High-level Learning

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Quiz 10 (pts)

• (3 pts) When training a Pro-MP model, how to normalize the phase of demonstrations?

• (3 pts) How to use a decision tree to learn the mapping function?

• (4 pts) Name two ways to represent task plan in high-level learning?
Pro-MP

Multiple demonstrations

Training

Human trajectories

Robot trajectories

Phase normalization

Correlated model

Human observations

Searching $\alpha^*$

Inference

Human observations

$y^0$

$\alpha_1$

$\alpha_2$

$\alpha_N$

Conditioning

$p(y_{1:T}; \theta^{new}) = \int p(y_{1:T}|w)p(w; \theta^{new})dw$. 
Decision Tree

- Training process
  - Learn state transition function as hierarchical classifier over features

\[ T_S(\vec{f}_t) \rightarrow S' \]
How to represent a plan?

- Bayesian models
- Finite-state Automaton
Assignment 10 – two options
Assignment 10 – Due Nov 28

• Read

• Understand how to integrate sensing uncertainty into the transformation system
Assignment 10 – Due Nov 28

• Prepare 4-6 presentation slides on (20 pts)
  • Make sure you either write a paper review digest, or integrate notes to your slides to explain your understanding
Assignment 10 (20 pts) – Due Nov 28

• Read
  • Section 5.5 Learning task features

• Prepare 7-10 presentation slides
  • Digest over multiple papers

• To reflect your understanding
  • Add notes to your presentation slides, or
  • Submit 2-page review
Learning task objectives
Learning task objectives

• Infer the task goal
  • Compare states before and after an action

• Infer the reward function
  • Reward states similar to those in human demonstrations
  • Derive explicit reward function (IRL)

• Extended applications
  • Use learned objective function to guide future motion planning
Create a Mind-reading Social Robot [11]

• How to infer the mental states of a human partner from their observable behavior?

• What could be the mental states?
  • Beliefs, intents, and desires
Task setup

Task 1

Actor's Goal: Looks in B
Task setup
Task setup

Task 3

Actor's Goal: Looks In C for key to B
A Simulation-theoretic Approach to Mindreading

• Theory of mind (also called mind-reading)
  • The ability to attribute mental states (e.g., beliefs, intents, desires, feeling, knowledge, etc.) to oneself and to others, and to understand these mental states can be the cause of and thus can be used to explain and predict the behavior of others

• Simulation theory
  • Certain parts of the brain have dual use: generating our own behavior, and infer the same of others.
Cognitive Architecture
Cognitive Architecture: Perception System
Cognitive Architecture: Motor System

- **Body**
  - Desired Body Pose
  - Mapped Body Pose

- **Motor System**
  - Idles
  - Moves to Point

- **Intention System**
  - Schema Recognition and Execution
  - Task Learning
  - Human
  - Robot

- **Recognition/Inference (Mindreading)**
- **Generation**

- **Motors**
- **Sensors**

- **Perspective Transformation**

- **Perception System**
  - "true"
  - "any-utterance"
  - "down"
  - "six"

- **Belief System**
  - Other's Beliefs
  - Robot's Beliefs

- **Desired Movement**
- **Matched Movement**
Motor system
Cognitive Architecture: Belief System
Build Robot’s Model of Human Belief

Data From Sensors
- Human 1 (50,100,0)
- Object O₁ (0,50,0)
- Object O₂ (50,150,0)

Updated Robot Belief System
- Transform and Rotate data to human coordinate frame using human location in Robot's Beliefs

Transformed Data From Sensors
- Human 1 (0,0,0)
- Object O₁ (50,50,0)
- Object O₂ (0,-50,0)

Final Input to Human 1's Belief System
- Self (0,0,0)
- Object O₁ (50,50,0)
Maintain parallel beliefs of human and robots

<table>
<thead>
<tr>
<th>Robot</th>
<th>a)</th>
<th>b)</th>
<th>c)</th>
<th>d)</th>
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<tbody>
<tr>
<td>Sensor Data</td>
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<td>Beliefs</td>
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<table>
<thead>
<tr>
<th>Human</th>
<th>Filtered Sensor Data</th>
<th>Beliefs</th>
<th>Human Present</th>
<th>Events</th>
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<tbody>
<tr>
<td></td>
<td>*position/rotation transform not depicted</td>
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<td>Human Leaves</td>
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Cognitive Architecture: Intention System
Inferring intent from observed behavior
Generating goal-directed behavior
How the robot can help a human partner?

- Robot detects human reaching to unlock **Box A**
- Traversing up the hierarchy, robot infers that human intends to get **Cookies**, which human believes to be in **Box A** (a wrong belief).
How the robot can help a human partner?

- Robot has computed the final goal of human, and plans to help human to get the Cookies.
- Robot figured out there are two ways to get the Cookies, and will choose the one of minimal efforts.
Learning model and reward function for a pole-balancing task [12]

• Human demonstration

• Robot Learning
  • Reproduce human hand trajectory – fail
  • Mimic human response to each situation – policy learning
  • Learn a task model and an optimization criterion

\[
dx_{k+1} = f(x_k, u_k) \\
C = \sum_k (x_k, u_k, k)
\]
Learned task model and optimization criterion

- Dynamics of balancing inverted pendulum
  \[
  \dot{\theta}_{k+1} = 0.0051 x_k + 0.0058 \dot{x}_k + 0.47 \theta_k + 0.997 \dot{\theta}_k + 0.052 \ddot{x}_k
  \]

  - Learned from 30 sec demonstration data

- Step cost to minimize
  \[
  r(x, u, k) = 125 x^2 + 50 \dot{x}^2 + 1200 \theta^2 + 25 \dot{\theta}^2 + 1.5 \ddot{x}^2
  \]
Learned poll-balancing
Further improvement using RL [13]
Constructing skill tree (CST) [14]
Merging two skill chains into a skill tree

(a)     (b)     (c)     (d)
Demonstration
Inverse Reinforcement Learning [15]

- Generate explicit reward function
  - Hand-engineer a set of reward features
  - Define reward function as a linear combination of these features
  - Learning = learn feature coefficients from demonstration

Apprenticeship Learning

- Bayesian Inverse Reinforcement Learning
LEArning to seaRCH (LEARCH)
Reference


Reference


Reference


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End