Workshop: Hybrid Production Systems

Introduction

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Objectives

- Continuation of the dialogue started in ERF2014
- Presentation of first results from FiaD, LIAA, ROBO-Partner and ReApp
- Exploration of possible synergy effects

➡ Initiate activities with regard to developing a **Reference Architecture for a Hybrid Production System**

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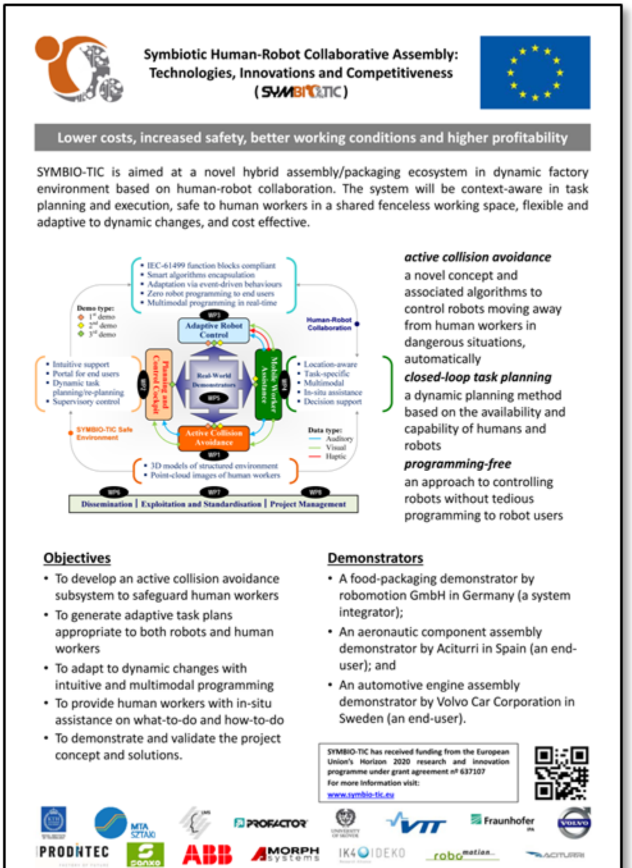
Welcome of 3 new FoF projects in the cluster

- Domain 5: Human-centred Manufacturing
  - Area 2:Human Robot Interaction



Symbiotic Human-Robot Collaborative Assembly: Technologies, Innovations and Competitiveness (SYMBIOTIC)

Lower costs, increased safety, better working conditions and higher profitability

SYMBIO-TIC is aimed at a novel hybrid assembly/packaging ecosystem in dynamic factory environment based on human-robot collaboration. The system will be context-aware in task planning and execution, safe to human workers in a shared fenceless working space, flexible and adaptive to dynamic changes, and cost effective.

active collision avoidance
a novel concept and associated algorithms to control robots moving away from human workers in dangerous situations, automatically

closed-loop task planning
a dynamic planning method based on the availability and capability of humans and robots

programming-free
an approach to controlling robots without tedious programming to robot users

Objectives
- To develop an active collision avoidance subsystem to safeguard human workers
- To generate adaptive task plans appropriate to both robots and human workers
- To adapt to dynamic changes with intuitive and multimodal programming
- To provide human workers with in-situ assistance on what-to-do and how-to-do
- To demonstrate and validate the project concept and solutions.

Demonstrators
- A food-packaging demonstrator by robomotion GmbH in Germany (a system integrator);
- An aeronautic component assembly demonstrator by Aciturri in Spain (an end-user); and
- An automotive engine assembly demonstrator by Volvo Car Corporation in Sweden (an end-user).

SYMBIO-TIC has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 637107
For more information visit: www.symbio-tic.eu

Symbiotic Human-Robot Solutions for Complex Surface Finishing Operations
SYMPLEXITY

Brilliance through Human-Robot-Collaboration

In almost every sector of industrial manufacturing polishing techniques are applied. Nonetheless most processes are performed manually as the required tasks partially demand high cognitive effort as well as motoric flexibility. SYMPLEXITY is closing the gap between the automated respectively manual polishing of simple respectively complex geometries by creating a safe environment of collaboration between the robot and the human worker.

Objectives
- Accurate and cognitive industrial robot systems enabling safe human-robot collaboration for surface finishing operations
- Easy to use interfaces for planning, control and re-planning of shared finishing tasks
- Collaboration oriented process technology for abrasive finishing, laser and fluid jet polishing
- Integrated and autonomous sensing system for objective identification of surface properties
- Introduction of developed collaborative finishing solutions into manufacturing industry

Evaluation
Due to the broad range of applied manufacturing technologies in the SYMPLEXITY project, different demonstrators from a variety of end users with different areas of application are processed, this covers parts from the
- medical sector
- automotive industry
- aeronautic sector
- tool and die making industry

SYMPLEXITY has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 637080
For more information visit: www.symplexity.eu

FOUR BY THREE
Highly customizable robotic solutions for effective and safe human robot collaboration in manufacturing applications
FOURBYTHREE

Can you imagine humans and robots working together in a fenceless industrial environment?

FourByThree is an alliance made up of 15 European partners, coordinated by IK4-TEKNIKER. The project started in December 2014 and will last for 36 months.

"We had some developments on series elastic actuators and thought they could be used for building a robotic manipulator for safe human-robot collaboration. We are bringing decades of research together into one single product."
José de Gea Fernández (DFKI)

FourByThree aims to develop a set of tools, hardware and software, to enable the creation of robots that have *four* main features:
- Modularity
- Efficiency
- Usability
- Safety.

Three main actors are involved:
- Humans
- Robots
- The environment

The results will be validated in four industrial pilot studies and different use cases:
- assembly and disassembly of small parts,
- collaborative welding,
- assembly of big parts.

A permanent Living Lab will allow a continuous evaluation of the results achieved

FOURBYTHREE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 637095
For more information visit: www.fourbythree.eu

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Agenda

14:00-14:10: Introduction

14:10-15:00: Project Presentations

- Human robot interaction for programming of assembly tasks – ROBO-PARTNER (Dr. George Michalos, LMS-University of Patras)
- Factory-in-a-day: wrap-up after year 1 (Prof. Gorden Cheng, TU München)
- Hybrid Workplace Design - LIAA (Ramez Awad, Fraunhofer IPA)
- Uniform capability description and reasoning for resources on the shop floor - ReApp (Dr. Stefan Zander, FZI)

15:00-15:25: Discussion of architecture and agreement of next steps

15:25-15:30: Conclusion

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Discussion

- **Discussion Points:**
  - ReApp Ontology
  - Reference Architecture
  - Other topics?

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Workshop: Hybrid Production Systems

ROBO-PARTNER

Human robot interaction for programming of assembly tasks

Dr. George Michalos

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Contents

- Introduction
  - Challenges and state of the art
- Robot Programming Framework
  - ✓ Human robot interaction mechanisms
  - ✓ Hierarchical decomposition of assembly operations
  - ✓ Human commands mapping to robot commands
  - ✓ ICT Integration architecture
- Application example

Introduction: Challenges

Flexible robotic equipment

Enable the execution of numerous manual assembly tasks

also..

Give the perception of human-like behavior

But

Programming methods still require robotics skills

and

Complex programming of assembly tasks

Therefore

Simpler methods for programming a robot are needed

New technology - sensors for interacting with human can help to reduce the complexity of programming

Introduction: Challenges

- Currently there are about 2.3 million industrial manufacturing SMEs in the EU (99% of all companies)
- Surveys by the European Business Test Panel (EBTP):
  - across 90 European companies
  - poor acceptance of robots within SMEs
  - 61% of SMEs use 1 to 10 robots / 32% between 11 to 50
- Challenges in adopting new technologies
  - Lack of flexible equipment for highly dexterous operations
  - Absence of user friendly programming techniques and interfaces
  - Difficulty to maintain and operate by non-expert users.

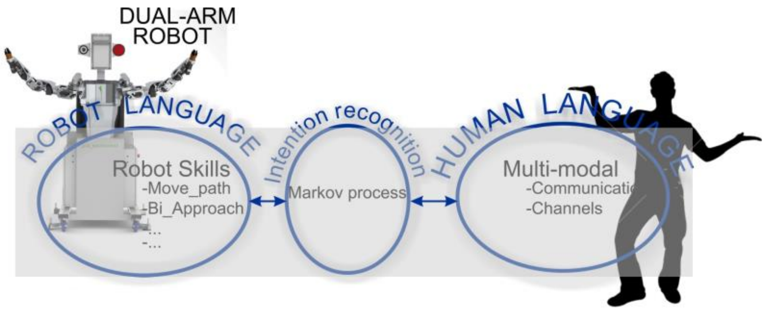
Introduction: Review of state of the art (1)

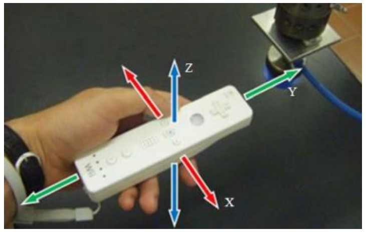
Methods for interactive programming

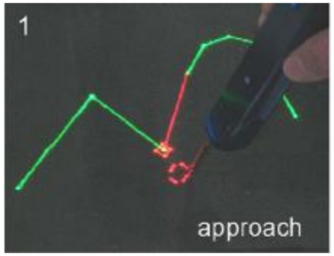
- Programming/ Learning by demonstration (PbD/LbD) approaches and instructive systems, aim at **demonstrating human-like behaviors** for programming and teaching robots, through commands such as voice, vision, haptics *[Biggs G. and Macdonald B., 2003] [Smith et al 2012][Zöllner et. al. 2004][Koenig et al 2010]*

- A few implementations in an industrial-like setup *[Reinhart et. al. 2008]*

- Human Robot Interaction architectures for programming *[Makris et. al. 2014]*







Introduction: Review of state of the art (2)

Robot programming languages

- motion-oriented, ‘**how to be done**’
- task-oriented, ‘**what**’ to be done rather than ‘how’

Task-oriented programming

is connected with the development of **interfaces** that will **help humans** to transfer high level commands to a sequence of robot motions and actions *[Mosemann and Wahl 2001][Thomas and Wahl, 2001] [Landzettel et. al. 2001][Iba 2004]*

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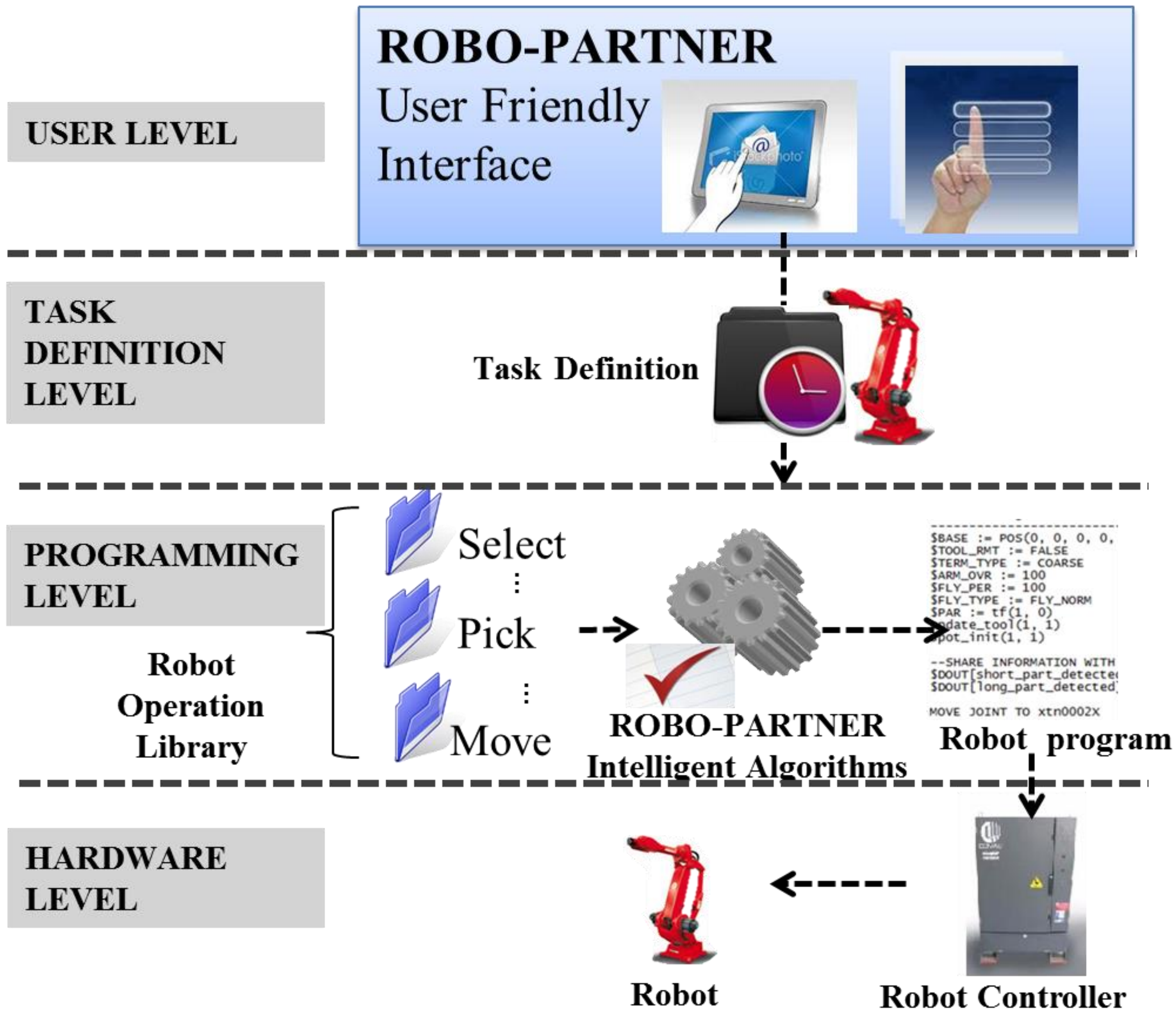
Simplified programming early concept



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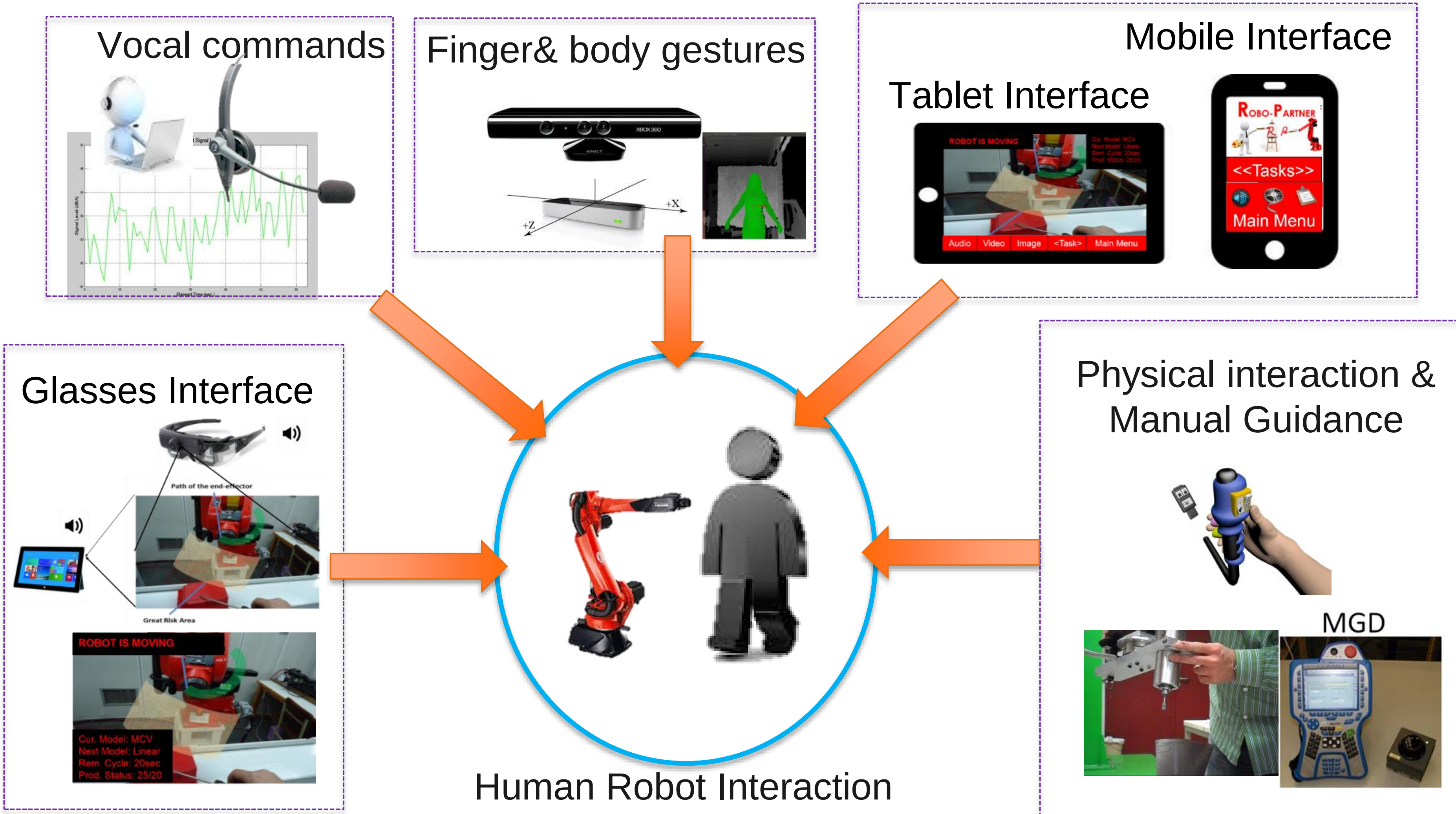
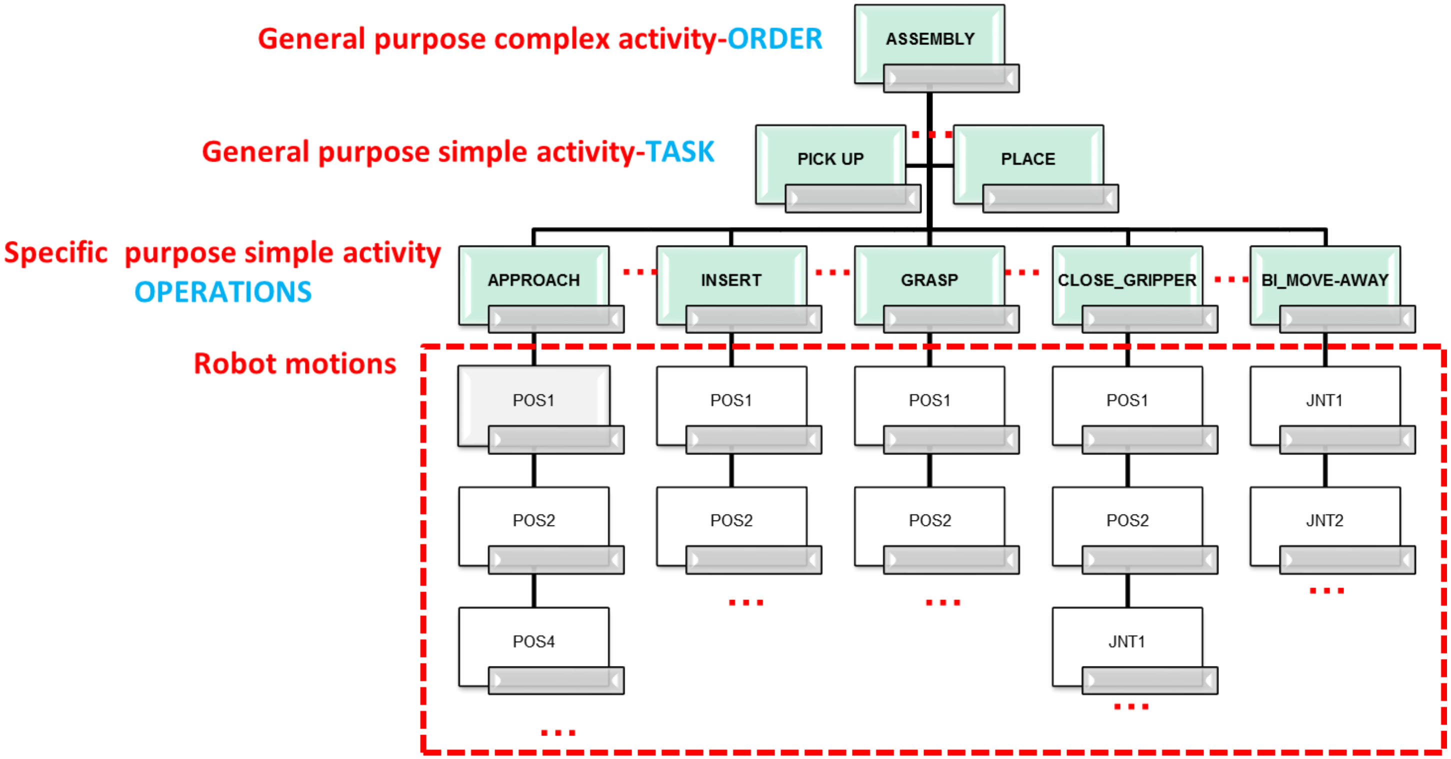
Human-robot interaction mechanisms



Hierarchical decomposition of operations

Decomposition of complex activities in simpler activities,

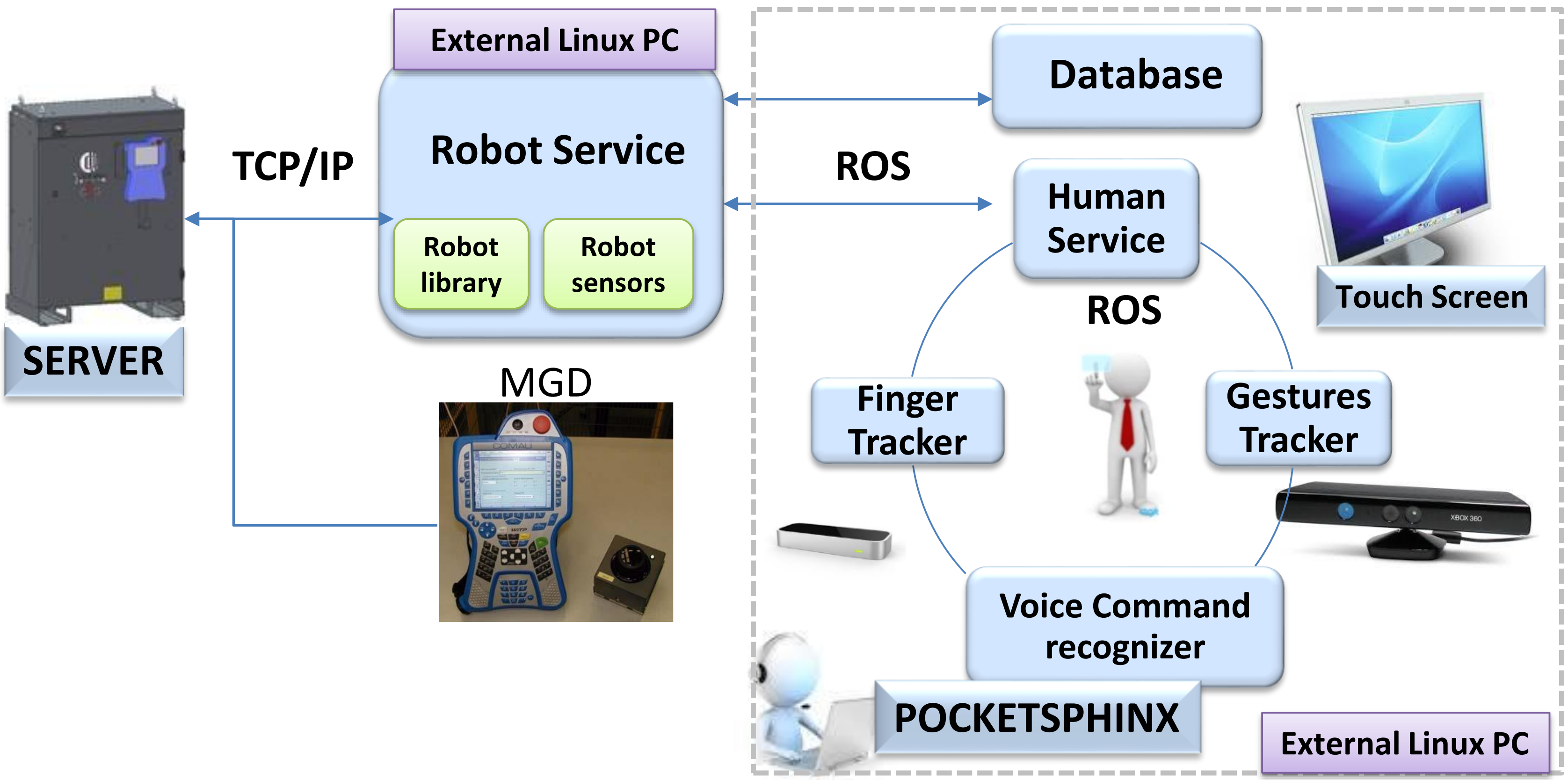
- Model assembly operations in a structured manner
- Combine with human interfaces
- Facilitate further programming of complex assembly operations



Makris, S., Tsarouchi, P., Surdilovic, D., Krüger, J., 2014, Intuitive dual arm robot programming for assembly operations, CIRP Annals - Manufacturing Technology, 63/1:13–16, DOI:10.1016/j.cirp.2014.03.017.

Programming module architecture

Synergy with



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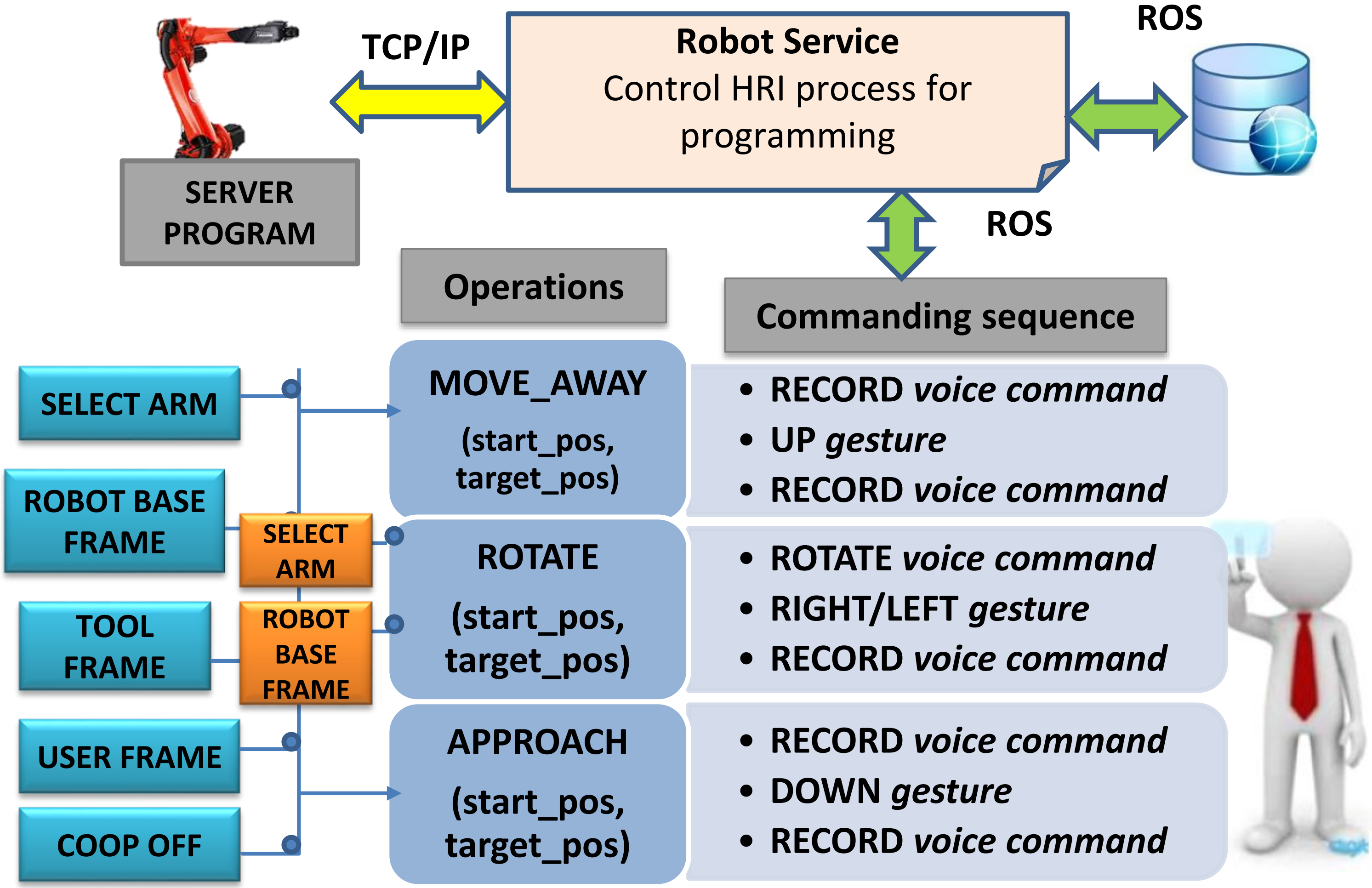
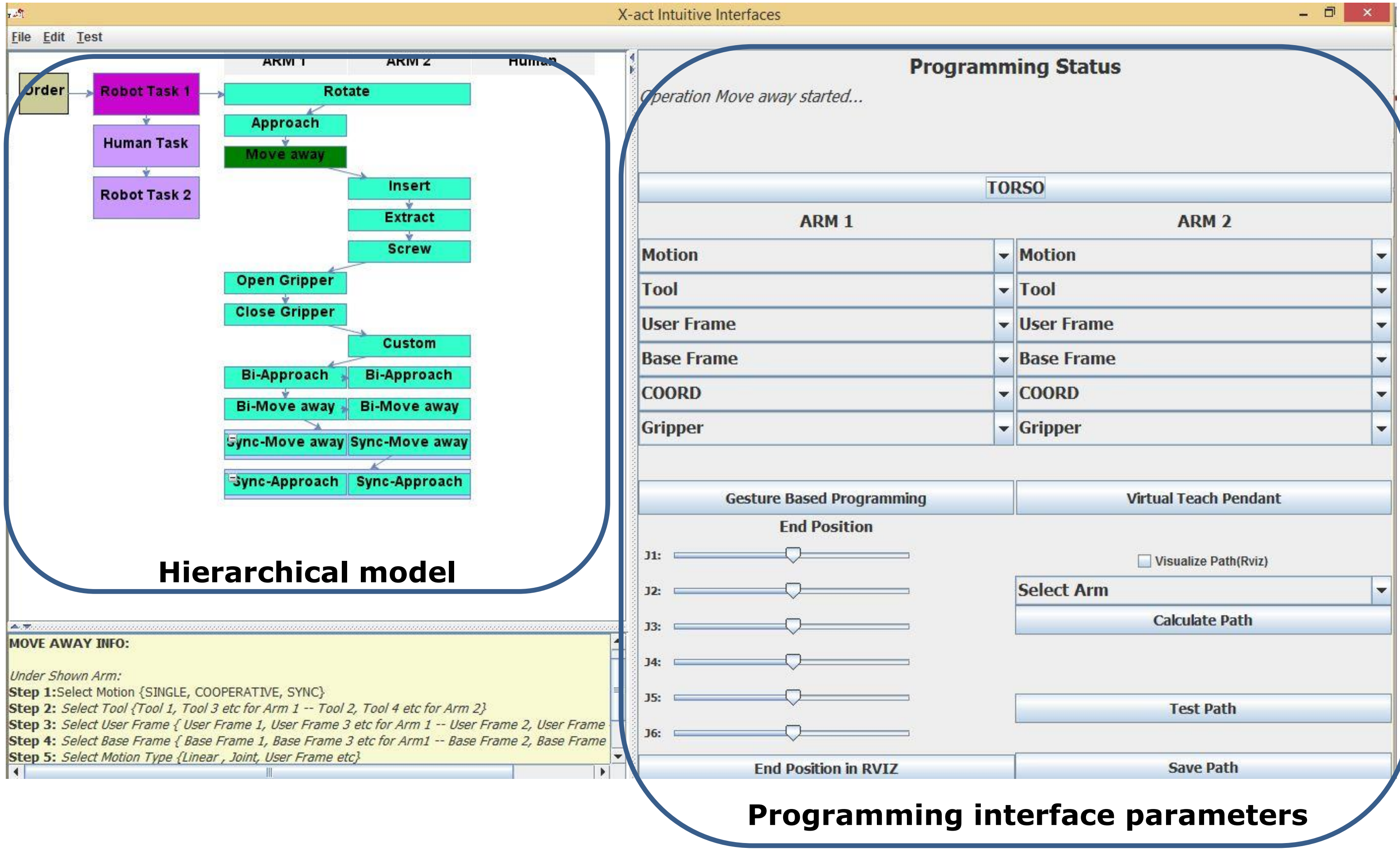
Human commands mapping to robot commands- an example

Synergy with



Graphical interfaces for programming

Synergy with



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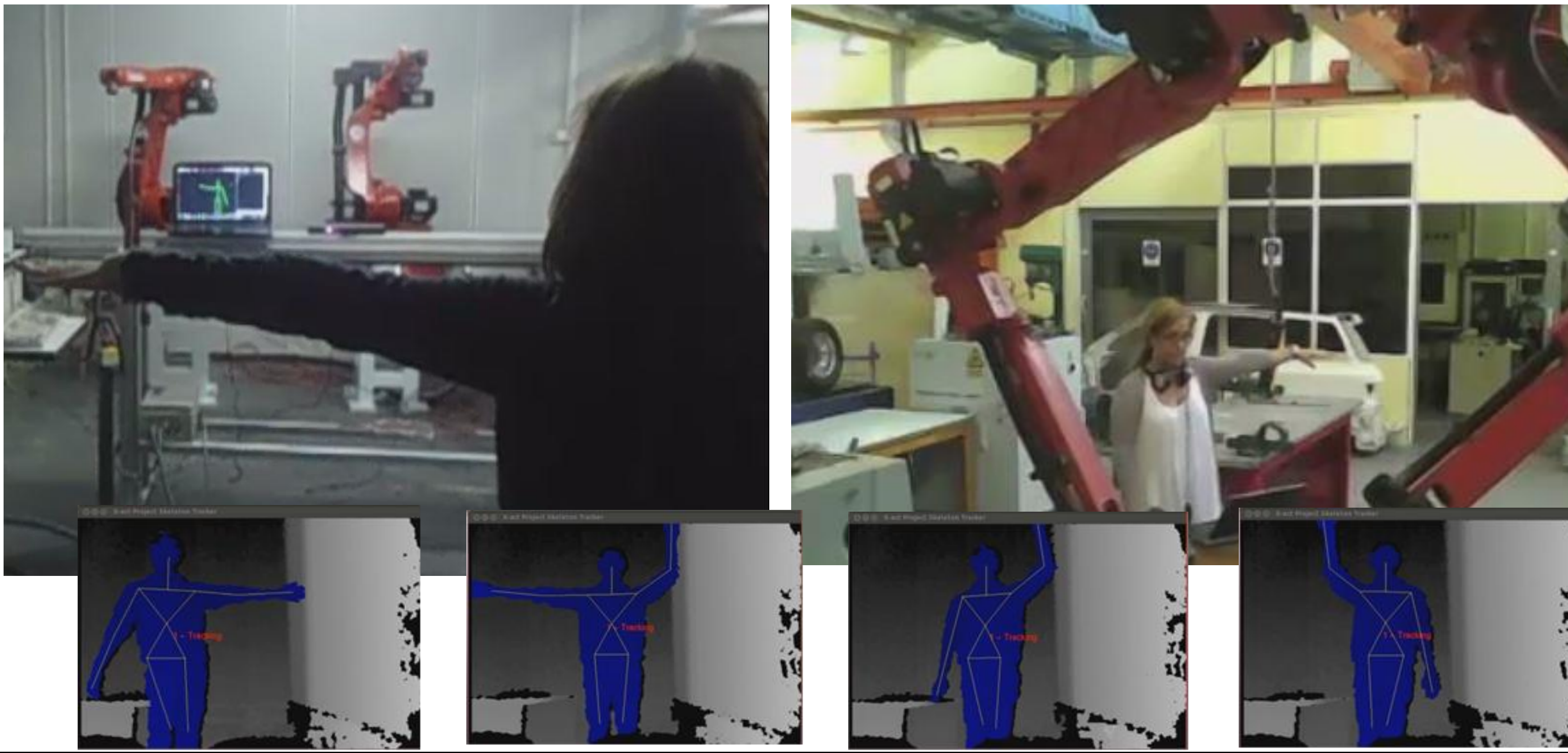
Assembly example (1/2)

Synergy with

Gesture commanding in single arm robot

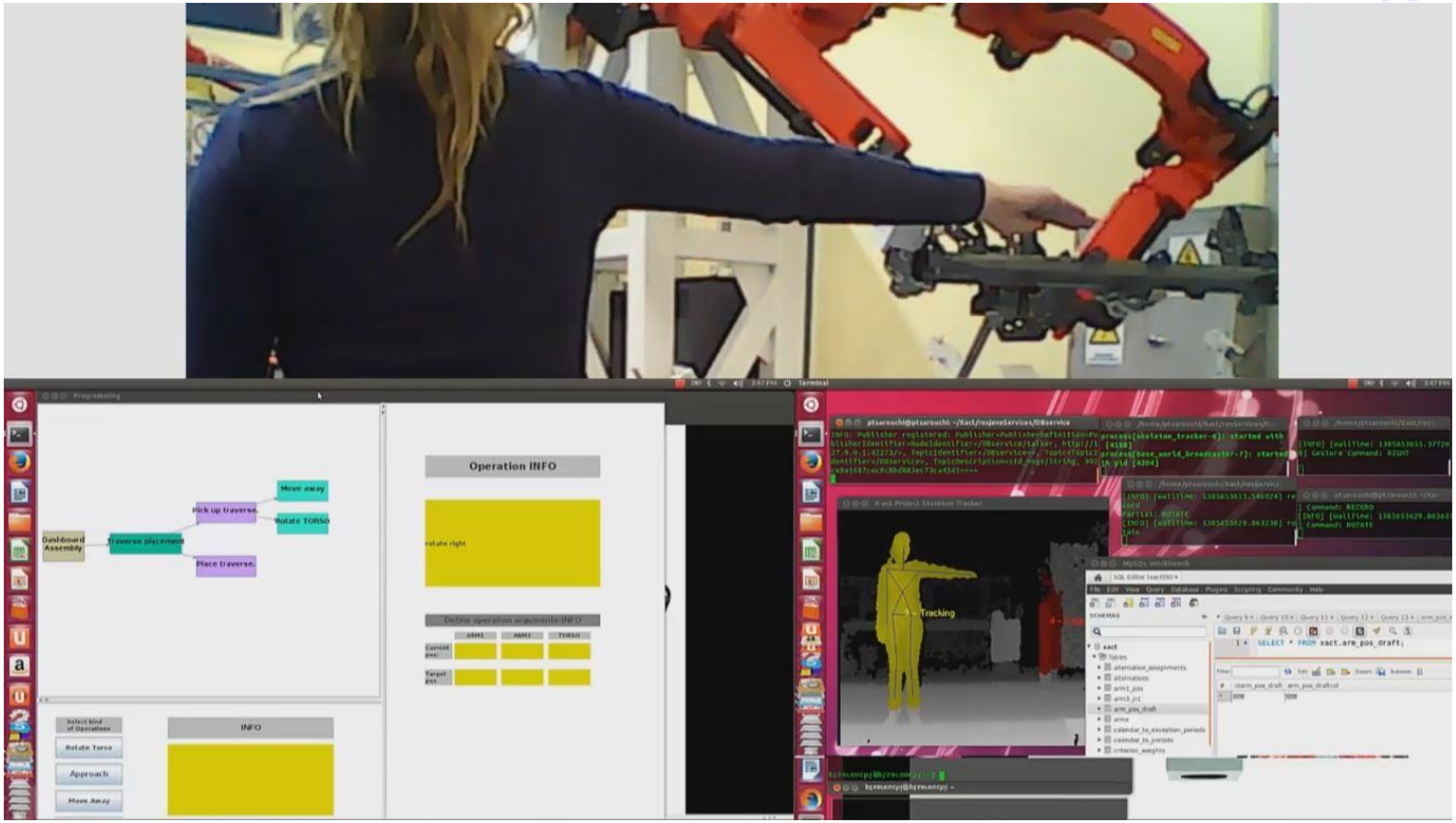
Gesture commanding in dual arm robot



Assembly example (2/2)

Synergy with

Programming Module application in dual arm robot



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For more information visit us at www.robo-partner.eu

Thank you for your Attention!

Questions?

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 608855

&

and the project X-act/ FoF-ICT-314355 (http://www.xact-project.eu/), funded by the FP7 framework.

Workshop: Hybrid Production Systems

Factory-in-a-day(Fiad)

Factory-in-a-day: Wrap-up after year 1

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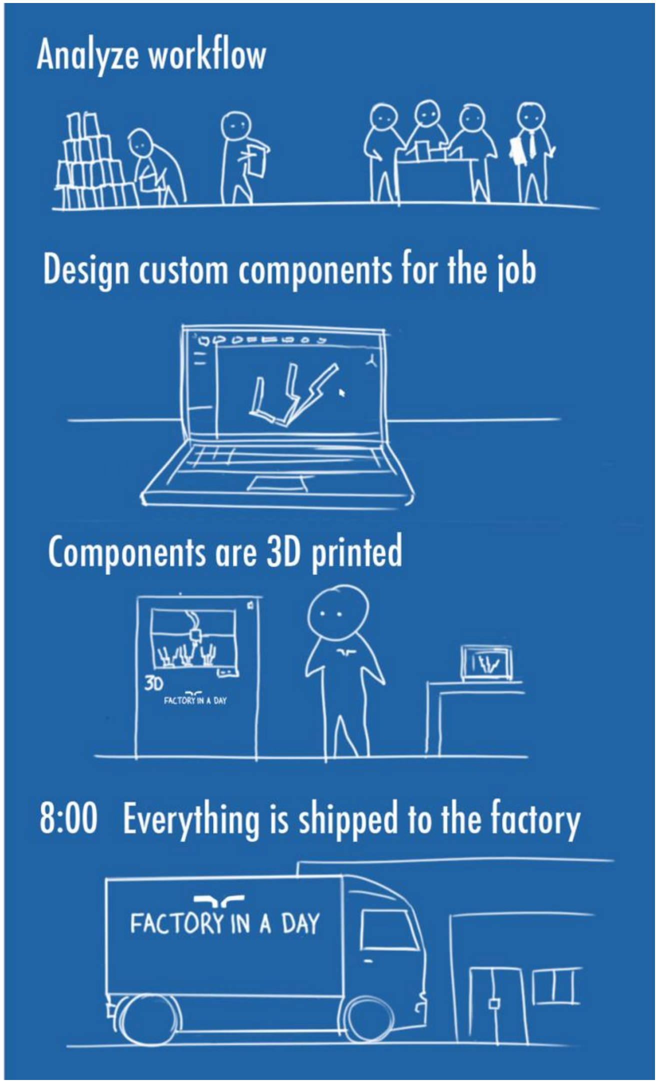
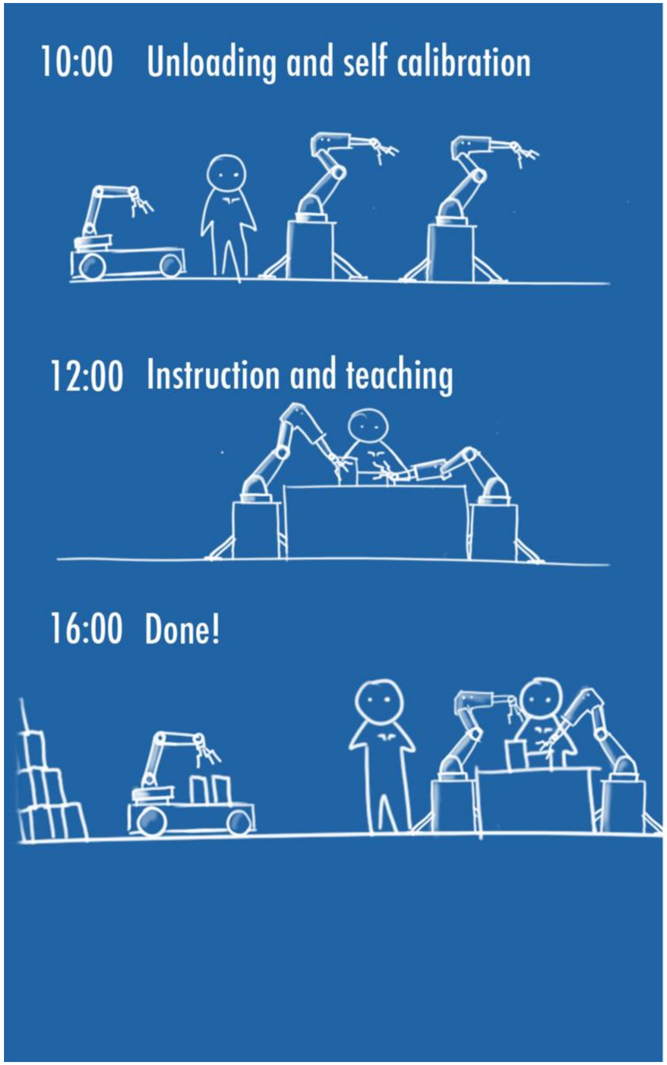
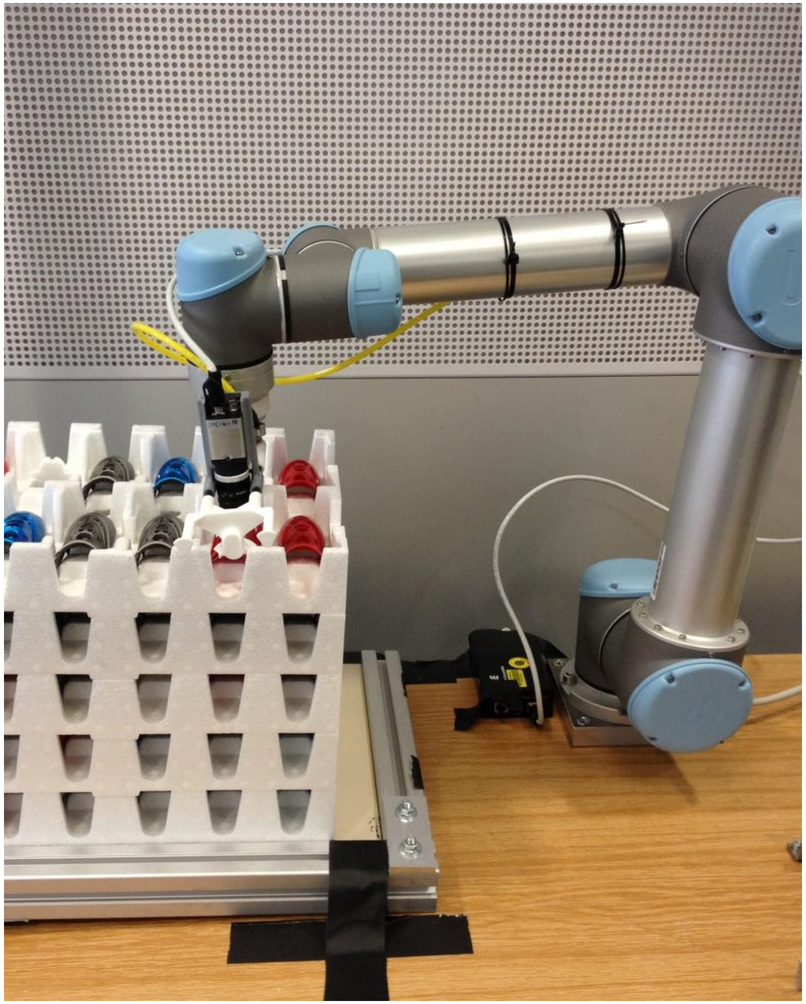
Factory-in-a-day: The Dream

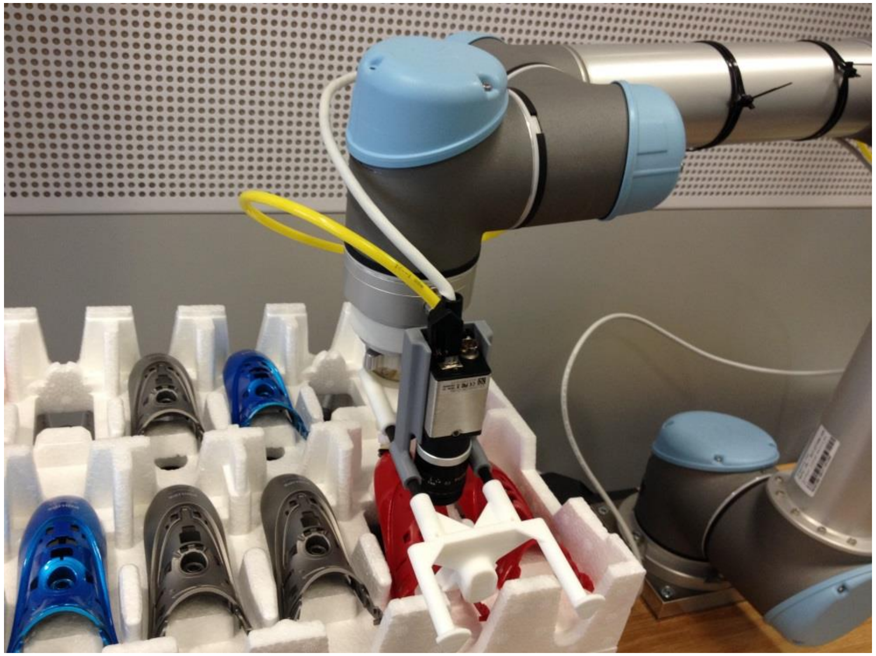




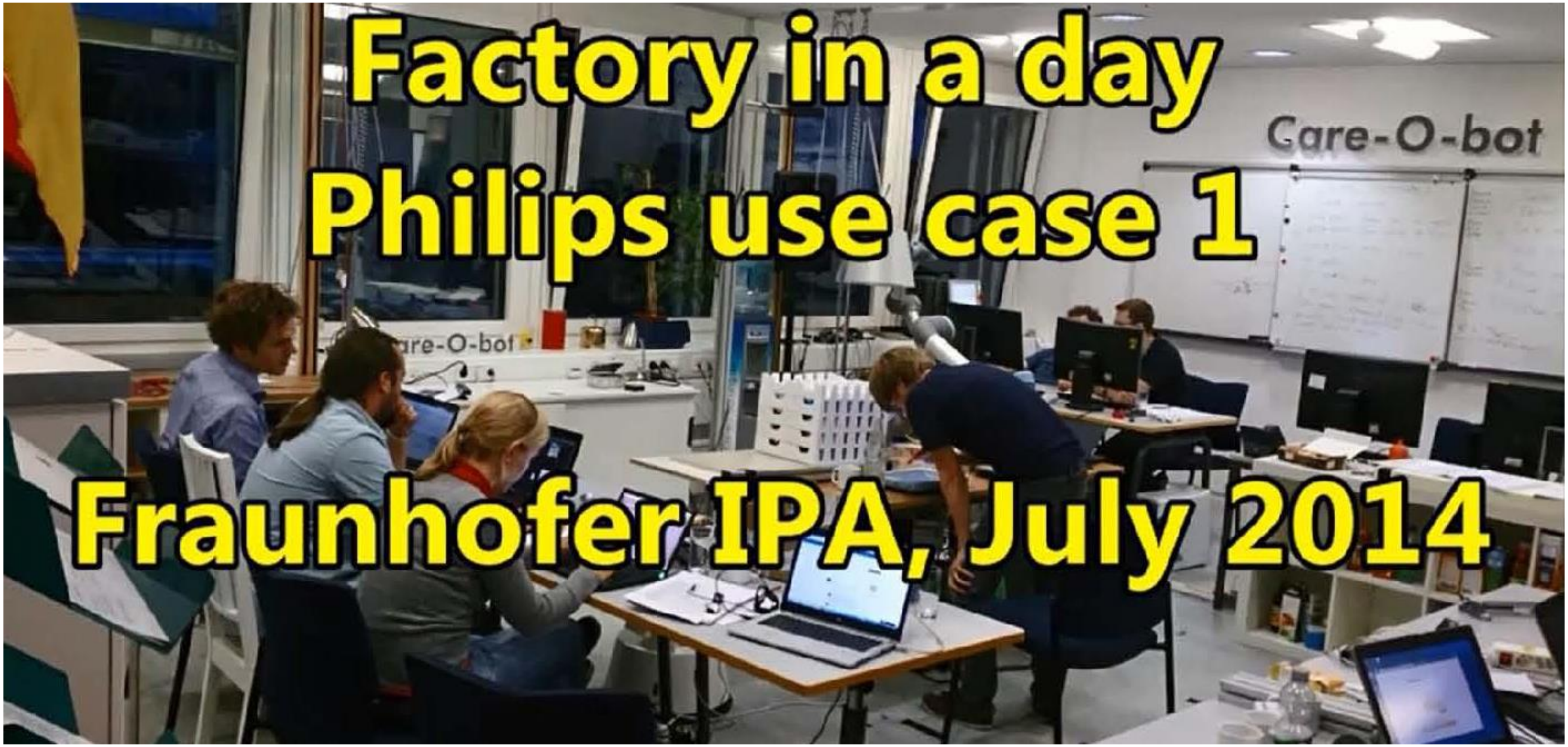
Example test case



Philips case: (un)loading of trays with razor parts for printing



Challenges?



http://youtu.be/p5ds-Q9_0CA

What did we do?

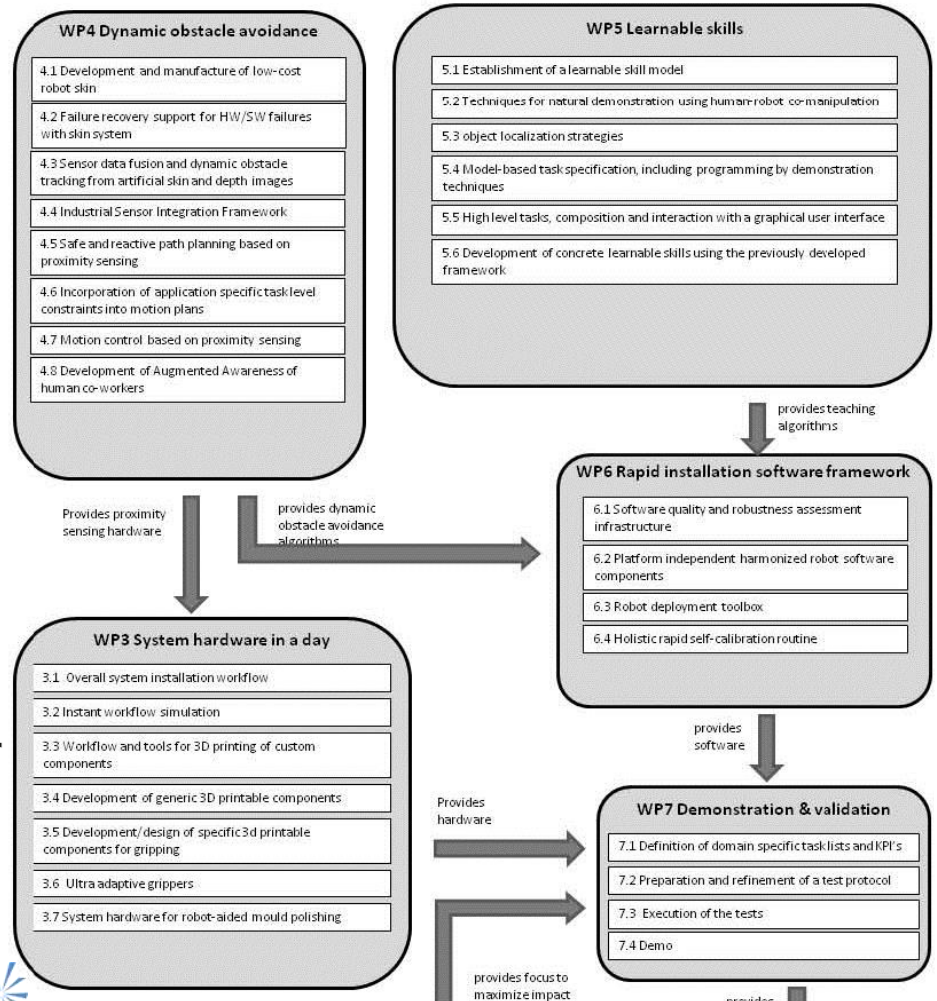
Direct tasks	Indirect tasks
Loading parts in the machine **Machine loading**	Fetch and bring lorries with trays with products
Unloading parts from the machine	Load and unload trays from lorries on supply and exit lin
Placing trays with new parts from supply line on workstation **Tray handling**	Machine ver
Placing trays with finished parts from workstation on exit line	Mix ne
Perform visual quality check	Swap tampo
Log outcome of quality check	Finetu
Quality checking	Cleani
	Break
	Teammeetings
	Fix machine errors/failures

How did we do?

Metric	Example industry	Hackathon July 2014
Installation effort	8750 [hrs]	200 [hrs]
Reuse value	25 %	65 %
Installation time	40 [weeks]	30 [days]
Cost of reconfiguration	200,000 [euros]	2,000 [euros]
Reconfiguration time	20 [weeks]	2 [days]
Uptime	91 %	40%
Production rate	12.0 [parts/min]	1.2 [parts/min]
Operator load	0.1 FTE	0.6 FTE
Automation level	130 [parts/min/operator]	2 [parts/min/operator]

Technical work packages in Fiad

Factory in a Day



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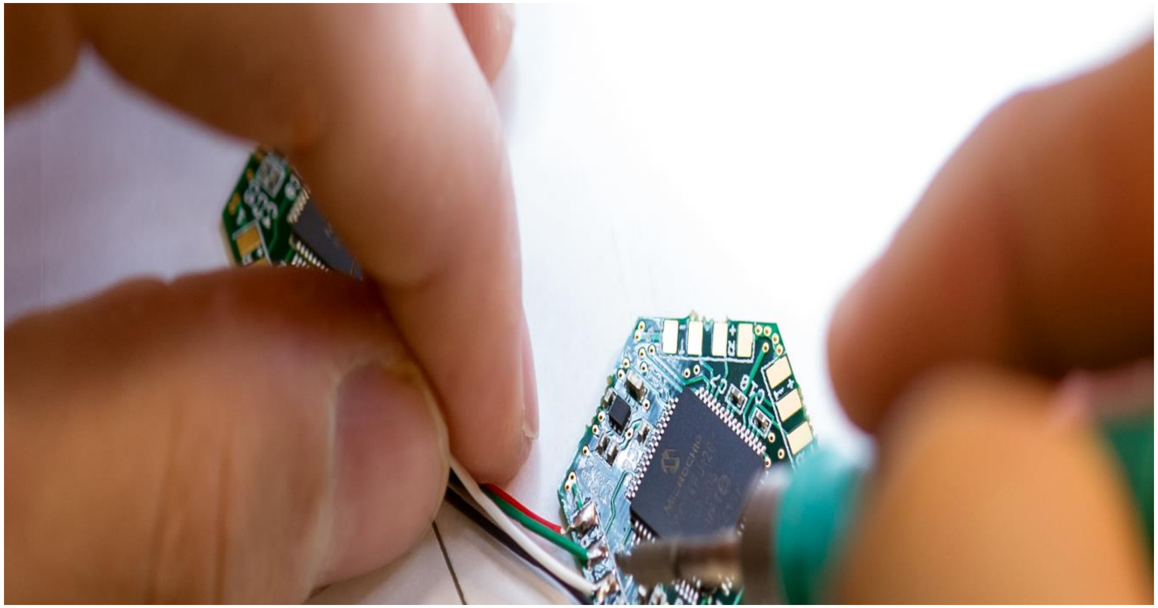
CellulARSkin

- CellulARSkin: hexagonal-shaped skin-sensor for robots
- Modalities: temperature, proximity, force and vibration
- max frequency, self-calibrating system
- Cell-to-cell communication



Integration of Robotic Skin in Fiad

The skin-sensors are integrated in the project on different levels:

T4.1: Development and manufacture of low-cost robot skin

T4.2: Failure recovery support for HW/SW failures with skin system

T4.3: Sensor data fusion and dynamic obstacle tracking from proximity sensing and depth images

T4.5: Safe and reactive path planning based on proximity sensing

T4.7: Motion control based on proximity sensing (8pm)

Task 5.1: Establishment of a learnable skill model

Task 5.2: Techniques for natural demonstration using human-robot co-manipulation

Task 6.4: Holistic rapid self-calibration routine

CellularSkin on robot Tom

Visit us in the exhibition area!

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Thank you for your Attention!

Questions?

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 609206.

For more information visit us at www.factory-in-a-day.eu

LEAN AUTOMATION

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Workshop: Hybrid Production Systems

Lean Intelligent Assembly Automation (LIAA)

WP03: Computer-Aided Symbiotic Workplace Design

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WP03 – Motivation and Objectives

- **Motivation:**
  - Design and evaluation criteria of hybrid work places → scarce

- **Objectives:**
  - Criteria and metrics for evaluating hybrid assembly workplaces
  - Risk Assessment methodology for hybrid assembly workplace designs
  - Safety Concepts for different risk levels
  - Guidelines (e.g. manual / wizard) incorporating planning and design principles for symbiotic human-robot-cooperation workplaces
  - 3D-simulation environment for evaluating the applicability of a workplace for symbiotic human-robot-cooperation

  - Computer aided symbiotic workplace design tool, that
    - highlights risk areas
    - calculates risk levels
    - suggests safety concepts

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Current Results

- A set of prototypes:
  - **Design Conceptualization Tool**
  - Part Supply Calculation Tool
  - **Robot Cycle Time Estimation**
  - KPI Computation Module
  - **3D-Automate**

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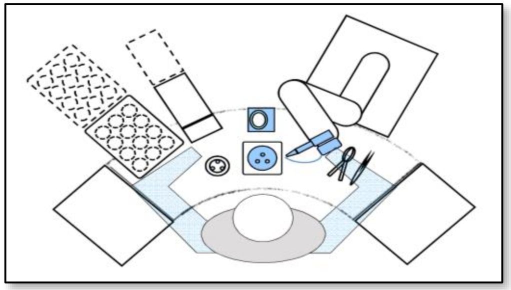
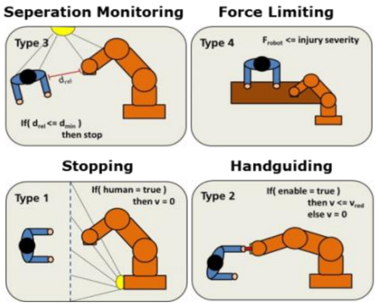
Design Conceptualization Tool (1/3)

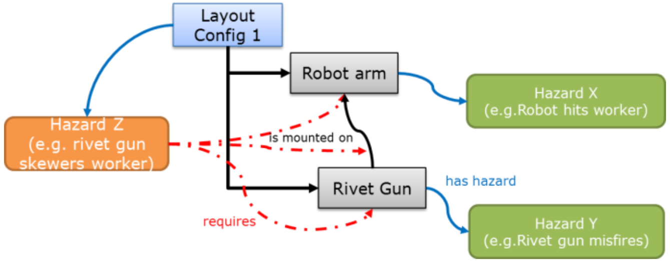
- **Lead Partner:** Fraunhofer IPA
- **Purpose:**
  - Consideration of hazards and the impact of safety measures on the KPIs of a workplace design during conceptualization phase.
- **Approach:**
  - Map potential hazards to equipment classes / processes /configuration of workplaces
  - Identify suitable Human-Robot-Collaboration (HRC-) Type w.r.t. assembly processes
  - Identify suitable Safety Principles and Measures for hazards/risk scenarios
  - Analyse impact of Safety Measures on KPIs.



Graphical representation of a design concept



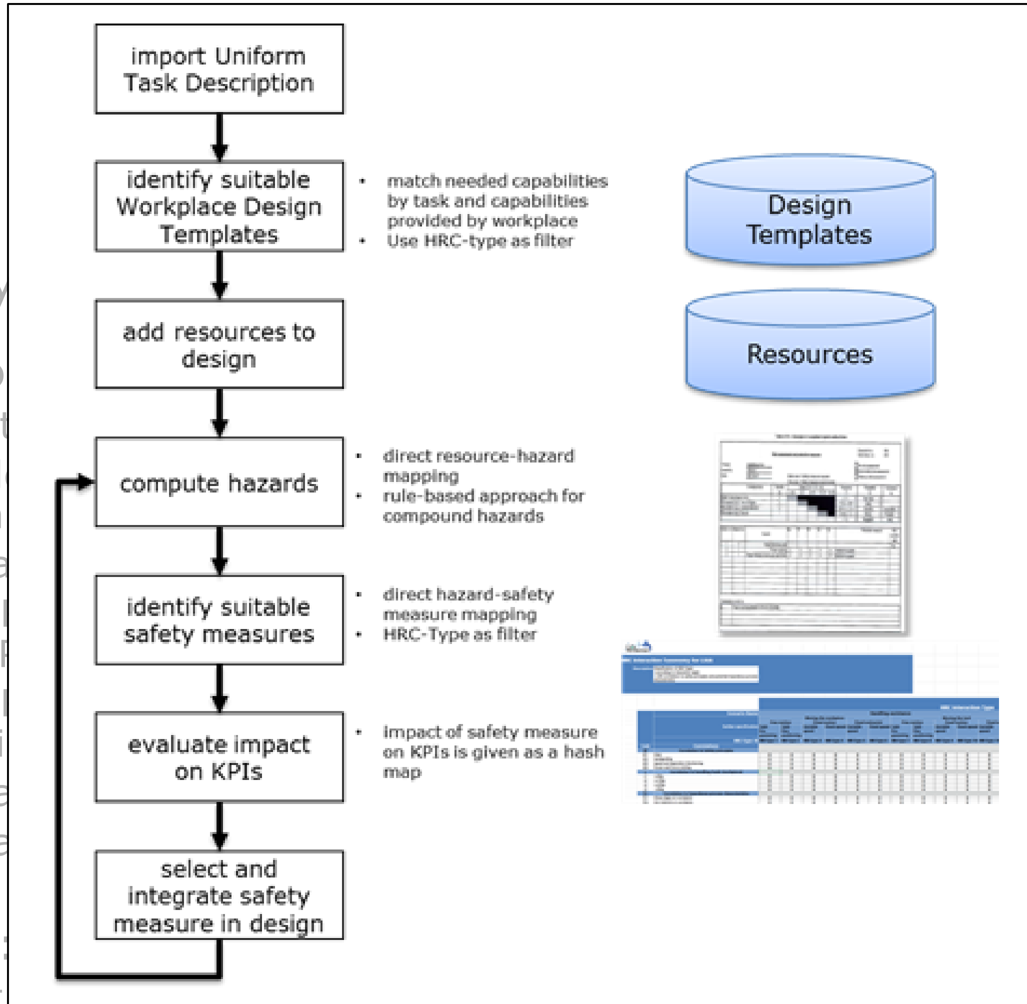
Safety Principles



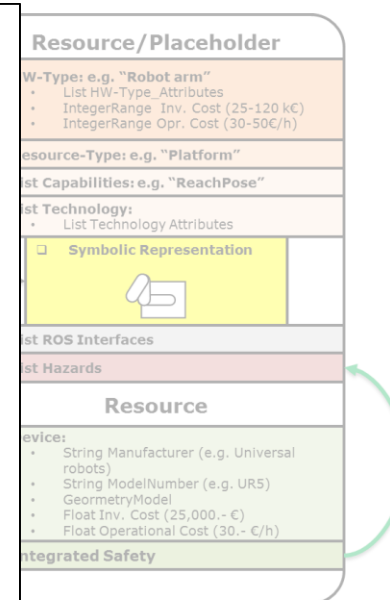
Compound Hazards

Design Conceptualization Tool (2/2)

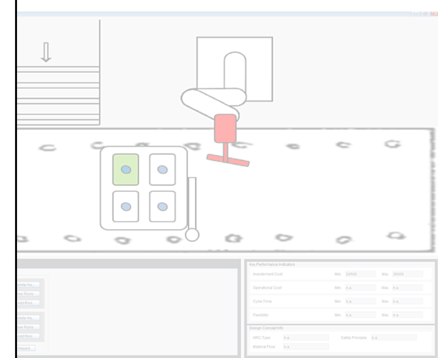
- **Status:**
  - Workflow
  - 1st prototy
    - import from D
    - evaluat
    - add ad Design
    - Correla
      - HI KI
      - HI pi
      - sa
      - sa
  - Next step:
    - impact



Conceptual Design Workflow



AA Resource Model


enshot of current GUI

Robot Cycle Time Estimation (1/2)

- **Lead Partner:** Opel AG

- **Purpose:**
  - Cycle time is needed to select suitable resources and to validate if user demands can be met
  - KPI estimation (WP03) and task assignment (WP04) need cycle time as input

- **Approach:**
  - As current state of the art robot cycle time can be determined using simulation (high effort) or experimentally (even higher effort)
  - System similar to MTM (human cycle time estimation) will be developed for robot cycle time estimation

➡ Robust cycle time estimation with low effort for early planning stage

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Robot Cycle Time Estimation (2/2)

- **Status:**
  - Prototype for articulated arm robot
  - Standard operations can be combined to evaluate complex tasks:
    - **Reach, Grab**
    - **Move, Release**
    - **Place/Join**
  - Validation and data generation on Kuka LBR iiwa 14
  - First version with compatibility to MTM UAS

Robot speed [mm/s] 500

Description	Code	Category	TMU		Occurance	Total TMU	
			Human	Robot		Human	Robot
Movement of operator to turbo charger storage box	KA	Bodymovements	25	N/A	2	50	N/A
Positioning into fixture	AH2	Pick and place	45	165	1	45	165
Closing of clamping lever	BA2	Operate	25	180	1	25	180
Build up pressure for clamping lever	ZD	Tighten or loosen	20	68	1	20	68
Removal of safety caps	AD2	Pick and place	45	210	5	225	1050
Remove safety caps	ZD	Tighten or loosen	20	68	5	100	340

Total Cycletime [TMU]	465	1803
Total Cycletime [s]	16,7	64,9

Robot MTM basic | Robot MTM adv | PnP | Database | Dropdown

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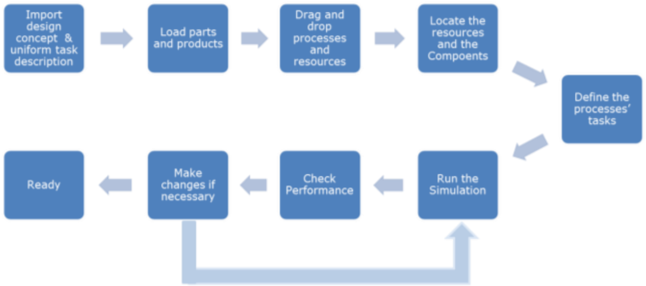
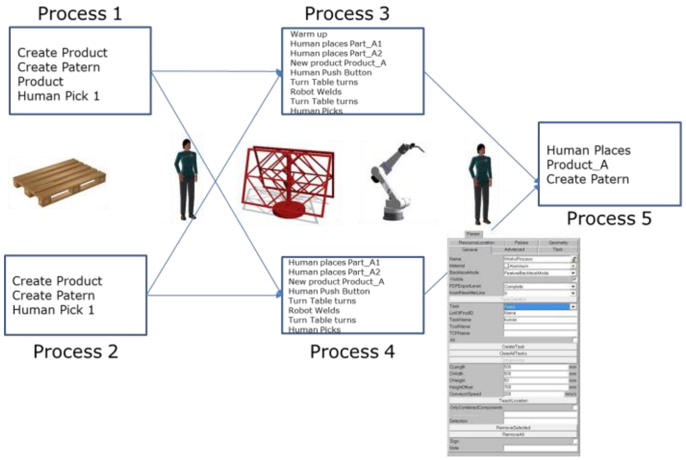
3D-Automate (1/2)

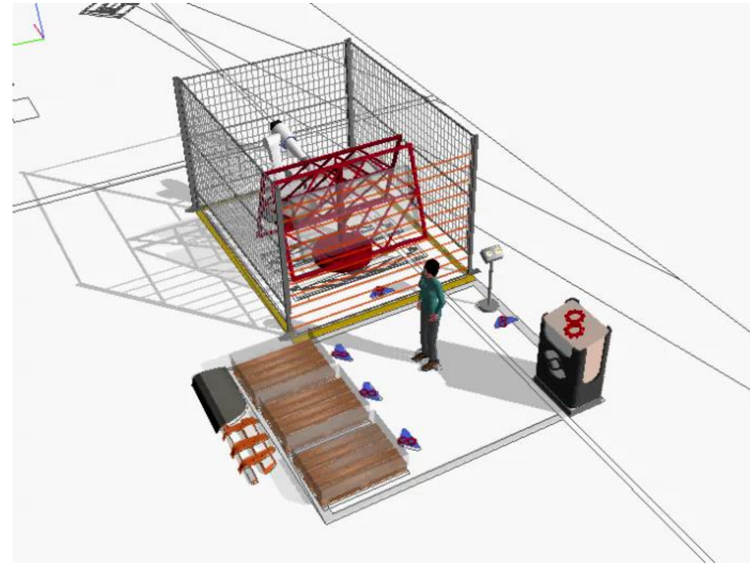
- **Lead Partner:** Visual Components Oy
- **Purpose:**
  - Simulate assembly tasks to evaluate geometrical and dynamic hazards/risk scenarios
- **Approach:**
  - Import Design Concept
  - Populate with geometric models
  - Import Uniform Task Description
  - Distribute tasks to resources
  - Run Simulation, evaluate hazard constraints w.r.t. speeds, forces, collisions.

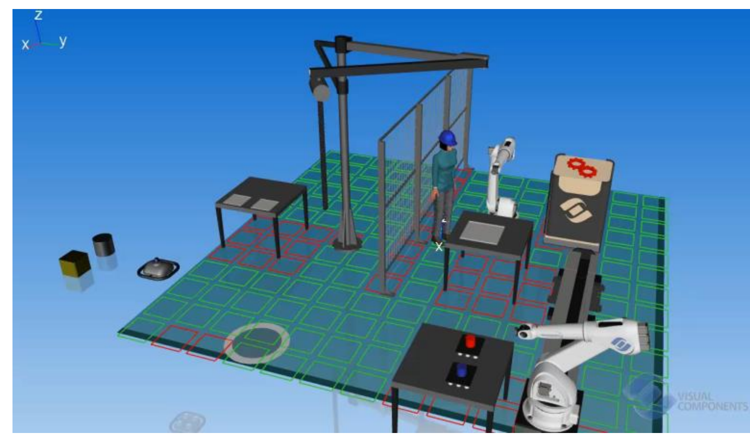




3D-Automate (2/2)

- **Status:**
  - 3D Automate is evolving the human model for providing a realistic human simulation, with new functionalities for the human works model
    - Adjust the carry position for components
    - Adjust the location of a human at a station
    - Visualization of transportation rules
    - Perform of human processes:
      - Creating the needed working conditions (high level definition) at a station
      - Reserve and allocate human resources to perform specifit tasks
      - Avoid collision and enforce safety rules while walking
      - Execute conditional tasks





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Thank you for your Attention!

Questions?

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Workshop: Hybrid production systems

Reusable robot applications for flexile robot systems based on Industrial ROS (ReApp)

Reasoning on Features of Robot-Centric Workplaces using Ontological Semantics

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Reasoning – A Working Definition

- Processing the **formal, model-theoretic semantics*** of the ReApp Ontologies and deducing **implicit knowledge** through the notion of **logical consequence**.

** Encoded in the form of logical axioms*

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Basic Inference Types

- **Subsumption** – find out whether class C is a subclass of D, i.e., $C \sqsubseteq D$
- **Class Equivalence** – find out whether class C is equivalent to D, i.e., $C \equiv D$
- **Class Disjointness** – find out whether C and D disjoint, i.e., $C \sqcap D \sqsubseteq \bot$
- **Global Consistency** – find out whether the ReApp knowledge base is globally consistent, i.e., that it has a model
- **Class Consistency** – e.g., find out whether a given class C is consistent, i.e., show that $C \sqsubseteq \bot$ is not a logical consequence of the given knowledge base
- **Instance Checking** – e.g., find out if an individual a belongs to a class C, i.e., check whether C(a) is a logical consequence of the given knowledge base
- **Instance Retrieval** – find all individuals that are member of a given class or class expression

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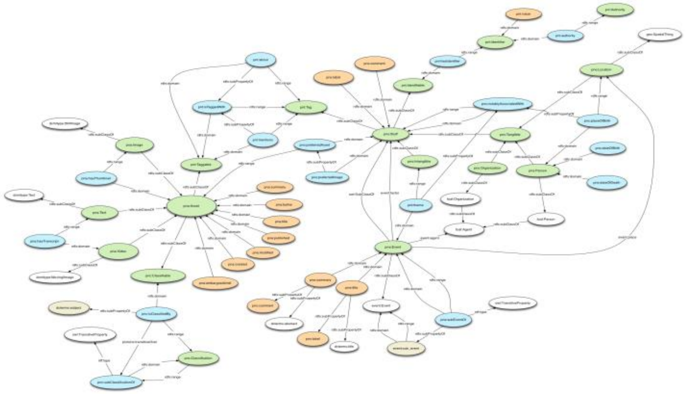
Terminological and Assertional Knowledge

HW-, SW-, & Capabilities Ontologies



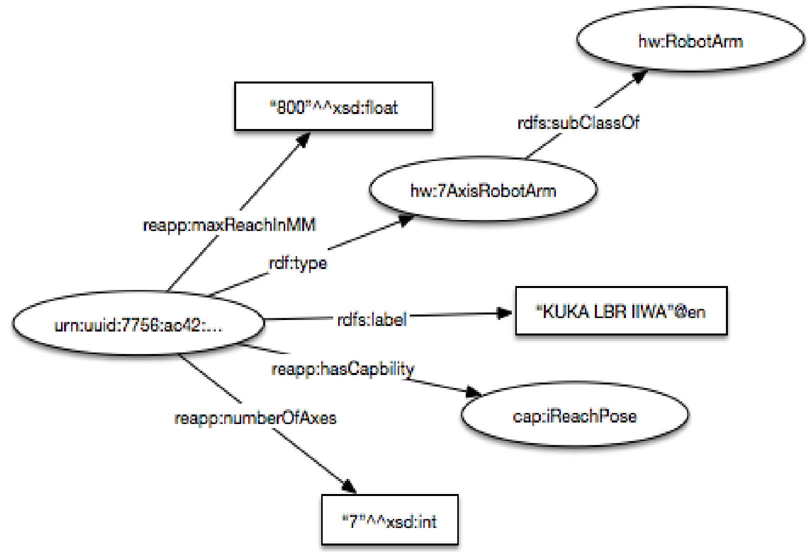
Source: http://data.press.net/ontology/images/big-ontology-picture.png

Terminological Knowledge
(Classes, Relationships, Constraints)

≙ Materialization

Used to represent data about a concrete instance of an App (ie., Device, ROS Wrapper, Software Component, Skill, Solution etc.)

TBox - Logic



ABox - Instances

Capabilities Computation

Encoding Capability Information

Problem:

- **How to represent capabilities of Components on TBox level?**
  - E.g., state that safety laser scanners (class) have the default capability safe monitoring of 2D fields

Solution:

- Encode capabilities in **subsumption axioms**
  - SafetyLaserScanner $\sqsubseteq$ $\exists$hasCapability.SafeMonitoringOf2DFields

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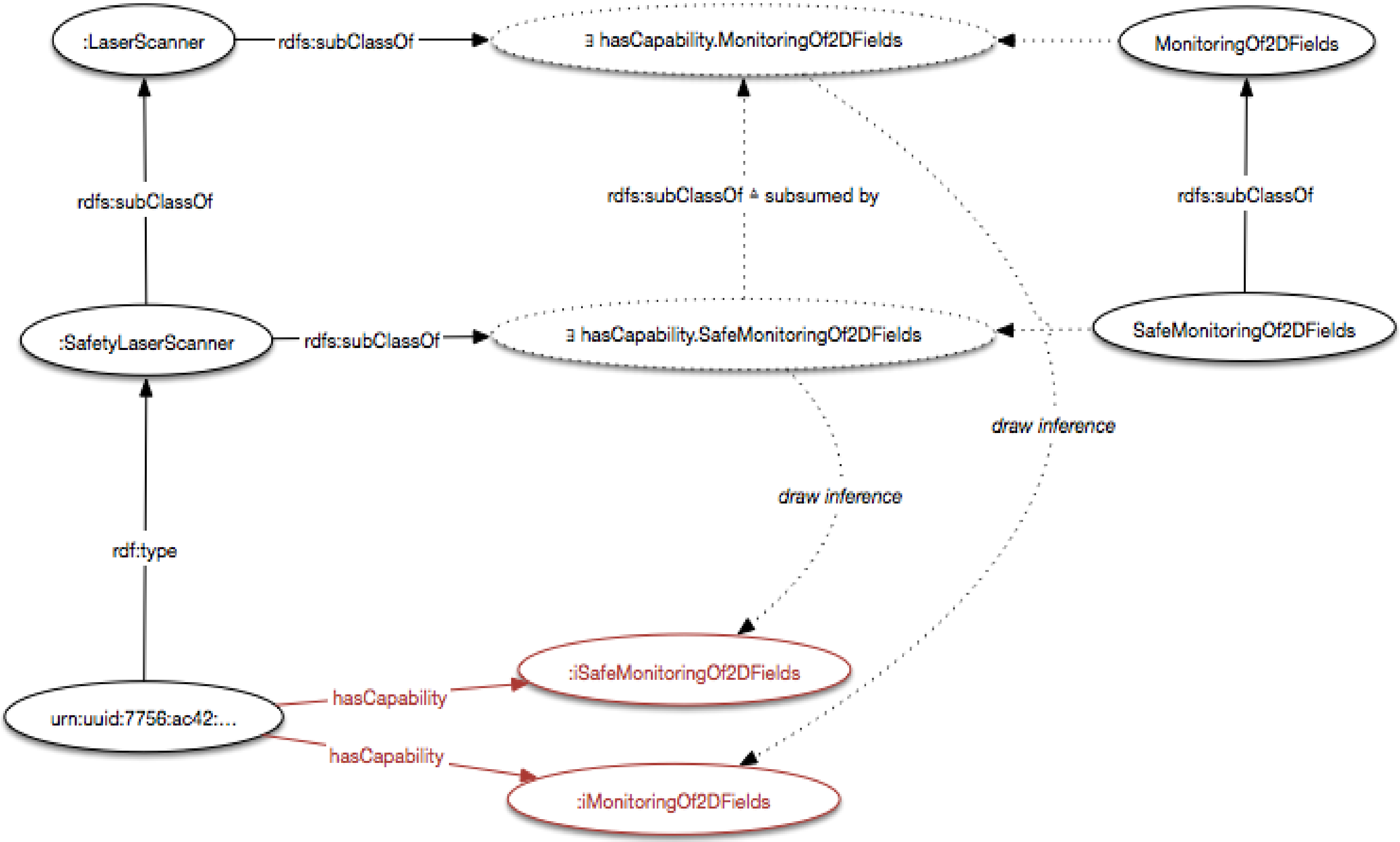
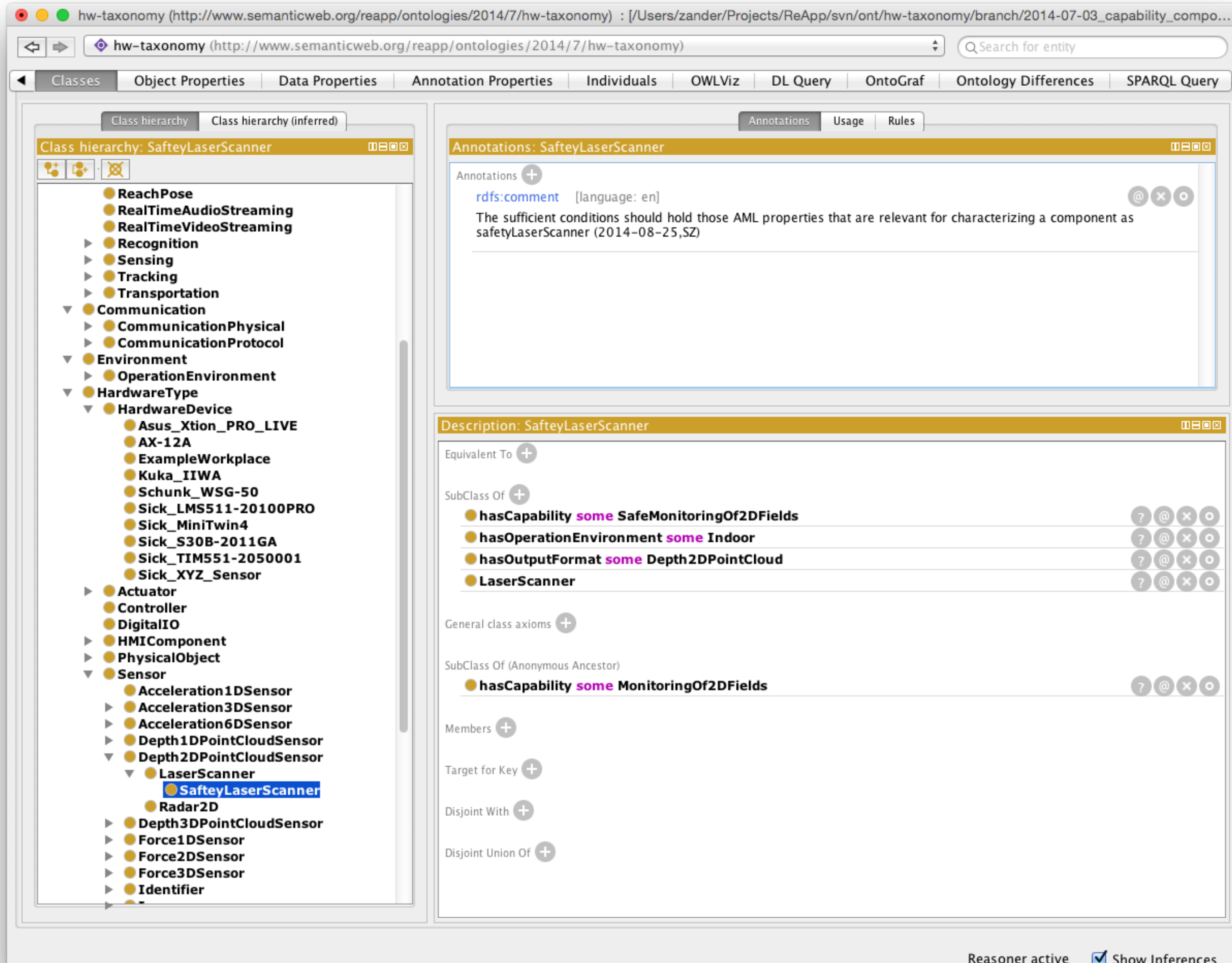
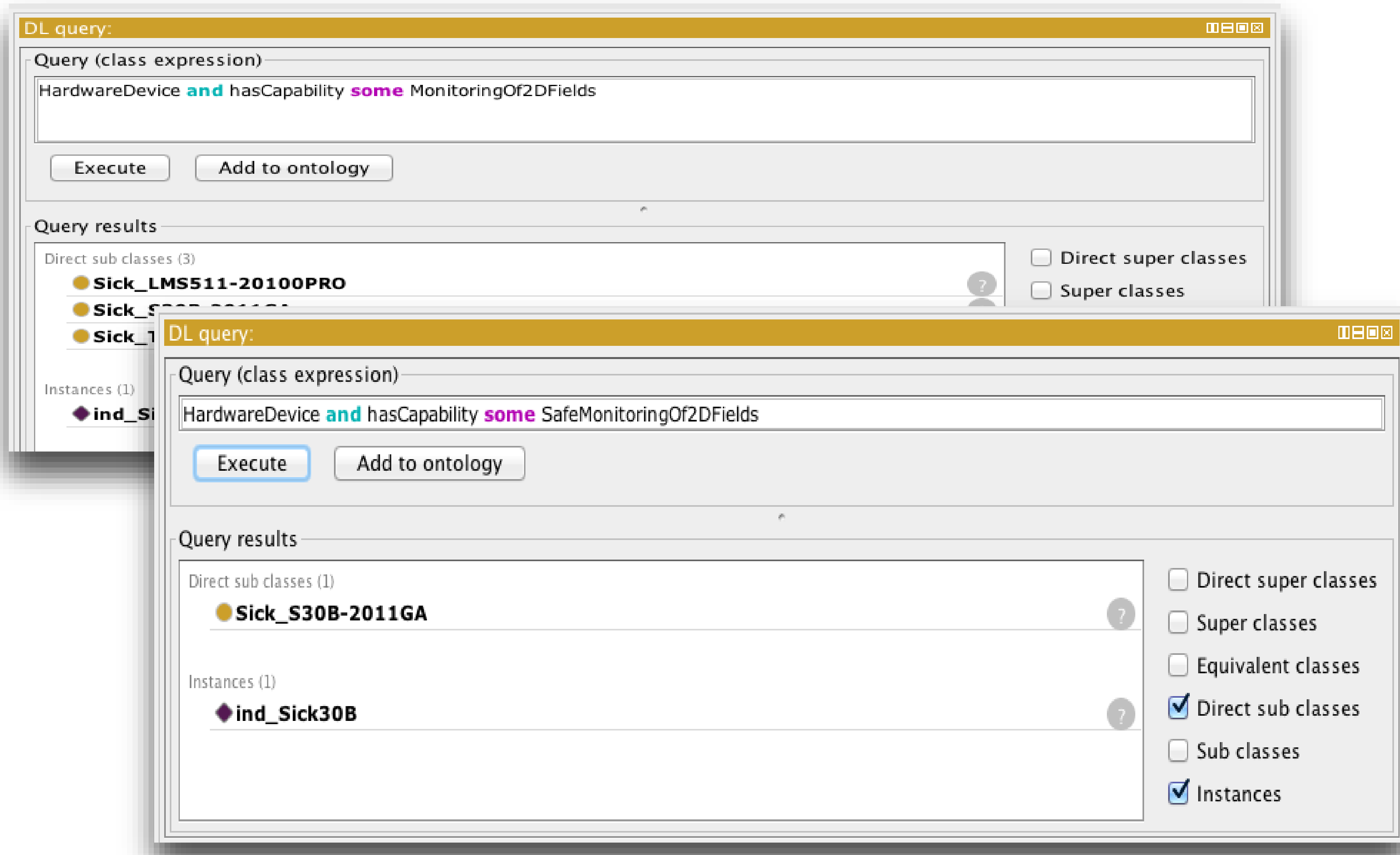
Feature Materializing for Components



Encoding of Capability Axioms



Query for Capability Information



Computing Complex Capabilities

Computing Complex Capabilities

Problem:

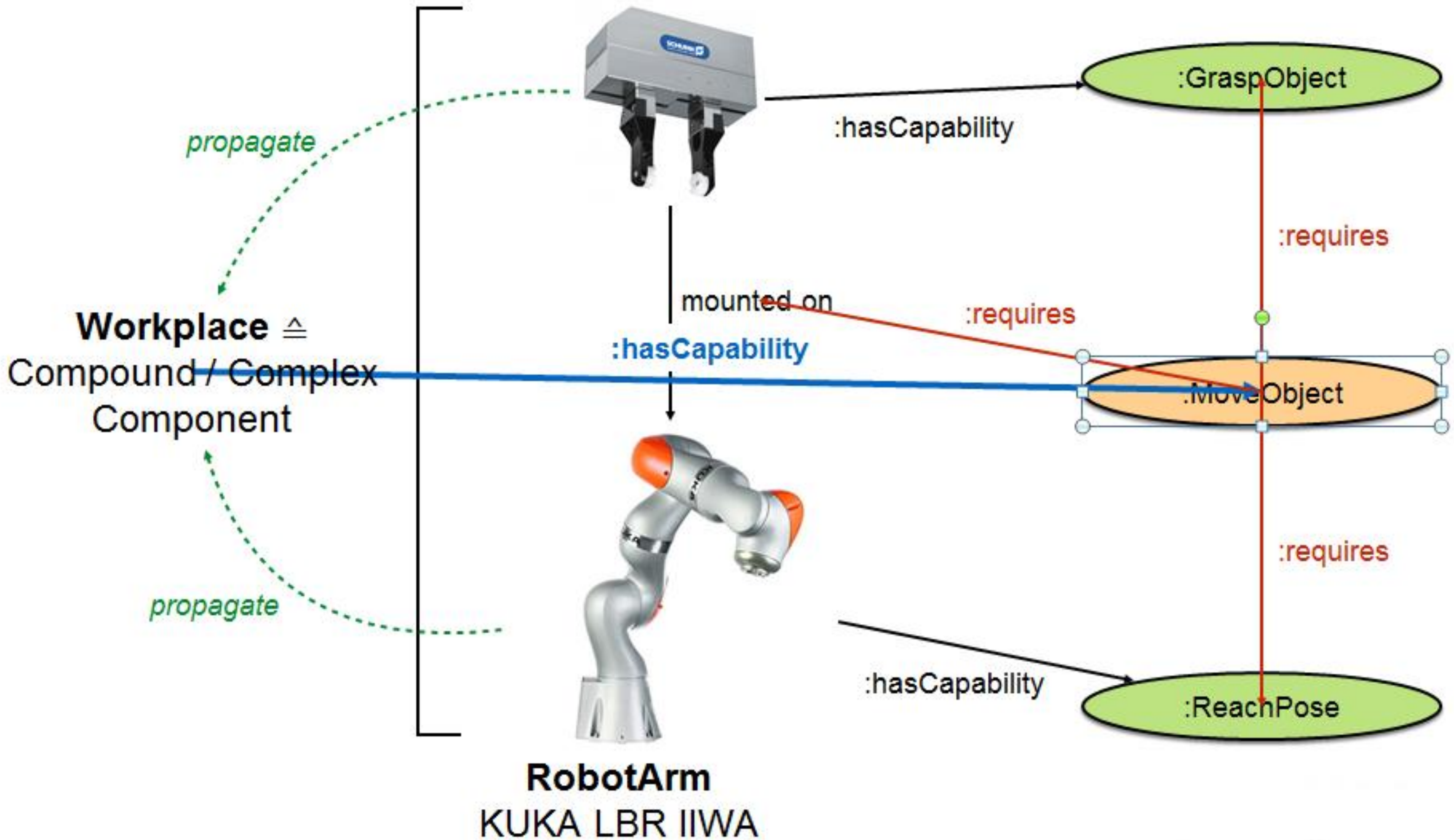
- Computing the capabilities of **compound components**
  - e.g., find out what are the capabilities of a component that consists of other components (e.g., robot arm and gripper)?

Solution:

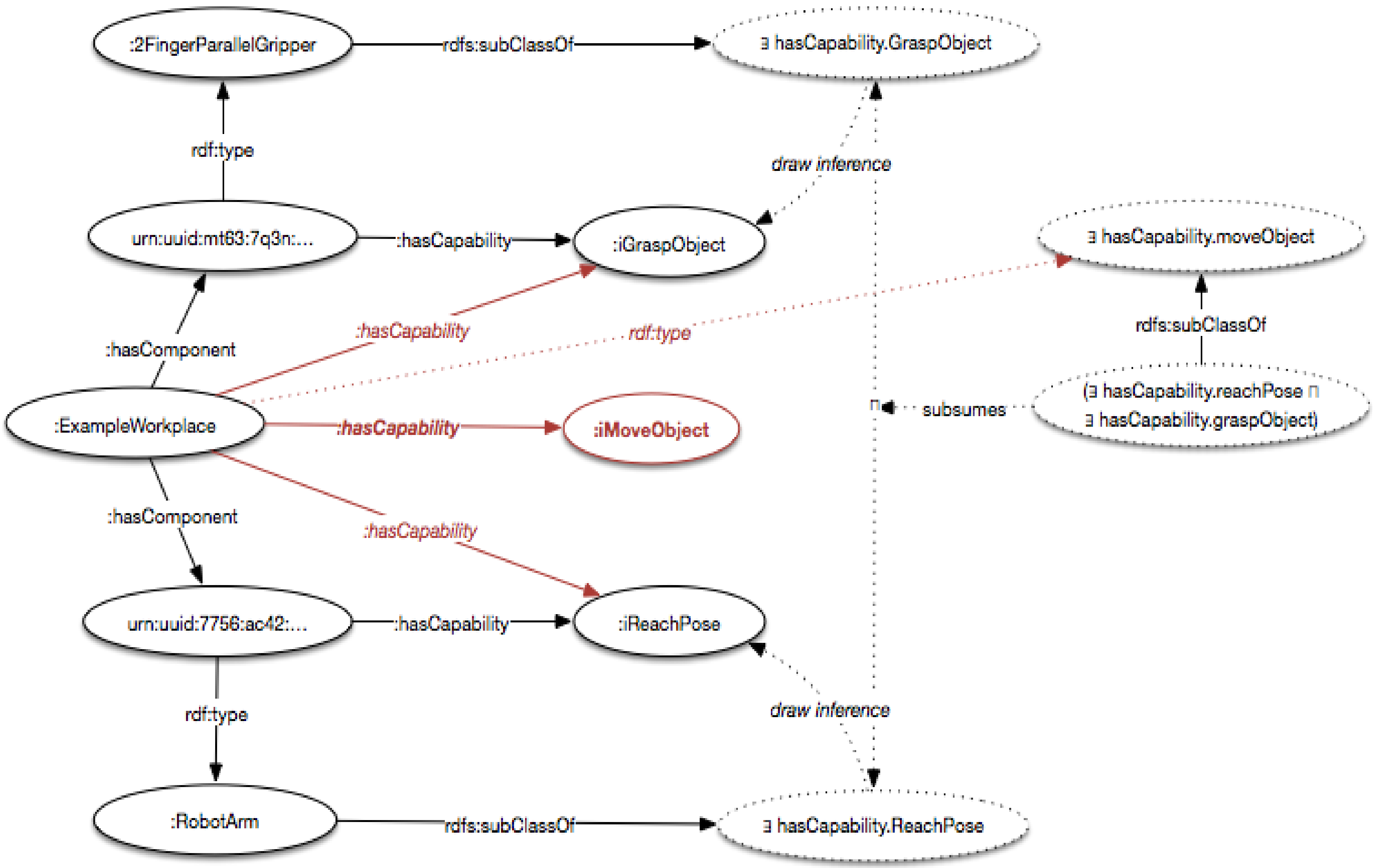
- Capability propagation via **property chain axioms** and **general class inclusion axioms**
  - e.g., $\exists$hasCapability.MoveObject $\sqsupseteq$ $\exists$hasCapability.ReachPose $\sqcap$ $\exists$hasCapability.GraspObject

Capability Propagation – Example

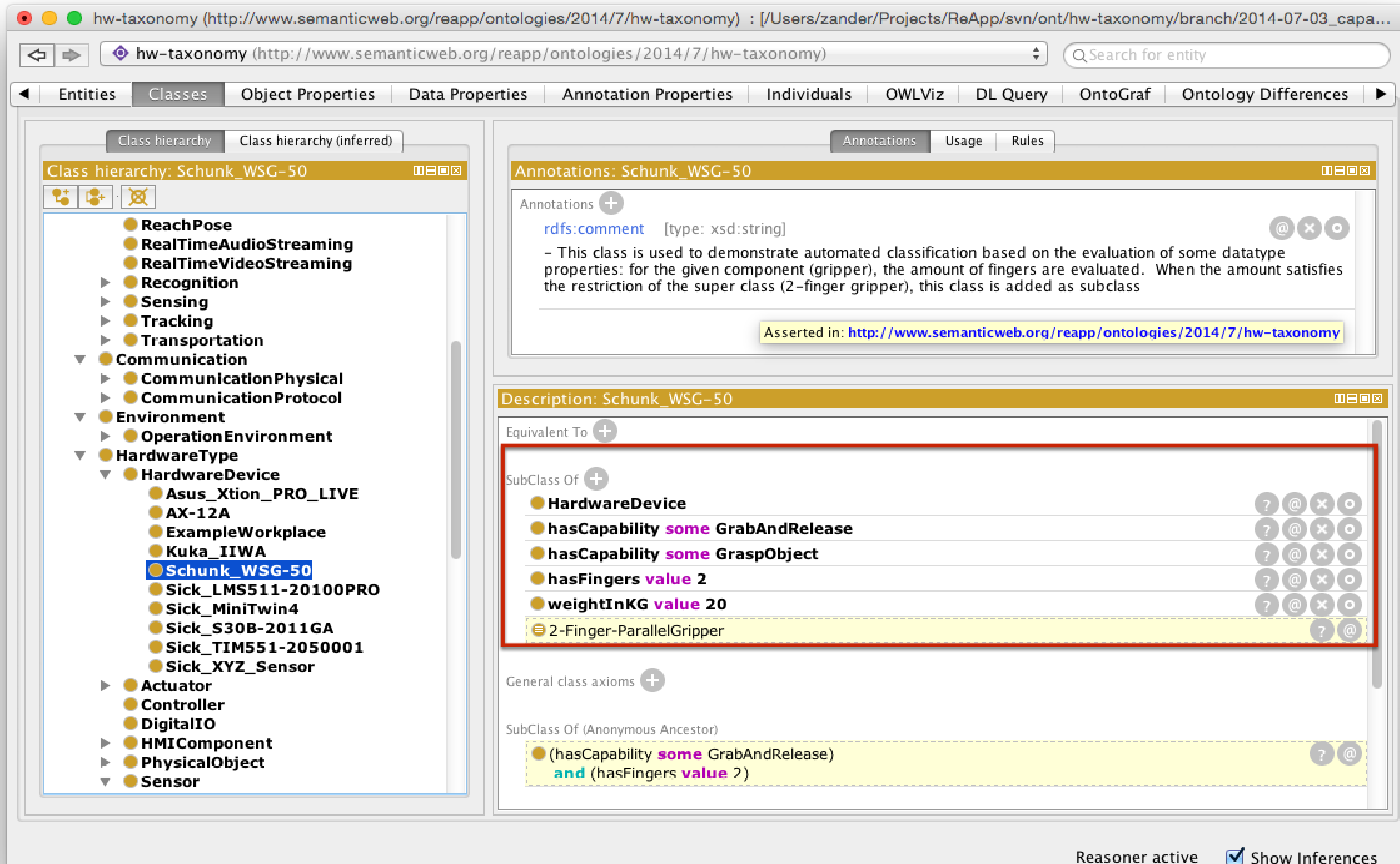
2-Finger Parallel Gripper
Schunk WSG 50



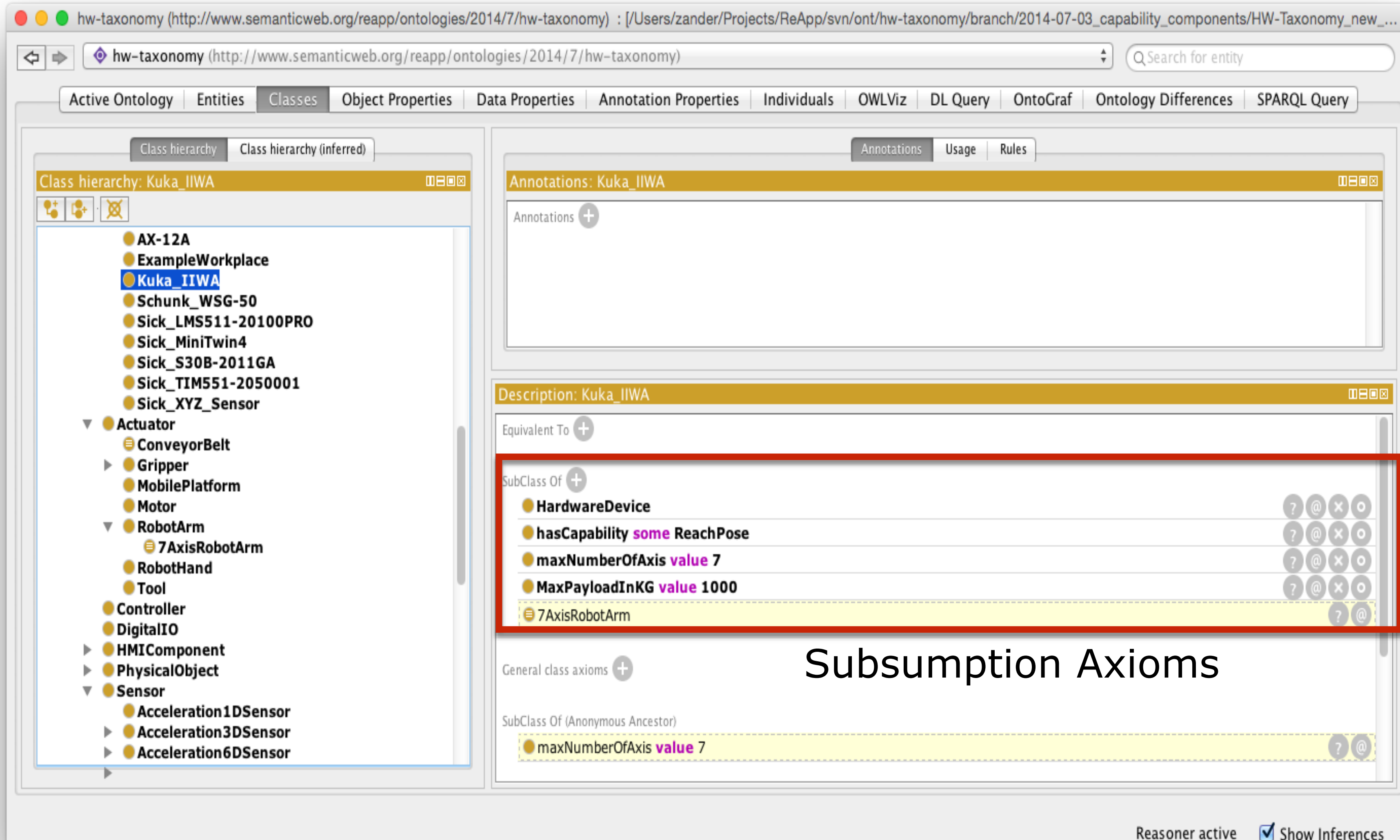
Computing Complex Capabilities



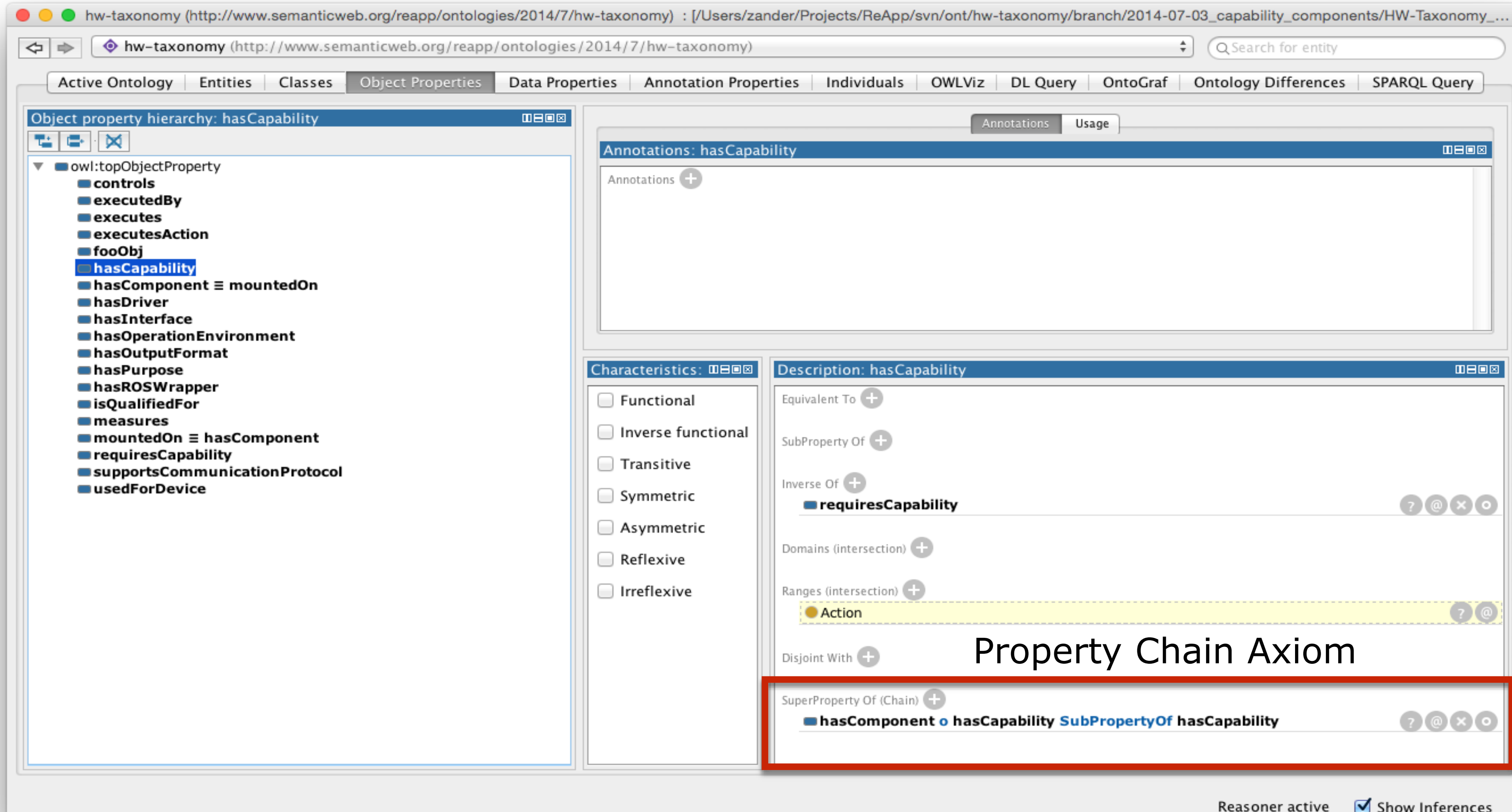
Computing Complex Capabilities in Protégé



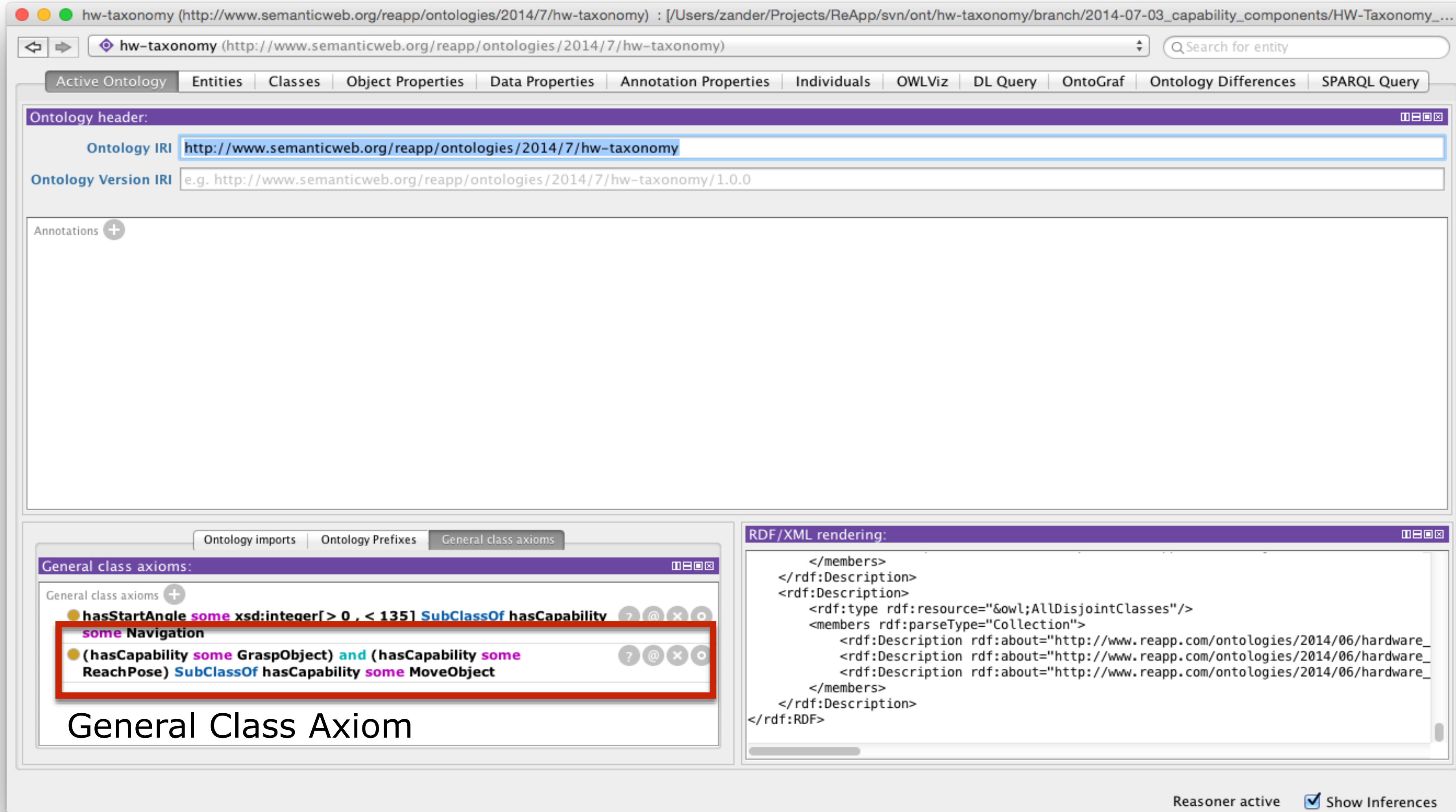
Computing Complex Capabilities in Protégé



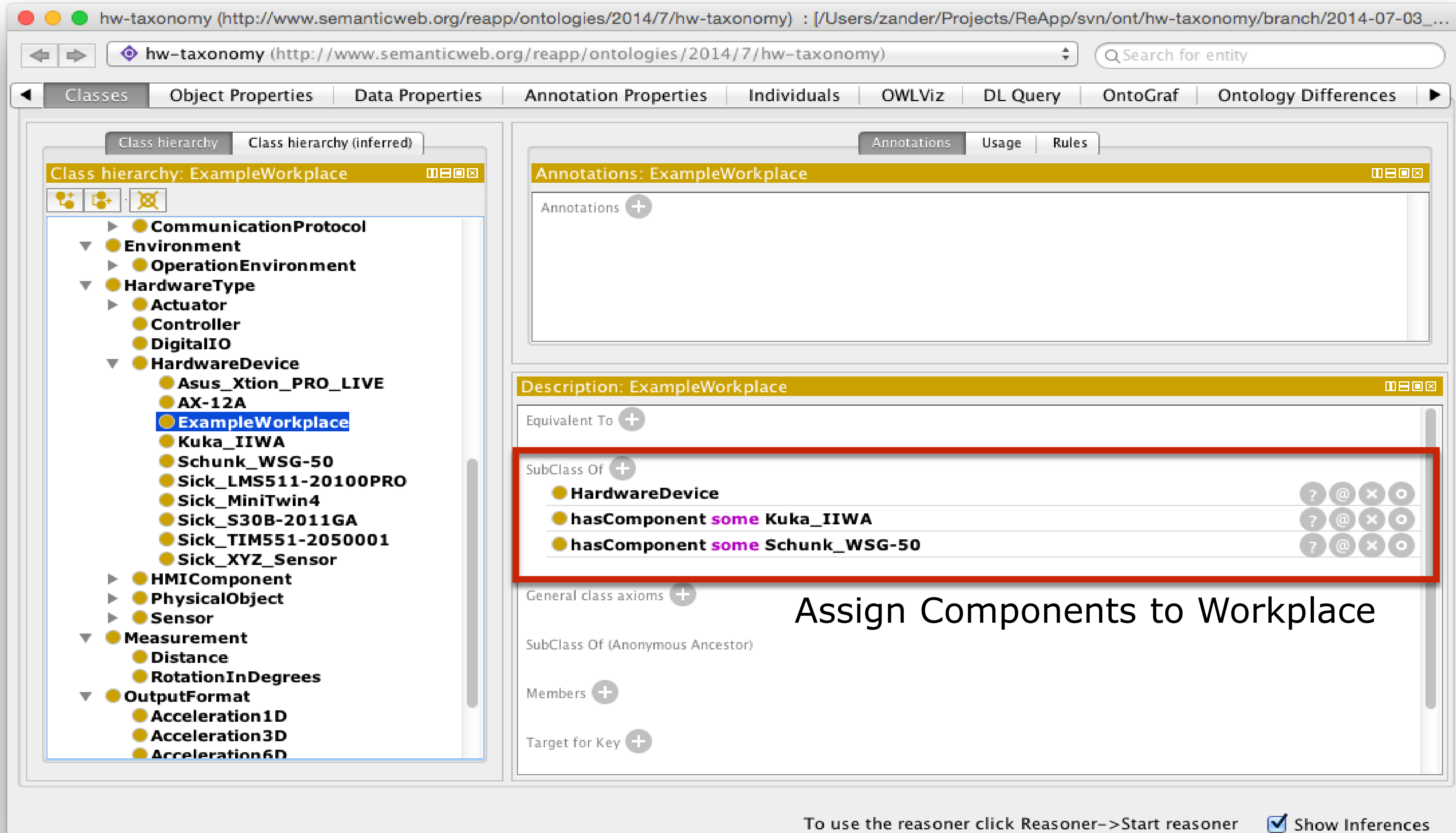
Computing Complex Capabilities in Protégé



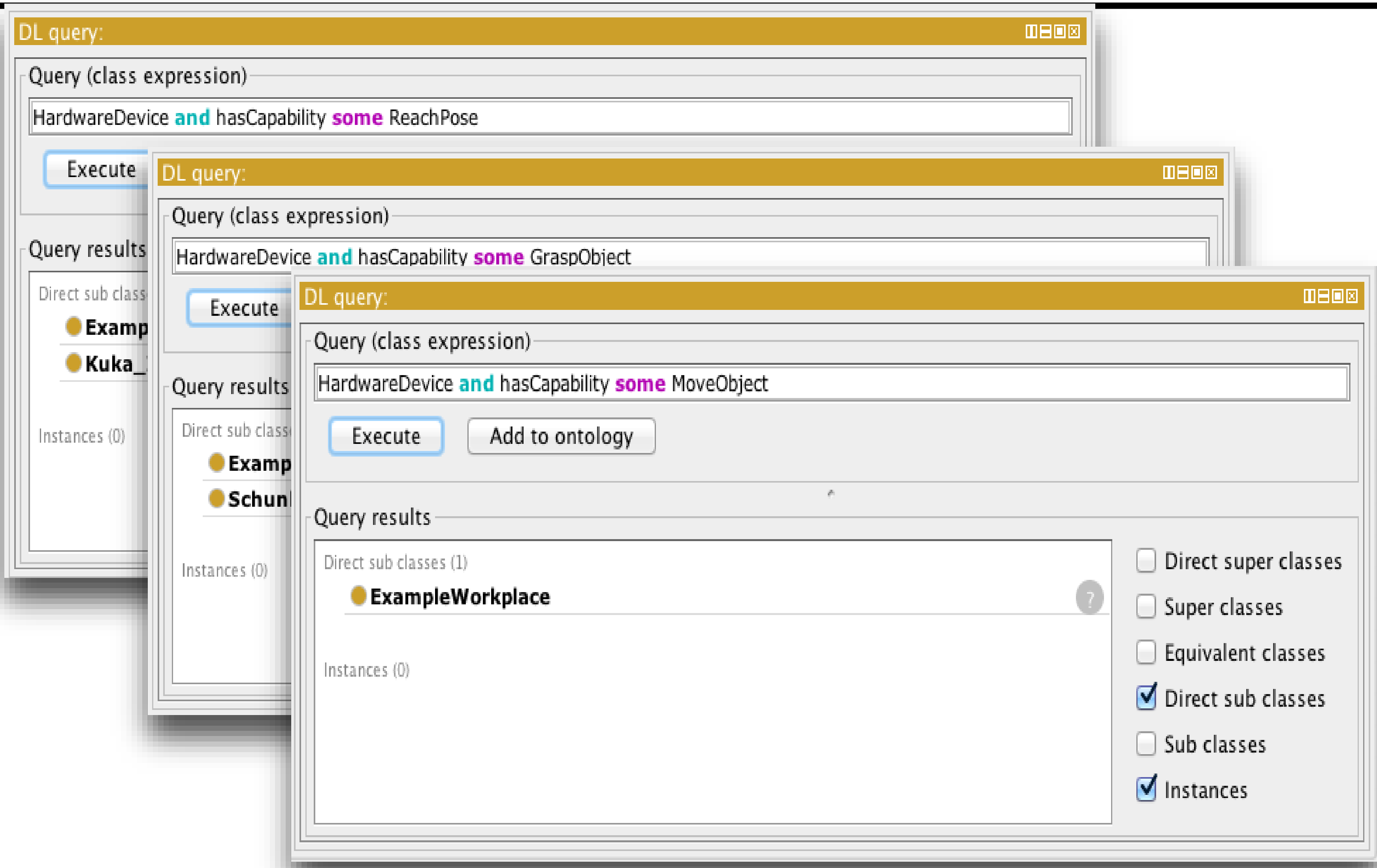
Computing Complex Capabilities in Protégé



Computing Complex Capabilities in Protégé



Querying Complex Capabilities



Conclusion

Summary

- Relation of features to components via subsumption axioms
- Feature propagation via role composition axioms
- Computation of complex features via a combination of
  - Role composition axioms
  - General class inclusion axioms

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Thank you for your Attention!

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