Research and Innovation Actions

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Open Robot Knowledge Service Infrastructure

Acronym: oRoKSI

#	Abbr.	Name	Country
1	UniHB	University of Bremen (coordinator)	DE
2	VUA	VU University Amsterdam	NL
3	HW	Heriot Watt University	GB
4	CycEur	Cycorp Europe	SLO
5	DLR	Deutsches Zentrum für Luft- und Raumfahrttechnik	DE
6	ALD	Aldebaran	F
7	NEUSTA	Team Neusta	DE

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OROKSI—
Open Robot Knowledge Service Infrastructure

What will the project achieve? The aim of OROKSI is the provision of a industrial-strength software infrastructure for ***knowledge-enabled robot control***. In knowledge-enabled robot control a robot control system can decide on the course of action or the parameterization of actions by querying a question answering system that is based on a comprehensive body of formally represented knowledge and inference methods that reason from this knowledge. In knowledge-enabled programming a programmer can state to parameterize an action to maximize the probability of success and the information about which parameterizations and their expected performance under different conditions as knowledge which can be queried and reasoned about at execution time. Making the knowledge, which is so far typically implicitly encoded in control programs, explicit, separating it from control, and providing is as a cloud service has a number of important advantages. Robot control applications can be programmed much more compactly, knowledge bases can be (at least partly) shared across different applications and domains, knowledge facilitates cognitive capabilities including reasoning, planning, and descision making, and it can turn robotic agents into agents that "know what they are doing". As Gill Pratt put it: **"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."**

OROKSI will be an open, community-supported knowledge service for robots: it will allow for access by both robots and humans and can be run as a cloud as well as a secure and private knowledge service. Key research challenges will be the anchoring of knowledge in the perception and actuation mechanisms of robots, real-time and embodied knowledge processing, the breadth and depth of the naive-physics and common-sense knowledge and the standardization of a knowledge interchange format for robotics applications. The knowledge that will be provided by OROKSI includes knowledge about robots, objects, tasks, environments, as well as experience and naive physics knowledge needed to perform advanced manipulation tasks.

Background to the project. The mastery of complex robot tasks in open, evolving applications or even across different applications will require the robots to exhibit a level of robustness, flexibility, and performance, which can only be reached by leveraging lots of knowledge. This knowledge includes knowledge about robots, their capabilities, the objects they manipulate, the environments they are to operate in, the tasks they are to perform and the contexts the tasks are to be performed in. Achieving the mastery requires us to equip robots with comprehensive knowledge and reasoning capabilities. Implementing these reasoning capabilities is a difficult and tedious programming task that requires proficiency in Artificial Intelligence (AI) reasoning and AI programming languages. For teams without a background in AI, the barriers for equipping their robots with "intelligent" problem-solving capabilities are often high. The potential and power of knowledge-enabled robot programming and knowledge services will be demonstrated as three reference applications in three different market fields: service and domestic robot scenario, factory scenario, and asset management in oilfields through underwater robots.

The provision of knowledge services that enable robot system developers and integrators to realize "intelligent" robot manipulation capabilities without requiring deep AI expertise will be an essential European public infrastructure. This infrastructure will not only facilitate the development of low-cost, knowledge-intensive robot applications in the consumer and commercial service market through cloud services possible but also enables companies to install their own secure and private knowledge servers that provide factory robots with knowledge about production processes and supply chains without access from the outside.

Expected results, lead users, and exploitation and dissemination plan. The main result will be a cloud-based knowledge service for crowdsourcing robot knowledge that will collect knowledge and provide it to robots. There will be three types of lead users. Firstly, hard- and software developers of autonomous robots will use OROKSI in order to substantially reduce their programming effort in order to implement complex robot tasks. Secondly, knowledge system developers will complement the OROKSI knowledge base with robot experience and naive physics knowledge that is needed for robot perception and manipulation capabilities. Thirdly, institutions that use autonomous robots that are interested in exploiting robot and application knowledge without giving sensitive data and knowledge to others. The project results will be disseminated to robot manufacturers, software developers, system integrators, researchers in robotics, students and teachers of robotics courses, and the general public.

Partners. The consortium is composed of leading partners in the fields of AI-based robotics, deployment of robotic agents, knowledge systems, semantic web and large-scale reasoning, web-based applications, and cloud-based computation.

B.1 Excellence

After investing more than a billion USD in AI-enabled robotics, RAS-TEC, a large high tech company, enters the robotics market with a new generation of autonomous manipulation robots for domestic, service, logistics and factory markets. This new generation of robots is characterized by superior sensing and action capabilities as well as their price, which is comparatively cheap because most of the intelligence and computationally hard tasks are performed offboard in the cloud.

The RAS-TEC robots have intensive data logging, compression, abstraction, and learning already deeply build into their operating systems. Because the robots are greedy brute force learning machines they use the huge amounts of experience data that they collectively acquire in order to learn flexible, robust, and efficient control routines for a large number of common subtasks in robot manipulation activities. The availability of these repertoires of learned routines makes the programming job of applying robots to new applications much easier and drastically reduces the amount of programming needed to deploy the robots.

As additional services RAS-TEC provides free analyses and suggestions for the adjustments to the hardware setup in order to optimize the robots for the application based on captured experience data. RAS-TEC also offers to retrain their low-level routines with these experience data in order to further increase the performance of the deployed robots. Finally, RAS-TEC monitors the robots continuously to detect which parts become worn out or which software components need to be adjusted and suggests targeted hardware upgrades.

RAS-TEC ensures the confidentialty of the logged data and gives the robot owners exclusive access to the data of their own robots and the applications they realize with them. Yet by logging the service calls of the deployed robots to the cloud services, RAS-TEC can learn in an unprecedented breadth and depth about robots, their capabilities, their tasks, the algorithms they use, the environments they operate in, and other aspects of robot tasks and operation.

RAS-TEC can learn this knowledge because the routines that they provide as the application programming interfaces do not only execute the service calls but they also log the program calls and semantically annotate the data structures that are the parameters of these calls and the results of the manipulation actions. For example, by instrumenting the service calls to their perception service and annotating them with the success and failure event of the subsequent manipulation task RAS-TEC collects training examples for tailoring the robot perception methods to the needs of the manipulation tasks. RAS-TEC learns the specific patterns of requests to the cloud service that different types of applications generate and can recognize applications based on the requests they send. RAS-TEC can also learn about the challenges that different applications pose on autonomous robots by learning failure predictors for robot tasks. It learns expected requirements of application types on robot capabilities. RAS-TEC can even learn the differences in behavior that differentiate between robots that can meet the challenges in application domains and ones that cannot.

Thus RAS-TEC has found a way to turn the best robot programmers world-wide into teachers for their systems. Whenever programmers think of clever algorithms that enable the robots of the company to accomplish novel complex tasks, the company can use the service call patterns that these programs generate as training examples to learn shallow mappings from input parameters to control output that mimick the behaviors of these algorithms.

The exclusive access that RAS-TEC has to these knowledge bases that are learned across all deployed robots gives it an immense commercial advantage over their competitors in the market.

Concerns have been raised many times about RAS-TEC's intentions of solidifying their market position by purposefully underselling their robotic platforms and obtaining ever-more data to widen the gap to potential competitors. However, at the end of the day, everyone keeps using their services. There are just too few alternatives.

Because of the sheer coverage and depth of the knowledge bases about robots and their applications that RAS-TEC can build up by turning deployed robots programmed by others as teachers for their own knowledge bases, it is extremely hard for potent competitors and even more so for SMEs to find segments in which they have an edge. The advantage is achieved by RAS-TEC's position as a manufacturer of a mass product of broadly applicable autonomous mobile manipulation platforms, the way they collect and exploit the data of these robots generate to improve their performance, and RAS-TEC's ability to transform huge amounts of data into knowledge.

Whether or not RAS-TEC's approach works for unconventional areas where less data is available is unknown. Generalizability is not considered an issue given the sheer amount of training data they can make available. Still, the SME's struggle to turn this weakness into an advantage and most do not attempt it. Without a common basis and infrastructure, the development of autonomous robots is too resource-intensive and most of their capital would be gone before even getting to the starting line.

Fortunately, the EC has already started in 2016 the project* OROKSI *as a research and innovation action that was to conduct open, forward-looking research into knowledge-enabled robot programming using knowledge services in the cloud. In OROKSI, a group of European researchers recognized the necessity for an advanced knowledge service in order to realize commercially viable autonomous robotics and the enormous advantages this would bring. Simultaneously they also pushed for the vision that such a powerful knowledge service should not only be in the hand of individual companies but rather there will be ***alternative robot knowledge***

services provided by an open community, in which robot users can decide themselves if and which parts of their data they want to contribute for building up such knowledge bases, where everybody has access to the knowledge in these services, and where also the software that learns from and reasons about this knowledge is opensource.

Building the foundations to support such a community and services, OROKSI enhances collaboration, standardization and generalization to various applications, and functions as a catalyst for European companies to enter the robotics market. The knowledge and software eco system initiated by the OROKSI project enables them to reduce the programming efforts in order to establish themselves in the disruptive robot market as they can concentrate on their own strengths and fall back to good-enough community solutions for the remaining components of their systems. Moreover, the OROKSI community enables robot developers and deployers to use the knowledge contained in the knowledge service without their own applications being automatically logged. The users can themselves decide what part of their log data and knowledge they want to give back to the community and share with others for the sake of everybody. **OROKSI** ***achieves a huge impact on the European and world-wide robotics market as it has laid the technological foundations for a powerful technology platform that enables SMEs and specialized robotics companies to cooperate supported by a community such as ROS or PCL, to take advantage of the collaboratively acquired knowledge bases, and keep their sensitive data under their own control.*** The OROKSI consortium believes that such community-based efforts are urgently needed as wealthy companies such as Google, Toyota, and IBM, are entering the market and invest more money individually than the combined research volume of the public funding sources world-wide. It is of key importance that smaller stakeholders in the robotics market and field, commercial as well as academic, have the possibilities to cooperate in order to compete with the highly potent competitors.

OROKSI overall vision:

- ***what:*** We propose the design and development of OROKSI (Open Robot Knowledge Service Infrastructure) as an open cloud platform that provides robot programmers with software tools and knowledge bases needed to specify flexible and robust high-performance robot control programs by making the programs knowledge-enabled.
- ***why:*** There are two main reasons why we consider the OROKSI project to be timely and necessary:
  - ***technological:*** OROKSI is in an excellent position to achieve a big step change in the generation and provision of generalizeable robot knowledge, which is considered a key accelerator for robot technology reference:Pratt.
  - ***strategical:*** for the research in the robotics field and its commercial development, it is essential that stakeholders have unrestricted access to existing robot knowledge and to methods for generating and processing such knowledge.
- ***how:***
  1. we start with OPENEASE, a laboratory prototype of an ***open knowledge service for robotics***, and develop it into an industrial strength open source knowledge service to be used and further developed by the opensource community
  2. we build ***ready-to-use generalizeable knowledge bases*** about robots, tasks, environments, and objects and make them available for the community through OPENEASE.
  3. we build ***reference applications*** including knowledge bases and simulation environments such that potential users can download with minimal effort a knowledge-enabled robot application and run it in simulation and experiment with it by modifying the source code and playing around with it.
- ***why us:*** the consortium combines:
  - the expertise in robot knowledge representation and processing including leading-edge technology plus a track record in making technology available as opensource and open knowledge.
  - the expertise in knowledge representation and processing, turning big data on the Web into formal representations, developing large scale high performance knowledge processing infrastructures (LARKC), and standardizing knowledge exchange formats (OWL)
  - the expertise of creating the world's largest, well-designed commonsense and general knowledge base (Cyc) and leveraging such knowledge bases for commercial use
  - pioneers in transferring knowledge-based AI technology into robot applications in three market segments: underwater robotics, factory automation, and domestic/service robotics.

B.1.1 Objectives

1. ***Robot Knowledge Services*** OROKSI will realize and deploy a pilot installation of the OROKSI software and knowledge platform and eco system software infrastructure as a knowledge service for robotics applications open to the community. The software will be opensource and include a extendible components for
   - the acquisition, management, and maintenance of robot knowledge bases
   - graphical programmer interfaces

   The knowledge service is to answer queries sent by robots or signal a failure if it is not able to answer the respective query. To this end, OROKSI provides a logic-based language in which the queries can be stated. The service also provides software tools to manage, maintain, and extend the knowledge bases and collect experience knowledge from robots. The knowledge service is an extension of the open-source ROS software library and can be used by robot control programs written in C++, Java, and LISP. The knowledge service will be available as a cloud service, an easy-to-install package on a Linux virtual machine (based on Docker) as well as in open source.

   OROKSI will design and implement a special purpose protocol and exchange language to support the interaction between robots and services.

   The cloud service will be able to serve at least 40 users (robots and programmers) simultaneously. We will validate the service in long-term experiments where robots have to perform everyday tasks in human environments.
2. ***Knowledge-enabled robot programming*** Off-the-shelf software infrastructure for robot control systems that enables robotic agents to use the OROKSI knowledge service and links the knowledge processing to the perception and manipulation sub-system of the robot. The software infrastructure, which can be added to robot control programs, consists of a query interface that enables robots to query the knowledge service and use the answers of these queries as local program parameters in the Robot Control Program. The infrastructure can be used together with the open-source perception framework ROBOSHERLOCK that enables the robots to ask queries about objects it sees and with CRAM (Cognitive Robot Abstract Machine) that enables robots to automatically perform action descriptions inferred by the knowledge service. In addition, using CRAM the robot can automatically record its activities, which enables the robot to effectively and efficiently learn about its capabalities, tasks, and environment. This will allow the robot to ask queries about what it did, why, how, what it saw when it carried out the activity, and translate the experiences into reusable knowledge.
   - implementation using the open source software tools ROBOSHERLOCK (for perception), CRAM (for plan-based control), and KNOWROB (for knowledge representation and processing)
   - blueprint for what needs to be done for other control frameworks to use the OROKSI services
3. ***Robot knowledge bases*** A repository of knowledge bases that can be used as resources and blueprints for building application-specific knowledge bases. The repository of knowledge bases include
   - *reference knowledge bases* for at least one underwater robot application (inspection of oilfield and/or underwater environment monitoring), for at least one factory application (lifelong assembly of factory logistics with fetch and place tasks), and at least one domestic/service application (table setting and cleaning up and/or meal preparation);
   - *core knowledge bases* for *robots* (including at least a submarine robot, a drone, an outdoor rover, a telepresence robot, a factory work cell, a humanoid robot, a teaching platform), *robot actions* (fetch, place, pour, screw, inspect, etc), *environments* (objects, kitchen, factory, outdoor), *ontologies combined with common sense and naive physics knowledge bases*, *semantic background knowledge bases* (WikiHow, Wikipedia, Google 3D warehouse, geo information systems, etc).

     core knowledge bases for robots, tasks, environments, and domains contain the upper onotologies and general background knowledge including naive physics and commonsense knowledge for the respective category of applications.
   - *big data databases of experience data that are uploaded by robots* and can be used for data and knowledge mining
   - *user contributed knowledge bases*

   OROKSI will make a ***proposal for the standardization of an exchange format for robot knowledge.*** The protocol will be based on open Web standards. Efforts will be taken to have the protocol standardized by the World Wide Web Consortium (W3C).
4. ***Lead application scenarios*** Three reference implementations of robot applications realized with OROKSI. These reference implementations include real world demonstrations and experience logs, a simulation environment for the application, a plan-based control system that works with OROKSI, and knowledge bases that can be worked with in OPENEASE. Each reference application can be run either in the cloud or easily downloaded and installed on a Linux virtual machine such as Docker.

   The reference applications are selected such that they are exemplary for important robot application domains.

The first one, led by partner HW will be underwater robotics for oilfield maintenance or automated environment studies. This one will be typical for outdoor applications that require knowledge from geo information systems and perform exploration and surveillance tasks. The second one targets at factory automation. Here we want to showcase semantic programming of assembly tasks (fasten the bolt, connect the parts with two bolts) and intelligent interfaces to an assembly processes. The last one is a domestic environment that might include a simple meal preparation and cleaning task ans some fetch and place functionality in a domestic environment.

5. ***Open research, open knowledge, open source*** A software tool and information infrastructure for the promotion of open research, open knowledge, open source in knowledge-enabled robotics and robotics in general. ORoKSI will provide
   - an ***eLearning tool in AI-based robotics***. The course "Intelligent Autonomous Systems" at the University of Bremen will use OPENEASE for getting an online learning experience that enables the students to ground learned concepts with real robot data.
   - a ***repository for reprodicble experimental data***, in which researchers can upload the experimental data when submitting research articles for publication.
   - an ***infrastructure for open robotics research*** in which researchers can share data and knowledge bases for common research activities.
   - ***tools for creating benchmark problems*** and evaluation software for specified research topics and challenges.
   - a ***tool for grounding and assessing the assumptions and results of inference mechanisms in real robot data.***

Objective	***Work plan***	***Deliverables***
Robot knowledge services	WP1: Robot knowledge services	
Robot knowledge bases	WP2: curated deep knowledge WP3: high-volume shallow knowledge WP4: robot knowledge	
Knowledge-enabled robot programming	WP5: Knowledge-enabled robot programming	
lead application scenarios	WP6: Lead application scenarios	

B.1.2 Relation to the Work Programme

The OROKSI proposal addresses the topic ICT-25-2016-2017 "Advanced robot capabilities research and take-up".
Addressing specific challenges of call ICT-25-2016-2017

The specific challenges of the call are:	Our project OROKSI will address them by ...
"The specific challenge here is to develop robots that respond more flexibly, robustly and efficiently to the everyday needs of workers and citizens in professional or domestic environments,"	***... achieving a step change in the representation of generalizable knowledge and the reasoning from these representations.*** The availability of a large body of knowledge that can be translated into informed decision making and low-level control will facilitate the flexibility, robustness, and efficiency of control systems. • ***Flexibility*** will be increased by separating *what* has to be done from *how* it is done. Using the knowledge the control system can reason about how to achieve *what* depending on the *context* and even *adapt* to opportunities and risks by reasoning from knowledge. • ***Robustness*** can be increased by forestalling failures by predicting them and reasoning about their consequences. For example, by knowing that eggs can easily break and that breakable items must not be squeezed beyond their limits, the robot can adjust the grasp force appropriately. Knowledge will also facilitate knowledge-based diagnosis and thereby improve the the prospects of failure recovery. • ***Efficiency*** can be improved through the appication of knowledge-enabled planning and the understanding and exploitation of opportunities. The knowledge provided by OROKSI includes knowledge about the workers, citizens, and environments, which allows the robots to act in a better informed way.
"... and which will also maintain Europe at the forefront of global research and development."	***... leveraging the leading-edge cloud-based robot knowledge service technology developed by the FP7 projects* ROBOEARTH *and* ROBOHOW *and combine it for the first time with the most advanced semantic web and web-scale reasoning technology.*** Europe has been at the at the forefront of research in cognitive and cloud-based robotics for a number of years. This is among others acknowledged by Jim Kuffner (former leader of the Google Robotics division and now area lead for cloud computing in the Toyota Research Institute) in his invited talk for the 50 year celebration of Shakey entitled "Imagining a cloud-enabled Shakey": *"... imagine we could unify all this information in a representation usable by robots. The* **RoboEarth** *(PI: Beetz) and* **RoboHow** *(coordinator: Beetz) projects are helping to build some infrastructure for that."* These two were the only external research projects mentioned in the talk. OROKSI is building and capitalizing on the results of these projects and for the first time bringing in some of the most established researchers in the areas of knowledge representation, large scale reasoning, and semantic web. van Harmelen has played a leading role in the development of the Semantic Web, which aims to make data on the web semantically interpretable by machines through formal representations. He had a leading role in the definition of the Web Ontology Language OWL. OWL has become a worldwide standard, it is in wide commercial use, and has become the basis for an entire research community. He was an architect of Sesame, an RDF storage and retrieval engine, which is in wide academic and industrial use with over 200,000 downloads. OROKSI has put together a unique combination of expertise that can be expected to achieve a major step change for generalizable knowledge and reasoning for robotic agents.
"The actions will address the whole research value chain, whether generic technology, developing RAS building blocks in the form of key technical capabilities, or market-led prototypes directly involving end users."	***... making substantial contributions to each step in the value chain of knowledge-enabled robot programming and knowledge services***, which is discussed in more detail in Section B.1.3.4. In particular, OROKSI will develop encyclopedic and commonsense knowledge bases that provide the background knowledge that is essential across robotic markets and tasks. OROKSI will also collect large volume shallow knowledge including robot experience and domain data, such as the products of webstores, the CAD models of furniture companies, etc., and methods for collecting such knowledge. OROKSI will develop the infrastructure needed for embodying knowledge-enabled robot programs into robotic agents and demonstrate the superiority of knowledge-enabled robot applications.

"End users will help drive Innovation Actions as active partners, setting the operating parameters for a given application as well as testing and validating the prototype solutions."	***. . . having programmers of the next generation of intelligent robots in different application domains and with their applications in the consortium.*** For OROKSI the end users are the programmers of intelligent robot applications. We have representatives of three important categories of robot programmers: • programmers of robot manufacturers that produce humanoid service and domestic robot for the mass market: Aldebaran with their Pepper robot. The Pepper robot is currently the most widely sold humanoid service and domestic robot. • programmers for leading edge robot factory automation applications including robot co-worker scenarios: DLR Robotics and Mechatronics. DLR designs, develops, and analyzes use cases for novel robot application areas in the large-scale EU projects SME-robotics and EUROC and a number of other projects highly relevant for OROKSI such as RobDream. DLR is also research and technology partner of big instrial companies including Kuka, Daimler, etc. • programmers of outdoor robots that are required to exhibit a very high level of longterm autonomy. In OROKSI we consider underwater robots that perform longterm asset management of oil fields in the North Sea and and the observation and exploration of underwater areas for applications in environment science. All three end user categories of end users have very high demands on the amount and quality of the formally accessible knowledge that the robots need. All three partners will realize knowledge-enabled robot applications inspired by existing applications, which will put them into an excellent position to compare the knowledge-enabled approach to robot programming to their existing solutions.

Addressing the scope of call ICT-25-2016-2017

The scope of call ICT-25-2016-2017 is:	**Our project OROKSI will**
"Open, generic forward-looking research into novel technical advances in robotics open to all robotics-related research topics and disciplines."	***substantially advance the knowledge and technology of "generalizable knowledge representation and cognition based on such representations"***, which is identified by Gil Pratt as the key enabler for the earnest and explosive development of the robotics field (see beginning of Section B.1.4). Knowledge representation and reasoning are not only topics in the strategic research agenda and the multi annual roadmap on their own but also the explicit or implicit preconditions of other system abilities including navigation, perception, and manipulation. Higher levels of manipulation ability require the robots to reason about the function and functional parts of objects, how to handle them, and the constraints that must be met when handling them (pointing sharp object parts away from people). Higher level of perception abilities will require robots to semantically interpret what they see, which will be tedious if not impossible without formal knowledge bases and powerful inference mechanisms working on them. Finally, the cognitive capability including the interpretation of tasks and environments, predicting and adapting the course of action based on foresight are intrinsically based on knowledge and reasoning. **Thus, the research topic "knowledge-enabled robot programming, knowledge representation, and reasoning" will play an essential role in the technical evolution of robotics.**

"Proposals are expected to address technical topics which cut across application domains"	***The need for knowledge representation, engineering, and reasoning is present in all application fields that require autonomous robotic agents to perform complex tasks***, in particular if some aspects of the application are open and cannot be sufficiently constrained to allow for narrow solutions. In oRoKSI we demonstrate the breadth of applicability by proving open reference applications of knowledge enabled robot programming in three market domains: • underwater robotics (outdoor, lifelong operation, geo information systems) • factory robots (lifelong assembly, semantic programming, experience-based optimization) • servics and domestic applications (need for natural tasking, need for broad background knowledge, commonsense and naive physics knowledge) In addition, oRoKSI will provide other robot knowledge bases including ones for fetch and place tasks in domestic environments, robotic agents conducting chemical experiments, robot teams in rescue scenarios, and knowledge bases for imitation learning of manipulation tasks.
"and which can be developed further with a view to achieving high future impact on markets or societal sectors in Europe."	***The potential impact that the oRoKSI technology will have can be seen I closely related technologies:*** from the emerging role of cloud robotics and the role that data and the information and knowledge that can be generated from the data be it in social media, business processes or other areas and the transfer of such technology to approaches such as Industry 4.0, but also from the quotation from Gil Pratt's article (see beginning of Section B.1.4).

Relation to the Strategic Research Agenda Knowledge representation and processing is a topic present throughout the strategic research agenda and the multi annual roadmap. It is particularly prominent in the perception, action, user interaction, and decision abilities of the robots. Whenever the abilities are characterized as being "semantic" or they require deeper interpretation of sensor data, actions and interactions there is a call for knowledge representation and processing capabilities. Thus by improving the knowledge representation and processing abilities we also indirectly improve the navigation, perception, manipulation, and interaction abilities of the robots.

Topics of the SRA:	**Our project oRoKSI will address them by**
*"**Manipulation ability** The ability of the system to handle objects. ... For dexterous manipulation it might specify the ability to discover how to hold and move unknown objects ... "*	***... raising the abstraction level at which robots can be programmed.*** The goal is to enable programmers to specify manipulation actions such as "fastening a screw". This will be realized by translating the abstract term "fastening a screw" into the corresponding numerical motion control problem.
*"**Perception Ability** The ability of the robot to perceive its environment. ... It includes the ability to interpret information and to make informed and accurate deductions about the environment based on sensory data."*	***... raising the level of understanding of visually perceived scenes.*** For example, by combining object perception with knowledge and reasoning the robot can perceive the objects it can pick up, or the ones that can break.
*"**Decisional Autonomy** The ability of the robot to act autonomously."*	***... enabling the robots to make more informed decisions***, such as handling breakable objects with more care.
*"**Cognitive Ability** The ability to interpret the task and environment such that tasks can be effectively and efficiently executed even where there exists environmental and/or task uncertainty. The ability to interpret human commands delivered in natural language or gestures. The ability to interpret the function and interrelationships between different objects in the environment and understand how to use or manipulate them. The ability to plan and execute tasks in response to high level commands. The ability to work interactively with people as if like a person"*	***... enabling the robots to interpret natural language commands*** such as "adding milk to the dough". Having the necessary knowledge the robot can infer that adding can be performed by a pouring action and that in order to to pour it has to pick up the container containing the milk, hold it above the dough and tilt it.

The OROKSI research goals are also tightly connected to the research agenda outlined in the multi-annual roadmap. Requirements for knowledge representation and processing are identified and pointed out throughout the document as all kinds of high competence abilities require reasoning from knowledge as a precondition. For example, the semantic interpretation of scenes that the robot sees (perception ability), the competence of tool and device handling (manipulation ability), navigating to places from which certain tasks can be performed (navigation ability), the making context-dependend and informed decisions (decisional autonomy). The most explicit links are: (1) system development (better systems and tools: modelling and knowledge engineering) and (2) cognition (better action and awareness: grounded knowledge representation and reasoning). They are discussed in more detail in Section B.2.1.2 on page 35.

System ability (from MAR)	OROKSI's target ability levels	Achieved by
Cognitive ability	Action: 6 Interpretive: 4 Envisioning: 2 Acquired Knowledge: 9 Reasoning: 4 Object Interaction: 5 Human Interaction: 3	OROKSI will combine different representation and reasoning frameworks, and extend these specifically for robotic systems. This is to enable robots to accomplish incompletely specified fetch tasks reliably and autonomously. In addition, the hybrid and online nature of the system facilitates the acquisition of knowledge and sharing thereof. The planned implementation of a software infrastructure that links the knowledge service to existing manipulation and perception modules addresses one of the key barriers for the wide scale deployment of cognitive abilities in robot tasks.
Perception ability	Perception: 8 (for selected domains) Object Recognition: 6 Scene Perception: 5	Perception ability is impacted through the integration of perceptual information with the reasoning and knowledge service. The OROKSI knowledge base together with the reasoning engines will enable the robot to infer properties of known objects even when these are not directly observable (perception ability level 8).
Decisional autonomy ability	Autonomy: 8	By providing comprehensive, diverse knowledge and reasoning services and an interface for integrating these into the control structure, robotic platforms based on OROKSI can expect to have a high degree of autonomy. This is complicated by our goal to deploy the system in a dynamic environment. The capability of the robot and the underlying knowledge service to support long-term autonomous operation are therefore explicitly addressed in one of the work packages.
Manipulation ability	Grasping: 8 Holding: 3 Handling: 8	OROKSI is expected to have a significant impact on cognitive and decisional autonomy ability, as outlined above. This allows for autonomous handling of unknown objects and increases the ability of robots to carry out sequences of manipulation actions. Additionally, the envisioned combination of knowledge service, control structure and open research platform are expected to make the programming of reliable manipulation sequences for (complex) objects substantially more straightforward.

B.1.3 Concept and Approach

Achieving the economic goals set out for the field of robotics and autonomous systems in the Horizon 2020 work programme requires European companies to program a large variety of robots for a large variety of tasks in a large variety of environments. The amount of programming required is expected to exceed by far the available programming capacity. Therefore the Horizon 2020 work programme sets the investigation, development, and demonstration of the necessary technical capabilities for the **"easy deployment of smart robots in everyday life"** as its main aim for the robotics and autonomous systems area. It refines the general aim into the specific challenge *"to develop robots that respond more flexibly, robustly, and efficiently to the everyday needs of workers and citizens in professional and domestic environments,"* prioritizing the transition from laboratory prototypes into market-ready technology.

B.1.3.1 Generalizing and Opening Robot Knowledge across Robots, Tasks, and Environments

The amount of programming that is required in order to build competent autonomous robots currently exceeds the programming capacity that is available in the European marketplace. The reason for this is that robots are programmed to perform very specific tasks within very specific situations. If the task or situation changes, then the robot has to be re-programmed. The big idea of /oroksi/ is to bring knowledge services to the robotics programming market in order to increase robot program reuse. By allowing significant parts of a robot program to be shared between different tasks, situations and robots, /oroksi/ is able to achieve significant reductions in the costs of robot (re-)programming.

Let us look at three real-world examples that are taken from the day-to-day robotics operations of three of the OROKSI partners:

- SOMENAME is a robotic shopping assistant that is currently employed in XXX stores in YYY countries. SOMENAME needs knowledge about the products that are sold in the store. It also needs to know the purpose of these products, whether one product can be used instead of another one, what the differences are between products, which ones are preferred by certain types of customers, for what reasons, and so on.
- SOMENAME is a submarine robot that performs asset management in oil fields in the North Sea. SOMENAME needs knowledge about the structure of oil platforms, their constituent components, possible hazards that may arise and how they can be detected and assessed. It also needs knowledge about geo objects, such as coral reefs and animals inhabit oil platforms as their habitat.
- SOMENAME is a robot that performs cooperative assembly tasks. SOMENAME needs knowledge about the objects it has to handle. It needs to know that bolts consist of a head and a thread, that if you want to fasten a nut to a bolt you have to hold the head of the bolt, that you have to align the main axis of the bolt with the center axis of the bolt's hole, etc.

These three concrete application scenarios, illustrated in Figure B.1.1, represent the following three lead application domains:

- The store assistant represents the service robotics application domain. This domain consists of humanoid robots that have to interact with human users. Service robots are sometimes used in domestic environments, work environments and public spaces. These application domains are characteristic for the market domains that OROKSI partner ***Aldebaran*** is targeting.
- The submarine robot represents automomous robots that have to perform longterm tasks in environments where geographic information is needed. Market domains with similar requirements include rescue, surveillance, and agriculture robotics. This is the application domain that OROKSI partner SOMETHING is targetting.
- The last lead application scenario stands for applications with high demands on complex manipulation capability and tasks that are to be repetitively executed in more structured environments such as factories.

OROKSI has chosen the lead application scenarios to be as diverse as possible, while at the same time being representative for large and potent application domains and markets. This variety allows OROKSI to show the impact of knowledge-enabled robot programming for a wide range of application domains and tasks.

The state of the art in robot programming is that the knowledge is implicitly hard coded into the robot control programs. For instance, a programmer specifies that a particular object in a particular assembly step should be held with a certain numeric orientation specification. This code implements an instance of the more general common sense rule that open containers with contents should be held upright. If a robot has to manipulate a new object the programmer has to check whether the very specific manipulation strategy that was previously programmed can be reused. Since there is a cost involved in letting the robot manipulate new objects in a new context, the cost of programming a robot is linear at best (i.e., without considering an increase in codebase complexity). This cost model disincentivizes the development of innovative robots that can handle a wide range of usage scenarios.

In OROKSI we will facilitate the easy deployment of smart, that is "knowledgeable", robots in a wide range of usage scenarios. We establish this by introducing the new programming paradigm of ***knowledge-enabled robot***

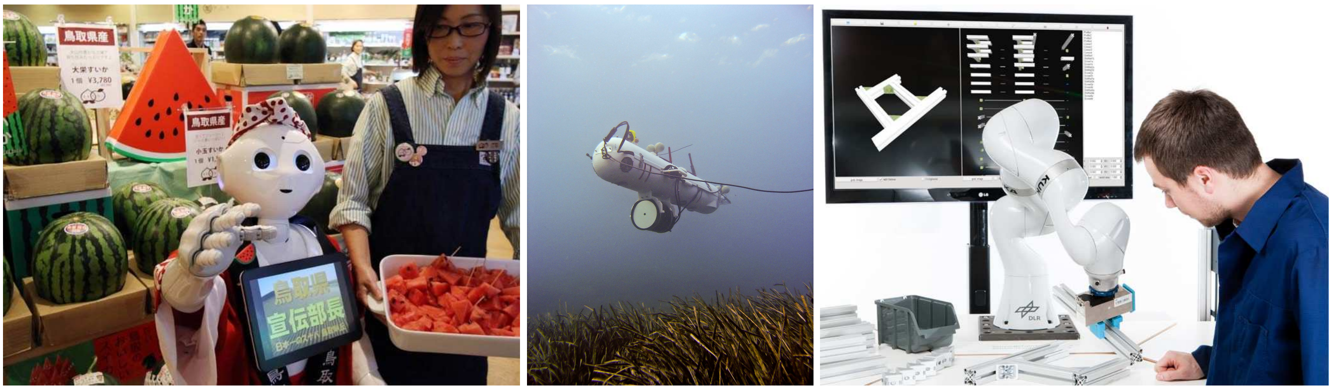


Figure B.1.1: OROKSI reference applications: three different robots, three different tasks, and three different environments.

programming that uses ***open robot knowledge services*** in order to drastically reduce the programming effort needed to adapt robot control programs to different robots, tasks, and domains.

The economic gain of knowledge-enabled robot programming largely depends on the availability of already existing knowledge bases that can be easily reused. In line with Metcalfe's Law [HG08], the economic value of a robot knowledge service will be proportional to the square of the number of reusable rules and facts recorded. Luckily, many knowledge sources that can provide such knowledge already exist today (Cyc, LOD Cloud). Existing Web Services and Personal Assistants (Siri, Cortana, IBM Watson, JoshAI) already make use of these knowlwedge sources in order to deliver smart solutions to human users. What is currently missing is a programmable API, Web Service and other infrastructure that allows robot users to tap into this knowledge and additionally share it back.

B.1.3.2 Main concepts

Figure B.1.2 shows the functional components of the OROKSI infrastructure. Each component maps to a project partner that is specialized in that component (mentioned between brackets). The concepts are detailed in the following subsections.

- A Knowledge-enabled robot programming, including automatic converters from raw robot logs into semantic representations of
- B Robot knowledge services (UniHB)
- C Robot knowledge bases
  - C1 Deep curated and common sense knowledge (Cyc)
  - C2 Large-volume Web knowledge (VUA)
  - C3 Learned robot knowledge (UniHB)
- D Application domains
  - D1 Social robotics (Aldebaran)
  - D2 Underwater robotics (HD)
  - D3 Factory robotics (DLR)

B.1.3.2.1 Knowledge-enabled Robot Programming

Knowledge-enabled robot programming is able to **raise the abstraction level at which robots can be programmed to a semantic level**. In the knowledge-enabled robot programming paradigm, programmers state generic plans for, e.g., pouring a liquid substance into or onto a specified destination. This generic plan (Figure B.1.3 left) specifies that in order to perform a pouring action the robot is to pick up the container in which the liquid is held, hold the container above the destination, and tilt the container until enough liquid is at the destination. In addition, the robot has to specialize the plan to a specific context in order to perform the action successfully (Figure B.1.3 right). E.g., the agent may or may not use a whisker to stir and must not squeeze too hard if the container is soft, such as a milk carton.

Besides the need to program robots abstractly another reason for the need of comprehensive use of knowledge is that for accomplishing the commercial success the companies have to develop robot control programs for a large variety of robots, tasks, environments, and application fields. The resulting challenge is visualized in Figure **??**: a robot that is to conduct chemical experiments (see Figure **??**(left)) needs information about chemical substances,

[1] TO DO: Is there a literature reference for the claim made in this first sentence?

[2] TO DO: What is currently missing is (1) how the knowledge service is used to retrieve part of this robot program, (2) whether reasoning is applied or not, (3) how the specialization of the plan is reused / learned for other robots to use later.

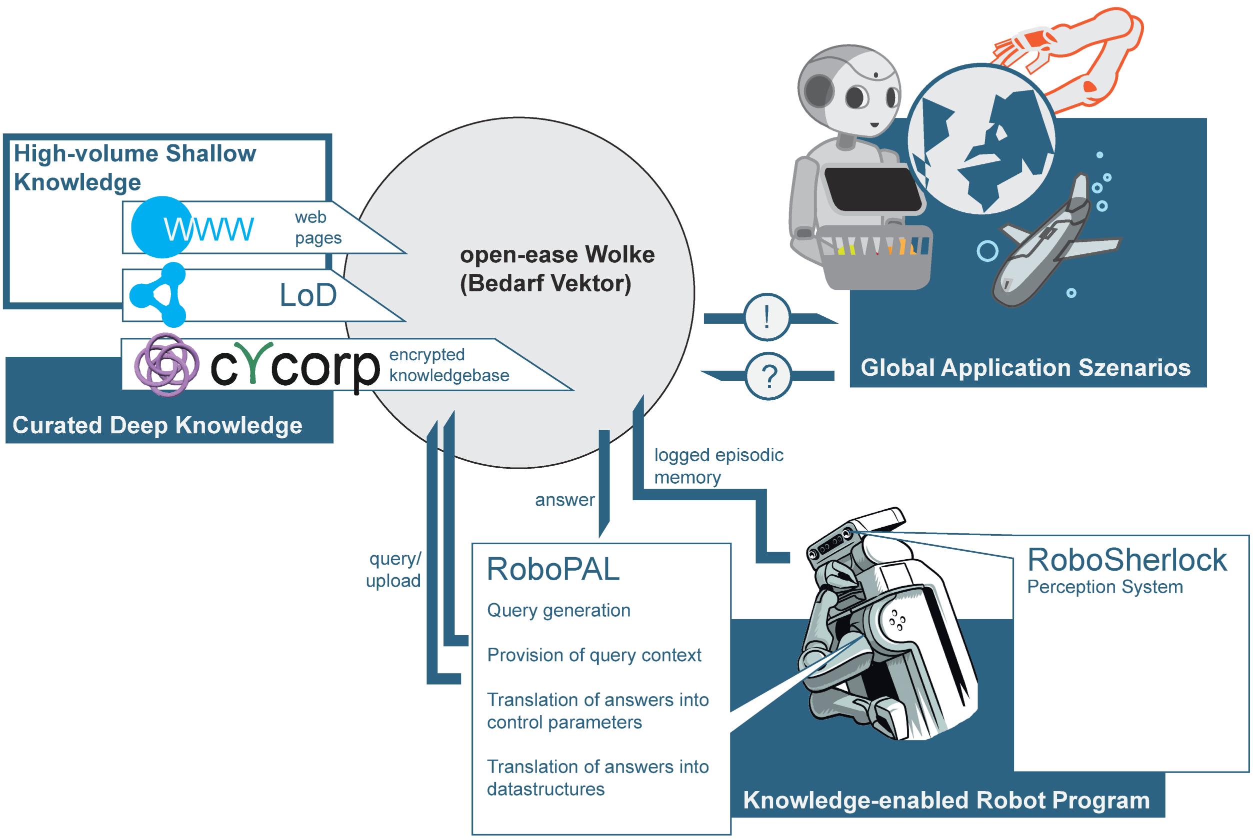


Figure B.1.2: Architecture of the OROKSI robot knowledge service infrastructure.

their properties, possible reactions, the tools needed for the experiments and how the tools are to be handled. Robots for rescue missions in outdoor environments (see Figure **??**(right)) need knowledge that is typically provided by geo information systems, about victims, how they move, and their visibility. Robots that are to perform meal preparation tasks such as making pizza need to know about the properties of dough, how to add water to the dough, and so on. There are substantial cost of not having this knowledge. ***If the robot does not have access to the necessary domain and task knowledge then the programmer has to hardcode this knowledge directly into the robot control program.*** ToDo:3

Knowledge-enabled robotics facilitates the easy deployment of smart robots in many ways. It makes the knowledge that must be injected into every robot control program explicit, modular, and transparent. It facilitates the transfer of programs to other applications and market domains by exchanging the background knowledgew.

B.1.3.2.2 Robot Knowledge Services

OROKSI *proposes to facilitate knowledge enabled robot programming by providing knowledge services in the form of open query answering systems for robots. The basic idea is to equip robots with query interfaces that enable them to retrieve missing situated knowledge by querying open robot knowledge services such as* OROKSI.

Similar knowledge services already exist for human users in the form of personal assistants in our smart phones. The Siri agent on the iPhone, GoogleNow, and Cortana are examples of such services. A user can ask them about a close-by movie theater that plays a science fiction movie tonight and a recommended chinese restaurant close-by to have dinner before the movie. The assistant would then take the GPS position and time of the smart phone look up openStreetMap to find the relevant movie theaters and restaurants, take the restaurant names to look up their ratings in a restaurant recommender systems, retrieve the showtimes of movies, look up the genre of the movies in a movie data base in order to make an appropriate recommendation [**Knoblock:TheaterLoc**].

Once a robot has access to such a knowledge service, it can ask how it can unscrew a light bulb. It could ask: "Where to grasp the light bulb? How the force profile of an unscrewing action feels? Whether there are safety issues to consider? What to do with the light bulb afterwards?" And so on.

There are also differences between the knowledge services that run on smart phones and the ones OROKSI will

[3] To Do: What does transparent mean here?

```
def-plan pour ( ⟨theme⟩         : (some stuff)
                ⟨source⟩        : (an object
                                     (type container)
                                     (contains ⟨theme⟩)
                                     (affordance (an action
                                                    (type pick-up))))
                ⟨destination⟩   : (a location))
            begin
                1.   take( ⟨source⟩)
                2.   hold( ⟨source⟩) (a location (above ⟨destination⟩))
                3.   tilt( ⟨source⟩)
                     until (amount (some stuff (at ⟨destination⟩))
                               ≥ (amount ⟨theme⟩))
            end
```

Figure B.1.3: Generic plan for pouring actions (left) and different behaviors that are generated for the instruction of adding milk to the dough.

provide. Smart phone-based knowledge services can use certain sensor data such as GPS positions, time and data, etc. For a robot the knowledge services can access a much wider array of sensors and can be deeply integrated into the perception-action loops of the robots and can potentially include a full representation of the internal state of the robot, including its 'beliefs', 'desires', and 'intentions' [**BDI**].

Another difference is that robots need more than the knowledge that is currently available on the Web. They need to understand commonsense and naive physics knowledge that is needed to perform everyday activities. Much of this knowledge is the result of experiences rather than the result of looking up the right Web pages.

OROKSI will propose a standardized protocol for the interchange of knowledge between robots and knowledge services (Task T2.SOMETHING).

OROKSI will realize a knowledge service for autonomous robots by addressing the following three challenges:

1. the context that the query is asked in and that includes what the robot intends to do, believes, and sees has to be communicated to the knowledge service so that it can be interpreted for query answering. This requires the semantic interpretation of the dynamically evolving data structures of the robot control system, the manipulation episode that the robot performs and what the robot is currently seeing;
2. transforming the answers of the queries into parameter values that adapt the actions in the desired ways. Such answers could be the 6D trajectory with which to reach for an objects, the 3D position of grasping points, or a force value with which to hold an object. In other words the answers are (imagined) entities in the physical world.
3. semantically interpreting the experience data of the robot so that the knowledge service can use the contained knowledge for query answering.

[TODO: write the questions and responses in the bubbles from the figure separately as well - they are not readable on my screen. I think printed out will be problematic as well. I think these bubbles are very important for the reader, to understand our proposal. I came back Current figure B.1.6 is very important! - it's the only source of "how exactly up to now.]

Thus a robot knowledge service is best imagined as an augmented reality system that completely logs the interpretation of the robot control program, the images captured by the robot, and their semantic interpretation by the robot. Having this query context the robot can e.g. ask how it should reach and grasp the object it intends to pick up. This is depicted in Figure B.1.4. Because the robot believes that the object is a bottle with pancake mix and the task context is a pouring action the knowledge service infers that it is better to grasp the body of the bottle than its top. It also infers that the bottle should be held upright to avoid spilling. The answers of the OROKSI service are parameterizations of the reaching motion, a CAD model positioned in the physical world that can be used for parameterizing the low-level control programs, for example by specifying the contact points for grasping. The answers a rendered in the augmented reality view depicted in Figure B.1.4.

[4] To Do: The robot knowledg interchange protocol is nowhere mentioned ATM.

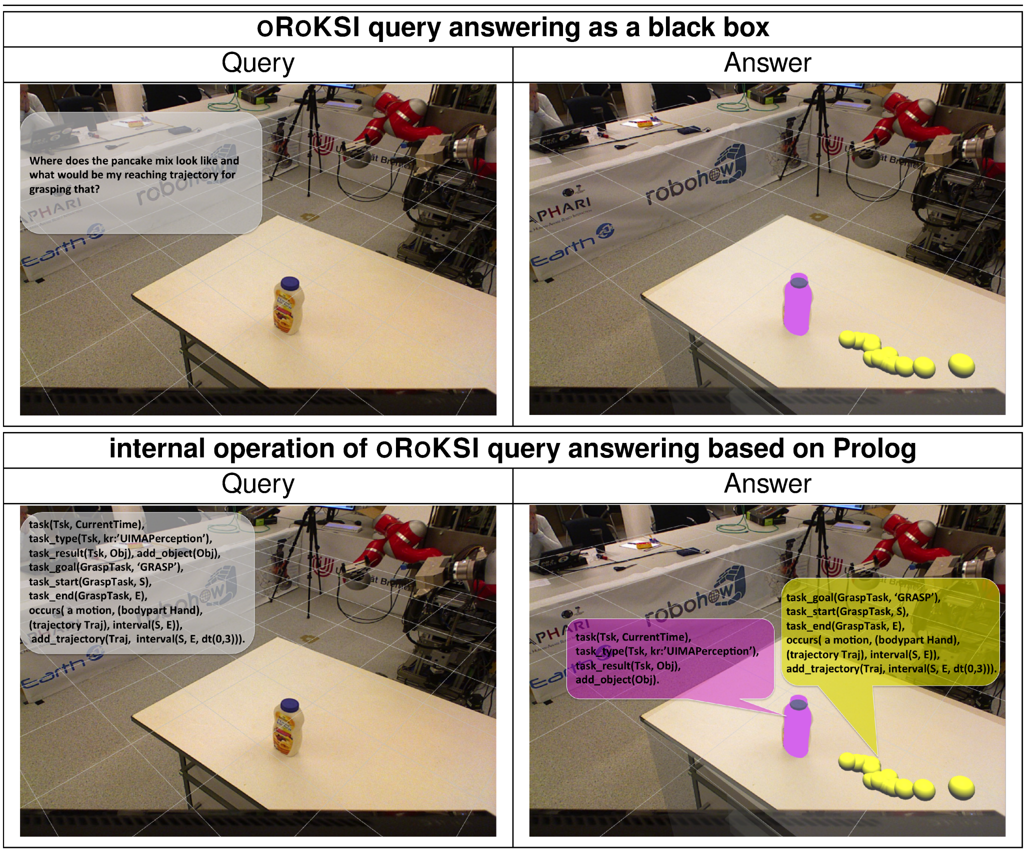


Figure B.1.4: Embodied query answering and knowledge processing.

The bottomline from these considerations is:

In* oRoKSI *we propose a novel way of making high level semantic action descriptions executable in a robot control program: the robot sends the action description, its current state and task and the perceived scene to a knowledge service and asks the knowledge service for the appropriate values of the parameters of the subroutines that need to be bound in order to execute them.

The knowledge services for robots must be very comprehensive because they have to allow for open querying. Robots will ask a broad range of queries in many different contexts. To this end, oRoKSI will define a query language based on the logic programming language PROLOG that provides a set of predefined relations or better predicates that can be combined in queries. One can imagine PROLOG queries as queries to a relational database with the difference that the queries can not only retrieve stored data but also infer implied knowledge to answer the queries.

Figure B.1.5 illustrates the range of queries and the respective answers that the knowledge service facilitates. We can see from the example queries that the possible queries include ones about background knowledge (such as the places where perishable items are stored), about the task-dependend navigation paths, about the poses in which certain actions were performed, the trajectories for reaching tasks, and the images that a robot hascaptured to detect certain objects. ***The ability to answer this broad range of queries transforms robotic agents into agents that "know what they are doing"* [Brachman]*. Robots that know what they are doing can answer questions about what they have done, how they have done it, why they have done it, what happened when they did it, or what they saw when they did it.***

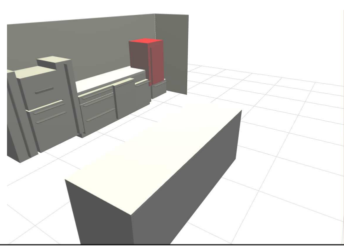
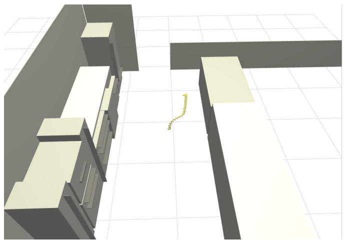
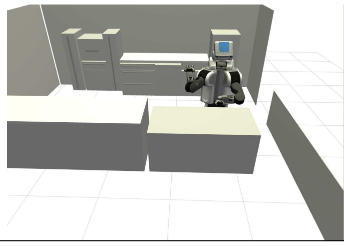
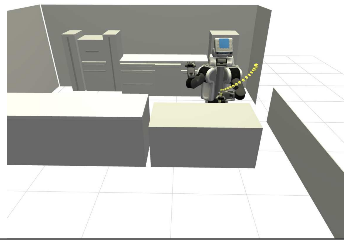
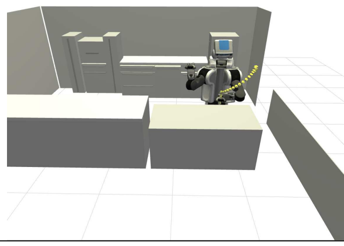
translation of the query into natural language	**query syntax to be used by OROKSI**	**visualization of answer**
What is the storage place for perishable items? *(highlight an instance of the type storage construct that can be used as a storage place for perishable items)*	owl_subclass_of(T, kr:'StorageConstruct'), class_properties(T, kr:'StoragePlaceFor',kr:'Perishable'), owl_individual_of(O,T), highlight(O).	
What was PR2's trajectory during the pick-and-place experiment? *(visualize the trajectory of the robot base in the time interval that is started by task start and terminated by the end of a task with the goal to place an object at some locations)*	task(T), task_goal(T, (PLACED-AT ?OBJ ?LOC)'), task_start(T,S), task_end(T,E), display(trajectory('/base_link'), interval(S, E, dt(0.5))).	
What was PR2's end pose after a putdown action? *(display the fullbody pose of the PR2 robot in gloabal map coordinates at the end of a putdown action)*	task_goal(T,'PUTDOWN'), task_end(T,End), holds(pose(PR2-robot,Pose,T), display(PR2-robot, Pose).	
What was the arm trajectory during this putdown action?	task_goal(T,'PUTDOWN'), task_start(T,S),task_end(T,End), mng_designator_props(T, 'LINK',TfLink), marker_update(trajectory(TfLink), interval(S, E, dt(0.1))).	
What was the arm trajectory during this putdown action?	task_goal(T,'PUTDOWN'), task_start(T,S),task_end(T,End), mng_designator_props(T, 'LINK',TfLink), marker_update(trajectory(TfLink), interval(S, E, dt(0.1))).	

Figure B.1.5: Example queries that illustrate the range of queries that can be answered by the OPENEASE knowledge service.

The bottomline from these considerations is:

The advantage of executing tasks with the help of open query answering systems is that the robot control program can be kept compact. We can use a generic plan that tells the robot to grasp and turn the object to be unscrewed repreatedly until the object is not connected any more. The specific details, such as the grasp type, the forces, the contact points for stable grasps, the forces to be applied, which are required as parameters for low-level control as well as modifications can then be asked from the knowledge service. In addition to the compactness the design also allows to separate the reasoning and decision making from the flow of control that makes the program more modular. Also, as much of the manipulation knowledge is common sense and naive physics knowledge it can be acquired collectively and shared through global knowledge services.

B.1.3.2.3 Robot Knowledge Bases

In order to provide the knowledge services that robots need, OROKSI must combine three existing knowledge representation and processing paradigms: (1) curated deep knowledge (Cyc), (2) large-volume Web knowledge (VUA), (3) learned robot knowledge (UniHB). Each of these three knowledge paradigms is well-established and has been applied in concrete applications by the respective OROKSI partners. However, in OROKSI these three paradigms will be synergetically integrated for the first time.

Curated Deep Knowledge (Cyc)

The OROKSI knowledge servide requires a well-engineered, comprehensive ontology and knowledge base of common-sense and naive-physics knowledge. This knowledge source provides the core concepts that are used in knowledge-enabled robot programming. This includes the following:

1. Knowledge about objects and materials.
2. Knowledge about environments.
3. Knowledge about physical processes.
4. Knowledge about tasks that can be performed.

Common-sense and naive-physics knowledge is used by humans every day, but is normally not stated explicitly. This includes knowledge about common properties of the world, such as the basic behavior of materials, liquids and gravity, common places where certain objects can be found or obtained from, and how to handle objects in a sensible way. This kmowledge is described in the Cyc Knowledge Base (Cyc KB)[1] [Len95; Wit07]. The Cyc KB is a formalized representation of a vast quantity of fundamental human knowledge: facts, rules of thumb, and heuristics for reasoning about the objects and events of everyday life. This knowledge is represented in a formal language (first and second order logic) which is understandable by computers and machines. Cyc KB contains over five hundred thousand terms (500k), including about seventeen thousand types of relations (17k), and about seven million assertions (7m) relating these terms. New assertions are continually added to Cyc KB by a combination of automated and manual means. Many more concepts can be expressed functionally in terms of the core Cyc KB concepts (e.g., “LiquidFn Nitrogen” describes liquid nitrogen), resulting in millions of additional, non-atomic terms that can also be expressed. In addition, a vast number of implicit assertions can be automatically derived by applying reasoning techniques over the explicit assertions. **Cyc will provide OROKSI with SOMETHING SOMETHING**

Large-volume Web knowledge

By using Cyc KB, the OROKSI knowledge service can tell a robot that milk is a dairy product that is commonly kept in a fridge. But a robot must interact with *specific* milk bottles. The Web of Data contains this knowledge about instances. It contains information about specific brands of milk, their caloric contents and their current price in different supermarkets. It also contains images of how common milk bottles look like. The Web of Data includes Semantic Web, Linked Open Data and Schema.org sources. It is a large-volume, heterogeneous and distributed knowledge base that is deeply integrated with today’s Internet. For instance, Microdata and Schema.org metadata annotations now occur in over 30% of all Web pages [MP12].

The LOD Laundromat [BR+14] is a unique resource that continuously mines the Internet for Semantic Web and Linked Open Data knowledge. The LOD Laundromat cleans and republishes all Semantic Web data in the world into a single, uniform and standards-compliant live queryable format. It ensures that large-scale and heterogeneous Web-based data can be processed by machines without having to pass through a dataset-specific and cumbersome data cleaning stage. At the time of writing the LOD Laundromat disseminates over seven hundred thousand (700k) datasets containing over fourty billion (40b) ground statements. In addition to serving clean data, the LOD Laundromat also allows all data to be queried live through the scalable Linked Data Fragments (LDF) paradigm [VH+14].

Existing large-scale reasoners such as QUERYPIE and WebPIE will be connected to the OROKSI knowledge base in order to derive new information and answer robot knowledge requests (Section **??**, Tasks T2.2-T2.4).

VUA will provide the entire Web of Data at OROKSI partner’s fingertips.

Robot Knowledge

The third type of knowledge is robot knowledge. Robot knowledge includes the following three aspects: ToDo:5

1. Representations of robot hardware. This includes its link structure the joints, the sensors and the effectors of the robot. Examples pieces of such knowledge are the CAD models of the robot parts, models of the 6D hand

[1] See www.cyc.com and http://sw.opencyc.org/

[5] TO DO: Make the following items more concrete.

poses that it can reach in its work space, dynamic models of the robot and so on. Much of the knowledge is available in the form of algorithms and low-level data structures but must be abstracted to be combined with other forms of knowledge.

2. Knowledge about the low-level control and its operation. For example, at the knowledge level a robot must know where it is. Most modern autonomous robot control system estimate the pose of the robot in the environment based on on the sensor data it receives and the control signals it sends using probabilistic state estimation algorithms. The probability distribution over the possible poses represents where the robot believes to be (the global maximum of the distribution), the certainty it has (the probability mass of the global maximum), the accuracy (the deviation of the distribution), the ambiguity (number of the local maxima). All this data that is needed for the robust control of the robot is already maintained in the low-level control system. OROKSI will have access to this data and abstract symbolic knowledge from it.
3. perceptual knowledge. Much of the knowledge introduced above is disembodied. The robot knows that a spoon has a handle and it should grasp a spoon by its handle. But seeing a spoon it must still be able to relate the abstract knowledge to a 3D object it is seeing.
4. The fourth kind of important knowledge is experience knowledge. If the robot records every piece of information that it experiences, its own poses, the images it perceives, the objects it recognizes, the actions it intends to execute, the motion it performs, the effects of actions on objects, etc it can collect detailed episodic memories. These episodic memories are the preconditions for many knowledge acquisition and learning tasks. From the episodic memory the robot can learn where objects are, which objects it can pick up with one hand, what might happen when picking up a glass of water, and so on.

The robot knowledge representation and processing system KNOWROB [TB13] and the accompanying knowledge service OPENEASE provides and processes all these kinds of knowledge and makes the knowledge operational in perception-guided robot activity. By now, KNOWROB is probably the most advanced and widely used knowledge processing infrastructure for autonomous manipulation robots. The high-level representations in KNOWROB are compatible and even use the representation mechanisms provided by Cyc and the semantic web.

The ability to answer an open range of queries is also essential for learning robot knowledge bases. For example, having uploaded all its experience data into the knowledge service the robot can retrieve all subepisodes in which it tried to pick up a heavy object from a table top. It can then consider the poses from which the robot started the action and categorize the the episodes in the ones where the pick up succeeded and the others in which it failed. Having these data the robot can then learn the concept “poses from which I can pick up a heavy object from the table”. This way a robot can learn informed decisions and action parameterizations that are expected to work for many of the vague parameterizations in our generic plan above. In a way it can build up a commonsense and naive physics knowledge base for the respective manipulation domain.

But the experience data and the learned robot knowledge is not only useful for the robot that collected the data and learned the model but it can potentially be useful for many others if the owner of the robot decides to share the data and knowledge with the community. Consider a company that evaluates the use of the same kind of robot in a factory setting and wants to investigate whether the robot has the needed dexterity and perceptual capabilities for successfully operating in the factory environment. This system designer can retrieve from OROKSI all episodes in which robots failed to successfully pick up objects in settings that are similar to the ones in the factory application and compute the distribution of failure causes. Much knowledge that might be tediously acquired and learned in one application might be of great use for others. For example, one might want to share knowledge about the capabilities of certain robots or one can share background knowledge about application domains (such as knowledge basis extensions to geo information systems, etc).

B.1.3.3 Approach

The ambition of OROKSI is a step change from imperative robot programming to knowledge-enabled robot programming. It will do this by providing the knowledge service infrastructure that is needed to automatically adapt generic plans to specific situations by querying the OROKSI knowledge service and knowledge bases.

OROKSI Milestones to achieve Step changes

The entry point for the step change is the current state-of-the-art where robots are programmed at abstraction levels that are far too low-level in order to be generalizeable and transferable to other applications.[2] Another problem with the hard coding of parameters of control programs is that the robots do not have adequate models of their control programs and the behavior and effects they generate and are therefore limited in their capabilities of diagnosing

[2]For example, the trajectories in which the robots have to move are often taught directly by moving the robot by hand and recording the respective key poses, the forces with which objects are grasped and lifted are often numerically encoded, and constraints are also stated numerically rather than at a qualitative and object part level.

failures in order to recover from them and supporting programmers in localizing and adequately changing flawed subroutines.

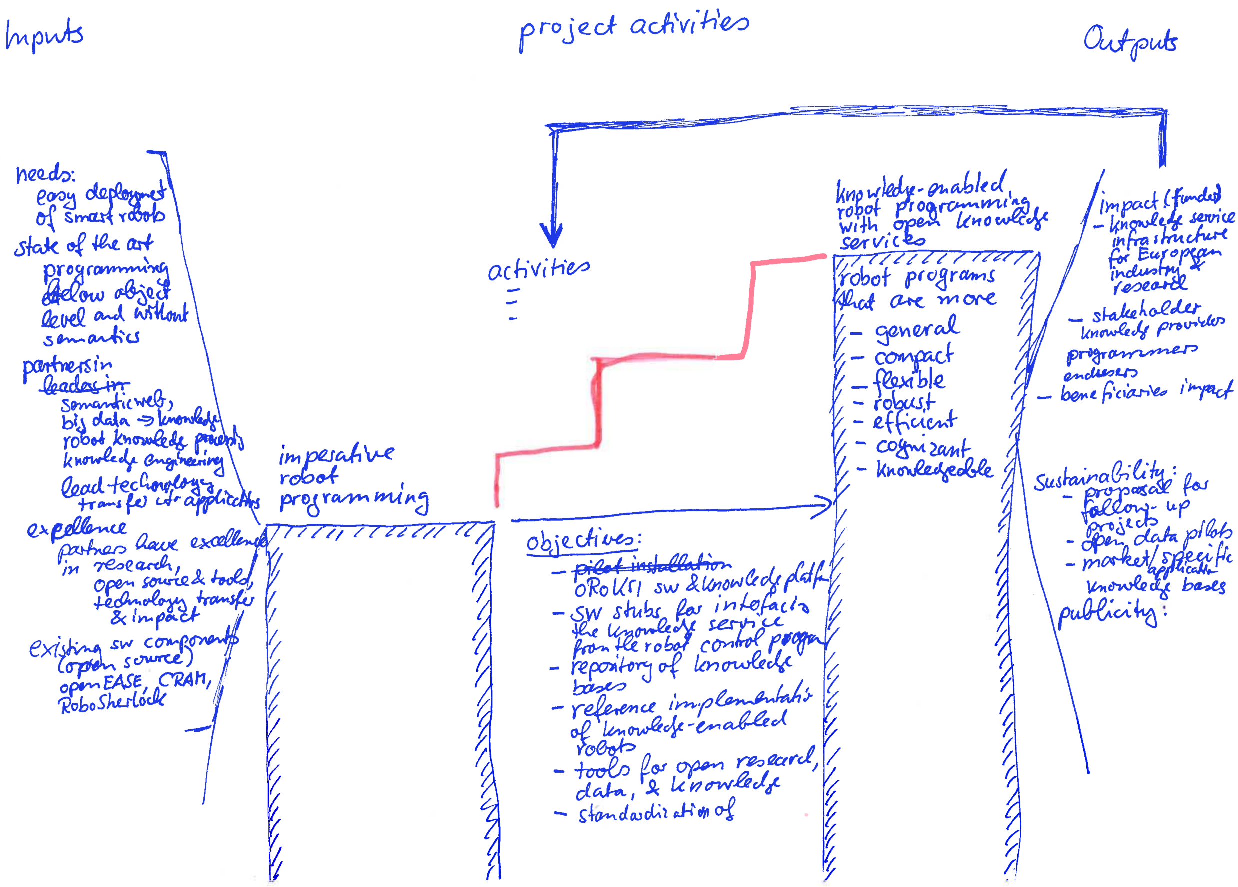


Figure B.1.6: The step change intended through OROKSI

Starting Point: the OPENEASE Laboratory Prototype

OROKSI builds upon and expands the existing OPENEASE laboratory prototype (TRL 3) and is to substantially advance the prototype towards a technical industrial strength prototype of a robot knowledge web service (TRL 5). It does so by extending and incorporating current technologies. The planned research and innovation activities are to result in step changes in technology that have impact on the abilities of robotic agents in the following ways:

The interface upon the cloud knowledge service will build on OPENEASE[3] [BTW15]. OPENEASE is currently a laboratory prototype of a remote knowledge representation and processing service that aims to facilitate the use of Artificial Intelligence technology by equipping robots with knowledge and reasoning capabilities. **The reviewers are invited to test OPENEASE through its Web site** `http://www.open-ease.org`**, which includes demonstration videos as well as interactive demonstrations of the robot knowledge Web Service.**.

The paper "OPENEASE – a Knowledge Processing Service for Robots and Robotics/AI Researchers" reporting on OPENEASE has been selected as finalist among almost 2300 submitted papers for the Best Conference Paper Award and Best Cognitive Robotics Paper Award of the International Conference of Robotics and Automation in May 2015. A version of the paper can be downloaded from `http://www.open-ease.org/wp-content/uploads/2015/03/knowrob-s.pdf`

OPENEASE provides databases that contain real execution data of modern autonomous manipulation robots, such as robot perception and manipulation results. The data is published under an open license and is freely accessible to the research community. It also provides the representational infrastructure to make very heterogeneous experience data from different robots and human recordings semantically accessible in a uniform and standardized concept vocabulary. In addition, it offers a suite of software tools that enable researchers and robots to interpret, analyze, visualize, and learn from experience data. For each execution episode, OPENEASE provides information regarding the robot's hardware, its capabilities, its environment and the objects it manipulated. The tools make it possible to reason about what the robot saw, reasoned, and did, also how it did it, why, and what effects it caused.

[3]EASE is the abbreviation of Everyday Activity Science and Engineering.

These queries can be sent either by humans via a Web-based graphical interface, or by robots that access OPENEASE via a cloud service API. This way, they can query and use OPENEASE's background knowledge to provide semantic meaning to their sensor data and to the data structures they use for control purposes.

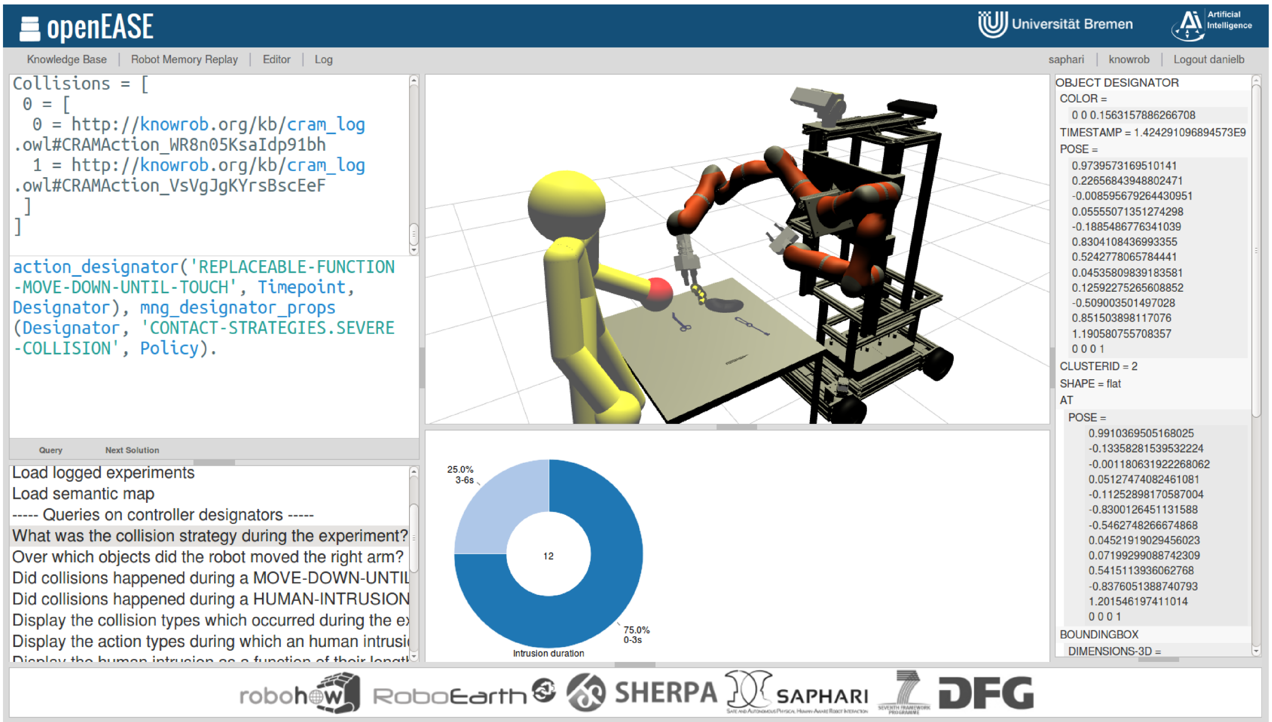


Figure B.1.7: Web interface of OPENEASE. The interface allows the user to type Prolog queries and commands and to see the answers to these queries. Query results such as robot poses, its environment, trajectories and object poses can be visualized in the 3D display pane. The web interface also comes with an editor, in which web users can develop their own private knowledge base (PROLOG program) that can be loaded in addition to the globally available OROKSI knowledge base.

The knowledge service is designed to work within the **cognition-enabled plan-based robot control** framework. Knowledge representation in OPENEASE is backed by KNOWROB which uses the robot perception system ROBOSHERLOCK [BBB+15] **(finalist of ICRA 2015 Best Conference and Best Service Robotics Paper Awards)** and plan-based control system CRAM (Cognitive Robot Abstract Machine) [BMT10]. CRAM is equipped with a data recording system that automatically logs comprehensive data during robot manipulation tasks. Large-volume, continuous sensor data is stored in an efficient, schema-less MongoDB database. Symbolic plan-events, such as the hierarchy of actions and sub-actions that are performed, their parameters, results and durations, are stored in KNOWROB.Both the symbolic and continuous data logs are represented with respect to a common ontology, which allows standardized semantic access to all information. OPENEASE offers a library of query logic predicates for reasoning about logs and extracting — on demand — symbolic knowledge from sub-symbolic log data. We call this concept a "virtual knowledge base" that is created on top of the semi-structured and often large-volume log data.

Lead Application Scenarios

One of the key channels for dissemination ([TODO: isn't this exploitation?]) are the OROKSI lead application scenarios, and demonstrations that are paradigmatic for robot application domains and markets. OROKSI has selected the following three lead application scenarios:

- factory robots doing lifelong semantic assembly [TODO: What is semantic assembly?] and other manipulation tasks. We consider scenarios of variant production where the challenge is to first, program the assembly robots at a semantic level, for example, by specifying to take a bolt by its head and inserting it orthorgonally into the hole of the nut. To this end CAD models have to be automatically segmented into their functional parts, the robot control systems use knowledge models of tools and machines, design knowledge, and instruction sheets, etc. Another charactistic of these applications is that the environment is designed and configured to enable robust and fast operation. This lead application scenario is characteristic for a large variety of production tasks in factory automation. The characteristics include the requirements for sophisticated high-accuracy manipulation skills, iterative tasks, and the need for speed and safety. This is realized by OROKSI partner **DLR** who has also access to independently developed scenarios from partnering with EU project ROBDREAM and/or SMEROBOTICS.
- underwater robots doing asset management in the oil fields in the North Sea and environment science and

monitoring in the ocean. The underwater lead application scenario is characteristic for many outdoor robot applications that require access to information that is provided by geo information systems. They also require task specific environment models. Even though they are acting in similar terrains, rescue robots that search for victims after avalanches have to interpret their environments in terms of where people might be found and under which conditions they are visible while a robot monitoring a possible vulcano eruption needs to interpret its environment in terms of geological concepts. The underwater robots are also required to have detailed models of their often redundant hardware components in order to diagnose possible faults and reconfigure themselves to continue their operations and safely come home afterwards. Robot application domains that share regarding to their requirement for knowledge-enabled control are rescue robotics, large-scale asset management and monitoring, robotic explorer tasks, and agriculture robotics. The underwater lead application scenario is done by oRoKSI partner **HW**.

- The third lead application scenario is a service robotics application that is also relevant for domestic home robot application and uses the Pepper robot from Aldebaran. The envisioned scenario a robot sales assistant in a store. The knowledge bases for the robot will include product catalogs of the products sold by the store either by accessing the store data bases or downloading the information from the webstore, background knowledge about the products from web pages such as wikipedia, recommendations of buyers from web stores but also knowledge about interaction patterns. The applications are characteristic for robot action and interaction in open, semi-structured environments that include some communication with people and the execution of natural language commands. This is done by oRoKSI partner **Aldebaran**.

For each topic we would develop a demonstration robot knowledge service (this we have to quantify) that provides question answering capabilities for robotic agents based on coheherent knowledge bases that consist of (1) curated deep knowledge that defines the necessary concept and provides the background and commonsense knowledge, (2) large-volume knowledge including information that can be automatically retrieved and mined from web pages, and (3) robot knowledge that includes robot experience, execution, and perception knowledge and concepts learned from this large-volume, low-level data.

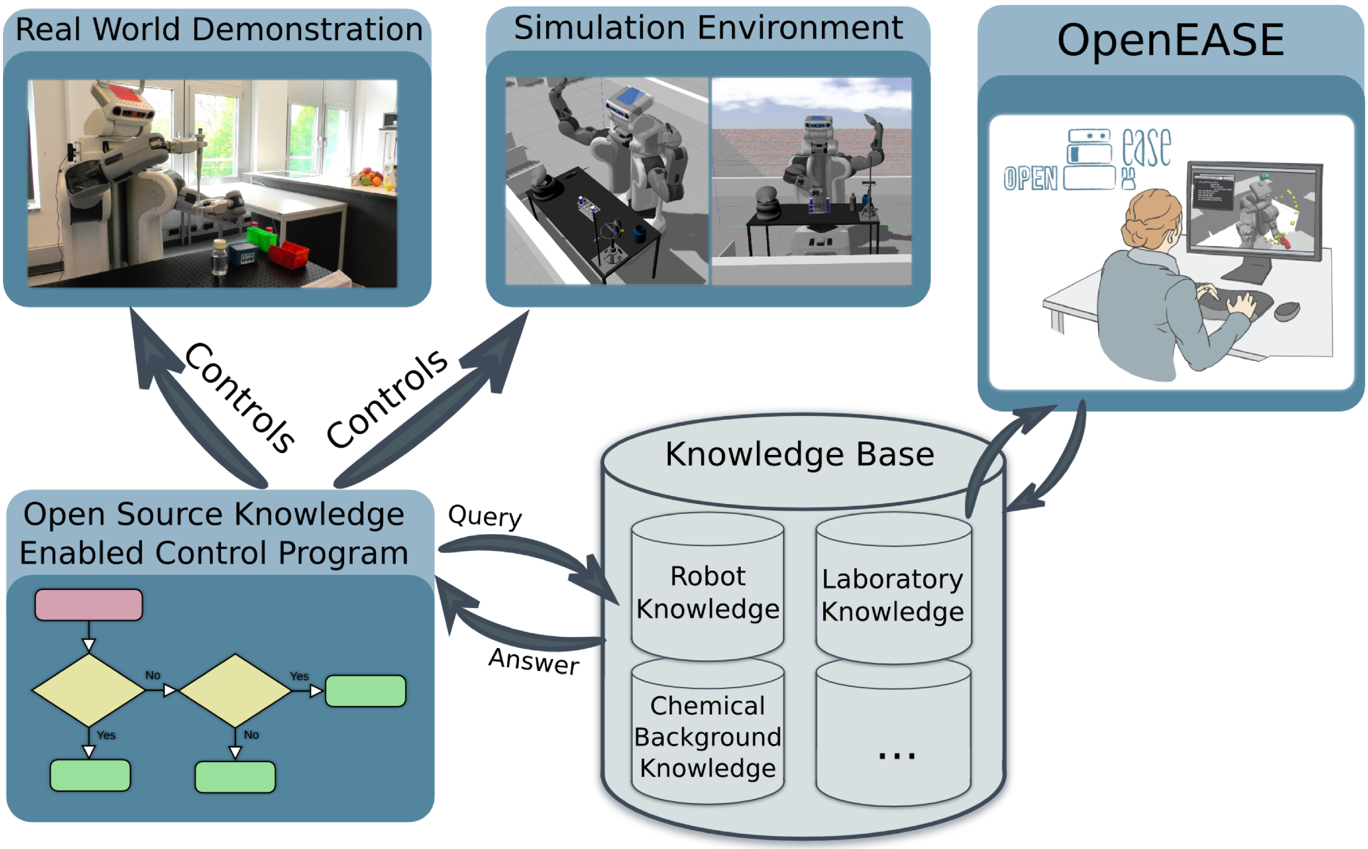


Figure B.1.8: The components provided by lead demonstration scenarios.

The lead application scenarios will be realized such that interested users have complete access to knowledge bases that are generated by logging real-world activity episodes of the robots. In addition, each lead application scenario will provide the code of the robot control system, a model of the robot and the simulation environment in which the robot can be controlled with the control program, and the complete knowledge

base. Thus, users can for each lead application download and run an open version of the application that they can modify in order to adapt the lead application to their applications. Technically, the downloadable version will run on any Linux machine using the Docker virtual machine infrastructure.

In addition, OPENEASE provides other knowledge bases and scenarios contributed by other projects:

- a home service robot that performs fetch and place tasks in a home environment. Knowledge would include where the objects can be found, how they look, affordances wrt grasping, holding, using them, possible failures in handling them, their usage in different task contexts, the context-dependent state of of objects (eg, plates can be expected to be dirty when clearing a breakfast table), and so on. The scenario provided by FP7 project ROBOHOW.
- robotic agents performing meal preparation tasks (possibly with support by WikiHow). Knowledge about manipulation tasks such as adding, cutting, wiping, flipping, etc, motion and force profiles to perform the tasks successfully, what can go wrong, how can a robot perceive that something is going wrong, etc. The scenario provided by FP7 project ROBOHOW.
- rescue robotic. Knowledge kinds: robot teams, roles, exploration and search tasks, mission knowledge representation, linkage to geo information systems, etc. The scenario provided by FP7 project ROBOHOW.
- a robotic scientist conducting chemical experiments. (combination with semantic web chemistry knowledge, laboratory protocols, chemical reactions, safety aspects). The scenario provided by FP7 project ACAT.

B.1.3.4 The OROKSI robot knowledge value chain

Creating a favorable business environment for knowledge-enabled robot programming and robot knowledge services and pushing for its accelerated adoption requires a concerted effort along the respective value chain.

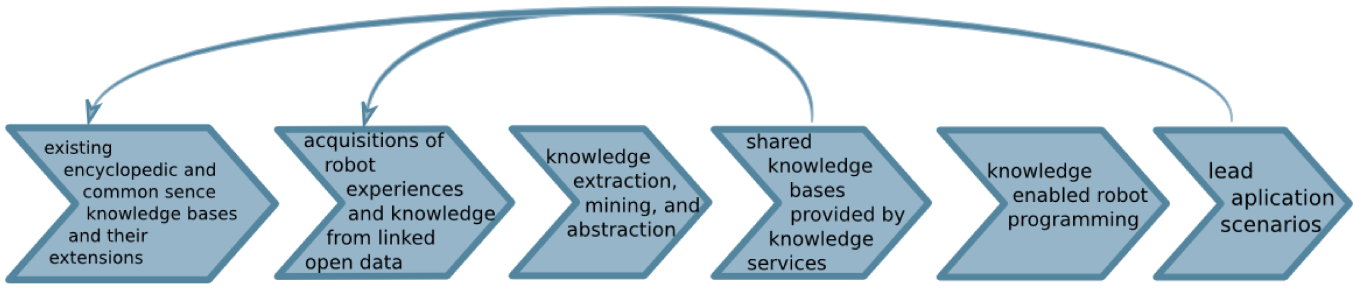


Figure B.1.9: The value chain for knowledge-enabled robot programming and robot knowledge services.

This value chain, depicted in Figure B.1.9, starts with existing encyclopedic and commonsense knowledge bases. These knowledge bases contain ontologies of concept definitions that are necessary for many robot applications. The concepts include robots as agents that execute actions, their hardware components, the kinematic link structure, and their capabilities, the plans that robots execute and the actions that the plans produce and the effects of actions, definitions of failure categories such as overlooking objects, the tasks that the robots are to perform, and the environments they operate in. These knowledge bases also contain knowledge pieces that the robot should point sharp objects away from humans in order to not hurt them, and so on. By linking data strucures to concept definitions, ie by asserting that a data structure is an instance of a certain concept, the robot can assign meaning to the data strucures and access the background knowledge that is available for the respective concept.

The second step is to extend the definitional knowledge with the experience data and linked open data in order to achieve the necessary breadth and depth of the knowledge bases. The definitional knowledge base might define the “place from which to pick up large objects with two hands” as the set of robot poses from which the respective pick up action is expected to succeed. This definition, however, is not actionable: given a particular scene and object it does not tell the robot *where* to position itself in order to pick up the object. Thus in the second step of the robot knowledge value chain the definitional knowledge is combined with sets of semantically labelled episodes in which the robot tried to pick up various kinds of objects. Given the experiences of where the robot has succeeded and failed the robot can learn the positioning connstraints for successful action execution. Or, while the definitional knowledge base might contain formal definitions of what cereal is, the linked open data, for example accessible from a web store might provide the robot with the images of the front faces of cereal boxes, their content, and weight, which would enable robots to find particular kinds of cereal in a supermarket.

The third step in the value chain is learn grounded concepts for robots. For example, knowing the definition of a place to pick up objects and having the experiences of picking up different objects, the robot can take all subepisodes in which it tried to pick up a large object and learn a classifier that predicts whether picking up the object from a particular position is expected to succeed. Using this predictor the robot can then learn the poses from which to successfully pick up the objects and use this concept for positioning the robot. Or, the robot can learn the types of cereals that particular family members prefer.

step 4

step 5

step 6

Europe needs strong players along the robot knowledge service value chain (Figure B.1.9) ranging from hand-crafted knowledge bases to the realization of knowledge-enabled robot application systems. All the links of the entire value chain have to be strong so that a vibrant robot knowledge service ecosystem based on such a value chain can evolve. The potential commercial impact of such data-centric value chains is widely discussed in a number of discussion papers for the "Industry 4.0" research initiative. some main findings.

Despite the growing number of companies active in robotics that apply data intensive and machine learning based technologies, an economic community supported by interacting organisations does not yet exist for the knowledge-enabled robot programming at the European level. The amount of data that robots create and that is used for optimization and improving the robustness of production and logistics processes is growing, but both in businesses and in research it is treated and handled in a fragmented way. In order to ensure a coherent use of robot knowledge and data, a wide range of stakeholders along the robot knowledge service Value Chain should be brought together to facilitate cooperation.

The stakeholders that will form the basis for interoperable ecosystems based on robotics knowledge bases for different kinds of robots, applications, environments, and domains as a source for new businesses and innovations in robotics are:

- producers of robots and robot components (Aldebaran, Kuka, PAL, Kastanienbaum, . . .)
- SMEs that provide solutions for some robot functionality (perception: Roboception, MVTec; robot motion planning and control: ArtiMinds, . . . , safe physical interaction, cloud robotics, . . .)
- SMEs that provide complete solutions for specific market domains (Magazino: warehouse logistics; Seabyte: underwater robotics, precision farming, . . .)
- ICT companies that extend knowledge and "Big Data" technology into robotics (IBM transfers their Watson technology into robotics including cooperation with Aldebaran, Robonaut, IBM Research Zurich)
- users of robotics technology (as for example production companies such as Daimler, BMW, VW, etc, automation companies such as Siemens, oil companies such as BP which plan to do the surveillance of their oil fields in the North Sea with autonomous underwater robots, logistics companies with big warehouses, etc)
- Researchers and academics who can provide knowledge and thought leadership

The cross-fertilisation involving these stakeholders and many ready-to-use robot knowledge bases is a key element for the advancing intelligent robotics economy.

B.1.4 Ambition

oRoKSI *aims at making a substantial step change in the acquisition, representation, and use of generalizable robot knowledge.* The role that knowledge representation and processing is expected to play in robotics is perhaps most succinctly stated by the former Darpa programme manager Gill Pratt, who oversaw the DARPA Robotics Challenge and several other programs in robotics (source: Journal of Economic Perspectives, Vol. 29, No. 3 (Summer 2015). Is a Cambrian Explosion Coming for Robotics?): **"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."** Later in the article he discusses the barriers that hold back the even faster evolution of robotics and their deployment in broader markets saying: **"The key problems in robot capability yet to be solved are those of generalizable knowledge representation and of cognition based on that representation."**

In this context* oRoKSI *makes the following value proposition:

oRoKSI *provides a "Siri agent" (or GoogleNow) for robots*

oRoKSI enables robots to query knowledge services to answer questions about how to execute vaguely and abstractly formulated actions in the respective action context as explained in Subsection [A] on page 12. The queries that can be answered include ones about what objects are, what they can be used for, what functional parts they have, how to manipulate them, how to position itself to perform actions successful, and so on. Thus, for robot programmers who get overwhelmed by the complexity of scaling their robot programs to complex real-world tasks and open contexts oRoKSI will provide a knowledge service infrastructure oRoKSI enables programmers to implement competent and compact programs by making use of common comprehensive knowledge bases.

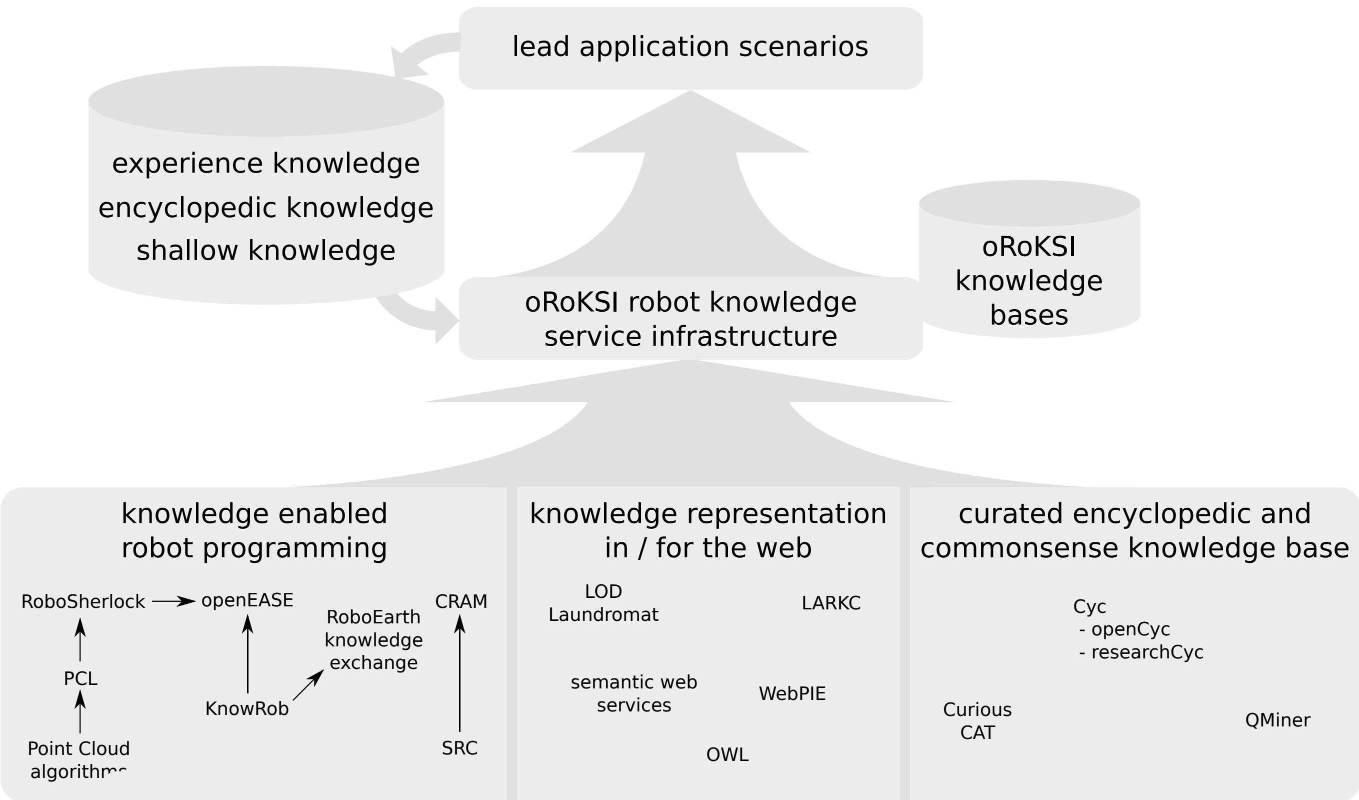


Figure B.1.10: The research ambition of oRoKSI with respect to knowledge-enabled robot programming.

As depicted in Figure B.1.10 oRoKSI combines for the first time leading-edge research and technologies in the areas of

- knowledge engineering of encyclopedic and commonsense knowledge bases, in which it builds upon today's largest encyclopedic and commonsense knowledge base. Doug Lenat estimated the effort to complete Cyc would be 250,000 rules and 350 man-years of effort. Cyc-EU to add here!
- semantic web and linked open data extraction and reasoning, in which we build upon OWL and LARKC and other high performance reasoning engines

- robot knowledge representation and processing Uni Bremen

As depicted in Figure ??? the combination of these technologies is both necessary and sufficient to accomplish the substantial step change for generalizable robot knowledge.

B.1.4.1 Beyond the State-of-the-Art

We will explain oRoKSI's ambitions in advancing the state-of-the-art in autonomous intelligent robot control along 4 dimensions: cloud-based knowledge services for robots, robot knowledge bases, knowledge-enabled robot programming, and knowledge-enabled robot applications.

B.1.4.1.1 Robot Knowledge Services

Cloud Robotics is a new control paradigm where robots exchange data and perform computation via networks building on emerging technology in cloud computing, machine learning, big data, open-source software, and major industry initiatives in the "Internet of Things", "Smarter Planet", "Industrial Internet", and "Industry 4.0."

State of the Art Research on cloud robotics was started by the EU project RoboEarth and efforts led by Google in context of the Google car. An early snapshot of the field was given in a special issue of the Robotics and Automation Magazine "A Special Issue Toward a WWW for Robots" in 2011. The current state of the art is comprehensively explained in an overview article "A Survey of Research on Cloud Robotics and Automation" and a "Special Issue on Cloud Robotics and Automation: A special issue of the IEEE Transactions on Automation Science and Engineering." These efforts were partly started in a US National Science Foundation Workshop on Cloud Robotics in February 2013. ROS the most widely used open-source software library offers webtools [OP+12] as a comprehensive basis for web-enabled robot systems.

Consortium Expertise and Contributions to State of the Art Partners of the oRoKSI consortium are among the leading ones in the areas of reasoning services in the WWW (VUA, CycEur) as well as in cloud robotics reasoning (UniHB). VUA has extensive expertise in creating very large, i.e., Web-scale, reasoning services such as QueryPIE and WebPIE [UK+10]. **oRoKSI will leverage the expertise of its parners in order to implement a very-large scale hybrid inference system.** The research group at UniHB were a key partner in RoboEarth developing in particular the knowledge representation and processing infrastructure [TP+12]. Beetz was one of the guest editors of Robotics and Automation Magazine "A Special Issue Toward a WWW for Robots" in 2011. He is also the coordinator of the EU integrating project RoboHow. The openEASE cloud-based knowledge service is already used within three European projects and several other projects have already asked for using the infrastructure.

Innovation Potential We expect oRoKSI to become one of the largest and most comprehensive knowledge service for robotic agents. The knowledge representation and processing capabilities will be tailored for perception-guided manipulation activities performed by robots. To this end, oRoKSI will provide particular support for common-sense and naive physics reasoning and the integration of these capabilities into robots.

B.1.4.1.2 Robot Knowledge Bases

To perform knowledge supported problem solving, such as figuring out possible locations of an object, one needs to couple knowledge with appropriate inference mechanisms. The term "knowledge system" covers various approaches and implementations of software systems which operate with explicit knowledge that can be maintained separately from the code that runs the program. In general, knowledge systems consist of reasoning algorithms, knowledge bases and additional tools.

State of the Art Knowledge systems are part of the Artificial Intelligence computer science subfield. Prolog [CR93] and Lisp [McC78] are used in knowledge systems such as IBM's Watson [IBM14], Cyc [Len95], and Clips [SGS05]. However, more recent systems often use their own implementations of reasoning algorithms and knowledge representations. Examples are Jess [Hil03] and Clips [SGS05]. Both can support fuzzy logic and rely on an improved version of the Rete algorithm [YYW11; Owe10], which is currently the standard for rule execution or forward chaining.

Clips, Jesse and similar systems do not provide any knowledge. That is, knowledge needs to be added manually for each task domain. Watson is a highly specific knowledge system that is optimized for answering trivia (Jeopardy) questions and only a small part of its functionality has been made available to the public [IBM14].

Cyc on another hand, comes with the world biggest commonsense knowledge base, which tries to encode all aspects of knowledge known to humans, and is open to a large extent [Len]. Furthermore, Cyc can be extended in case something is missing. Currently, Cyc KB contains over 500,000 terms, including about 17,000 types of relations, and about 7 million assertions relating these terms, excluding instance data which is usually prevalent in knowledge bases such as Freebase [BE+08]. Besides having the biggest commonsense knowledge base (it took more than 900 human years of effort to built), Cyc has also custom implementations for inferencing, which can cope with big knowledge graphs and isintegrated into a strong array of truth- and knowledge-maintenance tools.

Besides traditional knowledge systems, recent research has focused on developing a world-wide, distributed and heterogeneous knowledge system called the Semantic Web [BLHL+01]. The idea here is to assign names that are universally unique and that can be shared. Statements that are constructed out of these names can also be interpreted and reasoned over (RDFS, SKOS, OWL). Data publishers are encouraged to make unanticipated reuse of existing data though linking, resulting in Linked Open Data [Lin]. Large collections of Linked Data are currently being published, e.g., DBpedia [BL+09]. Consequently, research has forcussed on the large-scale storage of Semantic Web data for the purpose of querying and reasoning. This has resulted in dedicated database systems, so-called triple stores, such as Virtuoso [EM07], Jena [Apa] and GraphDB [Gra]. Reasoning has been dominated by a concern for complete inference with provable performance characteristics, implemented in Description Logic reasoners such as MSPASS, Pellet, FaCT++ and KAON2. However, interactions between the declarative programming, reasoning systems, and Semantic Web paradigm exist, e.g., ClioPatria [WB+15].

Consortium Expertise and Contributions to State of the Art CycEur and VUA have been involved in LARKC (EU project) [AC+11]. In LARKC, a large-scale reasoning platform over heterogeneous knowledge sources was created by relaxing completeness and by applying metalogical reasoning in an effort to select inputs to and control the direction of inference. LARKC has made significant innovations regarding the scalability of knowledge storage and automated reasoning. The former has resulted in an RDF data-layer (OWLIM, now GraphDB) capable of storing tens of billions of RDF triples [BK+11]. The latter has resulted in reasoners such as Marvin [OK+09], WebPIEurbani2012webpie, and QUERYPIE [UH+11], that can handle knowledge bases consisting of billions of statements.

Furthermore, CycEur was involved in the creation of a startup which sells an Artificial Intelligence assistant called Curious Cat[4]. Curious Cat takes a given incomplete knowledge base, identifies missing parts, and produces natural language questions that — when answered by a user — allow the knowledge base to be automatically extended.

Innovation Potential Within OROKSI, knowledge from three sources will be combined: (1) the curated, detailed knowledge base supplied by Cyc, (2) the large and dynamic but messy Semantic Web, Linked Data Cloud, and Schema.org datasets, and (3) new knowledge that will be created based on generalizations over episodic memories of robots. This will be achieved through several non-trivial knowledge integration tasks.

Within OROKSI, knowledge will be selected by robots in an innovative way. Given the size, heterogeneity and dynamicity of knowledge, robots must be able to select only those sources that are relevant with respect to certain *contexts*. This involves automated knowledge (source) selection and knowledge request federation (e.g., combining knowledge from multiple sources to serve a robot's request for information). The task at hand and the service description of the robot will be essential parts of the context.

Within OROKSI, different ways of reasoning will be considered and combined to circumvent the "toy problem"-problem. Commonsense and naive physics knowledge has traditionally been applied in relatively closed systems. Since OROKSI robots will operate in *open-ended environments*, reasoning approaches must be able to cope with uncertainty, dynamicity, and context-dependency. The forms of reasoning to be considered include RDF(S) + OWL deduction, causal reasoning through counter-factuals, Qualitative Reasoning, default reasoning, non-monotonic reasoning / belief revision, and induction from episodic (robot) memory. The approach will be supplemented with non-decarative extensions, incorporating aspects such as word occurrence and word similarity.

Reasoning processes within OROKSI will have to be *resilient*, supporting fallback cases ("what happens when something goes wrong?"). Resilience implies that the knowledge system exhibits *graceful degradation* of performance. For instance, a robot can not find a glass of orange juice but it can find a glass of water, still succeeding on the task "fetch liquid" though failing on the tasks "fetch orange juice". The reasoning paradigms that are chosen allow different kinds of fallback options. For example, Qualitative Reasoning allows causal explanation generation [FF90] and diagnosis upon failure [VRK03] as by-products.

B.1.4.1.3 Knowledge-enabled Robot Programming

Robots mastering object retrieval tasks will have to perform tasks as general as such as "bring me some water". We believe that an essential planning capability of robotic agents mastering everyday activity will be their capability to reason about and predictively transform incomplete and ambiguous descriptions of various aspects of manipulation activities: the objects to be manipulated, the tools to be used, the locations where objects can be manipulated

[4] http://www.curiouscat.cc

from, the motions and the grasps to be performed, etc. Vague descriptions of tasks and activities are not only a key challenge for knowledge representation and processing but also an opportunity for more flexibility, robustness, generality, and robustness of robot control systems.

We humans have an enormous amount of knowledge about all aspects of the activities we perform because they are variants of *everyday activities.* Anderson [And95] defines an everyday activity as *"a) a complex task that is both common and mundane to the agent performing it; b) one about which an agent has a great deal of knowledge, which comes as a result of the activity being common, and is the primary contributor to its mundane nature; and c) one at which adequate or satisficing performance rather than expert or optimal performance is required."*

So what is the commonsense and naive physics knowledge that a robot needs about an activity such as pancake making? [KB] reformulate the pancake making task as a qualitative reasoning problem in the sense of the "egg cracking" problem [Mor01]. The problem description includes the following questions:

What happens if: *"the robot pours too much pancake mix onto the pancake maker? too little? the robot pours the mix close to the edge of the pancake maker? the robot flips the pancake too soon? too late? the robot pushes only half of the spatula's blade under the pancake? the robot turns its wrist too slow? the robot uses a knife/fork/spoon to flip the pancake? the pancake mix is too thick? too thin? [. . .]"*

State of the Art Most robots employing knowledge representation and processing do so in a so-called 3T architecture, a software architecture that specifies robot control at 3 layers of abstraction. The lowest layer is the control level in which robot control is specified in continuous feedback loops.The highest level typically adopts model assumptions that consider actions to be black boxes. Plans are partially ordered sets of atomic actions with orderings being the only control structure available. The intermediate layer is needed to bridge between the model of the highest and the lowest layer. The intermediate layer is typically realized through plan executives or reactive plan interpreters.

The 3T architecture yields several problems making the competent execution hard. First, the course of action that is generated by the plan executive often differs substantially from the plan specified at the highest level of abstraction. Second, the highest level of abstraction cannot make use of the rich control structures that specify robust and flexible behavior that are used by the plan executive and the low-level control components. Third, because of the high level of abstraction the grounding of symbolic representations in robot execution is unnecessarily difficult.

Consortium Expertise and Contributions to State of the Art UniHB has a long history of designing, realizing, and investigating knowledge- and cognition-enabled control systems for robots. The main difference between these plan-based control systems proposed by UniHB and others is that our plans are allowed to specify concurrent, perception-guided behavior and execution-time reasoning. The potential of this programming paradigm has been shown in various demonstrations of robots performing complex manipulation tasks such as making pancakes, buttering toasts, cooking sausages, making popcorn, performing chemical experiments and long-term fetch and place tasks.

Innovation Potential oRoKSI will substantially increase the flexibility, robustness, and competence of robot control programs for object retrieval tasks. Robot plans will be very compactly and abstractly programmed with a clean separation of control programs and knowledge that is used for inferring how actions are to be executed. The knowledge infrastructure provided will enable robots to "know what they are doing". That is, robots can answer queries about what they did, how they did it, what they saw, etc.

B.1.4.1.4 Lead Application Scenarios

State of the Art

Consortium Expertise and Contributions to State of the Art

Innovation Potential

B.1.4.2 Innovation Potential

Using knowledge bases to provide services is an established technology as of today. Several prominent examples of so-called "intelligent personal assistants" include Apple's Siri agent, Amazon's Echo, HTC's Hidi or Microsoft's soon to launch Cortana. In case of these systems, the knowledge base is queried and the outcome is supplied to the user, but the common sense knowledge still resides with the human. Additionally, it does not interact with the user via cameras or actions and is not capable of relaying its learning experience and making them available for future use. Systems like Siri are limited in just compiling and distilling information from the internet; they do not possess the ability to gauge the implications that physical actions might have. This becomes very apparent when considering "intelligent personal assistant" facilitated translations. In many cases, any ambiguity in language will be translated as is, without any way to qualify the statement. For a robot, ambiguity is not an option. That is where the common sense component of ORoKSI comes in. It disambiguates and so allows bridging the gap from knowledge to action, thus enabling the robot to carry out actions in a sensible fashion. The knowledge database developed will not be a static repository, but will be employed in real-life situations, for example the planned use in a care institution for people with bodily handicaps during the project runtime. Of course, the major application at a later stage can be seen in industrial robotics. Up until now, industrial robots are controlled via a PLC with a very limited set of commands and virtually no ability for reasoning or learning. While this is entirely sufficient for example in a moving assembly line environment, more demanding and complex tasks require much more sophisticated capabilities. With ORoKSI and OpenEASE, perception is translated into action. The resources used and experiences made by the robot will in turn increase the knowledge database itself. With the reasoning capabilities afforded to the robot by this approach, human-robot work teams will be a safe, efficient and indispensable part of future production processes. Similar research projects are discussed above, like the Robo Brain project, which is superficially similar to ORoKSI, but differs in a lot of key aspects.

B.2 Impact

The objectives of the OROKSI project are fully aligned the draft of the action plan for **digitising European industry**, which is seen at political as well as top industrial level as a huge opportunity and challenge for sustainably growing the European business. In particular, OROKSI aims at contributing to the pillar 2 “digital industry platforms” by building an essential part of the technological foundations for a digital innovation platform for knowledge-enabled robotics.

According to the EC digital innovation platforms can be considered from an innovation point of view to be “reference architectures/implementations with an innovation ecosystem triggering broad value creation”. Platform businesses are dominating the digital economy with record-high market caps, and growing asymmetrically by crossing over traditional industry boundaries into entirely new markets. One of the most successful ones is the Watson subsystem of the IBM Bluemix platform. The Watson subsystem is a horizontal digital innovation platform, which enables programmers to implement cognitive programming applications across a broad spectrum of task and application domains. One of the application domains that is targeted by Watson is robotics. IBM cooperates with Softbank on social robotics and the IBM research laboratory in Zurich investigates the application of the cognitive programming technology to agriculture robotics.

We have already described a vertical digital innovation platform in the introduction of Section B.1, where we characterized the business strategy of the hypothetical high tech company RAS-TEC, which specialized on the robotics market but covers the development of hardware platforms to intelligent robot programming.

Looking at OROKSI as a digital innovation platform that brings together stakeholders that enable robots to turn the “big data” of robotics namely the experience data of robots including the images that robots capture, their behavior, and the effects of their actions into valuable knowledge allows us to illustrate the possible impacts of OROKSI very clearly and make use of this knowledge. This is because the impacts of “big data” and the transformation of the data into valuable knowledge has been discussed in recent years and the materizalization of this impact outlined in a number of roadmaps.

The role that this technologogy is expected to play for the European economy is described, for instance in the Strategic Research and Innovation Agenda, SRIA, which states: “The goal [...] is to increase the amount of productive European economic activities and the number of European jobs that depend on the availability of high quality data assets and the technologies needed to derive value from them.”

The strategic importance of big data as a primary asset for all sectors, organizations, countries, and regions is also emphasized in a number of statements. The EU commissioner for the digital agende who repeatedly stated that “big data is the new oil”. Ginni Rometty, President and Chief Executive Officer of IBM asserts “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.” The European Council concludes (24/25 October 2013) “As part of its growth strategy, Europe must boost digital, data-driven innovation across all sectors of the economy.”

Without doubt much of the big data will be generated by robots. Robots on the factory floor will collect production data at a unprecedented level of breadth and detail, high precision farming robots will navigate through fields, orchards, and vineyards and build models of how the harvest develops over the year from the sensor data of the robot interpreted with background knowledge, autonomous underwater robots will perform surveillance tasks in critical regions of the oceans and acquire valueble models for environment science, robots in smart cities will learn movement patterns of people and thereby automatically evacuate places in the case of disasters, domestic robots will learn patterns on how to effectively interact with humans, and so on. OROKSI will substantially advance the technological foundations of generating semantically interpreted information from robot experience.

Robotics will play a particular role as a data source in the big data field because robots generate the big data by interpreting the robot plans. This is important because at this point the robot can semantically label the experience data and thereby generate highly informative data. The second particularity of big data generated by robot behavior and activity is that the data generated fron intelligent activity corresponds to what we call commonsense and naive physics knowledge, the kind of knowledge that everybody has and uses but that is so difficult to spell out and very hard to read about. Finally, commonsense and naive physics knowledge has one big advantage over the commonsense and naive physics knowledge that humans have, namely the robot knowledge can be be put into the cloud and shared by all robots.

From position and strategy papers in the closely related “Big Data” research field (eg, [**BigDataValue**]) we can derive that comprehensive robot knowledge bases formed from big data will impact the European Unions priority areas as follows:

- **Economy:** Competitiveness of European enterprises will be significantly higher compared to its worldwide competitors with improved products and services and higher efficiency based on Big Data value.
- **Growth:** There is a blossoming sector of growing new small and large businesses with a significant number of new jobs that create value out of data
- **Society:** Citizen benefits from better and more economical services in trustful economy where data can be

shared with confidence.

B.2.1 Expected Impacts

B.2.1.1 Main Results of OROKSI

Main Result 1: Robot Knowledge Services to be written

Main Result 2: Robot Knowledge Bases to be written

Main Result 3: Lead Application Scenarios to be written

Main Result 4: Proposal for Standardization of a Knowledge Representation for Robots. OROKSI will propose a standardization for the exchange of robot knowledge. In a recent NSF strategic research workshop "Research Challenges and Opportunities in Knowledge Representation" (2013). The rapid evolution of the technology has been attributed besides technical advancements to the success of KR standardization efforts [**WS-Report**]: "For the first time since the advent of KR research, the last decade saw the development, and, more important, wide acceptance of international standards for describing data and ontologies on the Web and for reasoning with them. These advances lead to broad availability of structured data in standard formats for KR researchers and consumers." ***Such standardized languages will enable innovators and researchers in robot knowledge representation to automatically combine independently developed knowledge bases and collections of robot experiences.***

Main Result 5: Knowledge-enabled Robot Programming to be written

B.2.1.2 Expected Impacts from the Work Programme

Promote excellent science and technology knowledge in Europe, demonstrated by a high standard of research outputs (including publications, open source software or, as appropriate, patents);
expected impact on excellent science and technology knowledge
We aim at positioning OROKSI as a lighthouse project for knowledge-enabled robot control. In particular, OROKSI is intended to become a pioneering research project for the investigation of how generalizable and actionable robot knowledge can be acquired from high-volume data including robot experiences and shallow web information and provided through knowledge services. As such OROKSI is placed in the intersection of the areas of "Big Data" and generalizeable knowledge, which are of essential scientific and economic importance as argued in the introductions of Section B.1 and Section B.2. The key impacts of OROKSI on excellent science and technology will be • peer reviewed scientific publications at the most selective and visible conferences and journals in the fields of robotics and artificial intelligence (see Table B.2.5); • opensource software (see Section B.2.2.1.5) and open formally represented knowledge, which will be made accessible to the community through OPENEASE (see Section B.2.2.2); and • the promotion of open and repeatable research and open teaching (see Objective 5 in Section B.1.1).
success is measured by:
• through submissions to and publications at very selective conferences; other measures such as citation indices have time delays that are too long to be relevant through the 3-year funding period of the project; • access statistics to the main OROKSI web pages; • a scientific advisory board, in which we will invite key members of the topic groups in the EC road mapping initiative, including Michael Suppa (TG Perception), Alessandro Saffiotti and Markus Vincze (TG AICOR — AI and cognitive robotics), Giulio Sandini, David Vernon, Matthias Scheutz (IEEE Technical Committee on Cognitive Robotics). • attendance in OROKSI organized research schools, training units, and workshops.
OROKSI has the capabilities to achieve these impacts because
The OROKSI consortium is selected to achieve scientific and technological leadership in the area of knowledge enabled robot control. UniHB has contributed substantially over the last years to the field of cognition-enabled robotics. Several best paper awards and finalists for best paper awards were won by the team in topics essential for OROKSI. These include a paper on ROBOSHERLOCK, a cognition-enabled robot perception system which one the best service robotics award at ICRA 2015, OPENEASE, finalist for the cognitive robotics best paper award at ICRA 2015, best paper award finalist for a paper on the representation and exchange of robot knowledge for the journal IEEE Transactions on Automation Science and Engineering, a finalist paper on interactive scene segmentation for the best service robotics paper at ICRA 2013, The paper "RoboEarth language: Representing and Exchanging Knowledge about Actions, Objects, and Environments" has won the Best Cognitive Robotics Paper Award at ICRA 2012. The opensource software tools provided by VUA has been an international leader in the advancement of the semantic web technology and high performance representation and reasoning tools for knowledge representation in the web. Key publications about different aspects of the web ontology language OWL reach tremendous number of citations, including the OWL overview more than 4000 citations, OWL reference almost 3000 citations. These standardization efforts for knowledge representation efforts for web information are considered to be one of the most important advances for knowledge representation in the last decade. Essential for the OROKSI research impact are also the many influential papers on high-performance web reasoning engines including LARKC, querypie, and webpie as well as tools for automatically turning linked open data for their use as formal representations. In addition, VUA has pushed research in general knowledge representation with van Harmelen being editor of the Knowledge Representation handbook one of the reference publications in the field. In addition, CycEur as an off-spring of Cycorp was involved in the creation and use of today's most comprehensive formally represented encyclopedic and commonsense knowledge base called Cyc. The core ontology publicly available as open knowledge is used as a starting point in many international research projects. The remaining partners HW, ALDEBARAN, and DLR are recognized leaders in successfully applying knowledge-enabled programming to autonomous robot applications.

Develop a new generation of robotic and autonomous systems with clear and measurable progress over the state of the art in terms of step changes in technical capabilities, as evidenced by improvements in performance (including in terms of affordability, reliability and robustness, energy autonomy and user acceptability);
expected impact on new generation of robotic systems
OROKSI develops the knowledge representation and processing technology that enables robots to make decisions and parameterize actions based on inferences from knowledge bases. The new generation of robotic and autonomous robots will be knowledge-enabled robots facilitated by knowledge services as laid out in Section **??**. Reasoning about knowledge enables the robots to go beyond the functionality they have been explicitly coded for. They can act more flexibly, efficiently, and robustly by applying the relevant knowledge in the respective execution contexts. As a result the knowledge-enabled programming approach allows programmers to state robot plans and programs more abstractly, compactly, and modularily by automatically doing the necessary adaptation at execution time when the execution context gets known. The new generation of robot systems can be characterized as ***"robots that know what they are doing"***, that is robots that can answer queries about what they are doing, how they are doing it, what might happen if they are doing it, what theuy see or expect to see whan they are doing it, what the effects of actions might be , and so on. This capability of answering queries about actions is directly correlated with the performance of the robot because being able to answer queries improves the reliability and robustness of programs through integrated forsight and failure diagnosis for improved recovery. It also allows to exploit opportunities by being able to reason about how taking an opportunity might affect the course of action. The programming efforts needed for this new generation will be drastically reduced as the acquisition of knowledge can be crowd sourced and available knowledge be shared among the robots.
success is measured by:
The success is measured by the set of queries that can be answered using the OROKSI knowledge base. Example queries, which can already be answered using OPENEASE are displayed in Figure B.1.5. Relevant queries are queries about the tasks that the robot performs, the environment, the objects that it is to manipulate and handle, and the robot capabilities. We will specify a benchmark query set that is indicative for the knowledge and the reasoning capabilities that the robot has and use the benchmark queries for evaluating the capabilities of OROKSI. A second measure is based on the analysis of hardcoded robot plans. Here we will analyze robot control programs and consider all decisions and parameterizations that the programmer has preprogrammed and will measure the subset of queries that can be handled by OROKSI. This measure gives an indication of how much of the control programs can be rationally reconstructed in the knowledge-enabled robot programming approach and whether the necessary context information can be provided by the robot perception system and the answers executed with the control system. These experiments will be conducted using the CRAM (Cognitive Robot Abstract Machine) robot programming infrastructure that is available opensource from UniHB.
OROKSI has the capabilities to achieve these impacts because
Large software components that will be used in OROKSI are, as opensource laboratory prototypes, already available. These software components include KNOWROB (knowledge processing for robots: knowrob.org), OPENEASE (knowledge service for autonomous robots and robotics researchers: openease.org), CRAM (Cognitive Robot Abstract Machine: cram-system.org). They are available as source code, with documentation, installation guides, and tutorials. They are in use in several international research projects in the area of cognition-enabled robotics.

Greater industrial relevance of research actions and output as demonstrated by deeper involvement of industry and stronger take-up of research results;
expected impact on industrial relevance

OROKSI targets industrial relevance through three carefully chosen lead application scenarios and partners.

- ALDEBARAN will provide the biggest user group in domestic and service robot applications for OROKSI. Currently, more than 15.000 Nao and Pepper robots are deployed and Aldebaran provides an app store for its customers. OROKSI will add several free apps that showcase the power of knowledge-enabled robot programming. One of them is a self presentation of Nao and Pepper that accesses the representation of the robots and reasons from them.
- The second application domain is industrial robotics and in particular manufacturing. In this domain the OROKSI efforts are lead by DLR, which is an expert in technology transfer in the area of manufacturing robotics. Here, DLR takes a multiplier role for the OROKSI research also capitalizing on its key role in European projects including SMErobotics and EUROC, which are targeted at a successful transfer of robotics research into the relevant industry sectors.
- The third lead application scenario is characteristic for applications in which robots are specifically designed for applications and are required to operate outdoor over long periods of time. For such applications the strategy is to report on successful robot missions.

OROKSI will apply to participate in the EU coordination action RoboTTNet in order to receive consulting on how to develop a business plan for the technology developed in OROKSI.

success is measured by:

- participation of industry in OROKSI teaching and training events
- adoption of technology through industry through research and development and transfer contracts or industry-sponsored doctoral students who transfer the technology

OROKSI has the capabilities to achieve these impacts because

- input from HW, DLR, ALDEBARAN
- industrial advisory board
- innovation radar
- can we collect quotes about the potential benefit of OPENEASE/KNOWROB from Roboception, Magazino, Siemens, Bosch, SeeByte (David), Kuka, others, Cycorp, Daimler(?), BMW(?), please add

Fostering new links between academia and industry, accelerating and broadening technology transfer;

expected impact on fostering new links between academia and industry, accelerating and broadening technology transfer

- UniHB, HW (Edinburgh Robotics Centre) and DLR provide limited services of digital innovation hubs
- OROKSI web site provides direct open access to complete robot control programs. The programs can be run in downloadable and modifiable simulation environments
- teaching/training events (in particular OROKSI schools)
- participation in openAIRE (open data pilot)

demonstrated by . . .

success is measured by:

OROKSI has the capabilities to achieve these impacts because

- DLR: is a key partner in
  - SMErobotics: European Robotics Initiative for Strengthening the Competitiveness of SMEs in Manufacturing is set to bring cognitive robotics from vision to reality in a key segment of EU-manufacturing.
    The SMErobotics initiative pays careful attention to SME-related issues and scientific challenges, as is reflected by its strong industrial involvement supported by leading researchers and building on successful collaboration between industry and academia as well as on demonstration-driven research from the SMErobot project.
  - EuRoC:

Improving the competitive positioning of European robotics providers in the marketplace, in terms of their penetration in new or emerging robotics sectors.

Better Systems and Tools: Modelling and Knowledge Engineering

H2020 target: To develop methods and tools to integrate and map knowledge from different domains, and to share knowledge between robots. To develop methods and tools to transform different abstractions of models using additional domain or application specific knowledge. To develop meta-models and tools for knowledge representation that are specific to robotics.

OROKSI fully addresses the goals of the H2020 target. OROKSI develops

- a collection of knowledge bases for different tasks, robots, and environments that can be shared among applications;
- learning and representation tools that take annotated log data of robot activity episodes and generate generalizeable knowledge from it; and
- knowledge representation and reasoning tools that are specific to robotics.

Better Action and Awareness: Cognition Knowledge Representation and Reasoning

To leverage the use of available KR&R methods to allow robots to: understand their environment at the semantic level; cope with partial and inconsistent information; engage in meaningful interactions with humans; easily incorporate new knowledge about novel tasks and domains; and share knowledge and experience with other robots.

OROKSI fully addresses the goals of the H2020 target. OROKSI develops

- OROKSI will further extend the representations and tools for semantic environment models that are already available in the knowledge processing toolbox KNOWROB;
- OROKSI will be equipped with different reasoning techniques. Some of them are designed to deal with partial and inconsistent information.
- as depicted in Figure B.1.3 which depicts the refinement of vague natural language instructions shows some of the OROKSI mechanisms that enable easier interaction with humans;
- the lifelong collection and extension of knowledge bases and the sharing of knowledge between robots are the adopted goals of the OROKSI project.

B.2.1.3 Barriers/Obstacles and Framework Conditions

The OROKSI consortium has identified three main obstacles that may prevent achieving the desired impact. The first barrier has to do with the perception and acceptance of robotics in society, but also the perception of AI technology and tools for robotics in the robotics community itself, and with the community building aspects of the project. The latter is especially crucial for prolonging the project's lifetime and its beneficial results, as the desired developments, namely the open source software and the open access knowledge database, depend on an active and engaged community for use, enhancements and maintenance. The project consortium will build and engage the European robotics community form the very beginning of the project, based on the existing international network of scientists to mitigate this barrier as best as possible.

The second obstacle is based on privacy issues. As a core element of the open-access knowledge database the robots are capable of uploading information about what they perceived, how they acted and what led them to conclude a particular course of action that was appropriate. The use of these data has to be carefully and conservatively regulated. As a concrete example, the robots are equipped with high-resolution camera systems. This will require all filmed persons to provide consent that their likeness is uploaded to a database. Several measures are already investigated to prevent this problem from negatively affecting the project and the willingness of members of the community to upload their data onto the knowledge database. The first would be to replace all human footage with a wireframe model, essentially keeping all the relevant data regarding interaction, trajectories and placement intact while also providing a great measure of privacy protection. Before any data is uploaded, it is planned that a preview of the context that will be uploaded can be viewed, allowing the uploading party great control and insight into the sharing of their data. Furthermore, a confirmation of the uploader will be required stating that no privacy rights were violated generating the data and that the website will not be liable for the use a third party makes of the available data, while still trying to reduce the chance for misuse as much as possible.

The third barrier identified is inherently linked to the acceptance and perception issues discussed above. For a vast majority of people working in the field of robotics, AI technology does not come naturally. To get these crucial individuals and companies "on board" with the OROKSI project and its goals, it is imperative to provide the right impetus to motivate them to regard AI technology as an integral part of sophisticated robotics. In order to keep this obstacle as small as possible, several measures are already planned. In addition to providing visual aids to help people understand the aims, technologies and usability of the OROKSI project and its results, technology demonstrations will be available to let prospective users test out the system with their specifications and the information base grounded in the developed technology. This will hopefully ease any concerns about the unknown AI technology of robotics designers, manufacturers and users.

B.2.2 Measures to Maximize Impact

B.2.2.1 Dissemination and Exploitation of Results

B.2.2.1.1 Dissemination Plan

The OROKSI consortium follows a dissemination and communication strategy based on a cascading principle. At the first stage OROKSI disseminates and communicates the potential roles that OROKSI can play for the individual OROKSI partners. The second stage is the dissemination to the stakeholders of the OROKSI value chain and the business partners of the corresponding digital innovation platform. Here we will target the partners with information tailored to the respective stakeholder role. Finally, we will disseminate information about the project and the potential relevance to everybody's life to the general public.

Level 1: Internal dissemination

ALDEBARAN	• OROKSI principal investigators will visit ALDEBARAN in order to discuss further synergies and identify opportunities for OROKSI at ALDEBARAN.
CycEur	• OROKSI principal investigators will visit Cycorp in Austin in order to discuss opportunities for cooperation and promotion of knowledge services.
NEUSTA	• OROKSI principal investigators will visit ALDEBARAN in order to introduce OROKSI and its possibilities to the company.
UniHB	• use of OPENEASE for teaching • make oroksi visible to students (recruiting) • 2 OROKSI open days for the research focus area "Minds, Machines, and Media at the University of Bremen
VUA	
DLR	
HW	• OROKSI will present itself at information days of the Edinburgh Robotics Centre

Level 2: OROKSI Stakeholders Groups The stakeholders of the robot knowledge value chain, which have been identified in the Section B.1.3.4, are the main target groups of the OROKSI dissemination plan. The target groups together with the respective OROKSI dissemination goals and plans are shown in Table **??**.

Target groups	Goals & Plans
producers of robots and robot components	• **Goal 1:** engage producers to make models of robots and robot components available in OROKSI • **Goal 2:** convince producers to support knowledge exchange between customers using OROKSI • **Plan 1:** demonstrate the possibilities of OROKSI using the Nao and Pepper robots of ALDEBARAN as examples • **Plan 2:** teach the possibilities in international OROKSI schools and training events, ie provide some services of digital innovation hubs.
SMEs providing robot functionality	• **Goal 1:** make companies aware of the potential of combining knowledge processing with other robot functionality such as perception, motion planning, learning in order to make solutions more generalizeable and to ease programming • **Plan 1:** demonstrate the potential using downloadable examples on the OPENEASE web page, in particular in the context of the OROKSI perception system ROBOSHERLOCK and the plan-based control system CRAM • **Plan 2:** teach the possibilities in international OROKSI schools and training events, ie provide some services of digital innovation hubs.
SMEs providing complete solutions	• **Goal 1:** make providers of complete robot solutions aware of how they can profit from OROKSI • **Plan 1:** communicate the lead application scenarios and how they can be transferred to other applications • **Plan 2:** teach the possibilities in international OROKSI schools and training events, ie provide some services of digital innovation hubs.
ICT companies	• **Goal 1:** make ICT companies aware of the possibilities that the semantically annotated robot knowledge bases and “Big Data” robot log data that the knowledge bases of OROKSI will provide • **Plan 1:** OROKSI will provide high volume robot data as open data to the community and potential data users • **Plan 2:** teach the possibilities in international OROKSI schools and training events, ie provide some services of digital innovation hubs.
users of robotics technology	• **Goal 1:** convince end users of robotics technologies, such as manufacturing companies, of the superiority of knowledge-enbled robot programming over conventional robot programming methods • **Plan 1:** OROKSI will provides the lead application scenarios as examples to be communicated to end users • **Plan 2:** teach the possibilities in international OROKSI schools and training events, ie provide some services of digital innovation hubs.

In order to reach the different stakeholder groups more broadly, OROKSI will

- actively pursue the publication articles in technology scouting journals and websites such as MIT Tech Review. OPENEASE was already featured in an MIT Tech Review article “Robots learn to make pancakes from WikiHow articles” (August 24, 2015).
- OPENEASE was spotted as a high potential innovation/innovator by the EC innovation radar based on a high IPI (Innovation Potential Indicator) (see innovation radar paper). This gives the project higher visibility as, for example, a participation at the Cebit trade fair as ???
- intensify the contacts with international technology scouts to build networks of international cooperation that are necessary to build a community around OROKSI.
- use coordinated actions of H2020 to promote technology transfer. In particular, we plan to apply for consultancy by the robot technology transfer network ROBOTTNET *http://www.robott-net.eu/*

Dissemination into the academic community In order to build a digital innovation platform that boosts technological progress and innovation it is essential to obtain sufficient suport from the academic community.

The chances of getting the academic community involved are high as OPENEASE provides a number of services that are valuable for researchers. These services will include

- the possibility to upload semantically annotated log data of robotics experiments into OPENEASE and make

them accessible (if necessary anonymously) to other researchers. One application is to make the experimental data of an experiment of a submitted publication accessible to the reviewers and thereby make the experiments much more transparent and repeatable for the reviewer;
- the automatic generation of videos from robot log data that can highlight selected information such as objects, trajectories, poses, etc. The videos can be used to improve the presentation of research work;
- methods for semantically retrieving information from logged robot experiments and learning models from these data, which will greatly improve the generation and testing of research hypotheses;
- the provision of open access to comprehensive data of leading edge autonomous robot activities to research communities that, up to now, never had access to such data but performed the research based on self-generated abstract problem formulations. These communities;
- support for the definition of research benchmarks. Because of the comprehensive collection of robot experience data researchers can use the data to generate realistic benchmark tests. For example, a benchmark test for object perception can be collected by first learning the distribution of perception tasks that a fetch and place plan generates, retrieving the exact poses from where the perception tasks are to be performed, and the hand poses where the object was successfully picked up afterwards.

The OROKSI consortium believes that the services provided by OPENEASE are so valuable, unique, and useful that we can build up a research community using OROKSI.

Level 3: General Public
- Universum Bremen; Bremen's Tech Museum with organized events
- open robotics lab at University open day (Bremen)
- go4IT
- participation in European Robotics week
- ...

Dissemination actions towards the EU OROKSI will employ the dissemination opportunities provided by the European Commission and other projects funded within the Horizon2020 framework to their full extent. Each of the possibilities available through the European Commission will be carefully analysed regarding its possible benefits for the OROKSI project, and any beneficial dissemination opportunity will be taken.

In particular, OROKSI will aim to communicate through the following EC supported media channels:
- magazine aricles:
  - Horizon Magazine (http://horizon-magazine.eu/)
  - Project stories (https://ec.europa.eu/programmes/horizon2020/en/newsroom/551/)
  - research*eu results magazine (www.cordis.europa.eu/research-eu/magazine_en.html)
- a promotion video at Futuris Magazine (http://www.euronews.net/sci-tech/futuris/)
- participation in the open data pilot Openaire (www.openaire.eu)

These efforts allow the OROKSI project to penetrate the knowledge database and associated software for robotic tasks market at a European scale. The same is true for the European scientific robotics and AI communities. A detailed description of this area will be generated in parallel to the work performed for the exploitation planning of OROKSI.

B.2.2.1.2 Exploitation Plan

This chapter describes our initial ideas for the preparation of the Exploitation Plan, its basic structure and the necessary steps to be taken. The exploitation activities consist of promoting and planning the advertising and commercialisation of the knowledge database and its associated software developed within the project. The software mentioned will contain two distinct programs; one for knowledge base interaction like querying, managing and data exchange; the other one as a software module for the robot itself, allowing contacting the database, querying the hardware and perception systems.

This task will be initiated very early during the project's duration in order to prepare and steer - from the very beginning - the successful exploitation of the various expected project results, on an individual partner level and for the whole consortium. As the OROKSI project will result in products that are free to access and open source, the classical approach to project exploitation cannot be taken here. Due to the freeware nature of the results, the most important thing to consider is the **added value** generated for Europe as an innovative research environment for robotics and knowledge databases that justifies the joint investment of the EC and the project partners on an economic and social level. This level of the knowledge database and the associated software can be regarded as the rough work-in-progress version. It will, as said before, be available in the cloud, and is mostly intended for researchers and companies interested in trying out these newly developed approaches. As with many open source projects, the clear intention is to acquire a group of specialised scientist interested in further developing the database and its tools, even after the project ends. This kind of crowd-sourced technology development is very common especially in the field of robotics, as the software attains a level of complexity that cannot be readily tackled by most small- to medium-sized companies.

On the side of the commercial interests of the project consortium, it is planned to build upon the foundation of the open access and open source products and offer services that are of great interest to commercial incorporation. In such a scenario, the open-access knowledge base would be cloned and tailored toward high-performance systems. The same customization process would be carried out with the software. There are several incentives for customers to invest in the professional version of the products. Firstly, they would in effect generate a personalized version of the knowledge base, thus allowing confidential information and protocols to be implemented freely. The commercial version would be more polished, more resilient and streamlined towards the customer's actual needs and requirements.

An example for a customer would be a company working in the field of robotics. Being able to make use of the tailored offerings and enjoying training, maintenance and regular updates incorporating tested advancements from the open access products will considerably increase the competitiveness and product quality of a customer. It is planned to found the oRoKSI Company within the first two years of the project to provide these services to the market. Specific services include the installation of the cloud system to the technology of the customer, training courses, consulting, software maintenance, generating middleware as a mediator between already used software and oRoKSI and updating the database and software in regular intervals. Of course, the integration of specific other software would also be part of this companie's service portfolio.

Another important aspect that has to be considered as an exploitation operation is the generation of a standardization proposal during the project runtime. In the best case scenario, the oRoKSI products would be defined as the new gold-standard for robotic knowledge databases and querying software and protocols, but it would be overly ambitious to assume that this goal can be attained so quickly. In contrast, providing a solid standardization proposal is both an attainable and a highly desirable outcome of the project. It will allow the scientific community to focus its research towards one common goal and methodology, thus greatly increasing their efficiency.

The overall exploitation strategy will be conceived according to the model of Exploitation Parameters, presented in the following section.

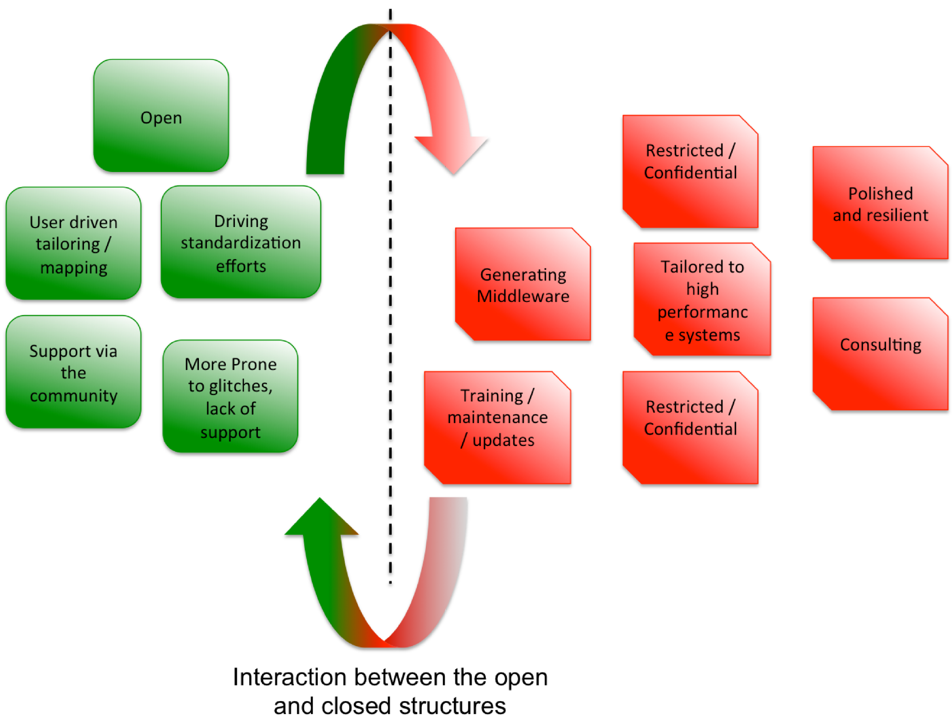


Figure B.2.1: Core exploitation competences for the open source and open access community versus the oRoKSI Company structure envisioned.

B.2.2.1.3 Exploitation Routes

The exploitation planning for the results of the oRoKSI project will run along two main lines:

1. Open Source Software/Open Access Research and knowledge base interaction
2. Provision of Services and Training by a newly established company

The first option does not require a lot of effort by the consortium, or so it might appear at a glance. But, unfortunately, the servers and other infrastructure needed to provide the software and host the knowledge base do require not inconsiderable funds. In order to guarantee a continued operation of the crucial infrastructure and thus the continuation of the positive impact the ORoKSI project has on the European and international robotics community and their scientific advances, several options are conceivable. One would be to create a foundation with an industrial partner that has a vested interest that the development continues in order to reap its rewards later down the development line. For example, Bosch is known to support projects that want to keep their open source software available for as long as possible. A follow-up project would be another alternative to conserve the lifespan of the project for as long as possible. Especially in such a complex field as robotics, this has been known to be going a long way in establishing long lasting positive impact to the field. Example of this can be found in the support of the American DARPA supporting the Open Source Robotics Federation (OSRF) in the past or in the actions taken by the University of Tokyo.

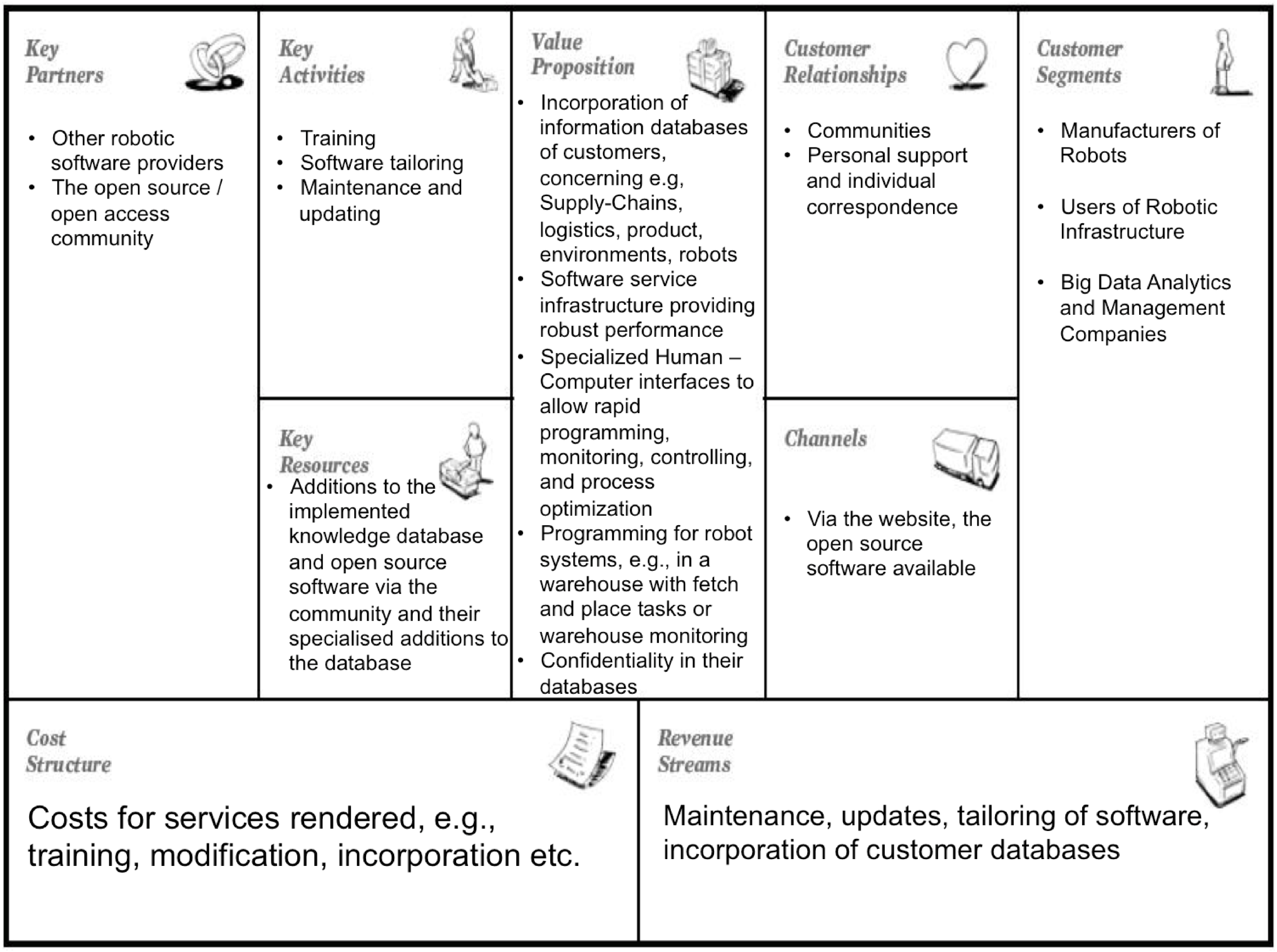


Figure B.2.2: Possible business canvas.

The second option, establishing a new economic entity as is the planned ORoKSI Company, is not meant as a way to take something away from the open source status of the other exploitation choice. Rather, it allows interested customers to utilize the know-how of experts in the field to make use of the knowledge database and the software programs to the fullest extend and exactly tailored to their specific needs and requirements.

For the company to be founded, we have included a very first draft of a possible business canvas, based on the model by Osterwalder and Pigneur [OP+11]. The Business model canvas consists of 9 fields. The value proposition stands at the core of the business model. Here the offering of the company is measured against the perceived value attributed to it by a customer. Tying together with the customer segment these two fields define what service will be provided and from which areas the core customers will be coming. Customer relationships define the major interaction pathways used to interact with customers and interested parties, whereas “Channels” refers to the primary modes of interest and awareness generation and product shipment. As a software and service company, the channels will play a smaller role than they would for a provider of a physical product. Key Activities, Resources and Partners describe what will be at the center of the business itself; what will be done to provide the service, what is required to be able to provide the service and where are the intersections with the value proposition of other companies. Lastly, the cost structure refers to the money that has to be invested in order to provide the service, while revenue streams are the different areas in which to turn a profit. The concept of the canvas tool requires an iterative approach to it, which is why the one found below is the consortium's actual draft. This canvas will stand at the core of the exploitation deliverable, or more specifically the part of the exploitation deliverable that is targeted at the company to be created. It is theoretically possible to devise a business model canvas for the other part, i.e., free software and open access to the knowledge database as well, but due to the structure and focus of the canvas itself this endeavour does not seem promising.

B.2.2.1.4 Partner's individual exploitation intents

Apart from the projects exploitation strategy with regard to the project results as a whole described above, **Academic Partners** will use the project results to stimulate work, to enhance the lessons to students, and to set up new research projects. All **Industrial Partners**, **Research Institutes** and **Consultants** have expressed an own exploitation intent described shortly in the Table B.2.3.

Partner short name	Partner Type	Exploitation interest	Horizon after project end
UniHB	Uni	• OPENEASE software as open source • OROKSI Company together with Neusta • open research • repeatable experiments • benchmarks • PhD, MSc, BSc Theses	ongoing
VUA	Uni	• Reusable OWL vocabulary for common-sense and naive physics knowledge on the Semantic Web • Standardization proposal for an OWL-based protocol and interchange format for robot knowledge requests. • PhD, MSc, BSc Theses	6-12 months
HW	Uni		
DLR	???		
ALD	???		
CycEur	SME	• Provide the Common-Sense Knowledge, Natural Language and Reasoning services and support to the real-world applications. This can cover more complex systems and the embedded devices as well. • upgrading CYC with the knowledge that can be obtained from experience and interactions with people. • Robotics as a potential new market for knowledge systems. • New way of Cyc knowledge manipulation (reasoning), which can be done locally in the machine but still contributing to global knowledge	ca. 6 months of productivization, then ongoing
NEUSTA	SME	• knowledge-enabled wearable interfaces for disabled people • cloud services for OPENEASE and the OROKSI Company customers	starting month 30

Table B.2.3: Individual exploitation plans

B.2.2.1.5 Open Software License Agreement/Terms of Use

In the OROKSI project, the fact that free to use / open source products constitute the desired outcome, the normally mandatory Exploitation consortium agreements have no real relevance. Instead, OROKSI will compile an Open Software License Agreement or Terms of Use that are compliant with current industry standards. In the case of the software component, the project will use the Open Source Robotics Association's ROS as an example. Regarding the knowledge database, it is foreseen that the partner CYC will be able to provide guidance, given their great experience with knowledge systems, even open source ones.

B.2.2.2 Managing data generated in the course of the project

The data management will be conducted with the regulation laid out by the EC in mind. In particular, all publishable material will be made available to the general public, if possible, on the website of the project itself. This will be achieved by endeavouring to publish peer-reviewed papers in accordance to gold and green open access, i.e. as publications that can be read by the general public, omitting direct costs or requiring the participation in costly portals. Additionally, the research data generated for the scientific publications will be made available, if no unforeseen constraints prevent the OROKSI consortium from doing so. Other published material will, precluding intellectual property right issues, be made available to the general public free of charge as well. The data will be uploaded into an appropriate repository that will be determined in the beginning of the project, ensuring that the data generated by OROKSI will be curated effectively and reliably.

It is the primary goal of* OROKSI *to build an open knowledge base for robots and to involve the community in extending the knowledge base to reach greater coverage. Already before the start of the OROKSI project the OROKSI knowledge base is used and extended by several European projects that use the common knowledge infrastructure but extend the knowledge base to serve robots that perform chemical experiments (EU project ACat), mixed human-robot rescue teams that search for victims after avalanches (EU project Sherpa), robotic co-workers that sort surgery instruments (EU project SAPHARI), and meal preparation (EU project ROBOHOW). Several other projects including the EU projects DREAM and STRANDS have experessed serious interest. In addition, the knowledge processing infrastructure is used for underwater robotics (Herriot Watt University) and for intelligent environments including robotic agents. ***In addition,* OROKSI *will propose a standard for exchange formats for robot knowledge based on the web ontology language OWL (task T1.4 in the work plan.)***

Within the consortium, the generated knowledge will be shared by employing an internal, confidential project repository, which facilitates fast knowledge transfer between the partners. The access rights and intellectual property rights will be regulated in the consortium agreement and amended if necessary.

All Knowledge Management and Intellectual Property Rights issues are governed by the provisions of the Consortium Agreement. All of its issues are fully compliant with the provisions of the EC Model Contract. The Consortium Agreement carefully identifies the foreground knowledge (generated during the project) and background knowledge (pre-existing know-how). Various areas will be covered by the Consortium Agreement including:

- Confidentiality the Consortium Agreement carefully governs issues related to the disclosure of confidential information in accordance to applicable laws and EC regulations;
- Obligation for use recognising the fact that the EC Model Contract requires the use of results (commercial exploitation or further research) the Consortium Agreement clearly specifies the responsibilities of the Partners to meet this requirement;
- Dissemination of knowledge all provisions of the Consortium Agreement regarding dissemination of Knowledge are in compliance with regulations affecting IPRs and reflect the requirements of the EC Model Contract. Recognising the importance of early dissemination of results, care has been taken to ensure that knowledge is protected from the project's start.

The Consortium Agreement regulates issues related to background knowledge, including the identification of specific background knowledge, conditions for use of such knowledge, differentiation between side-ground and background knowledge and issues related to potential disputes.

B.2.2.2.1 How the proposed measures will help to achieve the expected impact

Maximizing the science and technology knowledge in Europe impact
Maximizing the capabilities of knowledge-enabled robots and making these capabilities measurable
Maximizing the industrial relevance of research actions and output
Strengthening the links between academia and industry, accelerating and broadening technology transfer

B.2.2.3 Communication Activities

B.2.2.4 Target groups

The communication efforts of the OROKSI project will be targeted at two distinct groups. The first group consists of experts in the topics of AI technology, robotics and knowledge representations. The second group is basically everyone else. Both groups have, or should have, a vested interest in the OROKSI project and will be informed of its aims and progress during the project runtime.

B.2.2.4.1 Stakeholders

The stakeholders will be interested in the scientific side of the project. Therefore, measures will be implemented to allow them to experience the progress of the project first hand. The most important tool to communicate with this group is the website. In contrast to the usual type of project website, which has its uses but offers little in terms of interaction potential, the OROKSI website will allow interested parties to directly access the current state of the art. This enables these stakeholders to investigate the potential of the OROKSI project while it is being carried out. This will enable a dialog with the stakeholders on a level that can seldom be realised by collaborative project. In this, the idea that the software and the knowledge representation database will be available without charge provides a perfect opening for early connection to and engagement of a diverse group of interested stakeholders from academia or industry. Other communication measures that will be directed at this group will include visits to organisation that are potentially interested in the technology, providing seminars, workshops and trainings informing the stakeholders about the project, its current state and the objectives it is currently engaged in tackling.

B.2.2.4.2 General Population

The term "general population" is used to include all people that do not fall into the prior group. As robotics, and the inherently linked fields such as AI, knowledge databases and representations, will become more and more ubiquitous in the future, the general population should know what is currently possible, what is being done and why the EU is funding a specific project. It is therefore important to provide material and engage in communication measures that approach this target group in an understandable and relatable fashion without being patronizing. The OROKSI consortium has deliberately chosen the use case of "fetch-and-place" in relation to bodily disabled people to provide perspective what could be the ultimate result of the implementation of a knowledge base providing commonsense reasoning and nave physics capabilities to robots allowing human-level interpretation and manipulation. To enable the audience to understand the project and its goals, the OROKSI communication will use special channels, for example publication in non-scientific media such as local newspapers or magazines for laymen whenever possible and appropriate. WP8 contains several planned actions, while additional actions will be defined in the Dissemination and Communication strategy generated in task one of the mentioned work package.

B.2.2.5 Communication and dissemination materials and measures

There are several shared materials and measures for both communication and dissemination actions during the OROKSI project. The will be tailored to the above mentioned target groups and the corresponding dissemination level, if appropriate.

B.2.2.5.1 Project Leaflet and other printed material

The OROKSI project will release various target group oriented project leaflets, which will give the reader a comprehensive impression of the idea of the project, its objectives and the results expected to be achieved within the project's runtime. Other printed dissemination and communication material will be generated when needed, including but not limited to posters, flyers, roll-ups and brochures.

B.2.2.5.2 Project Web Site

A project web site will be established early in the project to provide wide dissemination of the results and papers, and information about the project. The web site will be tailored to the layman and the professional alike, and continuously updated. All public deliverables and all publications (barring copy-right restricted ones) will be available on the Internet site including the OROKSI project leaflet. The web site will be the main source of deliverables aimed at the wider research community and is already available in English language.

OROKSI will employ the website as a communication and dissemination tool to the fullest of its capabilities. This includes utilizing the platform aspects of the website to provide a place to discuss and develop the knowledge base and software with interested parties from academia and industry, to allowing interested people to run their own experiments on the website. This will be facilitated by the OpenEASE software already in place, acting as an open-science tool, and will enable interactions with the users, whether they are researchers or technicians form industry. It will even be possible for the user to employ the software in several use-case, for instance fetch-and-place in a factory warehouse environment or scenarios in which humans work side by side with robots. It will also be possible for the users to map the system according to their own requirements. This will provide deep insight into the inner workings of the system and will allow potentially interested parties to make informed choices about the applicability of the oRoKSI solution to their challenges.

The most important instrument for all communication and dissemination efforts and, thus, for prospective exploitation as well, is the website for the openEASE software. It functions as a portal for the knowledge database and is fundamentally different from any classical project website. In the latter, the aims, goals and progress of the project are reported and communicated. On the former, the project itself unfolds in front of the visitor's eyes. openEASE allows interacting, manipulating, and tailoring of the parameters in a virtual environment. Experiments can thus be conducted and tailored to a specific setting. The importance of openEASE, as of now already functioning, cannot be overstated. It ties in to virtually every aspect of the project, and in many cases is the fundamental deciding factor, for example, in the creation of a vibrant, engaged and contributing community for the maintenance and expansion of the open-source software and free access knowledge database. The knowledge database will be accessible from the very beginning and will continuously grow during oRoKSI and after.

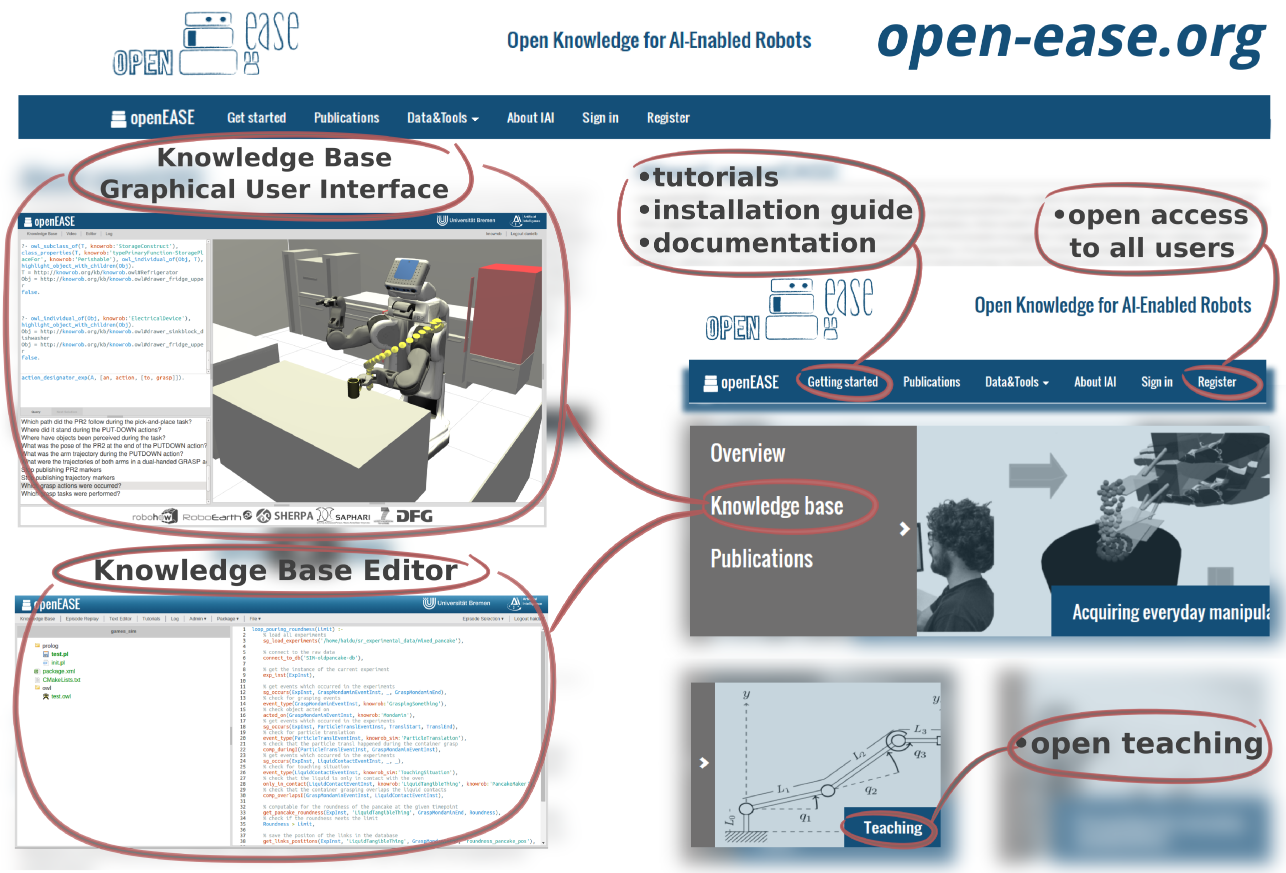


Figure B.2.3: openEASE web page

oRoKSI project will establish a community of dedicated researchers and developers through the openEASE knowledge base that will contribute measurably to the long-time success of the whole field of robotics.

B.2.2.5.3 Papers, Conferences, Exhibitions

There will be articles in trade journals, and other publications as part of the communication and dissemination activities. All public deliverables will be available on the project website.

oRoKSI will participate in related and interesting European Events, see below for planned venues, and, in addition, the consortium will identify at least 3 International Events at the end of the project development, where oRoKSI could present the main results of this R&I action.

Relevant Conferences Presenting the rationale behind the OROKSI project and selected results at conferences, fairs and workshops will provide the opportunity to not only disseminate the project to a wider audience, but also enable communication with other experts in the fields of knowledge bases and incorporation for robotics. Presentations are also a good first contact opportunity, paving the way for joint commercial interests later on.

In addition to the more scientific conferences fairs that are close to industry will also be visited. The OROKSI consortium intends to present some of the research results at the AUTOMATICA fair, Munich in 2018. This international industrial fair is one of the most important exhibitions on industrial robotics as well as service robotics worldwide. It is also a meeting and exhibition place for robotics research presenting their results to a wider audience, especially the industry. Other fairs that are of particular interest could be the Hannover Messe and the CeBIT, especially from project month 24 onward. Demonstrations in similar industry-oriented environments will be considered throughout the project. A live demonstration of the OROKSI technology is planned for the European Robotics Forum as well.

It is planned to contribute with workshops to the most important conferences in the field, for example to the IEEE or the IJCAI. Also, the OROKSI project will apply for a Dagstuhl Seminar, an invitational seminar for informatics that allows inviting the experts in a field from all over the world to a concise exchange of opinions, best practices and knowledge. The topic of the seminar would be “open knowledge representation for robots” and the consortium members would act as the main organisers for it.

Smaller informal workshops or visits of interested industrial parties to the university partners will be scheduled as is convenient.

The OROKSI consortium members have compiled overviews of national, European and worldwide conferences, fairs and exhibitions that are of interest for dissemination (Table B.2.5). This list will be amended throughout the project’s runtime.

Acronym	Full name
AAAI	Association for the Advancement of Artifcial Intelligence
AAMAS	Autonomous Agents and Multiagent Systems
ACS	Advances in Cognitive Systems
ECCV	European Conference on Computer Vision
ESWC	Extended Semantic Web Conference
ICCV	International Conference on Computer Vision
ICRA	IEEE Robotics and Automation Society’s flagship conference, a premier international forum for robotics research work.
IJCAI	International Joint Conference on Artificial Intelligence
IROS	IEEE/RSJ International Conference on Intelligent Robots and Systems, an annual academic conference covering advances in robotics.
ISER	International Symposium on Experimental Robotics
ISRR	International Symposium on Robotics Research
ISWC	International Semantic Web Conference
KR	Knowledge Representation and Reasoning
RSS	Robotics: Science and Systems Conference. Algorithmic or mathematical foundations of robotics, robotics applications, and analysis of robotic systems.

Table B.2.5: List of relevant conferences for the OROKSI project.

Relevant Journals The results and solutions obtained in a project generate a big impact most easily when a publication is made, enabling a large number of interested parties to inform themselves about it. Publications also have a longer shelf life than presentations or conference papers, leading to a better sustainability of the results, and also a much wider audience. The targeted journals are Advanced Robotics, AI Magazine, Artificial Intelligence, Computer Vision and Image Understanding, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Transactions on Robotics, International Journal of Robotics Research, Journal of Intelligent Service Robotics, Journal of Machine Learning Research, Journal of Web Semantics, Robotica, Robotics and Autonomous Systems, and Semantic Web Journal.

Another type of publication that will be pursued within the OROKSI project is the publication of results and general information about the projects in the blogs run by the IEEE and OSRF. These have a very high impact in their respective fields.

B.2.2.5.4 Cross-fertilisation communication

The Work-Programme of the European Commission is home to a number of projects, some of them relevant to the OROKSI project. The OROKSI consortium will therefore identify interconnected projects and establish an exchange of ideas to facilitate development for the whole robotics sector.

B.3 Implementation

B.3.1 Workplan

B.3.1.1 Overall strategy and general description

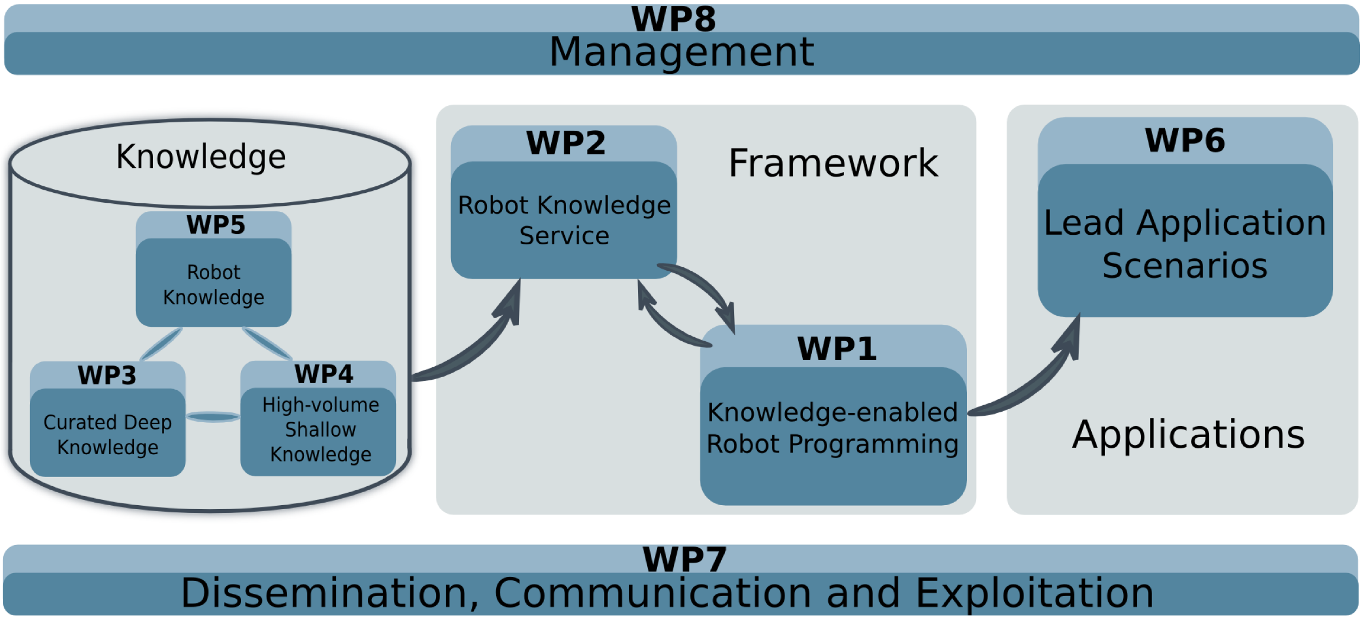


Figure B.3.1: Structure of workplan into work packages

Figure B.3.1 visualizes the structure of the workplan. The packages investigate the functional components that are necessary for the realization and dissemination of OROKSI. WP1 (Knowledge-enabled Robot Programming) and WP2 (Robot Knowledge Service) investigate the knowledge, representation, and reasoning methods necessary for object retrieval in domestic environments for the motion-impaired. Effective usage of these functions and the execution of the tasks is realized by work packages 3 (Curated Deep Knowledge) and 5 (Robot Knowledge Bases). Important practical considerations in using the suggested system are addressed in WP4 (High-volume Shallow Knowledge) and WP6 (Lead Application Scenarios). Since a key focus of OROKSI is to markedly facilitate the development and deployment of service robots, WP7 (Dissemination, Communication and Exploitation) develops tools that aid collaboration between robotics researchers, and the use and reuse of software and data. The activities in WP8 (Management) create awareness for the project and ensure the continued use of the OROKSI results in the future. WP9 () coordinates and manages the project. A list of the workpackages is provided in Table B.3.1.

WP No	Work package title	Lead participant No	Lead participant short name	PM	Start month	End month
1	Knowledge-enabled Robot Programming	TBD	TBD	TBD	TBD	TBD
2	Robot Knowledge Service	TBD	TBD	TBD	TBD	TBD
3	Curated Deep Knowledge	TBD	TBD	TBD	TBD	TBD
4	High-volume Shallow Knowledge	TBD	TBD	TBD	TBD	TBD
5	Robot Knowledge Bases	TBD	TBD	TBD	TBD	TBD
6	Lead Application Scenarios	TBD	TBD	TBD	TBD	TBD
7	Dissemination, Communication and Exploitation	TBD	TBD	TBD	TBD	TBD

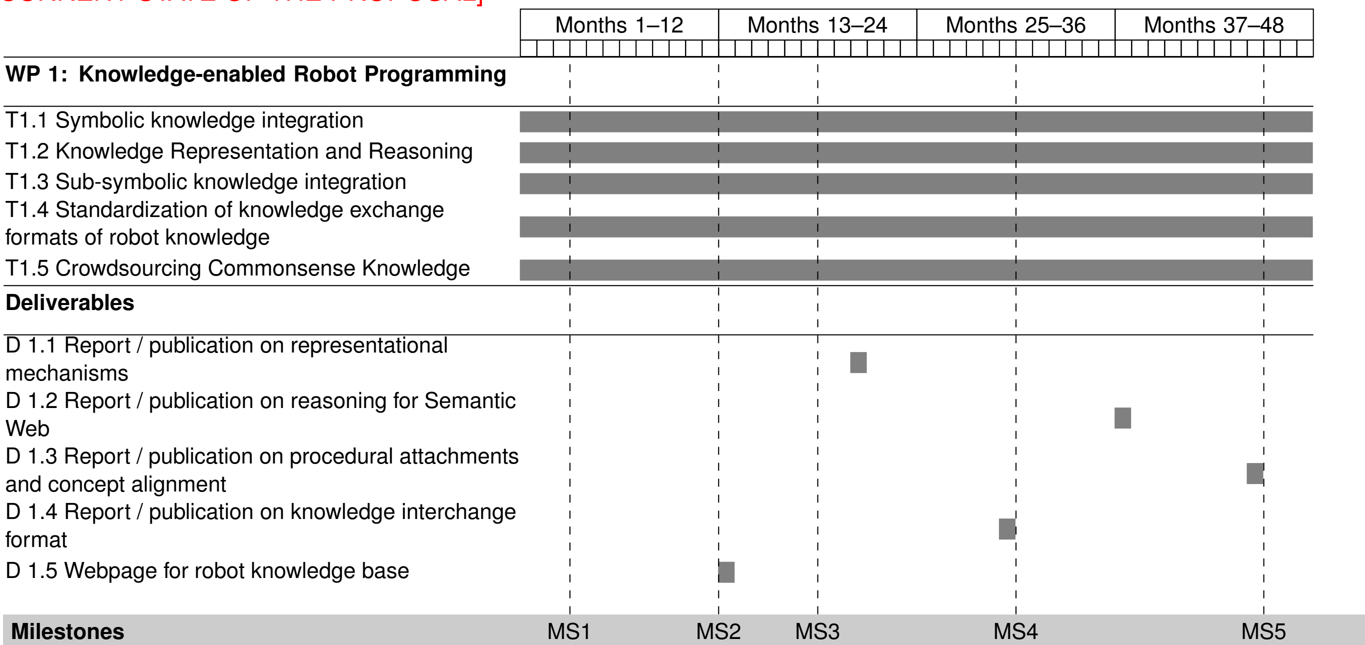
Table B.3.1: List of work packages

B.3.1.2 Timing of work packages and their components

Del. No	Deliverable name	WP No	Lead part.	Type[1]	Diss. level[2]	Del. date
D 1.1	Report / publication on integrating ROBOPAL	WP1	UniHB	R	PU	M12
D 1.2	Report / publication on ROBOPAL interfaces	WP1	UniHB	R	PU	M24
D 1.3	Report / publication on failure handling for queries	WP1	UniHB	R	PU	M36
D 1.4	Open-source software of ROBOPAL	WP1	NEUSTA	OTHER	PU	M42
D 2.1	Report on cloud-based service requirements	WP2	VUA	R	PU	M3
D 2.2	Report / publication on knowledge source selection	WP2	VUA	R	PU	M12
D 2.3	Report / publication on large-scale KB reasoning	WP2	VUA	R	PU	M24
D 2.4	Report / publication on Resilient Reasoning	WP2	VUA	R	PU	M36
D 2.5	Open-source software for cloud-based knowledge service	WP2	VUA	OTHER	PU	M47
D 3.1	Report / publication on...	WP3	TBD	R	PU	M1
D 3.2	Open software for...	WP3	TBD	OTHER	PU	M10
D 3.3	Knowledge base for...	WP3	TBD	OTHER	PU	M20
D 4.1	Report / publication on knowledge source selection	WP4	VUA	R	PU	M12
D 4.2	Report / publication on large-scale KB reasoning	WP4	VUA	R	PU	M24
D 4.3	Report / publication on Resilient Reasoning	WP4	VUA	R	PU	M36
D 5.1	Report / publication on...	WP5	TBD	R	PU	M1
D 5.2	Open software for...	WP5	TBD	OTHER	PU	M10
D 5.3	Knowledge base for...	WP5	TBD	OTHER	PU	M20
D 6.1	Report / publication on...	WP6	TBD	R	PU	M1
D 6.2	Open software for...	WP6	TBD	OTHER	PU	M10
D 6.3	Knowledge base for...	WP6	TBD	OTHER	PU	M20
D 7.1	Report / publication on...	WP7	TBD	R	PU	M3
D 7.2	Open software for...	WP7	TBD	OTHER	PU	M6
D 7.3	Knowledge base for...	WP7	TBD	OTHER	PU	M3
D 7.4	Knowledge base for...	WP7	TBD	OTHER	PU	M48
D 7.5	Knowledge base for...	WP7	TBD	OTHER	PU	M36

Table B.3.2: List of deliverables

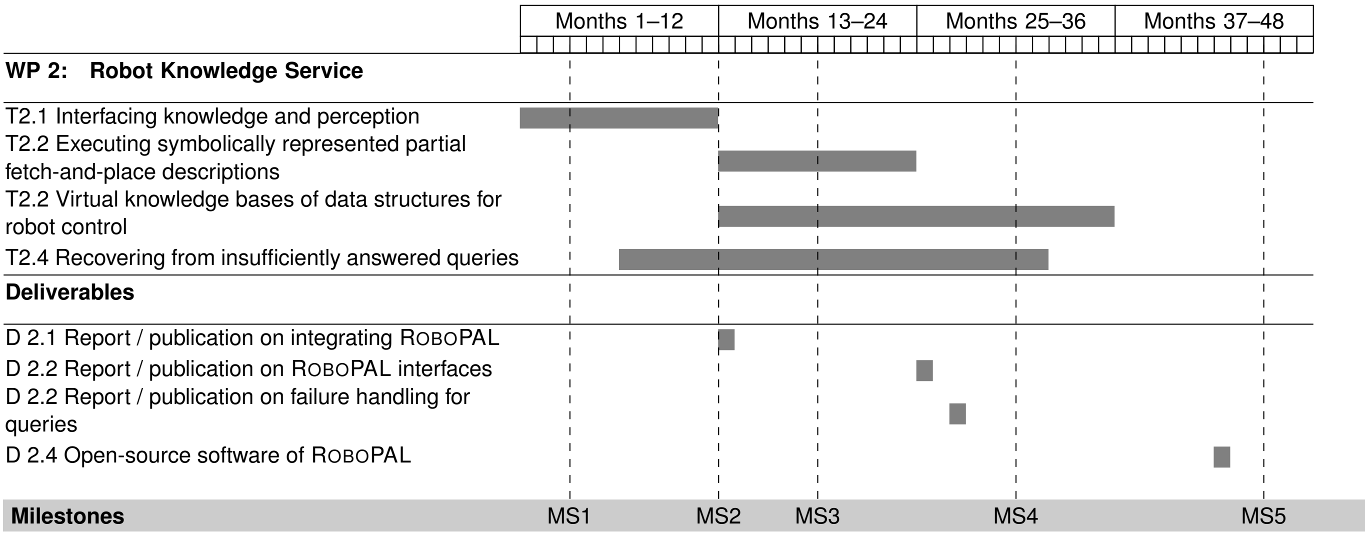
The major deliverables are listed in Table B.3.2. The timing of the work packages is illustrated in the Gantt charts below. [TODO: NOTE: THE CONTENT OF THE GANTT CHARTS WERE COPIED AND DO -NOT- REFLECT THE CURRENT STATE OF THE PROPOSAL]



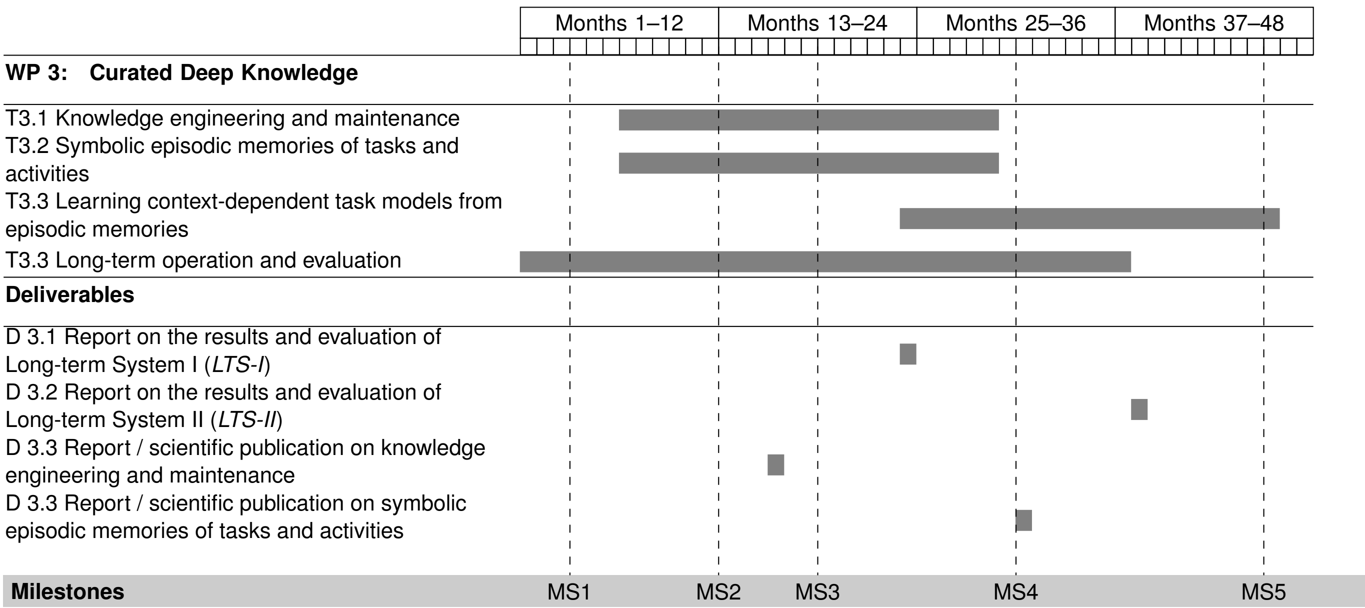
Schematic schedule for OROKSI (WP1) — Gantt Chart.

[1] **R** = Document, report (excluding the periodic and final reports)
DEM = Demonstrator, pilot, prototype, plan designs
DEC = Websites, patents filing, press and media actions, videos, etc.
OTHER = Software, technical diagram, etc.

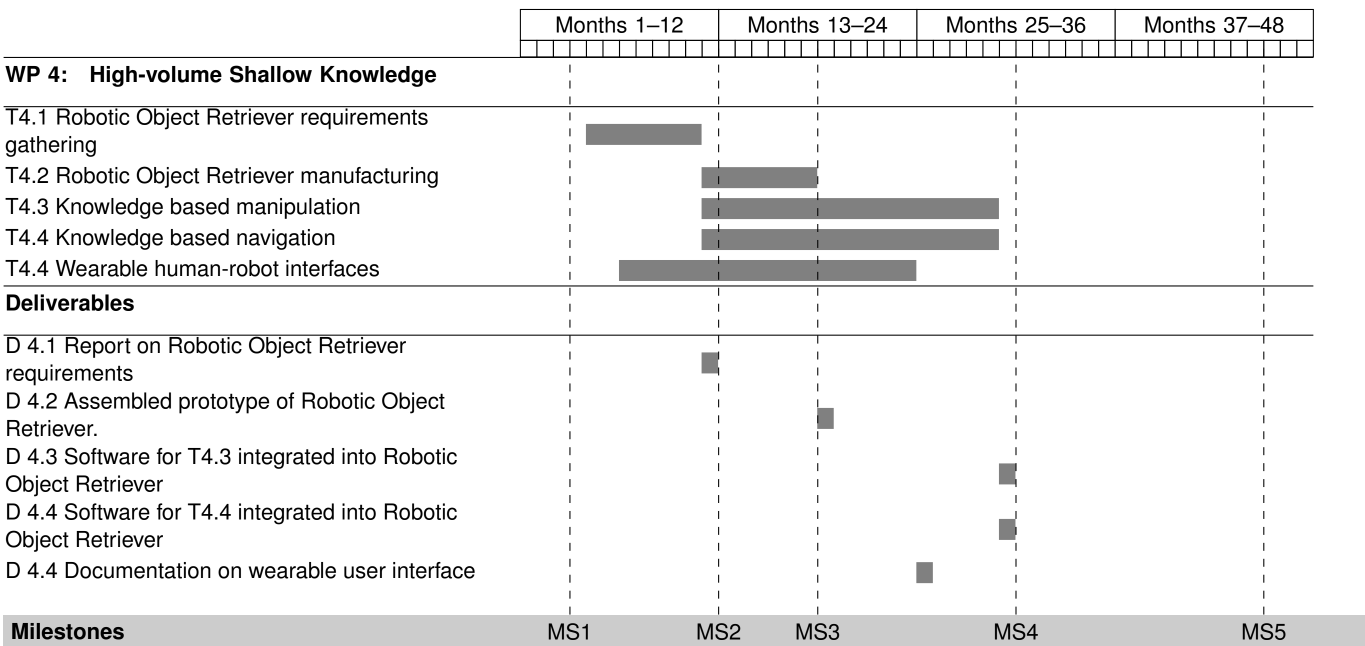
[2] **PU** = Public, fully open, e.g. web
CO = Confidential, restricted under conditions set out in Model Grant Agreement
CI = Classified, information as referred to in Commission Decision 2001/844/EC.



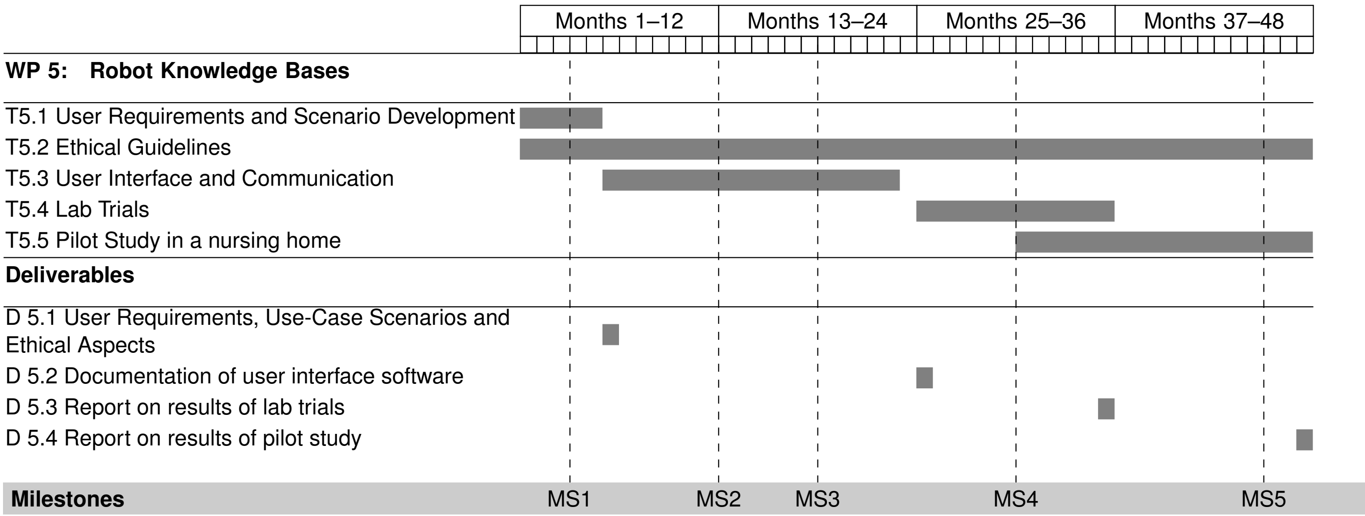
Schematic schedule for OROKSI (WP2) — Gantt Chart.



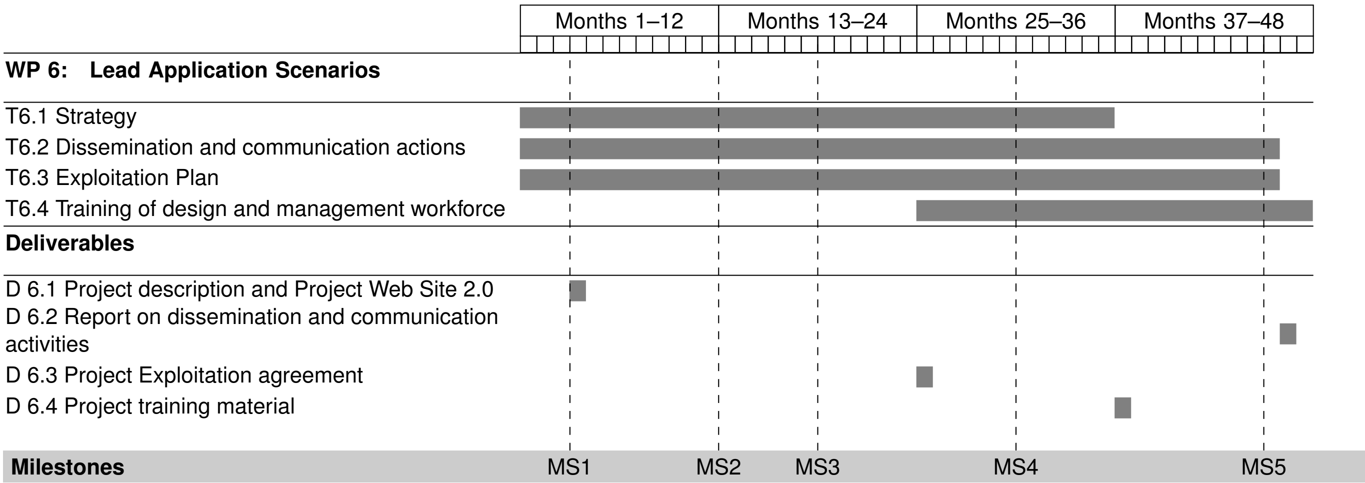
Schematic schedule for OROKSI (WP3) — Gantt Chart.



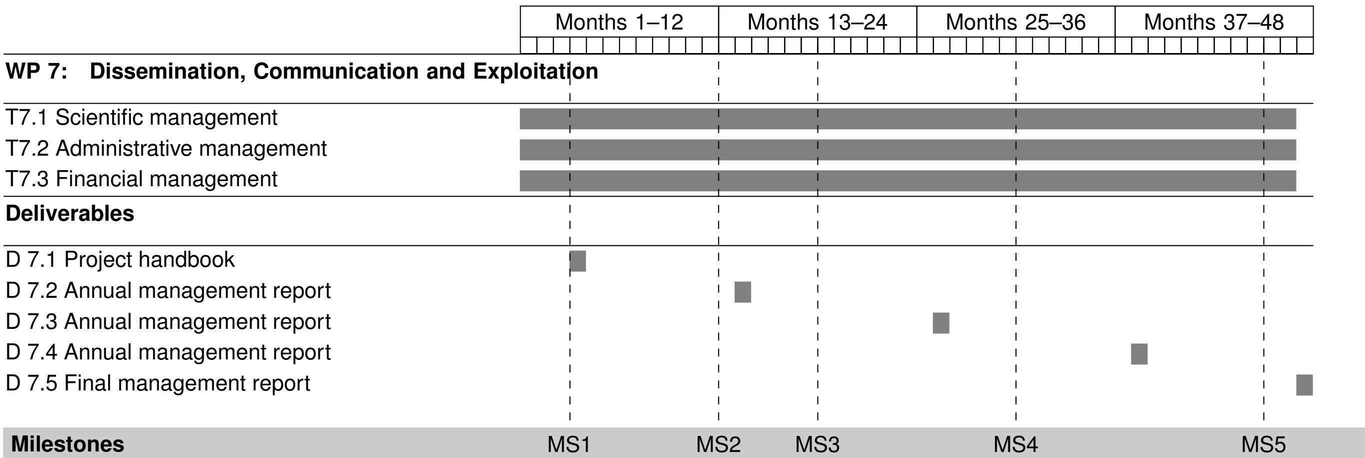
Schematic schedule for OROKSI (WP4) — Gantt Chart.



Schematic schedule for OROKSI (WP5) — Gantt Chart.



Schematic schedule for OROKSI (WP6) — Gantt Chart.



Schematic schedule for OROKSI (WP7) — Gantt Chart.

B.3.1.3 Detailed work description

Workpackage number	1			Start date or starting event		M1	
Work package title	**Knowledge-enabled Robot Programming**						
Participant number	1	2	3	4	5	6	7	
Participant short name	**UniHB**	VUA	Cyc-EU	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. The purpose of this work package is to provide reasoning extensions to Robot Control Programs. These enable control programs to automatically generate queries that take the respective execution context in consideration and use the answers provided by OROKSI in order to generate competent action. More specifically, the objectives are:

- Extending the open-source ROBOSHERLOCK perception system such that it can return the perceived context of queries sent to OROKSI.
- Translation mechanisms that can successfully execute partial descriptions for subtasks of object retrieval including the search of objects, picking them up, and placing them.
- Abstraction of robot data structures into declarative representation structures.
- Control structures and user interaction methods to recover from insufficiently answered knowledge queries.

T 1.1. Executing symbolically represented action descriptions (UniHB). This task will realize the knowledge bases and the reasoning needed for the execution of symbolically represented action descriptions. For example, if the robot is to get the milk from the refridgerator, it has to know that it has to open the fridge first by pulling the handle with a circular motion, that it has to position itself so that it can see the content of the refridgerator and conveniently reach it. In this context it is important that the inferred knowledge is transformed into continuous, numerical parameters that can be executed by the Robot Control Program.
In order to bridge the gap to the continuous action parameterization we will develop methods to learn mappings from symbolic parameters into continuous parameter subspaces that will achieve successful execution. To this end, we will investigate more powerful methods to learn action-related concepts [SF+12].

T 1.2. Interfacing knowledge and perception (UniHB). The purpose of this task is the integration of perception and knowledge. This integration considers different aspects. First, the use of knowledge and in particular knowledge about context in order to interpret and simplify perception tasks in the action context. For example, if the robot knows that the object it is looking for has a unique color, then detecting the object based on color might be easier than applying more error prone object categorization methods. If the robot is supposed to bring some water then it has to reason about which of the objects that it sees can be used to fill the water in. To deal with these issues the robot has to employ reasoning to decide how to perceive what it is looking for and to interpret what it sees in the light of the task it has to accomplish. Another necessary aspect of knowledge processing is that the perception system must be able to decompose the objects it sees into their functional components. For example, if it sees a pot it has to recognize its handles and its lid in order to make use of knowledge such as grasp the pot by its handles or if there is no lid on the pot then the pot is open, and so on. Often the respective kind of knowledge is called the affordances of objects.
In order to realize the needed reasoning support for perception we will employ hybrid reasoning techniques with Markov logic-based reasoning being one of the key mechanisms for completing incomplete descriptions by inferring the conditional probability of what the robot needs to know given what the robot sees. Research and innovation is required to scale the probabilistic first-order reasoning to realistic problem sizes.

T 1.3. Virtual knowledge bases of data structures for robot control (UniHB). A particular property of knowledge processing in robotic agents is that if a robot is successfully fetching and placing an object with some required robustness, it already contains a lot of knowledge necessary to perform the task. The problem is that the knowledge is hard-coded into the plan so that it is implicit in the data structures, algorithms, and control logic of the plan. In this task we will design, implement, and deploy a knowledge base of rules that are able to symbolically reconstruct the knowledge implicit in the plans in terms of the common representation framework. For example to compute the belief of where the robot currently is we can specify a symbolic rule with a procedural attachment that computes the pose from the respective probability distribution computed by a probabilistic state estimation algorithm.

T 1.4. Recovering from insufficiently answered queries (UniHB). This task investigates control structures for Robot Control Programs that can detect and recover from insufficiently answered queries. The failure of top-level object retrieval tasks will be recovered from by asking a human operator to perform the task through a telepresence inteface which will be realized on the basis of the Remote Robotic Laboratories open-source software infrastructure. The infrastructure will be extended to give specific support for object retrieval tasks and to learn new knowledge from the human operator.

Evaluation and benchmarking. This work package will be successful if ROBOPAL enables Robot Control Programs to employ the OROKSI knowledge service such that the execution context can be included in the queries, results of queries are executable, the use of OROKSI is synchronized with plan execution, and the control programs for object retrieval can competently recover from insufficient answers from OROKSI.

WP-specific Risks	Prob., Impact	Contingency Plans
Task 3.1: Real-world scenes are too complex for the perception system	medium, medium	We will restrict the set of scenarios the robot has to handle autonomously.
Task 3.2: Some object types can not be picked up with the robot hardware	medium, low	We will restrict the set of objects the robot has fetch.

Contribution to milestones. WP3 will realize the plan-based robot control system that will execute the object retrieval tasks with the help of OROKSI and ROBOPAL in the milestone systems MS3, MS4, and MS5.

Deliverables (brief description and month of delivery).

D 1.1 @ M12 Report / scientific publications describing ROBOPAL and its interaction with the ROBOSHERLOCK perception system and the CRAM execution system.

D 1.2 @ M24 Report / scientific publications describing interface of ROBOPAL to the low- and high-level robot control system.

D 1.3 @ M36 Report / scientific publications describing the handling of failed knowledge queries in Robot Control Programs.

D 1.4 @ M42 Documented open-source software package for ROBOPAL including installation guides, documentation, tutorials, issue trackers, and links to OROKSI (presumably accessible through the open-source software library ROS.org).

Workpackage number	2		Start date or starting event			M1	
Work package title	**Robot Knowledge Service**						
Participant number	1	2	3	4	5	6	7	
Participant short name	**UniHB**	VUA	Cyc-EU	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. This work package will deliver Web Services for servicing knowledge requests from robots. It will do so by creating a meta-architecture for querying and reasoning over very many heterogeneous knowledge sources of varying size. The knowledge service will have the following generic characteristics:

- Requests are serviced and supported by state-of-the-art Web Service API and cloud-based architecture.
- Request and response formats will be based on open standards and the to-be-developed robot exchange format (see Task 1.4).
- The knowledge base will be very large, involving very many knowledge sources, and will change dynamically.
- Trust and relevance of sources and (derived) statements will have to be determined by automated means.
- The reasoning itself will be based on existing high performance inference techniques, supplemented with non-declarative extensions where needed.
- provide a web interface for open research that will give researchers the means to publish experimental data in a reproducable form that allows for the analysis of experiments;
- provide an infrastructure for managing research blogs that allow a group of researchers to commonly work on a OROKSI knowledge base;
- provide a suite of software tools for analyzing episodic memories of robot experiments; and
- develop online interactive teaching material for a course in AI-based robot control.

T 2.1. Cloud-based service and computation infrastructure for serving robot knowledge requests (NEUSTA). Team NEUSTA uses for the software development a SCRUM approach and Microsoft Azure to set up the cloud based service and computation infrastructure for serving robot knowledge requests. Virtual machines as Infrastructure as a Service (IaaS) are used to migrate applications and infrastructure without changing existing code. By a Platform as a Service (PaaS) environment we create scalable applications and services and support multi-tier architectures and automated deployments. We use it for encoding, content protection, streaming, and/or analytics. The Microsoft data center in the Netherlands is used for back-up purposes. The Cloud Services will be containers of hosted applications. The application will be the enhanced OpenEASE platform as Internet-facing public web application. For the later planned exploitation we will use the private processing engines, e.g., for analyzing or processing custom specific data. Scaling and reliability are controlled by the Microsoft Azure Fabric Controller so the services and environment do not crash if one of the servers crashes within the Microsoft data center and provides the management of the user's web application like memory resources and load balancing.

T 2.2. Knowledge mining and machine learning for robot knowledge services (CycEur).

T 2.3. Representation support for natural language interaction (CycEur).

T 2.4. Knowledge source selection (VUA). This task ensures that knowledge requests posed by robots will be matched against collections of knowledge sources that are relevant based on context. Source selection will be fully automated and will allow the combination of knowledge from heterogeneous sources. The robot's task and the robot's service description are essential parts of the context, since different types of robots will perform different tasks in different ways. Trust and confidence profiles will be maintained for the knowledge sources.

T 2.5. Resilient reasoning services (VUA). This task ensures that reasoning processes employed within OROKSI are *resilient*, i.e., provide support for fallback cases ("what happens when something goes wrong?"). Resilience implies that knowledge source selection (Task 2.2) and reasoning (Task 2.3) exhibit *graceful degradation* in terms of performance and confidence levels. For instance, if the most relevant/trustworthy knowledge source becomes unavailable another will have to dynamically take its place. Which fallback options are available depends on the reasoning paradigms that are chosen and the way in which they are augmented and combined.

T 2.6. Graphical interface and user management of the OPENEASE web site (NEUSTA). This task extends the graphical interface to the OPENEASE website. The interactive and visualization modules will be improved to substantially increase the functionality, comfort, speed, and robustness of the interactive web interface. In addition, we will develop concepts such that programmers can overload parts of the global knowledge base with their own patches. The user management will ensure that common background knowledge bases can be shared among users but that the local knowledge base extensions overwrite the global ones and guarantee that others cannot access private knowledge bases.

T 2.7. Tools for Open research (UniHB). This task investigates how OPENEASE can be used to promote open research in the area of AI-based autonomous robotics. The task will realize an infrastructure that allows robotics researchers to

- generate reproducable experimental results and make them accessible through OPENEASE. Researchers will be able to link the experimental results section of their papers to an individual OPENEASE knowledge base of the experiment. The experiment knowledge base may contain videos of the experiment, the evaluation restated in terms of OPENEASE queries and semi-automatically generated experiment summaries and analyses. In addition the reviewer can ask other aspects of the experiments by formulating additional OPENEASE queries that can be executed on the experiments.
- provide benchmarks for learning, reasoning, and perception tasks. To this end, we will realize a query language that can generate sets of benchmark tasks that can be used by others to compare their research results. For example, researchers could use OPENEASE knowledge bases to create a perception benchmark that includes images taken by the robot from a distance between 2 and three meters of table top scenes with more than 5 objects on the table where at least one object is mostly occluded. The positions from where the images are taken should be equally distributed to account for different lighting conditions.
- create research problem blogs. Researchers can state a research question and provide an OPENEASE knowledge base associated with the research problem and invite other researchers to tackle the research problem as a team where everybody can contribute ideas, comments, criticisms, etc in order to solve the research problem.

T 2.8. Open software and open data (UniHB). This task aims at turning the research software components into components that can be further developed and extended by others in the open source communities. This includes the provision of installation guides, software documentation, and interactive tutorials for the software components. Most software components will be contributed to the ROS and the PCL software libraries.

T 2.9. Open teaching (UniHB). This task is about using OPENEASE for teaching a graduate course on Integrated AI-based Robotics. The modules of the course will use OPENEASE as an interactive teaching module for concepts in AI-based robotics as well as provide interactive exercises that practice the concepts and can test the solutions to the exercises. We plan to make the course available as open teaching material.

Evaluation and benchmarking. WP2 will be considered successful if OROKSI can serve up to 30 programmers simultaneously and will be adopted by at least 20 research projects by the end of the project. Further success criteria will be the collection of knowledge sources that can be used as well as the set of reasoning techniques that will be made available through OROKSI. We will provide means for users to give feedback about their experience and will use the feedback to improve and assess the usefulness of OROKSI.

WP-specific Risks	Prob., Impact	Contingency Plans
Task 2.2: Knowledge sources in the web are appearing, disappearing, and changing.	low	Infrastructure for dealing with dynamic sources is already in place. New Web sources will be automatically cleaned and updated through LOD Laundromat.
Task 2.3: Non-classical common-sense reasoning over large-scale Web data has not been attempted before	medium	Causal reasoning is well understood in non-Web domains but has not been applied (directly) to Web data yet. There is no reason why existing results could not be carried over under minor adaptations. In addition, VUA has performed prior research in contextualized reasoning.
Task 2.4: Resilient reasoning has not been studied in large-scale domains yet	medium	This task is there to anticipate risks related to reasoning appraches. Relations between graceful degradation and various reasoning approaches are well-studied, but their effects on large-scale reasoning tasks over non-curated knowledge is not.
Task 2.1 and Task 2.5: The programming infrastructure for Web Services will change and improve.	high, not critical	The consortium will mainly use open-source software tools and adapt to new software versions and new components early.

Contribution to milestones. The cloud-based knowledge service, the web-based programming interface, and the reasoning mechanisms will be used for query answering in the milestone systems MS3, MS4, and MS5.

Deliverables (brief description and month of delivery).

D 2.1 @ M3 Report describing the requirements analysis and implementation of cloud-based service and computation infrastructure for knowledge requests posed by robots within the fetch-and-place domain.

D 2.2 @ M12 Report / scientific publication on knowledge source selection, focussing on the specific use case of servicing robot requests in the fetch-and-place domain.

D 2.3 @ M24 Report / scientific publication on common sense reasoning tasks applied over a large-scale, dynamic and heterogeneous knowledge base.

D 2.4 @ M36 Report / scientific publication describing the concept of Resilient Reasoning, considered with the question of how existing KR reasoning approaches have to be combined and/or extended in order to be able to come up with alternative or suboptimal answers.

D 2.5 @ M47 Documented open-source software package including installation guides, documentation, tutorials, issue trackers, and links to OROKSI (presumably accessible through the open-source software library ROS.org).

Workpackage number	3		Start date or starting event		M1		
Work package title	**Curated Deep Knowledge**						
Participant number	1	2	3	4	5	6	7	
Participant short name	UniHB	VUA	**Cyc-EU**	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. In this work package we will deliver very high quality deep knowledge base exposed for use to the rest of the project. It will be based on Research Cyc KB (the biggest existing common sense ontology that can be used by machine reasoning - 900 years of human effort). The KB will be extended with the concepts and rules required to cover all the robots needs. It will be optimized for querying and reasoning about the spatial characteristics of the world robots reside in, its physics, the objects they can interact with and common sense knowledge that is very hard to obtain otherwise. Besides the semantic storage, this WP will prepare the big data storage mechanisms for episodic memories and raw logs of robots. Additionally methods for automatic and semi-automatic semantic learning based on episodic memories will be developed. This will allow us to gather new tasks and knowledge from the robot logs.

- prepare the deep reasoning and KB infrastructure for the project. Provide knowledge and reasoning support for other project parts.
- Prepare the infrastructure for the episodic memories storage and alignment with the semantic knowledge from the main KB.
- Develop and evaluate the machine learning methods and infrastructure for unsupervised/semi-supervised learning from episodic memories and raw sensor streams from robots.

T 3.1. ***[Task name (Partner)].*** *[Task description]*

T 3.2. ***[Task name (Partner)].*** *[Task description]*

T 3.3. ***[Task name (Partner)].*** *[Task description]*

...

Evaluation and benchmarking. *[Short description of measures for evaluation]*

WP-specific Risks	**Prob., Impact**	**Contingency Plans**
T1.1: *[risks for task]*	low/ medi-um/ high	*[What to do when it happens]*
T1.2: *[risks for task]*	low/ medi-um/ high	*[What to do when it happens]*
T1.3: *[risks for task]*	low/ medi-um/ high	*[What to do when it happens]*
. . .	. . .	. . .

Contribution to milestones. *[To which milestones the WP will contribute what]*

Deliverables (brief description and month of delivery).

D 3.1 @ M1 Report/ scientific publications describing . . .

D 3.2 @ M10 Open software . . .

D 3.3 @ M20 Knowledge base . . .

Workpackage number	4			Start date or starting event		M1	
Work package title	**High-volume Shallow Knowledge**							

Participant number	1	2	3	4	5	6	7	
Participant short name	UniHB	**VUA**	Cyc-EU	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. In this work package we deliver the high-volume Web knowledge component of the oRoKSI robot knowledge base. It will do so by creating a meta-architecture for querying and reasoning over very many heterogeneous knowledge sources of varying size that are extracted from the Web and enriched for use in oRoKSI.

T 4.1. Web-scale knowledge collection & enrichment. By using existing SotA tools we will scrape the Web in search for knowledge that is potentially relevant for a robot knowledge service. The scrape will identify a first set of potentially interesting knowledge sources that will be automatically cleaned to meet a wide array of data quality criteria (year 1). The scraping infrastructure supports a cyclic development model, allowing incremental Web scrapes to be run (year 2). This addresses the inherent dynamicity of the Web (sources are continuously being updated and added) as well as the fact that the knowledge need may change over time.

T 4.2. Large-scale knowledge integration. The hundreds of thousands of scraped Web sources will be integrated in order to be able to uniformly query and reason over them. We do not pursue a generic schema or mold in which all sources must fit, since such approaches are known not to scale to more than a couple of sources. We use SotA Linked Data approaches in order to more loosely couple the hundreds of thousands of knowledge sources, while still being able to enforce a stringent semantics (year 1). In addition, the curated deep knowledge of WP3 will be integrated (year 2) and integration will be tuned to optimize for common reasoning tasks (year 3).

T 4.3. Large-scale knowledge querying & reasoning. In order to optimize robot communication with the knowledge service, traditional querying approaches will not suffice. A robot may have to act quickly, in which case it cannot wait until the knowledge service has completely calculated a lengthy query. In addition, an economically viable knowledge service cannot perform most caluclations on a centralized server, as this will not scale to tens of thousands of robots. We will use recent innovations in anytime query evaluation (year 1) and streamed reasoning (year 2) in order to balance the computational cost between the robot clients and the knowledge service. This will allow us to scale to at least one thousand simultaneous robot clients (year 3).

T 4.4. Robust querying & reasoning. After implementing a de-facto querying and reasoning service over the robot knowledge collection (year 1), we will develop a new ranking approach that ranks the multiple answers that may exist for a robot request (year 2). As a robot progresses in performing its task, makes more observations or detects an error state, it is able to send additional information to the knowledge service. The knowledge service will be able to (non-monotonically) improve both the answer set and the ranking over it in order to send an improved response to the robot (year 3).

Evaluation and benchmarking. WP4 will be considered successful if

- The oRoKSI knowledge base will contain at least one hundred thousand fully integrated knowledge sources.
- The oRoKSI knowledge service is able to service at least one thousand robots in their knowledge requests through anytime querying and streamed reasoning.
- The oRoKSI knowledge base successfully integrates curated deep knowledge (WP3) with large-scale Web knowledge.

WP-specific Risks	Prob., Impact	Contingency Plans
Task 2.1: Knowledge sources in the web are constantly appearing, disappearing, and changing.	low	Infrastructure for dealing with dynamic sources is already in place as part of the LOD Laundromat infrastructure. This includes the ability to archive datasets and store multiple snapshots.
Task 2.3: Common-sense knowledge and reasoning (WP3) has not been integrated with large-scale Web knowledge before.	low	Causal reasoning is well understood in non-Web domains but has not been applied (directly) to Web data yet. There is no inherent reason why existing results could not be carried over under minor adaptations.
Task 2.4: Resilient reasoning has not been studied in large-scale domains yet	medium	The purpose of task 2.4 is to mitigate risks that arise when querying and reasoning of heterogeneous data. VUA has experience with large-scale reasoning in LarKC. In addition, graceful degradation of reasoning approaches has been extensively studied. The main risk lies in effectively integrating these two research results.

Contribution to milestones. **TODO: To be filled in when the milestones are clear.**

Deliverables (brief description and month of delivery).

D 4.1 @ M12 Report / scientific publication on knowledge source selection, focussing on the specific use case of servicing robot requests in the fetch-and-place domain.

D 4.2 @ M24 Report / scientific publication on common sense reasoning tasks applied over a large-scale, dynamic and heterogeneous knowledge base.

D 4.3 @ M36 Report / scientific publication describing the concept of Resilient Reasoning, considered with the question of how existing KR reasoning approaches have to be combined and/or extended in order to be able to come up with alternative or suboptimal answers.

Workpackage number	5			Start date or starting event		M1	
Work package title	**Robot Knowledge Bases**						
Participant number	1	2	3	4	5	6	7	
Participant short name	**UniHB**	VUA	Cyc-EU	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. In this work package we deliver part of the robot knowledge base that is derived from the robot's experiences. To this end we create an information processing infrastructure that will

- Collect in an efficient manner robot experiences comprising of camera images, other sensor data, motion trajectories, etc., and symbolic annotation of robot actions.
- Design and implement learning mechanisms on the basis of robot experience data, deliver action-related cues about tasks for plan execution.
- ...

T 5.1. Collection and extraction of knowledge from robot experience (UniHB). During execution of a robot control program, be it successful or not, the robot generates vast amount of knowledge that could be later utilized for learning from experience. Such knowledge includes low-level sub-symbolic concepts as manipulation trajectories, grasping configurations, positions where to stand to perform a manipulation tasks, etc., as well as symbolic knowledge such as what goals was the robot trying to achieve, which events and failures happened, which actions were executed in which order.
The amount and variety of knowledge generated at each moment of robot control program execution can become enormous. This task will realize mechanisms for extracting knowledge during robot activities and storing them at real-time in an efficient manner.

T 5.2. Compression, transformation, and management of robot experiences and knowledge abstracted from it (UniHB). Control program execution over time, especially for life-long tasks, as, for example, keeping the kitchen tidy, whenever a human is not around, will generate big data that requires elegant ways of storing, transforming and managing it.
This task will prepare the infrastructure for the episodic memories storage and alignment with the semantic knowledge from the main KB.

T 5.3. Learning action-related concepts from robot experience (UniHB). Sufficiently large and detailed knowledge about past task executions can reveal the general structure of an activity, allowing a robot to grasp the more abstract concept of what it is doing. A knowledge base holding this task structure allows projection of action effects and estimation of task outcomes, given a set of parameters. Robots that have access to this information can project their chances of success and can reparameterize their activities or change their current strategy if failure is probable. At the same time, divergence from the expected course of action when performing a task can be detected, helping to prevent fatal plan failures and unwanted changes in the environment. In this task we will design learning algorithms that make use of robot experience data and that action related cues about the task structure to expect, the general course of action when performing that particular task, and to-be-expected outcomes given a current situation.

Evaluation and benchmarking. *[Short description of measures for evaluation]*

WP-specific Risks	**Prob., Impact**	**Contingency Plans**
T1.1: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
T1.2: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
T1.3: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
...	...	...

Contribution to milestones. *[To which milestones the WP will contribute what]*

Deliverables (brief description and month of delivery).

D 5.1 @ M1 Report/ scientific publications describing ...

D 5.2 @ M10 Open software ...

D 5.3 @ M20 Knowledge base ...

Workpackage number	6			Start date or starting event		M1	
Work package title	**Lead Application Scenarios**						
Participant number	1	2	3	4	5	6	7	
Participant short name	**UniHB**	VUA	Cyc-EU	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. *[Introductory statements]*

- *[Objective 1]*
- *[Objective 2]*
- ...

T 6.1. ***[Task name (Partner)].*** *[Task description]*

T 6.2. ***[Task name (Partner)].*** *[Task description]*

T 6.3. ***[Task name (Partner)].*** *[Task description]*

...

Evaluation and benchmarking. *[Short description of measures for evaluation]*

WP-specific Risks	**Prob., Impact**	**Contingency Plans**
T1.1: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
T1.2: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
T1.3: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
...	...	...

Contribution to milestones. *[To which milestones the WP will contribute what]*

Deliverables (brief description and month of delivery).

D 6.1 @ M1 Report/ scientific publications describing ...

D 6.2 @ M10 Open software ...

D 6.3 @ M20 Knowledge base ...

Workpackage number	7			Start date or starting event		M1	
Work package title	**Dissemination, Communication and Exploitation**							
Participant number	1	2	3	4	5	6	7	
Participant short name	**UniHB**	VUA	Cyc-EU	HW	DLR	ALD	NEUSTA	**TOTAL**
PM per participant	0	0	0	0	0	0	0	0

Objectives. The main objectives of this work package are:

- to define and update the project dissemination plan including communication strategies and concrete activities to spread and promote the project outcomes within the scientific and medical communities as well as to a wider public and to create awareness on the subject (i.e. individuals, patient organisations, regulatory bodies);
- to conduct outreach to main industry stakeholders (i.e. Pharma, Medical Technology and Medical Imaging), in the EU Member States and Associated Countries in order to seek interested partners and/or additional private/public funding for possible Market Access/entry phase
- to develop an exploitation plan for the commercial valorisation of the project outcomes including strategies for Marketing authorisation and Market Access

T 7.1. Set-up communication and dissemination activities *[(Partner)]*.

To widely disseminate the project concept, developments and results to the general public as well as the scientific and medical community, we are using effective communication means and strategies as follows:

- Creation of a project communication and dissemination plan, outlining the process of dissemination planned for oRoKSI-Project, including the development of supportive communication tools;
- Development of a project brand identity, e.g. project logo, to reinforce the projects external image, as well as setup and maintenance of a user friendly oRoKSI-Project project website. The website will be regularly updated with new content and research findings; protected and internal information will be maintained within the projects own workspaces for exclusive use of the RCT sites and project partners;
- Creation and maintenance of an email distribution list targeting oRoKSI relevant stakeholders, such as scientific communities, patient organisations, regulatory bodies, industry stakeholders, etc., to distribute e-newsletters;
- Preparation of open access scientific publications and articles in peer-reviewed academic journals as well as lay journals;

T 7.2. Awareness rising and outreach to stakeholders *[(Partner)]*. The project partner will in liaison with the coordinator to advise and provide support to activities targeted at raising awareness and promoting the projects visibility, especially to relevant stakeholders. The following activities are planned:

- Presentation of the project and its outcome to relevant stakeholders, such as patient organisations, national and EU dementia/aging initiatives and networks (e.g. the AGE Platform Europe, the Joint Programming Initiative (JPI) “More Years, Better Lives”, etc.) as well as industry stake-holders (e.g. pharmaceutical companies etc.);
- Presentations at national and international conferences in oRoKSI, dementia and neurodegenerative disease such as ICAD. This will help to promote the translation of the research output of this project into clinical practice and advance global health of oRoKSI patients;
- Initiation and organisation of forums or workshop with relevant stakeholders in order to discuss the project as well as general developments and prerequisites in the field of oRoKSI and dementia;
- Organisation of press conferences with journalists for widespread dissemination of the project, its activities and results;
- Organisation of a final dissemination conference with all partners to disseminate the project to the scientific community and the public.

T 7.3. Exploitation and sustainability *[(Partner)]*. In order to ensure sustainable use of project results, oRoKSI- Project will develop an exploitation plan at the early project stages and continuously check upon exploitable assets. The sustainable use of the activity developed and in particular the RCT results will be followed up closely. From the beginning of the project, specific attention will be given to the protection and exploitation of Intellectual Property of results derived from project activities.

The following exploitation activities are planned:

- Protection of the outcomes and results of the OROKSI-Project clinical trial according to the signed co-operation agreement as well as the development of a common exploitation strategy on how to deal with unexpected results;
- Search for subsequent public and/or private funding sources to conduct the subsequent clinical phase III trial with the help of targeted investor materials; this includes the search for
  - Public funding sources;
  - Industry partners in the pharmaceutical and diagnostic sector to fund the enlarged clinical study or license the IP generated by or incorporated in OROKSI Project;
  - Innovative public-private partnerships.

Evaluation and benchmarking. *[Short description of measures for evaluation]*

WP-specific Risks	**Prob., Impact**	**Contingency Plans**
T1.1: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
T1.2: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
T1.3: *[risks for task]*	low/ medi- um/ high	*[What to do when it happens]*
...	...	...

Contribution to milestones. *[To which milestones the WP will contribute what]*

Deliverables (brief description and month of delivery).

D 7.1 @ M3 Dissemination plan

D 7.2 @ M6 Project web site

D 7.3 @ M3 Initial exploitation and sustainability plan

D 7.4 @ M48 Final exploitation and sustainability plan

D 7.5 @ M36 Targeted investor relations materials

B.3.2 Management structure and procedures

As the Commission recommends, any R&D project requires careful attention by the consortium in regards to overall management and coordination issues. A specially constituted management team, with dedicated staff covering a range of skills, will be established in oRoKSI in order to link together all the project components, over and above the technical management of individual work packages. The Project Management of oRoKSI will be structured according to the description detailed in the below and will be conducted according to the Consortium Agreement, which is intended to enter into force starting on the date the contract with the European Commission is signed.

B.3.2.1 Management and decisionmaking structure

The main goal of project management is to provide the project with a lightweight, flexible and powerful management service capable of ensuring an intensive, efficient and transparent dialog among the partners concerning key strategic and scientific issues. The rapid and effective decision making on technical and organizational issues, full and effective compliance with EU administrative and reporting requirements, design, implementation and management of the technological infrastructure of the project will all be given their due attention. Within this view Michael Beetz will serve as the coordinator of oRoKSI. He has experience in coordinating large-scale projects including the EU project RoboHow and as a vice coordinator of the German National Cluster of Excellence "Cognition for Technical Systems" CoTeSys (2007-2011). The project management activity will be performed utilizing a blend of techniques, methodologies and tools suitable to allow the Project Coordinator to design and implement a robust and efficient project management system. Consortium management will include:

- coordination at the consortium level of the technical and scientific activities of the project
- overall legal, contractual, ethical, financial and administrative management of the consortium
- coordination at the consortium level of knowledge management and other innovation related activities
- promotion and implementation of community building activities around the project
- ensuring that the impact of project achievements in both the scientific community and the market is maximised
- overseeing science and society issues, related to the research activities conducted within the project

Figure B.3.2: oRoKSI management structure.

As represented in Figure B.3.2, a suitable project management structure has been conceived, where different bodies each with specific tasks and objectives cooperate in order to achieve the aforementioned objectives. The project management structure will include the bodies and roles described in the following subsections.

B.3.2.2 Coordinating Partner and Project Coordinator

The Coordinating Partner acts as the intermediary to the EU Commission and will be represented by a Project Coordinator, nominated for all organizational and communication issues. The function of the Project Coordinator includes the following responsibilities:

- cochair the ORoKSI General Assembly meetings, together with the partner's Company Representatives, and ensure that minutes are taken and agreed as appropriate
- cochair the ORoKSI Executive Board meetings, together with the work package Leaders, again ensuring that minutes are taken and distributed
- oversee that the project is run in a concise, motivated and efficient manner
- resolve conflicts that may arise within the Consortium
- ensure that appropriate motivational aspects and human resource issues are addressed and direct training activities as well as team and collective culture building is carried out both at the leadership and the project member level
- act as the Chief Knowledge Officer for the project
- maintain high level contact with the European Commission regarding all contractual and administrative aspects of the project
- work closely with the partners Company Representatives in acting as the project ambassador and main contact for Communications
- ensure that technical, progress and financial reports are delivered on time supervise the ORoKSI office and oversees financial management
- prepare the Consortium Agreement and other contractual aspects together with the partners Company Representatives
- ensure that the ORoKSI strategy is maintained, and that should any deviations be unavoidable, ensure that these issues are properly understood, communicated and agreed within the General Assembly
- run the project in an efficient, motivational, transparent and productive manner on a day-today basis as the head of the project ensuring the effective progresses towards the ORoKSI goals
- ensure the establishment of standards, procedures and conventions regarding matters such as documentation or review procedures
- maintain highlevel contact with the European Commission regarding all the strategic issues of the project

B.3.2.3 Project Office

The Project Office, headed by the Project Coordinator and appointed by the Coordinating Partner in agreement with the consortium members, shall provide the necessary support for daybyday project management as well as reporting activities to the European Commission. The Project Office, represented in ORoKSI by UniHB, will assist the Project Coordinator in all matters concerning administrative management of the project, including:

- setting up the Project Handbook
- preparing project meetings and respective outcome documents (e.g. minutes)
- ensuring highquality and timely delivery of project achievements and documentation (e.g. technical reports, prototypes, cost statements, etc.)
- organizing for a project archive and tools for intraconsortium communication and information exchange
- assisting partners in all administrative and financial questions
- obtaining financial statements (FORM C) and certificates on financial statements, if necessary, from each of the participants and preparing the consolidated project cost statement.

B.3.2.4 General Assembly

This is the ultimate decision making body of the Consortium. Each partner will nominate at least one senior management level Company Representative for the General Assembly, empowered to commit their organisation to the decisions adopted. The General Assembly is under the responsibility of the Coordinating Partner and will be chaired in the meetings by the Project Coordinator, which will be appointed as chair of the Executive Board as well. The General Assembly will meet regularly, at least every six months, to discuss and decide issues related to:

- strategy for conducting the project and assessing the progress of the project
- exploitation strategy and requested revisions if applicable
- corrective actions and authorization of appropriate amendments to the work plan according to the recommendations of both the Executive Board and the EU Commission
- all amendments to both the contract and the Consortium Agreement
- all budgetary issues

- acceptance and exclusion of partners
- conflicts amongst partners and resolving disputes
- premature completion/termination of the project.

A minimum number of twothirds of all partners will be considered a quorum for the decision making procedure. The decisions of the General Assembly are expected to be taken in consensus. If such a consensus cannot be reached, decisions will be taken by a majority vote, each present partner having one vote. In the event of tie the vote of the Project Coordinator will decide.

B.3.2.5 Executive Board

Under the control of - and in compliance with - the decisions of the General Assembly, the Executive Board shall coordinate the project execution. The Executive Board assumes overall responsibility towards the General Assembly for the exchange of content and arranging of activities amongst the partners, as well as for analysing and approving the results generated by the project. The Executive Board is composed of the work package leaders properly nominated at the beginning of the project by the General Assembly and chaired by the Project Coordinator. The role of the Executive Board is to determine the technical direction of the project in order to fulfil its aims and those of the consortium members, including the development of consensus around recommendations and ensuring the adoption of technical amendments to the project work programme in order to mitigate risk and/or to develop corrective actions. The Executive Board shall be responsible for:

- supporting the Coordinating Partner in fulfilling all obligations towards the European Commission
- ensuring that all developments meet functional requirements
- reviewing and proposing to the General Assembly budget transfers in accordance with the Contract and the annual implementation plan, proposing changes in work sharing, budget and participation in the project
- deciding on updating the work plan for approval by the General Assembly before submission to the European Commission
- agreeing on press releases and joint publications by the contractors with regard to the project achievements
- agreeing on procedures and policies in accordance with the Contract, for dissemination of knowledge from the project
- make sure that all the technical objective are achieved (technical requirements, specification, design technology inventory, etc.) as well as the project pilots are delivered on time and evaluated/assessed, as major milestones in the project lifetime and drivers of the cyclic development approach.

It is expected that technical coordination will require a frequent exchange of information and a distribution of work. Consequently, the project will make use of several communication techniques such as teleconferences, video conferences, cooperative work through suitable tools and face-toface meetings whenever necessary, but at least every six months.

B.3.2.6 Advisory Board

The Advisory Board, nominated by the General Assembly, will be composed of wellknown persons of excellence in several projectrelated fields (e.g. robotics, software for knowledge bases, people at human-robotics interface, care personnel able to assess the usefulness of service robots in the care for disabled people, etc.). The purpose of the Advisory Board is to assist the General Assembly in self-evaluation of project results, to give advice on how to continue the work during the runtime of the project and to conduct an internal review process of the project progress. The Advisory Board will be considered a part of the project General Assembly team and will promote and highlight research initiatives and strategies to improve and update the oRoKSI overall research activities and to maintain a closed loop between the project activities/achievements and robotics community. It is expected that the Advisory Board will meet at least three times during the lifetime of the project. Each meeting will be devoted to a specific topic, either suggested by the General Assembly or chosen by the board itself.

The expected output of such meetings will be a position paper and/or a recommendation document on the topic discussed during the meeting.

An initial list of Advisory Board Members is given in Table B.3.3.

Due to the technical complexity of the subject matter, and thus the required work to be performed, the management envisioned has to have the potential to cope with all possible problems that might occur, while carrying out the routine task in an efficient and timely manner, as best as is possible. The proposed management structure will ensure that all decision made are discussed on the relevant levels, and enable the general assembly to be presented with condensed information by the members of the executive board. This will allow a transfer of highly-specialized inter-work package knowledge and concepts more easily than other management schemes that have the work package leaders reporting directly. Furthermore, due to the project office, this setup allows the coordinator to focus on the relevant strategic orientation of the project, while still maintaining a thorough overview of the project as a whole.

Name	Oranization	Nat.	Area of Excellence
Moritz Tenorth	entrepreneur	DE	expert in knowledge processing for robots
Charles Kemp	Georgia Tech	USA	expert in personal assistance robotics
Ashutosh Saxena	Stanford University, entrepreneur	USA	leading RoboBrain project
Chad Jenkins	Brown University	USA	leading robot webtools project
Ken Goldberg	UC Berkeley	USA	internet robotics
Uwe Haass	consultant	DE	former secretary general of euRobotics

Table B.3.3: Advisory Board members (unconfirmed).

The inclusion of external advisors will insure a high quality of the project, and allows detecting flaws early in the project's runtime.

B.3.2.7 Innovation management

Innovation management will be seamlessly integrated into the overall management architecture. Due to the nature of a research project, the part of innovation management that will be the most common occurrence in the OROKSI project is pushed innovation, i.e the type of innovation that is led by the discovery or development of a new type of product or technology in contrast to pulled innovation, which is grounded on consumer needs, i.e. the market demands. The management, represented in this by the executive board, will be approachable by the staff of partners for discussion about the use of project results in new and unique ways that were not envisioned during the initial conception of the project, during the whole runtime of the project. Another body that will be on the look-out for opportunities both internal and external will be the exploitation group, the main task of which is the development of suitable exploitation models and structures. Especially the latter allows reacting to opportunities with speed and precision, resulting in a better integration of innovation management into the running project. Other tools that will be employed on varying levels in the project are brainstorming (on the partner, work package and project level), idea management and product life cycle observations and evaluations, among others. The holistic nature of the management scheme will allow input from all levels of the partners to be effectively and efficiently assessed and implemented on short notice.

B.3.2.8 Milestones

The Executive Board will monitor the progress of the project carefully with the help of the milestones defined below. The decision if the project as a whole is on time, and if not what sub-parts are not on schedule, will be communicated to the General Assembly, which will, if necessary, inform the European Commission of the delay and develop plans how to progress in the future. The milestones have been specifically defined so as to allow an easy and reliable verification. In conjunction with the deliverables, the milestones provide a smooth and traceable means of tracking project progress and thus enable efficient decision making in a technical as well as administrative level, employing the management structure outlined above, all throughout the project's runtime.

Milestone short description	WPs	Date	verified by
Milestone 1 (MS1)			
"Work has started successfully" • project kick-off meeting • management structure established • project website operating • internal evaluation guidelines for quality management	WP8, WP9	M3	- completion of deliverables: D8.1, D9.1
MS1 detailed description			

Milestone 1 sets up the necessary project and internal infrastructure
• *Dissemination, Communication and Exploitation :* [WP8]
  • Workplan for project management and partner collaboration
  • Project website containing information regarding the project, including dissemination and communication activities
  Validation: All parties involved are informed about workplan, and website is online
• *Dissemination, Communication and Exploitation :* [WP9]
  • All information regarding information and rules for project participation are made available, including electronic communication media for the project and deliverable submission.
  Validation: All parties involved are informed about project handbook			

<table>
<tr><th>Milestone short description</th><th>WPs</th><th>Date</th><th>verified by</th></tr>
<tr><td colspan="4">Milestone 2 (MS2)</td></tr>
<tr><td>“Specification defined”
• Guidelines for software development specified
• Initial system design completed
• Initial requirements and evaluation scenarios sketched
• RTD activities have started successfully
• The project’s focus, challenges, methodological approach, system software integration design are documented in much more detail than as is presented in this proposal. The documentation includes
  • a concrete “Dissemination and Communication” plan until the end of Year 2
  • a concrete set of evaluation criteria for Milestone 3.</td><td>all</td><td>M12</td><td>- RTD personnel employed
- scenarios published internally
- submitted papes ≥ 4
- completion of deliverables: D1.5, D2.1, D2.2, D3.1, D5.1, D6.1</td></tr>
<tr><td colspan="4">MS2 detailed description</td></tr>
<tr><td colspan="4">Milestone 2 will make the first knowledge bases of several episodes of objects fetch tasks publicly available in OPENEASE. The activities do not need to be performed autonomously. The knowledge bases will be filled with knowledge chunks from every partner, meaning knowledge chunks that are extracted and transformed from Cyc, from the LOD service (partner: VUA), from the robot knowledge base (partner: UniHB), and from longterm spatio-temporal knowledge bases (partner: BHAM). The selected benchmark queries require knowledge from each partner. The successful answering of the queries will ensure that the knowledge representations used by the partners are integrated consistently. To ensure early integration OROKSI will schedule a one-week hackathon with all partners involved in knowledge representation and processing already in M3-M4 of the project. The answering of the queries is disembodied; that is, the queries are formulated by a human programmer and not automatically generated by the robot from the task interpretation and perceived scenes. Also, the answers returned by the OROKSI service will not be required to generate robot actions.</td></tr>
<tr><td colspan="4">Milestone 3 (MS3)</td></tr>
<tr><td>“Knowledge service” and “robot retriever” systems operational
The two subsystems of the OROKSI project, the knowledge service and the object retrieval plans including ROBOPAL are operational and loosely coupled. In this milestone selected queries are automatically generated by the robot perception system and the answers executed by the Robot Control System. We expect that at least 25% of the high-level decision problems in an object retrieval task can be solved using the OROKSI knowledge service. The robot will execute selected object retrieval tasks under simplified laboratory conditions. The objects will be selected from a small set of previously known objects and the scenes arranged such that they are realistic but not yield very complicated manipulation conditions.</td><td></td><td>M18</td><td>- submitted papers ≥ 10
- OROKSI knowledge base contains at least two Cyc microtheory knowledge bases, associational and shallow reasoning results to huge high-volume lower-quality knowledge bases originating from linked object data, and knowledge bases that result from at least 30 episodic memories of object retrieval tasks.</td></tr>
</table>

Milestone short description	WPs	Date	verified by
Milestone 4 (MS4)			
“Improved web service and robot retriever + demonstration of open research” • first prototype of a completely integrated robot control system that uses the OROKSI knowledge service • all work packages contribute a functional version of the respective software components • 60% of all queries of the robot are answered by the knowledge service • A database of episodic memories available in the knowledge service • Open research demonstration based on that database • Initial demo in the elderly home		M30	- submitted papers $\geq$ 22 - at least 1 workshop on experimental robotics has accepted experiments published with OPENEASE; - at least 6 research projects use OPENEASE as a means for open research and publishing research results - at least 2 benchmark knowledge bases are provided through OPENEASE - half of a course on AI-based robotics is available through OPENEASE
Milestone 5 (MS5)			
“Full functionality of using a cloud service on a robot retriever” • All system components are operational • the autonomous robotic agent for object retrieval will be shown in a real environment at a TRL 5 • the OROKSI knowledge service will be demonstrated at a TRL 7 • The knowledge service will have collected big amounts of data for long-term learning. Examples of interactive learning of robot knowledge will be demonstrated • Several system components have been provided as open source contributions	all	M45	- full operation is demonstrated on a selected set of tasks to be specified after milestone MS3. - Submitted papers $\geq$ 30 - at least 2 workshops on experimental robotics have accepted experiments published with OPENEASE; - at least 10 research projects use OPENEASE as a means for open research and publishing research results - at least 4 benchmark knowledge bases are provided through OPENEASE - at least 2 industrial users who are not project partners start using OROKSI. - the complete course on AI-based robotics is available through OPENEASE

B.3.2.9 Identified risks and associated contingency plans

A systematic and pro-active approach to risk analysis and management is essential in every project, particularly in one as technically demanding as the oRoKSI project. Risk management is the responsibility of both the WP leaders and the coordinator, the former concerned mostly with the technical aspects while the latter has to monitor the global risks associated with oRoKSI. The following actions related to risk analysis and mitigation will be performed during the project lifetime whenever necessary:

- Risk Identification: At the beginning of the project and at the start of each work package, risk identification will be conducted, especially in regards to the already determined risks provided in the WP descriptions and the table below. Risk identification will be conducted as a continuous process all throughout the project, adding new risks as soon as they are perceived.
- Risk Quantification: Identified risks will be graded in terms of likelihood and consequence. A table with identified risks will be provided and regularly updated in the project handbook.
- Risk Response Planning: For each identified risk, the Coordinator will appoint a WP Leader as risk owner (usually the one most affected by the risk). The risk owner, assisted by the coordinator and the other WP Leaders, will develop a risk response plan (e.g. avoid, mitigate, accept etc.).
- Risk Monitoring and Control: The status of identified risks will be monitored constantly by both the Coordinator and the WP Leaders, ensuring that efficient countermeasures are deployed as soon as a risk manifests itself. Risk mitigation measures will be implemented as soon as possible, lowering the risks probability of occurrence.

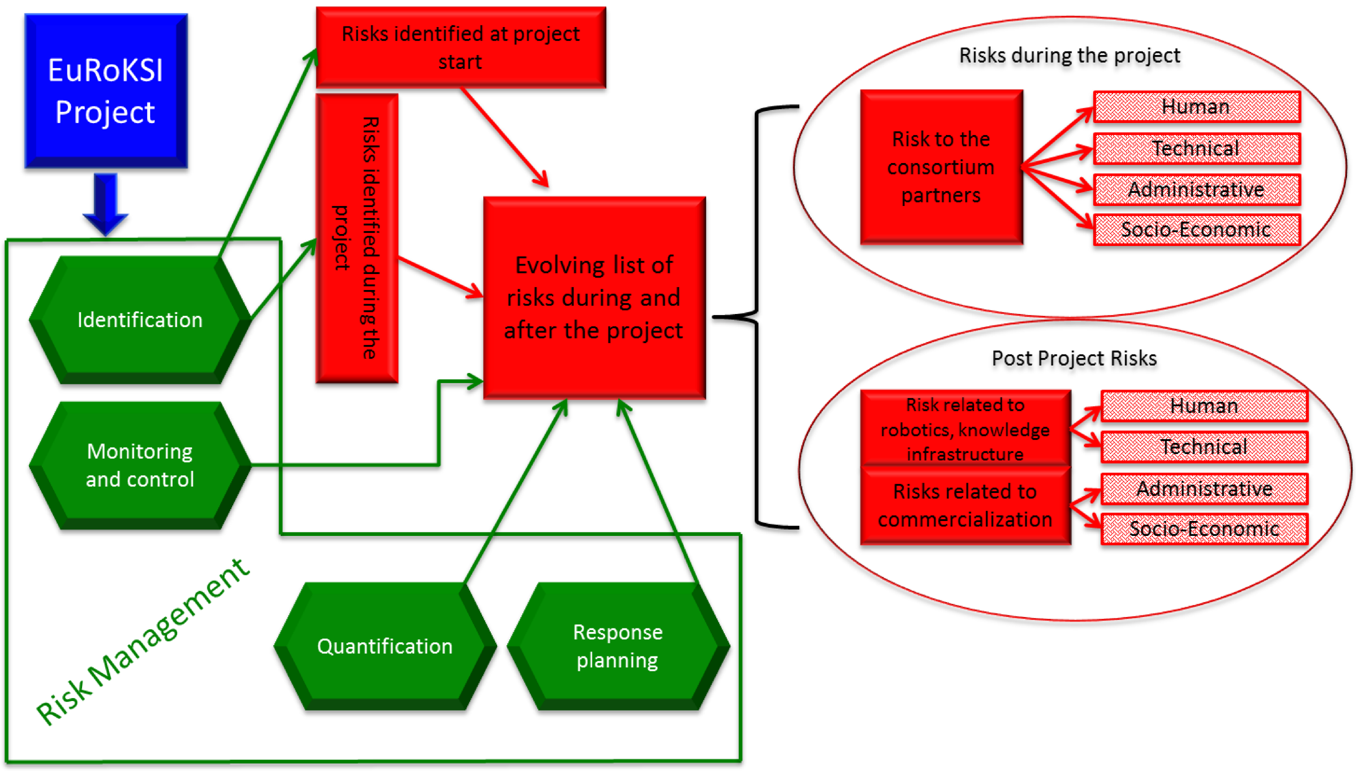


Figure B.3.3: Risk management and risk categories.

The oRoKSI consortium has already identified a number of risks that could affect the project during any of its development stages and that could lead to problematic situations, triggering appropriate reactions of both the EU Commission and other project stakeholders. Therefore significant risks categories as well as the risk management are presented in Figure B.3.3.

The risk of project failure is minimal. A prototype of the openEASE knowledge service is already implemented and used by researchers outside the laboratory using a graphical web interface. We have also already running a prototype version of a robot control system that can feed perception data into the knowledge base and execute actions represented in a symbolic representation language. In addition, the robot control system can already log activities in very detailed episodic memories that can be used as virtual knowledge bases. This means, that already at the project start we have functional prototypes of all essential components and their integration.

Table B.3.5 lists risks already identified by the consortium partners.

Description of risk	Risk type	Work package(s) involved	Proposed risk-mitigation measures
Malfunctioning software	Technical	WP1-WP5	the essential software components are either developed by partners of open source.
Incompatible software interfaces	Technical	WP1-WP5	All essential software components are already interfaced to each others.
Incompatible requirements for software versions	Technical	WP1-WP5	We will modify software modules such that they can run on the robot
Robot fails to operate fully autonomously	Technical	WP1-WP5	Task 3.4 includes the realization of a tele presence control interface

Table B.3.5: Critical risks for implementation.

B.3.3 Consortium as a Whole

In OROKSI we have selected research partners according to the following criteria:

- key OROKSI objectives are already present in the research agenda of the partners;
- partners lead or are integrated in larger research infrastructures and institutes with methods, software and robots that can build the groundwork for the OROKSI project work;
- partners share common goals such as promoting the research field through opensource software, bridging the gap between semantic/symbolic control and subsymbolic control, etc;
- partners are internationally leading in their respective fields of expertise;
- partners have extensive experience in the realization and deployment of integrated intelligent systems

To cover the needed areas of expertise, OROKSI is proposed by a consortium of seven distinguished partners coming from six different EU countries. The consortium is made up from industry, research and academic institutes. The partners' expertise and previous work which is contributed to OROKSI covers the research areas as follows:

Research Area	Partners	References
knowledge-enabled robot programming	**UniHB**: • recognizing objects based on partial symbolic descriptions • semantic object and scene perception • grounding knowledge processing into robotic agents • virtual knowledge bases • acquiring episodic memories of robotic agents • executing symbolic action descriptions	[BBB+15; WT+14] CRAM ROBOSHERLOCK
knowledge services	**UniHB**: • exchanging knowledge between robots (RoboEarth) • developing OPENEASE knowledge service for robotic agents **VUA**: • Web-scale crawling of Semantic Web sources. • Large-scale knowledge dissemination through web APIs. • Architectures for storing and querying RDF(S). **Cyc-EU**: • web interface to OpenCyc • hybrid and common-sense reasoning methods	[TB13; TP+13] ROBOEARTH ROBOHOW [BKVH02] [BR+14] LOD Laundromat[3] Open PHACTS API [FH+08]

[3] http://lodlaundromat.org

Research Area	Partners	References
	Neusta: • user interface design • intelligent wearable computing for healthcare applications • provider of commercial cloud computing infrastructure and services	[AL; AL13; KK+; LG+14] TUI cloud service
curated deep knowledge	**Cyc-EU** • largest industrial strength commonsense knowledge base • one of the largest encyclopedic knowledge bases	CYC
high-volume shallow knowledge	**VUA** • Web-scale crawling of Semantic Web resources • High-volume Semantic Web knowledge bases • (Non-)classical reasoning over large knowledge bases	[SC03] [UK+10] Open PHACTS LOD Laundromat
knowledge systems	**VUA:** • High-performance distributed knowledge systems. • High-volume Semantic Web knowledge bases. • Data integration of heterogeneous sources. • Standardization of (web) knowledge representation. • (Non-)classical reasoning over large knowledge bases. **Cyc-EU:** • largest industrial strength commonsense knowledge base • hybrid inference methods for commonsense reasoning • one of the largest encyclopedic knowledge bases • successfully commercializing knowledge processing **UniHB:** • open-source knowledge processing for robots (KNOWROB) • integration of knowledge and robot perception and action • execution time reasoning in robot control systems	[HPSVH03] [SC03] [AVH04] [UK+10] LARKC Open PHACTS [Len95; BS+05; CM+06; PM+06; WB13] CYC LARKC [TB13; MBB+14] OPENEASE KNOWROB ACAT

The consortium of whom partners have already or are successfully working together in European projects provides the breadth of knowledge and expertise and the experience required to achieve the OROKSI goals and realize the stated outcomes.

Partner	Roles	WPs	Expertise
UniHB	• **coordination of OROKSI** • **leading role** for embodied knowledge representation and processing • **leading role** for semantics of object perception in scenes • leading OROKSI plan-based control • integration leader for the robots Boxy and Raphael (PR2) • providing CRAM as a basis • bridging the gap between high-level robot control and perception and low-level control	all	• AI-based robot control • integrating perception, cognition and action into complete control systems • open source software for robots • acquisition and use of semantic environment models • vice coordination of lead of scientific programme of the German cluster of excellence CoTeSys (Cognition for Technical Systems): $>$ 100 researchers • link to EU project RoboEARTH • link to EU project RoboHow
VUA	• **Leading role** in the construction of reasoning services for assisting robots in the fetch-and-place domain. • **Important role** in the integration of curated and Web knowledge. • **Leading role** in the construction of a knowledge interchange format for robots.	WP2, WP4, WP5	• High-volume knowledge bases from linked data • Hybrid classical/non-classical reasoning • Standardization of exchange format for robot knowledge
CycEur	• **Leading role** in the integration of curated and Web knowledge • **Leading role** in supporting natural language interaction • **Important role** in knowledge mining and machine learning	WP2, WP3, WP5	• Provider of semantic technologies that bring a new level of intelligence and common sense reasoning to OROKSI • Contribute Cyc software combining an unparalleled common sense ontology and knowledge base with a powerful reasoning engine and natural language interfaces to enable OROKSI for the semantic web. • Entrepreneur in the semantic web domain • Large Knowledge Collider (LarKC): An EU FP-7 project that is aimed at creating a Web-scale reasoning engine for the Semantic Web.
NEUSTA	• **leading role** for the dissemination, communication and exploitation of the project results • **important role** for the design of a wearable human-robot interface and technical development of user interface • **important role** for using OPENEASE as an interactive teaching module • supporting role in setting up a cloud-based service • supporting role in user and data management on OPENEASE	WP2, WP5, WP6, WP7	• Cloud services: Cloud Engineering Service for Airbus/Toulouse (www.neusta.fr), "Mein Service" for TUI AG (2013 European Service Award for Travel and Hospitality) • User Interface design: www.insa-projekt.de, www.safemove-project.eu, assam.nmshost.de, www.rempark.eu, www.help-project-parkinson.com, www.vicon-project.eu, www.wearitatwork.com, www.chronious.eu • Wearable design: HELP-AAL (Home based Empowered Living for Parkinsons diseases patients) (AAL FORUM award 2012)

Evidence for outstanding consortium

- scientific excellence
  - publications, best papers
  - organization of scientific events
  - memberships in strategic alliances
  - roadmapping
- opensource
  - Google summer of code
  - web pages for opensource
    - not only opensource but also installation guides, tutorials, manuals
  - mailing lists
  - openCyc, ResearchCyc
  - SWI Prolog
  - PCL
  - KnowRob, RoboSherlock, CRAM, PRAC-MLN
- management of, and participation in, successful cooperative research projects
  - LARKC
  - RoboEarth, RoboHow, Saphari + quotes from the evaluation reports
  - experienced project managers
    - Edinburgh robotics centres
- dissemination
  - Royal Academy of Engineering
  - EU Robotics participation

B.3.4 Resources to be committed

B.4 Members of the consortium

B.4.1 Participants

B.4.1.1 Participants (applicants)

Id: **1**	*Name:* **Universität Bremen**	*Short:* **UniHB**	**Germany**

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Description of the legal entity and its main tasks

Universität Bremen

The University of Bremen is a mid-sized University with a broad array of disciplines. It contains four collaborative research centers, the DFG research center 'Ocean Margins', a cluster of excellence, two graduate schools of excellence and several research training groups. Two further collaborative research centers are located in the fields of logistics and spatial cognition – in both these areas, computer science is particularly prominent.
The designation of six high-profile areas further enhances the University's profile, which is rounded off by cooperation with the non-university institutes belonging to renowned research societies (Max-Planck, Helmholtz, Fraunhofer, Leibniz). Hardly any other university has in relation to its size so many non-university research institutions in its immediate neighborhood: this close proximity opens up possibilities for intensive cooperation on research projects and there are currently around 30 joint professors working both within and outside the University walls. This impressive research infrastructure is attracting more and more enterprises to locate in the technology park which encircles the campus. Some 400 high-tech corporations have already located here.
The Institute for Artificial Intelligence (IAI) directed by Prof. Michael Beetz is part of the Faculty of Computer Science and member of the Center for Computing and Communication Technologies (TZI) (http://tzi.de) at the University of Bremen. UniHB/TZI has profound experience in the field of pervasive computing. Michael Beetz and his group are in close contact and exchange researchers with leading international robotics research groups (Bosch, CMU, Georgia Tech, University of Tokyo, LAAS-CNRS, etc.).
Partner UniHB will coordinate the OROKSI project (WP9) and will take the lead in the work packages 3 and 7 with all its tasks and further lead the tasks T1.3, T2.3, T8.1 and T8.2.

Key researchers
Prof. Michael Beetz (male) is a professor for Computer Science at the Faculty for Informatics of the University Bremen and head of the Institute for Artificial Intelligence. He was a professor and head of the IAS group at the Department of Informatics at Technische Universitt München, the vice-coordinator of the German national cluster of excellence CoTeSys where he was also co-coordinator of the research area "Knowledge and Learning". He was a member of the steering committee of the European network of excellence in AI planning (PLANET) and coordinating the research area "robot planning". He is associate editor of the AI Journal. He has many years of experience in plan-based control of robotic agents, knowledge processing and representation for robots, integrated robot learning, and cognitive perception.

Relevant publications, and/or products, services

- AAMAS 2015: Jan Winkler and Michael Beetz, "Generalized Plan Design For Autonomous Mobile Manipulation in Open Environments"
- ICRA 2015: Michael Beetz, Moritz Tenorth, Jan Winkler, "Open-EASE – A Knowledge Processing Service for Robots and Robotics/AI Researchers". **(finalist for ICRA 2015 Best Conference and Cognitive Robotics Awards)**
- Michael Beetz, Ferenc Balint-Benczedi, Nico Blodow, Daniel Nyga, Thiemo Wiedemeyer, Zoltan-Csaba Marton, "ROBOSHERLOCK: Unstructured Information Processing for Robot Perception", In IEEE International Conference on Robotics and Automation (ICRA), Seattle, Washington, USA, 2015, accepted for publication. **(finalist of ICRA 2015 Best Conference and Best Service Robotics Paper Awards)**
- Jan Winkler, Moritz Tenorth, Asil Kaan Bozcuoglu, Michael Beetz, "CRAMm – Memories for Robots Performing Everyday Manipulation Activities", In Advances in Cognitive Systems, vol. 3, pp. 47-66, 2014.
- Zoltan-Csaba Marton, Ferenc Balint-Benczedi, Oscar Martines Mozos, Nico Blodow, Asako Kanezaki, Lucian-Cosmin Goron, Dejan Pangercic, Michael Beetz, "Part-Based Geometric Categorization and Object Reconstruction in Cluttered Table-Top Scenes", In Journal of Intelligent and Robotic Systems, Springer Netherlands, pp. 1-22, 2014.

Relevant previous projects or activities

- **RoboHow** (http://robohow.eu) is an FP7 project coordinated by the Institute for Artificial Intelligence of UniHB that enables robots to competently perform everyday human-scale manipulation activities – both in human working and living environments.
- **SAPHARI** (http://saphari.eu/) is an FP7 project that investigates Safe and Autonomous Physical Human-Aware Robot Interaction
- **SHERPA** (http://sherpa-project.eu) is an FP7 IP that develops a mixed autonomous ground and aerial robotic platform for support in search and rescue.
- **ACAT** (http://acat-project.eu/) is an FP7 IP that focuses on how artificial systems (robots) can understand and utilize information made for humans.
- **BayCogRob** was a project funded by Deutsche Forschungsgemeinschaft that aimed to advance autonomous learning in Bayesian cognitive robotics
- **CoTeSys** (http://www.cotesys.org) was an Excellence Cluster in Cognition for Technical Systems in which approaches were developed to equip robots with abilities to learn from observations and realize their environment.
- **PR2 Beta Program** (http://www.willowgarage.com) was an initiative of Willow Garage that distributed PR2 robots to laboratories around the world to foster software development for autonomous robots

Infrastructure and/or technical equipment

The Institute for Artificial Intelligence investigates methods for cognition-enabled robot control where the research is at the intersection of robotics and Artificial Intelligence and includes methods for intelligent perception, dexterous object manipulation, plan-based robot control, and knowledge representation for robots. The Institute runs for this purpose an own lab with different robots like Raphael-PR2, Boxy and TurtleBot (http://ai.uni-bremen.de/research/robots).

Robots performing complex tasks in open domains, such as assisting humans in a household or collaboratively assembling products in a factory, need to have cognitive capabilities for interpreting their sensor data, understanding scenes, selecting and parametrizing their actions, recognizing and handling failures and interacting with humans. In their research, IAI is developing solutions for these kinds of issues and implements and tests them on the robots in their laboratory. A particular focus of the group is on the integration of individual methods into complete cognition-enabled robot control systems and the release of the developed software as open-source libraries.

OpenEASE is the web-based knowledge service for robots with specific knowledge processing mechanisms and control programs able to deal with vague action and object descriptions while monitoring unexpected events and reacting to them.

ROBOSHERLOCK is a cognitive perception system build on top of the principles of unstructured management information architecture enabling robotic perception systems to better deal with the variations of appearances and perceptual properties that real-world objects exhibit perceiving the affordances of the variety of perceptual tasks they have to perform.

Id: **2**	*Name:* **VU University Amsterdam**	*Short:* **VUA**	**Netherlands**

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Description of the legal entity and its main tasks

VU University Amsterdam (VUA) is one of the large research universities in the Netherlands, with about 24,000 students, and is ranked in the Shanghai top 100 of research universities worldwide. Within VUA's Computer Science Department, the Semantic Web research group is one of the world's leading groups in the field. It initiated and coordinated the EU's first Semantic Web project On-To-Knowledge) in 1999 and has further participated in key EU-funded projects such as Knowledge Web (scientific coordination), SEKT, SWAP, OpenKnowledge and Open PHACTS. Members of the group have contributed significantly to the W3C Semantic Web effort: key OWL design contributions, co-chairing the OWL working group, co-chairing the Semantic Web Deployment Group, co-chairing the Provenance Working Group and key contributions to the SKOS recommendation. The group co-lead the EU-funded IP LarKC(the Large Knowledge Collider), a platform for massive distributed incomplete reasoning aimed at removing the scalability barriers of currently existing reasoning systems for the Semantic Web. VUA has extensive expertise in both the development and application of tools for Linked Data. In a recent development, the VUA Semantic Web research team has developed the LOD Laundromat, a unique single end-point for the entire content of the Semantic Web. This gives the VUA team a worldwide lead, with unified and efficient access to a knowledge web of 700.000 dataset containing close to 40B triples from their local servers. Partner VUA will take the lead in the WP1, will make significant contributions to WP2, and will make minor contributions to WP3 and WP4.

Key researchers
Prof. Frank van Harmelen (male) is professor in Knowledge Representation and Reasoning at the VU University Amsterdam. He has been involved in the Semantic Web research programme since it's inception in the late '90s. He is one of the co-designers of the W3C ontology representation language OWL, and was involved in the design of Sesame, one of the most frequently used RDF repositories world wide with over 200.000 downloads to date. He was scientific director of the Large Knowledge Collider (LarKC), which aimed to build a platform for very large scale distributed reasoning. Besides research into the fundamental questions such as inconsistency, scalability, heterogeneity, and dynamicity, he is also involved in a wide variety of applications of semantic technologies, among others in medicine, the pharmaceutical industry, scientific publishing and e-science. His work on the Sesame triplestore received the 2012 "ISWC 10 year impact award". He has over 200 refereed publications on his name, and these are highly cited, with an H index of over 60. He was admitted as member of the European Academy of Science (Academa Europea) in 2014, and as member of the Royal Holland Society of Sciences and Humanities (KHMW) in 2015.
Prof. Stefan Schlobach (male) is an Assistant Professor in the Department of Computer Science at the Vrije Universiteit Amsterdam. He received a PhD from the University of London for his research on knowledge extraction in Description Logics. He has been involved in several EU projects, such as SEKT on debugging inconsistent ontologies, and Knowledge Web project on approximate reasoning. He lead the NWO funded STITCH project on Semantic Interoperability in the Cultural Heritage, and the SOKS project, which aims at applying Self-Organisation technology to Semantic Web reasoning. His current research focuses on using non-standard techniques and semantics, e.g., Computational Intelligence based approaches for reasoning and querying, scalable reasoning through approximation and parallelisation, as well as reasoning services for ontology languages such as mapping, explanation or abduction.

Relevant publications, and/or products, services

- **Semantic Web Primer**, MIT Press, 1st ed. (2004) & 2nd ed. (2008) G. Antoniou & F. van Harmelen, 3rd ed. (2013) with G. Antoniou, F. van Harmelen, R. Hoekstra & P. Groth. https://mitpress.mit.edu/books/semantic-web-primer-0. 1903 citations.
- **From SHIQ and RDF to OWL: The making of a web ontology language**, I Horrocks, PF Patel-Schneider, F van Harmelen, Journal of Web Semantics, 1(1), 7-26, 2003. http://www.cs.vu.nl/~frankh/postscript/JWS03.pdf. 1486 citations.
- **Sesame: A generic architecture for storing and querying RDF and RDF Schema**, J Broekstra, A Kampman, F Van Harmelen, Internat. Semantic Web Conf. (ISWC 2002) LNCS Vol. 2342, pgs. 54-68, Springer Verlag 2002. http://www.cs.vu.nl/~frankh/postscript/ISWC02.pdf. 1333 citations. The accompanying software has been downloaded $>$ 200.000 times since its inception, and is in worldwide use in academia and industry.
- **OWL reasoning with WebPIE: calculating the closure of 100 billion triples**, J Urbani, S Kotoulas, J Maassen, F Van Harmelen, H Bal, European Semantic Web Conference (ESWC 2010), LNCS Volume 6088, pgs. 213-227, Springer Verlag 2010.
- **Streaming the Web: Reasoning over Dynamic Data**, Margara, A.; Urbani, J.; van Harmelen, F.; and Bal, H.Journal of Web Semantics, 2014. http://www.cs.vu.nl/~frankh/postscript/JWS2014.pdf.

Relevant previous projects or activities
The **Large Knowledge Collider (LarKC)**, the EU FP7 project.

Infrastructure and/or technical equipment
We are hosting the LOD Laundromat (http://lodlaundromat.org/), a world-wide unique infrastructure that gives efficient access to the entire Linked Open Data cloud from a single end-point. This endpoint also ensure that all available datasets are standards compliant and no longer contain redundant elements. As of March 2015, the LOD Laundromat is hosting 700.000 datasets, amounting to close to 40 billion atomic statements (triples).

Id: **5**	*Name:* **Cycorp Europe**	*Short:* **CycEU**	**Slovenia**

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Description of the legal entity and its main tasks

Cycorp Europe is a Slovenian company with the aim of developing and applying the Cyc System to the benefit of European business, government, and social organizations, and the joint aim of making real progress towards the goal of developing and applying genuine artificial intelligence. In addition to pursuing its own research in applications of symbolic AI to text processing and analytics, Cycorp Europe has access to the results of more than 20 years of development on the Cyc knowledge base and the Cyc inference engine, a modular, reflective automated reasoning system capable of inferences over millions of assertions in higher order, modal, contextual logic.
CycEU will take the lead for the tasks T1.1 and T1.2 and will be a main contributor to the other tasks of WP1, WP2 and WP4 with their semantic web expertise.

Key researchers

Dr. Michael Witbrock (male), the CEO of Cycorp Europe. Dr. Witbrock holds a PhD in Computer Science from Carnegie Mellon University and is particularly interested in automating the process of knowledge acquisition and elaboration, extending the range of knowledge representation and reasoning to mixed logical and probabilistic representations, and in validating and elaborating knowledge in the context of task performance, particularly in tasks that involve understanding text and communicating with users. Prior to founding Cycorp Europe, he has served as VP for research for Cycorp Inc, he was Principal Scientist at Terra Lycos, working on integrating statistical and knowledge based approaches to information retrieval and understanding web user behaviour; a research scientist at Just System Pittsburgh Research Centre, working on statistical text summarization; and a systems scientist at Carnegie Mellon on the Infomedia spoken and video document information retrieval project. He is author of numerous publications in areas ranging across knowledge representation and acquisition, neural networks, parallel computer architecture, multimedia information retrieval, web browser design, genetic design, computational linguistics and speech recognition, and is the holder of four patents.

Relevant publications, and/or products, services

- Lenat, D. B. (1995). Cyc: A Large-Scale Investment in Knowledge Infrastructure. Communications of the ACM, 38(22).
- Witbrock, Michael, and Luka Bradeko. “Conversational Computation.”Handbook of Human Computation. Springer New York, 2013. 531-543.
- Crago, S. P., McMahon, J. O., Archer, C., Asanovic, K., Chaung, R., Goolsbey, K., Yeung, D. (2006). CEARCH: Cognition Enabled Architecture. In Proceedings of the Tenth Annual High Performance Embedded Computing Workshop. Lexington, MA. Retrieved from http://cearch.east.isi.edu/papers/CEARCH-abstract-hpec-9-06.pdf
- Panton, K., Matuszek, C., Lenat, D., Schneider, D., Witbrock, M., Siegel, N., & Shepard, B. (2006). Common Sense Reasoning – From Cyc to Intelligent Assistant. In Y. Cai & J. Abascal (Eds.), Ambient Intelligence in Everyday Life (pp. 1 – 31). Springer.
- Baxter, D., Shepard, B., Siegel, N., Gottesman, B., & Schneider, D. (2005). Interactive Natural Language Explanations of Cyc Inferences. In In AAAI 2005: International Symposium on Explanation-aware Computing.

Relevant previous projects or activities

- Cycorp Europe is one of the partners in the 10M worth international project **LarKC** – large scale reasoning.
- Cyc Europe is as well collaborating in the 3.5M worth national funded project **TITRES** – Technology Innovation in Telecommunication for Rational Ecological Systems, where it provides background technology for the TITRES Intelligence services.
- Cyc is also being used in FP7 **EURIDICE** IP on intelligent cargo where Cyc provides reasoning and background knowledge for several cargo intelligence services.
- Cyc is used as a background knowledge, reasoning and natural language generator in the **Curious Cat** startup (www.curiouscat.cc), where the goal is to build a Siri like agent that learns from it’s users and then uses the gained non-personal knowledge to provide the shared knowledge access. The acquired knowledge is also used to reason about how to assist and help the users as a means of personal assistance

Infrastructure and/or technical equipment

The Cyc Knowledge Server is a very large, multi-contextual knowledge base and inference engine developed by Cycorp (since 1994). It's goal is to break the "software brittleness bottleneck" once and for all by constructing a foundation of basic "commonsense" knowledge–a semantic substratum of terms, rules, and relations–that will enable a variety of knowledge-intensive products and services. This AI system provides a "deep" layer of understanding that can be used by other programs or machines to make them more flexible. The Cyc technology includes the knowledge base, Inference engine and natural language processing module.

The Cyc Knowledge Base (KB) is a formalized representation of a vast quantity of fundamental human knowledge: facts, rules of thumb, and heuristics for reasoning about the objects and events of everyday life. This knowledge is represented in a formal language (first and second order logic), which is understandable by the computers and machines (as opposed of the unstructured data). At the present time, the Cyc KB contains over five hundred thousand terms (500k), including about seventeen thousand types of relations (17k), and about seven million assertions (7mio) relating these terms. New assertions are continually added to the KB through a combination of automated and manual means. Many more concepts can be expressed functionally, thereby enabling the automatic creation of millions of non-atomic terms, such as (LiquidFn Nitrogen) being used to describe liquid nitrogen. Additionally, Cyc adds a vast number of assertions to the KB by itself as a result of the inferencing process.

Because the amount of knowledge which is in the Cyc KB is so big, many approaches commonly taken by other inference engines (such as frame-based expert system shells, RETE match, Prolog, etc.) don't scale up. As a result, Cycorp has invested years of R&D effort to create a hierarchically-controlled, highly tunable, self-improving, and extremely modular reasoning architecture. The modularity allows it to be extended by various reasoning modules which does a special-purpose inferencing, and consequently, it allows it to be integrated in various external applications. On top of the knowledge base and the inference engine Cyc developed the language module, which is able to paraphrase almost every bit of the KB into the natural language, and on the other side, it is able to convert some natural language structures back into the logic. This allows it to do the question answering and NL processing with the help of the logic based reasoning.

Id: **6**	*Name:* **Neusta mobile solutions GmbH**	*Short:* **NEUSTA**	**Germany**

Location

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Contact

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Description of the legal entity and its main tasks

The Neusta mobile solutions GmbH (NEUSTA) does consulting and application development for mobile devices. These devices are e.g. Smartphones, Web tablets, and Wearables. NEUSTA was founded in 2004 and is a joint venture of the NEUSTA group with more than 600 employees and Bremen University. Amongst others, the group is dealing with the development of client specific software, the introduction of standard software, IT-consulting, Business intelligence, SAP, Online Marketing and Cloud Engineering.

The very close cooperation with the TZI (centre of computing and communication technology) of Bremen University strengthens neusta mobile solutions role as research- and innovation- driver within the NEUSTA group doing know-how transfer by people. The cooperation with the TZI allows NEUSTA to participate in research projects. In these projects, NEUSTA provides the expertise of professional software development, maintenance and exploitation in fields like (1) knowledge based mobile security, (2) user interface design in wearable computing using data mining and cloud computing and (3) application development using AI and machine learning methods e.g. in ambient assisted living scenarios. NEUSTA is specialized in intelligent treatment of complex data and user interface development. They will play a key role in T2.1 (Cloud-based service and communication infrastructure for serving robot knowledge request), T5.5 (Wearable human-robot interfaces) and T6.3 (User interface and communication) providing AZURE based cloud computing expertise and the mobile and wearable user interface development concerning the technical as well as user experience aspects. NEUSTA will furthermore be responsible for WP8 (Dissemination, communication and exploitation) and drive together with the coordinator UniHB the formation of the oRoKSI company. NEUSTA will be supporting the activities in WP1, WP2 and WP3 responsible for the cloud computing based infrastructure and the open software and open data task 6.2.

Key researchers

Prof. Dr. Michael Lawo (male) is currently Managing Director at NEUSTA and with TZI of Bremen University since 2004. He is professor for applied computer science and involved in numerous projects of wearable computing and artificial intelligence. He is a 1975 graduate of Ruhr-Universitt Bochum, got his PhD from Essen University in 1981 and became professor there in 1992. He has more than 20 years of experience in the IT industry in different management positions and is author, co-author and co-publisher of eight books and more than 150 scientific papers on numerous methods and computer applications also in healthcare, optimization, IT-security and wearable computing. Michael Lawo coordinated the WP6 IP wearIT@work (www.wearitatwork.com) on wearable computing, the FP7eInclusion project VICON (www.vicon-project.eu) on user interface design for people with age related mild to moderate impairments and the FP7 eHealth project Rehab@Home (www.rehabathome-project.eu) on stroke rehabilitation besides being involved in many other projects on mobile and wearable user interface design and cloud computing. He is teaching a graduate course in Wearable Computing with a focus on user interface design and context recognition at Bremen University.

Holger Bothmer (male) is one of the two managing directors of NEUSTA since 2009 after being there a senior consultant since 2006. He received his diploma degree in digital image processing and neural networks by Bremen University in 1994. He was after that in different companies in Germany and the United States of America working as a project manager, systems architect and analyst, director of business consulting and product development. His EC project experience dates back to 2006 with projects like wearIT@work Help-AAL, ASSAM, REMPARK and SafeMove.

Claas Ahlrichs (male) is a publishing research scientist within NEUSTA since 2011. He studied Computer Science at Bremen University and finished with a diploma thesis on the design, development and evaluation of a software framework for abstract user interfaces in the context of wearable computing. He published so far eleven conference/workshop papers and three journal articles. He is currently working in the EU funded research project REMPARK with a focus on appropriate machine learning methods for detecting symptoms in people with Parkinson's Disease (PD). Furthermore, he worked on the development of a DSS for clinicians in the context of PD.

Relevant publications, and/or products, services

- C. Ahlrichs, M. Lawo: Indicating Motor Symptoms in PD Patients Using AI-based Algorithms, in Proceedings of the ICTMH Workshop 19.–20.03.2013, Bremen.
- C. Ahlrichs, M. Lawo: Parkinson's Disease Motor Symptoms in Machine Learning: A Review, accepted for publication in HIIJ (Health Information International Journal), 2014
- G. Kalkbrenner, A. Mehmood Khan, M. Lawo: Activity Recognition using Wearable Computing and Ambient Computing, in Proceedings of the ICTMH Workshop 19.-20.03.2013, Bremen.
- M. Lawo, S. Gabrielli, L. Pannese, G. Bo: Rehab@Home: Ein EU Projekt zur nachhaltigen Rehabilitation mittels "Serious Games", 7. AAL Kongress, 2014

Relevant previous projects or activities
• **HELP**, AAL 1st Call, Jan. 1st, 2006, http://www.help-project-parkinson.com • **REMARK**, FP7 ICT, Nov. 1st, 2011, http://www.rempark.eu • **ASSAM**, AAL 4th Call, May 1st, 2012, http://assam.nmshost.de • **SafeMove**, AAL 4th Call, Jun. 1st, 2012, http://www.safemove-project.eu • **Rehab@Home**, FP7 eHealth, Oct. 1st, 2012, http://www.rehabathome-project.eu
Infrastructure and/or technical equipment As part of the NEUSTA group we have access to knowledge and more than 600 experts on software development, development for mobile and wearable device, IT-consulting, business intelligence, SAP, online marketing, cloud engineering, enterprise resource planning, communications and design.

B.4.2 Third parties involved in the project

Participant: UniHB	
No third parties involved.	
Participant: VUA	
No third parties involved.	
Participant: PAL	
No third parties involved.	
Participant: BHAM	
No third parties involved.	
Participant: CycEur	
No third parties involved.	
Participant: NEUSTA	
No third parties involved.	
Participant: AAF	
Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)	Y
AAF will ask employees from the Haus der Barmherzigkeit care hospital to contribute to OROKSI as experts, or as advisors on specific ethical issues. Also, we may require nurses or therapists at the Haus der Barmherzigkeit to devote time to OROKSI. All of these efforts must be treated as subcontracting as the people in question are not employees of AAF, which is situated at the hospital but functions as an independent association.	
Does the participant envisage that part of its work is performed by linked third parties	N
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)	N

Table B.4.1: Third parties involved in the project.

B.5 Ethics and security

[TODO: Missing tex file ’oe-51ethics’!]

[TODO: Missing tex file ’oe-52security’!]