KTH Computer Science
and Communication

Social Robotics

A strategic innovation agenda

Thank you!

The following agenda for social robotics was developed in a project led by KTH and funded by Vinnova. It is a result of cooperation between the following 35 partners:

Industry: ABB, Artificial Solutions, Ericsson, Furhat robotics, Intelligent Machines, Liquid Media, TeliaSonera

Academia: Göteborgs universitet, Högskolan i Skövde, Karolinska Institutet, KTH, Linköpings universitet, Lunds tekniska högskola, Lunds Universitet, Röda korsets högskola, Stockholms Universtitet, Uppsala Universitet, Örebro universitet

Public sector: Institutet för Framtidsstudier, Myndigheten för Delaktighet, Myndigheten för Tillgängliga Medier, Statens medicinsk-etiska råd, Robotdalen, SLL Innovation, Språkrådet

End-user organistions: Brostaden, Epicenter, EF Education First, Fryshuset Gymnasium, Hamnskolan, Investor, Kunskapsskolan, Silver Life, Svenskt demenscentrum, Tekniska Museet

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Agenda key persons: Joakim Gustafson (KTH), Peje Emilsson (Silver Life), Jan Gulliksen (KTH), Mikael Hedelind (ABB), Danica Kragic (KTH), Per Ljunggren (Intelligent Machines), Amy Loutfi (Örebro university), Erik Lundqvist (Robotdalen), Stefan Stern (Investor), Karl-Erik Westman (Myndigheten för Delaktighet), Britt Östlund (KTH)

Writing group: editor Joakim Gustafson, co-editor Jens Edlund, Jonas Beskow, Mikael Hedelind, Danica Kragic, Per Ljunggren, Amy Loutfi, Christian Smith, Peter Stany and Britt Östlund

The report can be downloaded from: www.speech.kth.se/socialrobotics

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Joakim Gustafson
Professor in Speech Technology, KTH
contact: jocke@speech.kth.se

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Summary

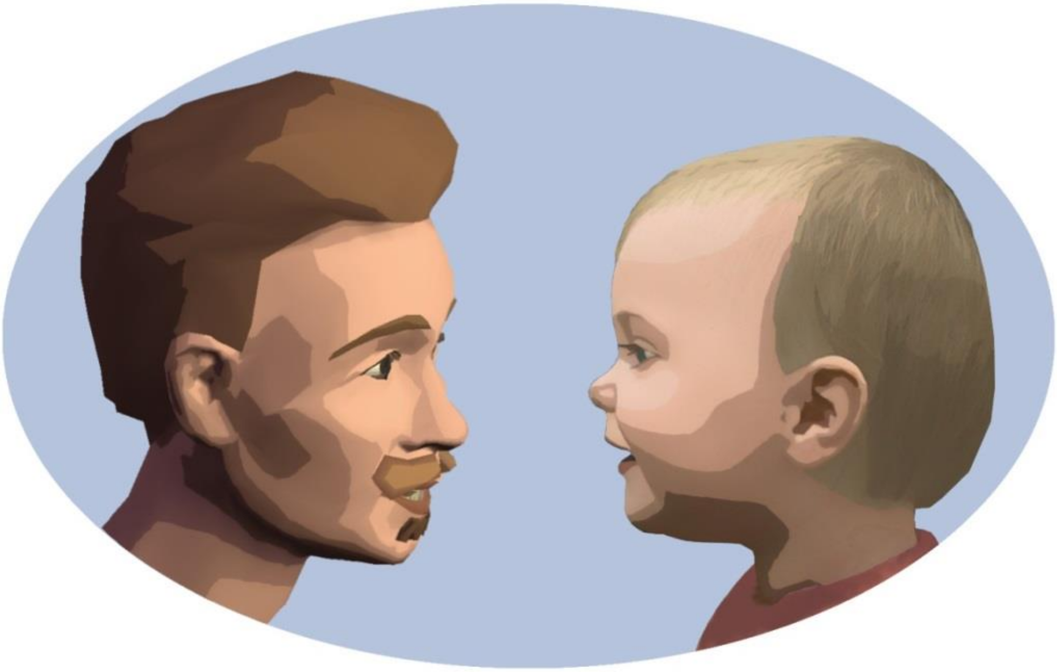
*The **Social Robotics Agenda** is a guide for Swedish innovation in a field of human-centred technologies that will have a transformative impact on many aspects of society, industry and daily life. Robots have entered the human environments from which they were previously barred, and their presence in these environments will only increase with time. These robots must be socially aware; they must know how to communicate on human terms and how to act safely in the vicinity of humans; otherwise we are likely facing a future where humans accommodate and serve machines rather than the other way around.*

Social robotics looks to accomplish this through substantial innovation and development of social and communicative skills for physical robots as well as pure software systems such as virtual assistants. No matter the type of system – physical or virtual; stationary or mobile; personal or public; entertainment oriented or task driven; autonomous or tele-operated; humanlike or machine-like – if it cohabits with people, it will be expected to respond appropriately to human behaviours and language.

Socially competent robots that can be taught new things and can collaborate with humans on human terms will in a near future have an impact on many different areas as diverse as manufacturing, health care, education, customer service and entertainment.

The question is not whether this development and its transformative effect on society and industry will take place. As this agenda clearly demonstrates, it is already on-going. The total annual market value in areas related to social robotics is estimated over €20 billion and growing exponentially. The question is instead whether Sweden will be a bystander allowing the development to be dominated by major US and Asian players, or seize the opportunity and be an active leader, building on Swedish core competencies in automation, information technology, and telecommunication, as well as a wealth of innovative SMEs and world-leading academic research.

*The **social robotics agenda** brings together researchers, innovators, and user representatives to allow a matching of the needs of humans with the affordances of technologies to guide technology development and research. It paves the way for the necessary rejuvenation, mobilization and trans-boundary collaboration. It provides the strategic path ahead that will allow Sweden to grab a unique opportunity and become a key player in a field that will change the way we lead our lives and the environments in which we live – the new, intriguing and highly interdisciplinary area of social robotics.*



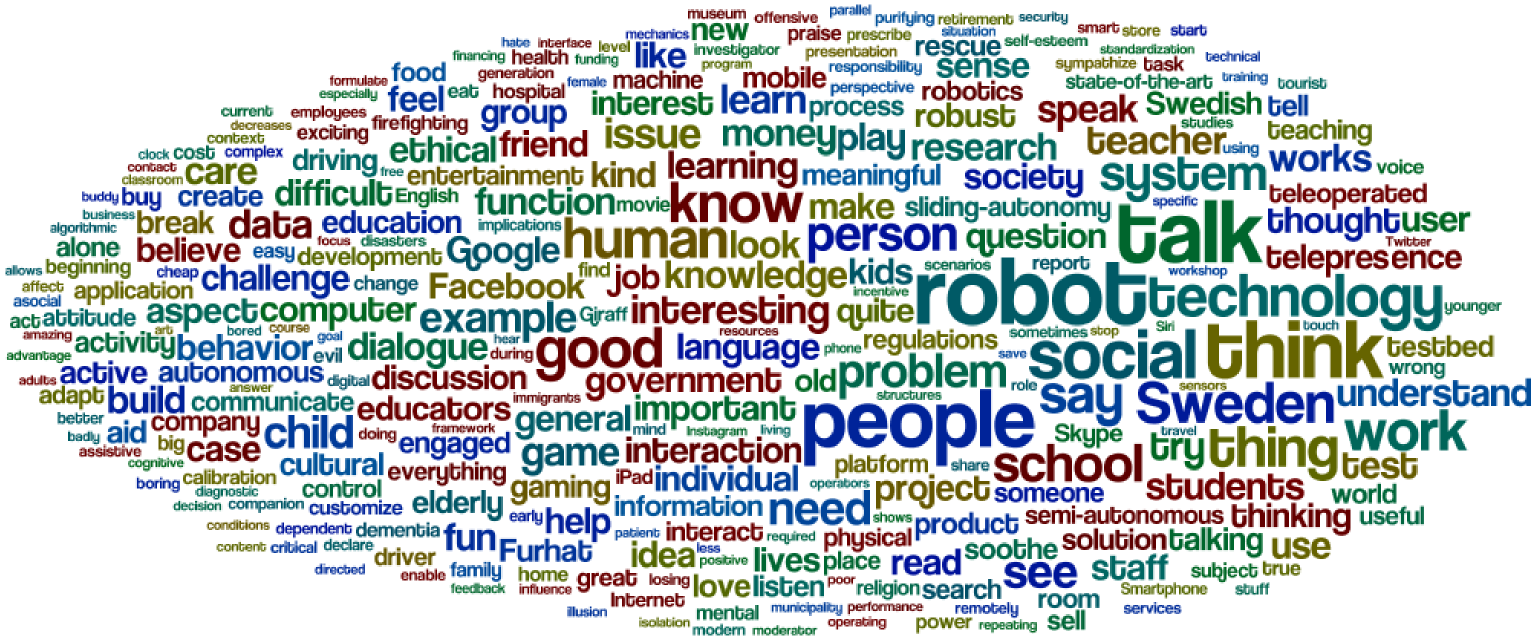
Introduction

In *social robotics*, methods for human-robot communication and collaboration on human terms are in focus. A common definition of "robot" is "*an autonomous machine, situated in the world, that senses, thinks and acts*". For social robotics, we open up this definition to include any situated agent that is able to *perform physical or virtual tasks*, and constrain it by requiring that this agent can *understand human behaviour and actions through sensors,* and that it *communicates on human terms*, typically through speech. With this definition, application space is extended beyond mechanical robots to personal assistants that reside on mobile devices and in smart environments.

Robotics traditionally deals with building stationary autonomous systems that perform physical tasks such as manufacturing in restricted environments where people, if at all present, have special training. Such set of tasks generally performed by such robots have been referred to as 3D (dull, dirty, dangerous). But the robot scene is undergoing fundamental transformation, and we have seen the advent of robots that move around autonomously and inhabit environments where people work and socialize. These advances open up a world of new possibilities, but at the same time bring radically new challenges: robots that cohabit with people will be expected to do so on human terms. For that, they will need social and communicative skills. Robots that share space with humans have to be given communicative abilities that enable them to interact with people and other robots in an intuitive and socially acceptable manner. This leads to a whole range of new technical challenges. For example, human spaces are difficult to model since they constantly change: people walk around freely and they manipulate and move objects in the environment. This stands in stark contrast to the controlled environments of traditional manufacturing robots. Social robots must also be able to navigate among people, understand people's physical actions, and understand the significance (to humans) of items that occupy their common environment. And critically, for robots to be accepted as social partners they need to communicate on human terms. This is equally important if the robots are to be able to efficiently assist and cooperate with people.

The value of communication on human terms is perhaps a truism, but it is associated with major scientific and technical challenges. By far the most common and the most primal form of communication between people is to simply talk. It is also the most developed means of communication within social robotics, where speech technology is central. Physical and virtual systems alike benefit from understanding and making themselves understood through human speech.

This innovation agenda outlines technological obstacles to overcome and gaps between technologies to bridge in order to unlock the full potential of modern robot technology and to make safe and enjoyable cohabitation of human and robot possible. Risks and potential ill effects are discussed, and some of the most obvious potentials and opportunities are highlighted. It is clear that we can only speculate in where and how the next generation robots will come into their on – it lies at the heart of new technologies that their best use is often not known in advance – but we believe that we should do the best we can to create the conditions necessary to fully exploit their possibilities. We hope that this agenda will achieve that goal.



The agenda work

The social robotics agenda is the result of a series of four workshops where 30-40 representatives for relevant innovation and research areas, government, industry and user groups convened to discuss the path forward. Each workshop had a theme:

- **Location-centered social robotics**: Focus on robots and virtual assistants that are linked to one place and have in-depth knowledge of it
- **Person-centered social robotics:** Focus on robots and virtual assistants, whose knowledge centered around an individual or individuals with a certain role
- **Social and ethical aspects:** broader theme, ethical considerations, data storage and privacy issues, as well as more general aspects of sustainability.
- **Representing Robots:** Robots acting stand-in for people who are not present to achieve telepresence in remote meetings or control the robots in dangerous environments. The last workshop also involved a agenda writing groups session.

The workshops followed roughly the same format with the programme of the day and an introduction to social robotics as the first item, followed by introductions of the participants and select invited presentations. The speakers and other participants to the workshops are listed in the Appendix. The main event of each workshop was a breakout session where participants discussed a set of open questions in smaller groups. A representative for the agenda writing group was present in each group, and each group session was recorded. All recordings have been run through a speech-to-text system to get a rough estimate of the discussions, see translated word cloud above.

The bulk of the draft writing was done by a small group at KTH, who collated what was expressed during the workshops into a single document. This document was circulated to the rest of the writing group consisting of a number of key persons identified at the beginning of the agenda work as well as to a smaller number of additional parties, and the resulting comments, additions and edits were again merged into the agenda by KTH.

Enabling technologies

Current progress in several technology fields provide affordances for a more social next generation of robots. Advances in haptic sensors bring the sense of feeling, which make the less dangerous to be around, advances in speech technology bring the sense of hearing and the ability to talk, advances in 3D sensors and computer vision bring the sense of seeing. With cloud-based computing and new methods for machine learning, robots approach a simile of intelligence and social skills at an increasing speed, making the vision social robots feasible in a near future.

- **2011:** **Apple Siri** the first mobile assistant that could understand speech
- **2012:** **Nuance Nina** an SDK for developing mobile personal assistants
- **2013:** **Samsung S Voice** a mobile personal assistant and knowledge navigator
- **2013:** **Google Now** provides situated personalized info using behavioral patterns
- **2014:** **Microsoft Cortana** a personal assistant as part of Windows 10
- **2014:** **IBM Watson** human-level reasoning and language modelling
- **2015:** **Amazon Echo** a personal assistant in the form of a wireless speaker
- **2015:** **Facebook M** a personal assistant that initially is driven in part by humans

Several Fortune 500 companies have recently released high-profile virtual assistants that use natural language. Speech recognition has improved immensely since the introduction of these systems due to their use of cloud-based solutions. Recorded speech is sent to central servers, allowing the companies to collect enormous amounts of speech data from their users, which in combination with computing power and advanced deep learning algorithms has allowed the technology to leap ahead[1]. As a result, a large part of the population can now access state-of-the-art speech recognition in their cell phones. A Northstar Research study conducted 2014 in the US cites that 51% of teenagers and 41% adults use voice search more than once a day[2]. As more usage leads to more data, this results in dramatic reductions of speech recognition errors. In 2015, Google reported that their word error rates had dropped from 23 to 8 percent the last two years[3] and in the latest version of Siri error rates reported at 5 percent[4]. This shows that today, the potential to develop high quality speech recognition is there. The existing speech recognition systems are trained to perform specific tasks, however, and for use in free communication with social robots in environments where more than one person is involved at a time, many challenges remain.

Furthermore, different situations call for different ways of communication. In some cases, using speech alone may be the best solution. In other cases, using text or gestures is more fitting. For humans generally use a combination when communicating with each other, and this would be usually be preferable in social robotics as well. For example, eye gaze has great communication value as it signals attention, confidence, the willingness to listen or speak, and is used to address a listener and to suggest the next speaker. Even the way we breath holds cues revealing our intentions, not to mention the way we move and gesticulate. In many areas, such as education or health care, it is also vital that the robots can form an educated opinion on the user's emotional state and attitude by observing how the person moves and talks.

Computer vision is another field that has shown remarkable technological advances. A fundamental challenge in the area, simultaneous localization and mapping (SLAM), makes for a good example: A review paper from 2008 concludes that the problem is almost unsolvable with then-current technologies[5], but two years later, Microsoft released the affordable consumer-grade game sensor *Kinect*, which in effect solved SLAM by combining a video camera with a depth sensor. The release of affordable consumer-grade sensors, as in the Kinect example, is a strong trend. KTH spin-off *Tobii*, a world leading developer of gaze trackers, have traditionally sold trackers to research institutions and developers of assistive technologies at prices in the range of 30.000 to 100.000SEK. In 2015, Tobii teamed up with Danish computer game company *Steelseries* to launch a consumer version of the Tobii gaze tracker[6], the *Sentry Eye Tracker*, which now sells at the same price level as the Kinect. Other innovative consumer sensors include the *LeapMotion* hand tracking device and INTEL's *RealSense* device that tracks objects and facial and hand movements. INTEL has also teamed up with Microsoft to provide their upcoming *Tango* smart phone the ability to track 3D motion in real-time.

The biggest supplier of new sensors to the general public is the smart phone industry[7]. Apart from microphones and cameras, phones are now equipped with accelerometers, gyroscopes, magnetometers, proximity sensors, light sensors, fingerprint sensors, barometers, thermometers, air humidity sensors, pedometers, heart rate monitors. There are also a large number of wearable sensors in smart watches and fitness trackers.[8] All these can be used to track our daily activities (e.g. *Google Fit*[9]) and to track disease and health patterns (e.g. *Apple's ResearchKit*[10]*, Watson for Oncology*[11]). This will facilitate personal virtual assistants that can be used for health monitoring and promotion, early diagnosis of diseases as well as rehabilitation and assistance.

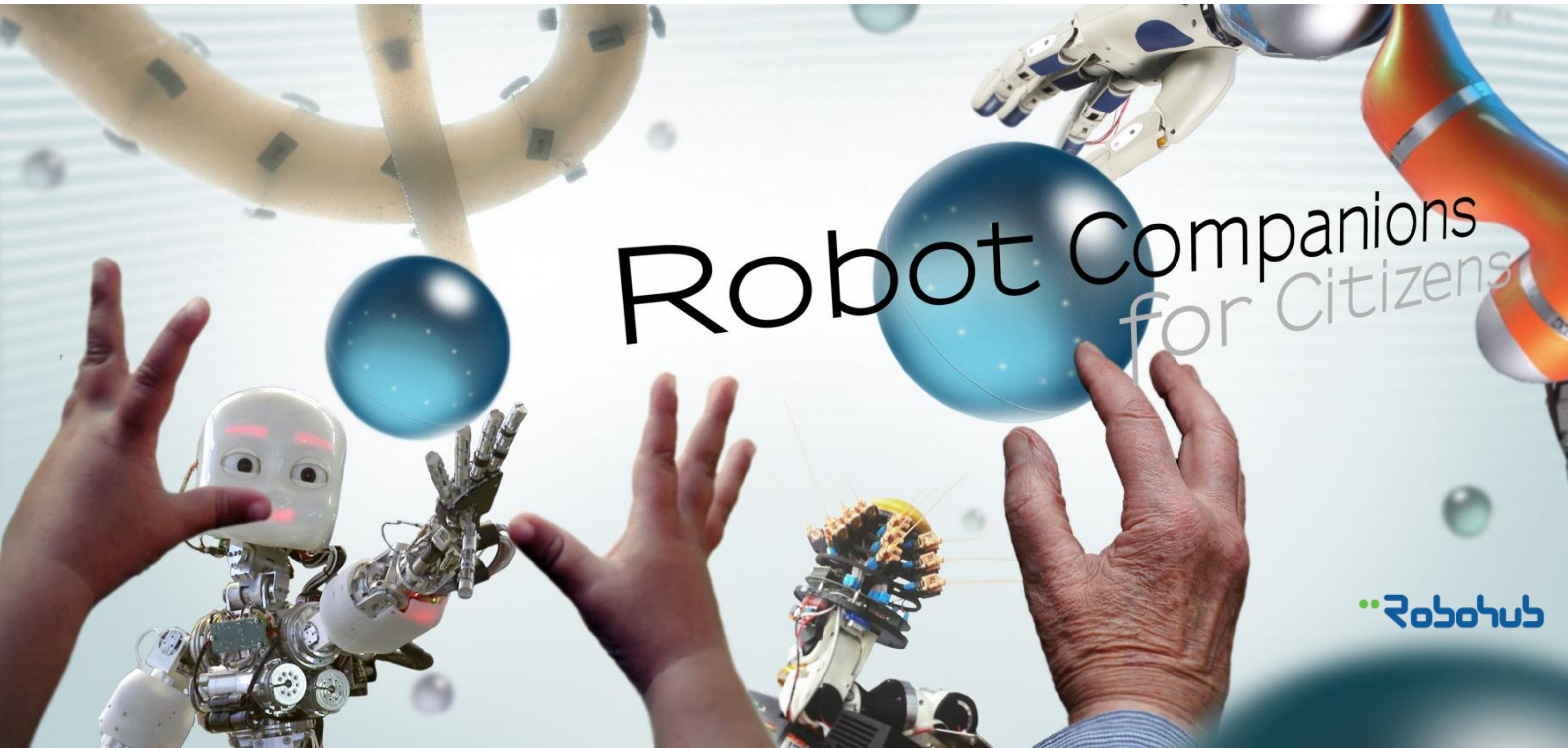
Advances such as these in a wide range of areas – notably sensor technologies, speech technology, computer vision, natural language processing, and reasoning – now allows us to move away from manual programming of machines towards equipping them with cognitive abilities, through which they can learn through interaction with people and data from the outside world.

The innovation area

As an innovation area, social robotics is characterized by border-crossing research and technology development. Advancing social robotics is a question of the orchestrated advancement of our knowledge of human interaction and of technology in many areas, including robotics, animation, assistive technologies, attitude and emotion modelling, cognition, computer vision, dialogue management, human-computer interaction and interface design, knowledge modelling, machine learning and natural language processing, planning and artificial intelligence, serious games and human computation, social signal processing, speech technology, systems architectures, technology enhanced learning. In many of these, Sweden has a long-standing record as a world leader.

Social robotics impacts society on a broad scale, and its stakeholders are found nearly everywhere. Key industrial stakeholders in social robotics include core technology companies from the robotics industry, the speech and language technology industry, the sensor and internet of things industry, and the telecom industry. Furthermore, companies in a range of industries use social robotics in their products, including the computer game industry, the entertainment industry, the tourism industry and the assistive technology industry. End-user stakeholders include user organizations, government agencies and the public sector.

An important goal of the workshops leading to this agenda was to identify a set of key areas where the social robotics potential to meet society's needs is great and clear. The following areas were identified as having particularly good starting conditions: small-scale manufacturing, domestic services, healthcare and eldercare, education, entertainment, and communications. More broadly, social robotics carries the promise of sustainability: it has the potential to reduce the waste of resources in production and services through increased efficiency and robustness, and person-representing social robots allow us to take advantage of all the benefits that the personal meeting gives without having to embark on energy-consuming journeys.



YuMi

Swedish strengths

In the industrial robot industry, Sweden is a long-standing leader. ASEA/ABB has released state-of-the-art industrial robots over the last 40 years, traditionally competing with strength and speed. In 2015, the effort is complemented with a new line of collaborative robots that competes with cognitive abilities and safe collaboration capabilities.[12]

A central aspect of future social robots is their ability to understand speech, to reason, and to access information. These are ensured through cloud-based computing and storage, and mobile cloud robotics will reduce the need for hardware and require less power to operate. Ericsson is at the forefront of developing, standardizing and testing the 5G technology which will provide the speed and extra capacity required to enable mobile cloud robotics.[13]

Finally, Sweden is very strong in the research and innovation fields related to social robotics, as made evident by the large number of related EU-funded projects with Swedish partners - during the last decade more than 100 projects in the areas of robotics, speech technology, affective modelling, serious games, technology enhanced learning and interaction technologies have been funded by the EU (see the lists of EU projects in the appendix). There are of course also a large number of nationally funded projects in these areas during the same period (from funding agencies like Vinnova, SSF, VR, FAS, RJ).

ASEA/ABB robots

1974: IRB 6
One the world's first commercially available all electric micro-processor controlled robots.

1986: IRB 2000
The first robot driven by AC motors and backlash free gearboxes

1991: IRB 6000
The first modular robot. It was the fastest and most accurate spot welding robot

1998: FlexPicker
One of the first delta robots. It was the fastest pick and place robot

2015: YuMi
A dual arm, small parts assembly robot, that safely can collaborate with humans

> *"It is essential that Sweden, both as a research center and an industrial nation, can become an international leader in autonomous systems and software development. This field represents a shift in technology, described by many as the fourth industrial revolution,"*
> Peter Wallenberg Jr., Chair of the Knut and Alice Wallenberg Foundation.

2015 saw the inauguration of The Wallenberg Autonomous Systems Program, WASP. It is a powerful research program focusing on basic research, education, training and recruitment in the field of autonomous systems and software development. The program is run by Chalmers University of Technology, KTH Royal Institute of Technology, and the Universities of Linköping and Lund. It forms a common platform for academic research, education and innovation, and is tightly coupled to the leading companies in Sweden, bringing them knowledge and competence for the future. 5 thematic areas comprise the program: Data analysis and learning; Collaboration and interaction; Model-based system engineering; Networks and distributed systems; and Software for engineering design, synthesis and autonomous systems.

Sweden has recently made enormous investments in the New Karolinska Hospital (with a construction budget almost twice that of the world tallest building, Burj Khalifa, in Dubai). In order to decrease the risk that the patients infect each other, and to increase their integrity, all patients will be given their own rooms. Managers expect that intensive care at the new hospital will require nearly 30 percent higher staffing - simply because the care will be conducted in single rooms.[14] In the future, this could be partially alleviated by social robotics, both in the form of robots that assist physically, and virtual assistants that can handle simpler information, guiding and entertainment tasks. Swedish health care has a strong reputation around the world and Sweden is a country that's very open to try new innovations. This will lead to the introduction of new and advanced technological aids in many parts of the Swedish health care sector.

Nya Karolinska


FurHat Robotics

The social robots of today

Social robots are not a thing of the future; they are already coming to market. As our concept of a social robot is very wide, viewing it in different perspectives helps give better insights. A very special kind of social robot is *representative* robots designed to act as stand-ins for people who are not themselves present at a physical location. This is a powerful means to achieving telepresence in remote meetings. The same technology can be used to allow humans to control the robots in dangerous environments and to explore future dimensions of human-machine interactions by having a human play the part of an automated system, much in the style of the Wizard of Oz, which is also the name by which the technique is commonly referred. There are a number of representative social robots on the market today: the company *Giraff* uses telepresence in homes for the elderly in order to a motivate social communication with relatives and friends and for long-term monitoring[15]; *Double Robotics* makes robots that give distance access to museums and apartments for sale[16]; the telepresence robot *VGo* is used to help chronically ill children to attend school[17]; *Geminoid HI-4* is a tele-operated android that has similar appearance of the original person[18]; and *iRobot*'s *RP-VITA* allow doctors to interact remotely with their patients[19]

Another type of social robots focus mainly on a specific person – normally their owner. These are just coming to market: Budgee is an indoor/outdoor personal load-carrying robot marketed to the disabled community[20], Zeno from *Robokind*[21] and NAO from *Aldebaran* are medium size (height 0.5 m) robots that can walk and talk that have been successfully used for training autistic children[22]; *Elemental path* are soon releasing *CogniToys* that will make use of cloud-based speech recognition and IBM Watson in order to answer questions[23]; *INTEL* will release the open source robot platform Jimmy, with cloud-based speech understanding and 3D models for printing body parts.[24]; *Sharp* corporation will release *RoBoHoN*[25], a small personal robot assistant that can walk, understands speech and facial gestures and has a projector in its head.[26] Finally *Jibo*, announced as the world's first family robot, has attracted $3,711,209 in crowdfunding.[27]

A final type of social robots centres its attention on a specific location, about which it acquires in-depth knowledge. Examples of robots that have been released include: SoftBank's *Pepper* that can be rented as a receptionist or guide.[28]; *EMIEW2* is a robot from *Hitachi* that is developed to act as a receptionist and assistant in work places.[29]; *Futurer Robot* sells *Furo-S*, that can give information to visitors in malls and airports.[30]; *Aloft hotel* has an autonomous robot, *Butlr*, that can help the hotel guests[31]; *Wakamaru* is a co-habitant humanoid robot, made by Mitsubishi, that is intended to provide companionship to elderly and disabled people[32].

The division into representational, person-centred, and location-centred social robots is not clear-cut, and it is easy to envisage robots that combine typical elements of the different categories. Another way to view today's robots according to the types of applications and domains they operate in. Social robots are already being used in health care[33], education and collaborative robots are used in manufacturing industries.

In 2015 researchers at the Worcester Polytechnic Institute got NSF funding to develop robots that will be used to aid healthcare workers caring for patients with Ebola and other infectious diseases.[34] The robots will be able to help the healthcare workers to remove their protective clothing, as well as telepresence robots that enable the workers to observe the patients without having to get all suited up. There are many other examples of robots in health care and rehabilitation. *AIST* sells the robotic seal *Paro*, that has been sucessfully used as a companion for the elderly in Sweden[35] and other countries. In Japan it was used to comfort the elderly victims of the tsunami[36]. *Personal Robot 2* is a robot from *Willow Garage*, that researchers from Berkely have provided with the ability to assist with everyday tasks, like sorting laundry[37]; *Toyota* have developed a *Human Support Robot*, that can assist people in their everyday activities[38]; *Robocare* sells the training robot *Silbot-3* to senior community centers and engineering schools. In Denmark, Aarhus municipal government has signed a deal to purchase three robots for a mental fitness program at senior community centers.[39]; *Fraunhofer* sells the *Care-O-bot 3* that can be used for communication and fetching tasks.[40] *RIKEN-SRK* Collaboration Center have developed *RoBear*, a nursing-care robot that can carry patients.[41]

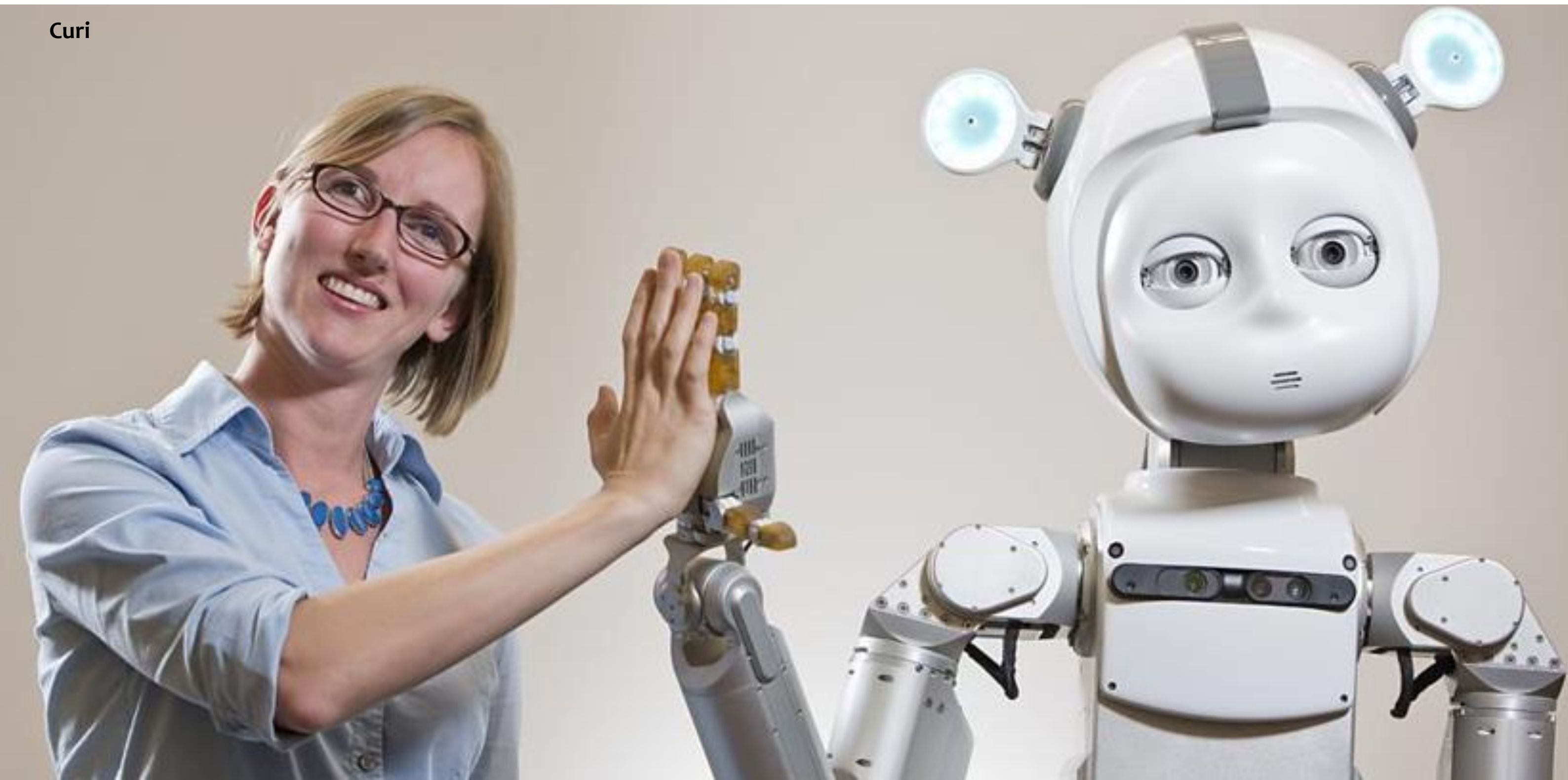
Applications from academia include the EU project EMOTE (with Göteborg University as Swedish partner) that places educational NAO robots in schools to motivate children in learning using emotion modelling[42] and the EU-project BabyRobot (with KTH and FurHat robotics as Swedish partners) will use robots as social mediators to provide encouragement and motivation for children with ASD in order to enhance their skills in communicating and collaborating with other children. In 2013 the robot company Aldebaran started *ASK NAO*, where robot scientist and specialist teachers use robots for developing social skills and learning abilities of autistic children.

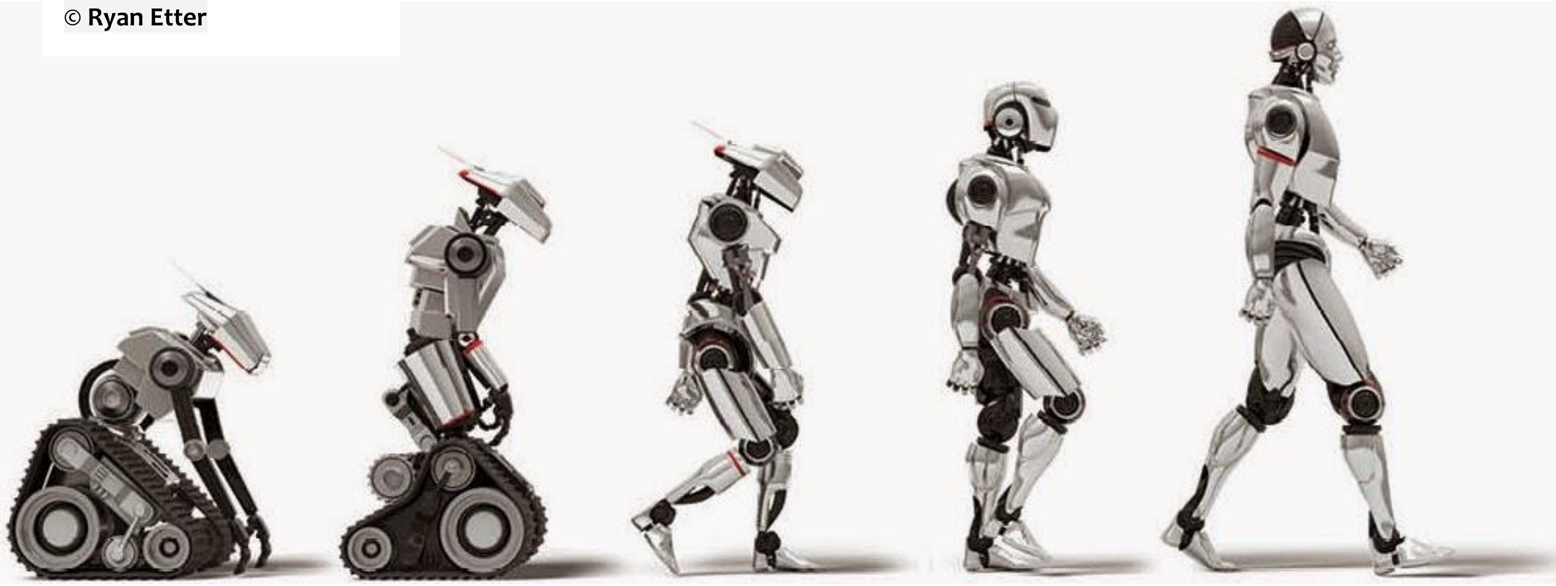
Baxter

Another application area that would benefit from social robotics is collaborative robots for manufacturing – an area that got a boost in 2012 when Rodney Brooks (MIT; cofounder of iRobot) started *Rethink robotics* which makes Baxter, a low-cost, easy-to-use factory robot.[43] It is designed for manufacturing companies with varying product lines by being harmless to be close to, and in that it can be taught what to do by example. Recently the key players in industrial robotics have also introduced collaborative robots: *KUKA* has introduced *IIWA* (Intelligent Industrial Work Assistant) with a design is based on a human arm with seven axis, and with built-in-high-performance collision detection algorithms[44]; *ABB* has launched *YuMi*[45] that is designed to meet the flexible and agile production needs of any small parts assembly environment thanks to its dual arms, flexible hands, computer vision and precise motion control; *FANUC* has released *CR-35ia* (Collaborative Robot with a 35 kg payload),[46] that is unique among collaborative robots in that it can handle heavy payload; *Universal Robots sells UR3*, as a "third-hand helper" robot in light-weight assembly[47]; *pi4_Robotics* have in collaboration with *Fraunhofer* developed the *WorkerBot* with two 7-degree freedom arms that has three cameras (including a 3D camera) that are used for object recognition and face recognition. Like Baxter it also has a "face" in the form of a LCD screen[48]; *F&P* Personal Robotics sells *P-Rob* to the automotive industry, that enables human-robot collaboration by using soft material, rounded shapes, limited forces and stop functions[49]; *Kawada* has developed *NextAge* that is meant to work alongside humans without safety barriers.[50] Its overall design is a bit different from most other collaborative robots, since it apart from a torso and two 6-axis arms also includes a "head" with two cameras, and a mobile base. *Willow Garage* was a company that provides open source tools (e.g. the Robot Operating System ROS), and a robot platform called *PR2* (Personal Robot 2).[51] As of 2014 the support and service is handled by ClearPath Robotics.[52] It is different than the other collaborative robots in that it aims at domestic usage. It has compliant arms and a multi-directional mobile base, which makes is possible for it to act as a helpful assistant at home. All these industrial robots would clearly benefit from better cognitive, social and communicative skills.

A number of social robotic research platforms also exist, produced by academia or industrial research centres. Many of these were developed within EU-funded projects. *iCub* is a 1 metre high humanoid robot testbed for research into human cognition and artificial intelligence.[53] It was developed by Italian Institute of Technology within the EU project RobotCub and has subsequently adopted by more than 20 laboratories worldwide. It has hands with fingers with tactile sensors which means that it can grasp small objects, such as balls and bottles. *FurHat* is a back-projected robot head for research and development in advanced human-robot interaction. The social robot was developed by *KTH* as part of the EU-project IURO. It can understand and generate speech and facial gestures, and has a very powerful multimodal dialogue system framework called IrisTK. It is sold as a research tool to universities and industrial research departments through the spin-off company *FurHat robotics*[54]. *Curi*, is an upper-torso humanoid research robot developed at *Georgia Tech*'s Socially Intelligent Machines Lab[55]. It can see objects and perform simple tasks on them (grabbing, recognizing, and sorting objects). It can also identify human faces, understand social exchanges, and appropriately respond with blinks, nods, shrugs, and other responses. *Philips Research* in the Netherlands developed *iCat*, a prototype of an emotionally intelligent user-interface robot[56]. It has the form of a small mechatronic toy cat that can display facial expressions. This capability makes the robot ideal for studying human-robot interaction and it has been used as an educational game buddy for children. *Kaspar* is a robot that *University of Hertfordshire* designed for social interaction with children with autism.[57] The design rationale of the robot was to develop a low-cost, minimally expressive robot - with realistic but simplified human-like features that can engage children and adults alike in a variety of interactions that can be tailored towards therapeutic or educational for children with autism. *Zeno* is a 56 cm high mechatronic humanoid robot able to show facial expressions and images on a screen on its chest. It has a lot of sensors: a camera, a microphone, a gyroscope, a compass and proximity sensors that makes it possible for it to respond to the outside world.

Curi





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Vision 2025

We predict that next generation systems will make use of social and communicative skills in very different ways, but that no matter the type of system –physical or virtual; stationary or mobile; personal or public; entertainment oriented or task driven; autonomous or tele-operated; humanlike or machine-like – if it cohabits with people, it will be expected to respond appropriately to human behaviours and language. Further we see that socially competent robots can be taught new things and collaborate with humans on human terms, which will transform many areas, e.g. manufacturing, health care and education, provided that we can achieve border-crossing development of a wide variety of technologies. These visions are in line with those of various organizations who has taken it upon themselves to peer into the future.

The *Rockit Roadmap* for Conversational Interaction Technologies predicts that in ten years' time, we will have mobile personal assistants and social robots that can speak a large number of languages. These will not only alleviate or fully remove the information seeking burden, but also deliver high-quality physical and psychological support services to the general public.

In a *Pew Center* report, a number of researchers and industrial leaders gave their views on the effect a future with smart machines will have on the job market.[58] Marc Prensky, director of the Global Future Education Foundation and Institute, wrote, "*The penetration of AI and robotics will be close to 100% in many areas. It will be similar to the penetration of cell phones today: over two-thirds of the world now have and use them daily*." Joe Touch, director of the Information Sciences Institute's Postel Center at the University of Southern California, stated, "*Automation will continue to displace certain jobs, but they also create new jobs (creating/maintaining automation) and free us to explore other jobs as well. I don't think this has changed since the dawn of the industrial revolution, even though every shift is decried for those displaced. Jobs will continue to shift, as will our notion of the distinction between white- and blue-collar positions*."

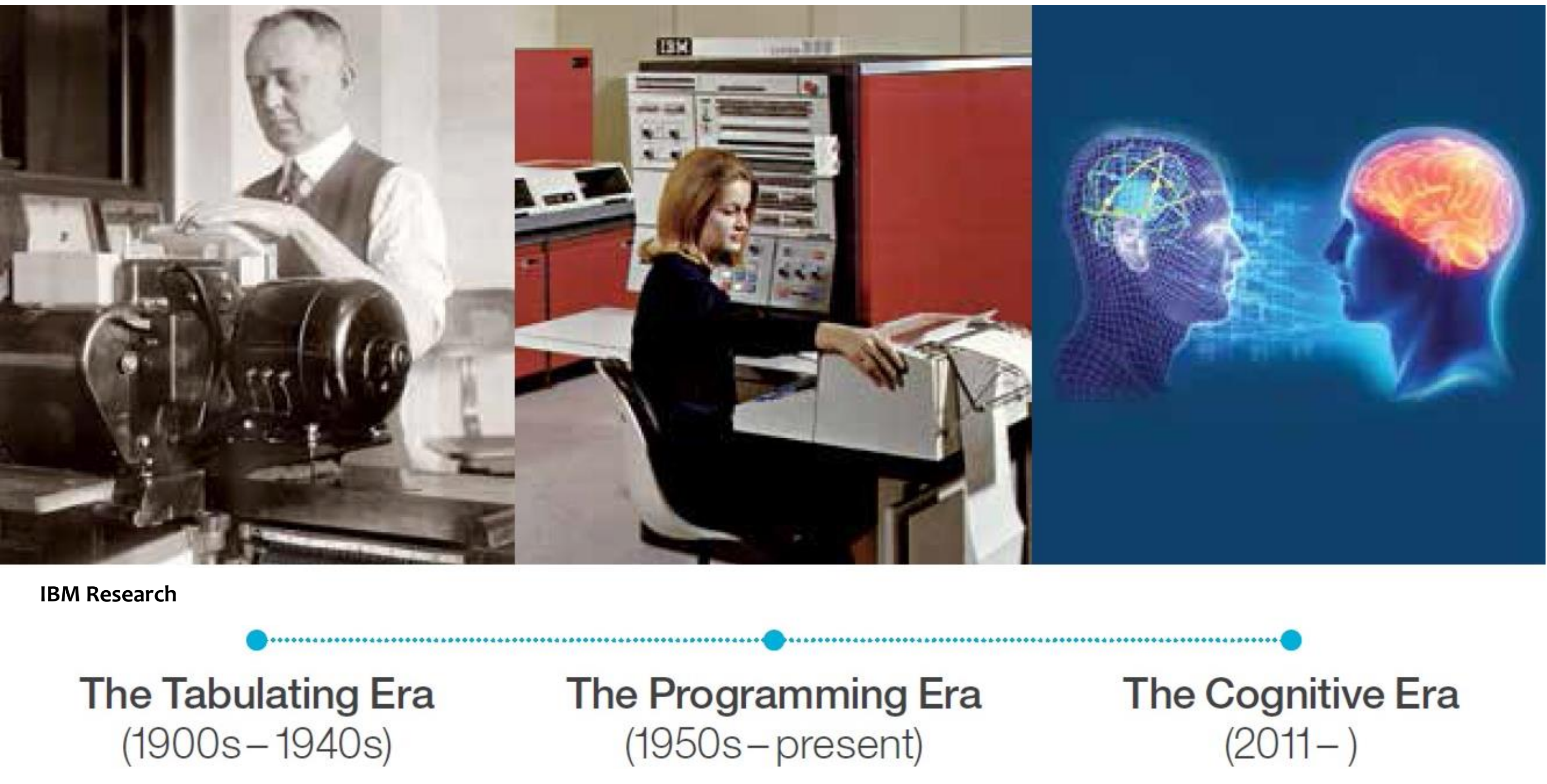
And the 2014 bestseller *The Second Machine Age*[59] has the following prediction as its closing words*: "As more and more work is done by machines, people can spend more time on other activities. Not just leisure and amusements, but also the deeper satisfactions that come from invention and exploration, from creativity and building and from love, friendship and community."*

Potential

Every year Gartner publishes a hype cycle for emerging technologies. In the 2015 hype curve Big Data have been moved out since Big Data is now omnipresent, and speech recognition was removed since it is regarded as a mature technology. According to Gartner officials the 2015 hype curve can be characterized by three themes:

BIO	biotech, biochips, bioprinting, human augmentation
SMART	smart advisors, smart cities, smart government, smart grid; smart machines; smart robots; connected home; wearable devices, natural language Q&A, speech-to-speech translation
PEOPLE-CENTRIC	people-literate technology; virtual personal assistants, citizen developer; citizen experience; corporate social responsibility; digital workplace; virtual care, affective computing

An interesting new area here is people-literate technology which targets smart machines that learn what humans want by observing human behaviours, activities and habits and by understanding human language. This is closely related to what IBM call *cognitive computing* that learn and reason from interactions with humans and unstructured data in the form of text, images and sound[60]. IBM claims that we are now entering the *Cognitive Era* of computing, and within 10 years they expect the Watson technology to grow to a $10 billion per year business.[61] In 2015 Gartner also released "*Top Strategic Prediction for 2016 and Beyond*"[62] where they predict a near future with robot authors, robot economists, smart co-worker machines, robot bosses and conversational assistants that recognizes the customer's face and voice. Their last prediction is called the *Post-app Era*, which builds upon the fact that mobile users on average use only 30 apps per month, from a gigantic list of 1.5 million downloadable apps. All the big players (Google, Apple, Microsoft) want to turn the massive number of single-feature apps into service providers for the backend system of their proactive personal mobile assistants. [63] This process has already begun with *Now on Tap*, *Siri Proactive* and *Cortana* accessing functions inside third-party apps.




Zashiki karakuri

In 2014 the Japanese prime minister Shinzo Abe announced that he wanted robots to be a key pillar of Japan's growth strategy, trebling its robot market to $22 billion by 2020. He even proposed to organise a *Robot Olympics* when Japan hosts the summer games that year.[64] In Japan, the acceptance of robots is greater than in other cultures, which is evident from a study that showed that 60% of elderly would like to be taken cared by a robot. The explanation might be found in popular culture, e.g. the 17th century mechanical dolls seen above[65] or the immensely popular 1950s cartoon *Astro Boy* – a robot with a soul, a conscience and human emotions.

In January 2015 the Japanese Ministry of Economy, Trade and Industry and Ministry of Health, Labor and Welfare announced a *New Strategy for Robots*[66], which states that in order for Japan to remain a robot technology leader it must set up structures that promote public-private collaboration projects in the area of robot innovation, and further it must provide strategic funding to robot usage in industry and society at large by setting up global standards and rules that promote businesses that make use of sensor and interactional data collected via autonomous robots. It emphasizes the need for development of next-generation technology, with the example that "*voice recognition technology is expected to help develop a robot with greater operability and usability through human instinct*". They will fund research in several fields that are needed in future robots: AI, machine learning, knowledge representation, speech understanding in noisy environments, computer vision in bad lighting, smell recognition, haptic recognition, mechatronics, middleware, security and safety. During a five-year period, the Japanese government will fund project that increase the utilization of robots in different sectors such as manufacturing and infrastructure. The biggest share (33%) of the program's budget (JPY 5.3 billion) will be devoted to funding robot development projects in the health and nursing sector. Finally, they expect universities to take an active role not only in basic and applied research, but also in systematizing the robot field into an academic field that will give direction and future perspective. In November 2015 Toyota announced the establishment of the Toyota Research Institute (TRI) in the US that will do research on autonomous cars and collaborative robotics. The centre will be placed at two sites near Stanford University and MIT. The $1 billion investment comes on top of $50 million Toyota announced in September 2015 to establish collaborative research centres at the two universities to study how humans interact with machines. [67]

Challenges

The fundamental challenge for successful and world leading innovation in social robotics lies in the sheer number of technological disciplines and research areas that intersect. Sweden is in good shape in virtually all of these disciplines, and the challenge is not primarily to find ways to push forward in the individual disciplines, but to orchestrate the effort to the benefit of social robotics. The social robotics agenda plays a crucial part here, as it is our hope that it will act as a beacon for those interested in pushing innovation in this direction. Other major challenges that will have to be addressed include the acquisition of and access to large quantities of relevant data, the relatively high costs involved in this line of innovation, and sadly, the issue of equality. As robots are introduced into our homes, workplaces and public spaces a number of challenges arise, apart from the obvious safety aspects. It will influence interior design, the dimensioning of our ICT infrastructure (4G vs 5G), and how to change the working practices to cater for human-robot collaboration on human terms.

Data

The key to successful progress in virtually every innovation area that social robotics relies on is access to large quantities of data. Taking the type of automatic speech recognition task performed by personal assistants like Siri, Now and Cortana as an example, these improve drastically with use largely due to the fact that they learn from their users. Seen from one perspective, the fact that much can be achieved with data driven methods is comforting – an opportunity. There are, however, risks involved, as a lack of sufficient quantities of relevant data can hamper or even halt advancement.

Speech and language data. A risk to be considered is, perhaps surprisingly, the success of the Fortune 500 companies working in the speech industry. The automatic speech recognition supplied by them today is, for the purposes for which it is designed, of a quality that smaller players cannot compete with, and their data influx makes their lead continuously grow. As long as they sell their speech services at reasonable prices this does not constitute a problem, but should they stop, tremendous stretches of ground must be covered to catch up. There is no simple solution to safe/guard against this, but Swedish interests are looking into ways of acquiring Swedish usage data in order to build accessible language resources. Work in the social robotics agenda should pay close attention (and contribute) to these efforts.

Multimodal, multiparty and situational data. A more pressing risk is the cost and the difficulty associated with acquiring data that is not limited to question-answer style conversations currently constitute the vast majority of spoken human-machine interaction. A social robot will only rarely find itself in a situation where it is being clearly and unequivocally addressed by one person. Robots inhabiting human environments will find themselves laughed at, pranked with, scolded, saluted, spoken over, spoken about – a far cry from what current technology can handle. There is currently very little data of this sort. This obstacle is not unique to social robotics, most likely, this will require the combined efforts of research institutes, government bodies, funding agencies and industry, but work within the social robotics agenda is closely connected to these issues and our involvement is essential.

FurHat Robotics

Investment levels

The specificities of social robotics make it a relatively capital intensive field, and significant investments are needed in not only in infrastructure, but in research and development as well. The creation of a single prototype for establishing proof of concept can be quite expensive in this field, and this commonly happens before the companies are near making profits. Suggestions to alleviate this problem and acquire long-term investments in high-tech start-ups include tax incentives – making long-term investment more advantageous from a tax perspective reduces its overall cost and thereby increase its attractiveness. Other suggestions include the more commonly implemented long-term research and innovation programmes, but it may also be possible to jump-start development by launching single, relatively simple applications that can attract users and lower costs for data acquisition as well as generate revenues for further innovation.

Demographic bias and equal rights

A rarely talked-about aspect of data-driven development is that of equal rights. The methods resulting from data-driven development are primarily useful, or *functional*, for members of the same demography that produced the data on which they were trained. That means that if the training data was obtained by recording the behaviours and the speech of techno-friendly urban males between 20 and 25 years of age, then the resulting components are likely to work well with that demography, and much less likely to work with middle-aged females from rural areas or with old-age pensioners, for example. Furthermore, data was collected in scripted scenarios, which makes the models less useful in interactive scenarios. However, in many cases today, data is collected from actual usage from the general public, but there still is a bias towards young male users. Furthermore, it is data in today's mobile assistant applications to support search and dictation, and not the future applications that social robotics will make possible. There is no easy solution to this problem, but it is one to always bear in mind, not exclusively but perhaps especially in the case of social robotics. A more urgent issue is to attract more female students and researchers to the area of human-computer interaction and robotics. Researchers in social robotics should showcase their research at primary and secondary schools in order to stimulate more girls to pursue higher studies in natural science and technology.

Risks

There are a number of concerns that are partially or wholly outside the control of participants in a social robotics agenda, but nonetheless strongly relevant. These concerns relate to society, to ethics, and to security and integrity.

Society

There is widespread concern that robots and artificial intelligence will render us all unemployed. Investigations in the USA[68] with followers in Sweden[69] and elsewhere warns that half of today's jobs can be automated in a very near future. However, many analysts claim that rather than seeing a threat to full employment, we should see an opportunity for a better quality of life for all. Japan recently presented a new robot strategy which states that *"[...] robots must be operated under a collaborating system with human where both parties supplement each other to draw an upward spiral for improvement*". The greater fear in this context is that today's tax and financial systems, which are built on a mass market of taxed salary workers who also act as consumers, will collapse. There are a number of proposed solutions to this such as adjustment of the tax system, introduction of guaranteed income for all citizens, and increased governmental funding of education and research. Work within the agenda clearly must be aware of these fears and of how they are being dealt with, but the proposed solutions are of such a nature that they must be implemented on a political and international level, which apart from advisory roles is clearly outside the scope of the agenda.

Security and privacy

Cloud computing is a major trend, and seen as an important facilitator for social robotics by large players such as Ericsson. This concerns machine-to-machine communication in manufacturing industries and smart homes, as well as compute servers for natural language understanding, computer vision and reasoning. In general, social robots are equipped with the capabilities to sense, process and record the world around them, privacy concerns become crucial[70]. Cloud computing clearly presents a great opportunity, but it also comes with security and privacy risks. Recently, Samsung were widely criticized because of their voice-controlled TVs. They posted a policy warning to their viewers mind what they said in their own living rooms, since the always-listening television might capture sensitive information and share it with undisclosed third parties[71]. *Mattel* recently made for a similar example when they teamed up with the *ToyTalk* to develop *Hello Barbie* – a WiFi-connected doll that understands children's speech through cloud-based speech recognition. The advocacy group Campaign for a Commercial-Free Childhood launched a petition to stop the listening doll, since it is in the nature of children to reveal a lot about themselves when they play, making them sitting ducks for all kinds of unsolicited advertisements[72].

The developments of the base technologies for secure cloud-based services lies outside the scope of this agenda. However, researchers and developers of social robots must be aware and make sure that data is handled with care. Furthermore, guidelines as to which types of data may be sent to servers and/or shared must be developed.

Ethics

Work on automation and robots leads to a number of ethical challenges, especially as the robots enter our homes and work places. Many conceivable robots could clearly harm humans, and there seems to be a need for regulations. The development and evaluation of suitable ethics frameworks lies clearly within the scope of this agenda. There is currently no special legislation regulating what type of robots may be researched, developed and produced, as is the case with other technologies that can potentially cause massive harm, such as the weapons and medical industries. The closest we have comes from science fiction where Asimov's laws state that robots cannot harm humans. A social robot could do other harm that physical, for example by lying or bullying. In order to give social robots rules to prevent this, they need to be equipped with self-awareness and artificial moral. However, this is technologically very hard to achieve and it could lead to entirely new problems. [73]

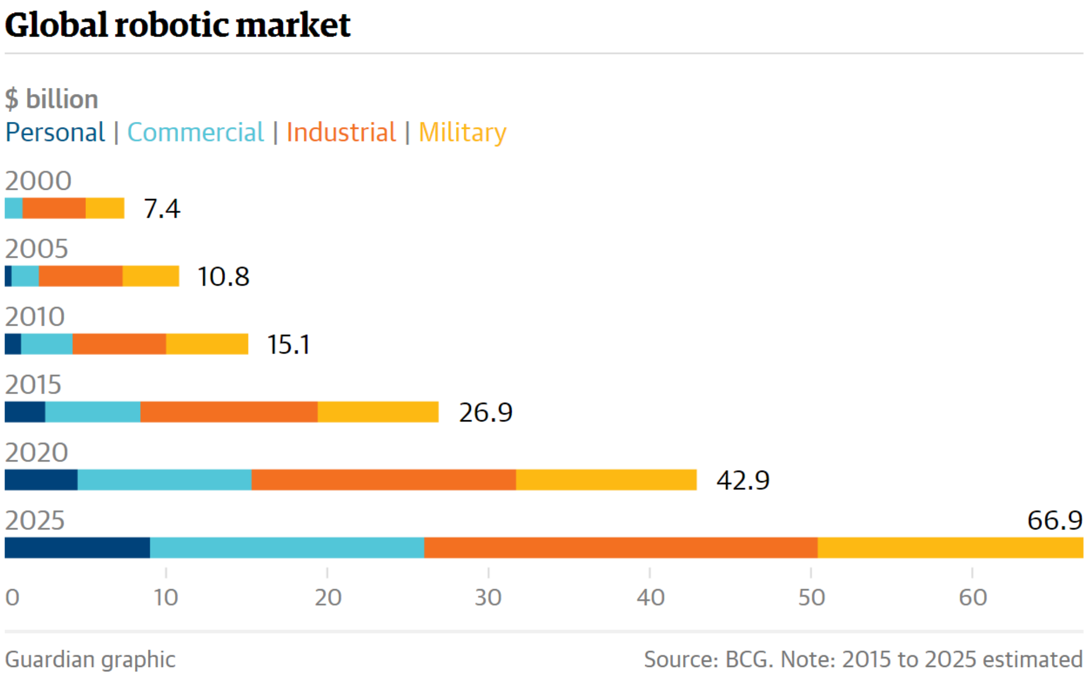
In 2014 the Swedish National Council on Medical Ethics (SMER) presented a report on the ethical aspects of robots and surveillance in the care of the elderly.[74] The report argue that in order to introduce a new health robot the responsible authority has to make sure that ethical values in health care are not threatened and that statutory requirements are met. This means that in each individual case when a care robot is to be introduced this must be in place:

- Before introduction: an assessment of the appropriateness and a consent form
- An initial trial period: where the patient can assess the usefulness of the robot.
- An evaluation period: where qualified personnel judge the solution
- A process where sensitive personal information and recorded data is secure

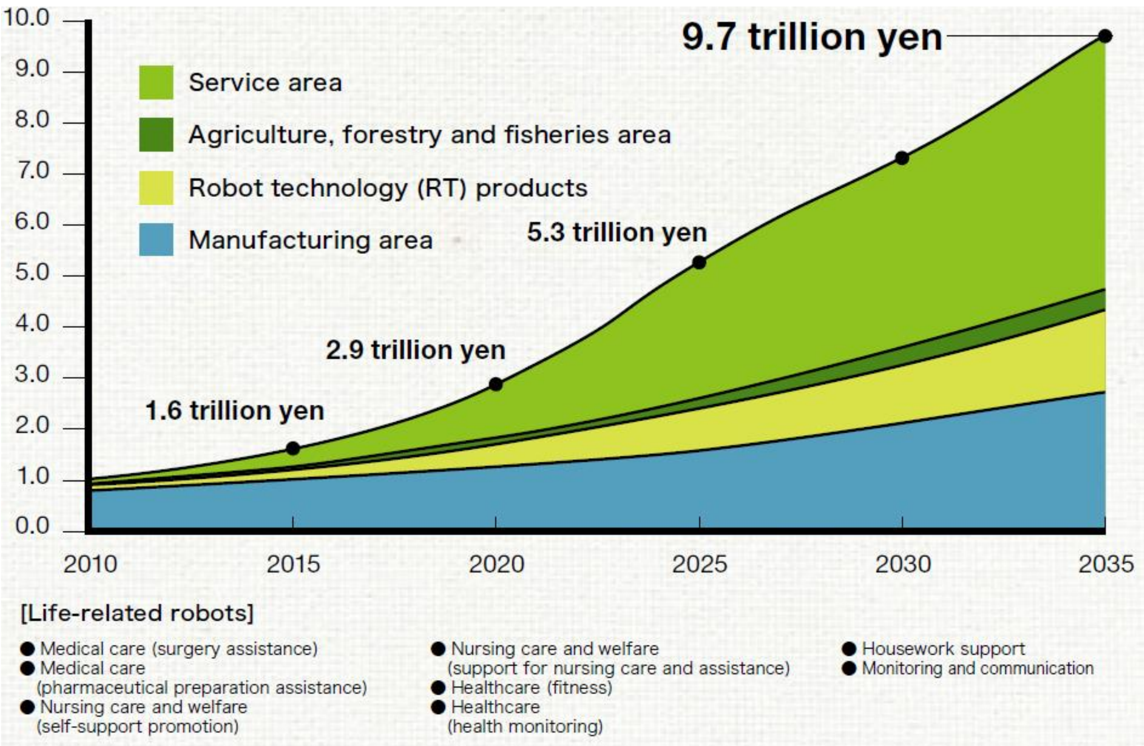
In a chapter on robot care in the book Robot Ethics Sharkey & Sharkey concludes the following: "*Before we go adopting robots in the large-scale care industry, we must be sure about which rights we may be violating. We must minimize these violations in a way that is customized for each individual, and we must ensure that the accrued benefits for an individual are proportionally greater than any losses due to the infringement of their rights. Having considered the field of robot assistance and care, our view is that robots could be of benefit to the welfare of the elderly, particularly if it maintains their independence at home for longer.*" [75]

Opportunities

According to a report from Merrill Lynch we are facing a "*robot revolution*" that will transform the global economy over the next 20 years.[76] According to the authors the penetration of robots and artificial intelligence has already hit every industry sector, and has become an integral part of our daily lives. They calculate that the global market for robots and AI will reach $152.7 billion by 2020, and estimate that these technologies could improve productivity by 30% in some industries.



According to the Japanese ministry of Economy, Trade and Industry, the Japanese market size of robotics is expected to reach 9.7 trillion yen in 2035. This will be fueled by high latent demand for service robots in the medical care and welfare industries, the security and disaster-relief field, agriculture, and other fields of social infrastructure.




F&P Personal Robotics

Collaborative robots in the manufacturing industry

A major opportunity for social robotics is found in the intersection of the manufacturing industry and robotics. Robotic technology has transformed the manufacturing industry ever since the first industrial robot was put in use in the beginning of the 60s. Yet contemporary industrial robots are still largely pre-programmed for their task, unable to detect changes in own performance or to interact robustly with the complex environments and human workers. The challenge of developing flexible solutions where production lines can be quickly re-planned, adapted and structured for new or modified products remains an important and unsolved problem. There is currently a fourth wave of industrial technologies called Industry4.0, where collaborative robots are central. According to the European Robot Initiative for Strengthening the Competitiveness of SMEs in Manufacturing[77], the most desirable new manufacturing technology is robots that can be used as a *third hand*, for example assisting workers at assembly lines by fetching and arranging components as they are needed. In a co-worker scenario, *collaborative robots* would need to be able to understand as well as provide verbal instruction, and their performance will depend on their ability to detect, understand, and respond appropriately to the multimodal social signals that underpin human communication. These processes are complex, with coordination being achieved by means of both verbal and non-verbal information.

The ABI Research study "*Collaborative Robotics: State of the Market*" predicts that the global collaborative robotics market will grow ten-fold from $100 million 2015 to $1 billion in 2020. The growth appears in three key markets: electronics manufacturers, small-to-medium manufacturers; and manufacturers with agile production methodologies[78]. Similar predictions are mad in the recently announced International Federation of Robotics (IFR) research study "*Positive Impact of Industrial Robots on employment*", which anticipates that more than two million jobs will be created in the next eight years because of robotics in industry[79]. The study concludes that countries in which manufacturers have embraced the use of robots show a greater manufacturing productivity as well as an increase in high-paid jobs.

Personal robots in domestic applications

Personal robots are service robots that educate, assist, or entertain at home. These include domestic robots that may perform daily chores , assistive robots, and robots that can serve as companions, pets, or entertainment. The personal and service robotics markets are immature markets, and quantitative studies suggest that this market is on the verge of dramatic growth. It is projected that sales of all types of robots for domestic tasks could reach almost 11 million units in the period 2012-2015, with an estimated value of $ 4.8 billion. In 2014, about 4.7 million service robots for personal and domestic use were sold. As for entertainment robots, about 1.3 million units were counted in 2014,. Numerous companies, especially Asian-based, offer low-priced toy robots, but among these mass products, there is an increasing number of more sophisticated products for the home entertainment market. For years now, the LEGO® Mindstorms® programme is one of the higher quality products offering software environments which reach well into high-tech robotics.

The global market for intelligent virtual assistants is estimated at $5.1 billion by 2022[80], growing at a high 30% compound annual growth, of which Europe will have a 35% share. This market covers personal mobile assistants for individual users, SMEs and large corporates, for which Sweden has a major international player in Artificial Solutions. Another market where social robotics will play a key role is smart homes. The market has been estimated to be worth $21.6 billion by 2020.[81] According to Gartner, by 2020, intelligent virtual assistants will facilitate 40 percent of mobile interactions, and the post-app era will begin to dominate.

ASIMO

Documentary: Alice Cares

Health and elder care robots

A third area of opportunity for social robotics is health and elder care. Merrill Lynch predicts that the global personal robot market could increase to $17 billion over the next five years, "*driven by rapidly ageing populations, a looming shortfall of care workers, and the need to enhance performance and assist rehabilitation of the elderly and disabled*".[80]Stephen Von Rump, (CEO of Giraffe Technologies that manufactures robots for elderly care) estimates the EU market alone for robots and other technology to take care of elderly in 2016 will reach €13 billion by 2016.[82] The Japanese government projects the Japanese market for nursing care robots for the elderly will expand to 404 billion YEN per year by 2035.[83]

In a recent overview of its policy for the elderly, the Swedish Government notes that increased life expectancy entails an aging population. Today, approximately 500 000 people in Sweden are 80 years or more of age, and by the end of 2040 they will be over 1 million[84]. The policy document states that municipalities should set up goals that allow their elderly to live independently in safe conditions, in dignity and well-being. This encompasses support for maintaining interests, habits and social contacts. The Japanese government has reacted to this issue by putting forth a "*Japan Revitalization Strategy*", that aims to support development of robots for medical and nursing-care services. Many of major Japanese companies are involved, including Toyota Motor that recently started clinical studies with care robots that use industrial robot and control technologies from their car production lines. Akifumi Tamaoki, general manager of Toyota Motor's partner robot division said: "*Looking hard at the future, we would like to make this kind of robot one of our strong businesses*"[85].

Another area for social robotics is in robot-assisted therapy for autistic children. The number of diagnosed children is increasing drastically (currently 1 in 42 in the US), confirming that ASD is an important and urgent public health concern. It is estimated that each person diagnosed with ASD accrues $3.2 million in societal costs throughout his/her life. Behavioural interventions aiming to improve ASD conditions require a large amount of time, energy, and human resources to be properly effective. However, children with autism are often spontaneously attracted to technology, and social robots have proven to be very useful for this kind of training. Several studies use robots with advanced communication capabilities for ASD children to learn and develop socio-cognitive skills, and human-robot communication is also proposed as a method to improve early diagnoses. Examples of robots that have been used for these purposes include Zeno, NAO and Kaspar.

Educational Robots

A related area for social robotic is *technology enhanced learning*. According to an OECD report schools and education systems are not able to make use of today's rapid advances in technology[86]. The teachers' and students' lack of knowledge makes it impossible for them to find the useful digital learning resources among a plethora of poor quality ones. The educational technology group at Lund University evaluated 100 educational apps for math and reading found that only 2-3 percent gave useful feedback.[87] Most apps should not be seen at teaching apps, but should rather be seen testing tools to check what students have already learned. In order to support learning the feedback has to be individualized and explanatory. Here social robots and virtual teachers have to possibility to make a difference.

Our world is rapidly changing, and particularly in the last decade this has led to dramatic changes in the types of skills required for employment. According to the WEF[88], we should be training our young generation on skills that are necessary for the workplace, such as the ability to engage in problem-solving, teamwork, communication and collaboration. These new demands have led to a deeper learning movement in education[89], where these 21st century skills are promoted. The rate of technology adoption in education should increase, and the technology should have a positive impact on modernising and improving the field. The EU commission has launched the *Open up Education* initiative, with the aim to stimulate teachers and educational institutions to test innovative digital approaches, and to encourage the recognition and validation of skills acquired through digital learning.[90] There is no doubt that social robots have a potential in education, acting as peers, companions, collaborators, tutors, and teachers. The social robots also have a role as a powerful tool for the student to learn how to program and teach robots new things. This could also engage more girls to pursue a career in computer science.

A great societal challenge of our time is to managing the people that move to new countries. The possibility to acquire language skills and social codes of the new environment is a great help. Learning a new language, however, calls for extensive practice with appropriate feedback, and the available language teacher resources cannot meet the demands. Social robots and virtual teaching partners can alleviate the situation. Social robots with facial expressions, gestures, speech and dialogue skills can help practice vocabulary, pronunciation and conversational skills.[91]

Related strategic projects

The agenda touches issues that are part of a number of other Vinnova innovation agendas. Since one of the key application areas for social robots is health care it has a natural connection to the agenda *Health and social care in the information society (VOIS),* that aims to use information technology to improve communication and coordination in order to achieve effective high-quality care. Another related agenda is *E-hälsa i hemmet* with the goal to give the individual care at home and for the elderly to live independently at home longer. The agenda *En åldrande befolkning* aims at creating and developing easy access to products and services that have been designed for the elderly.The agenda for social robotics aims at improving care for health and well-being of the elderly who are experiencing cognitive decline by providing interactive robots that monitor important signals of health and well-being trajectories. For autistic spectrum disease (ASD) children, social robotics can be used to collect audio-visual data for diagnostic purposes and for training and rehabilitation of for example verbal communication skills. Social robotics makes excessive use of data data-driven methods which gives the agenda a natural connection to the innovation agenda *Big Data Analytics*. Furthermore, many social robots (e.g. mobile cloud robots; smart home assistants) will rely on machine-to-machine communication. Here, the social robotics agenda intersects with base technology in the agenda for *Internet of Things,* the agenda *Trådlös kommunikation* and the *Swedish Agenda for the Future Internet*.

The 1.8 billion SEK *Wallenberg Autonomous Systems Program* (WASP) focuses on fundamental research in autonomous systems and software development. Targeted research areas include robotics, distributed systems, network dynamics, navigation, computer vision, machine learning, Internet of Things, cloud technology, software development and engineering[92]. There are three sub-projects in WASP: *Automated Transport Systems, Localization and Scalability for Distributed Autonomous Systems*, and *Integrating Perception, Learning and Verification in Interactive Autonomous Systems*. The last project deals with autonomous systems that interact with their environment and collect information about the outside world via various sensors. For the systems to work better and adapt their behaviour to different user situations, the project will develop machine learning methods that are based on combinations of sensors such as cameras, laser or tactile sensors. This will require a close collaboration between researchers in computer vision, robotics, control engineering, mathematics and artificial intelligence, Work in social robotics is complementary to the goals of WASP, as it focuses on developing methods for robots to interact with the *humans* in the environment. The resulting methods for providing cognitive, social and communicative skills will make state-of-the-art research in autonomous systems within WASP even more powerful.

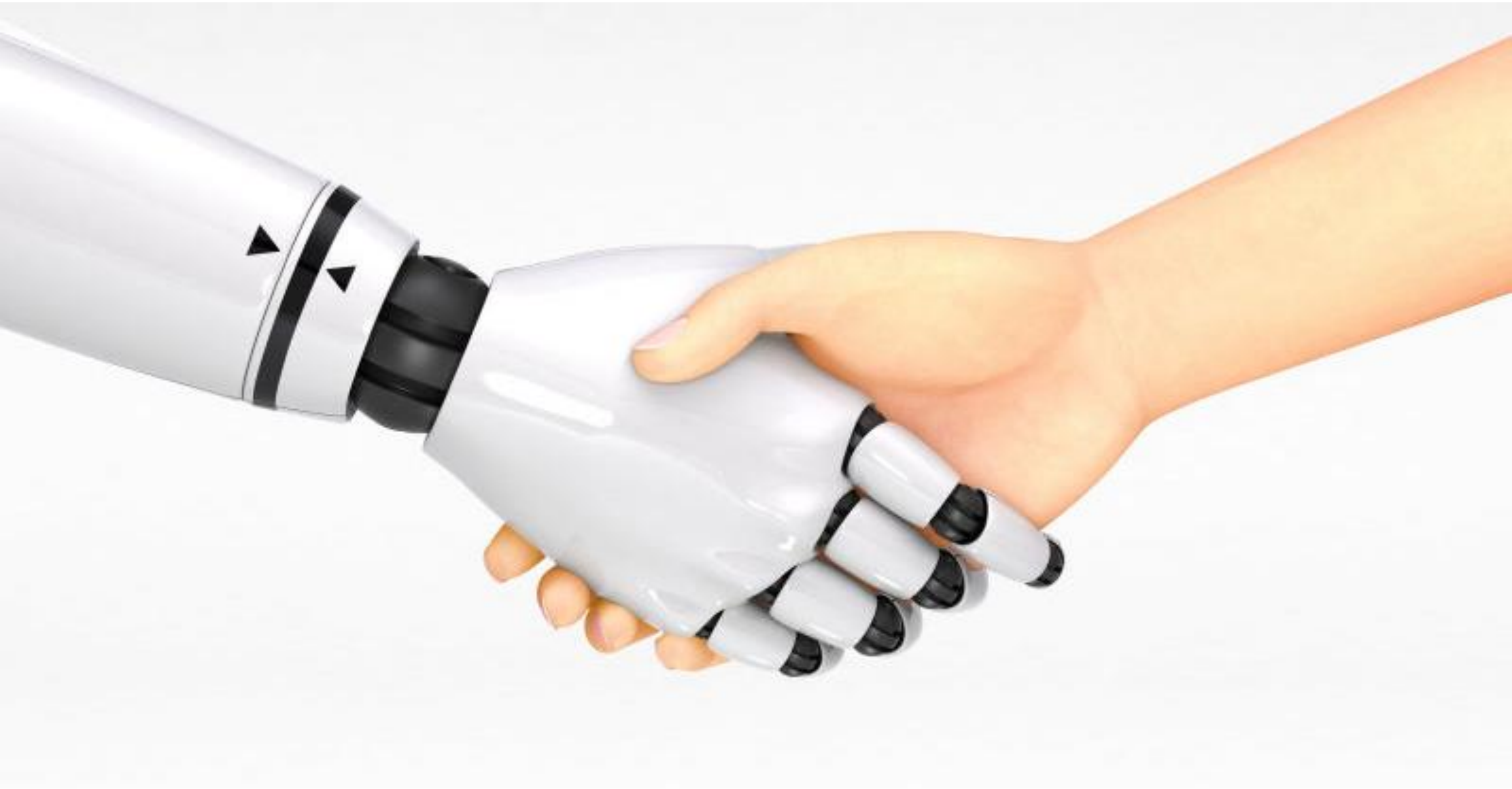
Robotdalen is a Vinnova funded innovation environment that brings together industry, academia and public sector. Its goal is to facilitate new robot solutions for industry, service and health care. Robotdalen offers living lab environments with robots and sensors that allows fir example companies and health care providers to develop new innovative solutions. The setup supports user involvement throughout the product development, thus resulting in robot innovations based on market needs[93].

Centre for Applied Autonomous Sensor Systems (AASS) is a multidisciplinary research centre that focuses on the perceptual and cognitive capabilities of autonomous systems. Its two major application areas are: development of autonomous professional vehicles, and autonomous-systems solutions for elderly care in domestic environments. This is for example done in the Ängen Research and Innovation apartment, an open platform for development and testing of robotics and intelligent systems in the home. *Ängen* is part of The VINNOVA supported Örebro Testbed.

The Centre for Autonomous Systems (CAS) is an interdisciplinary research centre at KTH. CAS bridges three KTH schools: CSC, EES and SCI. The centre performs research in (semi-)autonomous systems including mobile robot systems for manufacturing and domestic applications. The researched spans the areas of robotics, computer vision, machine learning and control. The centre was inaugurated 1. August 1996 first the first time and again in 2008 for a second round. The centre contributes to the social robotics agenda by its basic research in robotics and computer vision.

SSF has recently funded 250 million in the area of future industrial production.[94] One of the 8 funded five-year-projects is in the area of social robotics: "*Factories of the Future: Human-robot Cooperative Systems*" where a team of KTH researchers will work towards an envisioned future factory setup where humans and robots share the same workspace and perform object manipulation tasks jointly. This will require research beyond the state-of-the-art in the areas of object handling and grasp modelling; programming by demonstration; human motion and activity tracking, social signal processing and incremental dialogue management.

An important aspect of the need for Swedish excellence in social robotics is that the special needs and user groups in Sweden will not likely be met by foreign commercial interests. Yet it is important that social robots for Swedish conditions are trained for the very same Swedish conditions and that they understand the Swedish language. Developing technology that meets local, or in our case Swedish, conditions is something that is of notoriously low priority on the agendas of international Fortune 500 players, as has been noted by government and funding agencies alike. Within the area of speech technology, the Swedish government took action in 2014 when it gave *The Swedish Post and Telecom Authority* (PTS) the to draw up the outlines and a pilot of an infrastructure for Swedish spoken language resources to be used for the development of Swedish speech technology, for example to increase accessibility. KTH takes part in this work, and several members of the writing group and participants to the agenda workshops have provided input. KTH has also handed in a document pointing to the need for spoken language resources as part of the Swedish Science Foundation's inventory of the need for research infrastructures for 2016, and takes part in the recently inaugurated *Swe-Clarin* which works towards better exploitation of speech and language resources in humanities and social sciences. The Swe-Clarin efforts are likely to generate better and more available spoken language resources as a side effect. Notwithstanding these efforts to improve the state of data availability in Sweden today, data acquisition presents a key challenge for a successful Swedish future in social robotics.



Strategic path ahead

We are at a cross-road. By an overwhelming consensus amongst leaders, researchers and observers, robots will inhibit every environment traditionally reserved for people very soon. But our actions in the near future will decide whether Sweden will lead the development to a significant and sustainable beneficial impact on society, or meet a new and confusing world passively in the wake of technology development taking place elsewhere. With our current position in the relevant technologies, Sweden is poised to take the lead, but the challenge is great and will succeed only through an orchestrated effort by players from many areas. The purpose of this agenda is to guide Swedish innovation away from the many bleak dystopias of unemployment and people in servitude to machines, towards a future cohabited by people and machines in symbiosis. If we achieve this vision, the benefits are everywhere: improved health through better use of robots in healthcare; cost savings through more efficient use of robots in labour intensive tasks; better profitability through shorter set-up times in the manufacturing industries; and exports of know-how and technology within social robotics are but a few examples, and we also note that allowing robots and machines to communicate and interact on human terms is a matter of democracy, as it transcends exclusion and affords access to new technologies to all people.

Goals

We approach the vision through a series of goals that address known obstacles and challenges directly, and that create an environment in which unforeseen obstacles and risks can be managed fruitfully. The overreaching goal is *to move sustainable and beneficial social robotics from visionary dream to actual deployable solution*. We break down this overreaching goal into tangible sub-goals, a series of requirements on an innovation environment where these goals can be achieved, and a number of key strategic elements that will pave the way.

The sub-goals target the next 10 years, after which time the technologies should be in place that allows machines to perform a number of communicative and collaborative functions on a level that is on par with a human, including the following:

- Learn to recognize and manipulate objects through observation and collaboration with people.
- Incrementally following the progress of physical collaborative efforts through communication on human terms, with language and gesture.
- Understanding, at human level, who addresses whom and how to address specific persons or robots in multi-person and multi-robot environments. This includes when the machine is not an active participant.
- Understanding and achieving common ground: e.g. whether a listener is following, accepting, and agreeing with a speaker, and being able to signal the same.
- Learn to understand what people are attempting to achieve, and how to offer and give assistance.
- Learn what people can do to help achieve goals, and how to request help.
- Understanding the meaning of conversations in which the machine is involved, including contextual inference and situational knowledge, such explicit and implicit references to both physical objects and to events taking place in the room.
- Understanding peoples' different knowledge and different goals, and being able to act accordingly.
- Requesting help from non-professionals, both humans in the neighbourhood and collaborators and peers.
- Understanding fear, pain and displeasure in people, and being able to determine their cause, at least on a superficial level (e.g. can the robot do something to alleviate).
- Communicate inability to perform requests, and the reasons for this.
- Refuse requests that conflict with current goals, and communicate the reasons for refusal.
- Communicate the reasons for a behaviour or a choice upon request.
- Communicate uncertainty, as well as being able to talk about unknown objects.

Requirements and guidelines

The primary developmental requirement is (1) *to create a beneficial innovation environment* that will *provide enough flexibility for rapid prototyping and for testing new ideas* and simultaneously *supports long-term development and reuse*. The border-crossing nature of social robotics complicates matter further. Not only does it require collaboration over research areas that are currently not often combined, but hardware and software development must also go hand in hand. Hence, the innovation environment must *support collaborations leading to technology merging and adaptation*.

For societal as well as for industrial reasons, we aim for the development of social robotics to create solutions to problems and to meet needs, as opposed to technology development for its own sake. This is reflected in the design and evaluation procedures: social robotics must (2) *target real situations*. We will design for *real needs,* in *real environments*, with *real people as the beneficiaries*. The core evaluation principle is interleaved with the design procedure: to *involve end-users early in the iterative process, preferably at the design stage*.

The introduction of social robots in new arenas raises high demands on dissemination and tutoring. It will transform our working practices, as we move from well-known technical solutions targeting specific organizational challenges to technologies that bring new ways to collaborate and manage. When social robots support humans in their work, working conditions will be dramatically changed and new practices will be introduced. Dissemination and tutoring must (3) *raise the awareness of social robotics so that it may be utilized to its full potential* while *avoiding its pitfalls and liabilities*.

Finally, social robotics has the potential to radically reform many areas. This relies on collaboration over borders, from access to big data to forums for discussions of applications and generalizations. Industry penetration should (4) *reach the relevant players in relevant areas* with discussions on e.g. *data sharing*, *methodology*, *applications and technology transfer*, and *common development schemes*, and (5) *strategies to identify and create new markets*.

Key strategic elements

Putting the following strategic elements in place will make it possible to fulfil the innovation agenda. The key requirements targeted by each element is noted within parentheses.

- The development at hand is complex with a large proportion of unknowns, and we seek to leverage partial progress efficiently by supporting an iterative process chain of alternating development and evaluation (1)
- Use iterative development practices, where rapid prototypes can be seen as an early stage, and long-term field studies are used to gauge progress over time (1, 2)
- Encourage agreements on common APIs and definitions of standards and to map existing standard between disciplines in the academic and industrial communities(1, 4)
  - An international example is ISO 13482 - a safety standard for personal care robots that involve physical interaction with humans[95].
- Sensible selection of user groups. If social robotics is to be used for example by elderly, these should be involved from start with ideas on design, usability, useworthiness[96] (2)
  - The selection of participants in evaluation is therefore doubly important for the meaningful evolution of components and services: to acquire valid evaluation results that guide future directions, and again to acquire valid data for (re)training
  - Support for the setting up of user and focus groups
  - Guidelines for meaningful selection of user groups, both from a functional and from an equal rights point of view. (Addresses *Demographics and equal rights* risk)
- In order to inform further iterations, testing and evaluation of social robotics must predominantly take place in living labs or real-world environments with real end users(2)
- Construction and maintenance of living labs that are flexible enough to evaluate a wide range of social robotic applications (2, 4)
- Collaboration around informational and tutoring efforts (3)
  - Reusable documentation and tutorials
  - Instruments that support expansion or generalization of existing instructional materials
- Infrastructure allowing the industrial and academic communities in Sweden to share data, tools and open source software (4)
  - This task goes beyond social robotics, and must be coordinated with other efforts to create infrastructures for relevant data
  - Data collection and annotation should be viewed as an iterative process in itself, such that the infrastructure supports refinement of already collected data
- Specific support for border-crossing innovation (4)
  - Funding instruments for small and medium-sized border-crossing proof-of-concept projects
  - Establishment of minimally one venue supporting meetings (workshops, lectures, debates, small group discussions) across borders
  - Establishment of periodical meetings with a social robotics focus: a recurring yearly meeting and support for ad hoc workshops
- Platform for project proposals, project management and funding (4, 5)
  - Provide a common forum for shared business intelligence
  - Combine national and international efforts
- Yearly challenges; selection of hot application areas (4, 5)
  - Themed projects – solve one application or provide the best application in an application area – with associated challenge and review

Appendix

Social robotics agenda work participants

*(speakers that presented marked with *)*

Samer al Moubayed, Disney robotics, Furhat robotics
Lars Andersson, Ericsson
Mikael Anneroth, Ericsson
José Araújo, Ericsson
Anders Askenfeldt, KTH TMH
*Kjell Asplund, Statens medicinsk-etiska råd (SMER)
Christian Balkenius, Lunds Universitet
*Wolmet Barendregt, Göteborgs universitet
Anne Berman, Karolinska Institutet
*Jonas Beskow, KTH TMH
*Sonja Buchegger, KTH TCS
*Ginevra Castellano, Uppsala Universitet
*Simon Dobnik, Göteborgs Universitet
Rickard Domeij, Språkrådet
*Jens Edlund, KTH TMH
Anders Ekholm, Institutet för Framtidsstudier
*Peje Emilsson,Silver Life, Kunskapsskolan
*Joakim Formo, Ericsson
Morgan Fredriksson, Liquid Media
*Susanne Frennert, Designvetenskaper Lunds universitet
Gintary Grigonyty, Stockholms universitet
*Jan Gulliksen, KTH MID
*Joakim Gustafson, KTH TMH
Ebba Gustavii, Artificial Solutions
*Adam Hagman, Robotdalen
Anders Hallquist, Brostaden
*Mikael Hedelind, ABB
Mattias Heldner, Stockholms Universtitet
Hillevi Helm, Fryshuset Gymnasium
David Hjelm, Artificial Solutions
Sara Hjulström, Svenskt demenscentrum
Arne Jönsson, Linköpings universitet
*Tove Kjellmark, Konstnär
Hedvig Kjellström, KTH CSC CVAP
*Danica Kragic, KTH CAS
Staffan Larsson, Göteborgs universitet
*Per Ljunggren, Intelligent Machines, Board Chairman CAS

*Amy Loutfi, Örebro universitet
*Robert Lowe, Högskolan i Skövde
Björn Lovén, SLL Innovation
Erik Lundqvist, Robotdalen
Tom Magnergård, KTH innovation
*Wictoria Majby, Hamnskolan
Jacek Malec, Lunds Universitet
Elena Márquez, Uppsala Universitet
Kristina Nilsson Björkenstam, Stockholms universitet
*Mohammad Obaid, Göteborgs Universitet
*Chris Peters, KTH HPCVIZ
Mario Romero, KTH HPCVIZ
Kristina Sinadinovic, Karolinska Institutet
*Gabriel Skantze, KTH TMH
*Christian Smith, KTH CVAP
Peter Stany, Robotdalen
Stefan Stern, Investor
Niklas Sundler, TeliaSonera
*Magdalena Tavfelin Heldner, Tekniska Museet
Madeleine Thun, EF Education First
Elin Topp, Lund Universitet
Christina Tånnander, Myndigheten för Tillgängliga Medier
Barbro Westerholm, Riksdagen, SMER
*Karl-Erik Westman, Myndigheten för Delaktighet
*Preben Wik, Furhat robotics
*Lotten Wiklund, Tekniska Museet
Mats Wirén, Stockholms universitet
Tom Ziemke, Högskolan i Skövde
*Petter Ögren, KTH CVAP
*Britt Östlund, KTH STH, Röda korsets högskola

Lists of related EU projects with Swedish partners

Table 1. Projects with Swedish partners related to robotics in frameworks FP6(green), FP7(blue) and H2020(pink).

ROSETTA - Robot control for skilled execution of tasks in natural interaction with humans; based on Autonomy, cumulative knowledge and learning	ABB, LU
AREUS - Automation and robotics for european sustainabile manufacturing	Chalmers
Giraffplus - Combing social interaction and long term monitoring for promoting independent living	Giraff tech.ÖrU, LU, Örebro LL
TERESA - Telepresence Reinforcement-learning Social Agent	Giraff technologies
EMOTE - EMbOdied-perceptive Tutors for Empathy-based learning	GU
ICEA - Integrating cognition emotion and autonomy	HiS
DREAM - Development of robot-enhanced therapy for children with autism spectrum disorders	HiS
NeuralDynamics - A neuro-dynamic framework for cognitive robotics	HiS
ROSSI - emergence of communication in robots through sensorimotor and social interaction	HiS
NEUROBOTICS - the fusion of neuroscience and robotics for augmenting human capabilities	KI, KTH
COGNIRON - the cognitive robot companion	KTH
COMMROB - advanced behaviour and high-level multimodal Communication with and among robots	KTH
COSY - cognitive systems for cognitive assistants	KTH
EURON - european Robotics Network	KTH
PACO-PLUS - perception action and cognition through learning of object-action complexes	KTH
ROBOSWARM - knowledge environment for interacting robot swarms	KTH
CogX cognitive systems that self-understand and self-extend	KTH
eSMCs extending sensorimotor contingencies to cognition	KTH
FLEXBOT - Flexible object manipulation based on statistical learning and topological representations	KTH
GRASP emergence of cognitive grasping through emulation introspection and surprise	KTH
IURO interactive urban robot	KTH
RECONFIG - Cognitive, Decentralized Coordination of Heterogeneous Multi-Robot Systems via Reconfigurable Task Planning	KTH
ROBOHOW.COG - Web-enabled and Experience-based Cognitive Robots that Learn Complex Everyday Manipulation Tasks	KTH
STRANDS - Spatio-Temporal Representations and Activities For Cognitive Control in Long-Term Scenarios	KTH
TOMSY topology based motion synthesis for dexterous manipulation	KTH
TRADR - Long-Term Human-Robot Teaming for Robot-Assisted Disaster Response	KTH
BabyRobot - child-robot communication and collaboration: edutainment behavioural modelling and cognitive development in typically developing and autistic spectrum children	KTH, FurHat Robotics
BUCOPHSYS - bottom-up hybrid control and planning synthesis with application to multi-robot multi-human coordination	KTH
CENTAURO - robust mobility and dexterous manipulation in disaster response by fullbody telepresence in a centaur-like robot	KTH,LiU
RobDREAM - optimising robot performance while dreaming	KTH
SARAFun - smart assembly robot with advanced functionalities	KTH, ABB,, LU
socSMCs - socialising sensori-motor contingencies	KTH
SYMBIO-TIC - symbiotic human-robot collaborative assembly	KTH, ABB, HiS, Volvo
MACS multi-sensory autonomous cognitive systems interacting with dynamic environments for perceiving and learning affordances	LiU
DIPLECS dynamic interactive perception-action learning in cognitive systems	LiU, Autoliv
R5-COP - Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems	LTU, Swedish space corp.
ACROBOTER autonomous collaborative robots to swing and work in everyday environment	LU
COMET - Plug-and-produce components and methods for adaptive control of industrial robots	LU
HOBBIT - The Mutual Care Robot	LU
Goal-Leaders goal-directed adaptive builder robots	LU
PRACE - The Productive Robot Apprentice	LU
SMErobotics - The European Robotics Initiative for Strengthening the Competitiveness of SMEs in Manufacturing by integrating aspects of cognitive systems	LU
WYSIWYD - What You Say Is What You Did	LU
THE - the hand embodied	LU, SICS
RADHAR - robotic adaptation to humans adapting to robots	Permobil AB
LIREC living with robots and interactive companions	SICS
Prometheus prediction and interpretation of human behaviour based on probabilistic structures and heterogeneous sensors	FOI
TACMAN - Tactile Manipulation	UmU
WEARHAP - WEARable HAPtics for Humans and Robots	UmU
Robot-Cub robotic open-architecture technology for cognition understanding and behaviors	UU
ECAGENTS - embodied and communicating agents	Victoria
SILVER - Supporting Independent LiVing for the Elderly through Robotics	Vinnova, Västerås kommun
DustBot - networked and cooperating robots for urban hygiene	ÖrU
GeRT - generalising robot manipulation task	ÖrU
HANDLE - Developmental pathway towards autonomy and dexterity in robot in-hand manipulation	ÖrU
MOnarCH - Multi-robot cognitive systems operating in hospitals	ÖrU
RobLog - Cognitive robot for automation of logistic processes	ÖrU
Robot-Era - Implementation and integration of advanced Robotic systems and intelligent Environments in real scenarios for the ageing population	ÖrU
RUBICON - robotics ubiquitous cognitive network	ÖrU
SPENCER - Social situation-aware perception and action for cognitive robots	ÖrU
SmokeBot - Mobile Robots with Novel Environmental Sensors for Inspection of Disaster Sites with Low Visibility	ÖrU

Table 2. Projects with Swedish partners related to interaction technologies (such as speech technology, assistive technologies, educational systems, and affective modelling), in frameworks FP6 (green), FP7 (blue) and H2020 (pink).

DECI - Digital Environment for Cognitive Inclusion	Chalmers, Västra götalands LL
ProCAMS - Promoting Creativeness in Augmented Media Services	Codemill
UNCAP - Ubiquitous iNteroperable Care for Ageing People	Combain mobile
VICON - Virtual User Concept for Supporting Inclusive Design of Consumer Products and User Interfaces	Doro
TALK - Talk and look, tools for ambient linguistic knowledge	GU
EMOTE - EMbOdied-perceptive Tutors for Empathy-based learning	GU
MIROR - Musical Interaction Relying On Reflexion	GU
SSPNet - Social Signal Processing Network	GU
FUGA - The fun of gaming: Measuring the human experience of media enjoyment	HGo
I2HOME - Intuitive interaction for everyone with home appliances based on industry standards	HI
ICEA - Integrating cognition, emotion and autonomy	HiS
DREAM - Development of Robot-Enhanced therapy for children with AutisM spectrum disorders	HiS
ROSSI - Emergence of communication in RObots through Sensorimotor and Social Interaction	HiS
EDUMOTION - Education on the Move – Mobile access to educational content	Idevio
ASC-Inclusion - Integrated Internet-Based Environment for Social Inclusion of Children with Autism Spectrum Conditions	KI
ACORNS - Acquisition of communication and recognition skills	KTH
ASPI - Audiovisual to Articulatory Speech Inversion	KTH
BRAINTUNING - Tuning the brain for music	KTH
CHIL - Computers In the Human Interaction Loop	KTH
COMMROB - Advanced behaviour and high-level multimodal Communication with and among robots	KTH
COSY - Cognitive systems for cognitive assistants	KTH
HaH - Hearing at Home	KTH
HUMAINE - Human-machine interaction network on emotion	KTH
INSCAPE - Interactive Storytelling for Creative People	KTH
MonAMI - Mainstreaming on ambient intelligence	KTH, HI
MOBVIS - Vision Technologies and Intelligent Maps for Mobile Attentive Interfaces in Urban Scenarios	KTH
PACO-PLUS - perception action and cognition through learning of object-action complexes	KTH
S2S^2 - Sound to sense, sense to sound	KTH
Eunison - Extensive UNIfied-domain SimulatiON of the human voice	KTH
GET HOME SAFE - Extended Multimodal Search and Communication Systems for Safe In-Car Application	KTH
IURO - Interactive Urban Robot	KTH
LISTA - The Listening Talker	KTH
ProsocialLearn - Gamification of Prosocial Learning for Increased Youth Inclusion and Academic Achievement	KTH, Redikod
SAME - Sound And Music for Everyone Everyday Everywhere Every way	KTH
SkAT -VG - Sketching Audio Technologies using Vocalizations and Gestures	KTH
SpaceBook - Spatial & Personal Adaptive Communication Environment	KTH, UmU, Liquid media
SpeDial - Spoken Dialogue Analytics	KTH
DANCE - Dancing in the Dark	KTH
BabyRobot - Child-robot communication and collaboration: edutainment behavioural modelling and cognitive development in typically developing and autistic spectrum children	KTH, FurHat robotics
MICOLE - Multimodal collaboration environment for inclusion of visually impaired children	KTH, LU, Reachin tech
COSPAL - Cognitive systems using perception-action learning	LiU
HEARCOM - Hearing in the communication society	LiU
DIPLECS - Dynamic interactive perception-action learning in cognitive systems	LiU
IN LIFE - Independent living support functions for the elderly	LiU, Västra götalands LL
MIND RACES - from reactive to anticipatory cognitive embodied systems	LU
ABBI - Audio Bracelet for Blind Interaction: a new technology based on sensory-motor rehabilitation for visually impaired children	LU
WYSIWYD - What You Say Is What You Did	LU
HaptiMap - Haptic, Audio and Visual Interfaces for Maps and Location-Based Services	LU, Lunds kommun
CHORUS - Coordinated approacH to the EurOpean effoRt on aUdiovisual Search engines	SICS
IPERG - Integrated project on pervasive gaming	SICS, Hgo, Interaktiva institutet
LIREC - LIving with Robots and intEractive Companions	SICS
ALFRED - Personal Interactive Assistant for Independent Living and Active Ageing	Talkamatic
SAM - Dynamic Social and Media Content Syndication for 2nd Screen	Talkamatic
SIMPLI-CITY - The Road User Information System of the Future	Talkamatic
COMPANIONS - persistent multi-modal interfaces to the Internet	Telia, SICS
FANCI - Face and body Analysis Natural Computer Interaction	Tobii
Robot-Cub robotic open-architecture technology for cognition understanding and behaviors	UU
ECAGENTS - Embodied and communicating agents	Viktoria
HUMABIO - Human monitoring and authentication using biodynamic indicators and behavioural analysis	Volvo

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