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The ECHORD Project: A General Perspective

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Abstract. The European funded ECHORD project[1] European Clearing House for Open Robotics Development began in January 2009 with the ambitious goal of bringing together European robotics manufacturers with the excellent European research institutions. Europe has a very strong robot industry and there is significant research potential as well as technological knowledge. There has been a long history of outstanding research and development in both robot manufacturers and research institutes. However, finding common ground between manufacturers and the research community, especially when it comes to defining the future direction of robotics research, has proven difficult in the past. This is one of the recurring themes on both sides, and a new level of cooperation is long overdue. Thus, ECHORD acted as a clearing house to streamline successful know-how transfers.

1 Introduction

The idea of the ECHORD project was born before the economic crisis had its maximum impact on the robotics industry in 2008/2009. Therefore, the concept of a project with the clear goal to strengthen the collaboration between academia and industry was a good opportunity to support the industry by offering funding opportunities and fostering already existing networks and creating new partnerships with the academic world. The project itself was proposed as an Integrating Project (IP) in the Call ICT-2007.2.2 under the Challenge 2: Cognitive Systems, Interaction, Robotics and started in 2009.

[1] The research leading to the results presented in this book has received funding from the European Union through the 7th Framework Programme (FP7) under grant agreement number FP7-ICT-231143.

2 The Concept of ECHORD

The ECHORD concept comprises two instruments to reach the overall goal: the first one is the funding of so-called experiments, small research and development projects, carried out by typically 2-3 partners, both from industry and academia. The second instrument is the so-called structured dialogue, a means to strengthen the relationship between academic institutions and industrial companies, and to identify and support the knowledge transfer.

The project started with only three core partners from academia:

- Technische Universität München,Prof. A. Knoll, acting as the coordinator of the project
- Università di Napoli Federico II, Prof. B. Siciliano, acting as a co-coordinator[2]
- Universidade de Coimbra, Prof. N. Pires, acting as a co-coordinator

This core group was intentionally kept small, just fulfilling the legal requirements, in order to allow for a wide participation of institutions active in robotics research and development, as the coordinating partners were explicitely excluded from proposal submission and participation in the experiments.

These experiments were funded by the European Commission according to their rules, but the organisation of all processes which showed up during their full life-cycle are mainly handled by the core consortium.

3 Creating Awareness and Open Calls

As the word about the new project format spread in the community, there was a need to give clarifications about the project, the funding opportunities, requirements, and to start networking activities to link potential partners interested in the same fields of R&D. Therefore, two information days were held, one as a public opening event for the ECHORD project, held in Munich, Sept. 2009 and one in Lyon, Feb. 2010 with the aim to raise awareness especially in the French robotics community, which was under-represented in the first call. During these information days, potential proposers were informed about the funding scheme within ECHORD, the application procedure, and some special rules which apply in the project. Question and answer sessions with members of the core consortium clarified specific issues, mainly related to administrative aspects of the proposal and execution phase of the experiments. Another main goal of these events was the possibility to present the own research idea and to search for partners with complementary skills and expertise.

Three rounds of open calls were performed, leading to 243 submitted proposals, where 51 of them were finally selected for funding. The details of the three calls are given in Table 1.

[2] Università di Napoli Federico II is supported by third-parties belonging to PRISMA (Progetti di Robotica Industriale e di Servizio Meccatronica e Automazione) which includes researchers from the Università della Basilicata, Università degli Studi di Cassino, Seconda Università degli Studi di Napoli, Università degli Studi Roma Tre and Università degli Studi di Salerno.

Call	Num. proposals	Experiments funded	Indicative budget
1	108	16	4.5 M€
2	70	20	5.5 M€
3	65	15	5.1 M€

Table 1: Proposals and experiments

3.1 Evaluation and Selection

The evaluation and selection procedures were handled by the coordinating partners and the same strict set of rules as they were applied as in regular EU framework proposals. International experts were asked to evaluate the proposals, taking potential conflicts of interest into account.

Three independent experts acted as evaluators for each proposal in the first evaluation step, which was perfomed remotely using web forms and a blog functionality for the discussion between the experts to come to a consolidated assessment. In one single physical meeting per call, a subset of the experts involved in the remote evaluations formed a panel with the task of calibrating the individual evaluation reports and scores and to set up a fully ranked list of all proposals which passed the thresholds and were therefore eligible for funding. As the number of these proposals exceeded the indicative budget reserved for each call, only the highest-ranked proposals according to this budget were finally selected for funding.

3.2 Proposal Analysis

This section presents a summary of the results extracted in [12]. The data resulting from the set of 242 ECHORD proposals (one full copy resubmission was excluded from the complete set of 243) involves a total of 509 proponents, 264 institutions and 26 countries. The ECHORD core consortium lowered the entrance barrier by allowing single partner and single country proposals. The results presented in Fig. 1 show that, even in small projects (typically 18 months and 300k€), single partner projects have worse quality than multi-partner proposals: 48.1% versus 25,5% ($\chi^2(1) = 8.014; p = 0.005$).

In fact, the probability of a proposal with two or more partners to have a score above or equal to 10 is 2.717 times higher than in case of a single partner proposal (Odds-Ratio=2.717, IC95%[1.389;5.316]).

In terms of international cooperation, the ratio of proponents that participated in proposals whose evaluation score is above 10 with international cooperation is similar to the ratio for single country proposals. From these values one might conclude that the common mandatory requirement of multi-country proposals for EU financing may indeed promote the participation from peripheral countries but does not have a direct influence on the quality of the proposals.

From the analysis of the network of institution-level co-authorship, see Fig. 2, two conclusions were identified: (1) the clusters and the key players (with a

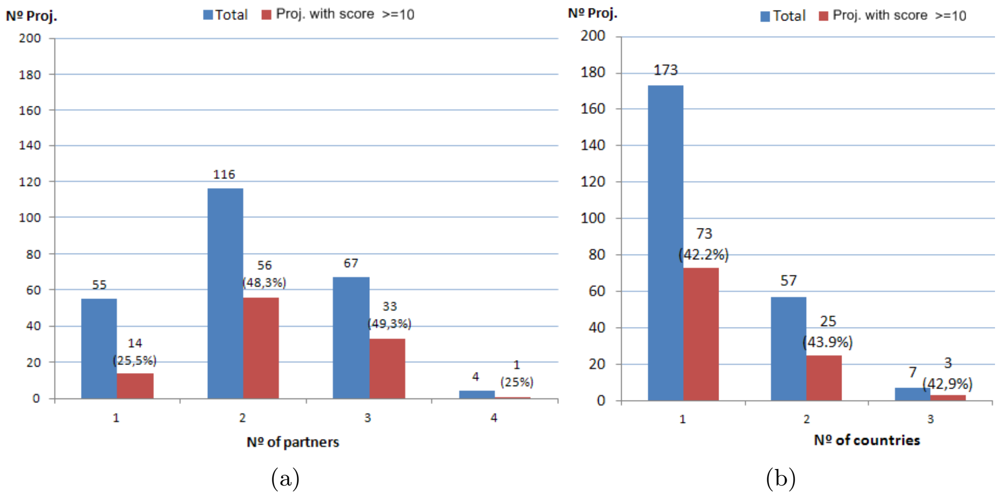

Fig. 1: Distribution of proposals per number of partners (a) and proposals per number of countries (b)

relevant number of connections or playing inter-cluster connections - labelled in Fig. 2) are organized geographically; (2) in addition to the major European robotics manufacturers (ABB, KUKA, REIS, COMAU, SCHUNK) there is a new group of key players that are small robot hardware suppliers with highly differentiating products coming from countries without significant tradition in this area, such as Spain, Austria and UK (Robotnik, FerRobotics, Shadow Robot Company).

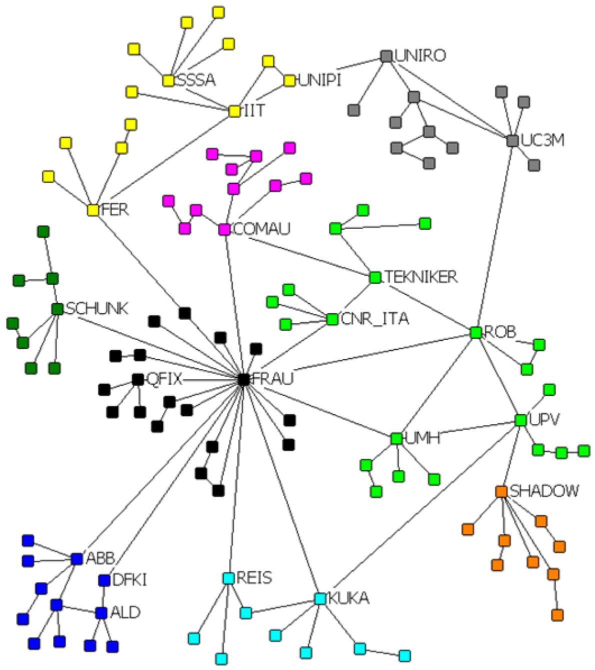

Fig. 2: Largest component of the institution-level co-authorship and clustering. Arrangement for visualization optimization. Adapted from [12]

In terms of the geographic distribution, the clustering of the proposals effecting the proposal production per inhabitant, the score and the international cooperation revealed that Belgium and Sweden constitute a cluster characterized by high proposal production, with very high scores and extensive international collaboration. Belgium also excels in another cluster analysis, being the only country for which 100% of proposals involved industry-academia cooperation and obtained scores above 10.

Industry-academia collaboration was one of the major foci of the ECHORD project. The collaboration patterns and the respective success are depicted in Fig 4 which reveals several facts: (1) the number of proponents from either industry or academia approximately doubles the number of proposals from research institutions. (2) research institutions collaborations with industry double their collaborations with academia. (3) partnerships for the proposals between research institutes have the highest quality judging by the score the proposals received.

Despite the high number of industry proponents in the ECHORD initiative, it is clear from the available data that usually industry plays a secondary role in the submission process: they usually do it together with universities or re-

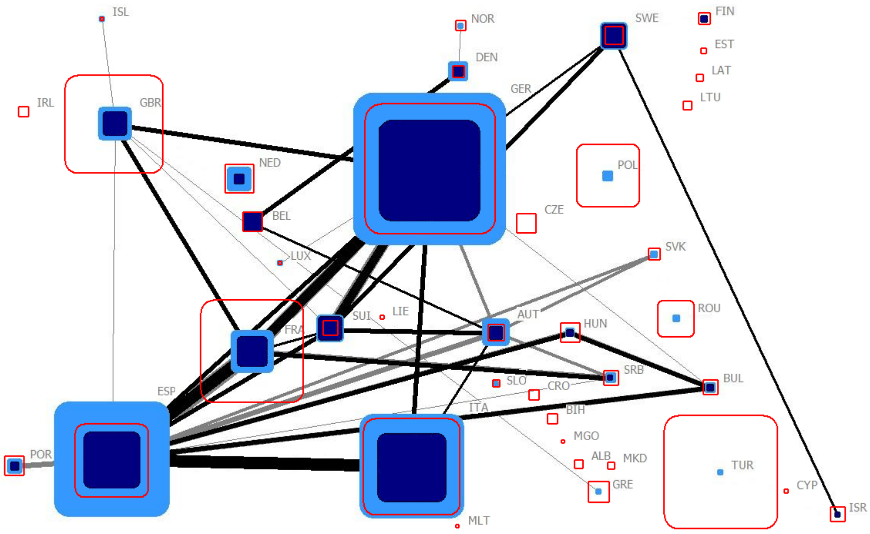

Fig. 3: Geographic distribution of ECHORD experiment proponents. The light blue in % is the number of proponents, the dark blue the number of proponents with reviews above 10 points and the red frame represents the population of the respective country in million inhabitants. Adapted from [12]

search institutes, and do not take the lead of the consortium. In fact, there were significantly fewer proposals led by industry than led by universities or research institutions, and ECHORD did not register a single successful proposal (score above 10) with only one proponent from industry.

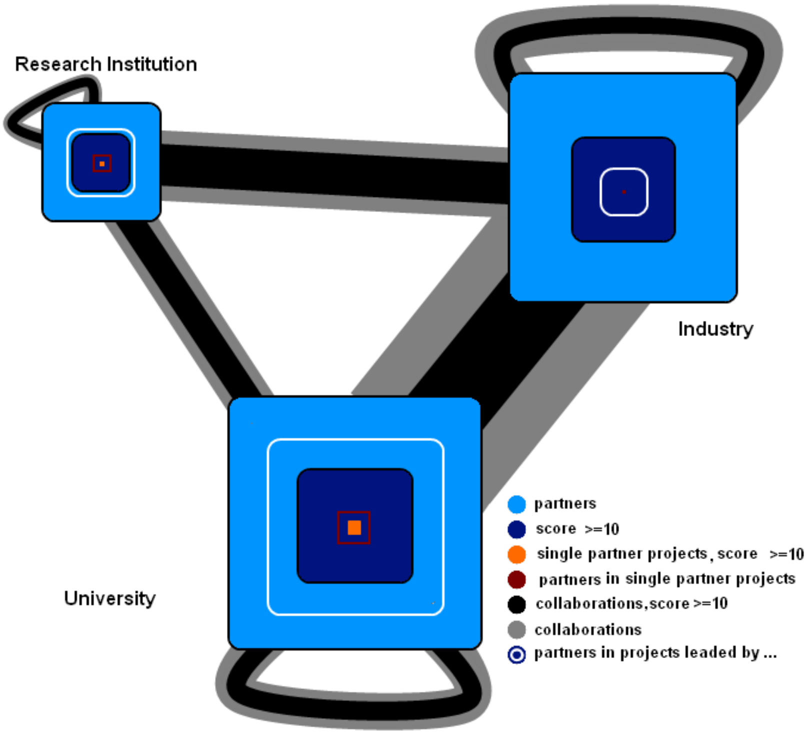

Fig. 4: Partner type distribution in ECHORD. The size of the squares represents the number of partners per type and the width of the connections represents the number of partnerships. Dark blue and black represent partners and partnerships of successful proposals. Adapted from [12]

4 Categorization of the Experiments

The experiments can be grouped according to several axes. To guide the proposers, the proposals were structured by scenarios, research foci, and experiment types.

Three scenarios for likely future robot use were defined to outline the scope of research work to be performed in the experiments. These scenarios intended to make it possible for all stakeholders to get a clear picture if and how their proposed work and envisaged results can be embedded into a coherent vision of robotic applications. Thus, they describe the application context from an exterior view.

For breaking down the application-driven scenarios into concrete research and development, four research foci were identified. The research foci guide the research work. They were chosen to provide complete coverage of the relevant aspects of the scenarios.

4.1 Scenarios

Three scenarioswere identified which are both scientifically challenging and commercially relevant. They represent comprehensive sets of challenges in an illustrative way, so that robotics experts can easily relate their own research to them. The scenarios build on each other.

- The first scenario of ECHORD is the **human-robot co-worker**. In this scenario, the traditional idea of pre-programmed robots was dropped, and the robot interacts with a human towards achieving a common goal. This scenario is especially relevant for future industrial applications, where the (physical or sensor-based) fences between robots and humans disappear.
- The second scenario is the **hyper-flexible cells** scenario. This scenario envisages not only one or more highly dexterous and cooperative robots, but also the hardware and software integration of the robots with an automatic warehouse system and the other devices present in the cell.
- The third scenario is the **cognitive factory**. This scenario aimed at taking the classical concept of the flexible manufacturing systems to a new level. The final goal is to create environments which configure themselves and are fault-tolerant, and which contain autonomous robots jointly participating in the production process with their human counterparts.

4.2 Research Foci

Within the scenarios, different research foci have been identified. The research foci are reference points for the expected scientific progress of experiment proposals. They bring together mechanical design and controller technology from manufacturers with the knowledge and experience in sensing, cognition and behaviour control from the research community.

- The first research focus is on **human-robot interfacing and safety**. Here, the main goal of the experiments is to show that safe human-robot cooperation is possible, taking all kinds of sensor failures and inconsistencies into account.
- The second research focus is on **robot hands and complex manipulation**. Here, the experiments show the improvement of laboratory setups towards practical usability as well as promising breakthroughs in the areas of sensors and sensor-guided manipulation.
- The third research focus is on **mobile manipulators and cooperation**. Here, mobile manipulators solve concrete problems in dynamically changing environments with moving obstacles and interaction with humans.

- The fourth research focus is on **networked robots**. Here, two areas are possible: one is networked industrial robots, where we expect demonstrators that can only be built in collaboration between industry and academia, with industry providing controller architecture and academia contributing knowledge in advanced real-time networking technologies, as well as service-oriented architectures. The second area concerns more loosely coupled systems, where experiments with mobile robots are expected to establish new showcases, e.g. in the area of search and rescue with robots, new applications of robots in urban areas, and robot systems for monitoring tasks.

4.3 Types of Experiments

As a third axes, the so-called type of an experiment was defined in order to categorize the experiment's main contribution to future applications:

- experiments of type **joint enabling technology development** aim at co-operative development of components or systems with the main focus on finding solutions for specific technical problems.
- The experiment type **application development** covers experiments that create robust prototypes for standard tasks in new areas or new tasks in known areas.
- The **feasibility demonstration** experiment type explores the possibility of applying robot technologies in completely new domains.

These classifications took place during the proposal phase by a self-assessment of the proposers. For the funded experiments, the statistics of the assignment to scenarios, research foci, and experiment types are given in Table 2. The statistics clearly show that, for this specific funding scheme, smaller, individual problems as in the scenarios human-robot co-worker or the hyper-flexible cell are better suited than the complex scenario of a cognitive factory.

After the selection of the experiments, other classification criteria turned out to be useful in addition to the ones mentioned before, namely the application area, concrete research topics, and technologies. This classification was only possible after the analysis of the successful experiment proposals, as the calls did not aim at restricting the ideas of the proposers. These additional classifications are shown in Fig. 5 and give a good impression of the variety of ECHORD's research. Robotics technologies for medical application, for example, are of increasing interest, both scientifically and economically. Several ECHORD experiments address this application area, despite the fact that this could not be predicted at the time of the calls. Also, autonomous inspection and surveillance, often making use of unmanned aerial vehicles, is a developing field.

5 Overview of Individual Experiments

This section presents an overview of the scientific content of all the experiments funded by ECHORD but which did not produce an extended contribution to this volume. In the following, the abstracts of these experiments are reported in alphabetical order.

Scenario	Num. experiments
human-robot co-worker	30
hyper-flexible cells	18
cognitive factory	3
Research Focus	**Num. experiments**
human-robot interfacing and safety	16
robot hands and complex manipulation	20
mobile manipulators and cooperation	12
networked robots	3
Experiment type	**Num. experiments**
Joint enabling technology development	17
Application development	20
Feasibility demonstration	14

Table 2: Categorization of funded experiments

ALEXA (An advanced light-weight robot arm for flexible and mobile applications in hyper-flexible cells). The ALEXA experiment tested the capabilities of a new lightweight manipulator built using the innovative and low-cost robolink construction kit from igus. The robolink joints are cable-driven and connected with lightweight, carbon fiber-reinforced plastic links. The Fraunhofer IFF developed a 5-DOF robolink manipulator for use as an assistant in flexible cells and demonstrated its high portability in a common pick-and-place scenario.

AssRob T.I. (Semi-Autonomous Surgical Tool Instrumentor for Robot Co-Workers in Hip-Surgery). The main innovation of the experiment was to create a semi-autonomous two-arm assistant bone lever holding robot system and to demonstrate that it can take over the tiring lever holding and handing over task from a human assistant. The goal was to show the capability of the robot to autonomously recognize the bone lever in space and then approach it close enough, just like a human assistant does, to enable the surgeon to connect already in situ placed bone levers and retractors to it.

BABIR (A better audition for a better interaction with humanoid robot). In this experiment, a robust vocal interface between human and robot was developed and implemented on the small humanoid robot Nao. Speech processing algorithms have been developed not only to recognize the speech but also for the localization of the speaker which is necessary to get the attention of the robot. Experiments were performed in a domestic environment.

BRACOG (Brain-Controlled Grasping). The research carried out in this experiment led to the development of a robotic arm that people with severe motor handicaps (due to traumatic injuries or strokes) can use to grasp and manipulate common objects, controlled by voluntarily changing their brain activity. The developed robot which is controlled by thoughts, was able to grasp unknown objects.

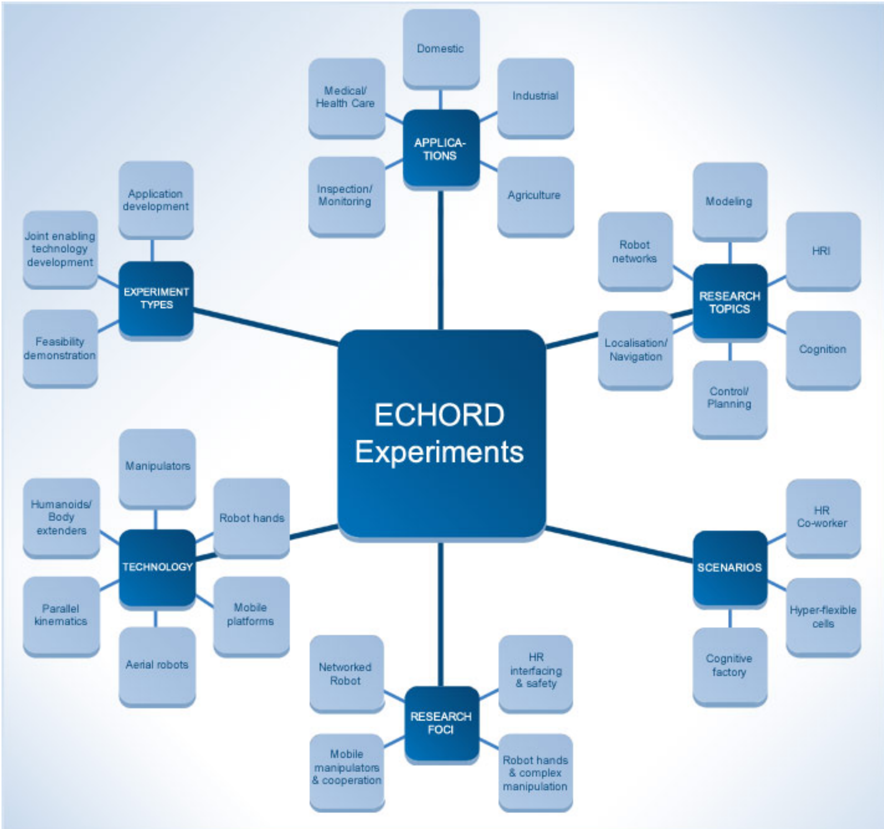

Fig. 5: Classification of experiments

C-KOMPAI (Providing Cognitive capabilities to the KOMPA Robot with the addition of a Cognitive Brain). The experiment integrated into the KOMPAI robot, a modular system for interaction with people. The CBRAIN (Cognitive Brain for Service Robotics) system, includes the following functionalities and capabilities: high-level perception and representation of the environment, robust and reliable autonomous discovering of the environment and map building functionality, cognitive navigation, intelligent problem solving. Possible applications of the robotic system are assistance to elderly people and floor scrubbing in the household.

ContainerBot (Stochastic impact-triggered mobile manipulation for fast cycle time unloading of variable-sized boxes from unordered piles). The experiment proposed new ways to empty standard shipping containers with new robot technology. This experiment used one or two KUKA lightweight robot arms to pick up light (up to 5kg) or heavy (up to 10kg) boxes of various sizes and shapes in unordered stacks. Applications are automatic emptying of parcel containers, assisting persons with robots for lifting or positioning of heavy equipment, and flexible use of robots in factory work cells.

COWBOI (Cooperative Welding employing Robot Intelligence). This experiment targeted a system to increase the efficiency and usability of welding robots by focusing on the interactive task specification from the human to the robotic workmate and the fast acquisition of unknown work pieces (through integration of a laser scanner and a Kinect sensor), as well as the automation of the path planning (releasing the human from this responsibility).

EASYPRO (Accurate Manual Guided robot programming). The aim of the experiment was the integration of a breakthrough programming approach combining a universal Manual Guidance Device (MGD) for a fast, intuitive but rough tool path programming with a 3D visual data analysis system to adjust the obtained trajectories and to allow accurate end-effector positioning. The results were validated in a laser cladding task.

EduFill (Filling the Educational Gap in Service Robotics). The experiment intended to bridge the gap between frontier research and education, by introducing state of the art concepts and solutions in mobile manipulation into the classroom. The project prepared a practical robotics curriculum, focused on modern concepts and solutions for mobile manipulation, such that students can bring their robot knowledge to the industry. The approach of hands-on learning was adopted, based on the use of a novel software (and partly hardware) toolbox centred on state-of-the-art educational and research robots.

ERICA (Evaluating Human-Robot Interaction and Cooperation-based on Analysis of 3D Image Sequences). The experiment had the goal of achieving safe human-robot-cooperation and to advance a system based on real-time estimation of significant parameters of human body kinematics. The knowledge about parts of the human kinematics is a key issue for cognitive vision based systems, which deal with real cooperation between man and machine. This knowledge was used in the experiment to guarantee safety for the human co-worker by estimating the risk of a situation and adapting the robots behaviour accordingly.

FIDELIO (FIxtureless DEburring of wheeLs by human demonstration). The experiment investigated the feasibility (and the related advantages) of the programming-by-demonstration paradigm in an industrial application scenario, exemplified by a fixtureless wheel deburring task. To this aim, a robotized cell was set up, composed of an industrial manipulator equipped with both vision and force sensors and a workstation where aluminium wheels are placed for deburring.

Flexprass (Flexible Precision Assembly with Mobile Robots). The partners of the experiment combined human-friendly modular industrial desktop robotics with high-precision equipment in order to setup a flexible precision assembly system for highly demanding products such as laser-systems.

GISA (Gesture Based Instruction of Safe Mobile Robot Arm). The experiment aimed at providing information about the consequences and effects of using mobile robot arms in real manufacturing environments. A gesture-based human robot communication was developed that allows a shop floor worker to provide commands to the robot on-the-fly without the need of hardcoding them into a robot program.

GOP (Generating optimal paths for industrial and humanoid robots in complex environments). This experiment combined state-of-the-art developments of path planning and numerical optimal control research areas. The objective was to create the algorithmic foundations to tackle real-time optimal control problems of industrial and humanoid robots in cluttered environments, trying to overcome the limitations of both domains.

HERMES (Hyper-flexible bimanual robot manipulation and packing of deformable parts in footwear industry). The experiment addressed the automation of the packaging process in the footwear industry, which is a growing market. The HERMES experiment demonstrated the potential to apply robotic technologies to such processes through detection and bimanual manipulation of non-rigid objects.

HipRob (Robot-Assisted and Ultrasound-Guided Navigation for Hip Resurfacing Arthroplasty). The experiment set up a robotic system that has the ability to aid orthopaedic surgeons in performing Hip Resurfacing prosthesis surgery with consistent high accuracy and precision. The solution is based on variable impedance control for physical surgeon-robot interaction integrated with an ultrasound image sensor for non-invasive real-time bone tracking.

HUBRINA (HUman-roBot co-woRking IN Agricultural master-slave systems). A master-slave robot control for agricultural activities was developed in this experiment and its feasibility demonstrated. The solution sees the human taking over the non-robotized tasks of safety prevention and feedback on the quality of work performed by the robot. A robotic master-slave system applied in agriculture was demonstrated beyond just the level of simulation using two tractors working in the main filed area.

HUROBIN (Human-Robot Object Interaction). The experiment focused on the human-robot interface and safety when the human operator and the robot handle the same object: the robot is supposed to bear the load while the human leads the movement of the object in a co-operative pick and place task. Distributed position sensors, a torque/force sensor on the robot, as well as a tracker sensor that tracks human motions ensure safety of operation.

HYFLAM (A Hyper-Flexible Work Cell for Biochemical Laboratory Automation). The experiment focused on the automatic execution of several complex manipulating actions that occur frequently in a biochemical laboratory. Several actions, like opening different types of laboratory plastic-ware, tubes and glass vials, pipetting, that had to be performed manually, before, were performed with a sophisticated robot hand leading to a significant enhancement of safety, flexibility and efficiency.

HYROPA (Hyper-flexible robot cells using reconfigurable passive kinematics). The experiment demonstrated the possibility of reducing the technical effort for highly flexible robot cells using passive kinematics and state-of-the-art serial robotic arms. The core idea of the experiment was the application of state-of-the-art industrial robots together with fixable, passive kinematic arms, which have a large number of degrees of freedom, but without their own drives. The industrial robot takes care of the reconfiguration of the passive kinematics.

Insewing (Development of a robotic manipulator of human tubular tissues for suture and support in anastomosis surgery interventions). The aim of the experiment was to develop a surgical robotic manipulator device, focused on the improvement of surgical interventions with anastomosis. In particular, the developed device was successfully tested in the anastomosis of pig intestines, thus simulating the hypothetic behaviour with human tissue.

InterAID (Interactive Mobile Manipulators for Advanced Industrial Diagnostics). The experiment demonstrated the feasibility of applying mobile robots with manipulation capabilities to advanced diagnosis and quality control in industrial environments. A mobile manipulator equipped with a dexterous hand was applied in the reliability lab of a white goods factory producing washing machines. The system is able to carry out the repetitive tasks of product quality control, such as open washing machine doors, pushing buttons and collecting results of the quality control test.

JILAS (Jig-Less Airplane Assembly in low volume production by enhanced human robot interaction). The core of the experiment was to realize a scenario where a human worker and a force-controlled industrial robot assemble airplane components in a classic human-robot co-worker cooperation. The robot has the capability to be hand guided by grasping and moving the gripped work piece. With the help of this robot, the human worker can pick up a component and move it near the final assembly position. The final position is then reached by moving the robot based on the accurate measurement of a laser tracker.

KANMAN (KANban integrated, magnetic orientated modular mobile MANipulator). The experiment developed an application in which a robotic co-worker supports a Kanban production process (a control method for just-in-time production) by taking care of the flow of materials. While the Kanban process is controlled by crates containing the production materials, these crates are transported by a mobile service robot platform with a manipulator. The experiment initially tested a magnetic approach for safe mobile navigation and manipulation.

KOMPEYE (Enhancing the Visual Perception Capabilities of Kompa Robot Using Parallel Processing). The experiment research activities led to a substantial improvement in the level of perception of current robots, in terms of human presence detection, recognition of faces and facial expressions, recognition of the gestures of people who ask the robot for help. This was accomplished using synergistically enhanced computationally intensive vision capabilities, achieved in real time through GPUs.

MONROE (Hyper-Modular Open Networked RObot systems with Excellent performance). The goal of the experiment was to enhance and apply a new type of hyper-modular parallel robot that also enables a performance increase in terms of stiffness, precision, and bandwidth with respect to feedback from external sensors. Forecasted applications are: small scale milling of aluminium casts, low-cost finishing of small plastic parts, assembly of consumer goods, handling and pick-and-place of large volumes.

MUCE (Modular Underwater Cleaning Equipment). The research focus of the experiment was on robust underwater positioning. The overarching goal of this project was to make a new generation of pool cleaner that replaces heavy mechanics with sensors and intelligent control.

ODEUO (Inner Oscillation Detection and Evaluation of Unknown test Objects). The experiment was aimed at performing with a robot what is a relatively simple job for humans, i.e. the detection of spare or lose parts by shaking objects. ODEUO investigated the sensorless detection and evaluation of inner oscillations of unknown test objects mounted on a compliant test bench constituted by a pneumatic hexapod. Successful tests were conducted on real automotive motor suspensions.

OMNIWORKS (Omnidirectional Vision for HUMAN-UAV co-working). The aim of the experiment was to exploit the growing interest and convenience of use of small scale UAV by developing a series of self-enclosed specialized and complementary modules and applications suitable for a large variety of commercial UAV currently on the market. The developed systems are easy-to-manage by a non-skilled person who can exploit the modules to automate easily different processes, such as mosaic maps, visual navigation based on maps, video stabilization, image tracking and servoing.

PRADA (Parallel Robot with Adaptive Dynamic Accuracy). The experiment aimed at improving the performance of high-speed parallel robots in terms of dynamic accuracy along complex paths and adaptability to changes in operational conditions. This was achieved by combining three enabling technologies specifically adapted to industrial parallel robots: adaptive dynamic control, sensor based control and actuation redundancy.

REMAV (Remote Eye for Micro Aerial Vehicles). The main goal of the experiment was to demonstrate the possibility to operate Micro Aerial Vehicles (small autonomous helicopters) precisely and safely in a dynamically changing environment consisting of fixed obstacles, humans and other MAVs. In order to achieve this goal, extremely precise position and speed control was developed based on a new specifically adapted miniature optical-flow based speed sensor for measuring both position and speed of the vehicle.

RIVERWATCH (Cooperating robots for monitoring of riverine environments). The experiment developed an autonomous multi-robot system for ecological monitoring of riverine environments. The multi-robot system is composed of an autonomous surface vehicle (ASV) with an unmanned aerial vehicle (UAV) piggybacked on it. The UAV overcomes the limitations imposed from observing the environment from the low viewpoint provided by the ASV. Conversely, the ASV, being equipped with a solar panel, is able to perform energy harvesting for itself and for the UAV, which is a key factor in long-lasting operation.

RODIN (Robust Control of Human-Robot-Environment Dynamic Interaction for Natural Stone Carving). The aim of the experiment was to prove experimentally the feasibility of concepts that extend industrial robot usage to an intelligent power tools carrier and act as an active assistant supporting dynamic physical human-robot-environment interaction during the complex and demanding artistic work of hard natural stone carving. Due to the strict physical interaction of the human operator with many parts of the robot, a specific risk analysis was carried out and measures for risk reduction were taken in view of the EC directive on machinery[3].

SPEAKY (SPEAKY for Robots). The experiment aimed at fostering the definition and deployment of voice user interfaces (VUIs) in robotic applications where human-robot interaction is required. It intended to promote speech technologies transfer towards manufacturing processes, to provide semi-automatic speech-based interface development for robotic platforms. A novel Robotic Voice Development Kit was conceived as an interactive environment aiding designers to define the voice interface according to the desired application requirements.

SprayBot (a Robotic Spray Booth for the Automatic Painting of Bodyworks). The objective of the experiment was to demonstrate that a robotic system (in particular a mobile manipulator), of affordable cost for the small/medium workshop, is able to carry out the painting phase in small/medium body shops improving the quality of the service with a reasonable investment. An effective varnishing control algorithm was devised based on vision feedback, which allows carrying out the varnishing task without a priori knowledge of the part shape, position and orientation.

[3] `http://ec.europa.eu/enterprise/sectors/mechanical/machinery/` [accessed: 08/20/2013]

TACTIP (Tactile fingertip for robots). The experiment developed a biologically inspired tactile robotic fingertip based on a silicone rubber deformable structure with edges and bumps and a miniature camera. The image data are then interpreted into contextual contact data, such as shape and direction of an edge or raised bump. The sensor was integrated on the Elu-2 robot hand to carry objects, providing the robot hand with new sensing abilities: identify when contact is made, monitor the status of a grip and detect when a slip occurs.

6 Results

The results of ECHORD can be described from different points of view: from a scientific perspective, the achievements of the research work are mainly visible in the form of publications, but also in the form of software which can be used by the community. From a commercial perspective, the creation of close-to-product prototypes, generation of patents and development of new business ideas, ideally resulting in setting up a new company or business unit, can be seen as a measure of success. In terms of public visibility and raising awareness for innovative solutions generated by the experiments, each individual experiment created a demonstrator or prototype to show the research and development results and produced a multimedia report in form of a video which can be seen on the project's YouTube channel "RoboticsEurope"[4].

Besides these aspects, one less measurable aspect is of eminent importance: ECHORD contributed to closing the gaps between academia and industry in the robotics area by fostering existing and creating new networks and partnership with a special focus on SMEs, where some of them participated for the first time in an international project. The entrance barriers for newcomers to European funding, mainly SMEs and smaller research institutions, were lowered by offering extensive support by the coordinating partners in handling the administrative issues. Seen as a new way of funding, the rules for participating in the experiments were relaxed in comparison to individual projects, STREPs or IPs. For example the requirement of a specific number of partners from different countries was already fulfilled by the core consortium and therefore, the experiments were free to choose their preferred cooperation partner(s), be it in the same city or in a completely different region of Europe. The fear of contact with unknown partners with a different cultural background, the day-to-day communication in a different language (English) were obstacles that were minimized in ECHORD which was appreciated in particular by the smaller companies.

For some experiments, already during their run-time or shortly thereafter, follow-up projects in the regular FP7 framework were proposed and granted. In these cases, ECHORD acted as an incubator for the further development of the European Robotics Community.

[4] `http://www.youtube.com/user/RoboticsEurope` [accessed: 08/20/2013]

7 The Second Pillar: the Structured Dialogue

In additon to the experiments, a second concept important to ECHORD is the structured dialogue. This is comprised of systematic exchanges between the robotics community and ECHORD about expected future trends in robotics. These future trends will be examined in the following section.
The structured dialogue was designed as an iterative process of information gathering and consensus finding between all parties. This approach is well suited to the structurally diverse and interdisciplinary field of robotics, with many potentially interesting directions. Based on a collection of ideas gathered in polls, web consultations and expert meetings, an initial set of ideas will be profiled, redistributed with specific questions for discussion (filtered through an economic, scientific, technology perspective). Many results can be found in Röhrbein et al. [8].

7.1 Introduction

This contribution is going to summarize the results of our efforts to study industry-academia collaborations. We will report on research topics and foci.
The goal is to identify both current concerns of the respective communities and emerging trends. The method for indentifying such emerging developments is often a quantitative look at the literature in the respective field [5]. For this purpose two instruments were used:

1. We are going to look at publications in journals and at conference papers to see which topics are currently being addressed by research and development efforts.
2. We distributed questionnaires at different venues and are going to report on those results.

The results were compared to similar studies which were conducted by other parties. We will argue that our results are comparable to those found by the EUCog questionnaire which was distributed among its members and the results of a questionnaire which was distributed at IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2012[5].
We hope to encourage further academia-industry collaboration and help to avoid the pitfalls which threaten to hamper such endeavours. One factor that one needs to keep in mind is the fact that ECHORD focused mainly on technology-transfer and industry-academia collaborations. Therefore, one needs to contextualize the findings in order to make them usable for this purpose.

7.2 Are Robots here?

In 2004 Rodney Brooks [2] predicted that robots would be as pervasive as electronic mail and the world wide web by approximately 2019. In 2013, one can

[5] http://www.iros2012.org/ [accessed: 08/20/2013]

already see a trend towards this vision becoming a reality as robots have become part of a consumer entertainment market (for example the Sony AIBO [1]). They are also being deployed in hospitals, museums [6] and in households [3]. The largest market for robotic applications is, however, still in manufacturing. According to the IFR world robotics statistics[6], the market value for industrial robots is estimated to be US$ 8.5 billion "without cost of software, peripherals and systems engineering." Including these costs, the market value is estimated to be US$ 25.5 billion. In contrast, the professional service robotics market is estimated to be US$ 3.6 billion and the service robotics market for personal and domestic use is estimated to be US$ 636 million, according to the statistics of the IFR world robotics[7]. If robots are to become even more prominent in all these areas, there are a number of developments which need to accompany the growth in market share. The market pull and the research push need to accompany each other. Steels [11] notes that in the early 1980s one could notice the advent of a change in artificial intelligence with the dawn of an application driven research agenda which was accompanied by huge conferences, venture capital and the increased founding of spin-off companies.

This justifies increased research efforts in a technology related field which are sometimes questioned due to the double-boom pattern [10], which accounts for the lag between a science-push and a market-pull in technological fields. One of the main goals of ECHORD is to support a decrease in this lag by facilitating a productive exchange between industry and academia.

7.3 Investigating Current Research Topics

In order to encourage increased activities in R&D in the field of robotics, one first has to address the issue of what research topics are currently being pursued in the field of robotics. For this purpose, the most suitable method is the analysis of journal papers and conference contributions.

All conference contributions that were submitted in the years 2011 and 2012 to both ICRA and IROS have been analyzed. These are the most pertinent venues for presenting results to the robotics community[8]. We analyzed the keywords that are used by the authors for paper submission in PaperPlaza. IROS and ICRA use the same list of keywords, i.e., the one permanently available at `http://www.ieee-ras.org/ceb/areas.html[accessed:03/15/2013]`. The RAS Conference Editorial Board is in charge of refining and updating this list for ICRAs and this list has been very stable over the past couple of years.

Overall, there are 9,726 associations with the 143 keywords, which is a number about three times higher than the number of papers. This is due to the fact that typically three keywords are assigned to each paper.

[6] `http://http://www.worldrobotics.org/uploads/media/Executive_Summary_WR_2012.pdf` [accessed: 08/20/2013]

[7] `http://www.ifr.org/service-robots/statistics/` [accessed: 08/20/2013]

[8] See for example: `http://www.ias.tu-darmstadt.de/Miscellaneous/ConferenceQuality` [accessed: 03/15/2013]

Fig. 6 below shows the most frequently used keywords from all accepted contributions to ICRA-11, ICRA-12, IROS-11 and IROS-12. One can see the number of papers for each keyword. Though the graphs also differentiate between papers that resulted from an academia-industry collaboration (in red) or from research which was not based on such a collaboration (in blue) by assessing the affiliations of all authors. In total, 594 assignments stem from industry-academia papers.

This list of top research topics remains very stable with regard to conference

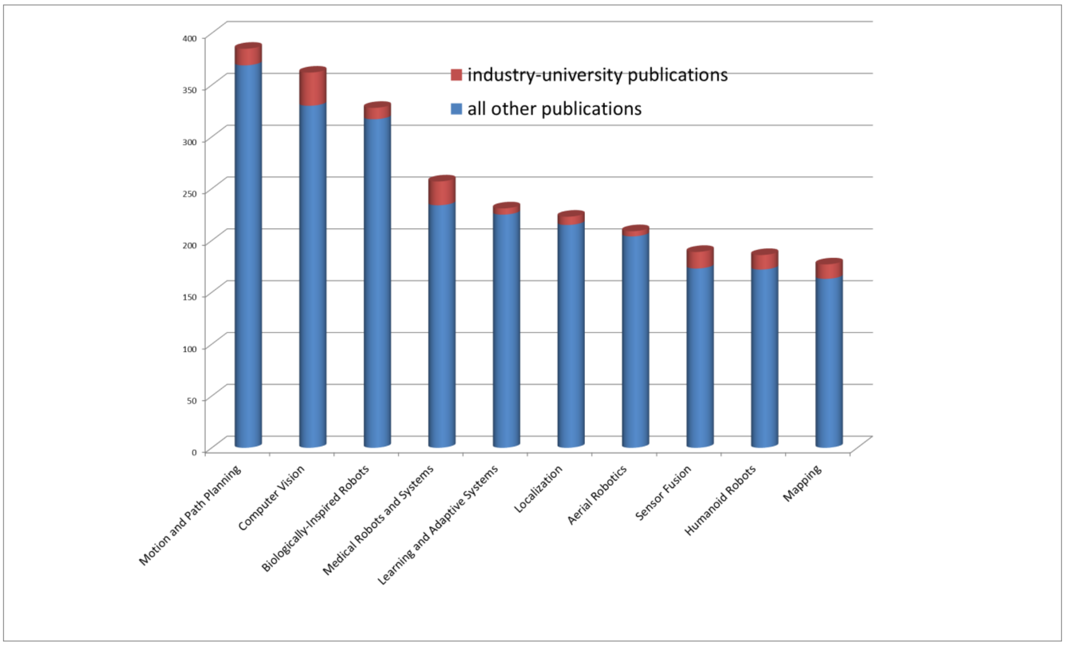

Fig. 6: The most frequently used keywords in all accepted contributions to ICRA 2011, ICRA 2012, IROS 2011 and IROS 2012.

(IROS, ICRA) and year (2011, 2012). The 7 highest-ranked topics from Fig. 6 above are in the individual top 10 lists of all four conferences (with only one

exception)[9].
For these 7 research topics, there is a clear increase in the number of academia-industry collaborations: At IROS, the share increased from 5.5% to 7.3%. The share more than doubled at ICRA (see Fig. 7). The numbers are averages based on the topics Aerial Robotics, Biologically-Inspired Robots, Computer Vision, Learning and Adaptive Systems, Localization, Medical Robots and Systems, Motion and Path Planning.

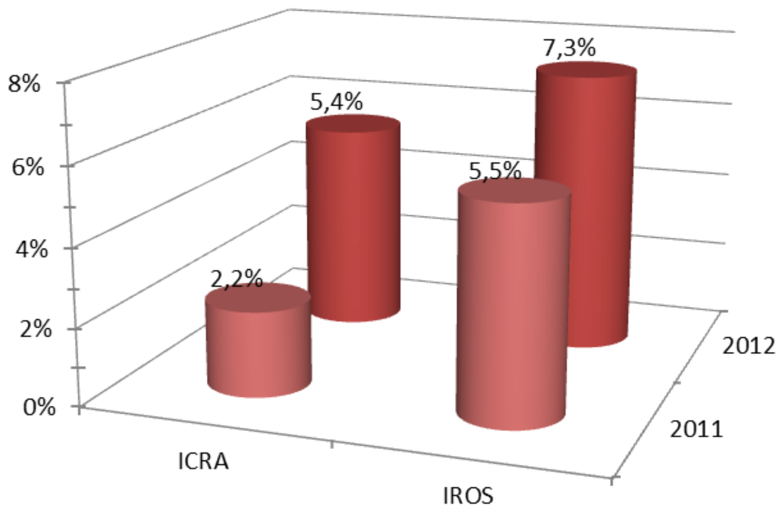

Fig. 7: The most frequently used keywords from all accepted contributions to ICRA-11, ICRA-12, IROS-11 and IROS-12.

Next, we had a closer look at all topics with a high share of industry-academia collaborations. Fig. 7 below displays all those keywords that were attached to conference papers whose share in industry-academia was above 10%.

For journal papers, a similar keyword analysis is complicated by the fact that no predefined list of keywords exists from which the authors can select. As a consequence, a far larger set of keywords was used and they are overlapping

[9] The topic "Learning and Adaptive Systems" was only ranked number 11 at ICRA 2011.

etc. Here we would need an ontology. We have already begun work here but it has not been completed.

Table 3: Topics in conferences and journals

	Conferences	Journals
1.	Mechanisms Design of Manipulators	Computer Vision
2.	Medical Robots and Systems	Mobile Robots
3.	Computer Vision	Medical Robots and Systems
4.	Intelligent Transportation Systems	Mobile Distributed Robotics
5.	Collision Avoidance	Sensor Fusion
6.	Motion and Path Planning	Motion Planning
7.	Recognition	Path Planning
8.	Localization	Localization
9.	Personal Robots	Distributed Systems
10.	Distributed Robot Systems	Force Control

Nevertheless, there is a high overlap in keywords to be found in papers produced in collaboration between industrial partners and academic research institutes published in journals and those accepted for conferences. This is illustrated in the following Table 3 which lists the 10 most often used keywords for industry-academia collaborations.
How can one connect industry and academia effectively? To find an answer to this question, we decided to study the publications further. What leads to a successful, productive collaboration?
As part of the structured dialogue, we interviewed a number of experts with a record of successful technology transfer projects. The following quote is from an interview with Prof. Brooks, which illustrates what can be done to better connect industry and academia [9]:

> "I think that in industrial robots and manufacturing in general, we haven't really seen the impact of information technology in the same way we've seen it in the office and information spaces. [. . .] It is the simplicity of use which then leads to high adoption and high rate of adoption. So, I think we haven't seen that penetration. So, how to make the things easy for ordinary people to use, instead of making the people adapt to the technologies. Adapt them to people, not the other way around. So that's where I think the big payoff is going to be."

Rodney Brooks's statement suggests that a higher market penetration is desired by the industry. For this purpose, the technology needs to be developed further. Brooks mainly points toward human-machine interaction. He claims that this is the area where most work is required. However, we chose to look at future topics and emerging research trends in the field of robotics.

Our method used for investigating future topics and emerging trends is comparing results from our own literature survey (see [8]) with results from firstly, a recent poll conducted by *The European Network for the Advancement of Artificial Cognitive Systems, Interaction and Robotics (EUCog)*[10] and secondly, a survey organized by the IROS-2012 organization committee.

Main topics from the ECHORD literature survey were:

- Autonomy
- Bio-inspiration
- User interface, human robot interaction
- Vision & Recognition
- Sensor technology
- Language and emotion
- Advanced control
- Automatic path / motion planning
- Modular robotics & multi-agent systems
- Advanced cognition
- Safety and Security
- Test and Validation

EUCogII (the second phase of the network as an EU FP7 coordination action) conducted a survey among its members which is similar to those surveys conducted by the ECHORD team, but with a broader focus on future research topics in cognitive systems & robotics. In the EUCog survey, a list of research topics was given to the participants and their task was to rate them on a scale from 1 (not important) to 5 (very important). Fig. 8 briefly summarizes the main results by focusing on those topics that received a rating of 4 or higher by at least 50% from all 211 participants.

It is evident that most topics are similar to those identified previously (blue columns), but there are also some noteworthy differences.

Topics only mentioned in the EUCog list (grey columns):

- architectures and machines
- novelty detection and prediction

Topics only mentioned in the ECHORD list (blue columns):

- Language and Emotion
- Advanced Control
- Automatic path motion planning
- Modular robotics & multi-agent systems
- Safety and Security
- Test and Validation

[10] `http://www.eucognition.org/` [accessed: 08/20/2013]

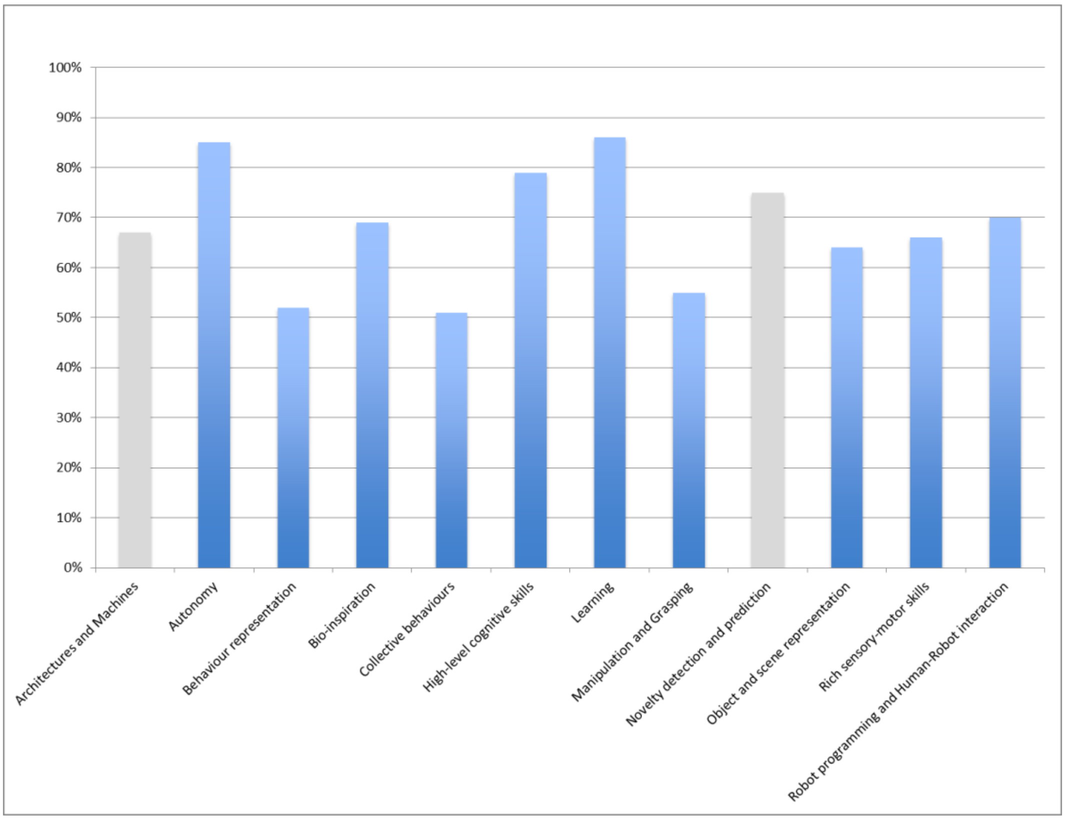

Fig. 8: Research topics to the EUCog questionnaire in comparison to the ECHORD questionnaire. The blue columns indicate research topics mentioned in the ECHORD replies and grey columns indicate research topics only mentioned in the EUCog replies.

Mainly due to a different focus with regard to robots, in our survey the results differ slightly. Our results echo the Brooks statement above in determining interactive capabilities (Language and Emotion, Safety and Security) more than the EUCog participants, who seem more focused on the reasoning of an individual agent, though both groups also mentioned Human-Robot Interaction as one possible topic for further research.

The other items in our list, which were not mentioned frequently by the EUCog members, are all related to robot motion apart from Test and Validation, which is, of course, needed in practical applications. The terms in the ECHORD list are more strongly oriented towards the need of the market and practical applications whereas many (but by no means all) EUCog members are more interested in more fundamental research questions.
In comparison to the IROS-2012 survey 116 forms were collected. The participants (the IROS attendees) were able to select up to three areas of research for future research for each question asked. Here we only present the results regarding the answers to two out of the four questions:

1. for effectively tackling such grand societal challenges, research should mainly focus on
2. in the next decade robotics R&D should focus mainly on the following grand research avenues

The IROS questionnaire identifies four topics which more than 10% of the participants suggested future research should focus on. The most freuqent answer given was improved control schemes and AI methods. This is related to the items Advance Cognition and Advanced Control, which were also frequently named by the participants in our study. The second most frequent response in the IROS answers relates to sensors which were also named frequently our study. The third most frequent reply to the IROS questionnaire relates to human-machine interaction which is also an important topic to the people who were we asked. The final topic which was named by more than 10% of respondents for the IROS questionnaire relates to system integration. This is a topic which the participants questioned in our study did not mention explicitly.

It is very likely that this difference arises from the fact that IROS is a conference which attracts system integrators and therefore this topic is assigned a high value. Also, there is quite a lot of overlap between the 10% of research avenues which the IROS 2012 participants named and the topics for future research which our participants named. Medical robots and prosthetics is the most frequent answer for the IROS 2012 participants. This is hard to map on to the responses to our questions and therefore, constitutes a difference. However, the other answers above 10% – Embodied Intelligence, Cognitive Vehicles and Cognitive Robotics – all relate to the topics Advanced Control, Advanced Cognition and Autonomy in our topic set. Therefore, a large overlap between the answers can again be seen.

7.4 Conclusions Regarding Current Research Trends

We found a strong agreement between the topics named by the EUCog members, the IROS 2012 participants and our ECHORD study. Many answers relate to autonomy and cognition, which have already been identified as an important topic for the future [7]. These are, of course, issues which relate to the core interests of all three communities.

Future trends will be decided by both a science-push and a market-pull. Increasing activities which bring together academia and industry will ensure that both parties decide jointly which topics are relevant. Our investigation of research topics does, however, suggest that the topics and interests are already converging to a certain degree.

References

1. Bekey, G. A.: Autonomous Robots. MIT Press, Cambridge, MA (2005)
2. Brooks, R. A.: The robots are here. Technology Review 107, 30 (2004)
3. Forlizzi, J., DiSalvo, C.: Service robots in the domestic environment: a study of the roomba vacuum in the home. In: Proceedings of the 1st ACM/IEEE international conference on Human-robot interaction (HRI). 258–265. IEEE Press, New York (2006)
4. Knoll, A., Siciliano, B., Pires, N. and Lafrenz, R.: ECHORD-The new face of academia-industry collaboration in European robotics. IEEE Robotics & Automation Magazine 17 (4), 21–22, (2010).
5. Leydesdorff, L., Cozzens, S., Van Den Besselaar, P.: Tracking Areas of Strategic Importance Using Scientometric Journal Mappings. Research Policy 23, 217–229 (1994)
6. Pitsch, K., Wrede, S., Seele, J. C., Süssenbach, L.: Attitude of German Museum Visitors towards an Interactive Art Guide Robot, In: Proceedings of the 8th ACM/IEEE international conference on Human-robot interaction (HRI). IEEE Press, New York (2011)
7. Müller, V. C.: Autonomous cognitive systems in real-world environments: Less control, more flexibility and better interaction. Cognitive Computation 4 (3), 212–15 (2012)
8. Röhrbein, F., Griffiths, S., Voss, L.: On Industry-Academia Collaborations in Robotics. Technical Report TUM-I1338 (2013)
9. Röhrbein, F.: Academic and industry collaboration (Part 1): Interview with Rodney Brooks. http://robohub.org/academic-and-industry-collaboration-part-1-interview-with-rodney-brooks/[accessed:09/10/2013]
10. Schmoch, U.: Double-boom cycles and the comeback of science-push and market-pull. Research Policy 36, pp. 1000 – 1015 (2007)
11. Steels, L.: Fifty years of AI: From symbols to embodiment-and back. In: Lungarella, M., Iida, F., Bongard, J., Pfeifer, R. (eds.) 50 Years of Artificial Intelligence. LNCS, vol. 4850, pp. 18–28. Springer, Heidelberg (2007)
12. Veiga, G., Silva, C., Araújo, R., Pires N., Siciliano B.: The ECHORD project proposals analysis Research profiles, collaboration patterns and research topic trends, Elsevier Expert Systems with Applications, Volume 40, Issue 17, 1 December 2013, Pages 7132-7140, (2013)