openEASE —
A digital innovation platform for intelligent robotics

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Robots Curve
Market requires many robots in many environments performing many tasks
The role of knowledge for robotics

Ginni Rometty (IBM):

- “Data is the world’s great new natural resource. What steam power was to the 18th century, electromagnetism to the 19th and fossil fuels to the 20th, data will be to the 21st.”

Gill Pratt (Toyota Research Institute, Is a Cambrian Explosion Coming for Robotics?. Journal of Economic Perspectives, Vol. 29, No. 3 (Summer 2015)):

- “Robots are already making large strides in their abilities, but as the generalizable knowledge representation problem is addressed, the growth of robot capabilities will begin in earnest, and it will likely be explosive.”

- “The key problems in robot capability yet to be solved are those of generalizable knowledge representation and of cognition based on that representation.”
Why Is Knowledge so Important?

the cost of not knowing

- if the robot does not know about the task, the environment, the robot the programmer has to hardcode everything

- programming/instructing at an abstract/semantic level
  - put the bolt into the nut and fasten it
  - pour water into the glass
  - ...
Challenge 1: Closing knowledge gaps

Action description

pour the water out of the pot

(perform
  (an action
    (type pour)
    (theme water)
    (source pot)))

infer motion parameters and constraints such as

- grasp the pot by the handles
- hold the pot horizontally
- tilt the pot around the axis between the handles
- hold the lid while pouring
- etc
Challenge 2:
Symbolic action descriptions cause different behavior

*Pouring Plan*:
```
def-plan pour {}:
    (theme) : (some stuff)
    (source) : (an object
        (type container)
        (contains (theme))
        (affordance
            (an action
                (type pick-up)
                (body-part (a box))))
    (dest) : (a location))

begin
1. reach (source)  /* {includes grasp, pregrasp} */
2. lift (source) (a location (above (destination)))
3. tilt (source)
    until (amount (some stuff (at (destination)))
    ≥ (amount (theme)))

end
```

*Action Description*:
```
(perform
    (an action
        (type adding)
        (theme (some substance
            (type milk)))))
    (destination
        (some dough))))))
```
Challenge 3:
Action success requires motion skills
A generalized action plan for pouring

\[\text{def-plan} \quad \text{pour} \quad (\langle \text{theme} \rangle \quad : \quad \text{(some stuff)}) \]
\[\quad \langle \text{source} \rangle \quad : \quad \text{(an object)} \]
\[\quad \text{(type container)} \]
\[\quad \text{(contains } \langle \text{theme} \rangle \text{)} \]
\[\quad \text{(affordance } \text{(an action)} \]
\[\quad \text{(type pick-up)} \]
\[\quad \text{(body-part } \text{(a body-part } \text{(type hand)}\text{))}) \]
\[\quad \langle \text{dest} \rangle \quad : \quad \text{(a location))} \]

\[\text{begin} \]
\[\quad 1. \quad \text{reach}(\langle \text{source} \rangle) \quad /* \text{(includes grasp, pregrasp)} \]
\[\quad 2. \quad \text{lift}(\langle \text{source} \rangle) \quad \text{(a location } \text{(above } \langle \text{destination} \rangle \text{))} \]
\[\quad 3. \quad \text{tilt}(\langle \text{source} \rangle) \]
\[\quad \text{until} \quad \text{(amount } \text{(some stuff } \text{(at } \langle \text{destination} \rangle \text{))} \]
\[\quad \geq \text{(amount } \langle \text{theme} \rangle \text{)} \]
\[\text{end} \]
A generalized action plan for pouring

```lisp
(def-plan pour (theme) : (some stuff)
  (source) : (an object
              (type container)
              (contains theme)
              (affordance (an action
                            (type pick-up)
                            (body-part (a body-part (type hand))))))
  (dest) : (a location))
```
Generalized Cognition-enabled Motor Plan/Program

inspired by [Flanagan]
RoboPAL — a personal assistant for robots

- **given:** I want to pour water into the cup
- **question:** how should I grasp and hold the cup
This is not science fiction!!!

look at Google Home, Amazon Echo, Siri, Viv, ...
how should I grasp the cup?

?- current-task(Tsk),
  task-exp(Tsk,
    [an, action,
      [type, pouring],
      [destination, [an, object,
        [type, container]]],
      [support-action, Spt-Tsk]],
    task-exp(Spt-Tsk,
      [an, action,
        [type, grasping],
        [subactions, Motions]],
      subaction([a, motion
        [type, reaching],
        [pregrasp-pose, PG-pose],
        [grasp-pose, G-pose],
        [grasp-force, G-force]],
      Tsk),
    show(PG-pose,G-pose,G-force).}
how should I grasp the cup?

?- current-task(Tsk),
  task-exp(Tsk,
    [an, action,
      [type, pouring],
      [destination, [an, object,
        [type, container]]],
      [support-action, Spt-Tsk]]),
  task-exp(Spt-Tsk,
    [an, action,
      [type, grasping],
      [subactions, Motions]]),
  subaction([a, motion
    [type, reaching],
    [pregrasp-pose, PG-pose],
    [grasp-pose, G-pose],
    [grasp-force, G-force]],
    Tsk),
  show(PG-pose,G-pose,G-force).
Knowledge needed for answering

**rule base**

- if a container is filled & open then hold it upright
- if an object can break then don’t squeeze too hard
- if the task context is pouring then grasp close to the com
- if the task context is pouring then don’t grasp mouth

**rule base (ctd)**

- choose motion parameters that are predicted to succeed
- grasp an object such that you have good visual feedback
- don’t get to close to breakable objects
Knowledge needed for answering

rule base
- if a container is filled & open then hold it upright
- if an object can break then don’t squeeze too hard
- if the task context is pouring then grasp close to the
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rule base (ctd)
- choose motion parameters that are predicted to succeed
- grasp an object such that you have good visual feedback
- don’t get to close to breakable objects

many motion constraints are semantic
many apply in many situations
relevant ones might be inconsistent
### Knowledge-enabled programming

#### fetch-and-place plan schema

<table>
<thead>
<tr>
<th>def-plan pour (⟨theme⟩, ⟨source⟩ ⟨destination⟩)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. take(⟨source⟩)</td>
</tr>
<tr>
<td>2. hold(⟨source⟩)</td>
</tr>
<tr>
<td>(a location</td>
</tr>
<tr>
<td>(above ⟨destination⟩))</td>
</tr>
<tr>
<td>3. tilt(⟨source⟩)</td>
</tr>
<tr>
<td>until (amount (some stuff</td>
</tr>
<tr>
<td>(at ⟨destination⟩))</td>
</tr>
<tr>
<td>≥ (amount ⟨theme⟩))</td>
</tr>
<tr>
<td>end</td>
</tr>
</tbody>
</table>

#### knowledge

- filled open containers must be held upright
- soft objects must not be squeezed beyond their limits
- an open tetrapak is soft
- you have to tilt a pot around the axis between the handles
- when tilting a container with an unconnected lid then the lid might fall down
- objects with handles are conveniently held by their handles
- objects that are to be picked up with two hands must be reachable by both hands
- ...

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Knowledge processing for robots

- Question answering
- Logic-based language
- Hybrid reasoning
- Recording episodic memories
- Perception
- Learning
- Simulate
- Imagine
- Minds eye
- Dreaming
- Data structures
- Symbolic knowledge base
- Ontology & axiomatizations
- Generalized knowledge
- Collections of episodic memory

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Virtual knowledge bases

Virtual symbolic view

Virtual symbolic view

Computable predicates

Robot-internal data structures

well-localized(robot):-
dist ← pose-distrib(robot)
if num(peaks(dist)) == 1
then return true
else return false

at-pose(robot):-
dist ← pose-distrib(robot)
return max(peaks(dist))
Mirror world knowledge bases

Please set up the table for breakfast.
One person will eat.

You can press 'P' at any time to check the hotkeys.
Knowledge acquisition and episodic memories

question answering

logic-based language

hybrid reasoning

symbolic knowledge base

data structures

ontology

&

axiomatizations

imagine

simulate

mirror system

observing

reading

dreaming

perception

recording episodic memories

learning

collections of episodic memory

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Episodic memories

Knowledge

- Experience
- Story, narrative

Motion control

Episodic memory

- Action: flavoring
  Tool: type <spoon>, percept <149330024>
  Theme: type <tomato sauce> [...]

- Motion: reach <tool>
  Knowledge:
  pregrasp: <pose_FaMSjK>
  grasp: power grasp
  grasp: power grasp

Cognitive capabilities

Monitoring/ failure detection
Query-based decision making
Prediction

Learning
Observation

Knowledge acquisition
Components of episodic memories

Images

Poses
Components of episodic memories

- **Images**
- **Poses**

fetch the object

navigate

perceive

navigate

navigate

pregrasp

examine

grasp

look up in knowledge base

- **t₀**
- **t₁**
- **t₂**
- **t₃**
- **t₄**
- **t₅**

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Components of episodic memories

- detecting objects on table
- looking for container with coffee
- estimating exact pose for grasp
- positioning to pick up object

Images

Poses

- t₀
- fetch the object
  - navigate
    - perceive
    - navigate
      - navigate
        - examine
          - look up in knowledge base
    - pregrasp
      - grasp

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Components of episodic memories

- Images
  - fetching the object
  - navigating
  - perceiving
  - examining
  - looking up in knowledge base
  - pregrasp
  - grasp

- Poses

- detecting objects on table
- looking for container with coffee
- estimating exact pose for grasp
- positioning to pick up object

- Events:
  - occurs(ev123,t2)
  - event-type(ev123,detect)
  - perception-task(ev123,obj-descr246)
  - object-description(obj-descr246,[an,object,...])
  - perception-result(ev123,obj-descr345)
  - object-description(obj-descr345,[an,object,...])
  - captured-image(ev123,img456)
  - image-region(obj-descr345,reg567)

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Semantic retrieval from episodic memories

?- task(Tsk),
   task-action(Tsk, [an, action,
                [type, pick-up],
                [object-acted-on,
                 [an, object
                  [type, pot],
                  [weight, Weight]]]]),

   Weight >= 2kg,
Semantic retrieval from episodic memories

?- task(Tsk),
  task-action(Tsk, [an, action,
                   [type, pick-up],
                   [object-acted-on, 
                    [an, object
                     [type, pot],
                     [weight, Weight]]]]),

  Weight \geq 2\text{kg},
  task-start(Tsk, TskStrt),
Semantic retrieval from episodic memories

?- task(Tsk),
   task-action(Tsk, [an, action, 
                  [type, pick-up], 
                  [object-acted-on, 
                  [an, object 
                    [type, pot], 
                    [weight, Weight]]]]),

Weight >= 2kg,
   task-start(Tsk,TskStrt),
   holds(pose(pr2,Pose),TskStrt).

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Supervised learning from episodic memories

?-

task(Tsk),
task-action(Tsk, [an, action,
    [type, pick-up],
    [object-acted-on,
        [an, object
            [type, pot],
            [weight, Weight]]]),

Weight >= 2kg,

,  
task-start(Tsk, TskStrt),
holds(pose(pr2, Pose), TskStrt),

.
Supervised learning from episodic memories

?- setof(Pose, 
    task(Tsk), 
    task-action(Tsk, [an, action, 
      [type, pick-up], 
      [object-acted-on, 
        [an, object 
          [type, pot], 
          [weight, Weight]]], 
      weight, Weight]],), 
    Weight >= 2kg, 
    task-outcome(Tsk, success), 
    task-start(Tsk, TskStrt), 
    holds(pose(pr2, Pose), TskStrt), 
    Poses).
Learning control concepts from longterm experience
Perception

- question answering
- logic-based language
- hybrid reasoning
- ontology & axiomatizations
- symbolic knowledge base
- generalized knowledge
- data structures
- collections of episodic memory

- imagine
- simulate
- dreaming
- minds eye
- observing
- reading

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Final remarks
Final remarks (2)
An Open Knowledge Service for Robotics

Knowledge Service

Curated knowledge
High-volume shallow knowledge
Robot knowledge

Management Learning Query answering

Lead Application Scenarios

RoboPAL
Query generation
Provision of query context
Translation of answers into control parameters and data structures
Logged episodic memory

openEASE Graphical Interface

web mining

1 query
2 answer
3 upload

RoboSherlock
Perception System

Knowledge-enabled Robot Program
OPENEASE: other tools

open research/innovation

probabilistic reasoning

knowledge processing

perception
Thank you

for your attention