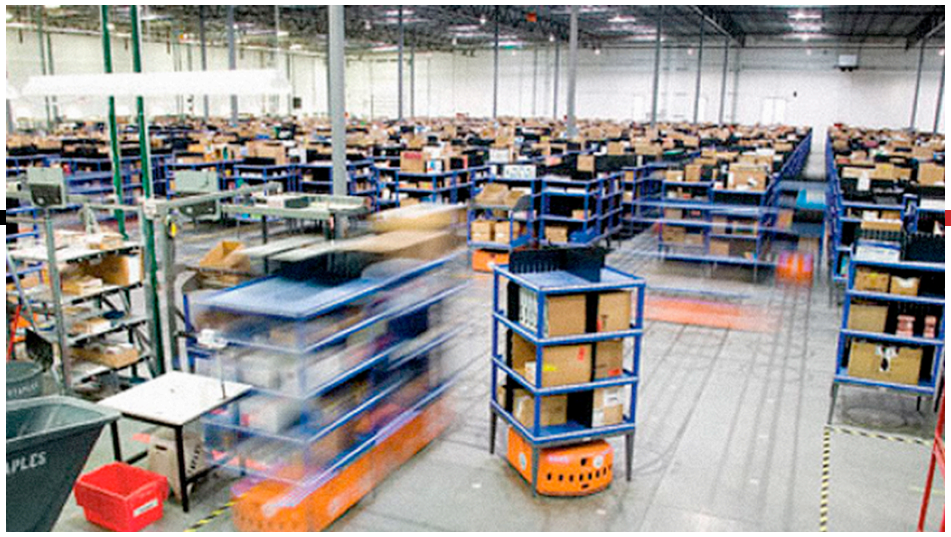
Robotics and Human-Robot Interaction



Slides based in part on www.jhu.edu/virtlab/course-info/ei/ppt/robotics-part1.ppt and -part2.ppt and Intro to AI, Dr. Paula Matuszek

1

Bookkeeping

Please don't panic! The exam was too long (for which I am sorry), but that means there will be a significant curve.

- Midterm
  - We will try to return these Tuesday
  - Reminder: 24 hours from exams return before we discuss grades
  - I encourage you to go back to materials and seek answers!
- HW3
  - **Now due 10/25—please see schedule**
  - Posted: Writeup on information gain
- Writeups
  - Posted: Filtering example and spreadsheet with worked math
  - Posted: Variable Elimination overview

All on the schedule!

2

Today's Class

- What's a robot (really)?
- What parts do they have?
- What are they used for?
- What kind of AI do they need?
- Human-Robot Interaction (HRI)
- Future Questions

3

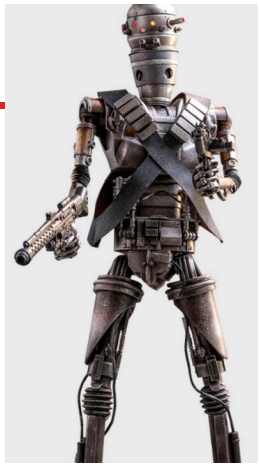
Fictional Robots

Jeff

Wall•E

Westworld

Optimus Prime



IG-11

R2-D2

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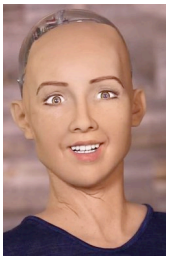
Some Current Robots



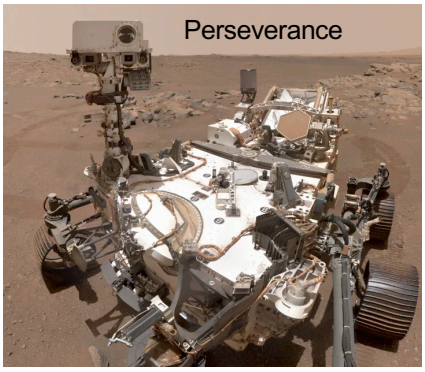
Sophia

MQ-1

Da Vinci

Roomba

Spot



5

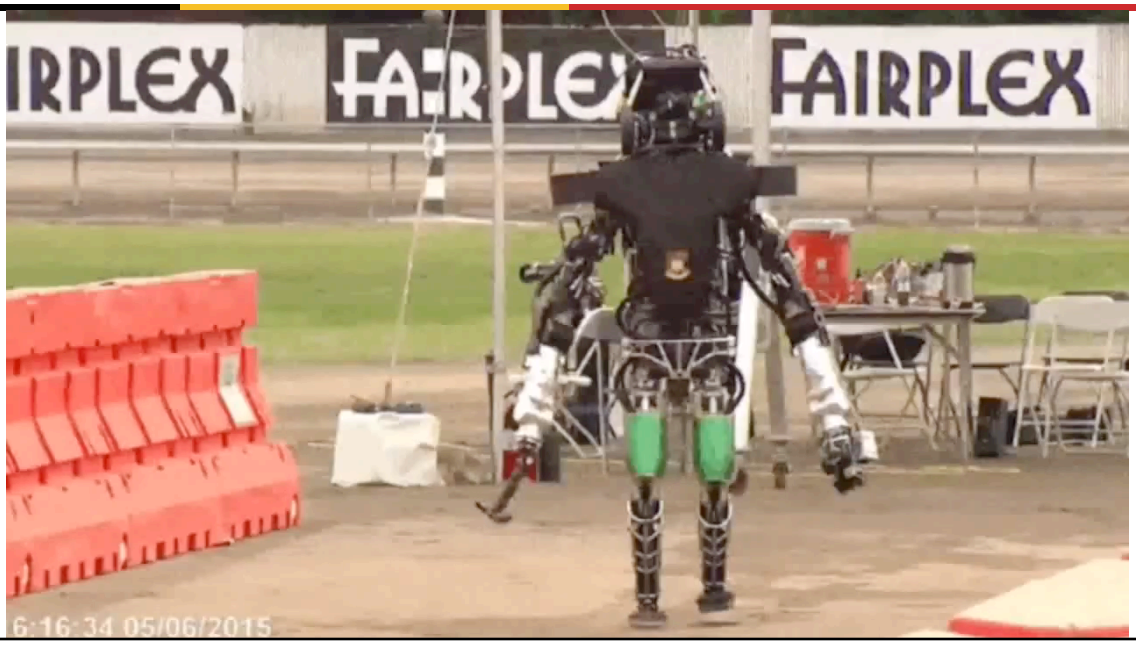
What is a Robot?

- "A robot is a reprogrammable, multifunctional manipulator designed to move … through variable programmed motions for the performance of a variety of tasks." (Robot Institute of America)
- "A robot is a one-armed, blind idiot with limited memory and which cannot speak, see, or hear."
- **In practice:** robotics intersects with any space in which computers move into the physical world.

6

What Are They Good At?

www.youtube.com/watch?v=g0TaYhjpOfo



7

What Are They Actually For?

- What is hard for humans is easy for robots.
  - Repetitive tasks.
  - Continuous operation.
  - Complicated calculations.
  - Referring to huge databases/knowledge sources.
- What is easy for a human is (sometimes) hard for robots.
  - Reasoning.
  - Adapting to new situations.
  - Flexible to changing requirements.
  - Integrating multiple sensors.
  - Resolving conflicting data.
  - Synthesizing unrelated information.

this class!

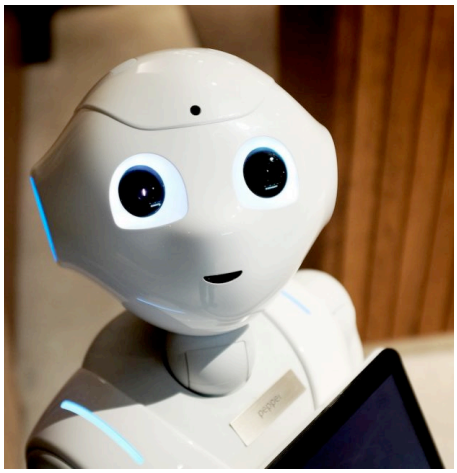


Image: tricycle.org/article/bad-buddhists-good-robots/

8

What Are They Actually For?

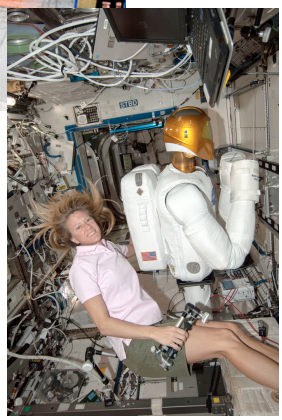
The three D's of robotics: Dull, Dirty, or Dangerous

- Boring and/or repetitive
  - welding car frames
  - part pick and place
  - manufacturing parts
- Inaccessible
  - space exploration
  - disaster cleanup
- High precision / speed
  - electronics testing
  - surgery
  - precision machining
- Dangerous
  - Search and Rescue
  - chemical spill cleanup
  - disarming bombs
- All of the Above
  - Continuous reef monitoring
  - Military surveillance

9

Categories of Robot Systems

- Manipulators (usually arms)
  - Anchored somewhere
  - Factory assembly lines
  - International Space Station
  - Hospitals
  - Common industrial robots
- Mobile Robots
  - Move around environment
  - UGVs, UAVs, AUVs, UUVs
  - Mars rovers, delivery bots, ocean explorers
- Mobile Manipulators
  - Both move and manipulate
  - Packbot, humanoid robots



10

Subsystems

- Robots have:
- Sensors
  - Some way of **detecting** the world
- Actuators (or effectors)
  - Some way of **affecting** things in the world
  - Manipulation
  - Mobility
- Control/Software
  - Everything we've seen so far in this class and more…

11

Sensors

- Perceive the world
  - **Passive** sensors capture signals from environment (cameras)
  - **Active** sensors probe the environment (sonar)
- What are they sensing?
  - The environment (range finders, obstacle detection)
  - The robot's location (gps, wireless stations)
  - Robot's own internals: **proprioceptive** sensors

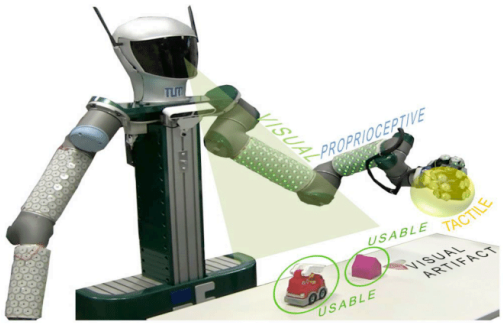
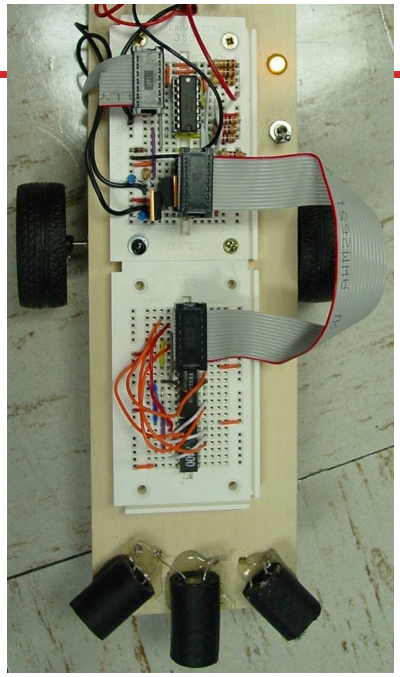


Image: Lanillos & Dean-Leon & Cheng. (2016). Yielding Self-Perception in Robots Through Sensorimotor Contingencies. IEEE Transactions on Cognitive and Developmental

12

What Are Sensors Used For?

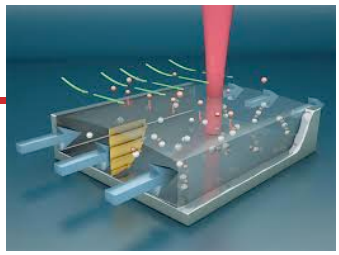
- Feedback
  - Closed-loop robots use sensors in conjunction with actuators to gain higher accuracy – servo motors
- Decision making
  - Mobile robotics
  - Telepresence
  - Search and rescue
  - Pick and place (with vision)
- Human interaction



13

Some Sensors

- Optical
  - Laser / radar
  - 3D
  - Color spectrum
- Pressure
- Temperature
- Chemical
- Motion & Accelerometer
- Acoustic
  - Ultrasonic
- E-field Sensing



14

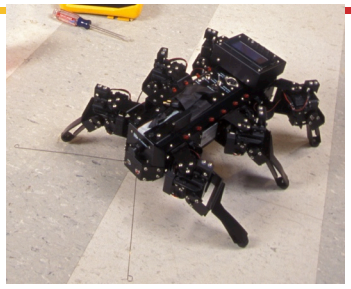
Actuators / Effectors

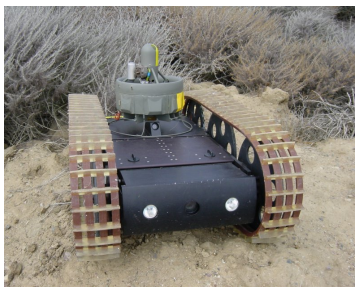
- Take some kind of action in the world
- Involve movement of robot or subcomponent of robot
- Robot actions include
  - Pick and place: Move items between points
  - Continuous path control: Move along a programmable path
  - Sensory: Employ sensors for feedback (e-field sensing)

15

Mobility

- Legs
- Wheels
- Tracks
- Crawls
- Rolls





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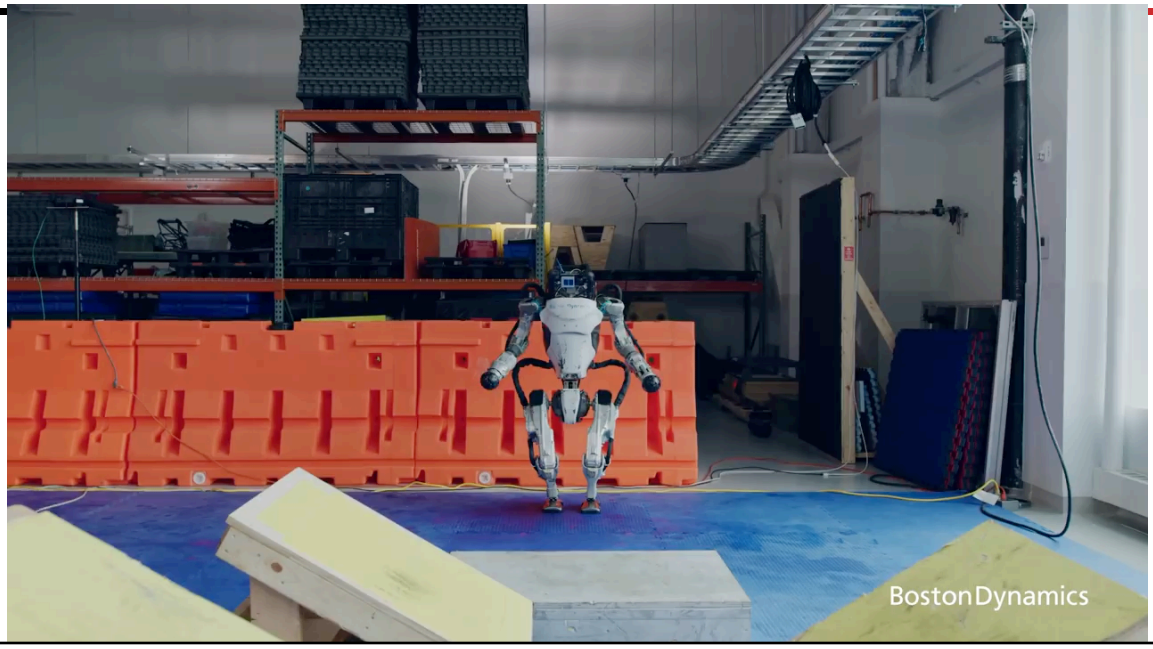
16

https://www.youtube.com/watch?v=tF4DML7FIWk

Atlas



17

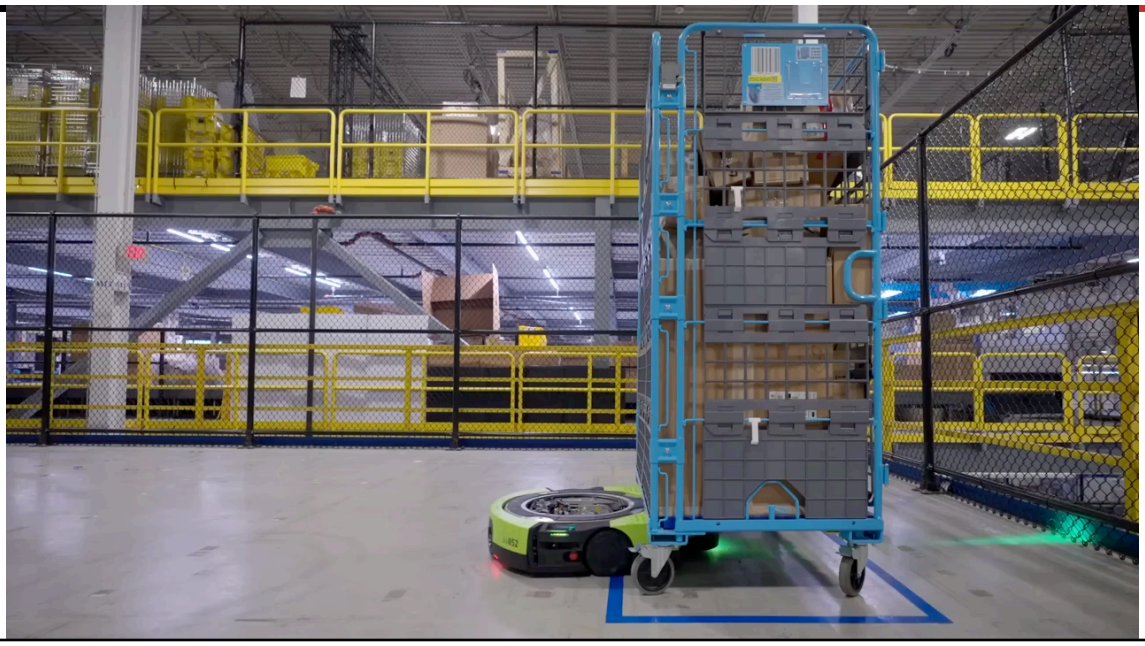
https://www.youtube.com/watch?v=6Zbhvaac68Y

Spot

18

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

Proteus



19

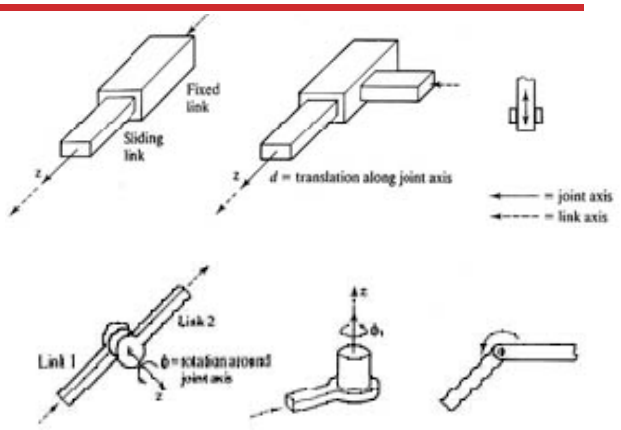
https://www.youtube.com/watch?v=lqxFvYgo5S8

Sparrow

20

How do robots joints move?

- Simple joints (2D)
  - Translation/Prismatic — sliding along one axis
    - square cylinder in square tube
  - Rotation/Revolute — rotating about one axis
- Compound joints (3D)
  - ball and socket = 3 revolute joints
  - round cylinder in tube = 1 prismatic, 1 revolute



21

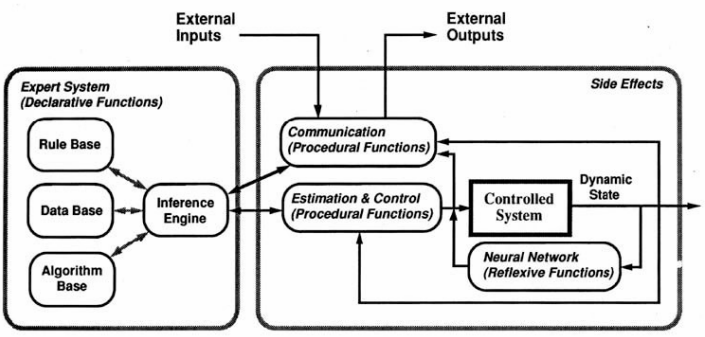
Degrees of Freedom (DOF)

- Degrees of freedom = Number of independent directions a robot or its manipulator can move
  - 3 degrees of freedom: 2 translation, 1 rotation
  - 6 degrees of freedom: 3 translation, 3 rotation
- How many degrees of freedom does your knee have? Your finger?
- Variations on controllable DOFs:
  - Underwater explorer might have up or down, left or right, rolling. 3 controllable DOFs

22

Control: The Brain

- Open loop, i.e., no feedback, deterministic
  - Instructions
  - Rules
- Closed loop, i.e., feedback
  - Learn
  - Adapt



23

Where Is AI Needed?

- Sensing:
  - Interpreting incoming information
    - Machine vision, signal processing
    - Language understanding
- Actuation:
  - What to do with manipulators and how
    - Motion planning and path planning
- Control:
  - Managing large search spaces and complexity
    - Accelerating masses produce vibration, elastic deformations in links.
    - Torques, stresses on end actuator
    - Feedback loops
- Firmware and software:
  - Especially with more intelligent approaches!

So, basically everywhere

24

Robotic Perception

- Sensing isn't enough: need to **act** on data sensed
  - Data are noisy
  - Environment is dynamic and partially observable
- Must be mapped into an internal **representation**
- Good representations:
  - Contain enough information for good decisions
  - Are structured for efficient updating
  - Are a natural (usable) mapping between representation and real world

Image: www.javatpoint.com/knowledge-representation-in-ai

25

Belief State

- Belief state: model of the state of the environment (including the robot)
  - X: set of variables describing the environment
  - X_t: state at time t
  - Z_t: observation received at time t
  - A_t: action taken after Zt is observed
- After A_t, compute new belief state X_{t+1}
- Probabilistic, because uncertainty in both X_t and Z_t

26

Some Perception Problems

- **Localization:** where is the robot? Where are other things in the environment?
- **Mapping:** no map given, robot must determine both environment and position
  - SLAM: Simultaneous localization and mapping
- Probabilistic approaches are typical
  - Especially machine learning!
- What about common sense? Learning?

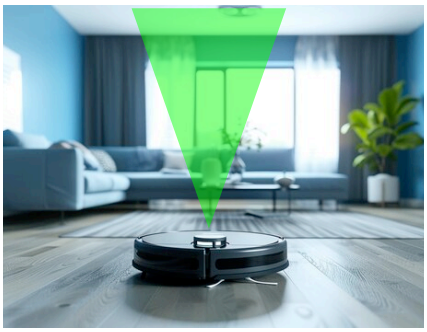


Image: Freepik

27

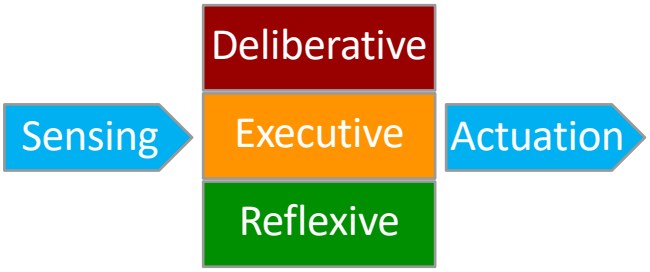
Software Architectures

- Low-level, reactive control
  - Bottom-up
  - Sensor results directly trigger actions
- Model-based, deliberative planning
  - Top-down
  - Actions are triggered based on planning around a state model
- Which is an intelligence approach?
  - The first? The second? Neither? Both?

28

Hybrid Architectures

- Usually, actually doing anything requires both reactive and deliberative processing.
- Typical architecture is three-layer:
  - Deliberative layer: global solutions to complex tasks, model-based planning, decision cycle of minutes
  - Executive layer: glue that accepts directions from deliberative layer, sequences actions for reactive layer, decision cycle of seconds
  - Reactive Layer: low-level control, tight sensor-action loop, decision cycle of milliseconds



29

Performance Metrics

- Speed and acceleration
- Resolution (in space)
- Working volume
- Accuracy
- Cost

- …plus all the evaluation functions for any AI system.

30

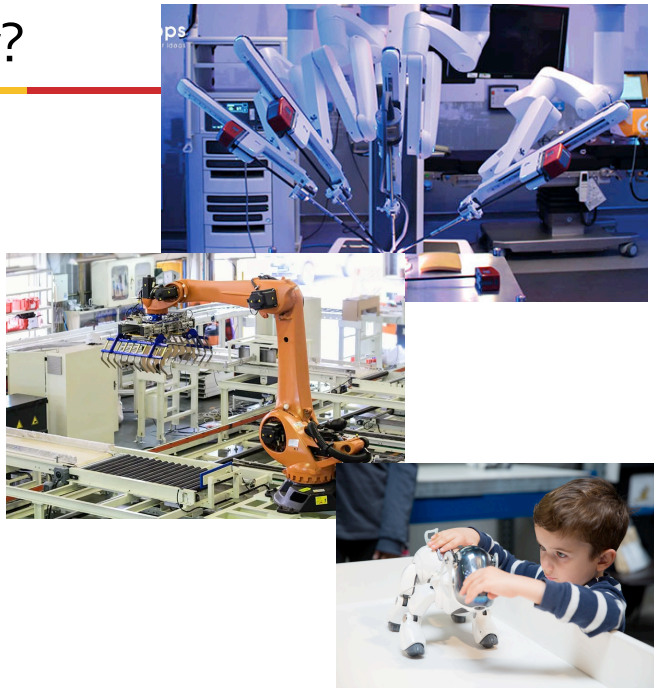
https://www.youtube.com/watch?v=YL9XjyXsKKk

Putting it Together

31

Where Are Robots Now?

- Healthcare and personal care
  - Surgical aids, intelligent walkers, eldercare
- Personal services
  - Roomba
  - Information kiosks, lawn mowers, golf caddies, museum guides, …
- Entertainment
  - sports (robotic soccer)
- Human augmentation
  - walking machines, exoskeletons, robotic hands, etc.



Images: www.inapps.net/examples-of-robots-in-everyday-life

32

And More...

- Industry and Agriculture
  - assembly, welding, painting, harvesting, mining, pick-and-place, packaging, inspection, ...
- Transportation
  - Autonomous helicopters, pilot assistance, materials movement
- Cars (DARPA Grand Challenge, Urban Challenge)
  - Antilock brakes, lane following, collision detection
- Exploration and Hazardous environments
  - Mars rovers, search and rescue, underwater and mine exploration, mine detection
- Military
  - Reconnaissance, sentry, S&R, combat, EOD
- Household
  - Cleaning, mopping, ironing, tending bar, entertainment, telepresence/surveillance

33

Tomorrow's Problems

- Mechanisms
  - Morphology: What should robots look like?
  - Novel actuators/sensors
- Estimation and Learning
  - Reinforcement Learning
  - LLM-based learning and interaction
  - Learning from Demonstration
- Manipulation (grasping)
  - What does the far side of an object look like? How heavy is it? How hard should it be gripped? How can it rotate? Regrasping?

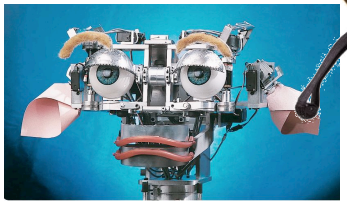
Image: https://www.youtube.com/watch?v=ubVoZik-Q2w

34

And more…

- Medical robotics
  - Autonomous surgery
  - Eldercare
- Biological Robots
  - Biomimetic robots
  - Neurobotics
- Navigation
  - Collision avoidance
  - SLAM/Exploration



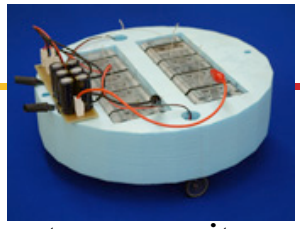



Images: codeant.org/the-future-of-robotics/
www.core77.com/posts/125756/A-Useful-Non-Humanoid-Robot-Just-a-Pair-of-Arms-and-Legs
www.researchgate.net/figure/Robots-both-fiction-and-non-fiction-used-as-examples-in-the-discussion-Top-C-3PO_fig1_279682599
www.researchgate.net/figure/The-robot-used-in-the-study-previously-published-used-with-permission-Hoffman-et-al_fig1_351281479

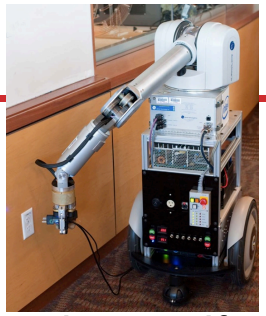
35

Self-X Robots

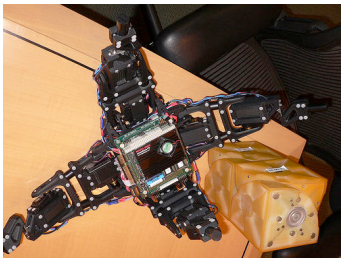
- Self-feeding
  - Literally
  - Electrically
- Self-replicating
- Self-repairing
- Self-assembly
- Self-organization
- Self-reconfiguration



eats mosquitoes for power



plugs itself in



organizes into structures

photo-synthesizes??

36