Towards Web-enabled Robots

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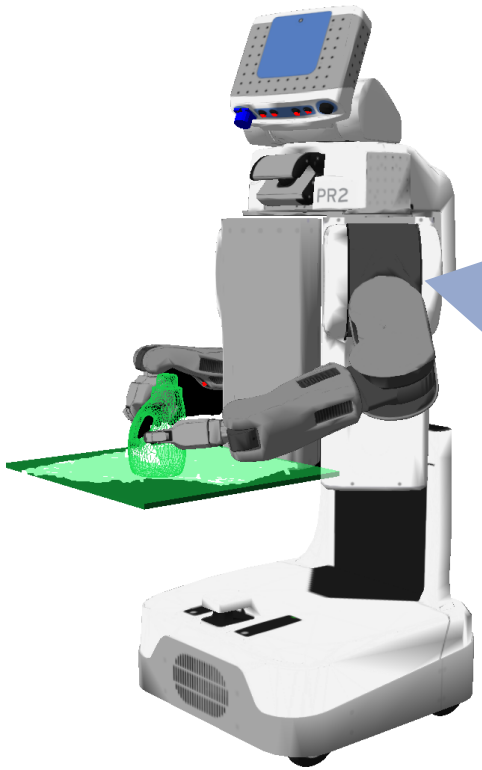
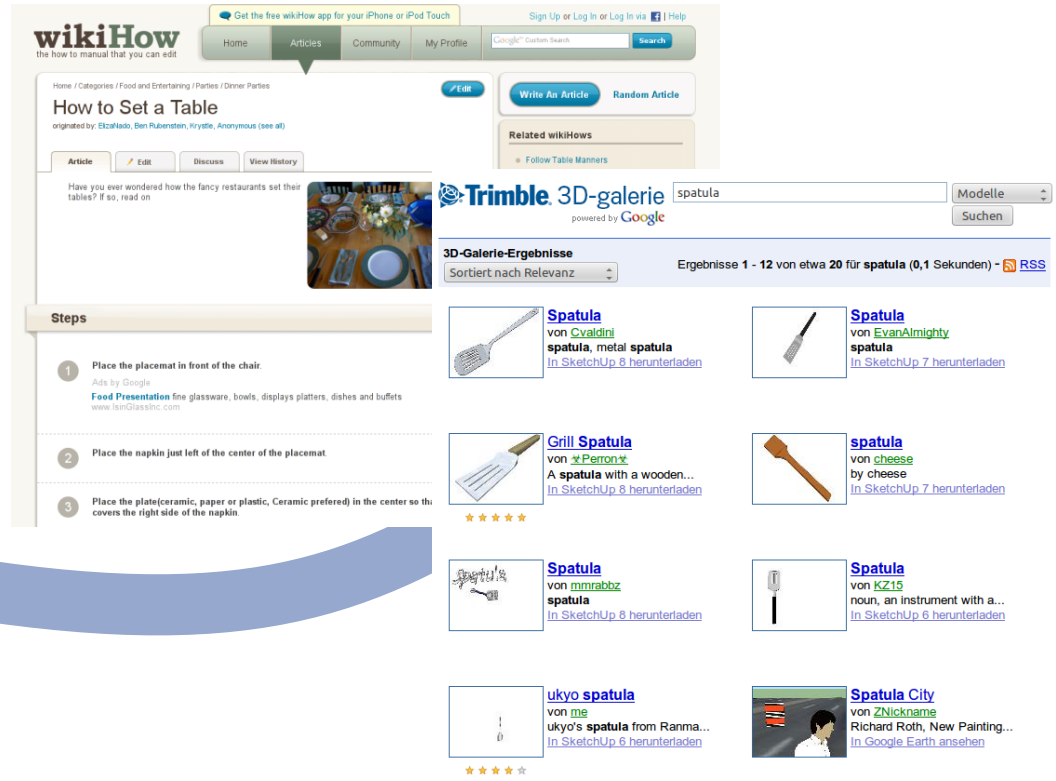
Use Case 1: Using the Web as Knowledge Source





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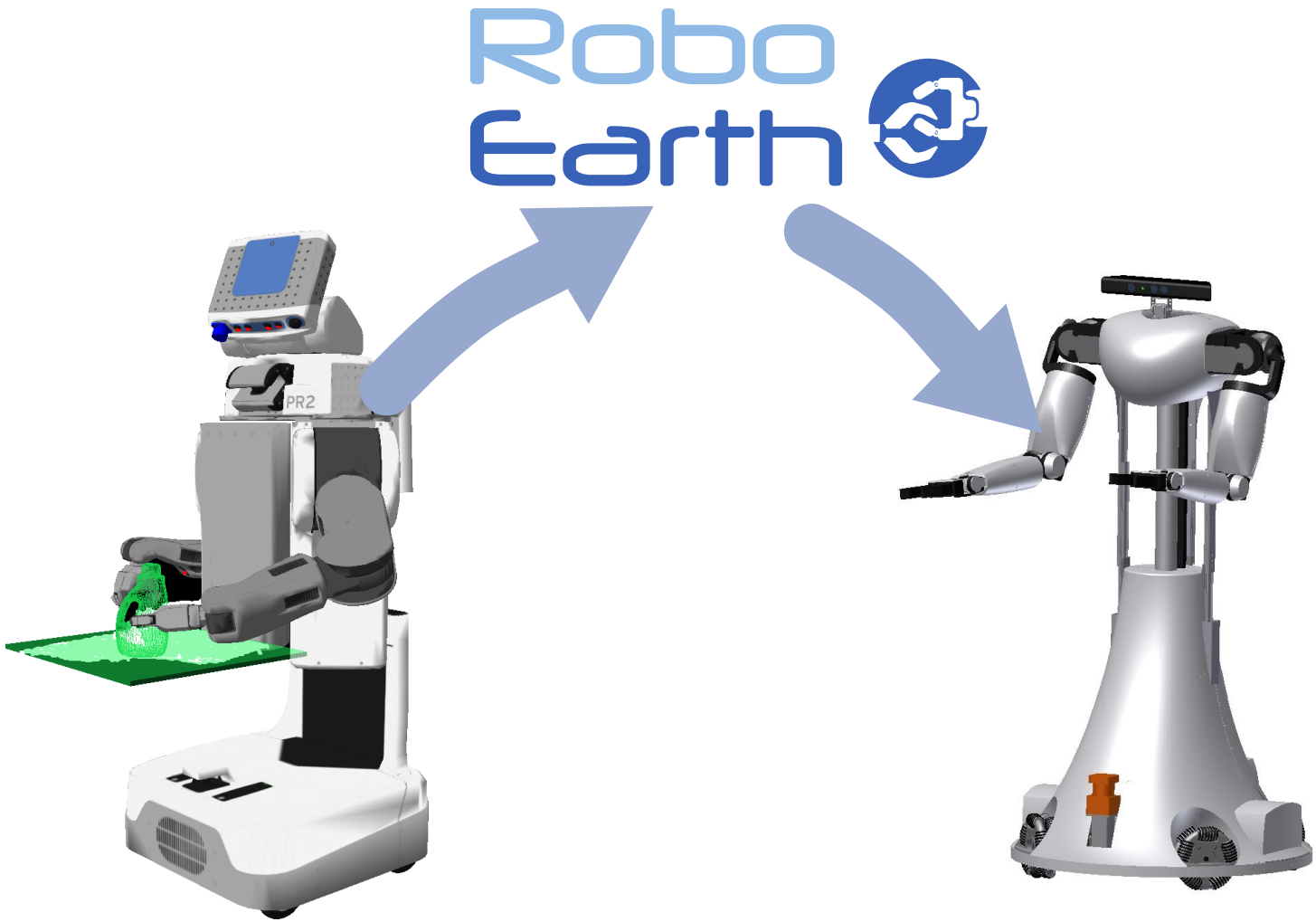
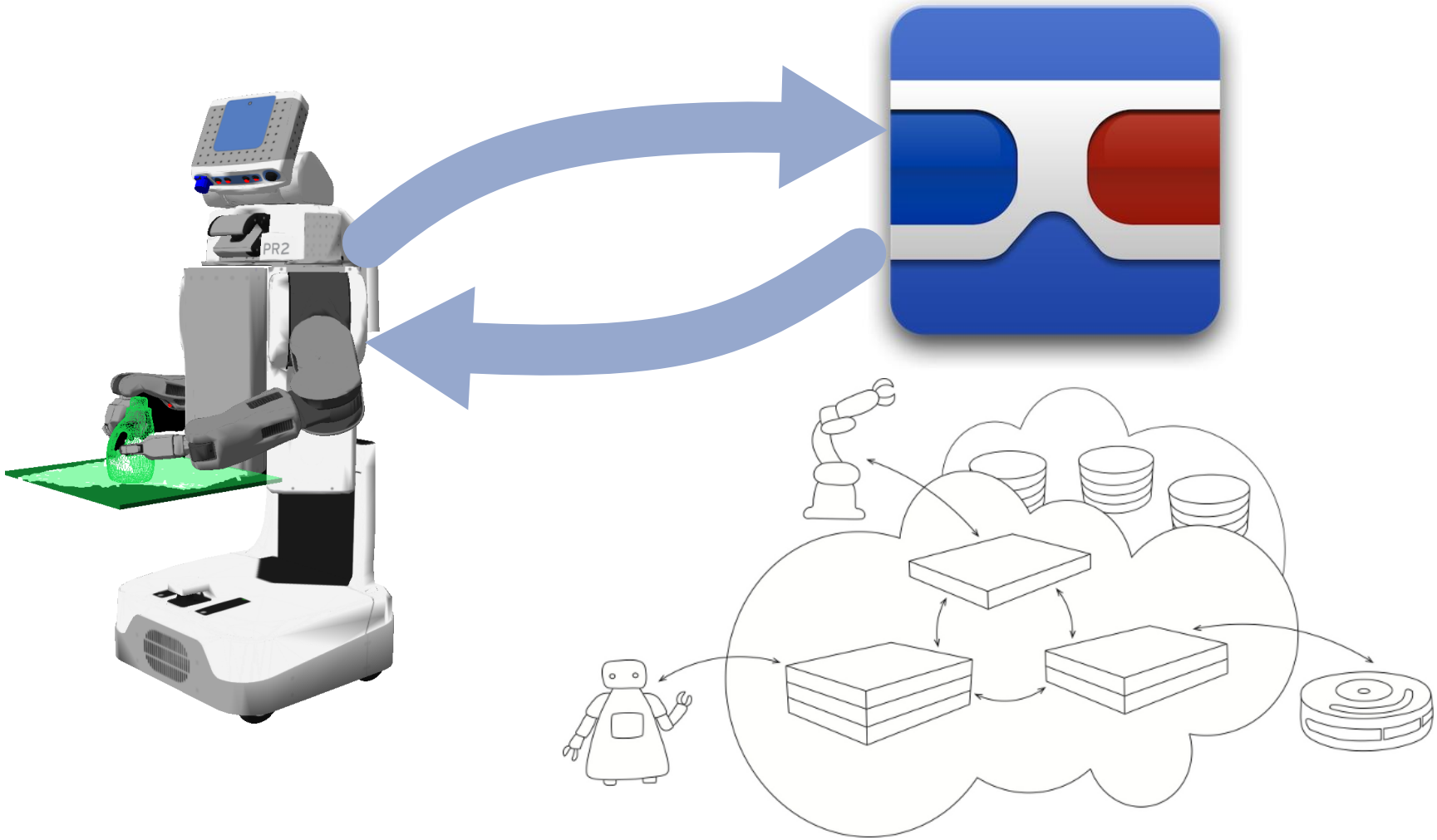
Use Case 2: Exchanging Information via the Cloud



Use Case 3: Outsourcing Services to the Cloud



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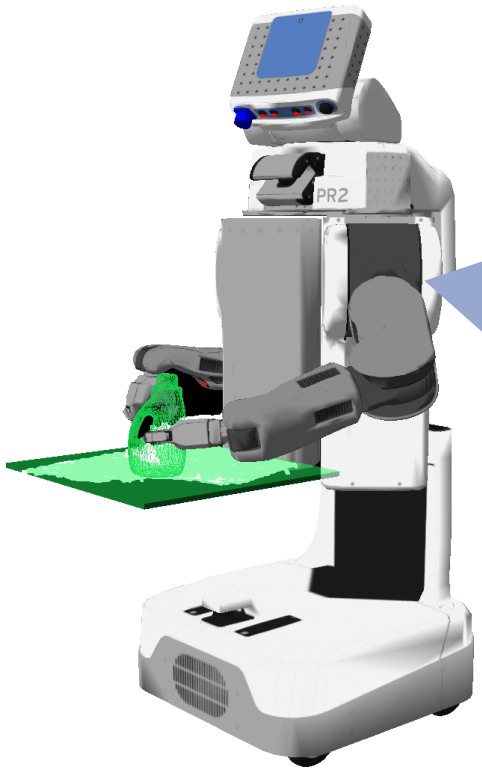
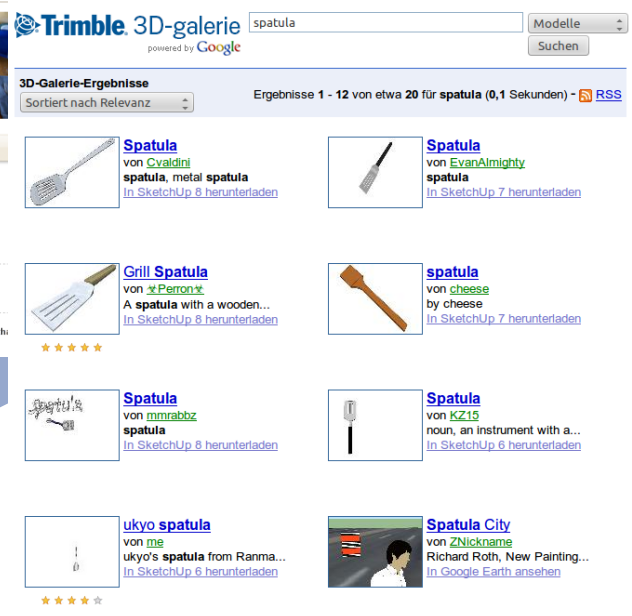
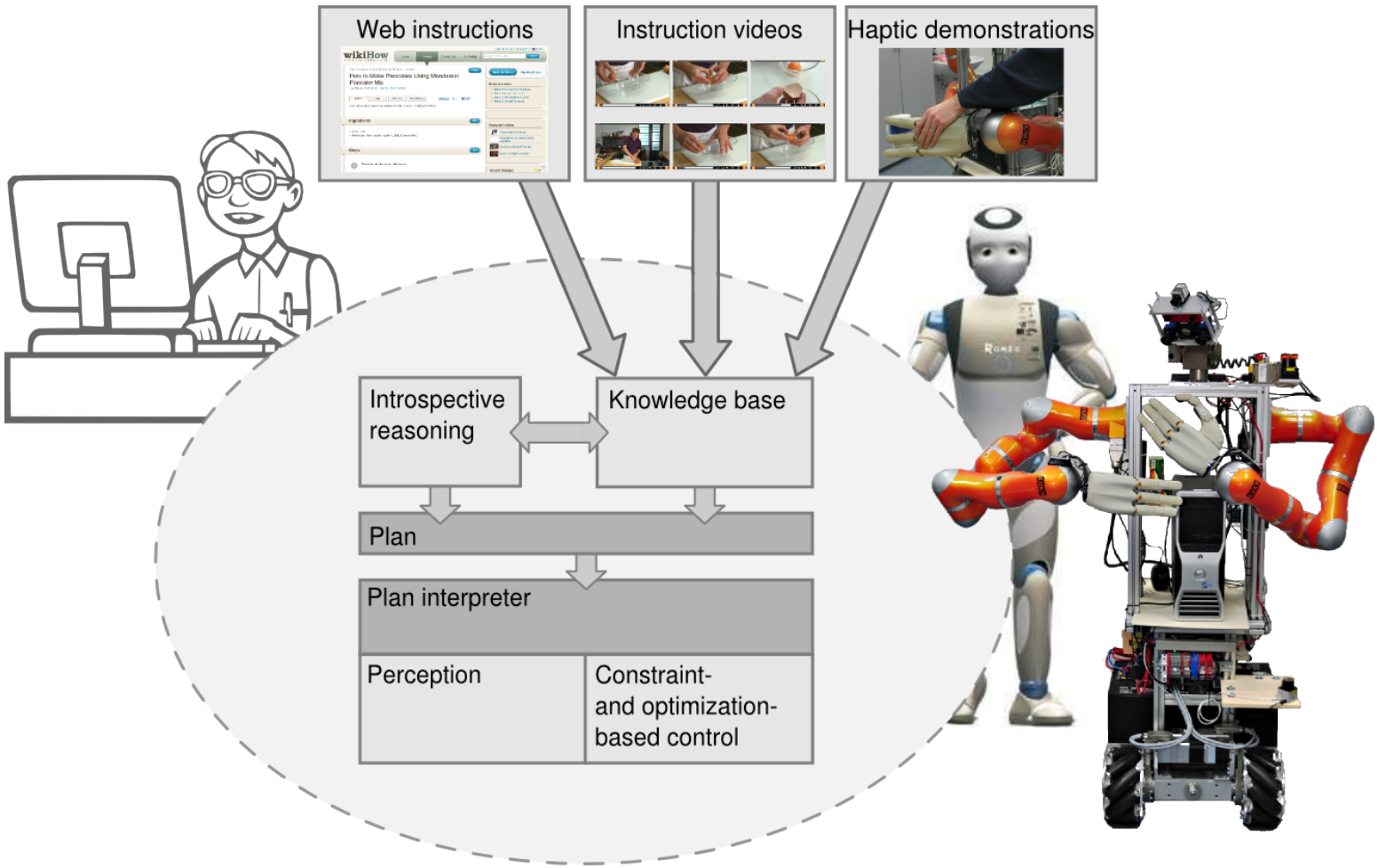




The RoboHow Project



http://www.robohow.eu

Using the Web as Knowledge Source

Research Problems

- **Understanding information made for humans**

Using the Web as Knowledge Source

Research Problems

- **Understanding information made for humans**
  - Natural language processing to convert into formal representation

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- **Grounding abstract information in the robot system**

Using the Web as Knowledge Source

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- **Grounding abstract information in the robot system**
  - Grounding object info in perception, actions in movement descriptions

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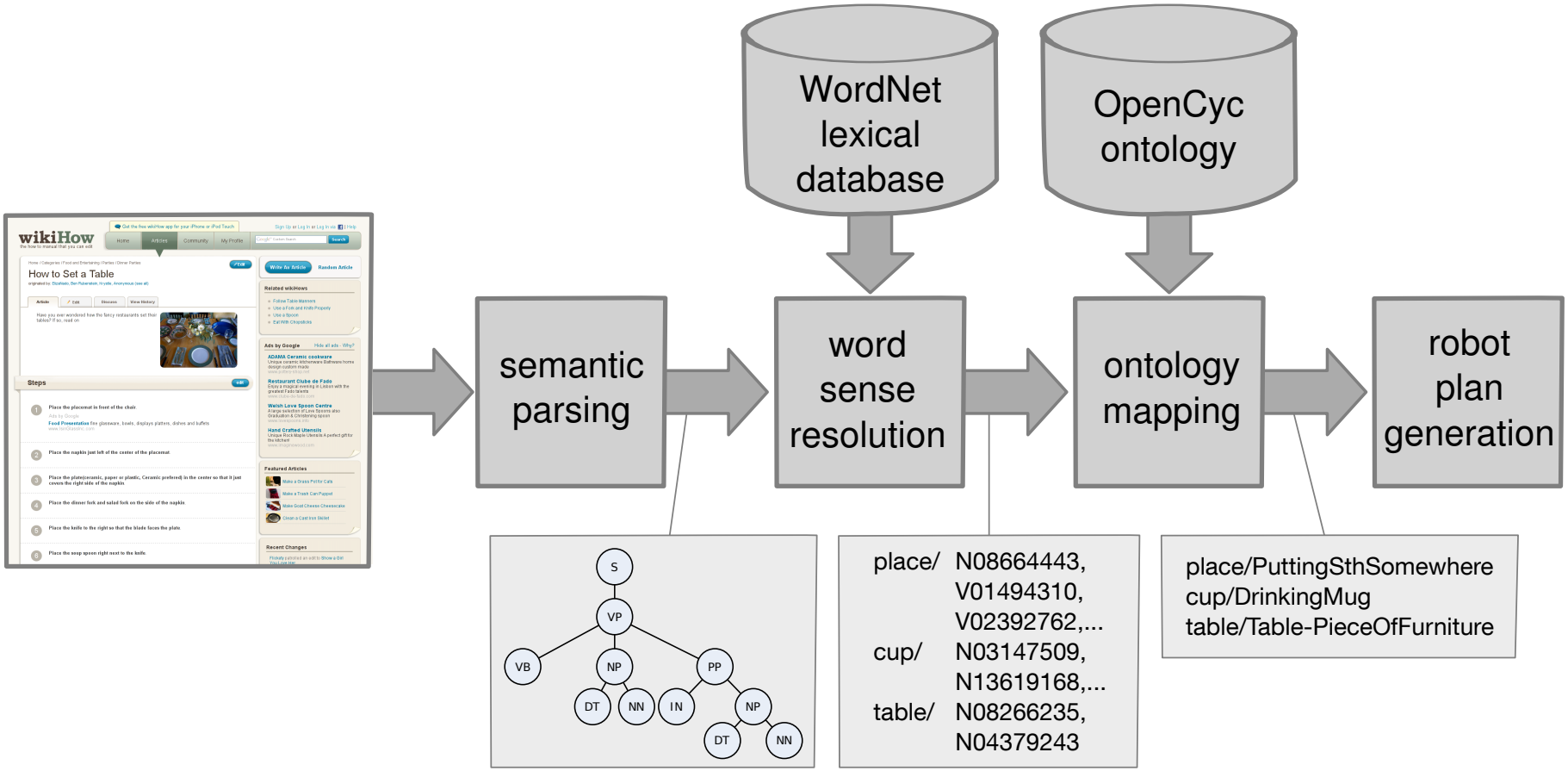
- **Integrating complementary knowledge sources**
  - Convert natural-language information into formal representation as extension of a common ontology

Task instructions from the WWW

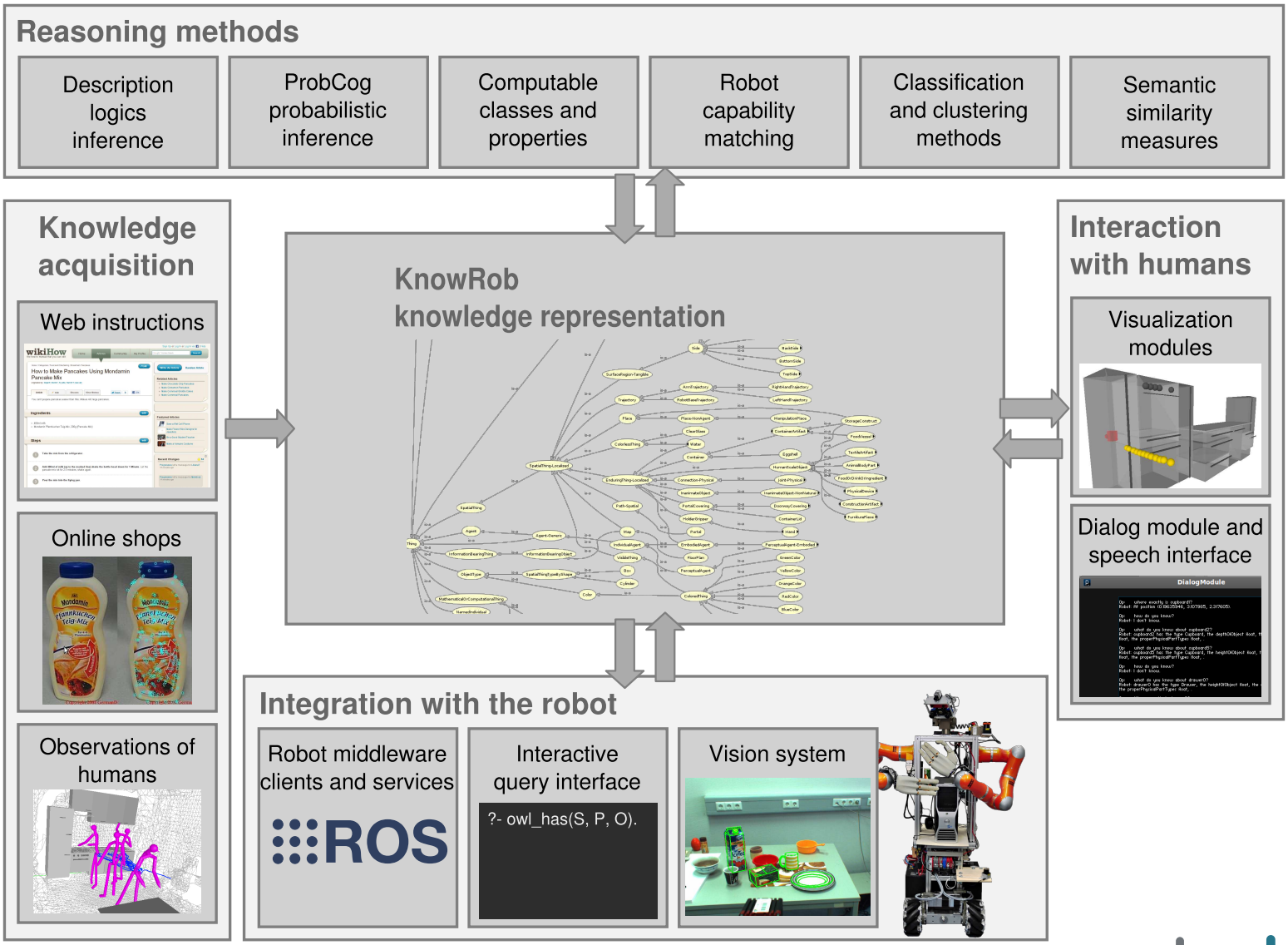


Understanding and Executing Instructions for Everyday Manipulation Tasks from the World Wide Web. Moritz Tenorth, Daniel Nyga and Michael Beetz. ICRA 2010

Demonstration:
Import of natural-language instructions

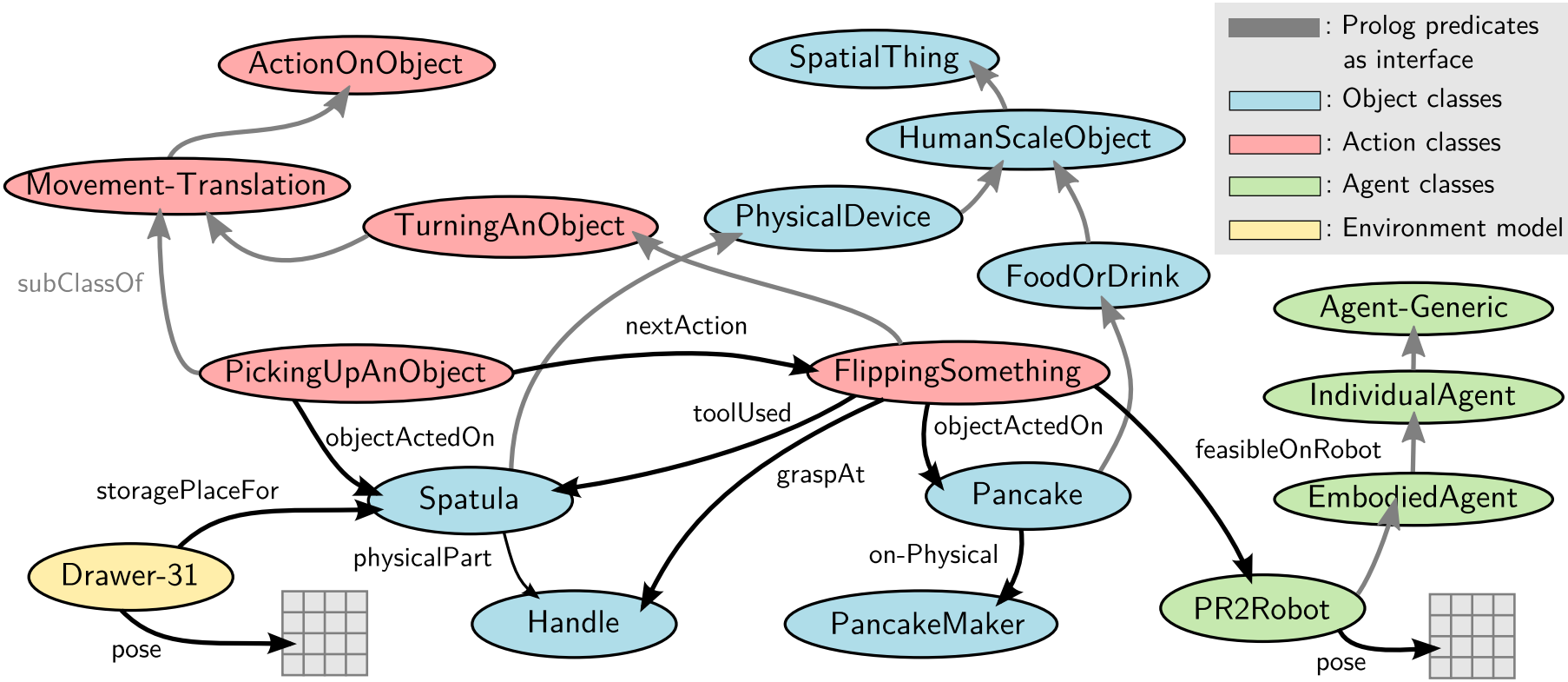
`http://knowrob.org/doc/robots_and_the_internet`

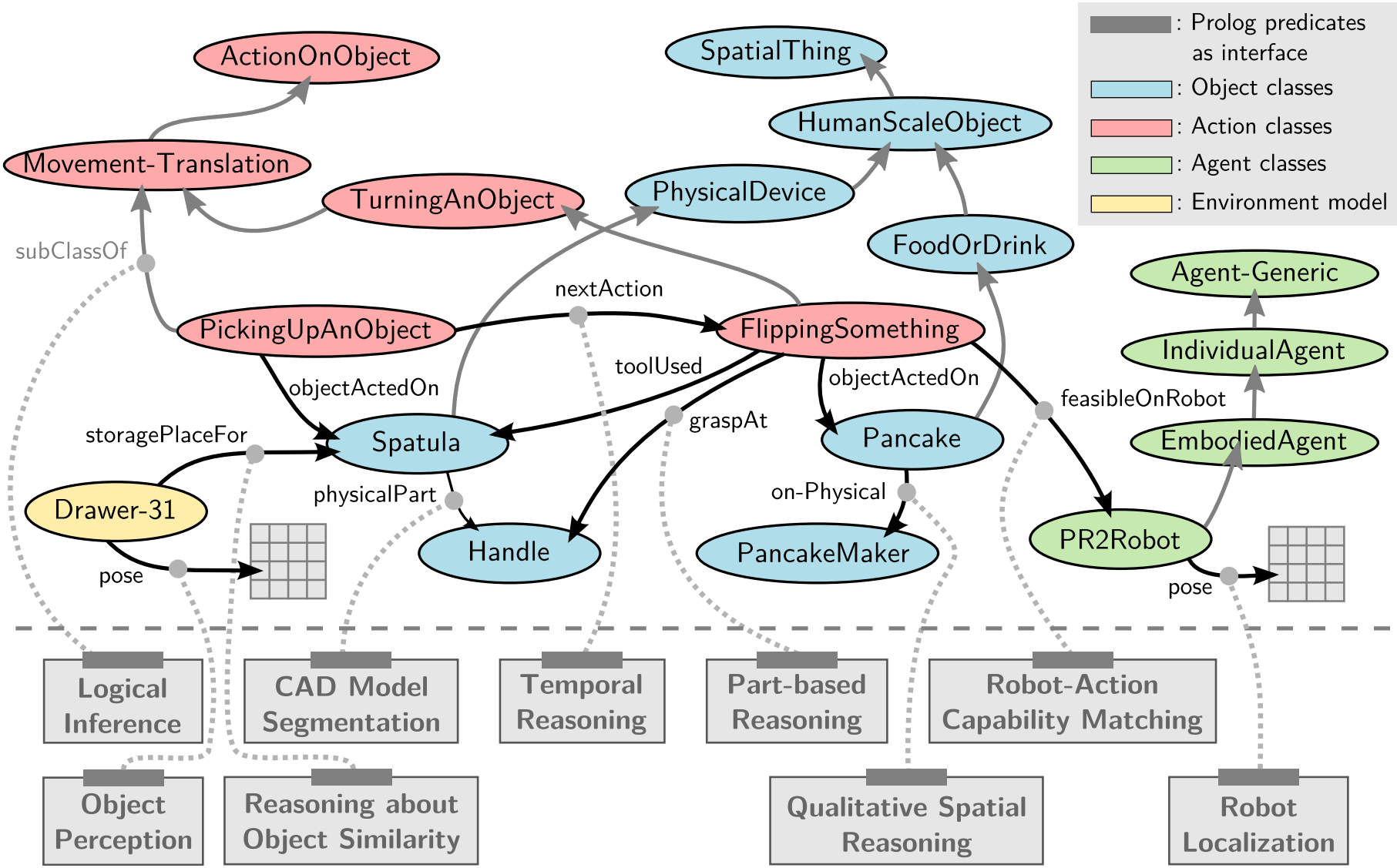
KnowRob: A knowledge base for robots



KnowRob: Techniques used

- **Prolog**
  - Main query interface + inference engine
  - Useful combination of declarative and procedural aspects
- **Descriptions Logics / OWL**
  - Common ontology: "Vocabulary" for describing the knowledge
  - Representation of actions, semantic environment maps, object models, robot self-models, ...
- **Procedural attachments**
  - Computation of qualitative information from metric data
  - Integration of external data sources (e.g. vision system)
  - Integration of other kinds of reasoners (e.g. OWL, Markov Logic)


: Prolog predicates as interface
: Object classes
: Action classes
: Agent classes
: Environment model
ActionOnObject
SpatialThing
HumanScaleObject
Movement-Translation
TurningAnObject
PhysicalDevice
FoodOrDrink
subClassOf
nextAction
Agent-Generic
PickingUpAnObject
FlippingSomething
IndividualAgent
toolUsed
objectActedOn
objectActedOn
feasibleOnRobot
graspAt
storagePlaceFor
Spatula
Pancake
EmbodiedAgent
physicalPart
on-Physical
Drawer-31
Handle
PancakeMaker
PR2Robot
pose
pose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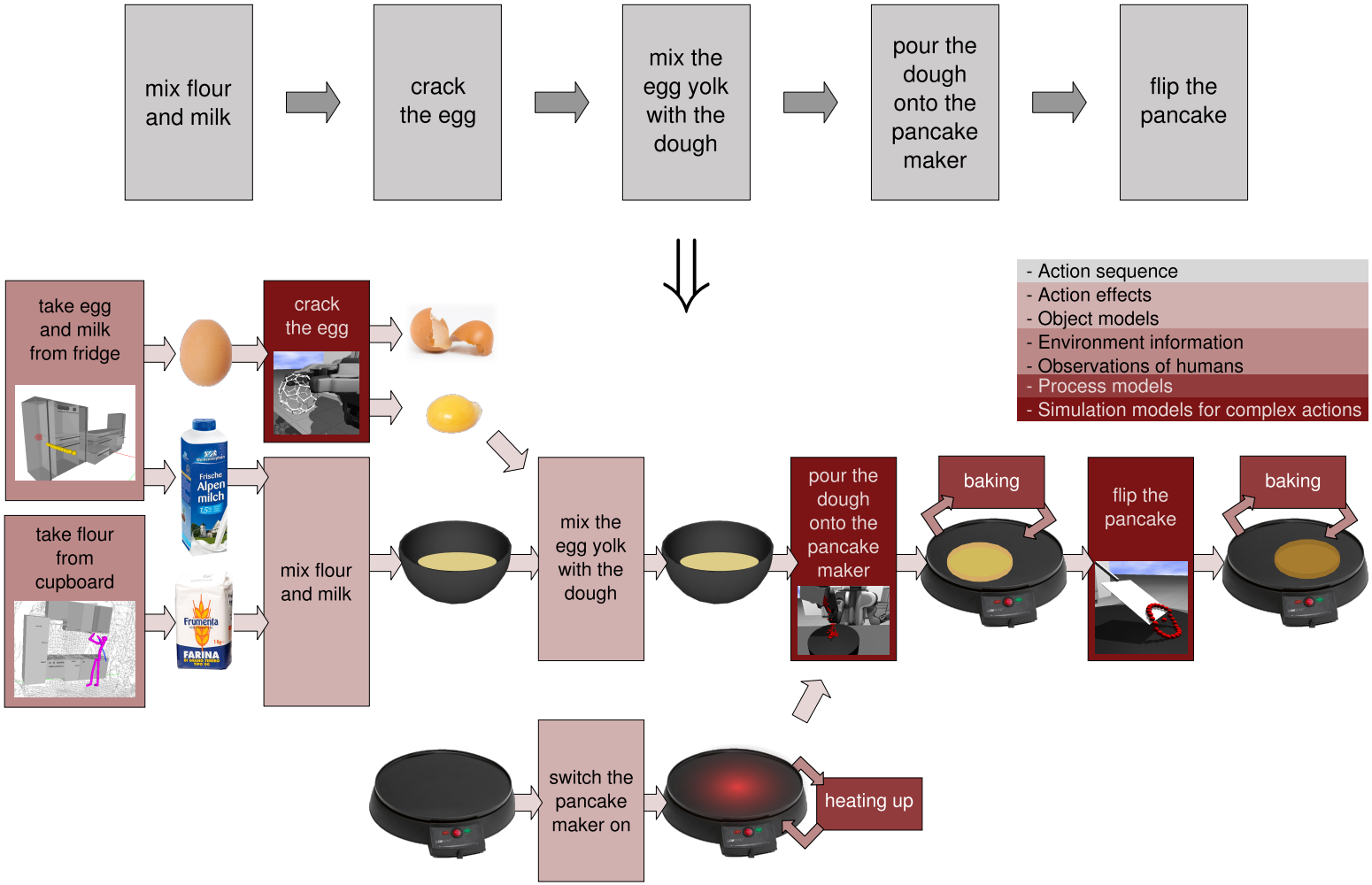
pose
pose
Logical Inference
CAD Model Segmentation
Temporal Reasoning
Part-based Reasoning
Robot-Action Capability Matching
Object Perception
Reasoning about Object Similarity
Qualitative Spatial Reasoning
Robot Localization

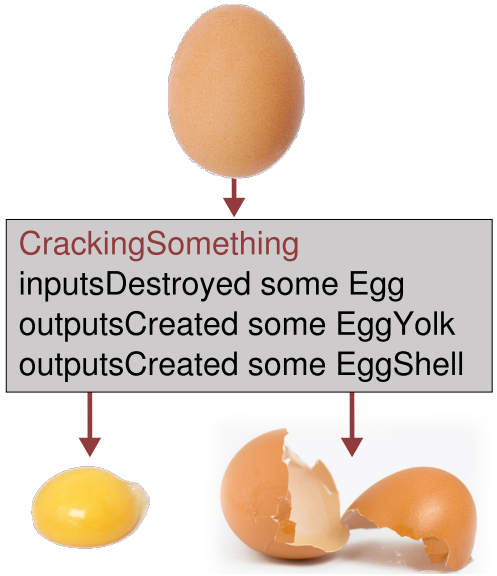
Completing Instructions with Qualitative Reasoning

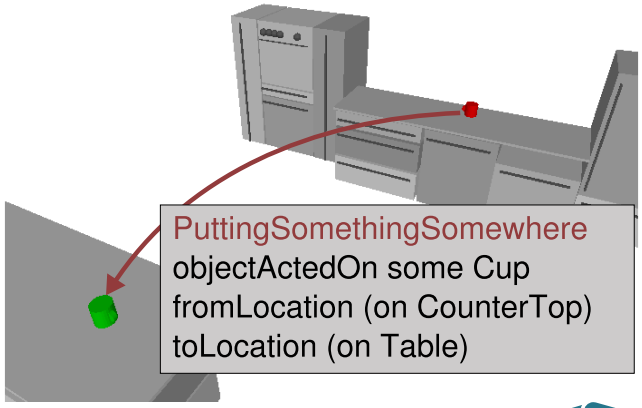


A Unified Representation for Reasoning about Robot Actions, Processes, and their Effects on Objects. Moritz Tenorth and Michael Beetz, IROS 2012

Modeling action effects

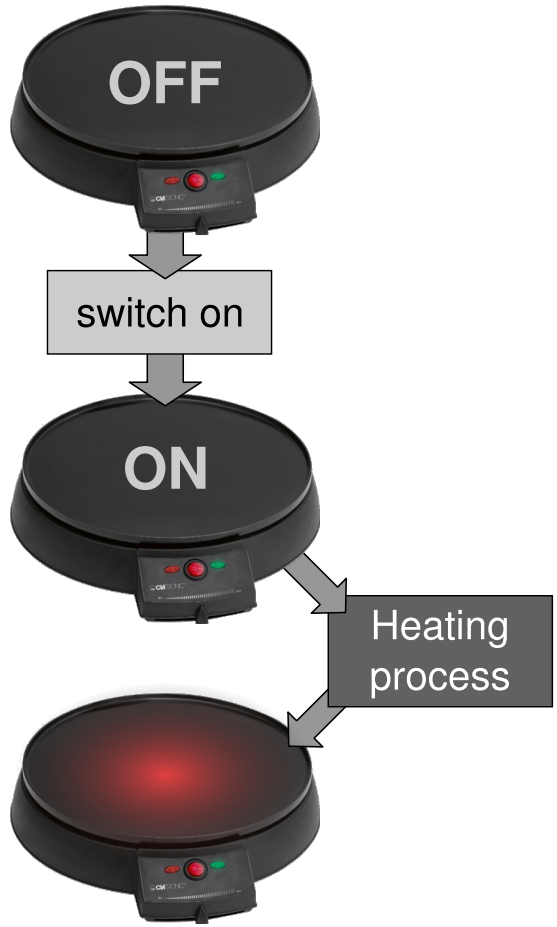
- Actions can move, split, destroy, create, join, open, and close objects, switch them on and off, etc...
- Goal: represent and reason about these interactions
- Hybrid representation of action effects:
  - Declarative specification for planning
  - Procedural rules for projection



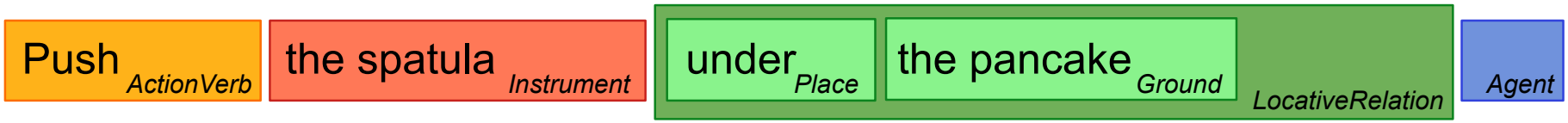


Combined representation of actions and processes

- Processes as indirect effects of actions: Heating up, melting, baking, ...
- Qualitative process representation: preconditions + effect model
- Similar to Forbus' Qualitative Process theory
- Joint planning and projection → perform an action in order to start a process



Filling Gaps with Action-specific Knowledge Bases



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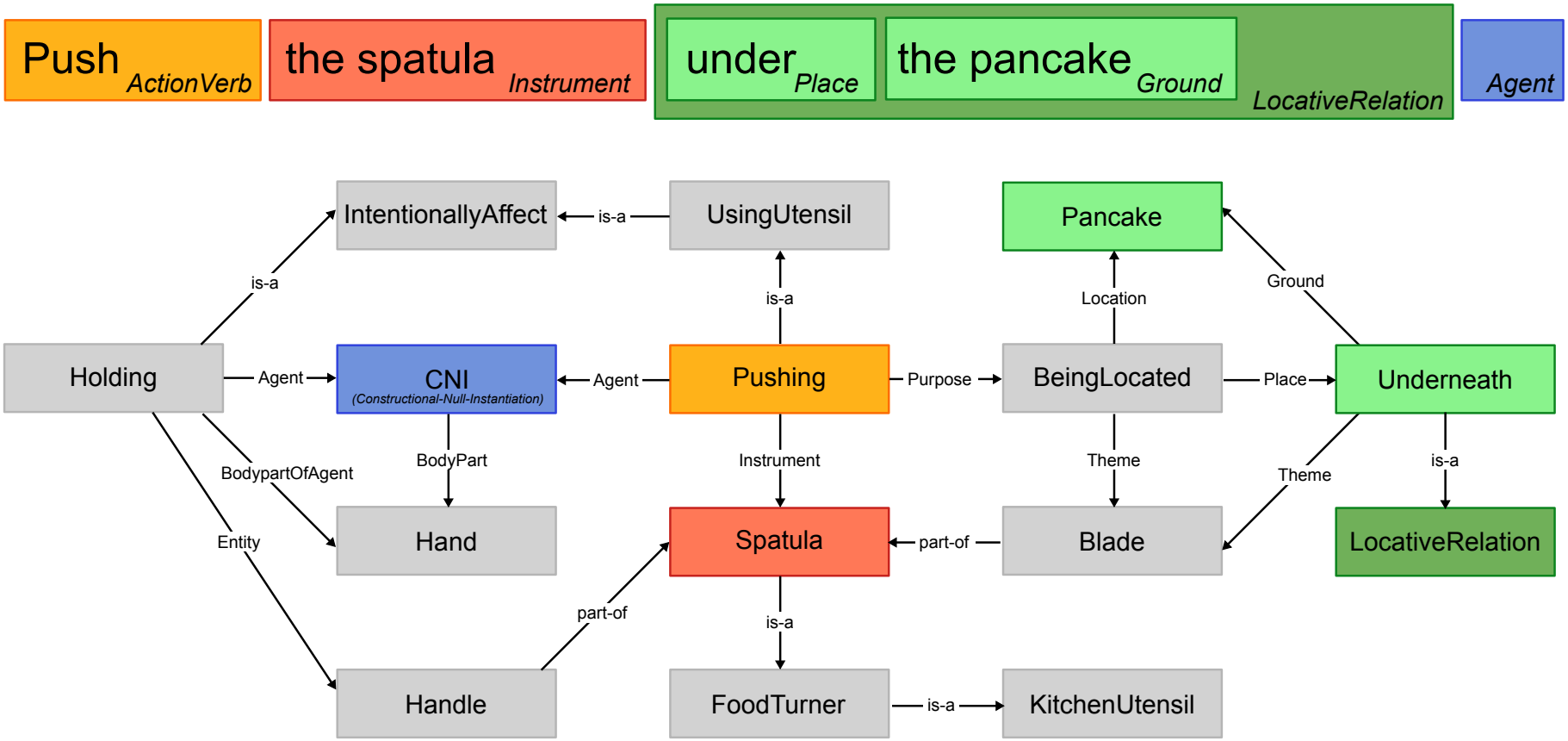
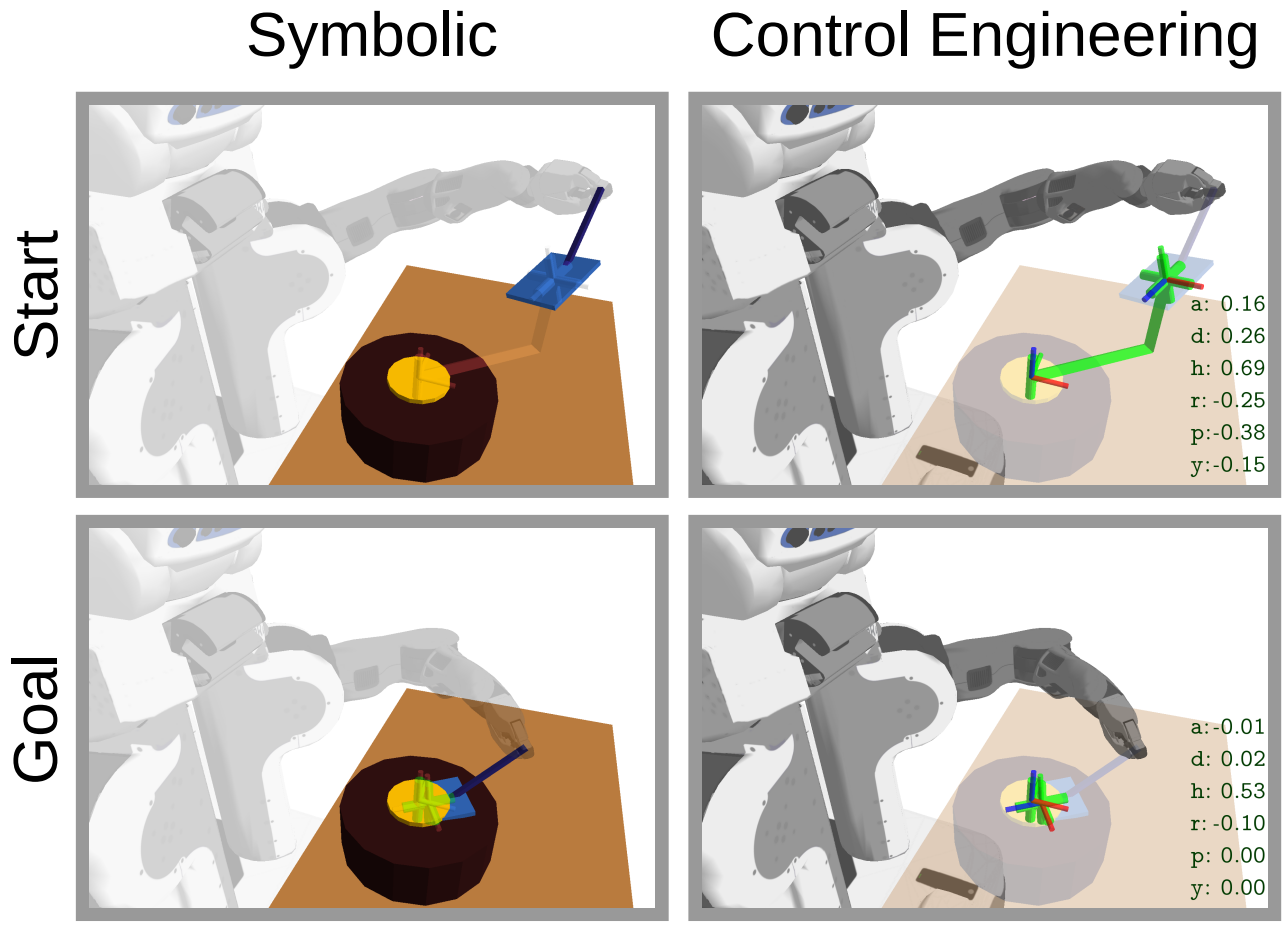


Everything Robots Always Wanted to Know about Housework (But were afraid to ask).
Daniel Nyga and Michael Beetz. IROS 2012

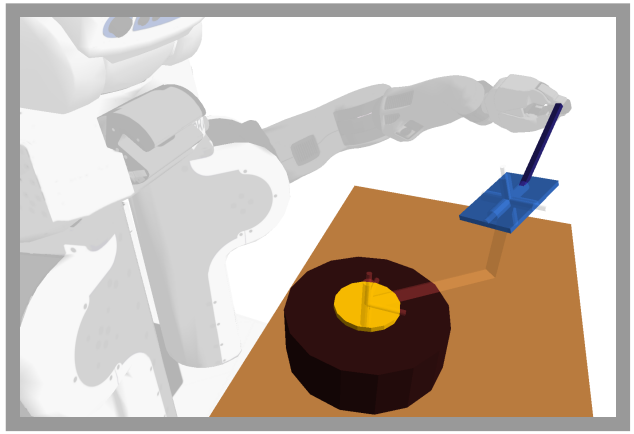
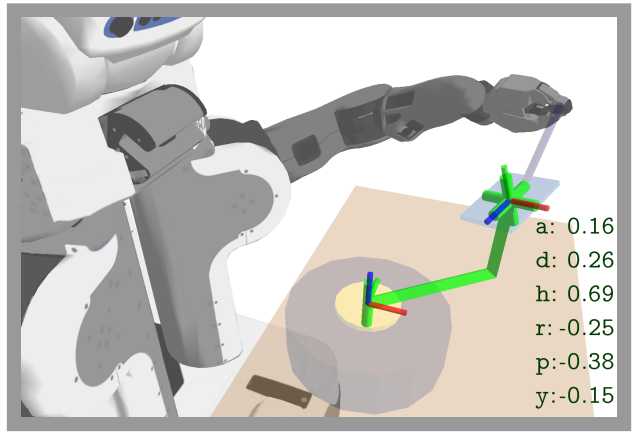
Symbolic Movement Descriptions

Two ways of representing "putting a spatula under a pancake":



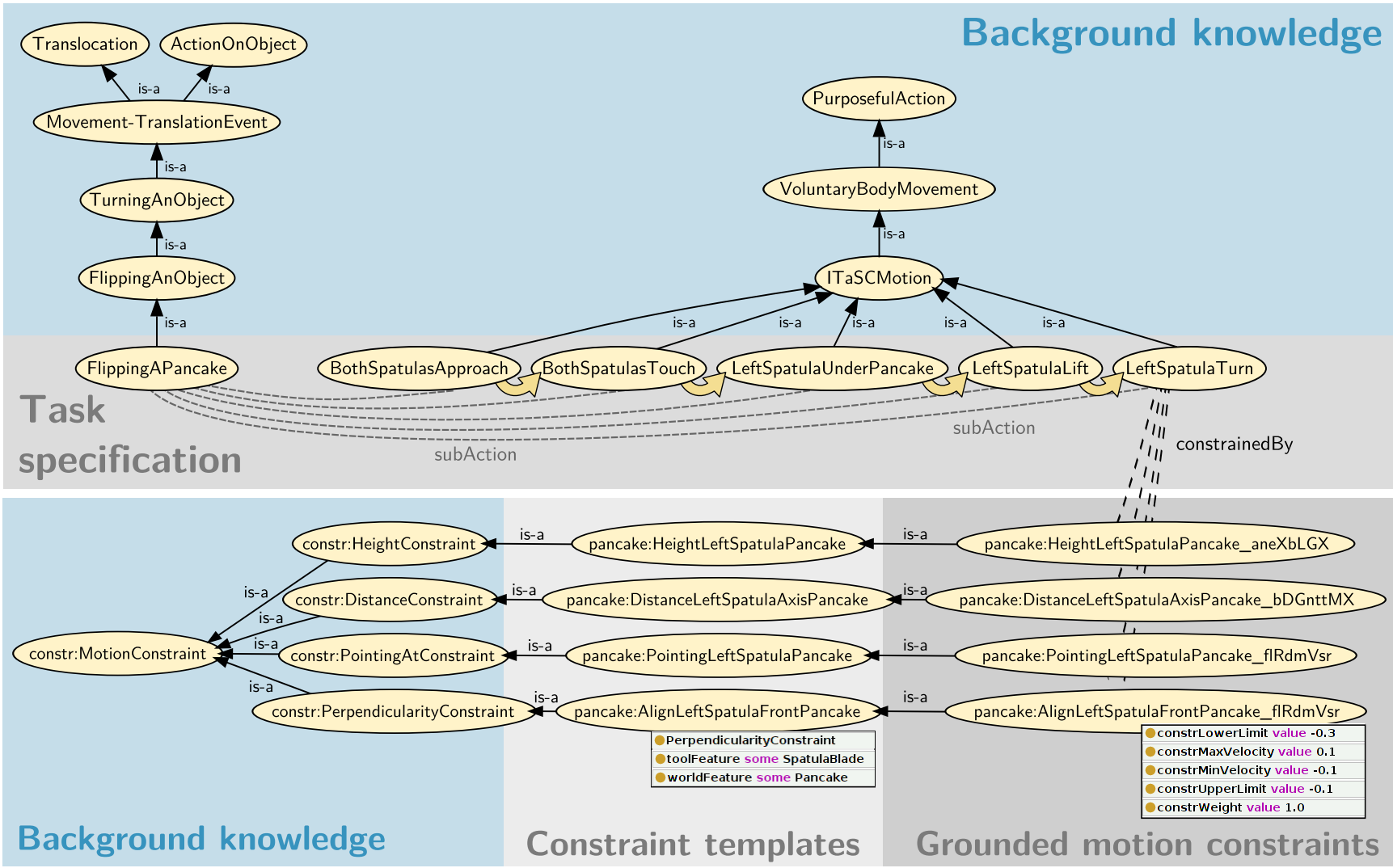
Symbolic Movement Descriptions

Two ways of representing "putting a spatula under a pancake":

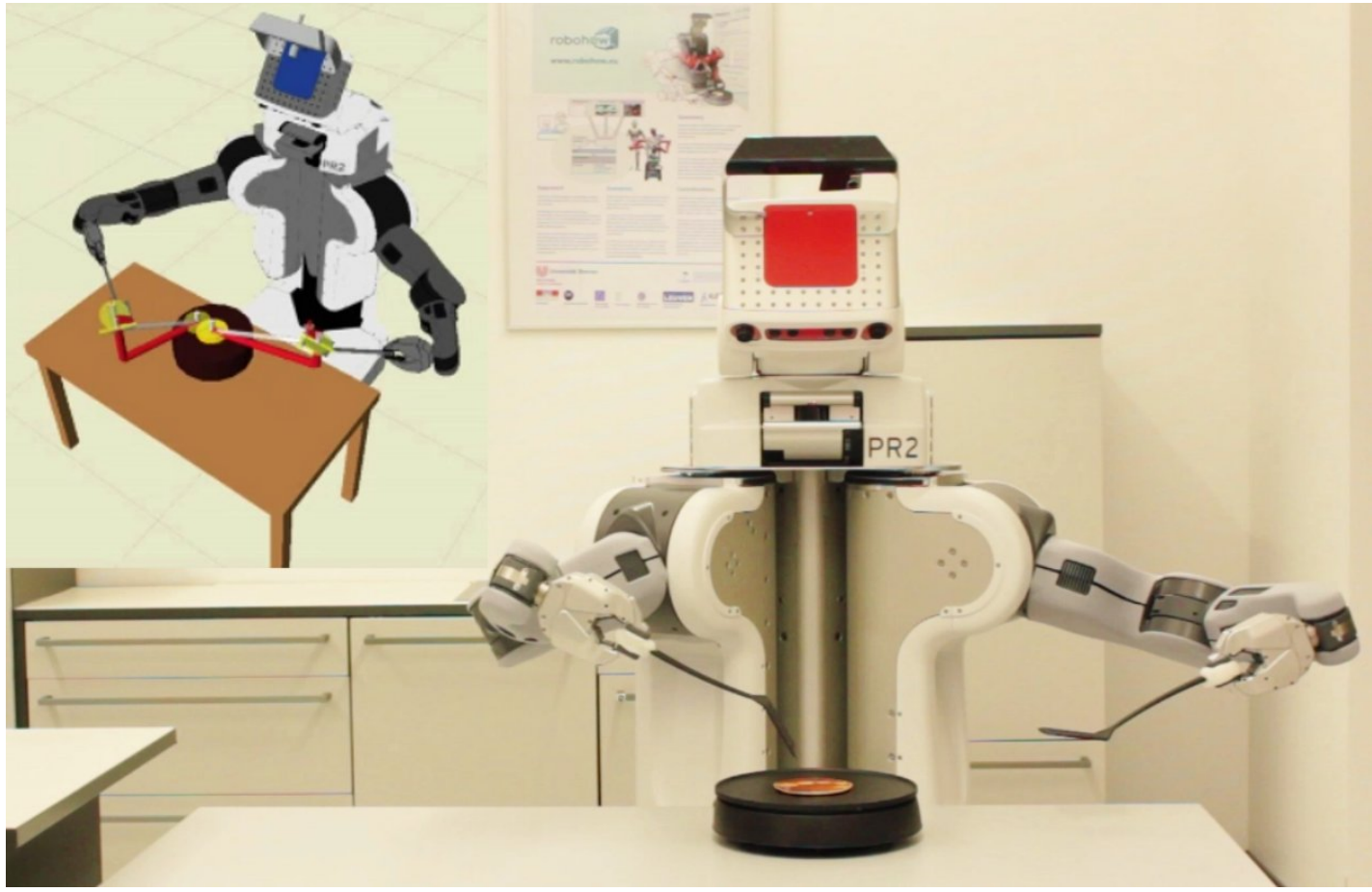
Symbolic	Control Engineering
	
▸ Objects ▸ Desired effects ▸ Task context	▸ Control frames ▸ High reactivity ▸ Dyn. & kin. models

Gap to bridge: How to associate actions with motions?

Constraints as Symbolic Motion Descriptions...



...that can also be executed



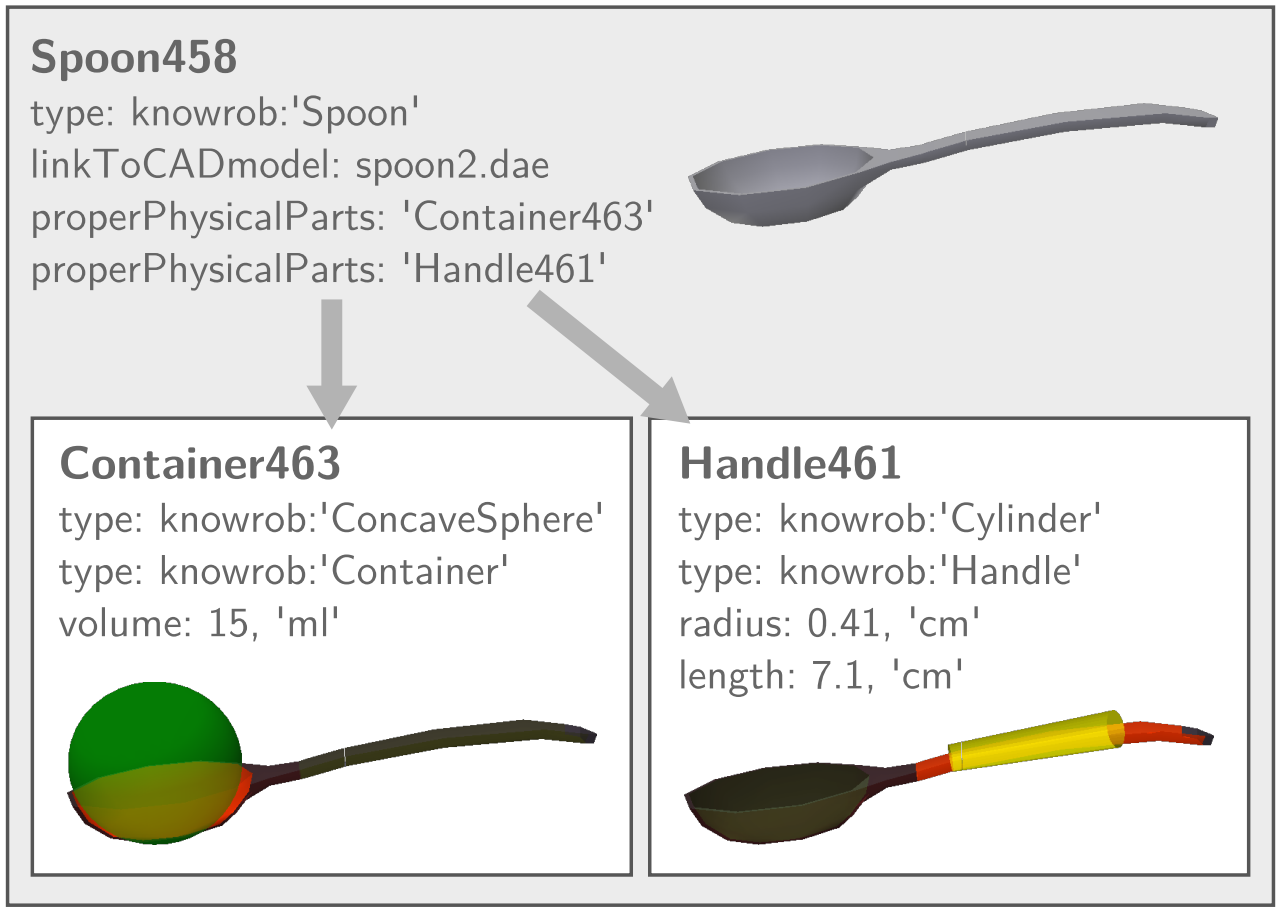
Constraint-based Movement Representation grounded in Geometric Features.
Georg Bartels, Ingo Kresse and Michael Beetz. Humanoids 2013.

How to know which object part to control?

Spoon458
type: knowrob:'Spoon'
linkToCADmodel: spoon2.dae

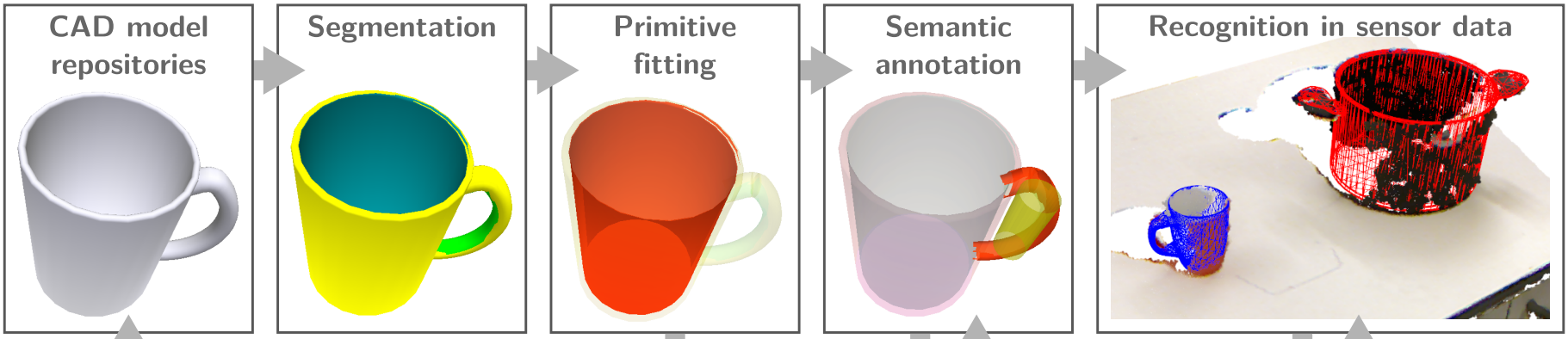
- **Hypothesis:** Functional parts can serve as interlingua to translate between symbolic and geometric object models

How to know which object part to control?



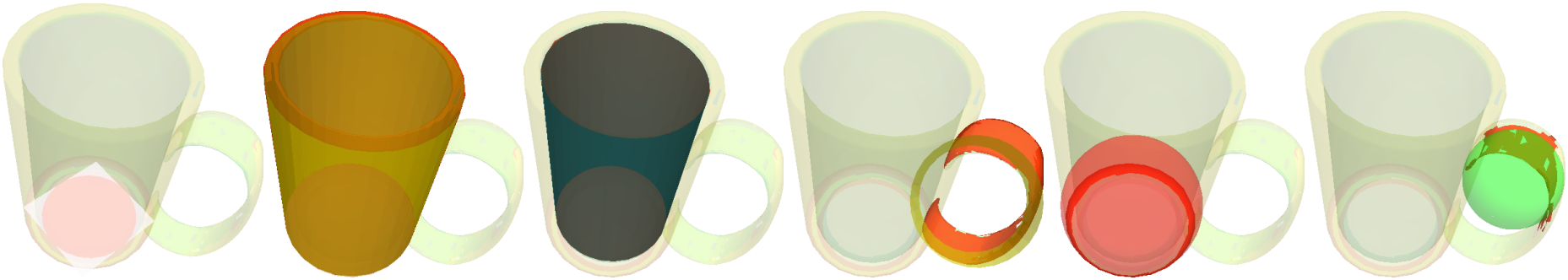
- **Hypothesis:** Functional parts can serve as interlingua to translate between symbolic and geometric object models

Grounding Action Knowledge in Object Models



Decomposing CAD Models of Objects of Daily Use and Reasoning about their Functional Parts. Moritz Tenorth, Stefan Profanter, Ferenc Balint-Benczedi and Michael Beetz. ICRA 2014.

Identification of Geometric Primitives



- Currently: Planes, spheres, cones/cylinders
- Two-fold representation as
  - annotation of the surface mesh
  - instance of the primitive class (e.g. 'Cone') in the knowledge base
- Forms the basis for the application of logical rules

Object representation

Planar surfaces
normalDirection (vector)
objectLongSide (vector)
objectShortSide (vector)
areaOfObject (float)
areaCoverage (float)
SupportingPlane (computable class)

Cones/cylinders
radius (average radius, float)
maxRadius (float)
minRadius (float)
volumeOfObject (float)
lengthOfObject (float)
longitudinalDirection (vector)
areaOfObject (float)
areaCoverage (float)

Spheres
radius (float)
volumeOfObject (float)
areaOfObject (float)
areaCoverage (float)
ConcaveTangibleObject (computable class)

Containers
volumeOfObject (float)
longitudinalDirection (opening direction, vector)

Handles

Handle (computable class)

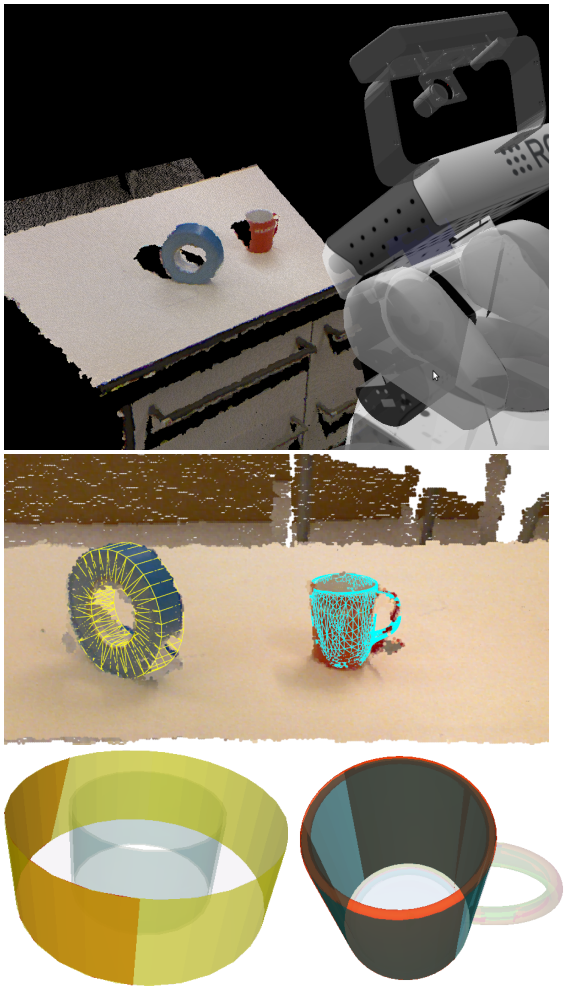
Semantic Annotation of Object Parts

- **Bottom-up:** Segmentation and geometric primitive fitting
- **Top-down:** Identify semantic parts defined in terms of geometric primitives using logical rules
- Advantage of rule-based definitions: **Composability!**

- Currently semantic annotations for
  - Handles, containers, supporting planes, bottle caps

Selecting appropriate containers

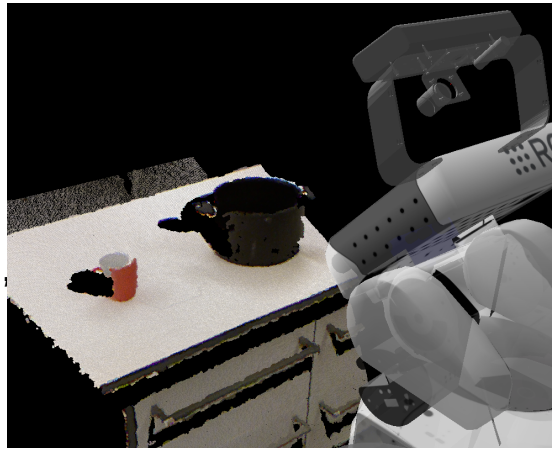
```
?- owl_has(Obj, kr:properPhysicalParts, C),
   owl_individual_of(C, kr:'Container'),
   rdf_triple(kr:volumeOfObject, C, V),
   V > 0.001.
Obj = kr:'pot1',
C = kr:'ContainerArtifact_FqDosfsb',
V = 0.00293
```

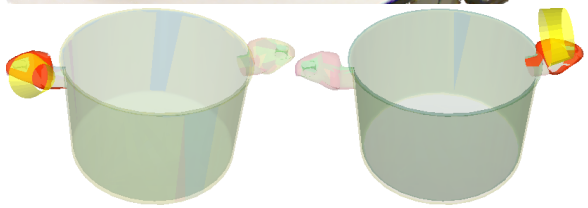


Finding grasping points

```
grasp_point(Obj, GraspPoint) :-
   rdf_triple(kr:properPhysicalParts,Obj,Handle),
   rdfs_instance_of(Handle, kr:'Handle'),
   annotation_pose_list(Handle, GraspPoint).
```

```
?- grasp_point(kr:'pot1', P).
P = [ 0.001, 0.062,-0.9980,-0.173,
     -0.998, 0.062, 0.0019,-0.109,
      0.062, 0.996, 0.0628, 0.115,
      0.000, 0.000, 0.0000, 1.000]
```

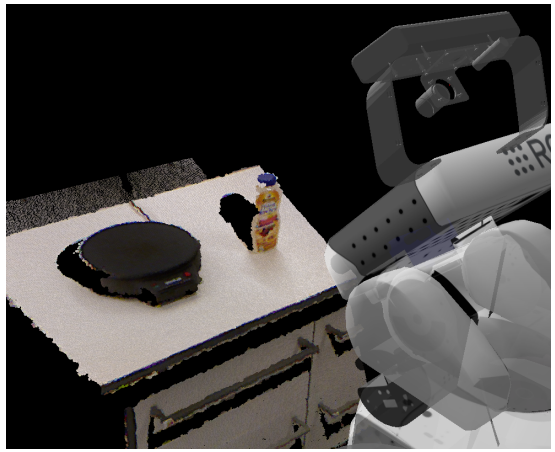


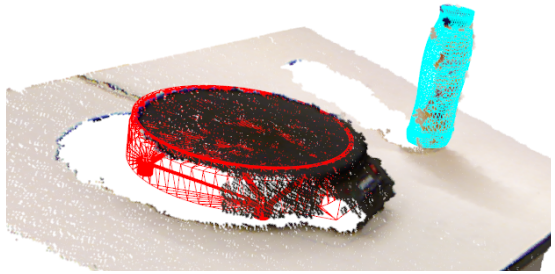


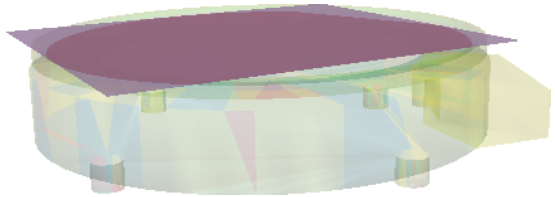
Determining which surface to pour batter on

```
pour_onto(Obj, Part) :-
  findall(A-P,
    (rdf_triple(kr:properPhysicalParts,Obj,P),
     rdfs_instance_of(P,kr:'SupportingPlane'),
     rdf_triple(kr:areaOfObject,P,A)),Planes),
  keysort(Planes, PlanesAsc),
  last(PlanesAsc, _-Part).

?- pour_onto(kr:'maker1', Part).
Part = kr:'FlatPhysicalSurface_UosqOAfb'.
```



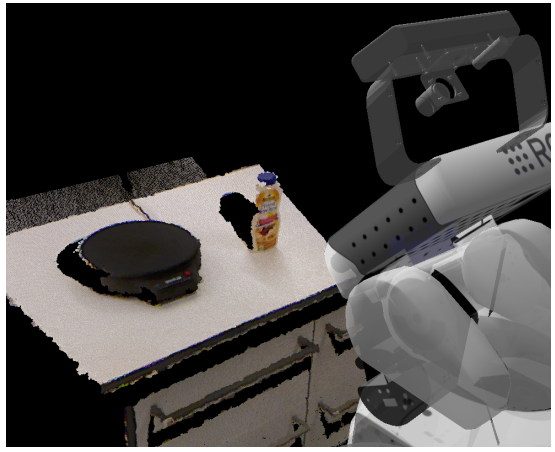




Identifying bottle caps

```
bottle_cap(Obj, Cap) :-
  findall(Z-P,
    (rdf_triple(kr:properPhysicalParts,Obj,P),
     owl_individual_of(P, kr:'Cone'),
     objpart_pos(P, [_,_,Z])), ConePos),
  keysort(ConePos, ConePosAsc),
  last(ConePosAsc, _-Cap).

?- bottle_cap(kr:'pancakemix1', Cap).
Cap = kr:'Cone_vcRxyUbK'.
```



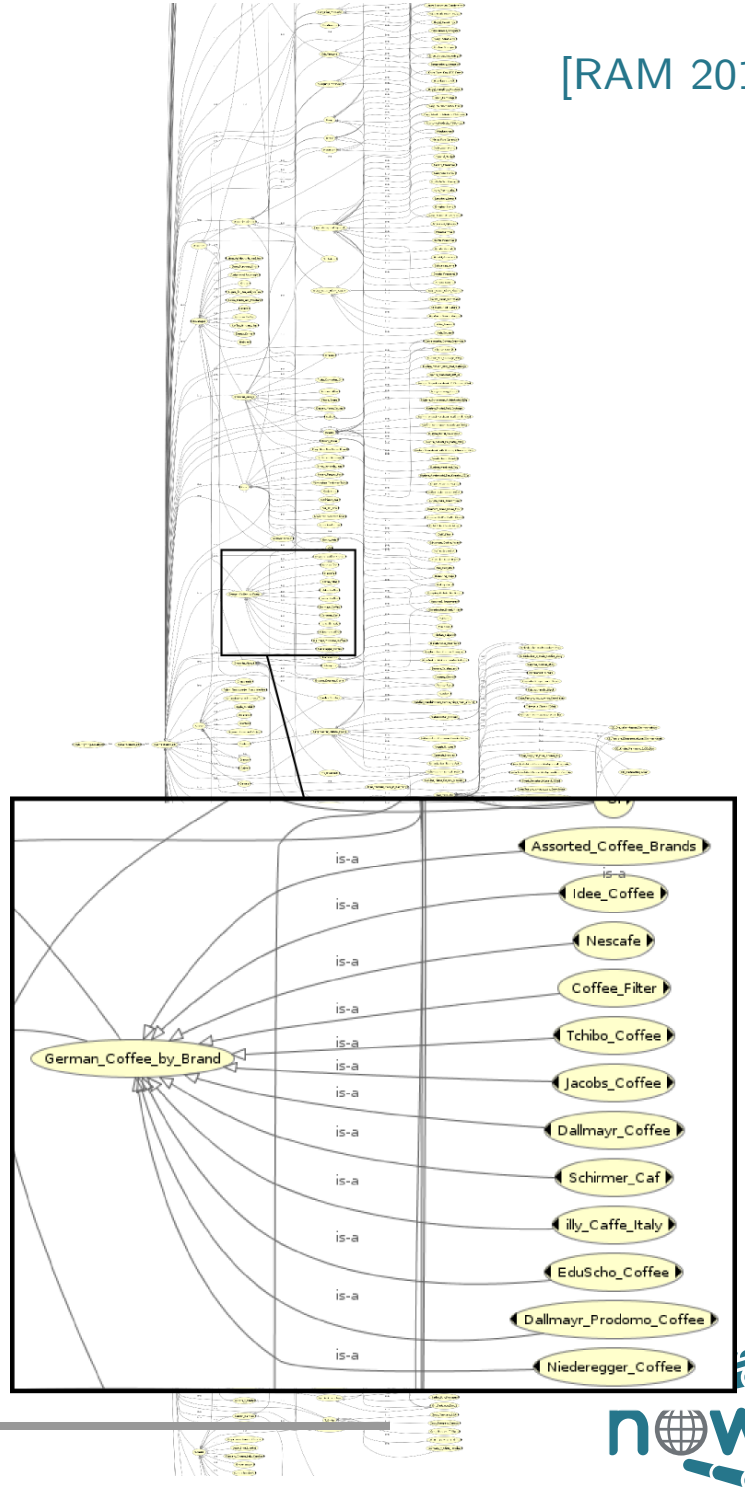
Demonstration: Segmentation and Interpretation of Geometric Object Models

http://knowrob.org/doc/robots_and_the_internet

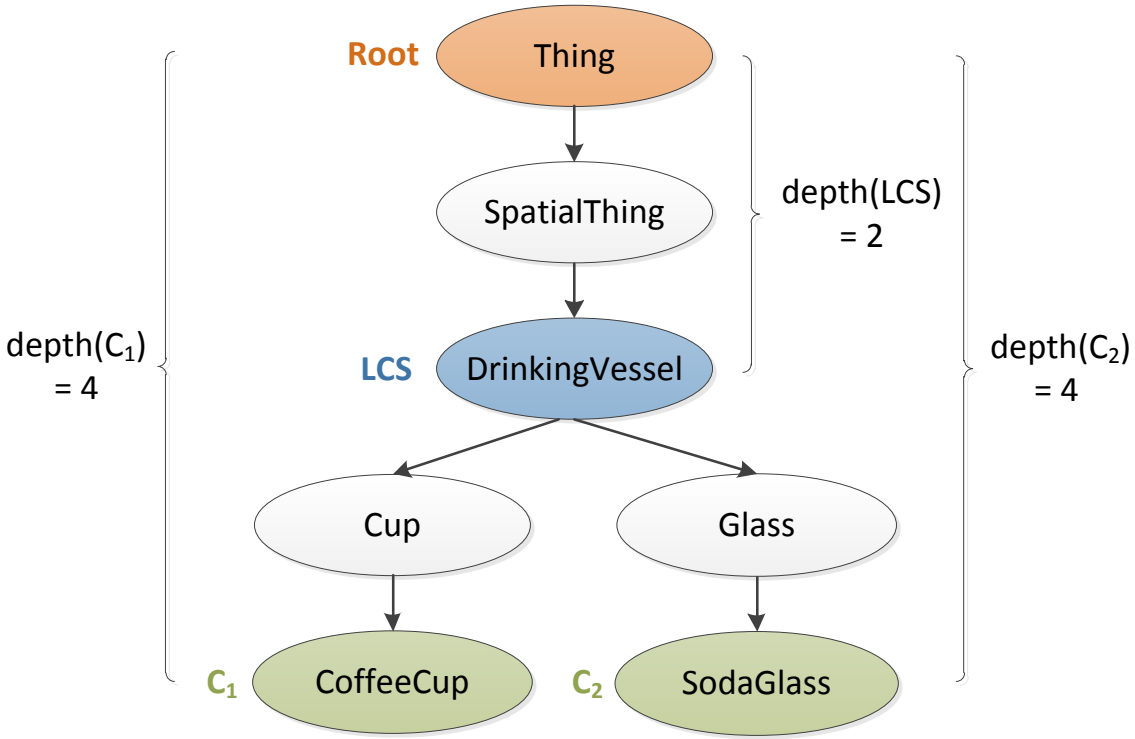
Mining object knowledge

[RAM 2011a]

- Automatically created ontology of >7500 objects from the online shop germandeli.com
- Class hierarchy from categories + perishability, weight, price, origin, ...
- SIFT recognition models from product pictures (work by Dejan Pangercic)



Infer storage locations based on semantic object similarity



Learning Organizational Principles in Human Environments.
Martin Schuster, Dominik Jain, Moritz Tenorth and Michael Beetz. ICRA 2012

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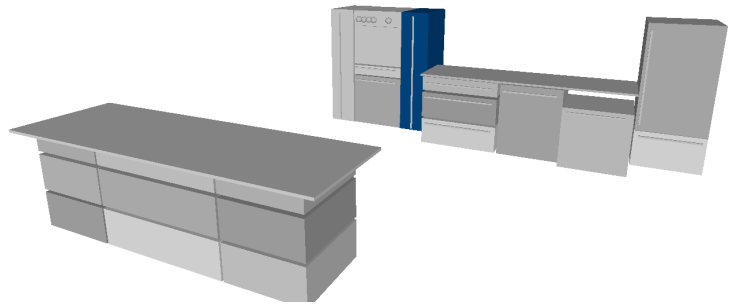


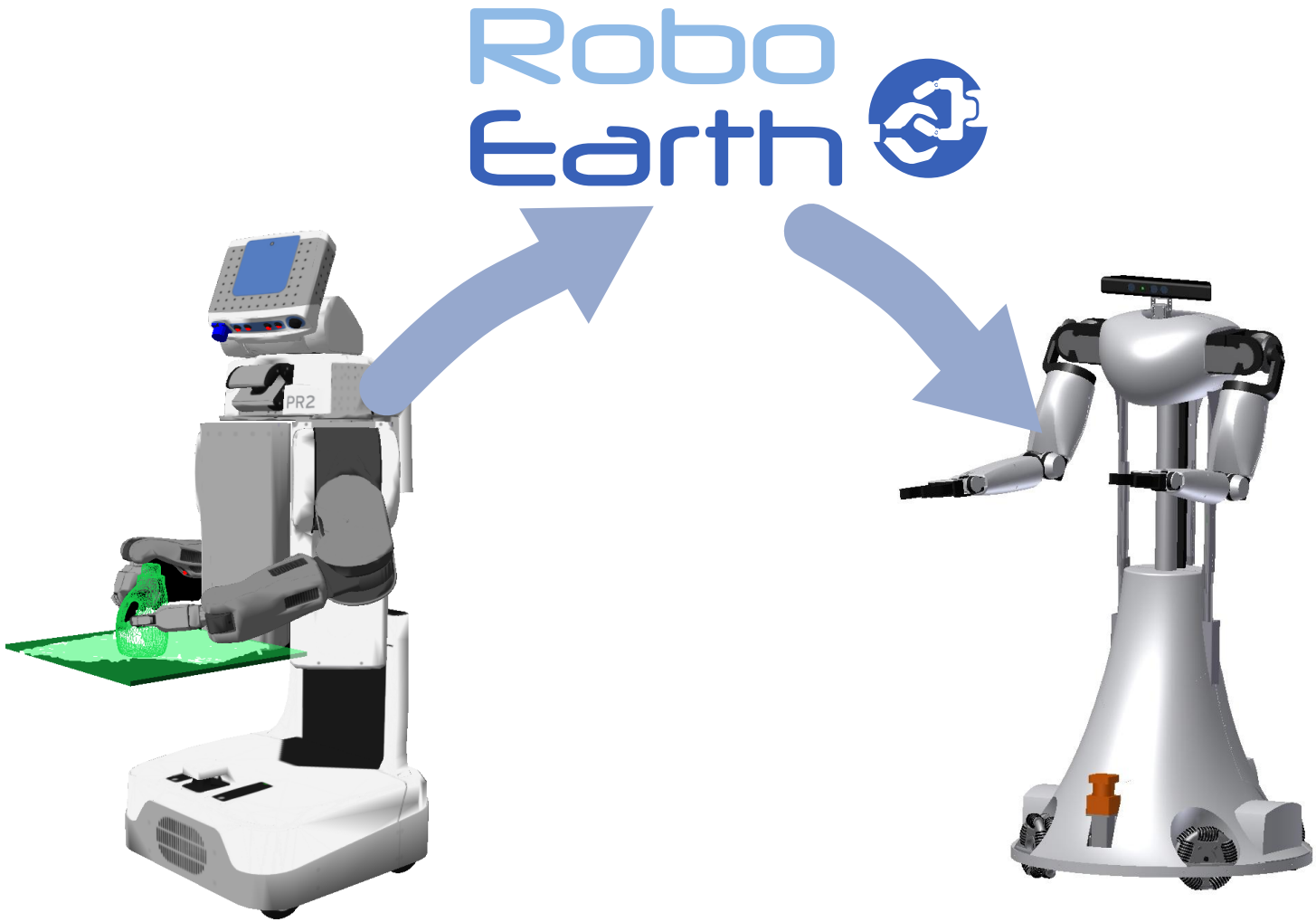
```
?- highlight_best_location_dtree(
orgprinciples:'CoffeeFilter1', Canvas).

Best location:  knowrob:Drawer7
Objects at location knowrob:Drawer7:
WUP similarity:  object (class)
0.87500:  orgprinciples:CoffeGround1
(germandeli:Dallmayr_Classic_Ground_Coffee_250g)
0.75000:  orgprinciples:EspressoBeans1
(germandeli:illy_Espresso_Whole_Beans_88_oz)
0.70588:  orgprinciples:Sugar1
(germandeli:Nordzucker_Brauner_Teezucker_500g)
0.66667:  orgprinciples:Tea2
(germandeli:Teekanne_Rotbusch_Tee_Vanille_20_Bags)
```

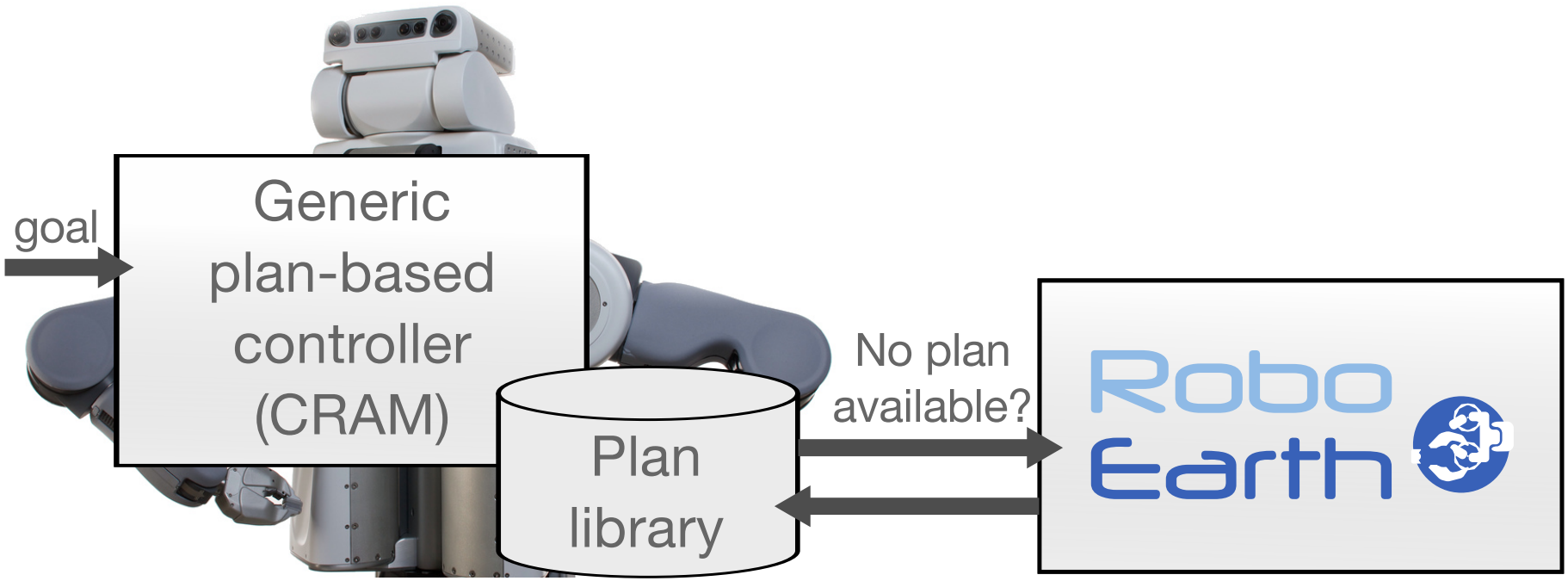
Demonstration:
Object Ontology generated from an Online Shop

`http://knowrob.org/doc/robots_and_the_internet`

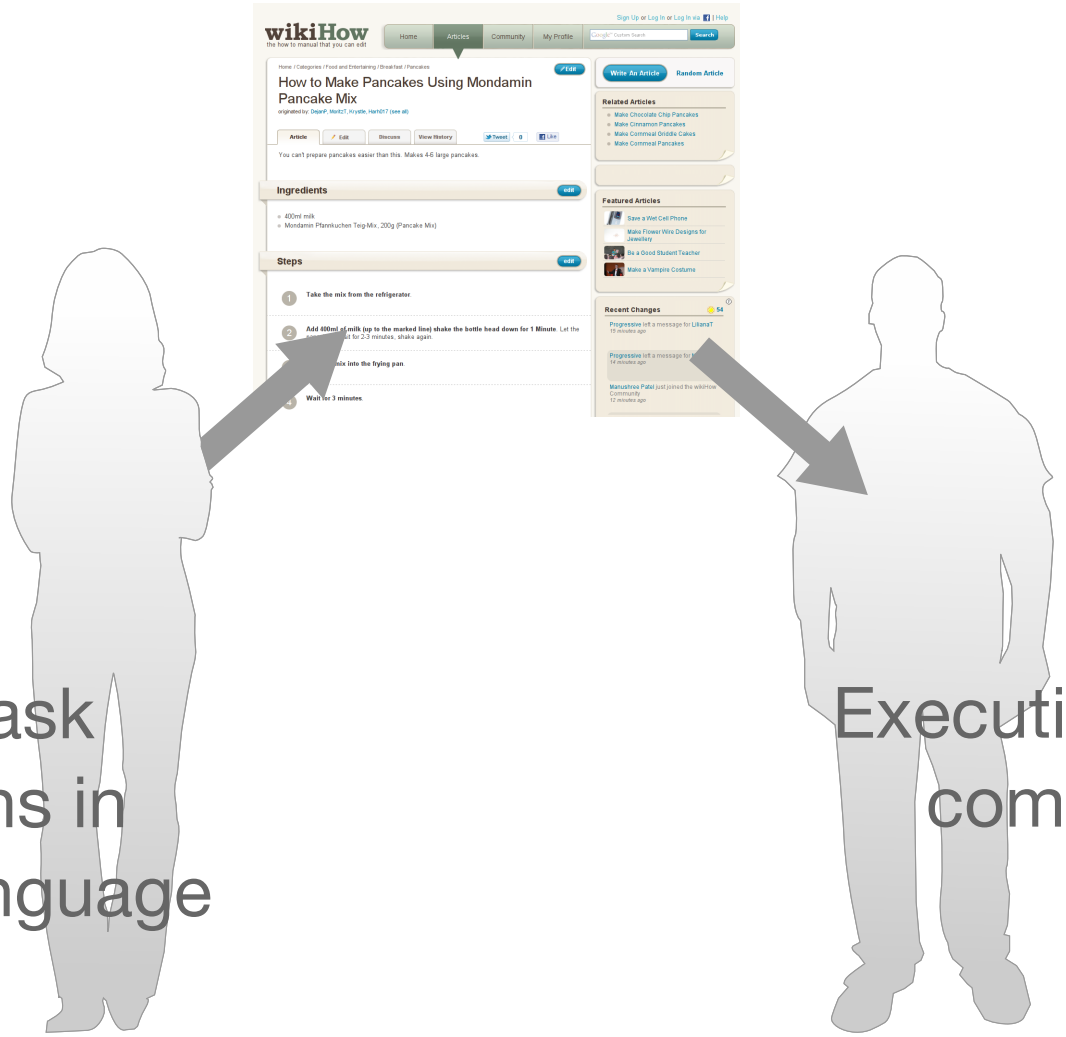
Use Case 2: Exchanging Information via the Cloud



A generic Web-enabled Robot Control Program



Information exchange among humans



Informal task instructions in natural language

Execution requires common-sense knowledge

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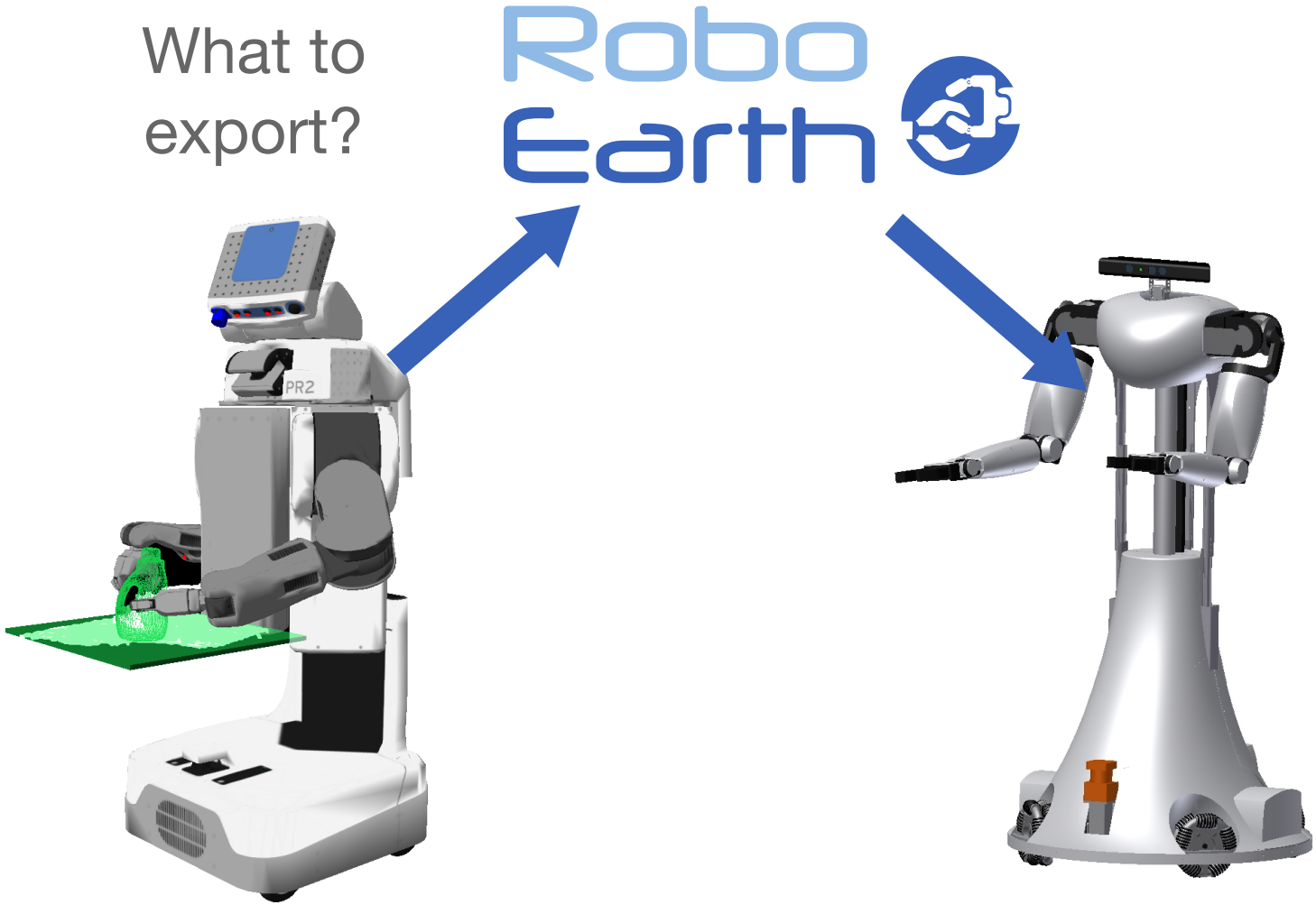
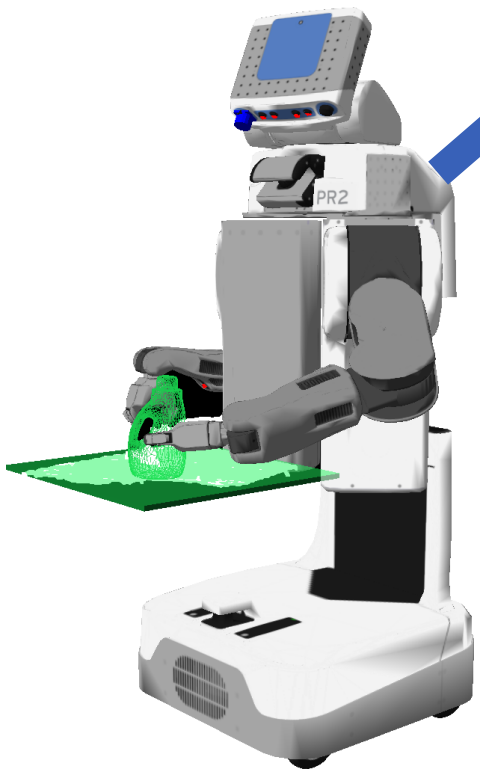
Information exchange among robots

What to export?



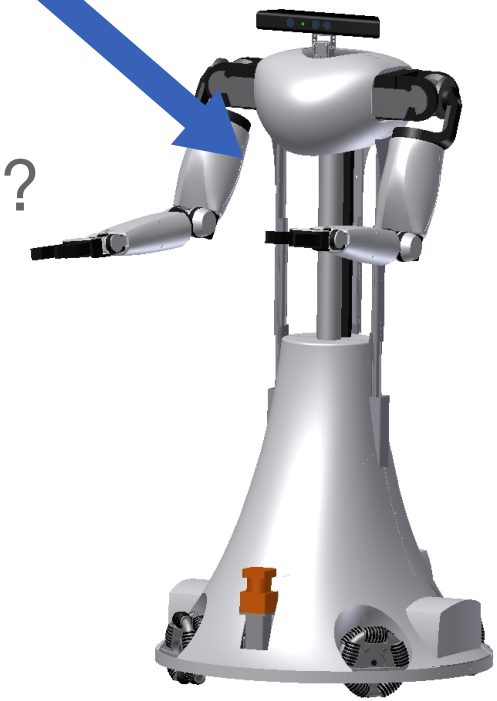
Information exchange among robots

What to export?



Robo Earth

How to represent information?



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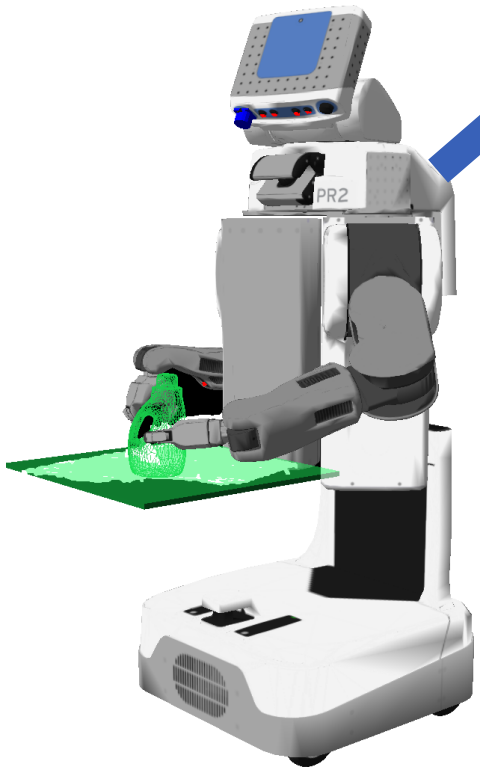
Information exchange among robots

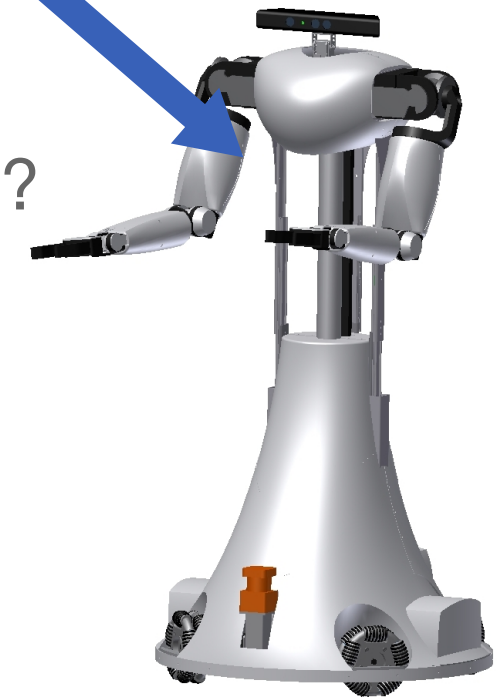
What to export?

Robo Earth

How to find information?

How to represent information?





robohow

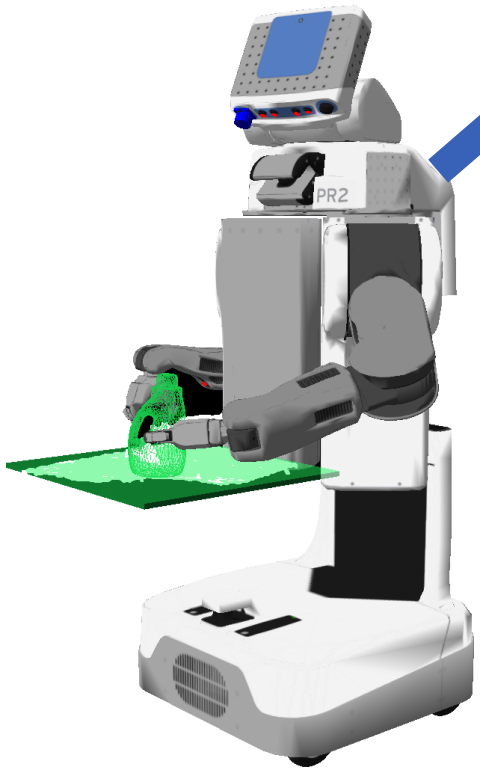
Information exchange among robots

What to export?

Robo Earth

How to find information?

How to represent information?



How to execute?

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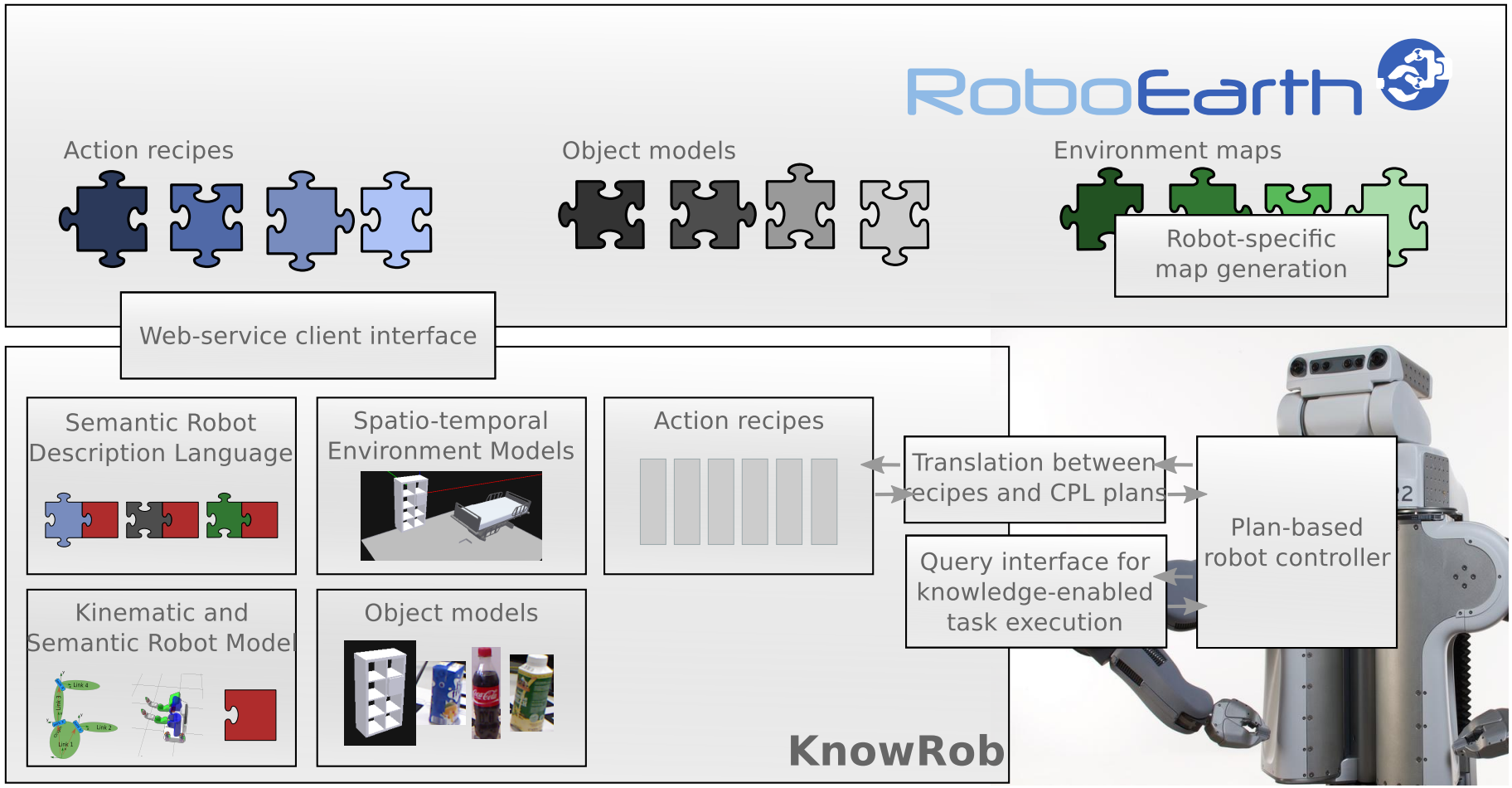
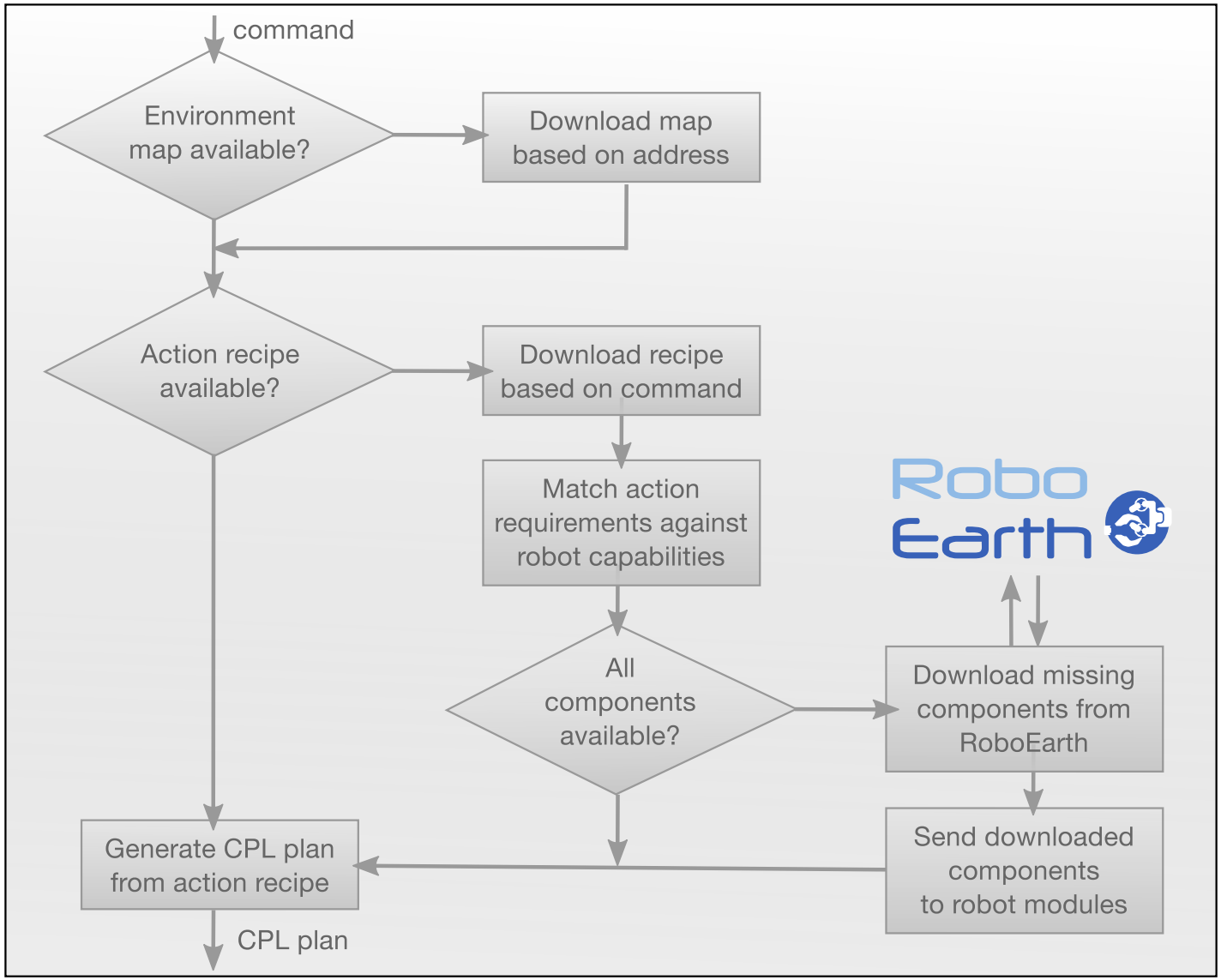
The RoboEarth system



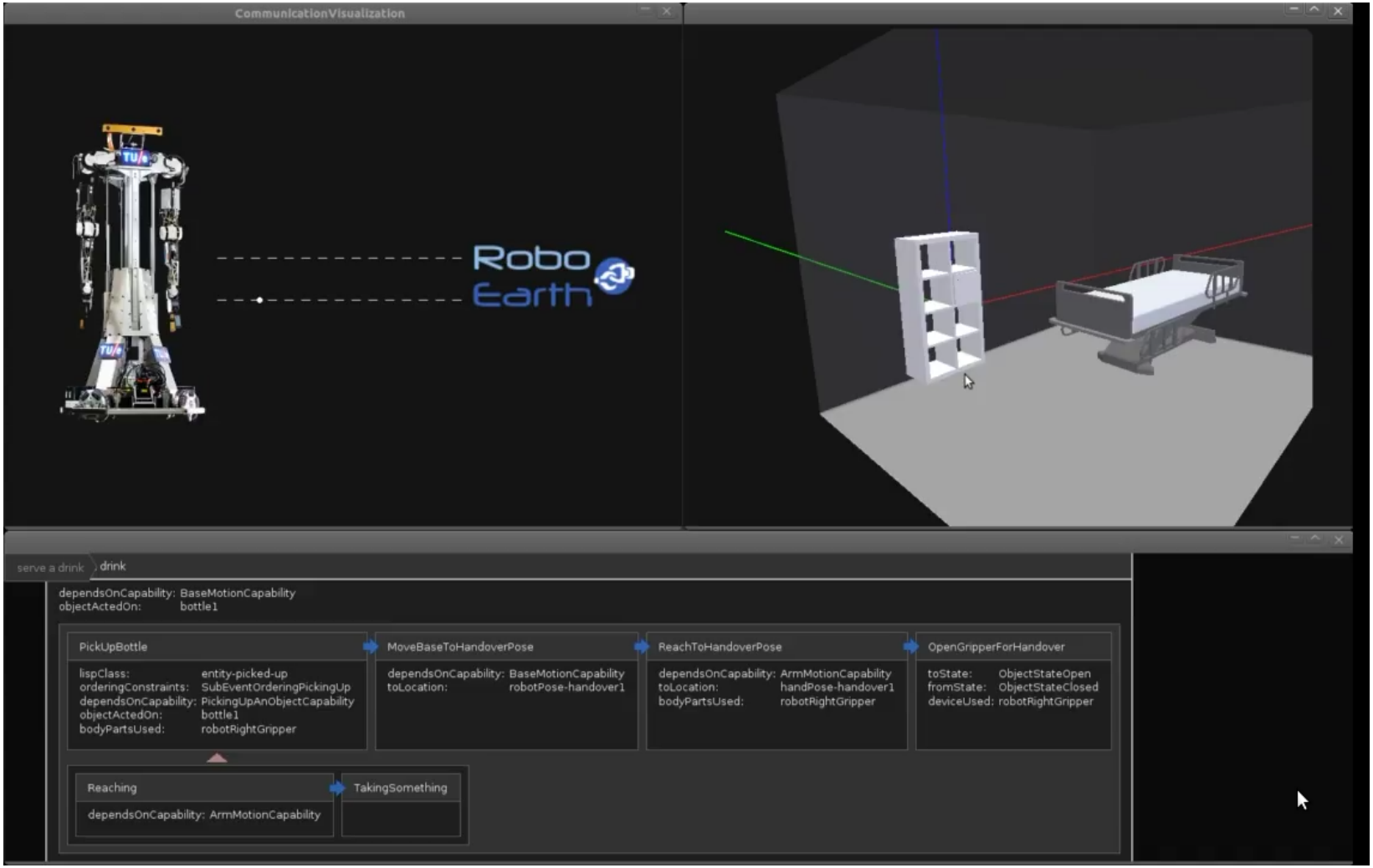
http://www.roboearth.org

[ICRA 2012]

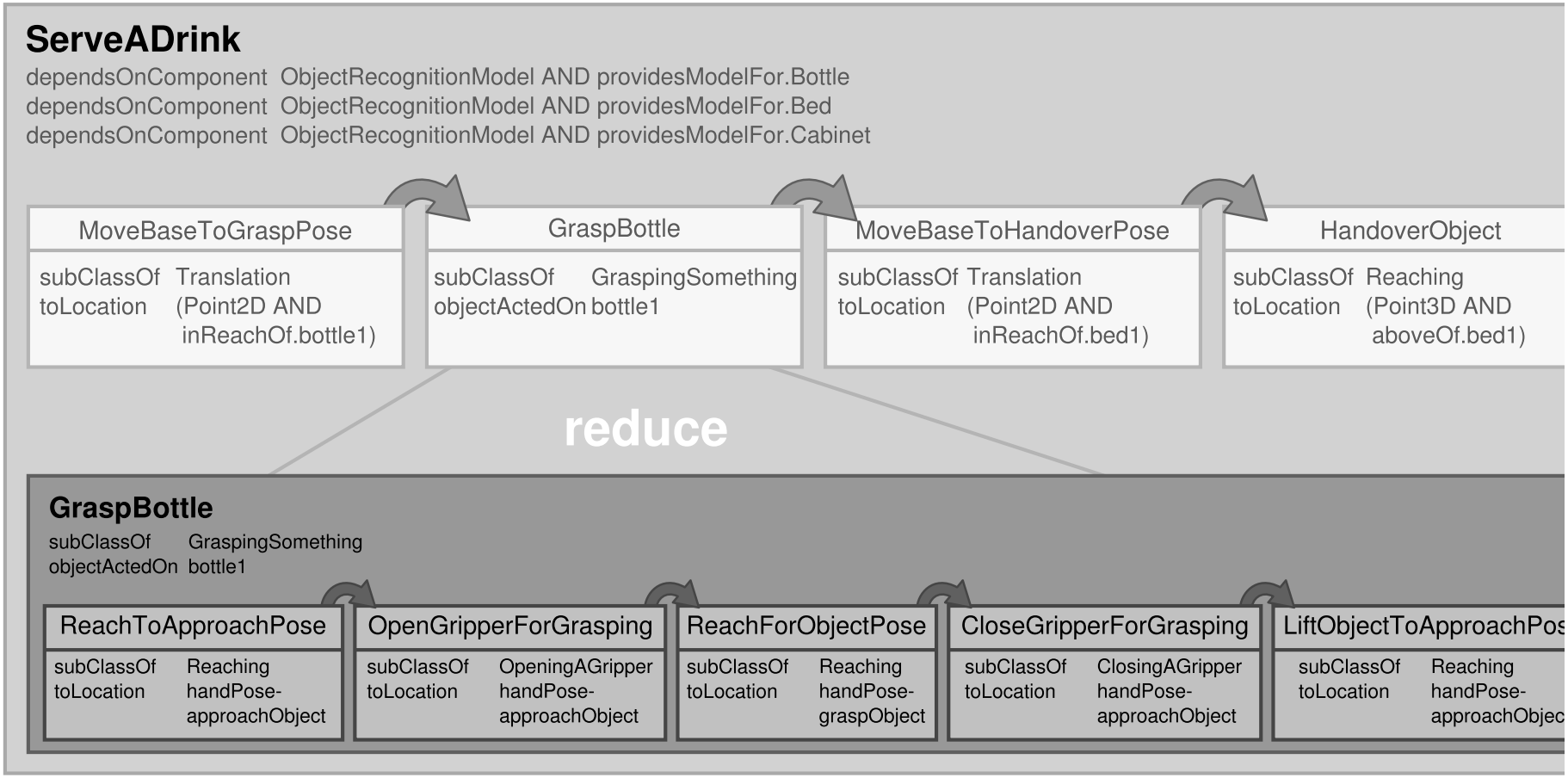
Downloading recipes, objects, and maps



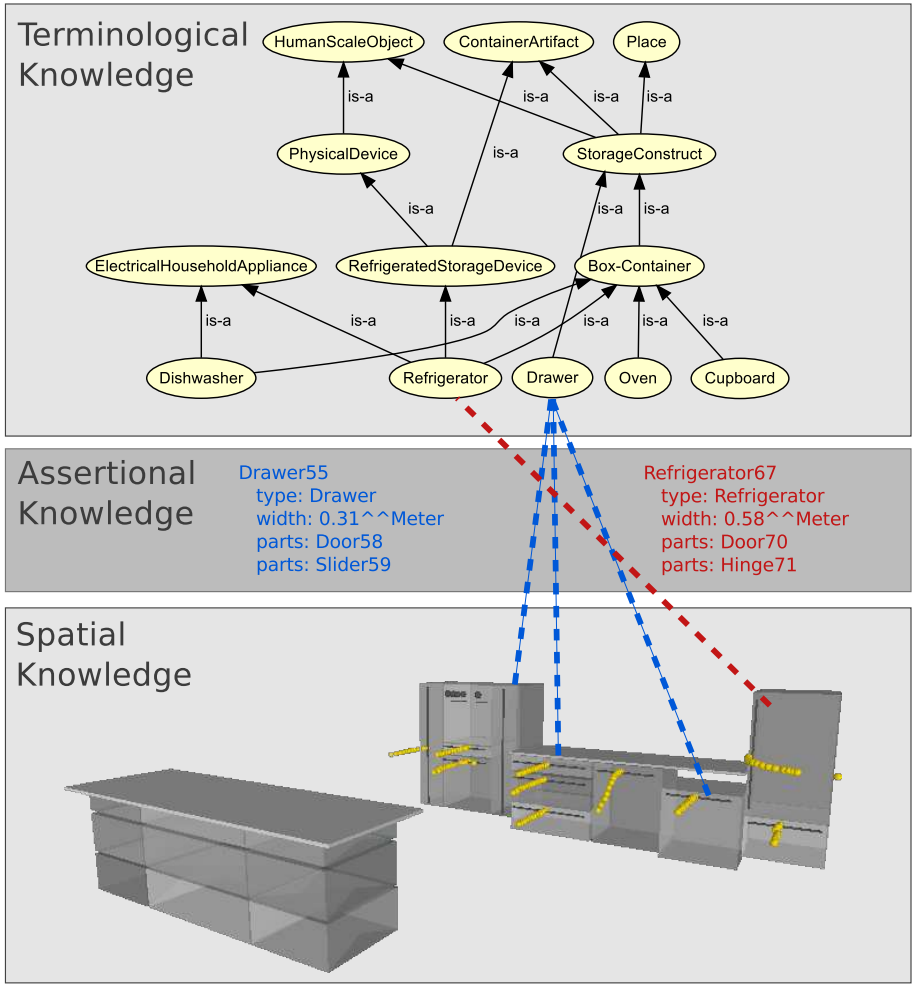
Video: Downloading recipes, objects, and maps



Action recipes



Semantic map representation



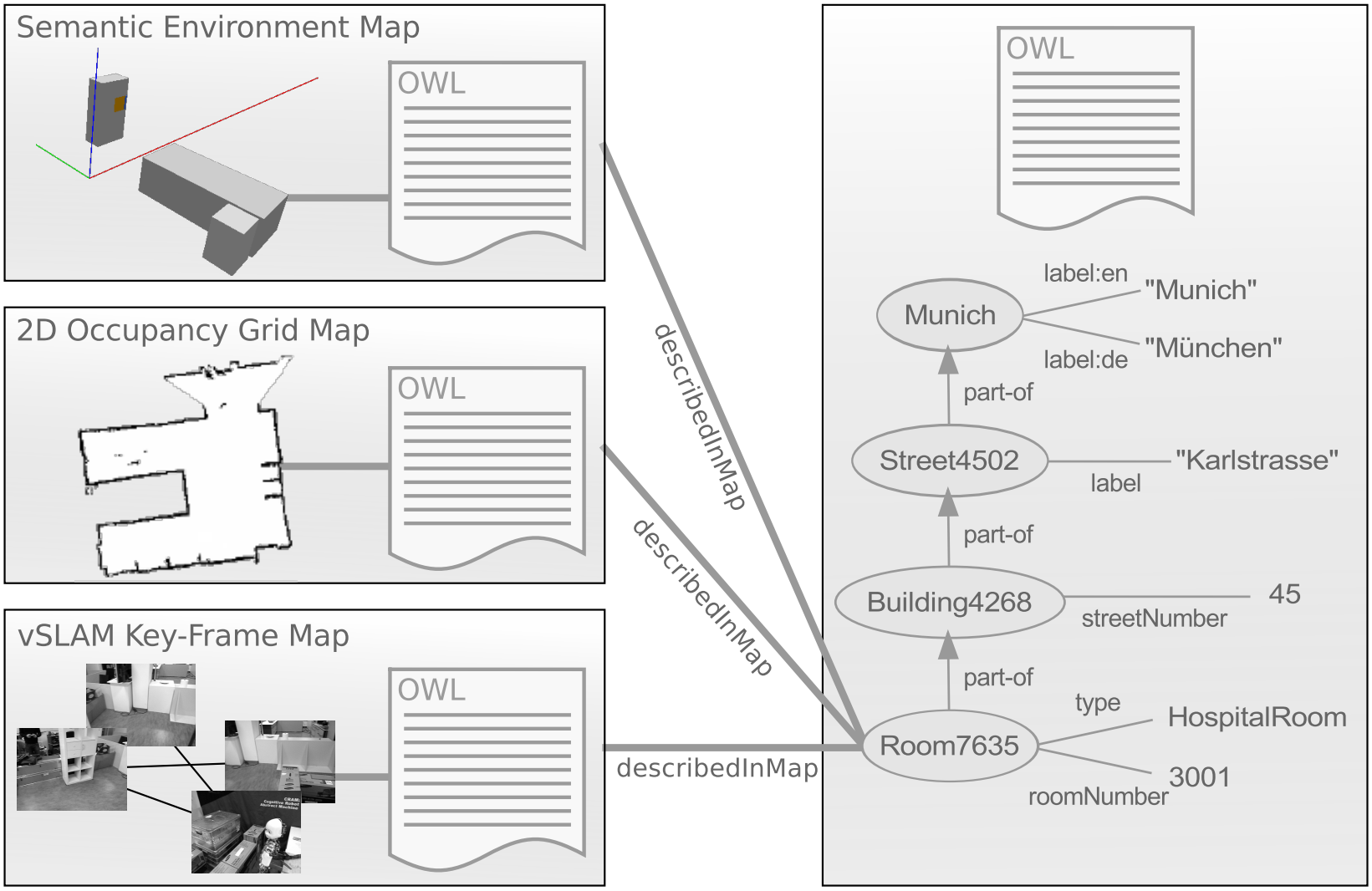
Abstract knowledge about object classes

Object instances and component hierarchy

Poses in the environment and their changes over time

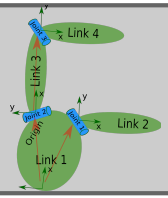
Related: TBOX/SBOX, Galindo et al (RAS 2008)

Meta-data on Environment Maps



Action Dependencies vs. Robot Capabilities

Kinematic robot model



Semantic robot model

Robot capabilities

Action requirements

SRDL

Semantic Robot Description Language

Inference system

```
?- hasComponent('TUM_Rosie', C)
C = rosie:'TUM_Rosie_Camera1'

?- missingCapabilitiesForAction(
      srdl:'ChocolateCakeBaking',
      'TUM_Rosie', Caps
Caps = ['OperateOvenCapability'].
```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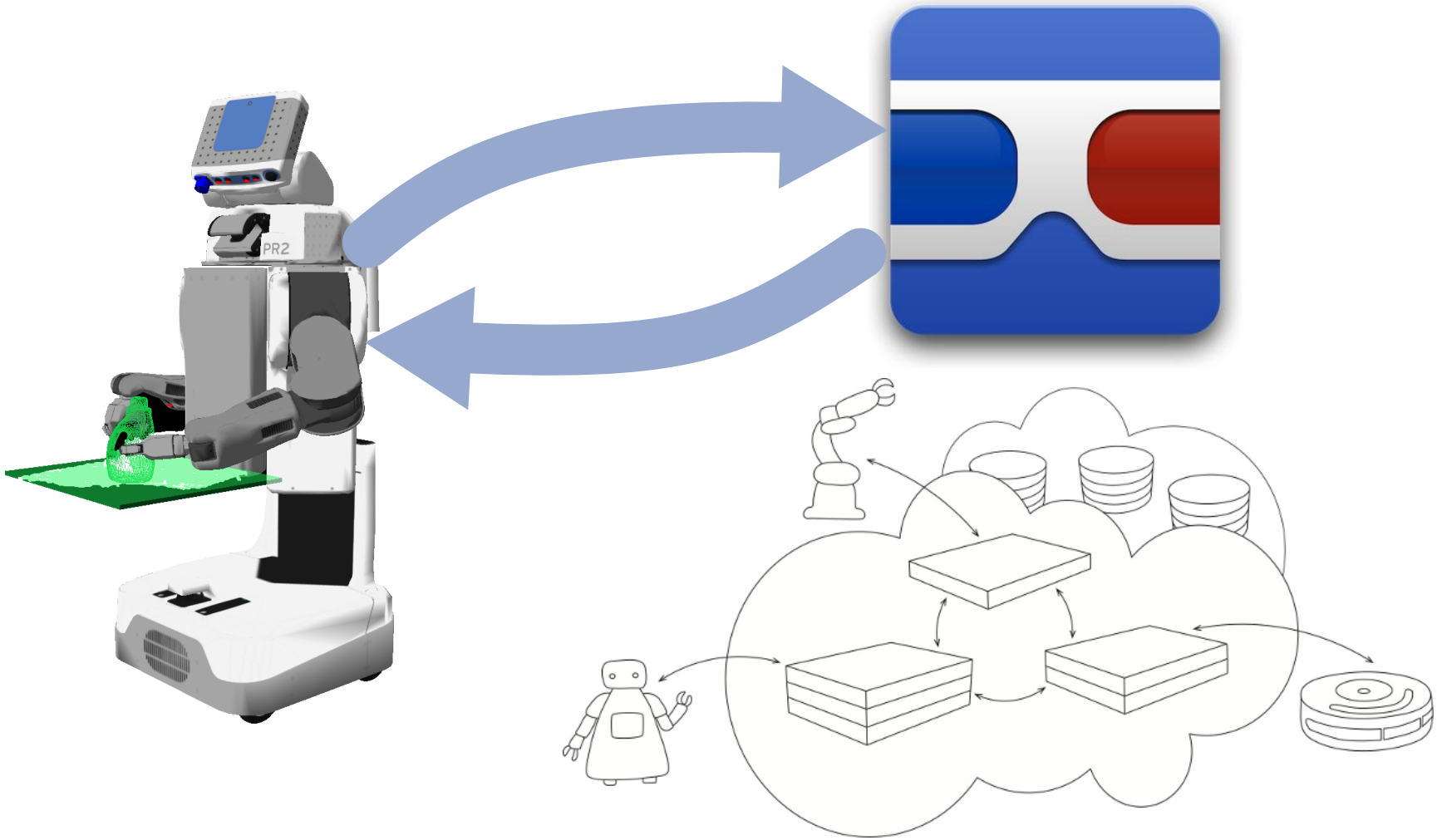
Demonstration:
Exchanging Information via RoboEarth

`http://knowrob.org/doc/robots_and_the_internet`

Use Case 3: Outsourcing Services to the Cloud



Outsourcing Services to the Cloud

Research Problems

- **Integrating multiple complementary (cloud) services**

Outsourcing Services to the Cloud

Research Problems

- **Integrating multiple complementary (cloud) services**
  - Knowledge representation describing the services and their content

Outsourcing Services to the Cloud

Research Problems

- **Integrating multiple complementary (cloud) services**
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Outsourcing Services to the Cloud

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  - Schedule sending queries early in the plan
  - Integrate cloud services into ensemble-of-experts architecture

Outsourcing Services to the Cloud

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Outsourcing Services to the Cloud

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  - Cloud services should only give added value, but at least safety controllers have to be local

Outsourcing Services to the Cloud

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Outsourcing Services to the Cloud

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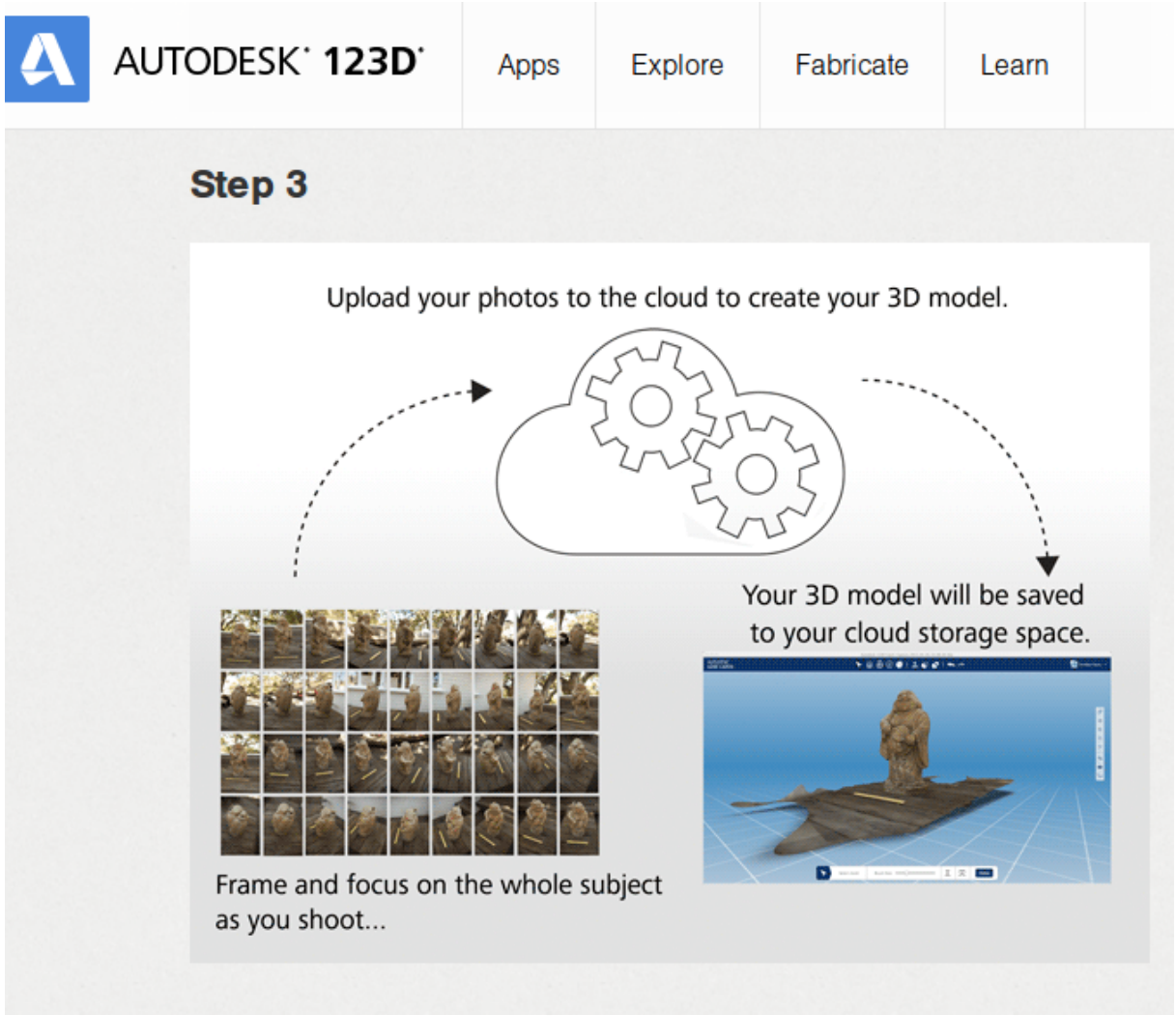
- **Ensuring safety also if cloud becomes unavailable**
  - Cloud services should only give added value, but at least safety controllers have to be local
- **Privacy aspects and security of information**
  - Similar to cloud computing, but robots often know private details...

123D Catch: Object Modeling

- Service for building 3D models from a set of images of an object
- Potential to massively simplify creation of new object models

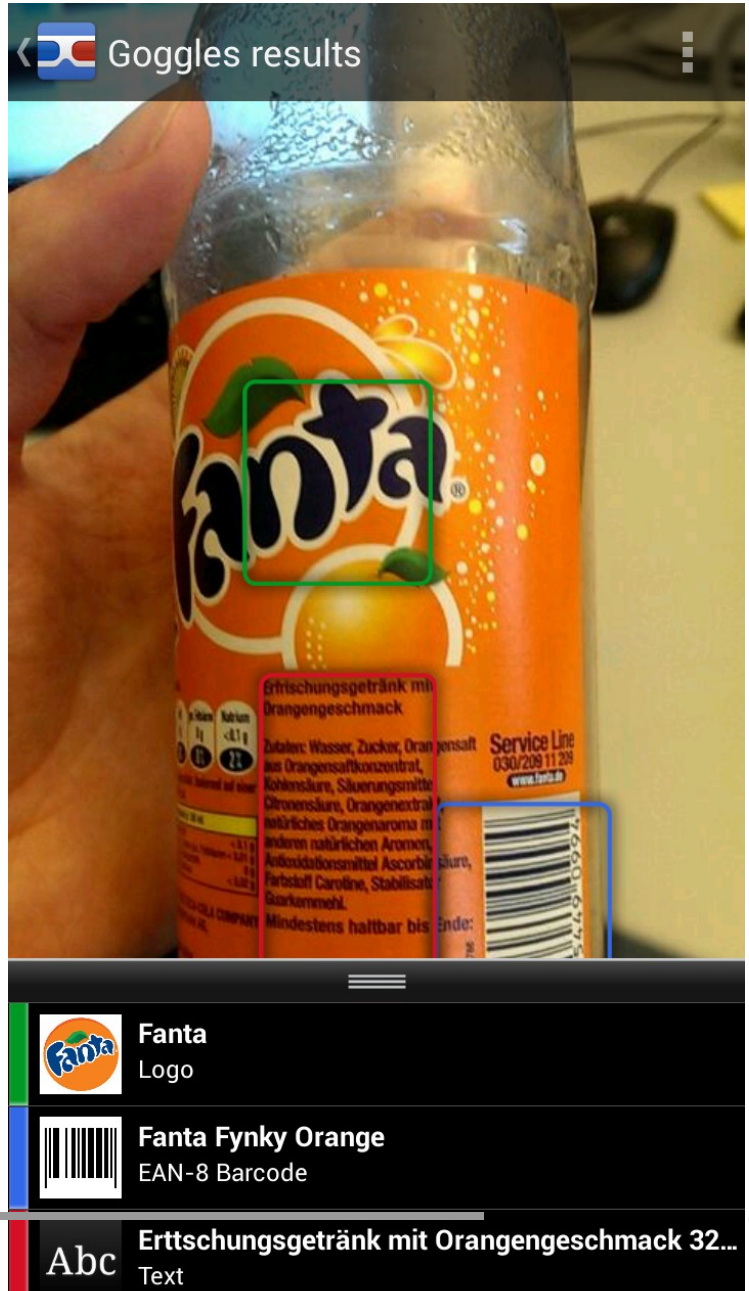


Barcoo: Barcode Recognition

- Barcode recognition in camera images
- Shows detailed information about the objects (e.g. price, comments, nutrition and health information)
- Source for detailed semantic information about objects

Google Goggles: Object Recognition

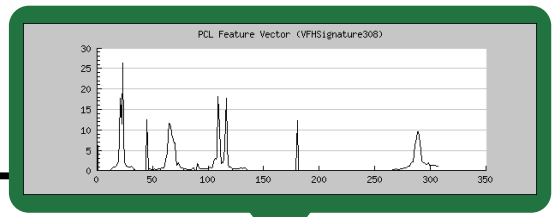
- Recognizes text, logos, barcodes, etc in camera images
- Rich semantic information about the objects
- Fast: 1-3 seconds
- Varying quality of the results depending e.g. on viewing angle



Combining Local Analysis with Cloud Information

Google Goggles Annotator

Pcl Feature Annotator VFH



GogglesAnnotation: Logo "Dr Oetker"

GogglesAnnotation: Product Vitalis Crunchy Choc, $8.99

Classification Framework VFH

ClassificationAnnotation: Shape: "box" 88.9%

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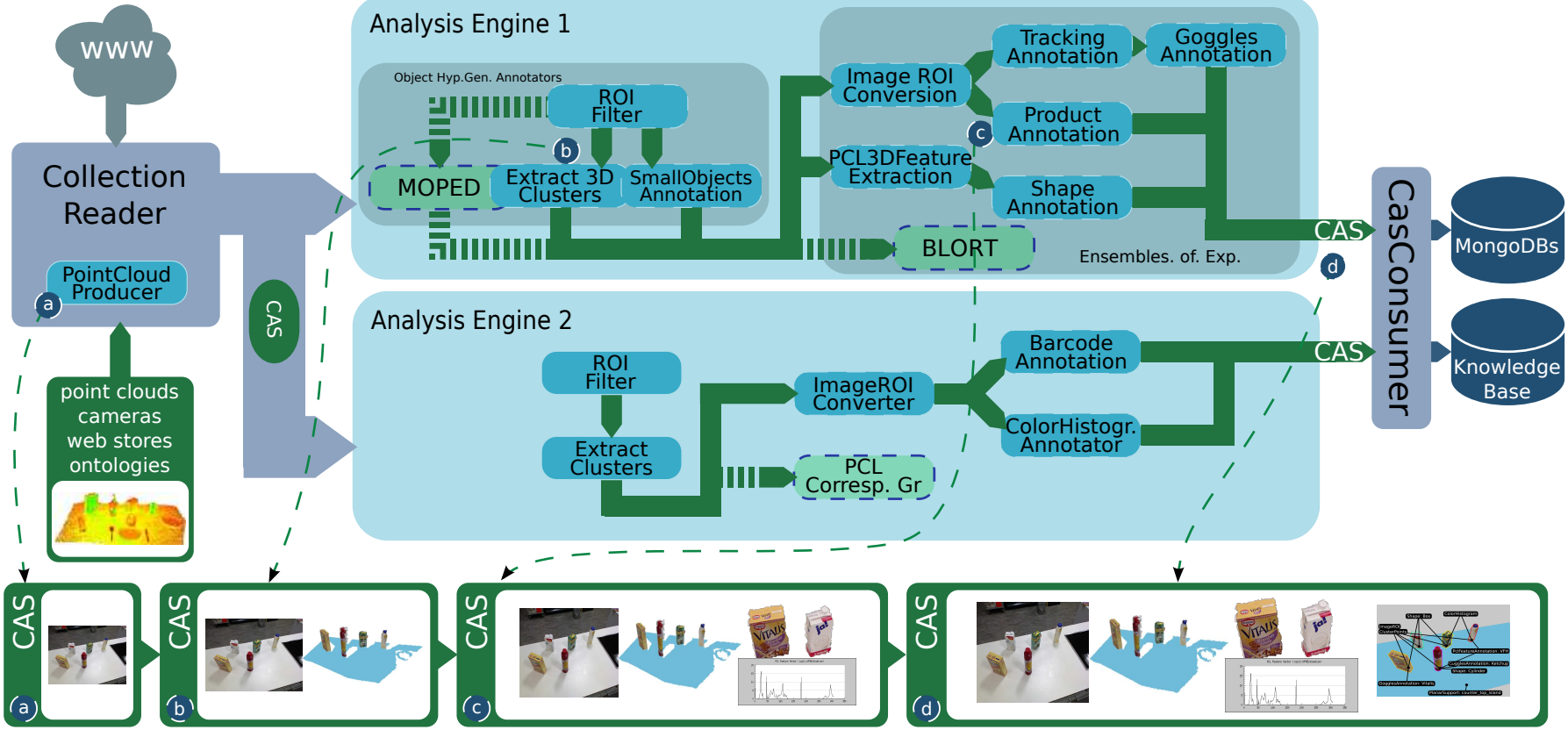
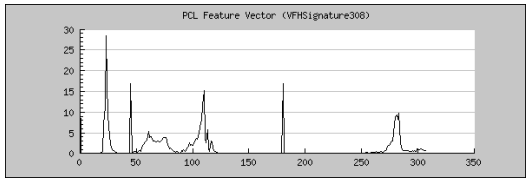
Ensemble-of-Experts Architecture for Perception



RoboSherlock: Unstructured Information Processing for Robot Perception.
M. Beetz, N. Blodow, F. Balint-Benczedi, Z. Marton, D. Nyga, F. Seidel, and C. Kerl.
Under review for IJRR.

Example: Scene Interpretation

PclFeatureAnnotation



GogglesAnnotation

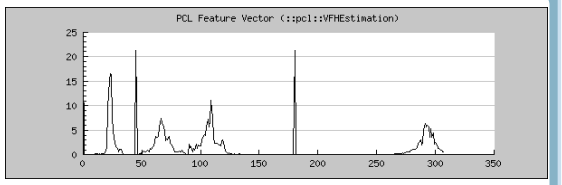
Similar Image: Hela Curry Ketchup
Bounding box: 28x53+37+110
URL:
Search More ⚓ High-Res Image ⚓ Found on Page ⚓

Text: Curry
Bounding box: 44x15+23+126
URL: Translate ⚓ Copy ⚓ Search More ⚓

ProductAnnotation

Source: GermanDeli.com
Product Name: Hela Scharfer Curry Gewürz Ketchup 400ml (Hot Curry Sauce 13.5oz)
Description:
Hela Gourmet Sauces are unique combinations of all-natural spices and seasonings. This versatile sauce adds a wonderful zesty taste to a wide variety of dishes including chicken, steak, pork and shrimp.... or even a plain hamburger. We use this curry ketchup (catsup) for our Curry Wurst! Truly an all-purpose gourmet sauce. Store on shelf and refrigerate after opening
Ingredients:
Tomato juice, sugar, dextrose, salt, curry, pepper, paprika, chilies, cloves, wine vinegar, modified starch, acidifying agent: citric acid, thickening agent: (E 412, E 413), herbs, ph-regulator: sodium lactate, flavor enhancer: E 621 monosodium glutamate
Brand: Hela
Country of Origin: Germany
Item #: 4027400168280
Rating: 5 stars
Weight/Size: 13.5oz (400ml)
Price: $5.79
Perishability: 1 (non perishable)

PclFeatureAnnotation



BarcooAnnotation

EAN / Barcode: 4000400112156
Manufacturer: Unilever

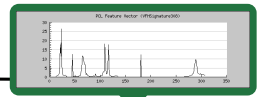
Mondamin Pfannkuch Shake
Unilever Germany
Rated 4 of 5

Google Goggles Annotator

GogglesAnnotation: Logo "Dr Oetker"

GogglesAnnotation: Product Vitalis Crunchy Choc, $8.99

Pcl Feature Annotator VFH



Classification Framework VFH

ClassificationAnnotation: Shape: "box" 88.9%

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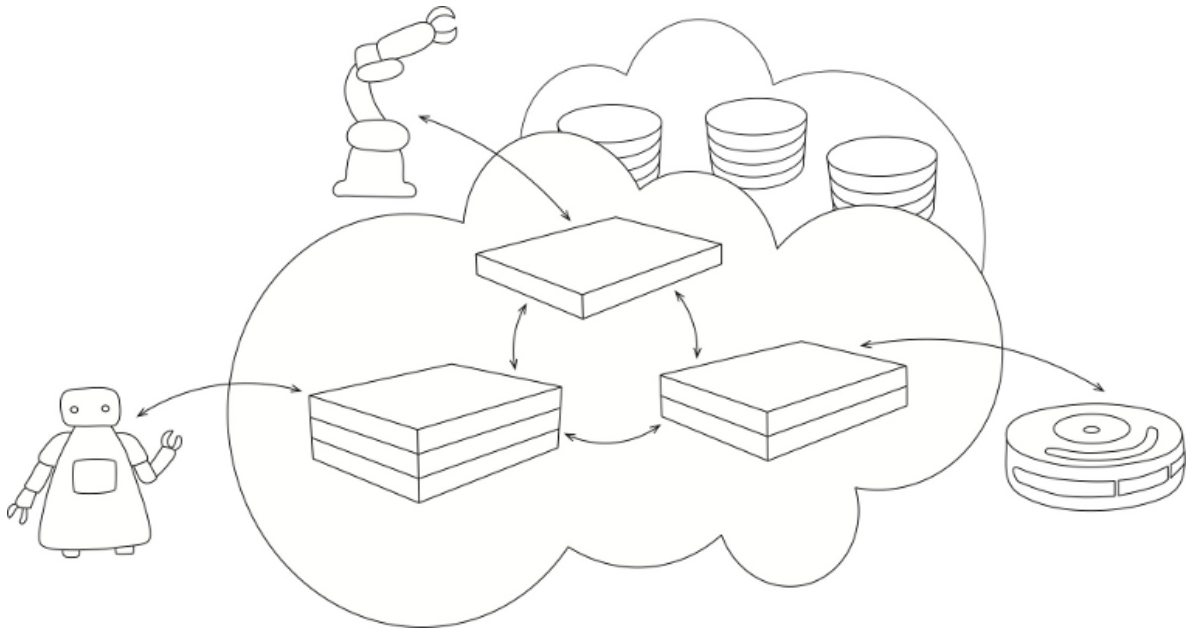
Demonstration:
Cloud-enabled Ensemble-of-experts Architecture for Robot Perception

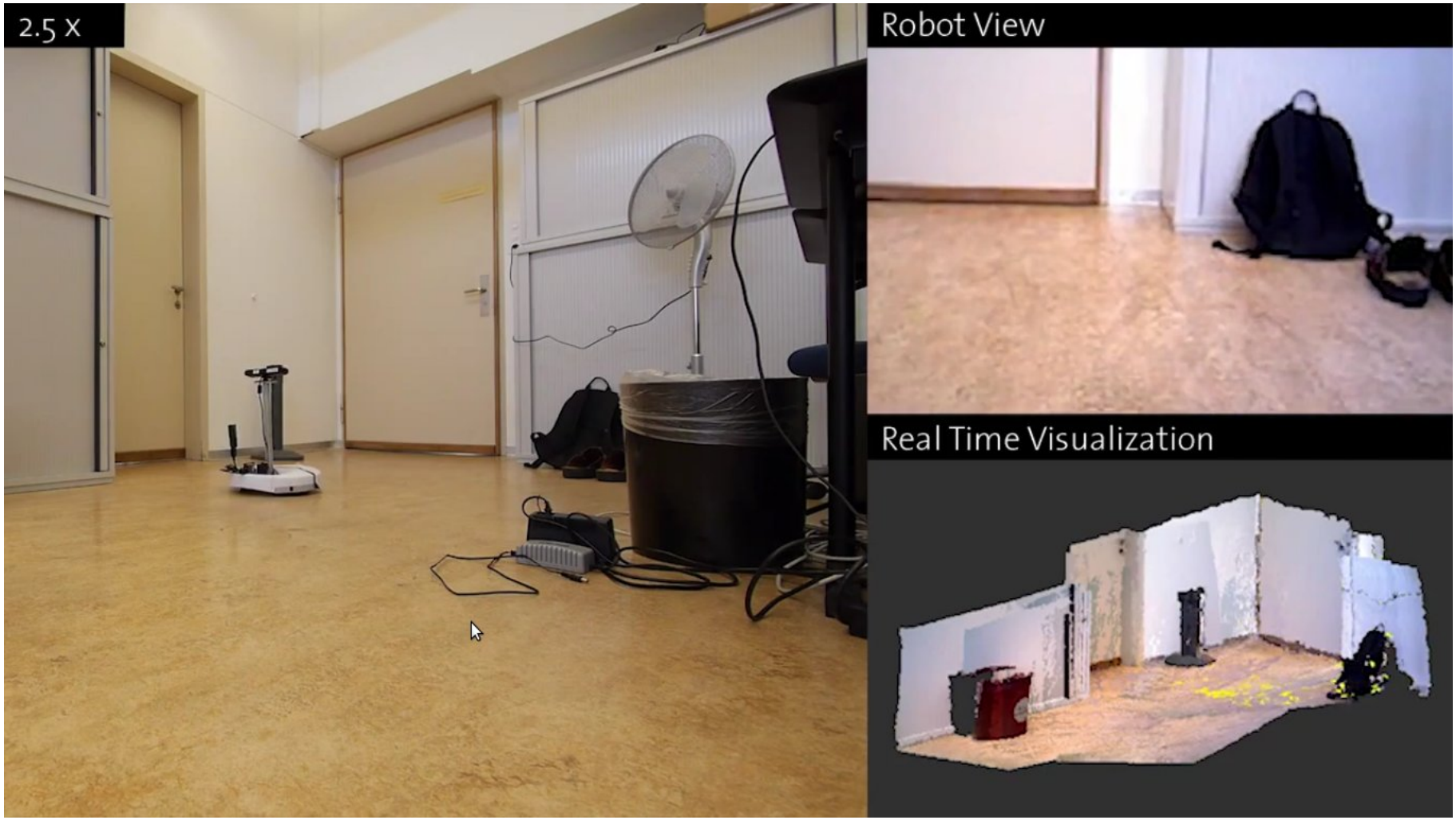
http://pr2-looking-at-things.com/

Offloading Computation to the Cloud



- Rapyuta: RoboEarth cloud engine
- Robots can connect to a ROS infrastructure in the Cloud via a Websocket interface
- Lightweight virtualization using Linux Containers

Video: Cloud-based Mapping (ETH Zurich)



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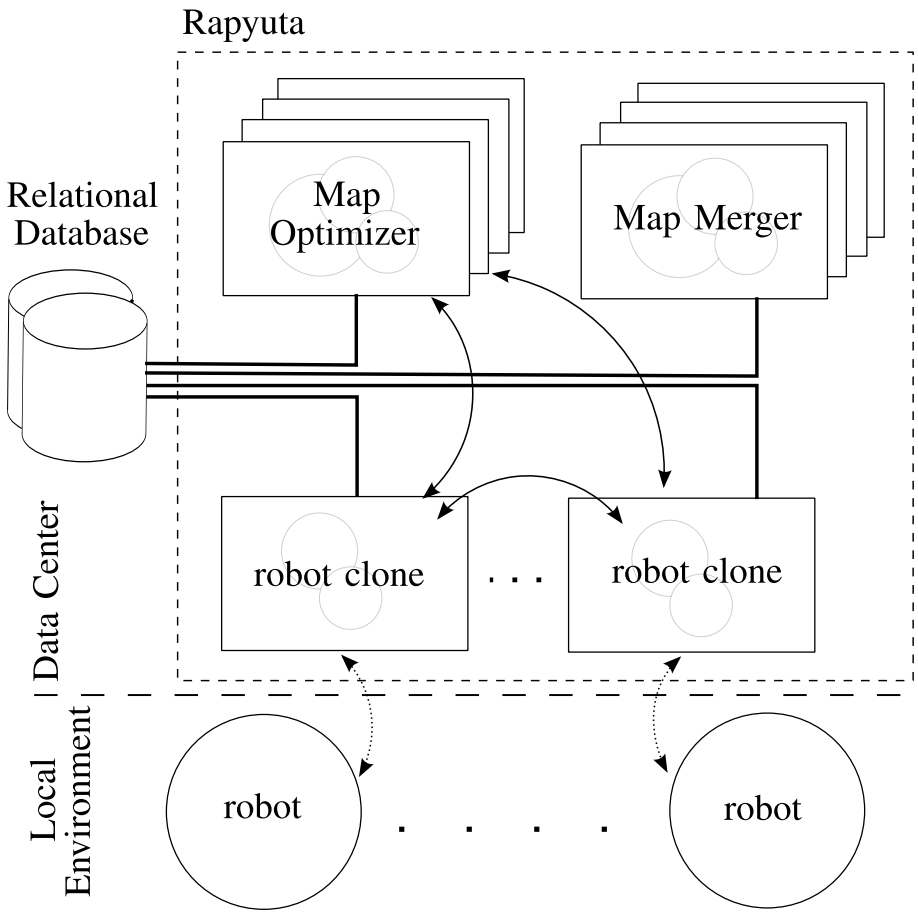
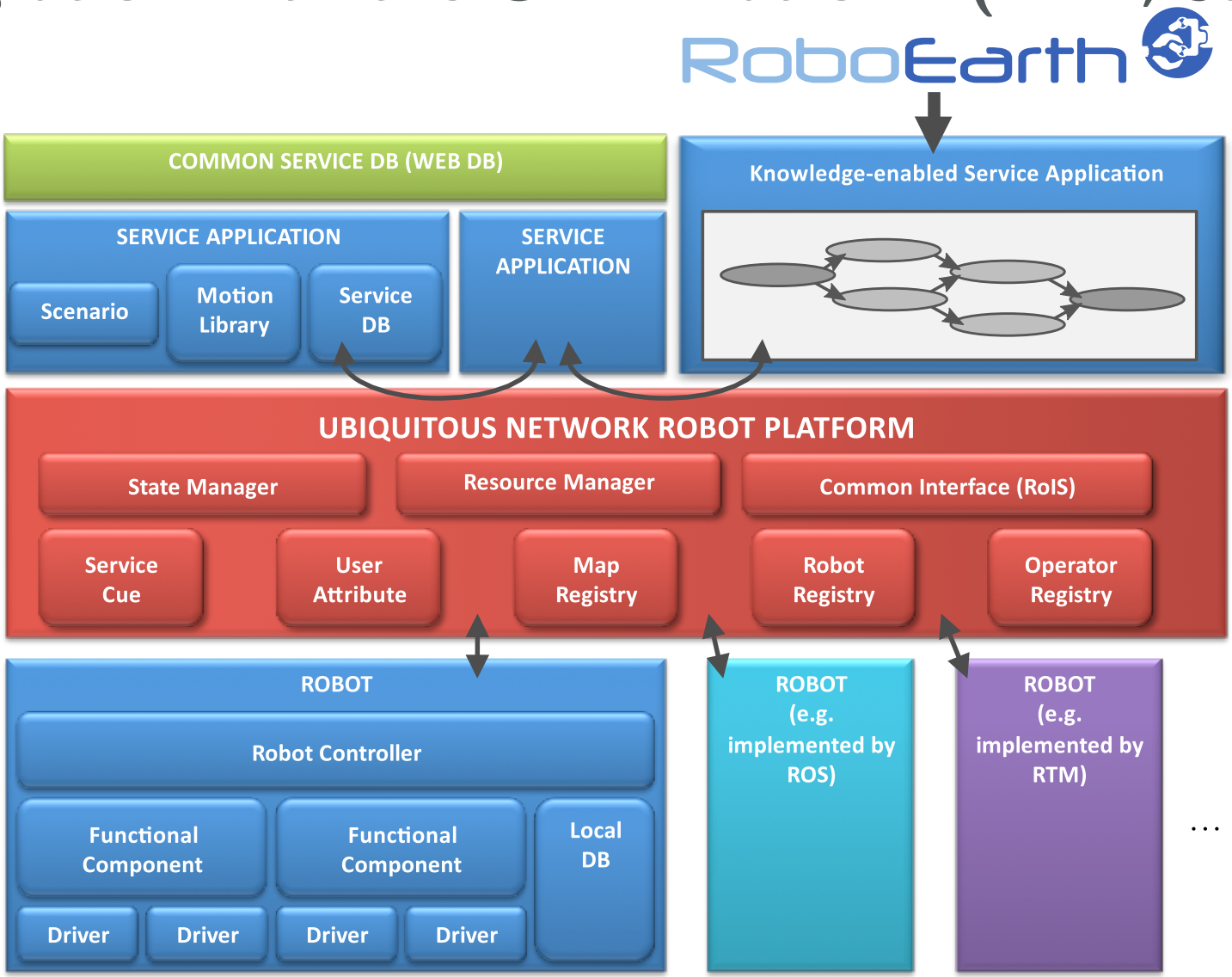
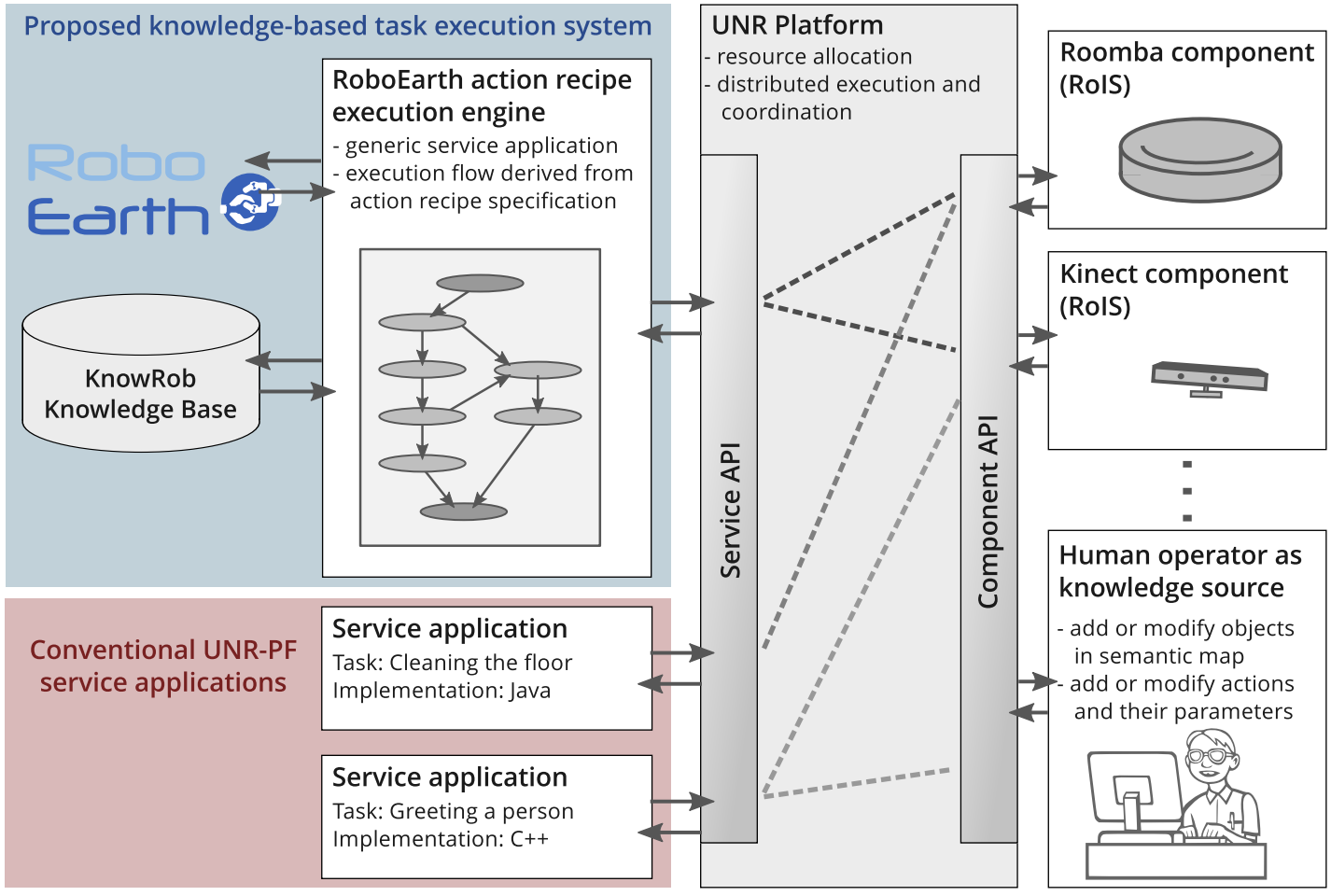


Cloud-based Collaborative 3D Mapping in Real-Time with Low-Cost Robots. V. Usenko, M. Singh, M. Waibel, and G. Mohanarajah. Submitted to ICRA 2014.

Integration with the UNR Platform (ATR, Japan)

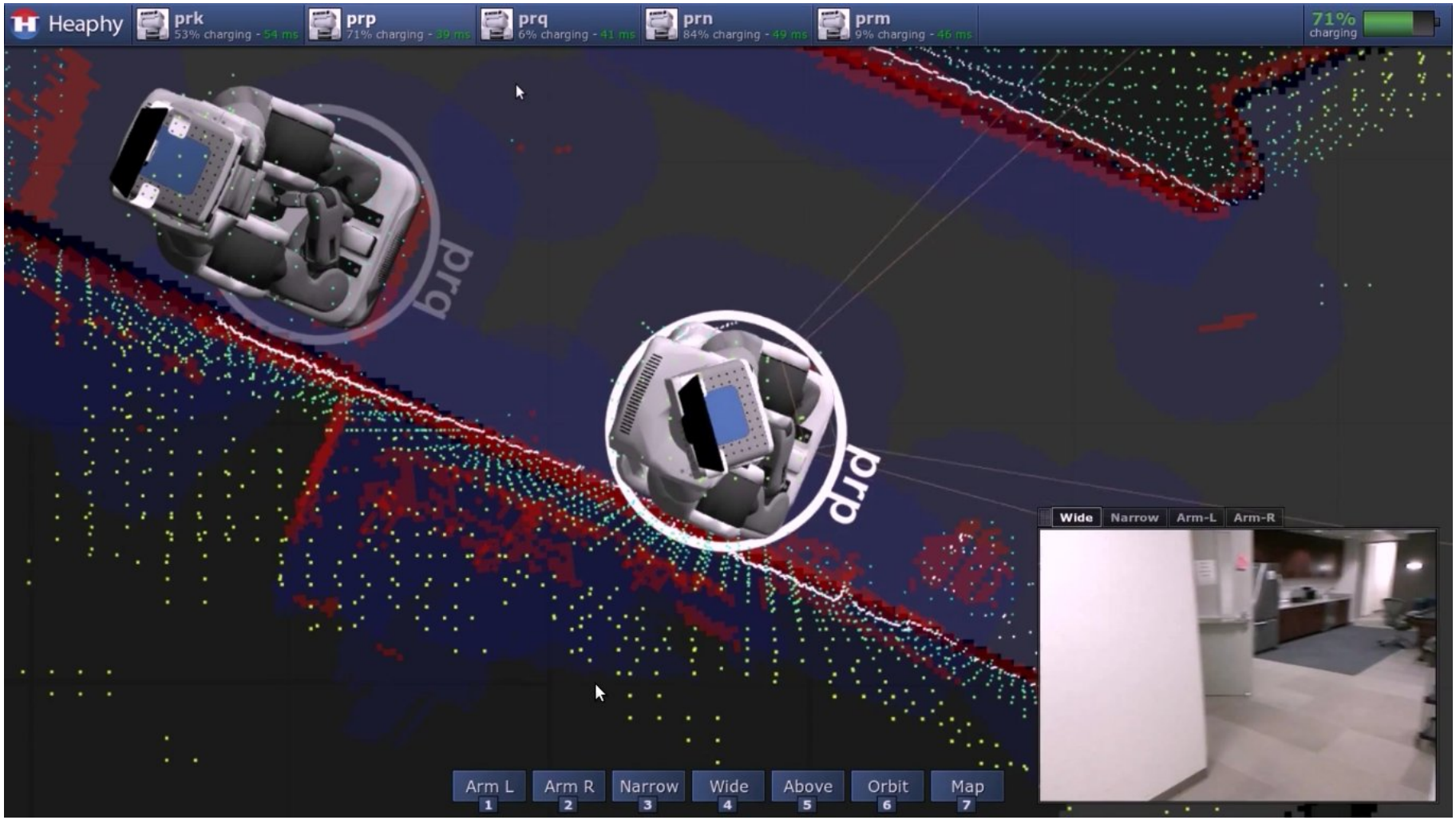


RoboEarth-enabled service applications

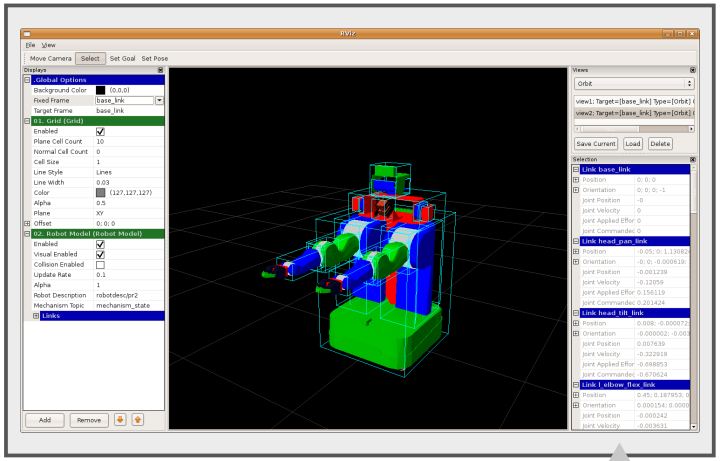


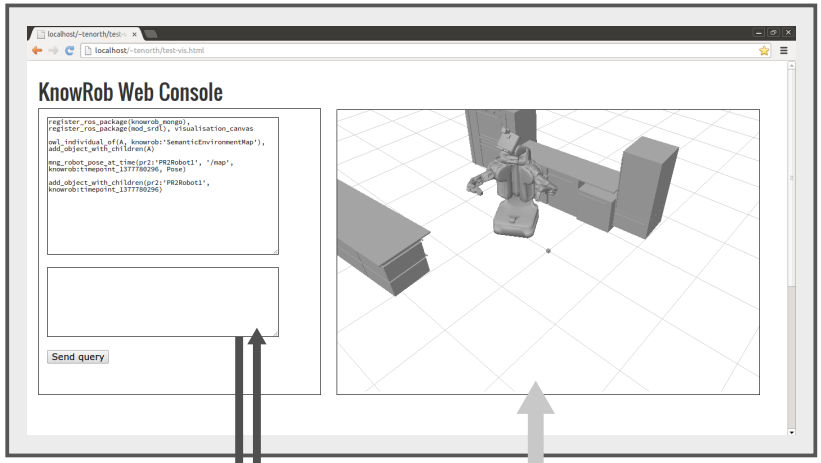
Building Knowledge-enabled Cloud Robotics Applications using the UNR Platform.
Moritz Tenorth, K. Kamei, S. Satake, T. Miyashita and N. Hagita. IROS 2013

Video: Heaphy Robotics (Willow Garage)



Cloud-based Robot Knowledge (WIP)





Internet

Prolog shell

KnowRob

Local visualization canvas

json_prolog ROS node

Visualization marker publisher

Websocket interface

rosbridge

/visualization_marker topic

robohow

Demonstration:
Remote Web-based Knowledge Processing

`http://knowrob.org/doc/robots_and_the_internet`

Shameless advertisement

- Most of the presented software tools are available as open-source ROS packages (at least all from our group)
- **KnowRob:** Knowledge processing system for robots
  http://www.knowrob.org
- **RoboEarth:** Web-based shared robot knowledge base
  http://www.roboearth.org
- **CRAM:** Plan language and high-level executive
  http://www.cram-system.org (soon)
- **RoboSherlock:** Ensemble-of-experts perception system
  http://pr2-looking-at-things.com/ (soon)

Conclusions

- Web and Cloud applications have huge potential for robots
- Interesting use cases:
  - Acquiring knowledge from the Web
  - Exchanging information via cloud-based knowledge bases
  - Offloading computation by using cloud services
- **But:** as in real life, not everything can be done online...
  - Information from the Web is abstract and disembodied
  - Common-sense knowledge is hard to find since "everybody knows it"

Thank you for your attention!

http://ai.uni-bremen.de/team/moritz_tenorth

http://www.knowrob.org

This work has received funding by the DFG Cluster of Excellence "CoTeSys" and the EU FP7 projects "RoboEarth" and "RoboHow".