Robotics and Human-Robot Interaction

Bookkeeping

- As posted: today is not probabilistic planning
- Phase II due date pushed back 1 day (see schedule)
- Project discussion updated
  - A discussion of logical equivalence
  - Debugged examples
- HW4 graded, HW5 back after holiday

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

- ED-209, RoboCop 2014
- Optimus Prime, Transformers 2007-2017
- Sentinel, X-Men, Days of Future Past 2014
- Ava, Ex Machina 2015

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.

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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.

What Should They Do?

- 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

Categories of Robot Systems

- Manipulators
  - Anchored somewhere
  - Factory assembly lines
  - International Space Station
  - Hospitals
  - Common industrial robots
- Mobile Robots
  - Move around environment
  - UGVs, UAVs, UUVs, 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
  - Everything we’ve seen so far in this class and more...

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?
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

Big Dog

Putting it Together

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
  - So, basically everywhere
- **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, stresses on end actuator
  - 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
  - $X_t$: state at time $t$
  - $Z_t$: observation received at time $t$
  - $A_t$: action taken after $Z_t$ is observed
- After $A_t$, compute new belief state $X_{t+1}$
- Probabilistic, because uncertainty in both $X_t$ and $Z_t$

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?

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 for, 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.

Big Dog Later

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, senry, SAR, combat, EOD
- Household
  - Cleaning, mapping, 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?

Since the DARPA challenge...

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

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, then take your second left."

Novel Concepts

- Grounded L.A.
  - "Understanding" semantically
  - Mapping to representations
- 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

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?"

λx. orange(x) ∧ 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 intentions?
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?

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- All of the Above
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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

- Eldercare
- Law enforcement
- Politics
- Space exploration
- Underwater exploration
- Monitoring
- Military surveillance
- Military monitoring
- Domestic surveillance
- Unsupervised surgery
- Unsupervised driving
- Child care

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.