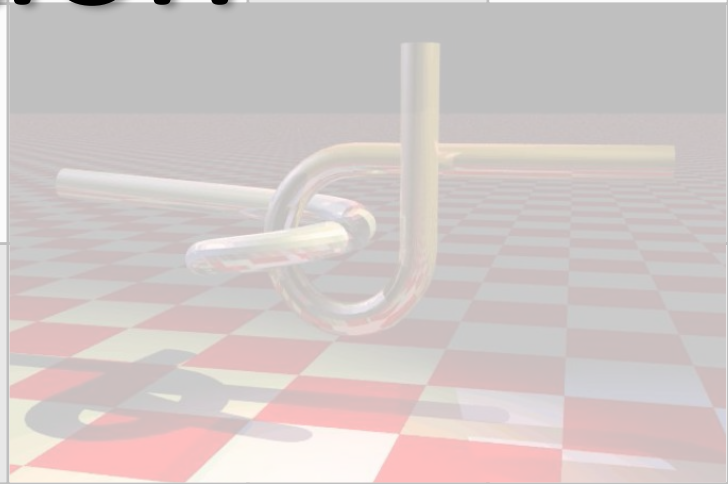
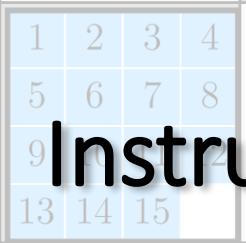
CS 460/560
Introduction to Computational Robotics
Fall 2019, Rutgers University



Lecture 01
Introduction







Instructor: Jingjin Yu

Lecture Outline

What is a robot? Why use them?

Why study robotics?

A little bit of the ancient history

Rough taxonomy

Today's robots and applications

The three components – sensing, planning, and control

What is a Robot?

A robot is an **autonomous machine** handling repetitive/complex tasks

- ⇨Most have all sensing-computation-control sub-components
- ⇨But may only have a subset of these components

Waymo (google) autonomous car

Kiva warehouse system (Amazon Robotics)

Atlas (Boston Dynamics)

da Vinci surgical system (Intuitive Surgical)

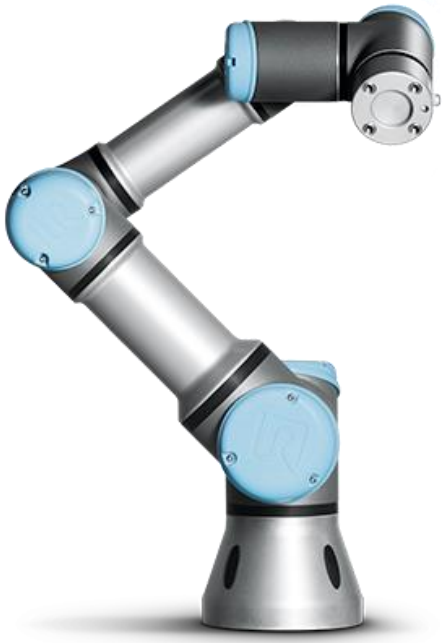
Weasel ball

Why Robots?

Help us with the work!

- ⇨Duplication or extensions of certain human capability
  - ⇨ Capable of precisely exerting small or very large forces
  - ⇨ Pose precise to micrometer level and beyond

Robot crane dance, 80-foot tall, 150 tons
(Santosa Island in Singapore)

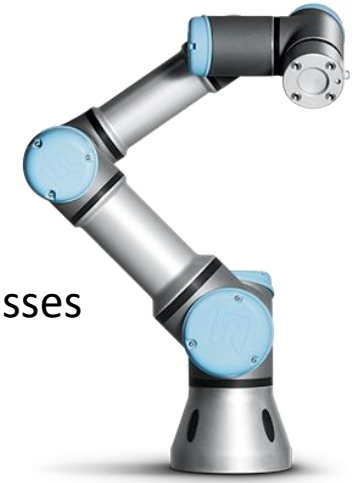


Universal Robots UR5e
Pose repeatability: $\pm 0.03mm$

Why Robots?

Help us with the work!

- ⇨Duplication or extensions of certain human capability
  - ⇨ Capable of precisely exerting small or very large forces
  - ⇨ Pose precise to micrometer level and beyond
- ⇨Can be better in many ways
  - ⇨ High consistency – statistically, less variance than manual processes
  - ⇨ Durable and high speed
    - ⇨ Robots, when properly designed, do not experience fatigue
  - ⇨ Safer for both workers and consumers
    - ⇨ Examples for workers: mining, mine removal
    - ⇨ Examples for consumers: food packing, surgery, taxi



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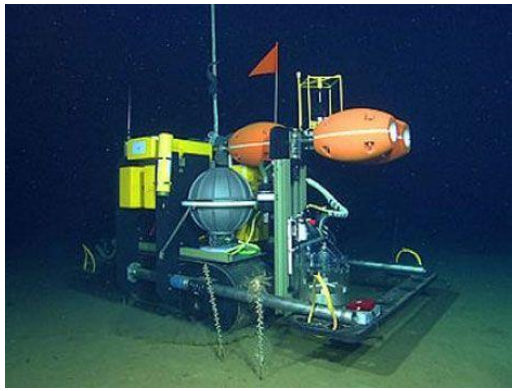
    - ⇨ Examples for consumers: food packing, surgery, taxi
  - ⇨ More accessible
    - ⇨ Space and outer space
    - ⇨ Pipes, underground, under water
    - ⇨ Other harsh environments

Can also be companions!

Curiosity rover

Big Bertha “boring” machine



Benthic rover (MBARI)

Sony Aibo

Why Study Robotics?

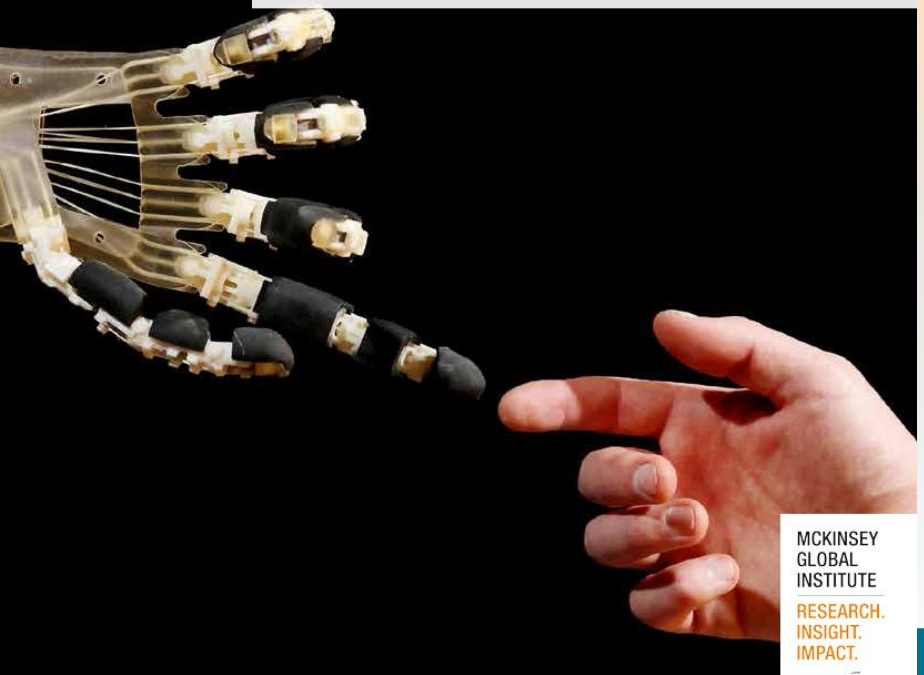
McKinsey&Company

MCKINSEY GLOBAL INSTITUTE

A FUTURE THAT WORKS: AUTOMATION, EMPLOYMENT, AND PRODUCTIVITY

JANUARY 2017

EXECUTIVE SUMMARY



MCKINSEY GLOBAL INSTITUTE

RESEARCH. INSIGHT. IMPACT.

AUTOMATION

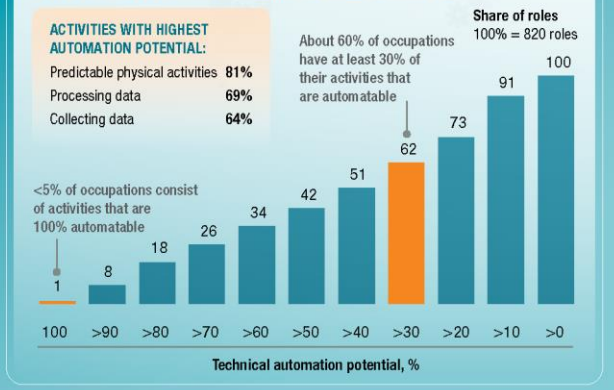
A global force that will transform economies and the workforce

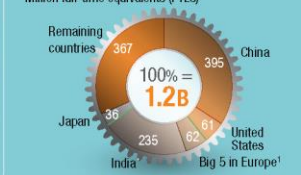
Technical automation potential by adapting currently demonstrated technologies

While few occupations are fully automatable, 60 percent of all occupations have at least 30 percent technically automatable activities

ACTIVITIES WITH HIGHEST AUTOMATION POTENTIAL:

Predictable physical activities	81%
Processing data	69%
Collecting data	64%



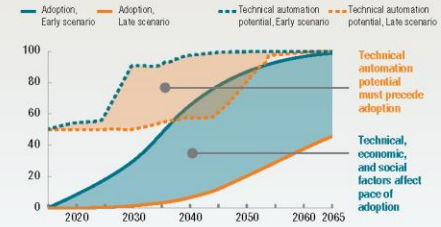


¹ France, Germany, Italy, Spain, and the United Kingdom.

Five factors affecting pace and extent of adoption

1. **TECHNICAL FEASIBILITY** Technology has to be invented, integrated, and adapted into solutions for specific case use
2. **COST OF DEVELOPING AND DEPLOYING SOLUTIONS** Hardware and software costs
3. **LABOR MARKET DYNAMICS** The supply, demand, and costs of human labor affect which activities will be automated
4. **ECONOMIC BENEFITS** Include higher throughput and increased quality, alongside labor cost savings
5. **REGULATORY AND SOCIAL ACCEPTANCE** Even when automation makes business sense, adoption can take time

Scenarios around time spent on current work activities, %

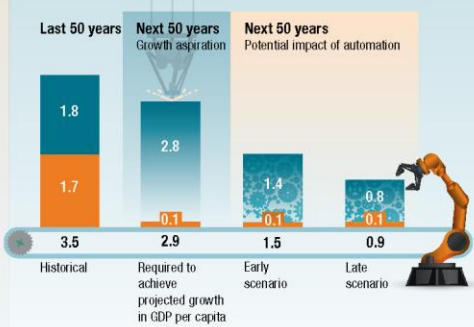


MCKINSEY GLOBAL INSTITUTE

Automation will boost global productivity and raise GDP

G19 plus Nigeria

- **Productivity growth, %** Automation can help provide some of the productivity needed to achieve future economic growth
- **Employment growth, %** will slow drastically because of aging

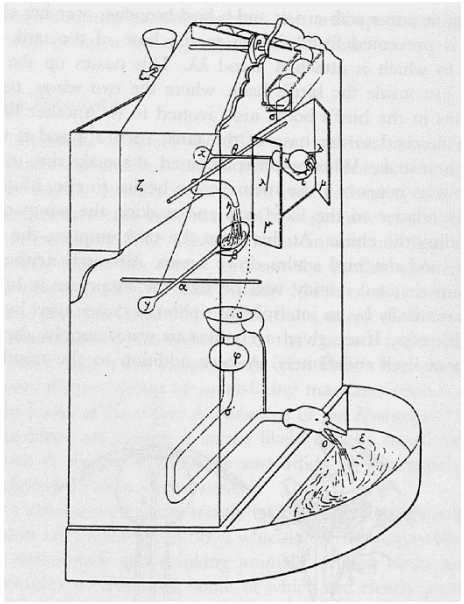


McKinsey&Company

A Bit of Ancient History of Robots

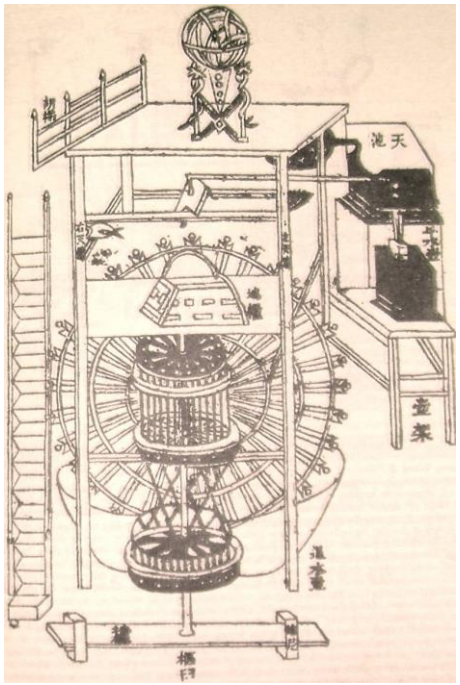
Early autonomous mechanical systems

- ⇨Escape mechanisms (Ctesibius, ~270 BC)
- ⇨Seismometer (Zhang Heng, ~150 AD)
- ⇨Water astronomical clock (Su Song, 1066 AD)
- ⇨Most of these are cleverly made but still relatively simple automata
- ⇨Read more on wikipedia (robot)



An early escape mechanism

Zhang Heng's seismometer



Su Song's water clock

Taxonomy

We may roughly classify robots based on certain properties

- ⇨Autonomy and complexity
  - ⇨ Indoor or outdoor, structured or unstructured environment

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- ⇨Terrain (ground robots)
  - ⇨ Fixed base
  - ⇨ Flat surface
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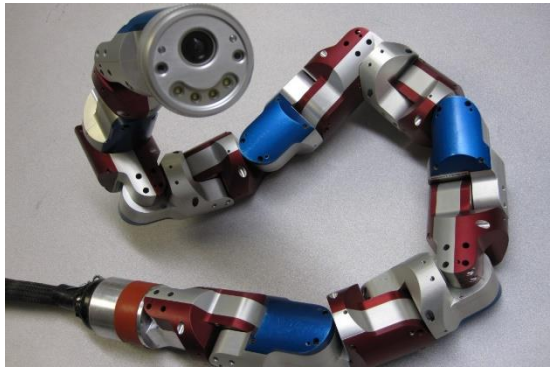
  - ⇨ Flat surface
  - ⇨ Uneven surface
- ⇨Types of locomotion (ground robots)
  - ⇨ Wheeled
  - ⇨ Legged
  - ⇨ Railed
  - ⇨ Snake



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  - ⇨ Railed
  - ⇨ Snake
- ⇨Body type
  - ⇨ Rigid
  - ⇨ Soft
- ⇨For aerial robots, fixed wing, multi-rotors, or a mixture.

Robot Systems in Practice

We will look many examples (of current robotics applications)

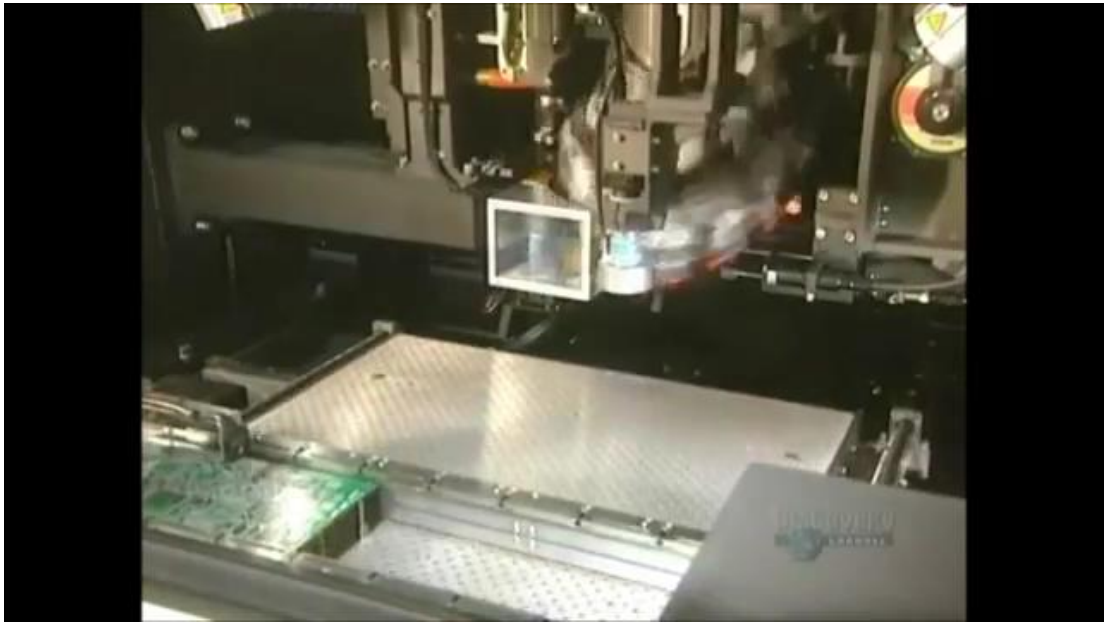
- ⇨Industrial robots
  - ⇨ Manufacturing (e.g., cars, food, electronics)
  - ⇨ Good/freight handling systems
  - ⇨ Construction
- ⇨Service robots and machines
  - ⇨ Tour guides
  - ⇨ Commercial and home cleaning robots
  - ⇨ Lawn care
  - ⇨ Delivery
- ⇨Transportation – autonomous vehicles
- ⇨Medical
- ⇨Agriculture
- ⇨Scientific and exploration
- ⇨Social and entertainment
- ⇨Military (just make other robots tougher and/or add a gun)
- ⇨Many many more…

Industrial: Manufacturing

Large scale: car assembly

⇨Note the parallelism

Small scale: circuit boards



Full videos:
https://youtu.be/LVtBjFUfFLE
https://youtu.be/cvkHbGo-OKc

Industrial: Shipping

Large scale: port automation (Rotterdam, Brisbane, Singapore)

Container cranes

Straddle carriers

Industrial: Packing

Normal scale: warehouse systems

Kiva warehouse system (Amazon Robotics)

https://youtu.be/z_R8feyCu-M

Industrial: Construction

(huge) Boring machine (semiautomatic)

Bertha tunneling machine

https://youtu.be/qx_EjMlLgqY

Industrial: Food

Pancake staking robot (ABB)

3D food printing

Food Ink

https://youtu.be/v9oeOYMRvuQ

3D printed candy (ChefJet Pro)

Service: Museum Tours

⇨Tour guide for visitors in museums, parks, etc. providing info

⇨Remote tour robot

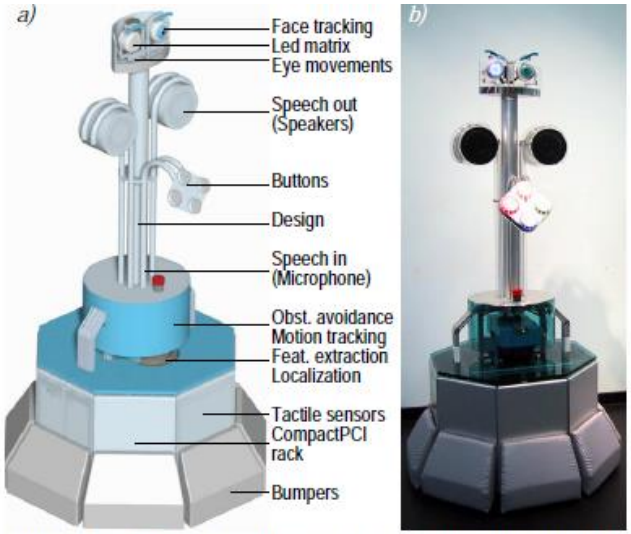


Figure 1: a) Functionality of the tour guide robot RoboX. b) An image of RoboX 9.

EPFL museum tour guide (2002)

More modern version

Service: Cleaning

Many robots doing cleaning tasks

- ⇨Commercial
- ⇨Home

iRobot Roomba

Intellibot cleaning robots

Mint hard floor cleaning robot

Service: Lawn Mowing

Strong competition in the area

- ⇨Easier than making a home cleaning robot
- ⇨Mowing is a labor-intensive task people don’t want to do
- ⇨Not very smart – most just randomly moving with self charging

RoboMow (RoboMow)

Landroid (Word)

Tango (Jone Deere)

RoboMower (Friendly Robotics)

Service: Delivery

Many experimental delivery drones

⇨Amazon, google, DHL, Wal-mart, …

Also, ground delivery robots

⇨Uber?

⇨“Starship” – can be problematic

⇨Amazon – similar system in testing

Amazon Prime Air

Google Project Wing

Starship delivery robot

DHL delivery drone

Transportation: Autonomous Vehicles

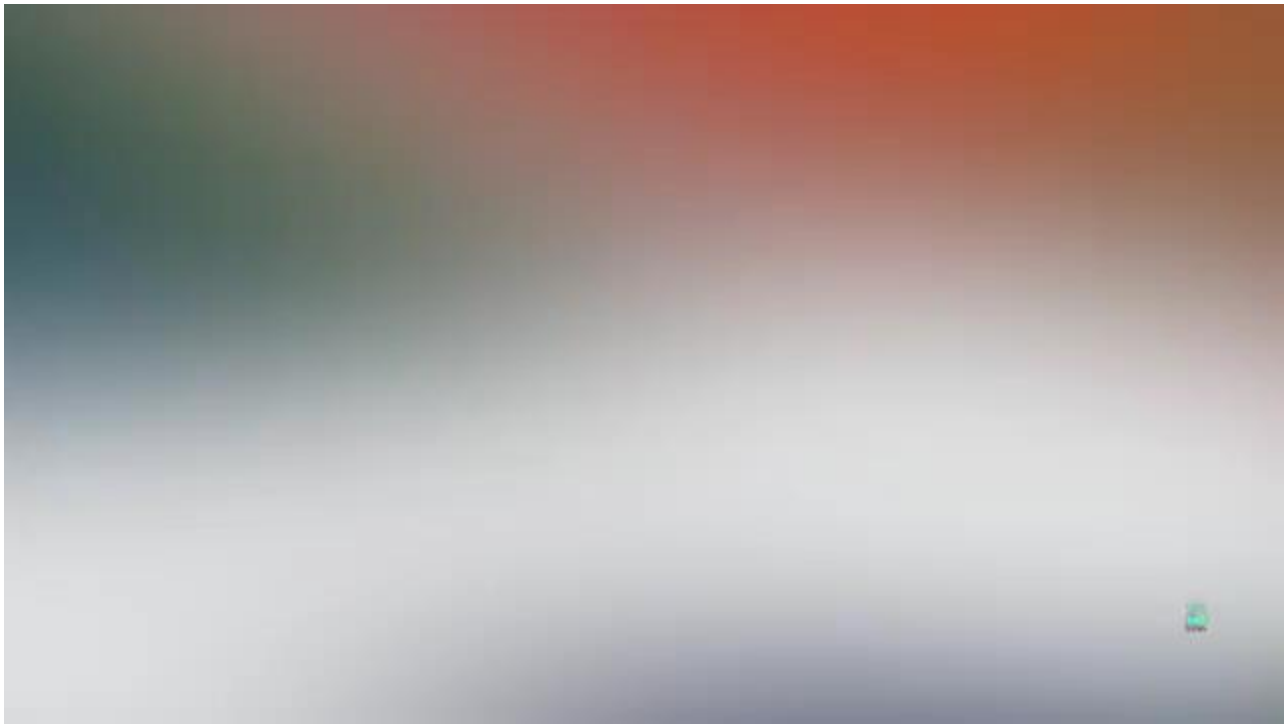
DARPA Grand Challenges

Google (now Waymo)

Tesla “autopilot” mode

Stanford “Stanley”

CMU “Boss”



Waymo autonomous car

Tesla Model S

https://youtu.be/7oCe0aLye-U Longer TED talk https://youtu.be/tiwVMrTLUWg

Transportation: Autonomous Vehicles

Many others

- ⇨Nutonomy
- ⇨Uber
- ⇨All major automakers

And trucks!

nuTonomy autonomous car

Uber autonomous car

Daimler autonomous truck

Otto (sold to Uber)

Medical: Surgical Robots

da Vinci surgical system

- ⇨~5000 units, > 1M surgery done?
- ⇨Tele-operated, Minimally invasive
- ⇨Filter out tremor from doctor's hands
- ⇨High precision and minimum lag

da Vinci surgical system (Intuitive Surgical)

https://youtu.be/0XdC1HUp-rU

Agriculture

Mostly mechanical harvesting systems

⇨E.g., carrot harvesting and many others

Multi-robot systems

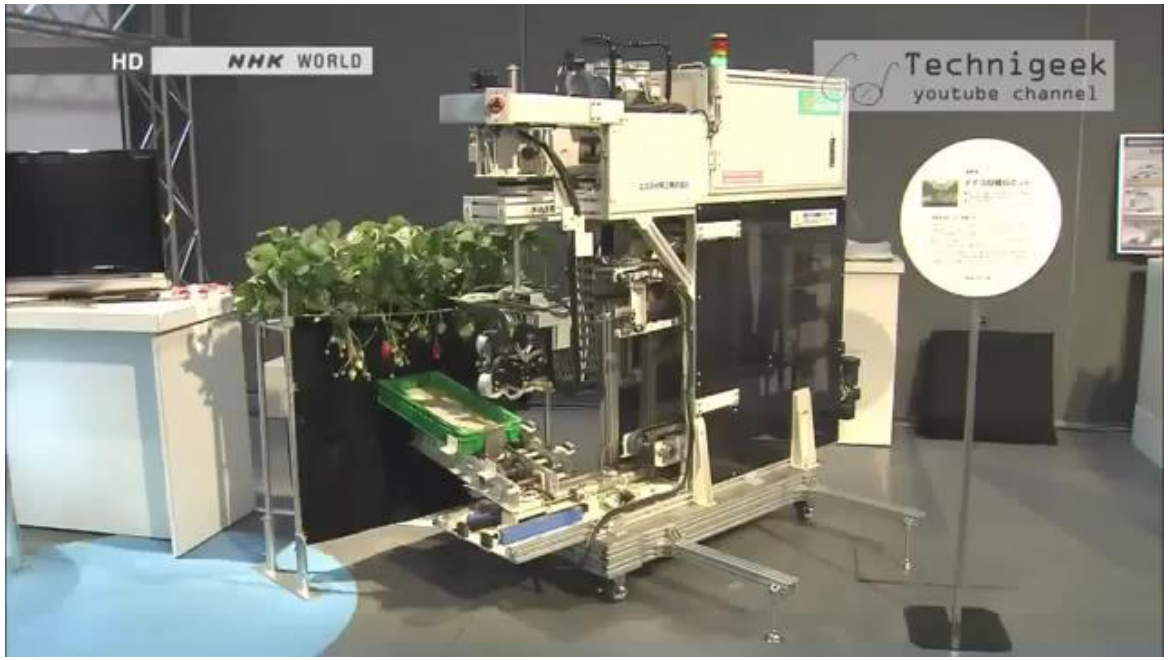
Smart and autonomous ones

⇨Apple picking, strawberry picking

Carrot harvesting

HV-100 (harvest automation)

Apple picker (Abundant Robotics)



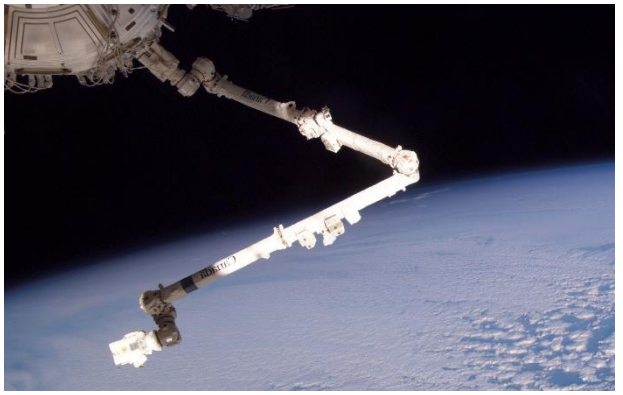
https://youtu.be/fUGVBTxheHo

Scientific and Exploration

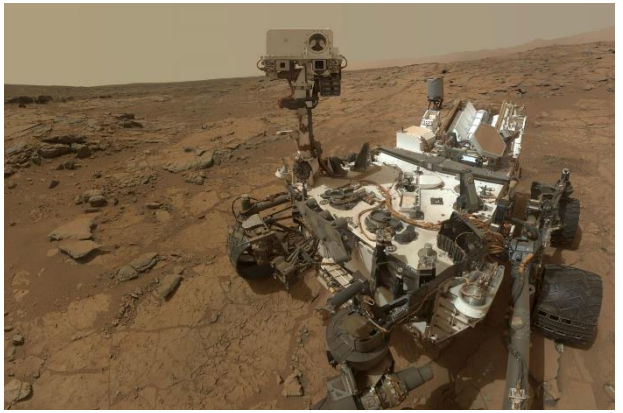
Outer space

- ⇨European robotic arm
- ⇨Mars rovers
- ⇨Humanoid

Research: PR2, Nao, underwater…



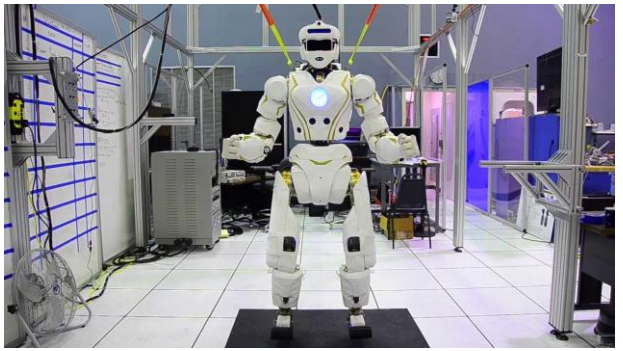
ISS European Robotic Arm (ESA)



Curiosity rover (NASA)

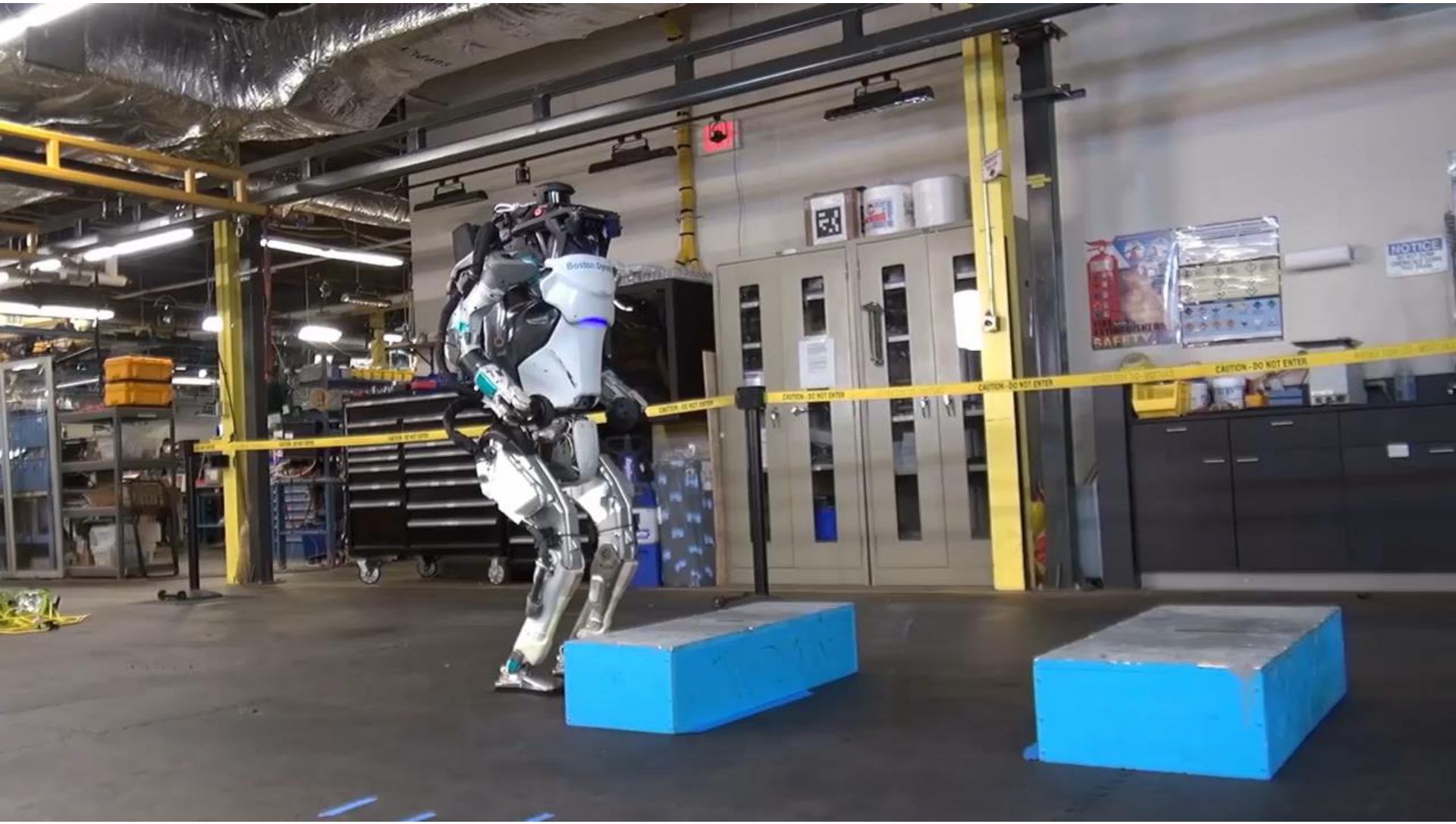
PR2 cloth folding (Berkeley)

Underwater gliders



Valkyrie (NASA)

Atlas from Boston Dynamics



Social and Entertainment

Crowded field

- ⇨Companion
- ⇨Early education
- ⇨Personal assistant
- ⇨Home monitoring
- ⇨Entertainment

Buddy

Jibo

Sony Aibo

Woobo

Sphero BB-8

Parrot mini drone

Parrot Bebop

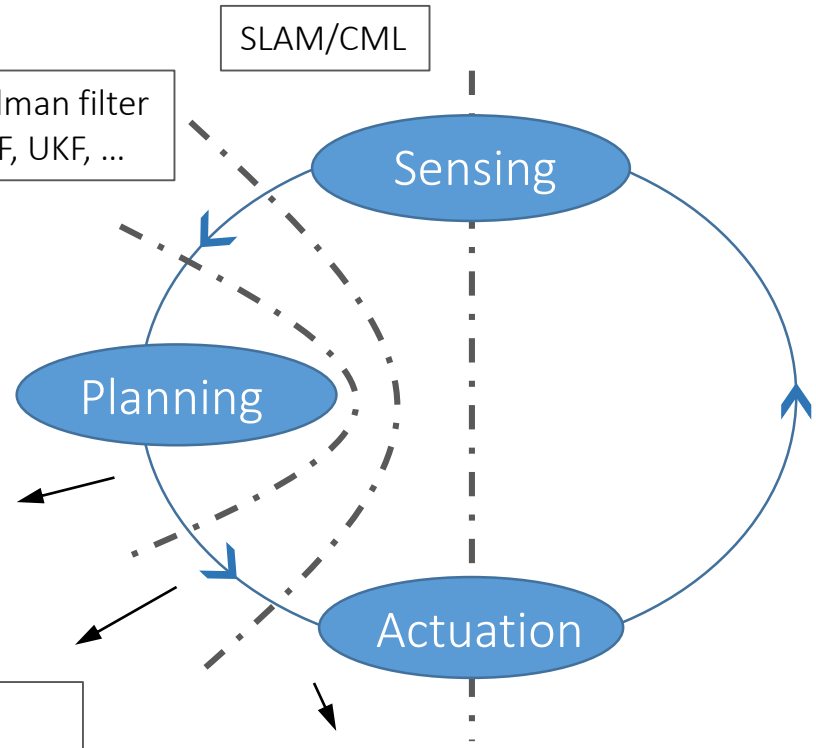
DJI Phantom 4

Full video: https://youtu.be/3N1Q8oFpX1Y

The Sensing-Computation-Actuation Loop

Machine

Environment



We look at computational issues of the loop with a planning focus

Course Scope – Another Perspective

Robotics is a large field: hardware, mechanism, computer vision, planning, control… we can only cover a small portion

This course: an **introduction** to how things work individually and how they fit together from a **computational perspective**

The course is **not** about: hardware, computer vision, learning, … in all of the glory (gory) details.

Up next …

We will do some review of some important mathematical concepts

Can be hard to fully grasp, but pay attention to the concepts

- ⇨What is the subject trying to capture? I.e., what is the problem?
- ⇨How is the problem modeled (simplified) and solved?