High-level Learning

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No Quiz Today! Student talk

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• Sinan Morcel
• Hanqing Zhang
Plan for Final Weeks
Next two weeks are our final weeks

• Literature review presentation (Dec 3, 5)
• Final project presentation (Dec 10, 12)
• Extra credit homework due Dec 12 by noon
Dec 3 – Literature review

- Perception-action + Sinan (20 min talk + 3 min Q&A)
- High-level learning (15 min talk + 3 min Q&A)
- Mostafa (7 min talk + 2 min Q&A)
Dec 5 – Literature review

- Handover (15 min talk + 3 min Q&A)
- Reach-to-grasp (15 min talk + 3 min Q&A)
- Loco-manipulation (15 min talk + 3 min Q&A)
- Physical Fatigue (12 min talk + 3 min Q&A)
Dec 10 – Final Project Presentation

- Handover (15 min talk + 3 min Q&A)
- Reach-to-grasp (15 min talk + 3 min Q&A)
- Loco-manipulation (15 min talk + 3 min Q&A)
- Physical Fatigue (12 min talk + 3 min Q&A)
Dec 12 – Final project presentation

- Perception-action (15 min talk + 3 min Q&A)
- High-level learning (15 min talk + 3 min Q&A)
- Soft hand (7 min talk + 2 min Q&A)
- Kinect teleoperation (7 min talk + 2 min Q&A)
Evaluation criteria for project proposal

• Most people/team get A (90%)

• Criteria
  • Balanced efforts in theory and practice, and among team members
  • Strong preliminary work, done by students in this class
  • Presentation must be within the time limit, preferably fluent

• Report revision – Dec 5
  • Your grade can be changed if you revise your report to address my feedback comments
Literature review evaluation criteria

- Material interest
  - Is the content interesting? – Beyond the course lectures
- Material novelty
  - Is it new? – Recent research, state-of-the-art
- Material relevancy
  - Does the content matter to the team's project?
- Material breadth
  - Did the team cover enough material to be useful? About 3-4 paper per person
- Member contributions
  - Did everyone do work? – Include one slides for task-sharing
- Presentation quality
  - Within time limit, clarity, depth, visualization, fluency
Final presentation evaluation criteria

- Problem Description
  - Is the project objective clear?
- Research Depth
  - Does this project tackle a good research question?
- Technical Contribution
  - Does the project implement a useful method(s)?
- Results
  - How much has this team delivered towards their objective?
- Task Division
  - Did the team divide tasks among their members effectively?
- Presentation Structure
  - A good balance of high-level ideas and low-level details?
- Presentation Quality
  - Is the presentation given fluently?
Teaching evaluation

- **Dec 10 (Monday)** Make sure to bring your computer/phone to the class, to fill in the course evaluation

- Additional questions for evaluating your student mentors
  - Clear about project objective, Provide enough guidance in literature review; help with your understanding of theory/algorithm; help with technical details of experiment/implementation; Communicate effectively; manage the team efficiently; approachable
Evaluation of project success

- All the teams are required to finish their planned experiments
  - Shared-autonomous teleoperation teams – Complete the training, testing and interface evaluation experiments
  - Handover team – data for handover experiment
  - High-level learning – data for simulation game experiment
  - Soft hand – data (video) for system evaluation
  - Physical fatigue – data from Vicon teleoperation experiment
  - Kinect teleoperation – demonstration
Beyond this course

• You may continue your project for
  • Direct research, RBE 550 course project (Spring 2019), Conference Publication, Thesis

• Please let your project mentor know if you would like to continue. I will have a meeting with them soon to come up a plan for future research
Learning object affordance
Learning object affordance

- Affordance
  - Properties of the environment that afford a certain action to be performed
  - Enable the user to categorize objects by their functions
  - A compact and useful representation of manipulation skills
Learning affordance

- Exploration
  - Act on object and observe the reaction $\rightarrow$ correspondence

- Visually observing human or other robot
  - Manipulating tasks
  - Full-body environmental interaction
Represent affordances as Bayesian networks

- Encode the dependencies between actions, object features and the effects of those actions.
- Learn structure using Markov Chain Monte Carlo (MCMC)
- Resulting model interprets the effects of observed actions
Bayesian Network

Symbol | Description | Values
--- | --- | ---
A | Action | grasp, tap, touch
H | Height | discretized in 10 values
C | Color | green1, green2, yellow, blue
Sh | Shape | ball, box
S | Size | small, medium, big
V | Object velocity | small, medium, big
HV | Hand velocity | small, medium, big
Di | Object-hand velocity | small, medium, big
Ct | Contact duration | none, short, long
Bayesian Network

• Demo 1
  • A tap on a small ball resulting in high velocity and medium hand–object distance

• Demo 2
  • A grasp on a small square resulting in small velocity and small hand–object distance

<table>
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<th>action</th>
<th>grasp</th>
<th>tap</th>
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<td>Yellow, small box</td>
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<td>0.06</td>
<td>0.00</td>
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Detection of objects in human action sequences

(a) Ground truth: book
(b) Ground truth: magazine
(c) Ground truth: box
(d) Ground truth: box+pitcher
(e) Ground truth: cup+pitcher
(f) Ground truth: cup+pitcher

= book, = magazine, = hammer, = box, = cup, = pitcher.
Detection of objects in human action sequences

\[
\begin{array}{cccc}
\chi_1^a & \chi_2^a & \chi_3^a \\
\circ_1 & \circ_2 & \circ_3 \\
\chi_1^o & \chi_2^o & \chi_3^o
\end{array}
\]

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<th>Pour</th>
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<td>Pour</td>
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Learning affordance in full-body environmental interactions – FOCUS algorithm

- Model inanimate objects in the environment by structural and functional definitions
  - Structural definition = Capture a simple and generalized visual definition of an object by feature detection
  - Functional definition = Capture object affordance properties

- Object classification
  - Recognize an object by associate an observed action with a particular environmental feature
Process of learning visual features

1. Camera → Raw Video → Face Recognition and Tracking → People’s Positions → Activity Recognition
2. Raw Video → Feature Detection → Features → Object Grab and Generalize → Object Class
3. Object Class → Updated Visual Object Definition → Object Class Library

- Chair: Affordance, Sitting, Temporal association: δ(t), Spatial association: δ(p)
- Door: Affordance, Entry, Temporal association: δ(t), Spatial association: δ(p)
- Visual Features: [1, 1, ...]
Examples
Learning Task features
Learning task features

- Feature selection
- Eliminate redundant and irrelevant features
AfD’s feature elimination

- Automated state abstraction from demonstration
  - In the limit of infinite data, the feature subset it yields will not negatively affect the accuracy of the learner

- Feature elimination judgement
  - Never remove a feature if it negatively impacts accuracy
  - Judgements are based on some held out portion of the data
Example – Learning to play Frogger Game

• Collect demonstrations from human players
  • Play the game for 10 min
  • 306 features in the state representation

• Data processing
  • Only use successful games
  • Remove redundant samples (not pressing keys while thinking or taking a small break)
Performance
Learning Reference Frames
Learning frame of reference

- Five possible frames
Choose the correct frame [8]
How to choose the correct frame?

- Data normalization
  - Rescale data in all dimension to have the same variance and mean zero

- Measurement for framing quality
  - Robot does not have access to the relevant dimensions of the different tasks it is to perform
  - Need a way to measure the quality of a framing by just looking at the raw demonstration data.
Input: \( D, M, N, x_{q0} \)
- \( D \) is the full database encoded in an incremental kd-tree like structure for fast approximate nearest neighbours search;
- \( x_{q0} \) is the initial current state;
- \( N \) is the number of local points;
- \( M \) is the number of gaussians in the GMM
- \( \lambda = (\lambda_1, \ldots, \lambda_M) \) is the GMM parameter list;
- \( D_f(x_{q_t}) \) is the local database consisting of \( N \) points retrieved given the current state \( x_{q_t} \) and using framing \( f \), for \( f=1,2,3 \)

repeat
for \( f = 1 \) to \( 3 \) do
  i) Given the current state \( x_{q_t} \) at iteration nr \( t \); find the local database \( D_f(x_{q_t}), N \) for framing \( f \) with fast approximate nearest neighbours search.
  ii) Initialize a GMM parameter list \( \lambda_{0f} \leftarrow k\text{-}mean(D_f(x_{q_t}), M) \).
  iii) Compute the GMM parameter list using EM, \( \lambda_{x_{q_f}} \leftarrow EM(D_f(x_{q_f}), \lambda_{0f}) \).
  for \( i = 1 \) to \( M \) do
    iv) Compute \( h_i(x_{q_f}) \) using (3)
  end for
  v) Predict the desired vector \( \hat{v}_f(x_{q_t}) \) using (4)
  vi) Get the total framing angle error \( E_f \) of \( D_f(x_{q_t}) \) and the weight of framing \( f \) as \( w_f = 1/(0.001 + E_f) \)
  end for
  vii) Now we have \( \hat{v} = \sum (\hat{v}_f(x_{q_t}) \times w_f) / \sum w_f \)
  viii) Use \( \hat{v} \) to update the position and get the new state \( x_{q(t+1)} = x_{q(t)} + \hat{v} \times \tau \), where \( \tau \) is a time constant
until Reproduction done
Example
Learning and Generalization of Complex Tasks from Unstructured Demonstrations [9]

• Proposed a method for
  • Segmenting demonstrations
  • Recognizing repeated skills
  • Generalizing complex tasks from unstructured demonstrations

• Beta Process Autoregressive HMM Algorithm
  • Combines many of the advantages of recent automatic segmentation methods for LfD into a single principled, integrated framework
Framework

Autonomous demo segmentation

Learning frames
Learning task frame

• Define coordinate frames centered on each known object, gripper, world frame

• Cluster the end points of demo plotted in each frame

• Demo of clustered end points in a particular frame →
  • The reference frame in which motor skill often occurs
Reference – feature elimination


Reference


Reference


End
 Incremental, Local, Online Gaussian Mixture Regression (ILO-GMR) [8]

• Objective
  • learn incrementally and online a variety of new context-dependent tasks

• Challenges
  • Unknown task number and complexity at programming time
  • Demonstrator is not allowed to tell the system when introducing a new task
  • Robot figure it out itself → How?
Infer new task information from continuous sensorimotor context

• Key idea
  • Build online and on-demand local Gaussian Mixture Regression models of the task

• Incremental learning of
  • Task category
  • Task framing
ILO-GMR Process

• **Learning**
  • Store all demonstration of all (different tasks)

• **Reproduction**
  • Search in database for N points closest to the current robot states
  • Input these points to local GMR model (with 2-3 basis) to predict near-future behavior

• **Question**
  • What do you mean by closest? – by what features?
Assignment 15 (30 pts) – Due Dec 4

• Read
  • Section 5.6 Learning frame of reference

• Prepare 4-6 presentation slides

• To reflect your understanding
  • Add notes to your presentation slides, or
  • Submit 2-page review
Assignment 15 (30 pts) – Due Dec 4

- Grading and reward policy
  - 4 best work: grade = 100% for this assignment
  - Select 2-4 for student presentation: replace a low-grade assignment or quiz with 100%
Extra Assignment (50 pts) – Due Dec 11

• Read
  • Chapter 7 in Robot learning from human teachers

• Prepare 20 presentation slides

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