Robotics and Human-Robot Interaction
AI Class 27 (no reading)

Bookkeeping

- Closing in! Almost there!
- Doodle poll for review date (tentative: 16th)
- Last schedule slips
  - Phase II: due 11:59 Dec 12
- Final survey
  - How did the project go? Who contributed what?
  - Due before final
- TTBOMK, all Phase II materials are up
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?
- HRI
- Future Questions

Familiar Robots

- Ava. Ex Machina: 2016
- Optimus Prime. Transformers: 2007-current
- Wall•E: 2008
Some Current Robots

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.
What Are They Good At?

- 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.
  - Creativity.

What Should They Do?

- Boring and/or repetitive
  - welding car frames
  - part pick and place
  - manufacturing parts

- High precision / speed
  - electronics testing
  - surgery
  - precision machining

- Dangerous
  - chemical spill cleanup
  - disarming bombs

- Inaccessible
  - space exploration
  - disaster cleanup

- All of the Above
  - Continuous reef monitoring
  - Military surveillance
## Categories of Robot Systems

- **Manipulators**
  - 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

## Subsystems

**Robots have:**

- **Sensors**
  - Some way of *detecting* the world

- **Effectors**
  - Some way of *affecting* things in the world
  - Manipulation
  - Mobility

- **Control/Software**
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*
    - Stop and think about that one for a moment. Close your eyes - where's your hand? Move it - where is it now?

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
**Some Sensors**

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

**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)
Mobility

- Legs
- Wheels
- Tracks
- Crawls
- Rolls

Control: The Brain

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

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
Belief State

• Belief state: model of the state of the environment (including the robot)
  • X: set of variables describing the environment
  • Xₜ: state at time t
  • Zₜ: observation received at time t
  • Aₜ: action taken after Zₜ is observed
• After Aₜ, compute new belief state Xₜ₊₁
• Probabilistic, because uncertainty in both Xₜ and Zₜ.

Some Perception Problems

• Localization: where is the robot, where are other things in the environment
  • Landmarks
  • Range scans
• Mapping: no map given, robot must determine both environment and position.
  • SLAM: Simultaneous localization and mapping
• Probabilistic approaches typical
  • Especially machine learning!
• What about common sense? Learning?
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?
  • A? B? Neither? Both?

Low-Level, Reactive Control

• Augmented finite state machines
• Sensed inputs and a clock determine next state
• Build bottom up, from individual motions
• Subsumption architecture synchronizes AFSMs, combines values from separate AFSMs.
• Advantages: simple to develop, fast
• Disadvantages: Fragile for bad sensor data, don't support integration of complex data over time.
• Typically used for simple tasks, like following a wall or moving a leg.
Model-Based Deliberative Planning

- **Belief State model**
  - Current State, Goal State
  - Any of planning techniques
  - Typically use probabilistic methods
- **Pros:**
  - Can handle uncertain measurements and complex integrations
  - Can be responsive to change or problems.
- **Cons:**
  - Slow!
  - Developing models, e.g., driving, is cumbersome.
- **Typically used for high-level actions**
  - Whether to move and in which direction.

Hybrid Architectures

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

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

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

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.
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

Tomorrow’s Problems

- Mechanisms
  - Morphology: What should robots look like?
  - Novel actuators/sensors
- Estimation and Learning
  - Reinforcement Learning
  - Graphical Models
  - Learning by 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?
And more...

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

Self-X Robots

- Self-feeding
  - Literally
  - Electrically
- Self-replicating
- Self-repairing
- Self-assembly
- Self-organization
- Self-reconfiguration
Human-Robot Interaction

- Social robots
  - In care contexts
  - In home contexts
  - In industrial contexts
- Comprehension
  - Natural language
  - Grounded knowledge acquisition
  - Roomba: “Uh-oh”
- Basic idea: Human-centric environments

Why?

- Robots are getting smaller, cheaper, and more ubiquitous
- Humans need to interact with and instruct them, naturally
  - Language, gesture, demonstration, …
- Key requirements:
  - Language understanding learned from data
  - Follow instructions in a previously unseen world
  - Learn to parse natural language into robot-usable commands
Robots in Human Spaces

- Robots now:
  - Expensive
  - Complex
  - Special-purpose

- Environments
  - Dedicated
  - Constrained

- Use and Management
  - Controlled by trained experts
  - Slow and expensive to reconfigure/repurpose

Some current problems

HRI
World Learning
Ethical Questions
Human-Robot Interaction

- How do *humans* handle human interaction?
  - Assumptions about retention and understanding
  - Anthropomorphization

- How do robots make it easier?
  - Apologize vs. back off
  - Convey intent
  - Cultural context (implicit vs. explicit communication)

Use Cases: Games
Direction Following

- **Grounded Language Acquisition:**
  - "Understanding" = transforming natural language into semantically meaningful representations
  - Mapping that information to perceived world

- **Learn a parser**
  - Produce robot-executable commands from NL instructions

Direction Following

```
(turn-right)
(do-n-times 2
  (until (exists left-loc
    (move-to forward)))
  (turn-left))
```

“Turn right, then take your second left.”

Novel Concepts

- **Grounded Language Acquisition:**
  - "Understanding" = transforming natural language into semantically meaningful representations
  - Mapping that information to perceived world

- **But, this assumes we already know what things exist to map to!**

- **World modeling:** learn new concepts from interactions

This is a red thing that you can eat, but don't eat these blue ones
Learning is required

- Robotic systems see new physical things
- Jointly model perceptions and language to create a new, consistent world model
- Learn previously unknown attributes from descriptions
  - Yellow: new word describing new idea

"All these blocks are yellow."

Please fetch the blue encyclopedia on the desk in my office.
Why?

- Some concepts are hard without situated learning
  - Green, round, …
  - “Turning towards” something
- And the world is complicated.
What is the Parent Saying?

Watch the video, then describe what the parent is saying to the child, in complete sentences.

• Pretend you are a parent teaching a child about something.
• The question is:

How does the parent describe this group of objects?

Your answer should be the sentence(s) the parent said while pointing to these things.

“This one’s an orange ball.”

\[ \lambda x . \text{orange}(x) \wedge \text{spheroid}(x) \]

Multimodal Interactions

• Larger data set of interactions
• Capturing:
  • Speech
  • Gesture
  • RGB-D
• How do data sources combine?
• Can we model
  • …world?
  • …language?
  • …user intention?
Multimodal Human Input

“These are green objects seeming like vegetables. This one is a ... a cucumber ... or a dull oval thing. And this one is a pepper. Like slightly rounded ... high cone.”

What Should They Do?

- Boring and/or repetitive
  - welding car frames
  - part pick and place
  - manufacturing parts
- High precision / speed
  - electronics testing
  - surgery
  - precision machining
- Dangerous
  - chemical spill cleanup
  - disarming bombs
- Inaccessible
  - space exploration
  - disaster cleanup
- All of the Above
  - Continuous reef monitoring
  - Military surveillance
# What Shouldn’t They Do?

- What decisions can be made without human supervision?
- May machine-intelligent systems make mistakes (like humans can)?
- May intelligent systems gamble when uncertain (as humans do)?
- Can (or should) intelligent systems exhibit personality?
- Can (or should) intelligent systems express emotion?
- How much information should the machine give the human?

# Jobs For Robots

<table>
<thead>
<tr>
<th>Elder care</th>
<th>Military surveillance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Law enforcement</td>
<td>Military monitoring</td>
</tr>
<tr>
<td>Politics</td>
<td>Domestic surveillance</td>
</tr>
<tr>
<td>Space exploration</td>
<td>Unsupervised surgery</td>
</tr>
<tr>
<td>Underwater exploration</td>
<td>Unsupervised driving</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Child care</td>
</tr>
</tbody>
</table>
The Future

- Robots that can learn.
- Robots that interact smoothly with people.
- Robots that do ticklish things autonomously.
- Robots that make other robots.
- Robots with “strong” AI.

..?