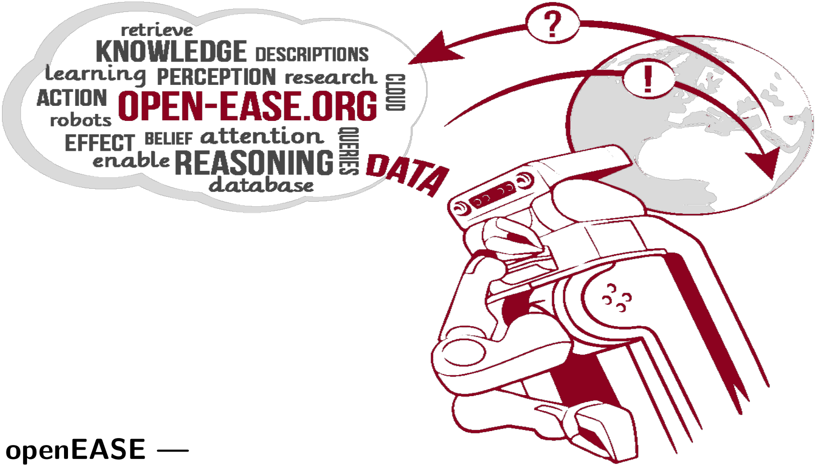
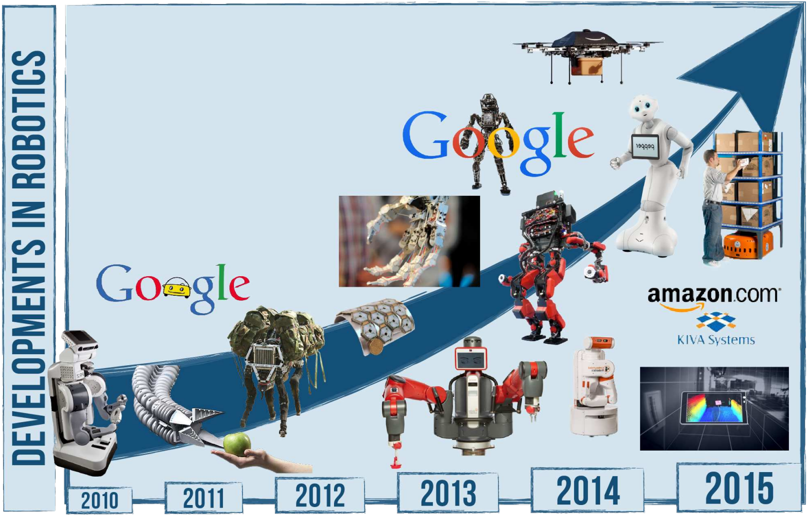


openEASE — A digital innovation platform for intelligent robotics

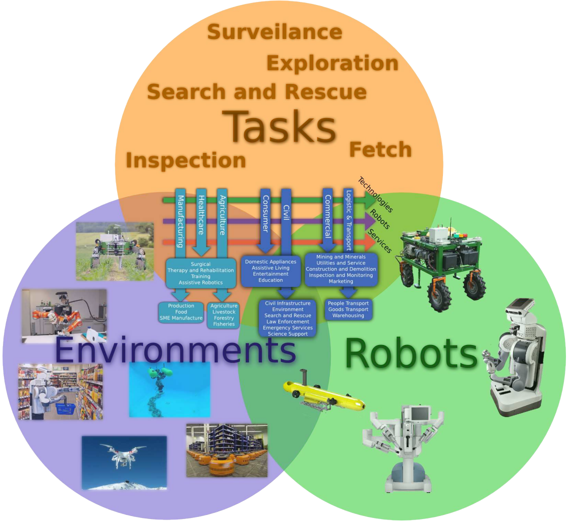
Michael Beetz,
University of Bremen

ROS Industrial Conference, November 2016

Robotics 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)):

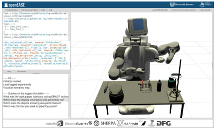
- **"Robots are already making large strides in their abilities, but as the generalizable knowledge representation problem is addressed, the growth of robot capabilities will begin in earnest, and it will likely be explosive."**
- **"The key problems in robot capability yet to be solved are those of generalizable knowledge representation and of cognition based on that representation."**

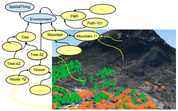
Why Is Knowledge so Important?

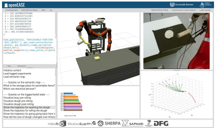
Wikipedia: Screw

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

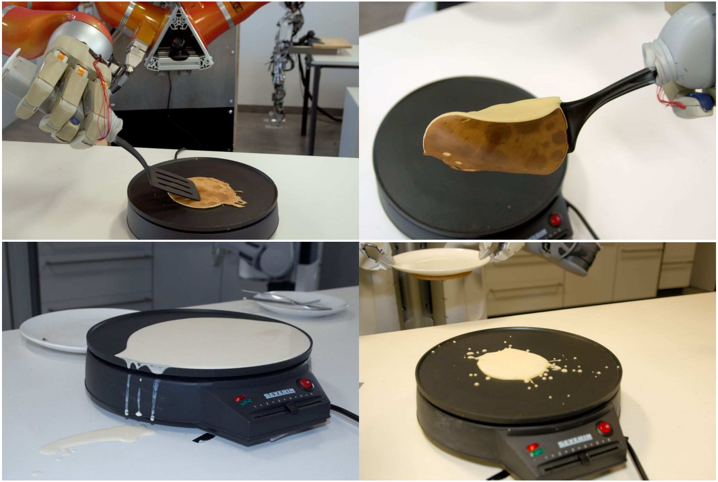
```
def-plan pour ( ⟨theme⟩   : (some stuff)
                ⟨source⟩  : (an object
                               (type container)
                               (contains ⟨theme⟩)
                               (affordance (an action
                                              (type pick-up)
                                              (body-part (a bo
                ⟨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

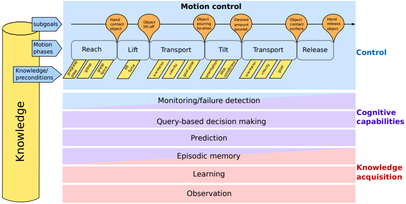


A generalized action plan for pouring

```
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))

    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
```

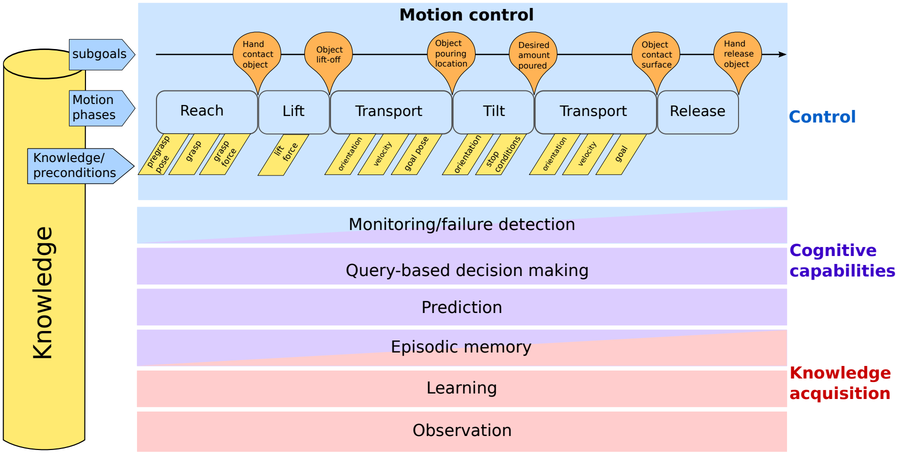
A generalized action plan for pouring

```
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))
```

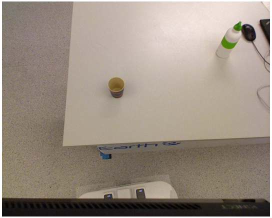


Generalized Cognition-enabled Motor Plan/Program

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

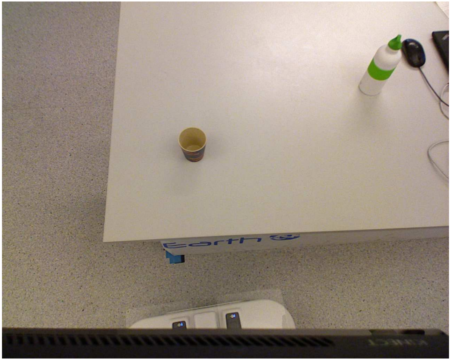
This is not science fiction!!!

look at Google Home, Amazon Echo, Siri, Viv, . . .

ROBOPAL — a closer look

how should I grasp the cup?

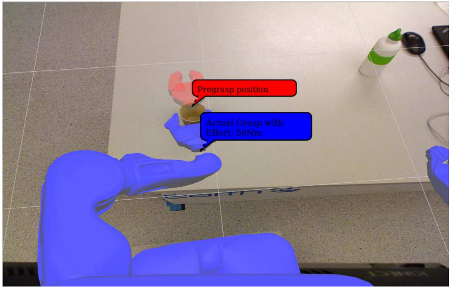
```
?- current-task(Tsk),
   task-exp(Tsk,
            [an, action,
                 [type, pouring],
                 [destination, [an, object,
                                    [type, container]]],
                 [support-action, Spt-Tsk]]),
   task-exp(Spt-Tsk,
            [an, action,
                 [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).
```



ROBOPAL — a closer look

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 answerin

many motion constraints are semantic
many apply in many situations
relevant ones might be inconsistent

rule base

- if a container is filled & ope
  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

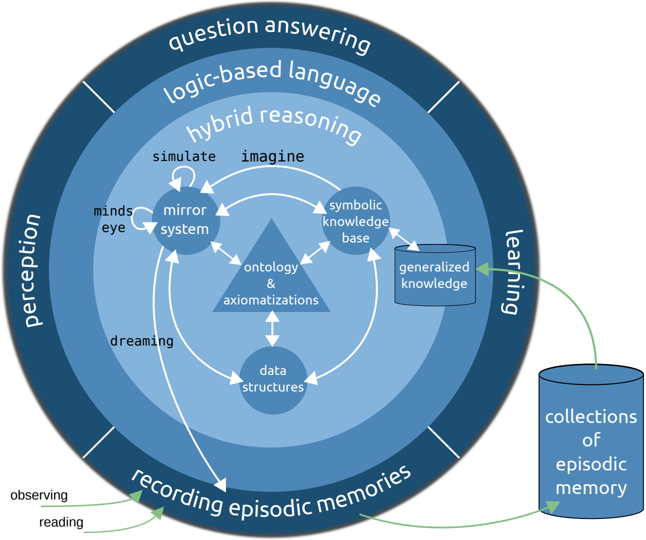
rule base (ctd)

- **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

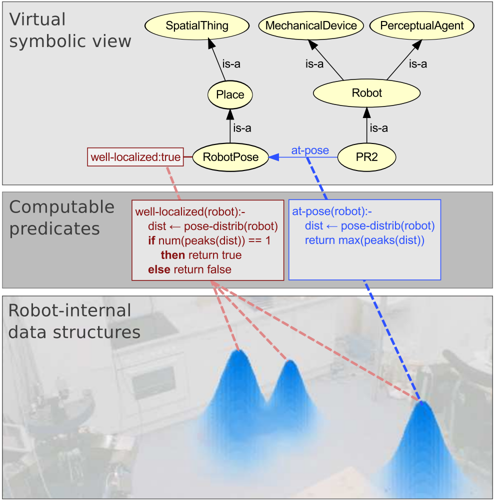
Knowledge-enabled programming

fetch-and-place plan schema	knowledge
def-plan pour (⟨**theme**⟩, ⟨**source**⟩ ⟨**destination**⟩) 1. take(⟨**source**⟩) 2. hold(⟨**source**⟩) (a location (above ⟨**destination**⟩)) 3. tilt(⟨**source**⟩) **until** (amount (some stuff (at ⟨**destination**⟩)) $\geq$ (amount ⟨**theme**⟩)) **end**	• 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 • ...

Knowledge processing for robots

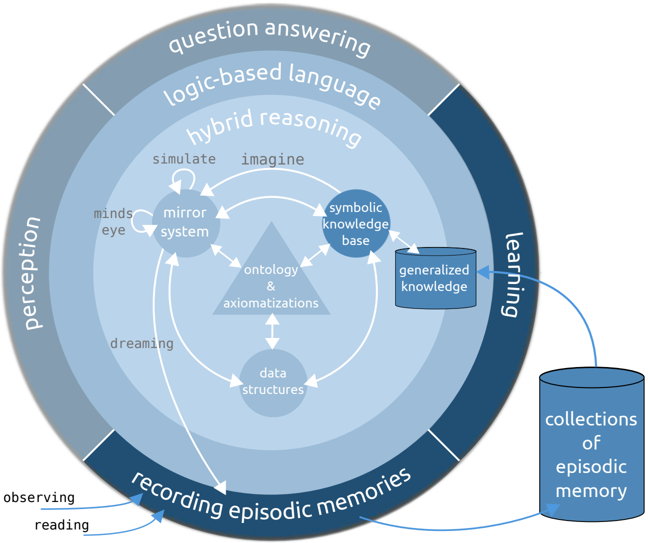


Virtual knowledge bases

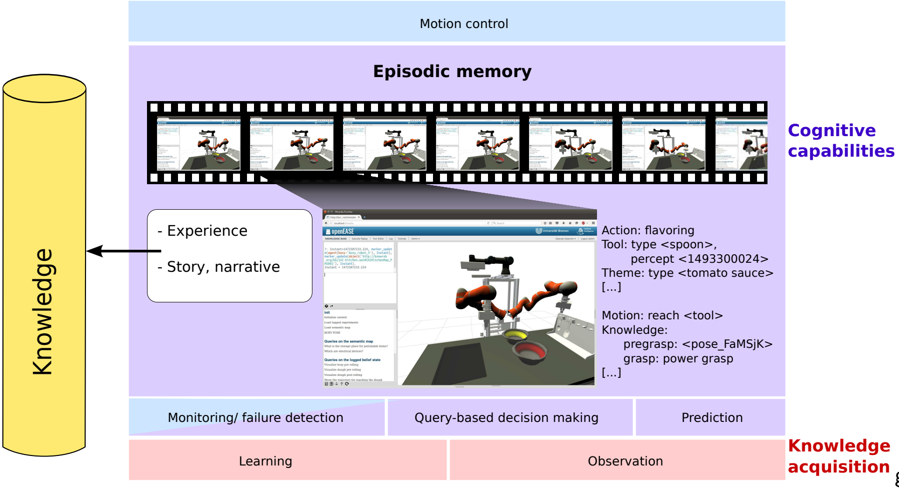


Mirror world knowledge bases

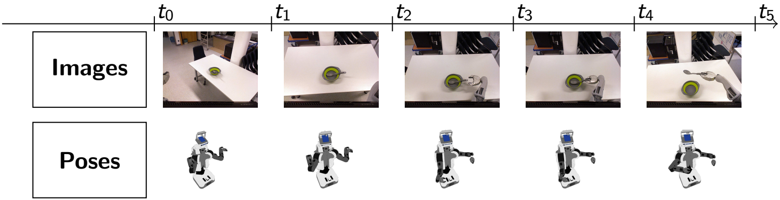
Knowledge acquisition and episodic memories



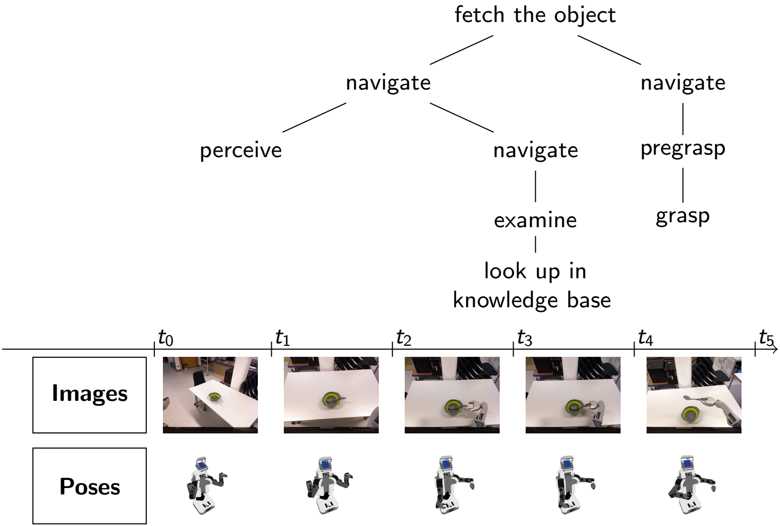
Episodic memories



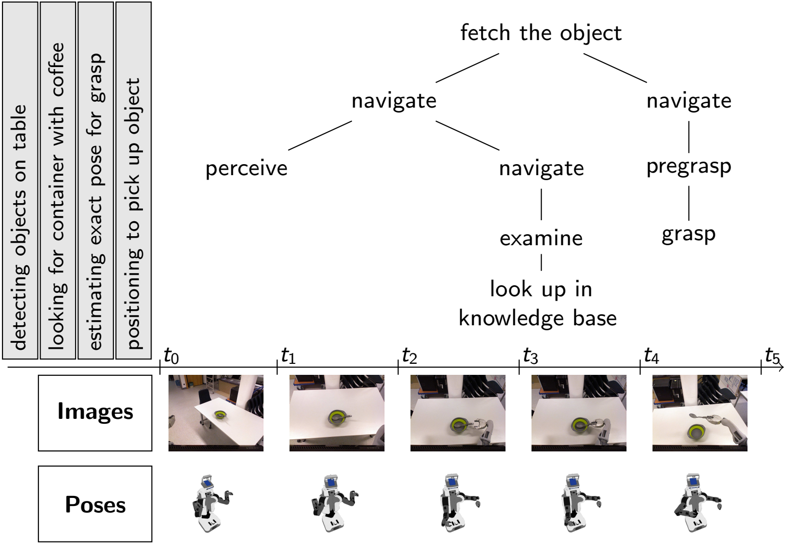
Components of episodic memories



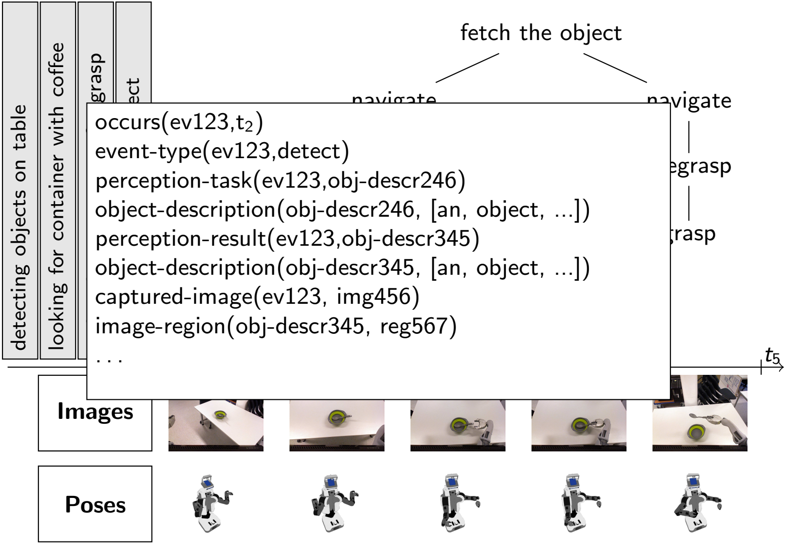
Components of episodic memories



Components of episodic memories



Components of episodic memories



Semantic retrieval from episodic memories

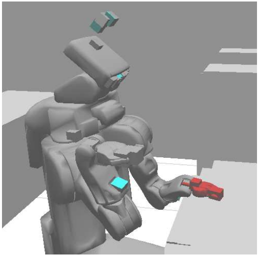
```
?- task(Tsk),
   task-action(Tsk, [an, action,
                      [type, pick-up],
                      [object-acted-on,
                        [an, object
                          [type, pot],
                          [weight, Weight]]]]),
   Weight >= 2kg,
```

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 >= 2kg,
   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).
```



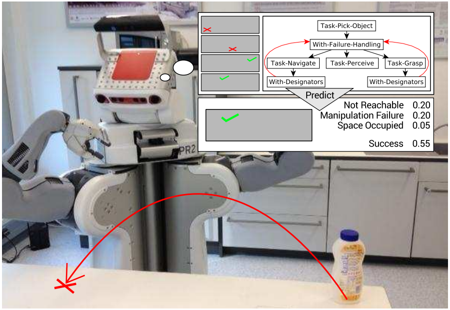
Supervised learning from episodic memories

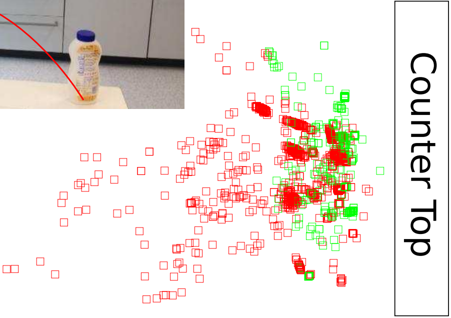
```
?-
    task(Tsk),
    task-action(Tsk, [an, action,
                          [type, pick-up],
                          [object-acted-on,
                              [an, object
                                  [type, pot],
                                  [weight, Weight]]]]),
    Weight >= 2kg,
                                  ,
    task-start(Tsk,TskStrt),
    holds(pose(pr2,Pose),TskStrt),
      .
```

Supervised learning from episodic memories

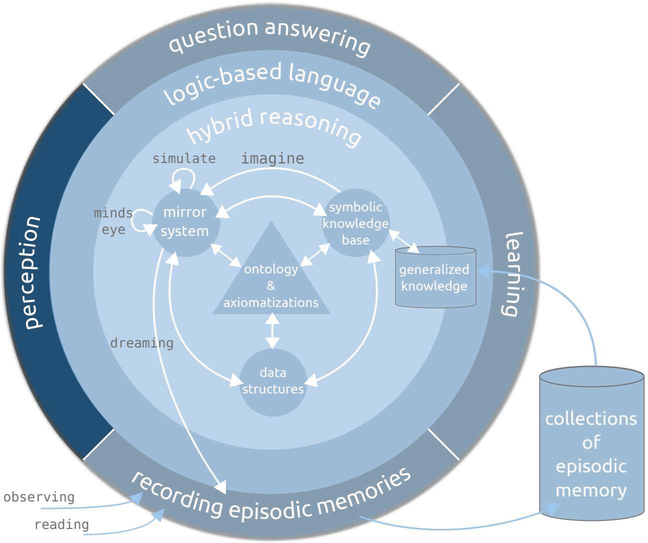
```
?- setof(Pose,
         task(Tsk),
         task-action(Tsk, [an, action,
                            [type, pick-up],
                            [object-acted-on,
                               [an, object
                                  [type, pot],
                                  [weight,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

Learning control concepts from longterm experience

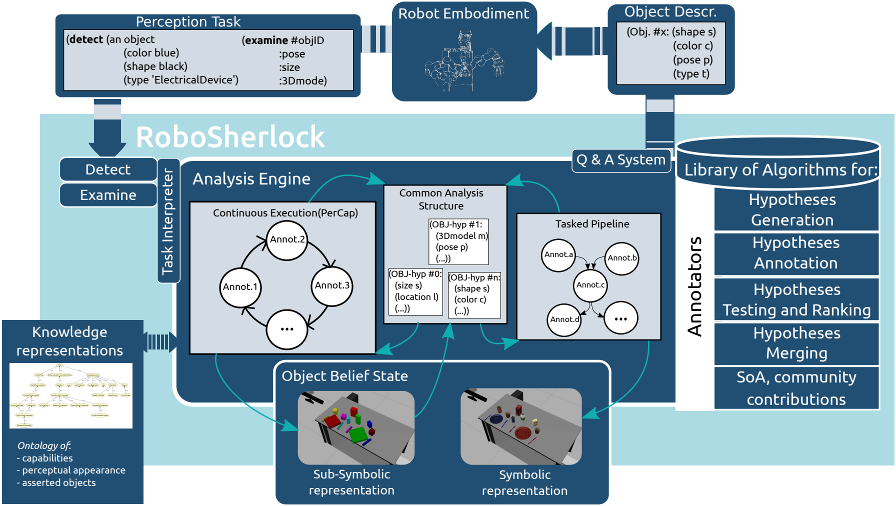




Perception


question answering
logic-based language
hybrid reasoning
simulate
imagine
minds eye
mirror system
symbolic knowledge base
generalized knowledge
ontology & axiomatizations
dreaming
data structures
perception
learning
recording episodic memories
collections of episodic memory
observing
reading

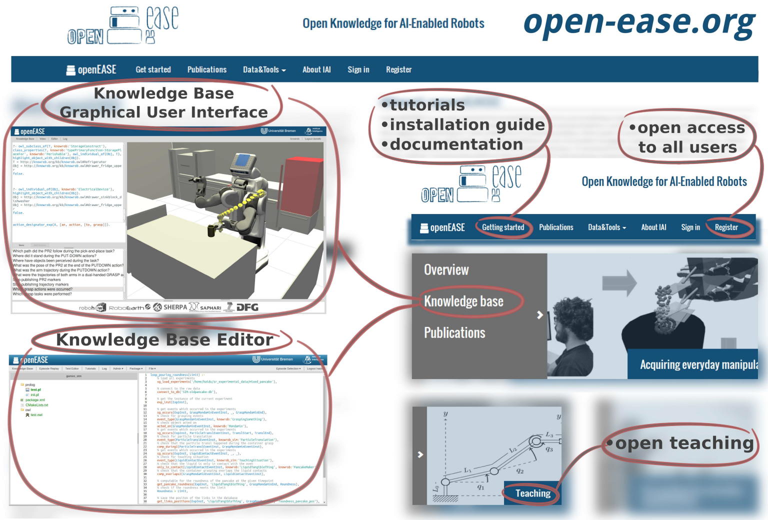
Cognition-enabled perception



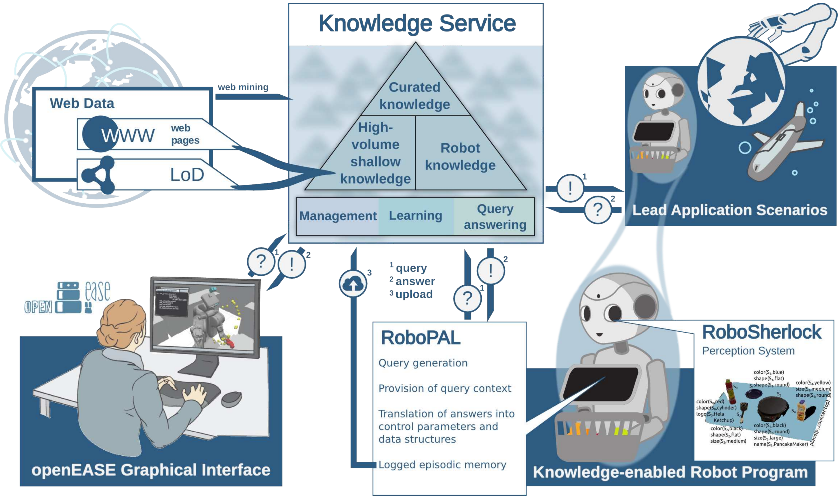
Final remarks

openease/scenario-components.png

Final remarks (2)

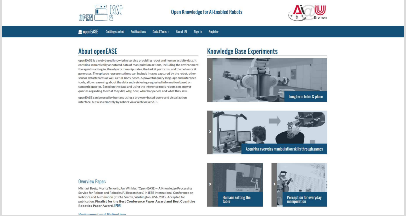


An Open Knowledge Service for Robotics



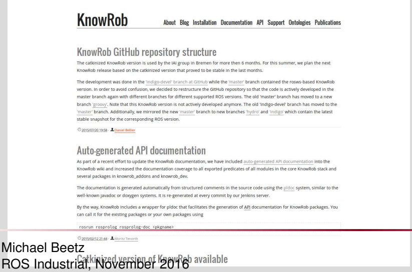
OPENEASE: other tools

open research/innovation



probabilistic reasoning

knowledge processing



perception

Thank you

for your attention

Pepper at AI/Uni-Bremen

First integration during the final RoboHow review (EU project).

Pepper at AI/Uni-Bremen (2)

Pepper at AI/Uni-Bremen (3)

- Integration into the kitchen environment
- First attempts at localization using infrared markers (Optitrack tracking system), but would like to replace it by on-board localization when available.
- Communication from the ROS-World using a bridge, to explain OpenEASE data to participants