
# Technology Foresight
# - on Cognition and Robotics

Ministry of Science
Technology and Innovation

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# Technology Foresight
## on Cognition and Robotics

Danish Ministry of Science, Technology and Innovation
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# Executive summary

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Recent years have seen major investments, at international level, in the development of increasingly advanced robots. These robots can perform more and more advanced tasks and functions, either independently or in interaction with humans.

Robots are often called intelligent, but compared to humans and animals, technological intelligence still leaves a lot to be desired. Even the most advanced robots today are a far cry from the level of humans and animals, and some would even claim that robots are not yet intelligent and even not intelligent at all in human terms.

This is the background for the present foresight study, which takes an in-depth look at the topics of cognition and robotics. *Cognition* stems from the Latin *cognoscere*, which means to know, to recognise, to understand. This study takes a close look at the perspectives, possibilities and consequences of the development and utilisation of cognitively advanced robots.

Cognitive robots can interpret information from their surroundings and act based on sensory impressions. For instance, they can react to irregularities or avoid obstacles and find a path to a given target in open terrain.

This study concludes that research and innovation in this area will make it possible in future to develop robots with more and more advanced cognitive capabilities and that there is great potential in such robots for alleviating critical problems and promoting innovation in areas of importance to society.

This study identifies five areas where the utilisation of cognitive robotics would be particularly promising for Denmark, namely:

> *Industry* – including flexible robots and production systems for various types of automation in the manufacturing and food industries, for instance material finishing, pallet picking, welding, painting, cutting and item handling.

> *Agriculture* – including robots for both plant production and animal production in conventional and organic agriculture, horticulture, nurseries, tree plantations, crops for energy production, farming of plants for medicinal purposes, etc.

> *Experiences, play and learning* – which covers activities of a playful and entertainment nature for both children and adults, including cognitive robots in relation to lifestyle, quality of life, leisure time, the home, entertainment, culture, experiences and education.

> *Service and care* – including care for the elderly, personal care, assistance for people with physical disabilities, services in the home, security in the home, cleaning, etc.

> *Hospitals and health* – including diagnostics, surgery, rehabilitation, laboratory analyses, patient care and in-house transport at hospitals.

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It is the conclusion of this foresight study that robots with more advanced cognitive capabilities would be able to contribute within these areas to objectives that are important to society, such as:

- Keeping industrial and food production in Denmark through increased efficiency and competitiveness
- Environmental improvements in agriculture through new weed control methods that reduce the use of pesticides
- New growth industries in the area of experience-oriented products and services
- Better physical working environment, in which dangerous tasks are performed by robots
- Increasing the self-sufficiency of people with physical disabilities

Users and experts with insight into the different areas and who have been involved in this foresight study agree that cognitive robotics would make promising innovation possible within these areas. Furthermore, at an interdisciplinary level there is great interest in Denmark choosing to invest in exploiting this potential.

However, the wishes and needs of the users of the cognitive robots of the future indicate that there are significant research-related and developmental challenges which will require us to work across the different disciplines and professional environments. This foresight study, therefore, identifies a number of specific research and innovation initiatives in the overlapping area between cognition and robotics that industry, users and researchers can work together on in the short, medium and long terms.

It is the recommendation of this report that the perspective for such an interdisciplinary effort should be a balanced interaction between user-driven and research-driven innovation. Instead of the highly ambitious “man-on-the-moon” focus we see in many international robot technology initiatives, a Danish initiative should rather focus on the problems users experience in the practical use of robots and on the needs of research to be able to regularly define its research agendas and redefine its critical problems in this light.

From this perspective, this report specifically recommends:

- *Improving opportunities for free interdisciplinary research*
  The foresight study recommends that the Board of the Danish Councils for Independent Research and the scientific research councils improve the possibilities for interdisciplinary research-initiated projects to obtain funding.

- *Strengthening interdisciplinary strategic research*
  The foresight study recommends that future ICT-related strategic research programmes be opened so that interdisciplinary projects on cognition and robotics can achieve support. Further, the study recommends that the Danish Council for Strategic Research incorporates cognitive robotics in the Council’s Innovation Accelerating Research Platforms.

> *Incorporating cognitive robotics as an element in the Danish High Technology Foundation's strategy in the field of ICT*
The foresight study recommends that the Danish High Technology Foundation includes cognitive robotics as an element in its ICT strategy.

> *Improving opportunities for networking and innovation*
The foresight study recommends that the Danish Council for Technology and Innovation considers how it can help promote networking and innovation within development and utilisation of cognitive robotics.

> *Exploiting funding options, forming networks and formulating specific interdisciplinary research projects*
The foresight study recommends that organisations within the five application areas consider how they can help form networks among users, researchers and manufacturers of robot technology solutions and that companies and researchers work together to exploit existing funding opportunities.

> *Debating possibilities within cognitive robotics and considering educational initiatives*
The foresight study recommends that the Danish Board of Technology carries out a project on the ethical and societal aspects of cognitive robotics and that the managing bodies of universities and departments, along with researchers and staff-student study committees, mutually discuss the needs and possibilities in terms of research and educational initiatives within and across cognitive and robotics research.

> *Establishing a separate research and development programme in the longer term*
The foresight study recommends that funding be earmarked, in extension of the Danish Government's Globalisation Strategy, for a separate research and development programme in robot technology and cognition.

# 1. Introduction

## Why cognition and robotics

In recent years, significant amounts in dollars, euro and yen have been invested, both nationally and internationally, in the development of increasingly advanced robots that can, independently or in interaction with humans, perform increasingly complex tasks and functions. Literature contains many fascinating stories about robots, and robots are often found on the front pages of newspapers and on television. Most recently in Denmark, we have seen HM Queen Margrethe greet and speak to Honda's robot Asimo during a visit to Japan.

However, intelligent robots are not just entertainment to captivate, or perhaps frighten, us. Robot technology has an extremely wide range of applications, and users are formulating promising perspectives for innovation. For instance, intelligent technological toys, advanced welding robots, robots for tending to animals in the agricultural sector, robots for complicated surgery at hospitals, robots that can navigate and collect samples on Mars or robots that can understand and respond to human speech.

There is probably no doubt that increasingly advanced robots and intelligent products will be developed in the future. But technical intelligence still leaves a lot to be desired. To date, we have only been able to produce robots that are programmed to perform repetitive tasks with a series of specific movements and functions. We have a way to go yet, before the fast agendas in the media and science fiction about intelligent, humanoid robots become reality. Even the most advanced robots are far from the level of humans and animals. In fact, some might claim that they are not even intelligent yet – and not intelligent at all in human terms.

Advanced robots are not only a question of technology and intelligence. Increased utilisation of robot technology can also lead to a need for debate on the ethical and societal aspects resulting from the way robot technology will affect our daily lives – both at home and at work.

There is, therefore, a need to take a step back from the fast agendas to examine the perspectives, possibilities and consequences of development and utilisation of advanced robotics. We need to dig deeper if we want to prepare the foundation for prioritising our resources and efforts today so that we can begin progressing towards the future we want.

This is the background for the present foresight study, which takes an in-depth look at the topics of cognition and robotics. *Cognition* stems from the Latin *cognoscere*, which means to know, to recognise, to understand.

## What is a technological foresight study?

A technological foresight study is a systematic attempt to look into the future through dialogues on and analyses of developmental prospects in terms of science, technology, economy and society. A foresight study is not about predicting the future, but about considering, debating and proposing in a structured manner how the future might look. The overriding reasons for conducting a foresight study are:

- To debate possible future scenarios
- To build insight into and readiness for the next decade of technology development
- To contribute with knowledge on initiatives that can strengthen welfare, sustainability and competitiveness
- To strengthen the knowledge base for future research, technology and innovation initiatives
- To stimulate dialogue and the creation of networks between the players in the national innovation system

## The foresight study on cognition and robotics

This report on cognition and robotics is the result of a comprehensive foresight process. Based on user surveys, five development agendas are presented for potential and highly promising innovative development in five areas that build on the utilisation of robots with cognitive capabilities. Furthermore, a number of proposals are presented for interdisciplinary research themes and innovation initiatives that can help promote the realisation of the five development agendas.

This report has been more than a year in the making. The process has been conducted as a broad dialogue between users and makers of robot technology solutions as well as researchers and experts in cognitive and robotics research. The goal has been to formulate a robust and broadly accepted foundation that can be used to identify promising opportunities for innovation associated with the development of robot technology. The dialogue has included, among other things, player surveys, expert reports, interviews, focus group meetings, workshops and company visits. In all, approximately 100 people participated in the process in one way or another. All of the activities carried out during the foresight study are included on the enclosed CD-ROM as appendices to this report.

The five development agendas presented in this report are not tried and tested recipes for the future within the five areas. They are solely an expression of a possible course of development that it might be worthwhile to realise. The development agendas should be seen as five visions that can form a basis for planning future interdisciplinary research themes and innovation initiatives.

The timeframe for the foresight study has been ten years, with a focus on promising application and business-related potentials as well as user-driven innovation.

To oversee the management of the foresight study, the Danish Ministry for Science, Technology and Innovation appointed a steering committee comprising researchers and representatives from the business community with various competencies and professional approaches. This steering committee is responsible for synthesising the foresight process into what is presented in this report. It is the opinion of the steering committee that the synthesis has successfully united the many different points of view and attitudes that have been expressed during the process to form a constructive and future-oriented development agenda that meets the viewpoints and interests of the users, the business community and researchers in the short and longer terms. The steering committee recognises that other perspectives and conclusions than those presented here could also have be drawn as important results of the foresight process.

The Steering Committee comprised:

- Annelise Mark Pejtersen, research council professor, Systems Analysis Department, Risø National Laboratory (chair)
- Christian Clausen, associate professor, Department of Manufacturing Engineering and Management, Technical University of Denmark
- Gert Fredericia, sales director, Philips Medico A/S
- Erik Granum, professor, Computer Vision & Media Technology Laboratory, Aalborg University
- Lisbeth Harms, associate professor, Center for Visual Cognition, University of Copenhagen
- Henrik Jacobsen, head of robot activities, ABB A/S
- Henrik Hautop Lund, professor, Maersk Mc-Kinney Moller Institute for Production Technology, University of Southern Denmark
- Theresa Schilhab, associate professor and head of research, Learning Lab Denmark, Danish University of Education

A project group from the Risø National Laboratory and the University of Southern Denmark has acted as secretariat as well as consultant in matters of methodology for the steering committee. The project group comprised:

- Per Dannemand Andersen, head of programme, Systems Analysis Department, Risø National Laboratory, (head of project)
- Birgitte Rasmussen, senior researcher, Systems Analysis Department, Risø National Laboratory
- Henrik Gordon Petersen, professor, Maersk Mc-Kinney Moller Institute for Production Technology, University of Southern Denmark
- Hans H. K. Andersen, senior researcher, Risø National Laboratory, and Klaus Bærentsen, associate professor, Department of Psychology, University of Aarhus, have provided the project group with expert assistance in the field of cognitive science.

The target group for the foresight study is the Danish Ministry of Science, Technology and Innovation, relevant advisory and grant-awarding bodies within research and innovation, relevant knowledge institutions and universities as well as companies on both the development and user sides of the technologies that are the focus of this study.

## How the foresight study was conducted

The overall design of the foresight study is presented in the following figure. The key elements are:

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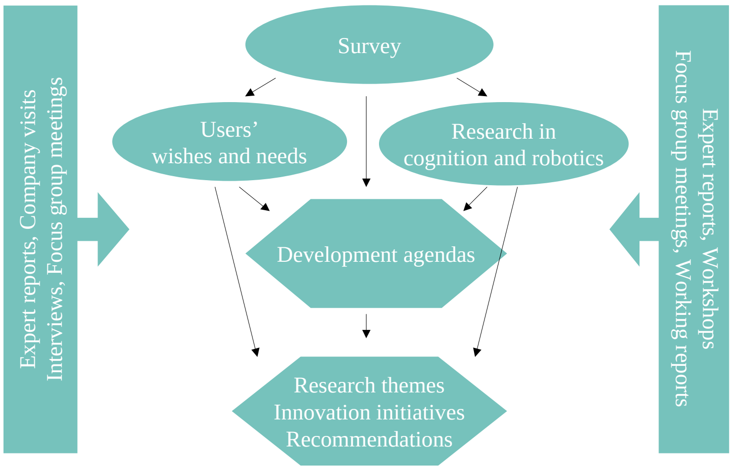
> Through dialogue with users and experts, a broad survey was conducted of the prospects for innovation that robots with cognitive capabilities can help create.

> On the basis of this survey and dialogue, five application areas were selected where the use of robots with cognitive capabilities appears, from a business and societal point of view, particularly promising. For each area, a development agenda has been formulated.

> In extension of this, players with insight into the selected application areas were asked to formulate which user wishes and needs for robots and their cognitive capabilities would be crucial to realising the prospects of innovation within the different areas.

> Finally, based on these wishes and needs, a selection of proposals was formulated for interdisciplinary research themes and innovation initiatives, which would need to be initiated in order to promote the development and utilisation of robots with cognitive capabilities.

**Project design – technological foresight study on cognition and robotics**




Throughout the entire foresight process, two central questions have been in focus:

1. Is it possible to formulate research themes across cognitive and robotics research that are truly interdisciplinary, problem-oriented and balanced?
2. Would such an interdisciplinary research initiative produce a positive contribution to the development of robots with more advanced cognitive capabilities in the short, medium and long terms?

The answer to these questions is yes.

# 2. Robots, cognition and user research

## What is a robot?

The word *robot* stems from the Czech word *robota*, which means enslaved labourer or feudal serf. A robot is a programmable machine that can autonomously perform a variety of tasks through interaction with its surroundings. A fully autonomous robot can regulate its own behaviour and is a functional, self-sustaining system.

A distinction is often made between industrial robots and service robots. In addition, there are robots that are embedded in conventional products.

> An *industrial robot* is an automatically controlled, re-programmable, broadly applicable manipulator that is either fixed in one place or mobile and can be used for industrial automation solutions.

> A *service robot* is a robot that can perform services that benefit humans and equipment. A distinction is often made between service robots for private use and professional use.

> There are no similar definitions for *embedded robots*. But a wide variety of traditional products are expected to be equipped with robot technology in the future. On the basis of the above definitions of robots, embedded robots fall outside the scope of this foresight study.

**Types of robots and examples of application areas**

| **Industrial robots** | **Professional service robots** | **Private service robots** | ***Embedded robots*** |
|---|---|---|---|
| Handling and processing<br>Welding<br>Assemblage<br>Surface finishing (paint robots)<br>Pallet picking<br>Micro robots | Weeding robots<br>Professional cleaning<br>Inspection systems<br>Construction and demolition robots<br>Logistics systems<br>Robots for the health sector<br>Defence and security<br>Underwater systems<br>Mobile platforms<br>Laboratory robots<br>Public relations robots<br>Humanoid robots | Cleaning<br>Play and learning<br>Assistance for the physically disabled<br>Personal transport<br>Private security and surveillance<br>Lawn mowing | *Refrigerators*<br>*Coffeemakers*<br>*Stereo systems*<br>*Furniture*<br>*Kitchen elements*<br>*Walls*<br>*Pacemakers*<br><br>*(fall outside the scope of this foresight study)* |

Robot technology is based on many different technologies. And each of these is built on a number of technical and scientific disciplines. The core of robot technology is, thus, integration of many different technologies, areas of knowledge and disciplines. For instance:

> Control theory, which is geared towards the development of technologies for advanced low-level steering of robots in relation to input from a series of sensors.

> Calculation-based classical mechanics, which are geared towards regulation based on dynamic models for robots. Such models are necessary if modular robots are to be able to compete with conventional robots in terms of speed, strength and precision.

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- Mechanical and topological optimisation, which is geared towards optimal design of the physical form of robots in terms of strength and range.
- Movement planning, which is geared towards calculating collision-free paths for robots, but which is also applicable in e.g. computer games and reaction kinetics in chemistry.
- Computer vision, which in this context is the development of effective methods to detect the shape of and activities in the surroundings based on sensor input from e.g. a camera, a laser scanner or an ultrasound scanner. In this context, the field is geared towards the development of artificial robot sight.
- Multi-agent systems, which are geared towards distributed high-level steering of robots.
- Cognition, which is geared towards the interaction of robots with their surroundings (including with humans) that also includes the ability to interpret e.g. surroundings and error situations.
- In addition, robotics research also draws on breakthroughs in other areas, such as effects technology, battery technology, reconfigurable electronics, sensory technology and materials technology.

### What is cognition?

In the same way that robot technology integrates many disciplines, there are many different approaches to cognition and intelligence. The precise definition of cognition depends on the approach in question. There are researchers who focus on cognition in a machine-related context. Others conduct research in cognition based on a biological or human perspective, while still others focus on cognition as the result of something human, social and material.

In this foresight study, cognition research is the broad collection of research inspired by health-science as well as biology, sociology and psychology that focuses on understanding the processes, circumstances and conditions that underlie the ability of humans and animals to recognise both material and virtual objects.

This broad approach to cognitive research makes it possible to involve many different scientific disciplines in the development of robots with more advanced cognitive capabilities. For instance:

- Cognition psychology, which is oriented towards human cognition including all mental processes and structures that are involved in human information processing.
- Research in neural network models and artificial intelligence (AI).
- Research in biological cognition, which examines the collection of processes that enable an organism to act appropriately, including in interaction between an organism’s body, its surroundings and previous history.
- Cognitive neuroscience, which is oriented towards the cognitive and neural processes and correlations between simple cognitive tasks and the brain activity that accompanies the task.
- Cognitive system theory, which views cognitive decision processes and actions as context-dependent and expressions of humans’ adaptive and targeting behaviour in dynamic surroundings.

The broad approach to cognition research of this foresight study also means that research that is not normally considered part of cognitive research can be involved in the development and, especially, utilisation of robots with more advanced cognitive capabilities. For instance:

- Socio-technological research that deals with the design of complex socio-technological systems, including planning interactions between many different players with different knowledge bases and perspectives.
- Work and organisational analysis, including design and evaluation of human-robot interaction and user interfaces.

These approaches all share the view that cognition is a product of socio-technological and socio-material processes – that is, as an outcome of the interaction between humans and machines. In the foresight study, the term was used as a catchall to include all user research relating to these approaches.

# 3. Why invest in robots with cognitive capabilities

Robots with cognitive capabilities enable the machine to operate and behave in different ways depending on the surroundings within which it finds itself. The robot understands and can interpret the meaning of information from its surroundings, and it can act under the control of rules or sensory perceptions. Cognitive robots will be capable of sensing and learning motor skills. Examples of robots with cognitive capabilities are:

- Mobile robots, which are capable of avoiding obstacles and finding paths to a given target.
- Robots that can understand, speak and respond on the basis of a programmed lexicon or linguistic rules.
- Robots with the ability to monitor production systems and to react to irregularities.

Robots have many applications, and with more and more advanced cognitive capabilities they will, in future, be able to promote important innovation within a wide range of areas of importance to society. For instance, cognitive robots will be able to contribute to:

- Increased efficiency and competitiveness in industry
- Keeping industrial and food production in Denmark
- New types of experience-oriented products and services
- New weed control methods that greatly reduce the use of pesticides
- Improving physical working environments – tasks that can have a negative effect on people’s health can be performed by robots
- Increasing the self-sufficiency of people with physical disabilities

Developing robot technology is not only a technical and economic issue. Utilising robot technology can have a number of other consequences which also need to be clarified. Ethical and societal issues will develop out of the broad application of robots, and these issues need to be discussed, analysed and taken into account in the decision-making process on an equal basis with the technical and economic aspects. Examples of ethical and societal aspects related to the utilisation of robots are:

- Certain types of jobs and workplaces will disappear
- The technology will place new demands on the user, which not everyone will be able to live up to
- Surveillance systems can be considered “Big Brother”-like
- Less patient contact, if care functions in the health sector are taken over by robots
- Robots can make people more independent, but with an increased risk of social isolation
- Animal welfare in technology-based livestock production

Robot technology, like any other technological advancement, will be affected by a variety of megatrends that will, in their own ways, help pressure for the development of new solutions and new ways of doing things. The steering committee has identified the following megatrends, which are expected to influence the future development and utilisation of robot technology in Denmark:

- *Globalisation:* Globalisation can be defined as growth in economic and societal activities that traverses national and regional borders. Globalisation presents major challenges and opportunities for the future labour market in the form of, among other things, stronger competition for products or the ability to educate and attract qualified manpower.

> *The ageing society:* The ageing population presents a challenge for all OECD countries in coming years. Ageing in societal terms means more elderly, in both relevant and absolute terms. Whereas in Denmark today there are 3.6 people in the working-age range of 20 to 64 to finance provision for each person under 20 or over 65 years of age, in the year 2030, there will be only 2.5 people. This change in the composition of the population means greater demands in several areas, including health, care, housing and experiences as well as reduced availability of manpower to meet these demands.

> *Knowledge society:* The knowledge or information society is characterised by a dominance of information or knowledge functions. In politics, business and public institutions, knowledge and information, as well as access to them, have become a factor of power and a competitive parameter. Knowledge has become a key word, but knowledge is not a simple, quantifiable thing. Knowledge production and information technology have required significant changes in company locations, organisation, divisions of labour, etc.

> *Strained resources:* Population increases and economic growth are expected to result in increases in global energy consumption. This is especially the case in the new industrial nations (primarily in Asia and South America), but also in less developed countries (e.g. in Africa). The share of the global energy consumption for these countries is expected to increase from approximately 35 per cent in 1990 to 60 per cent in 2050. At the European level, the total energy demand is expected to have increased by 35 per cent on today's level by the year 2030. According to the OECD, population increases, economic growth and globalisation in future will also place significant pressure on the environment unless strong regulatory initiatives are implemented.

> *Health and security:* Increasing prosperity in the wealthy parts of the world will increase demand in areas such as health and well-being. This will make way for new products and new types of consumption. For instance, the increasing average age will mean increased demands for treatment; an older population will be more susceptible to infectious diseases; there will be a market for devices for self-diagnosis of illness and state of health. Security, in its many different forms, will also be of great importance. This includes military and terrorist threats as well as security for the individual in the form of e.g. surveillance and alarm systems.

> *Experience economy:* Also as a result of increasing prosperity in the wealthy part of the world, there is increasing demand for entertainment and experiences. Demand is so great that some say we are developing an experience economy. The experience economy can be described in general terms as a "cross field" where culture and creative powers meet the business community and commercial interests. The production of experiences opens up for new possibilities for an entire food chain of suppliers of e.g. electronics, design, materials, robots, etc. There is a growing need to balance the increasing technologisation – high-tech – with more human – high-touch – aspects, such as art and spirituality. Companies should no longer only aspire to high-tech, they should also incorporate high-touch dimensions into their products and services.

## Danish activities in the area

A good deal of robot technology will probably be driven for the most part by major international companies. But in Denmark, we also have companies and research environments with activities and interests in the areas of cognition and robotics, cf. the following tables.

**Examples of Danish companies with activities or interests in cognition and robot technology**

- ABB A/S
- AMROSE Robotics
- Bila A/S
- Budweg Caliper A/S
- Devitech ApS
- Giben Scandinavia A/S
- Grundfos A/S
- Ideal Engineering A/S
- Image House A/S
- Inropa ApS
- Kjærgaard A/S
- LEGO System A/S
- Microbotics A/S
- Migatronic Automation A/S
- NMP A/S
- Odense Production Information – OPI A/S PJD A/S
- ProInvent A/S Technology Development
- RoboTool A/S
- SCAPE A/S
- SIMCON A/S
- T&O Stelectric Development A/S
- TriVision
- Unisensor A/S
- Vestas Blades A/S
- Videometer A/S
- Aalborg Industries A/S

*This list is not exhaustive. More in-depth descriptions of the activities of the individual companies are available on the enclosed CD-ROM.*

In terms of research, Denmark has environments in cognitive research, robotics research and user research, with all three areas appearing to have equally strong representation in the Danish research community. In terms of applications, geography and volume, these research environments are spread out relatively thinly, and many of the environments are relatively small. The geographic spread of the environments is even, in that almost every major Danish university is represented with between two and four different institutions or centres each.

What characterises Danish research institutions is that most conduct major application-oriented research. Many of the research institutions have cooperative partners in industry and work with other universities and other public and semi-public-sector knowledge institutions, e.g. hospitals, Authorised Technological Service Institutes (GTS institutes) or sector-oriented knowledge centres. There are varying degrees of application orientation within the different disciplines. Collaboration with industry is most highly developed within the technical and natural science research environments.

The following table shows examples of Danish knowledge and education environments in the area. Because the timeframe for the foresight study is ten years, only environments that are assessed as relevant within this perspective are included. The steering committee is aware that research on the human brain will, in time, also contribute strongly to developing cognitive artificial systems and to the interaction between humans and these systems, and that there is significant international interest in this research potential.

**Examples of Danish knowledge and educational environments with major or minor activities in the field – robotics research, cognitive research and user research**

**Robotics research**

- Aalborg University (Dept of Production; Center for Sensory Motor Interaction; Dept of Control Engineering; Inst. of Media Technology and Engineering Science)
- Technical University of Denmark (MEK, Ørsted)
- University of Southern Denmark (Maersk Mc-Kinney Moller Inst.)
- Danish Meat Research Institute
- Danish Technological Institute
- Danish Inst. of Agricultural Science
- Force Technology
- College of Engineering
- IT University of Copenhagen

*This list is not exhaustive*

**Cognitive research**

- University of Aarhus (Dept of Psychology; CFIN; Namicona; Inst. of Information and Media Studies)
- Aalborg University (Cognitive Psychology Unit; Center for Sensory Motor Interaction; Dept of Computer Science and Dept of Mathematical Science)
- University of Copenhagen (Center for Visual Cognition; Dept of Media, Cognition and Communication; Center for Language Technology)
- Danish University of Education (Learning Lab)
- University of Southern Denmark (NISLab)
- Technical University of Denmark (IMM, Ørsted)

**User research**

- University of Aarhus (Dept of Psychology; Inst. of Information and Media Studies; CFIN)
- Copenhagen Business School (Dept of Management, Politics and Philosophy; Dept of Informatics)
- Technical University of Denmark (MEK, IPL, CICT, BYG-DTU, Ørsted)
- Risø National Laboratory (Systems Analysis Dept.)
- Roskilde University (Dept of Communication, Journalism and Computer Science; Dept of Environment, Technology and Social Studies)
- University of Southern Denmark (MCI)
- Aalborg University (Dept of Architecture and Design; Dept of Communication and Psychology)
- IT University of Copenhagen

In addition to the potential of cognitive robots for underpinning important innovation, megatrends that push for new solutions and the fact that we have companies and research environments in the area, there is one more reason for investing in robotics-based innovation in a Danish context, namely that a dynamic development of robots with cognitive capabilities requires cooperation across organisational boundaries, something for which Denmark has a long tradition.

In Denmark we focus strongly on the interaction between institutions and companies with a view to knowledge-sharing and business opportunities, and we are good at collaborating. We are a small country with a flat social structure, short chains of command and great flexibility, and we are internationally recognised for user-driven technological design and development. Thus, we have excellent prerequisites, both with regard to implementation of robot technology and development of new concepts and technologies, for mobilising the kind of interdisciplinary collaboration necessary. In this context, it should be noted that several networks exist in the area including, among others, Dansk Automationsselskab (Danish automation association), Dansk Robot Forening (Danish robot association) and RoboCluster.

# 4. Five development agendas

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Robots with more advanced cognitive capabilities will make innovation possible within a wide variety of areas. The foresight study has identified – based on expert reports, focus group meetings, workshops, interviews and company visits – ten areas where cognitive robots can promote innovations that are especially relevant in a Danish context. Please see the table below.

| Application area | Key words characterising application area |
|---|---|
| Personal service and care | Care of the elderly, personal care, assistance for the physically disabled, telepresence, security in the home, cleaning, security and surveillance, home service (vacuum cleaners, lawn mowers) |
| Hospitals and health | Robotic surgery, training robots for physical therapy, cognitive therapy in centres for dementia, routine tasks in laboratories, logistics tasks, production and service areas |
| Handling of hazardous substances and handling in difficult/dangerous locations | Demolition of buildings and structures, handling of hazardous substances/materials, field robots, environmental technology, handling of refuse, micro-handling, micro-robots, handling in unstructured, dynamic and undetermined surroundings |
| Offshore and underwater systems | Repair of pipelines and offshore structures, monitoring of submerged installations, identification and handling of sea mines |
| Industrial automation | Industrial automation (including pallet picking, packing, sorting, grinding, welding), food/processing industry, robotics for meat processing, quality control, biotechnology, biological process control, linking information and robot technology, laboratory robots, logistics systems |
| Play, entertainment, learning | Intelligent toys, robots for confidence-building and therapeutic purposes, learning environments with new possibilities, physically interactive computer games |
| Building, installation and construction | Architecture, intelligent buildings, building and construction, engineering |
| Agriculture, forestry and horticulture | Weeding robots, robot-controlled tractors, cleaning of pigsties, milking robots, optimisation of field operations, storage of knowledge about animal welfare in robots |
| Military, defence, contingency | Disarming mines/ammunition, robots in military operations, security check of people at airports |
| Transport | Transport industry, AGVs (autonomous guided vehicles) |
| Miscellaneous | Traceability in general (automatic screening and automatic scanning), combined robots and microanalyses (mass analyses), robot technology for programming, mobile platforms for general applications, algorithms for new robotics systems, development of sensory motor technologies, robot interaction modules based on natural language technologies, embedding robot technology into standard products |

The steering committee considers five of these application areas to be particularly promising for Denmark. These are (not necessarily in order of priority):

> *Industrial automation*: including, among other things, flexible robots and production systems for various types of automation in connection with the manufacturing and food industries, e.g. material finishing, pallet picking, welding, painting, cutting and item handling.

> *Agriculture – both plant production and animal production*: including conventional and organic farming, horticulture, nurseries, tree plantations, crops for energy production, farming of plants for medicinal purposes, etc. Forestry is of less interest in a Danish context.

> *Experiences, play and learning*: including activities of a playful and entertainment nature for both children and adults. Application areas in relation to lifestyle, quality of life, leisure time, the home, entertainment, culture, experiences and education.

> *Service and care*: including care for the elderly, personal care, assistance for people with physical disabilities, services in the home, security in the home, cleaning, etc.

> *Hospitals and health*: including, among other areas, diagnostics, surgery, rehabilitation, laboratory analyses, patient handling and in-house transport within hospitals.

The five areas were selected based on the following four criteria:

> *Megatrends:* understood as general, international trends for social development that will influence promising application and business-related potentials, e.g. the importance of globalisation.

> *General importance of area to society*: that is, areas where the use of robots with cognitive capabilities can alleviate critical, general societal problems or challenges, e.g. environmental issues in the agricultural sector.

> *User needs in the area*: i.e. application areas where robots with more advanced cognitive capabilities can lead to improved problem solving and conditions of applications for users, e.g. increased self-sufficiency for people with physical disabilities.

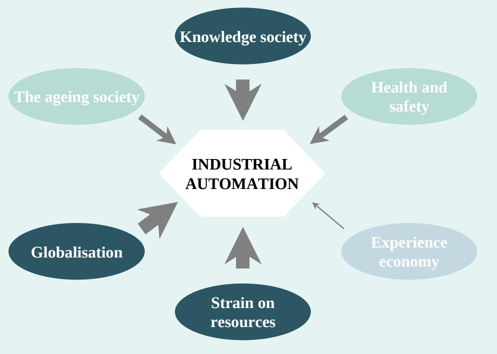
> *Research and business opportunities*: in terms of the competitiveness of Danish companies, there are three underlying criteria – new products, new markets, new production systems. Focus is especially aimed at areas where Danish companies can, through user-driven innovation, utilise existing technology, Danish companies' already existing lucrative niches as well as first-mover or fast-follower advantages in the global market.

In the following, a brief development agenda is described for each of the selected application areas which should be seen as a kind of vision – or a portrait – of the prospects for innovation that advanced cognitive robotics will present.

## Cognitive robots in Danish industry

The manufacturing industry plays a significant labour-market, financial and strategic role for Denmark and Europe. Globalisation, however, is putting massive pressure on the traditional manufacturing industry. Thus, there is a huge social challenge inherent in developing and promoting new innovative solutions so that large parts of the manufacturing industry continue to remain in our part of the world.

The manufacturing industry in Denmark is often characterised by rapid product renewal, production processes with large variations and small series, which place demands on flexible production lines with short change-over times. In addition, small and medium-sized Danish enterprises, in particular, solve relatively uncomplicated problems, so there is no need for highly advanced cognitive robots, but rather for robots that are flexible and that can quickly be recalibrated for other production series.




*Significance of megatrends for industrial automation*

The robotics industry points out that Denmark has business strengths in sectors that produce low-tech products with high-tech production systems. These include such areas as furniture, toys, toilet seats, disposable medical-technology products and plastic, wood and metal products. Also included here are the agricultural and food sectors, which in many other countries are considered low-tech and labour intensive. This presents some special needs and opportunities for the utilisation of industrial robots in a Danish context, with an important perspective being, in particular, robot-based *process innovations*.

Cognitive industrial robots, which are, for instance, better at sensing with the help of sensory input from cameras and other sensors, will, in the short term, enable promising new process innovations in industry within areas such as item handling, sorting, assemblage, welding, pallet picking, grinding, packing and food processing (e.g. meat cutting).

Through process innovations in such areas, cognitive robots in industry will be able to contribute to increased efficiency and competitiveness in industry, but they will also have an effect on employment. On the one hand, robots can take over routine tasks, possibly resulting in fewer jobs. On the other hand, robot technology can make it possible to keep advanced production in Denmark, and new types of more specialised and higher-paying jobs can be created. Furthermore, increased utilisation of robot technology can have an influence on the working environment. It can result in improvements, as tasks that are detrimental to health (e.g. heavy lifting, repetitive tasks) and dangerous tasks can be performed by robots. The technology can also produce new types of working situations and ways of organising tasks. Therefore, the implementation of robot technology should, from the outset, be assessed for the entire set of work processes and the associated infrastructure to create a holistic production concept.

*"The industry's needs in robot-based innovation within a time frame of ten years are primarily related to further development of the robot technology that is in use today. Creating more investment-friendly standard solutions within cognitive robot technology presents huge challenges even though cognitive in this regard is only sensing through vision along with other sensors and preprogrammed reaction patterns.*
*"As far as industry is concerned, we would really love to shift focus towards establishing a better balance between the interests of industry and the very research-intensive part that is needed outside of industry.*
*"Similarly, it is important for industry that the focus is not only on new application areas, but more on increasing efficiency and penetrating the existing application areas."*

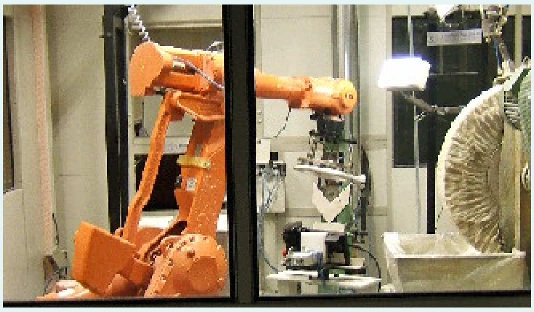
Leif Dalum, chair of Dansk Robot Forening and managing director of ProInvent A/S and Videometer A/S

**Future needs and possibilities**

The industry's needs within a timeframe of ten years will primarily be in relation to the development of standard solutions and systems to make the implementation of robot technology more efficient.

An important key concept for robots in Danish industry will be production cells that consist of machinery, equipment, sensors, robots and operators. And there will be the need and opportunity to make integration and communication between the various elements of a cell more efficient and targeted towards varied one-off production and a high degree of process variation.

Furthermore, there will be a need to develop intelligent user interfaces that can promote interaction between robots and operators and



*Pressalit A/S is a Danish company that manufactures, among other things, toilet seats. The company has met the challenges of globalisation by utilising robots in the Danish manufacturing facilities rather than moving production to low-wage countries. The company has many product variations and small production series, and therefore has a need for production lines that can be changed quickly. The assembly robots have cognitive capabilities in the sense that the robots can figure out, with the help of several cameras, exactly where a hinge, for example, is to be mounted.*

Sources: Pressalit A/S and ProInvent A/S that can help the user to quickly and flexibly understand a new task.

There will also be a need and opportunity to develop better ways of simulating robot and vision systems. These would be used to study the speed of image processing, communication and movement in order to form a foundation from which to work with the process before it is actually implemented. Further, there will be a need for research in light systems that can make vision systems less sensitive to light in production halls. Finally, there will be a need and opportunity to develop better vision equipment with zoom and auto focus capabilities.

Within the next five-ten years, Danish industrial firms are expected to have acquired many flexible production systems. This is because robots:

- Will have increased use of computer vision.
- Will have increased flexibility and change-over capabilities in terms of type of production.
- Will have increased safety levels in relation to interaction with humans and surroundings and will contribute to a better working environment.
- Will be modular within the individual robot series.
- Will have internal logical decision-making systems that continuously prioritise the robot’s tasks.

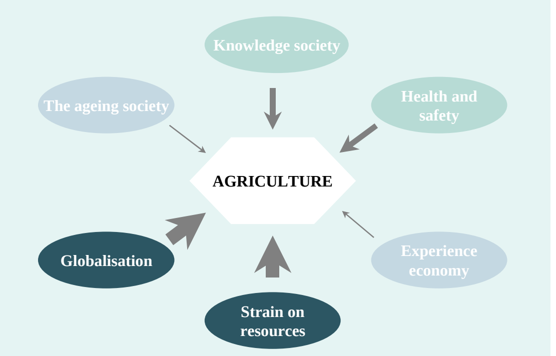
In addition to development in terms of one-off production, the need for flexible cells for micro-handling will increase greatly along within the development of new high-value products. Micro robots are robots that operate with a range of relatively few cubic centimetres and with a precision of approximately 1-10 micrometers. They are used in such areas as the manufacturing of hearing aids and the pharmaceutical industry. For Denmark, micro robots are significant in that the pay level for the manufacturing of micro products is not as crucial a competitive parameter.

Strong growth is also expected in the use of AGVs (autonomous guided vehicles) in industry. Today there are more than 100,000 AGV systems in operation. One example is the Volvo factories, which use more than 4,000 AGV systems for transporting heavy items.

## High-tech robot-based agriculture

In terms of global competition, lower transport costs and lower pay and energy costs in other countries are placing rising pressure on the agricultural and horticultural sectors in Denmark. Globalisation and international competition are resulting in rapid structural development in Denmark. The number of units is increasing and the number of employees in agriculture is diminishing.

Since World War II, Danish agriculture has doubled its productivity every decade. Thus, a Danish farmer today is 64 times more productive than a farmer was in the 1940s. This trend is expected to continue.



*Significance of megatrends for agriculture*

Jobs in future agriculture and horticulture are consequently expected to have a high knowledge content, and it is expected that in future a farmer's work will consist of fewer routine and physically demanding tasks, such as driving tractors, feeding pigs, heavy lifting and major cleaning tasks.

At the same time, with the requirements of globalisation in terms of structural development, society increasingly also requires an agricultural sector with lower resource consumption, cleaner forms of production and less impact on the environment, as well as requirements for healthy and safe foods.

Like many other countries, Denmark has a long tradition for agricultural production and food processing. What makes Denmark different from other countries is, among other things, a tradition for development and utilisation of new technology in the agricultural sector. There are also strong research institutions and knowledge centres in Denmark, as well as good advisory networks. This provides very special opportunities to utilise robot technology in agriculture. The perspective here is to adjust international robot technology in order to utilise it in Danish agricultural production. There is also a strong agricultural machinery sector in Denmark that can participate in the development of robots for agriculture. For this industry, a home market that is willing to take risks would be very helpful.

Two other recent technological foresight studies, "IKT fra jord til bord" (ICT from field to table) and "Grønt teknologisk fremsyn om miljøvenligt landbrug" (Green technological foresight study on environmentally friendly agriculture) point out that robots in agriculture will help ensure a healthier economy for the agricultural sector as well as produce environmental benefits.

### Future needs and possibilities

In the agricultural sector of the future, there will be less contact between humans and animals. It is therefore a requirement that robots can be part of the interaction between machines and animals, and that the robots are given an understanding of animal welfare.

Design and user-friendliness are very significant requirements. Robots should not be too boring or ugly, and they should be easy to use. In this regard, it is important to note that design is a cultural concept. There can be different views on good and bad design and different requirements pertaining to user-friendliness from country to country.

Robots in agriculture should be able to integrate data between different systems, for instance, networks of sensors in connection with precision agriculture, fleet management and communication between machines and agents as well as planning systems for field operations such as harvesting or fertilising.

Finally, it is important that the robots are robust. They need to be able to function in corrosive environments and in unstructured surroundings – both indoors and out.

The following areas show special promise within the timeframe of ten years:

> Weeding robots can be developed for both conventional and organic agriculture based on sensory identification of weeds. One possibility is robots that conduct single-drop application of pesticides or robots that carry out mechanical weeding. This will mean reduced consumption of pesticides, lower consumption of labour and better finances for the farmer.

> Monitoring crops in growth combined with vision-based plant protection and fertilising of fields with a view to optimising the use of chemical fertilisers.

> GPS-based automatic steering of large agricultural machines such as tractors and harvesters will mean that the machines can navigate the fields on their own and that they can perform their tasks with much greater precision. This means lower consumption of e.g. pesticides and fertilisers, but also lower consumption of fuel.

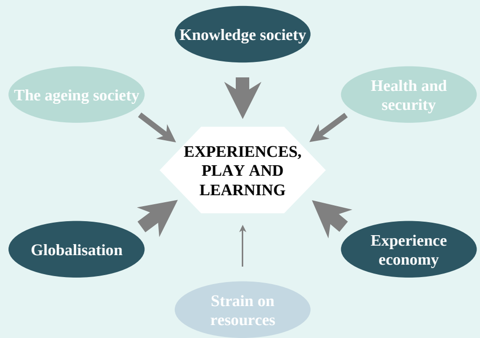
*Weeding robots and sensors in the agricultural industry could significantly reduce the amount of pesticides used. Before this vision can be realised, robots need to be able to recognise the difference between weeds and crops. This is where cognitive research can help speed the development in future of robust and efficient systems, e.g. through knowledge on how humans recognise and diagnose plant diseases and pests. The Danish Institute of Agricultural Science is working with autonomous robots and biosensors for future food production.*

Source: Svend Christensen,
Danish Institute of Agricultural Science

- With regard to smaller machines, we will see lawn mower robots for standard lawns and hard to reach areas, such as slopes.
- Even more advanced and flexible milking robots can be developed for milking larger herds in buildings and in the field. Especially the latter can help organic dairy production on a larger scale.
- The utilisation of mobile milking robots can promote free-range dairy herds.
- Robots for washing and mucking out various types of livestock buildings equipped with systems of sensors that can measure the quality of the cleaning. This would result in a better working environment, healthier animals and improved food quality.
- Robots for feeding, e.g. pigs, and which also monitor the individual animal's weight and food intake to optimise feed consumption.
- Robot systems can be developed for routine veterinary inspections, including assessing the health and welfare of animals. This would result in better animal health and better finances. The significance of technology-based livestock production for animal welfare should be considered in this context.
- Robot-based production of medicines or other products for use in connection with genetically modified plants. This kind of production requires great precision in cultivation and high requirements for safety, documentation and monitoring. The area-requirements of this type of production are relatively small, so it is well suited for robot technology.

## Experiences, play and learning – fun and serious applications

The experience economy is one of the key driving forces for robot technology in our part of the world. Within as little as a three-year timeframe, the special-interest organisation World Robotics expects there to be five times as many entertainment robots.




*Significance of megatrends for experiences, play and learning*

Technology and technical knowledge represent an increasingly central part of society, and it is important that everyone has the prerequisites to participate in the dialogue and develop their own opinions. Children are also surrounded by technology and they need first to understand and navigate this reality. In primary school education, robots have been used in understanding science through story-telling and play. Teaching is based on a qualitative approach to technology and, among other things, aims to give children an understanding of the causal mechanisms. Children observe and describe robots, trying to explain robot behaviour by establishing simple rules for the situations that produce specific behaviour.

In health and socio-economic terms, there can also be significant benefits associated with utilising robot technology to develop physically interactive experiences and games that users can move around in. More than 65 per cent of the adult American population is overweight, which results in related annual healthcare expenses of around USD 80 billion. A similar trend can be seen in Europe, where all types of initiatives to promote physical activity in an entertaining and fascinating way are increasingly seen as a societal necessity.

*"Today, more and more people are demanding games that combine physical activity with interactive entertainment. We can see this in the international success of dance and movement games, so there will definitely be a market for intelligent playgrounds."*

Peter Weile, chair of the Danish multimedia association, Multimedieforeningen

*"Today's children aren't active enough, and that's disastrous. They become overweight and contract all kinds of weight-related diseases. This is an enormous problem in large parts of the Western world. Imagine if you could help combat the global obesity epidemic by getting people to be more active. The possibilities in this area are endless. For example, we could decode how the soccer player David Beckham runs. His speed, movements and style. Then we could make a 3-D figure copy his run."*

Henrik Hautop Lund, professor, University of Southern Denmark

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All things considered, there is a huge potential for robot technology in the area of experiences, play and learning. Denmark has business-related positions of strength in the quality of life and entertainment industries, including products for experiences, play and learning. It is assessed that Denmark, with its tradition for user-driven innovation, has a unique opportunity to develop new up-market products in the area of experiences, play and learning through collaboration between product developers and research institutions.

### Future needs and possibilities

Wishes for future robot technology applications in experiences, play and learning include precision and durability, user-friendly technology, cordless and flexible solutions.

User studies and user involvement are important prerequisites for developing robots for experiences, play and learning. In this context, knowledge about the adaptive abilities of people and knowledge about the correlation between age and learning are of great importance. Studies show that IT has led to increased intelligence in children who have become better at being creative – recognising patterns, visual orientation, problem solving, understanding stories communicated through IT, etc.

Robots for play and learning should be of high aesthetic quality. Further, the play and learning processes should have a clear purpose and their content should be well-founded. Robots should not replace functions, but enable activities that are not currently possible.

There is great potential in artificial intelligence (AI) and robot technology combined with research in play, product design and development in the area of physically active playing. Some of the possibilities are:

- Personalising robot technology within experiences, play and learning by combining modern artificial intelligence with robot technology.
- Artificial intelligence in combination with robot technology can be used to

*Robotic playgrounds promote general play and physical activity. For several years, the Danish playground manufacturer Kompan A/S has conducted research in interactive and technologically advanced playgrounds. Experiences and confrontations with the "tough judges" – children – it is not the technological advances that attract children. "Robotic playgrounds" must be immediately understandable and without screens or manuals. And children often develop entirely new ways to play with them that the developers had not thought of.*

Source: Kompan A/S

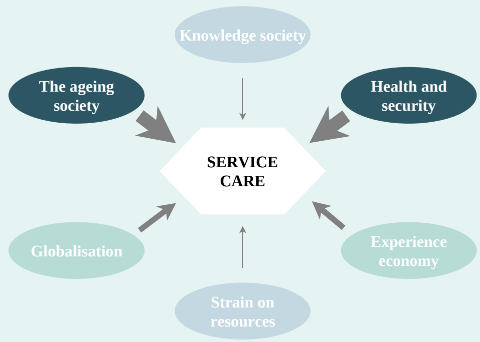
develop products with embedded robot technology that can recognise individual users and adapt accordingly. This can be used to promote physical activity in children by motivating them to use their bodies in fun and challenging ways.

- Intelligent toys are becoming more and more sophisticated, and in some cases have perhaps even begun to replace the need for pets.
- Robots for security, therapy and entertainment purposes with increased cognitive capabilities. The toy will be able to recognise different children and react on the basis of their facial expressions, what they say, their movements, etc. For adults, intelligent toys can also include sex toys.
- Combining play and learning, so that the robot provides a capable and meaningful challenge. This will be relevant in terms of playgrounds, (role-playing) games, physical therapy in the healthcare system and in other learning with kinaesthetic learning patterns for humans.
- Developing physically interactive games geared towards exercise and combating obesity.
- Developing large physically demanding computer games that automatically adjust to users and that are based on modern artificial intelligence combined with advanced robotics.

## Cognitive robots for service and care

The general ageing of the population as well as the wish for better and more efficient service and care, both in the private sector and the public health sector, are the most important driving forces behind the expectations for service robots.

In this area, the prospects are great for developing robots for both professional and private use.




*Significance of megatrends for service and care*

Robot technologies for the elderly and people with physical disabilities that can help compensate for reduced functional capacity will provide increased self-sufficiency and improved opportunities for people with reduced functional capacity to live in their own homes. Furthermore, such robot technologies could be developed for specific working situations, thus, helping more people with physical disabilities enter the labour market.

**The market potential for technology for personal service and care – selected key figures for Denmark – 2004:**

- 200,000 receive long-term home care
- 17,000 receive long-term home care from private-sector providers
- 1,100 recipients of personal assistance schemes for people with physical disabilities (Services Act, s. 77)
- 300 people with impaired vision have seeing-eye dogs
-

Source: Inger Kirk Jordansen, Danish Centre for Assistive Technology

Another example is robots for performing routine service tasks in the home and as assistance for home care professionals in connection with tasks that require heavy lifting and repetitive work. If such applications are realised, the result could be a reduction in the number of work-related injuries and a release of resources that can be put to better use in other areas.

It is assessed that there would be welfare-related economic perspectives in developing robots for personal service and care. There is a significant home market for technology for personal service and care, and today there are significant public funding schemes for such technologies (see box). But it is also important to understand that the increased independence that comes with technology can also lead to social isolation when a person’s resources dwindle.

Another promising area is professional service robots for e.g. logistics, warehouses, maintenance, repair, monitoring and surveillance tasks in trade and industry. Here too, there will be an opportunity to develop robots with cognitive capabilities that can contribute to better and more efficient solutions for various service tasks.

Finally, there are applications in the private sector. This area includes robots for cleaning (vacuum cleaners), lawn mowing and entertainment. Since the launch of automatic vacuum cleaners in 2000, more than 1 million of these robots have been sold. The market for private-sector service robots now has an annual growth rate of 400 per cent. This explosive growth has motivated countries like Korea to invest relatively large resources in capturing a share of the market. Sweden is one of the countries in Europe that has invested heavily in the area. Husquarna has sold more than 25,000 AutoMowers, as it calls its robotic lawn mower, and Electrolux has sold more than 30,000 of its robotic vacuum cleaner, Trilobite.

The Danish business-related positions of strength and the opportunities relating to this type of inexpensive mass-produced consumer product will primarily be within various types of sub-supplier positions and in the development of sensors and software rather than mass production itself.

The development of robots for service and care that work with users in their normal surroundings is a major challenge. These systems have to be very safe and reliable, and they have to be simple to use. Building such systems requires new methods for designing manipulators and user interfaces that have much more flexibility than is currently the case.

The robots need to be mobile and self-regulating and they need to be able to move and position themselves. They must also be able to orientate themselves and grasp and operate in all directions. Finally, the robots should be flexible and it should be fast and easy to change between various functions.

For private-sector service robots, it is crucial that the user can voluntarily choose which type of assistance he or she needs and that the technology is designed to meet the needs and wishes of the user. Robot technologies should not be introduced as standard solutions that the individual cannot deselect. Robots can perform boring, routine tasks, thus, hopefully, leaving more time for “real” care. What is most important is that personal contact remains the key focus. The development perspectives should not be that care and attention are replaced by robots.

In this connection, it should also be emphasised that the combination of robotic systems, monitoring and surveillance systems and alarms, e.g. web monitoring, can be construed as “Big Brother”-like.

### Future needs and possibilities

Professional service robots can be used in a wide range of areas. Robots can operate in places that are difficult for people to reach or where it is dangerous for people to be, for instance:

- Robots for demolition tasks in the building and construction sector
- Robots integrated in major warehouse and logistics systems
- Robots for industrial cleaning, e.g. removing graffiti with the use of high-pressure washing
- Robotic submarines for repairing submerged pipelines or disarming sea mines

- Robots that can identify and collect samples in connection with hazardous substances and products

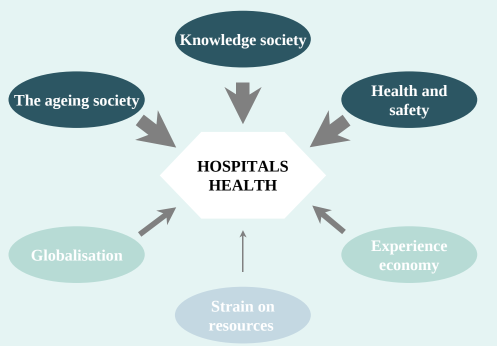
Examples of application areas in relation to people with physical disabilities:

- Robotic arms for grabbing, lifting, collection and opening tasks, i.e. for assistance in connection with impaired movement in hands and arms.
- Service robots for compensation of lack of skills, e.g. vacuuming, washing floors, lawn mowing (there is also a general market for such devices).
- Performing of care functions, e.g. robots that can help the physically disabled with eating, toilet and bathing functions. It is important that robots can perform functions selected by the users. In each individual case, the technologies should be assessed based on a general principle of weighing the advantages against any disadvantages.
- Monitoring surveillance robots, e.g. web monitoring or alarms which react to the absence of activity or to some other kind of information and which send a message to the family or care workers.
- One advanced idea is an assistance skeleton with artificial muscles (an exoskeleton) – a device a person can put on or step into. This exoskeleton would help elderly people or people with physical disabilities to move about, walk, lift things, grasp, etc.

>

## Robots for hospitals and healthcare – precision and quality

The number of surgeries carried out at hospitals is increasing all over the world due to such circumstances as demographic changes (larger elderly population), longer life expectancies and more people seeking cosmetic surgery. This is especially the case in the wealthy part of the world. The challenges faced by the hospital system are, among other things, to improve diagnostics, increase the quality of treatment, increase productivity, improve communication and information, put an end to waiting periods and increase patient safety. Robot technology and automation in general can contribute with improvements that will benefit both patients and staff.




*Significance of megatrends for hospitals and health*

In addition to surgery, the hospital sector has many routine tasks and labour-intensive jobs where robot technology can be used, thereby freeing up personnel resources for care and treatment tasks. A relatively new study indicates that nurses spend more than 15 per cent of their time on transport tasks, e.g. food, linen, laboratory tests, etc. Such tasks could be automated today, and it is likely that this will happen in the near future.

There are excellent prospects in Denmark for building an industry around robots for hospitals and the health sector in general. Denmark has excellent prerequisites in that we have a relatively centralised hospital service system and a unique organisation that makes it easy to implement new solutions.

Another aspect that can make Denmark a leader in this area is that we have the technical know-how, especially in health IT, where we lead the way in communication and infrastructure. One of the disadvantages, however, is that for many reasons the hospital sector in general has a somewhat conservative attitude towards these new devices.

### Future needs and possibilities

Within a ten-year timeframe, a number of robot technologies for hospitals and the health sector can be realised, while other possibilities are only realisable in the long term. Examples of future possibilities are:

> Known technologies within play equipment, medical technology and IT can be used in clinical areas such as physical therapy, ergo therapy, surgery, cognitive therapy and testing for dementia.

> In laboratories, robots (analysis devices) can be used in clinical biochemistry, clinical microbiology, clinical immunology, etc. In these areas, robots can perform a large number of routine tasks.

>

> It is expected that robots will be developed that can perform surgery with greater precision and quality than today's surgeons.

> Patients will be able to be operated on at a different location than where the surgeon is located. By way of a telemedical connection, a medical colleague/specialist at another hospital will be able to participate in the operation across a long distance.

> Patients can stay at home while still being "admitted". Monitoring can take place electronically via a link to the professional staff.

> In the long term, it is possible that advanced robots will be developed for therapy that can adapt, via cognitive capabilities, to match the user's progress and provide feedback in this regard. One possibility is robot-assisted rehabilitation of patients with problems that affect their ability to walk.

*In Funen County, tests have been carried out with "intelligent therapy technology". Here robotic playgrounds are used to rehabilitate patients recovering from sports injuries.*

Source: Peder Jest, Sygehus Fyn Hospital

> In future, advanced robotics might be used to replace lost functions, including entire body parts. Some possibilities are robots with mechanical parts and user interfaces linked to the body's neuromuscular system or robots with cognitive capabilities based on natural sensory information combined with artificial sensors.

> A future perspective is robots that are implanted or injected into the body and that can improve bodily functions from inside the body. Examples might be an intelligent pacemaker that is connected via a server to monitoring equipment or a diabetes patient who has an implanted chip that sends messages and recommendations to the patient's mobile telephone when blood-sugar levels have been too low for a period of time.

# 5. User wishes for future cognitive robots

One way to realise the development perspectives described above is to start with the needs and wishes of the users as regards future robots. The foresight study, therefore, included a broad dialogue with users and experts with specialist knowledge within the five areas in question.

This dialogue is summarised in the following list, which comprises wishes that are common to all five development agendas and specific wishes that are important within the individual areas.

**Robots should be**

- Easy and simple to operate
- Able to interact intelligently with their surroundings
- Very flexible and easy to adjust
- Portable
- Safe (without protective screens) for people
- Reliable, precise and robust
- Integrable with other systems, e.g. product quality, communication
- Operable within a small working area (only a few $cm^3$)
- Able to monitor and interact with animals
- Able to function in corrosive environments and unstructured surroundings
- Of high aesthetic quality
- Able to perform functions selected by the user
- Mobile and be able to position themselves
- Able to reach out and operate in all directions
- Able to perform surgery over a telemedical connection
- Able to perform tasks that are dangerous
- Able to perform tasks in hard-to-reach or dangerous locations
- Able to function in cordless and flexible solutions with other types of technology
- Able to recognise and make adjustments according to the individual users (personalisation of products)
- Able to provide the user with a capable and meaningful challenge
- Self-regulating and able to plan the next step in a process
- Able to improve functions within the body (implanted or injected)

This list gives an idea of the many and varied requirements users have for future cognitive robots. It also shows that we are dealing with a comprehensive research and development challenge that will require cooperation across various disciplines and scientific environments.

The list only contains generalised statements of user wishes. In practice, user wishes will always have a specific meaning in relation to the specific situation for which the robot is to be used. For instance, a general user wish that robots should be able to interact intelligently with their surroundings can have an entirely different meaning depending on whether we are speaking of an industrial robot that needs to interact with the operator and other devices in a factory hall or a service robot that needs to perform a specific task at a hospital in interaction with patients and hospital staff.

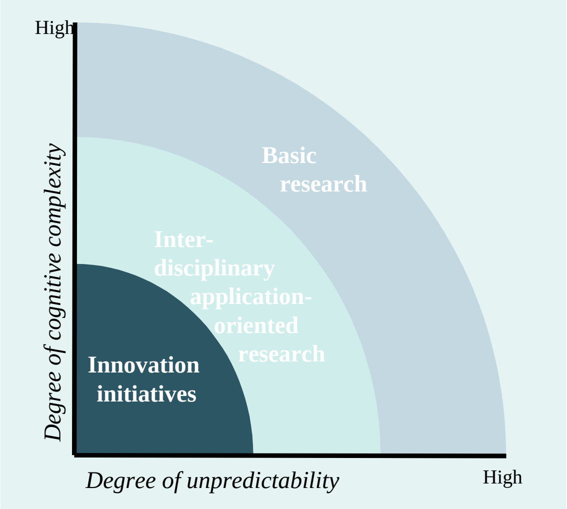
There are also user requirements on the list which are mutually conflicting. That robots should be able to perform functions selected by the user is, thus, an important user wish in terms of robots that assist people with physical disabilities, but the requirement for robots used for play may be the exact opposite because the wish here is for the robot to challenge the user.

The list of user wishes and requirements is, therefore, not directly translatable into themes and initiatives that research and development work on robots with more advanced cognitive capabilities should focus on in future.
This is why the foresight study, in dialogue with users and experts in the five application areas, has also focused on the specific problems and challenges that prevail within each area.

This dialogue shows that there are two general aspects, in particular, that can help establish a framework for an interdisciplinary research and innovation initiative:

> One aspect is the *degree of unpredictability*, that is, how predictable/structured or unpredictable/unstructured are the situation and the surroundings within which the robot is to operate. For industrial robots, for instance, the surroundings within which the robot must operate might perhaps be relatively simple and well-defined. For a weeding robot, on the other hand, which moves about in a field, the surroundings are not as well-defined. And if we are speaking of a robot that is to perform a care function in relation to people, the situation is characterised by a high degree of unpredictability.

> The second aspect is the *degree of cognitive complexity*, that is, how advanced do the cognitive capabilities need to be in relation to the situation within which the robot is to operate. For instance, the industrial robot's working areas and tasks will often be pre-programmed reaction patterns with well-defined cognitive requirements. In contrast, a service robot that is to interact closely with humans must be able to interpret and react to the unpredictable actions and reactions of people.




This figure shows the principles for an interdisciplinary research and innovation initiative based on these two aspects.

The foresight study's dialogue with users has revealed that within all areas there is a need for developing robots for both predictable and unpredictable situations, and robots with both low and high degrees of cognitive complexity.

The steering committee, therefore, finds it relevant to distinguish between short, medium and long-term initiatives, as well as distinguishing between initiatives that focus on innovation, interdisciplinary application-orientation and basic research.

# 6. Interdisciplinary research themes and innovation initiatives

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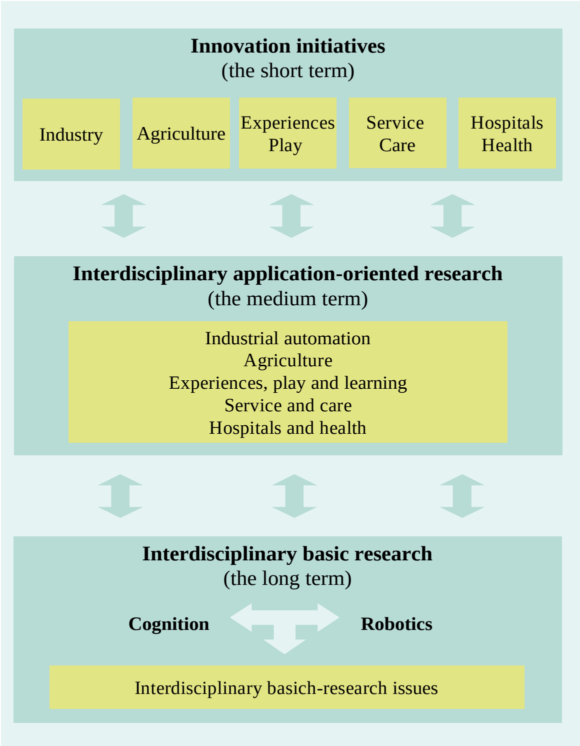
User wishes and needs present a major challenge to research that requires cooperation across various disciplines and scientific environments. The foresight study has revealed many relevant research themes and innovation initiatives in the overlap between cognition and robotics that could contribute to realising and implementing new robot technology solutions. And as is always the case, a foresight study on a new area tends to pave the way for a discussion of well-defined initiatives as well as more basic scientific issues.

This figure presents the steering committee's overall view of the perspective that should form the basis for an interdisciplinary research and innovation initiative.

The arrows in the figure indicate the interaction and interplay that exist between the different levels. Short-term initiatives can help call attention to questions and issues that need a more long-term investment. In contrast, the more basic questions can also result in new innovative approaches with the possibility of concrete technological developments geared towards specific applications.




The following is a presentation of the steering committee's proposals for a series of research themes and innovation initiatives. The initiatives deal with the issues associated with varying degrees of complexity in the cognitive interaction between users and robots as well as with issues associated with the development of robots that can handle varying degrees of unpredictability.

## Innovation initiatives

In the short term, the steering committee proposes innovation initiatives in which robots with simple cognitive capabilities can be used to help solve concrete known and well-described problems in specific applications. These are robots that function as parts of systems with well-structured surroundings and high predictability, as well as robots with pre-programmed reaction patterns and limited interaction with users/operators. In the short term, these initiatives are expected to be geared primarily towards industrial applications.

The steering committee proposes the following short-term innovation initiatives:

*New vision and sensor technology*
Development of sensors for registering data in the physical world as well as systems for processing comprehensive amounts of sensory information. Development of vision systems that are less sensitive to external light as well as vision equipment with zoom and auto focus capabilities.

*Production cells*
Development of complete concepts that integrate machinery, equipment, sensors, robots and operators. Integration and communication between the cell's elements is efficient and geared towards varied one-off production with a high degree of process variation.

*Standard solutions and standard systems*
Further development of the robot technology already in existence today for standard solutions and standard systems to make robot technology more efficient to implement, e.g. by using advanced design tools.

*Construction toys and games*
Development of robot technology elements that inspire playing and learning through simple constructions. Understanding the homogeneity or heterogeneity of the components, how they communicate and the distribution of sensors, processing and actuators. User groups should be involved in participatory design-processes for the development of robot technology and elements for building interactivity in connection with construction toys and games. The opportunities for robot technology to contribute to developing creative, dynamic and educational play scenarios should also be a central object of study.

*Improved user interfaces*
Modular robots that can quickly be changed to perform various tasks in the industrial, agricultural, service and play and learning sectors. Demand is great for highly flexible interfaces that can quickly help the user understand a new task. There is a need for robots with "interaction interfaces" that support different users such as nurses, patients and cleaning staff.

*User studies in robot development*
This area includes methodology from user studies, work analysis, activity analysis and participatory design to understand the interaction between user and robot and user involvement in robot development. Denmark holds a position of strength in this area which should be exploited in the development of new robots.

*Working environment and safety*
The working environment can be a driving force in the development and propagation of robots. The utilisation of robots is often based on the robot's potential for improving the working environment, and there are opportunities for innovation in the short term. Research is needed into how this potential can be further exploited, bearing in mind that robot technology applications are part of a complex interaction with work structures and production concepts.

## Interdisciplinary application-oriented research

In the medium-term, the steering committee points to application-oriented research and development in which robots with cognitive capabilities are incorporated into specific applications with semi-structured surroundings and a certain degree of unpredictability in the robot's tasks.

The steering committee proposes the following medium-term interdisciplinary and application-oriented research areas:

*Mobile robots that can navigate outdoors and indoors*
In the medium-term, this research initiative would deal with robot applications in a semi-structured environment as well as integrating robots with existing IT systems. Among the challenges are: developing robust solutions for sensing and interpreting/recognising dynamic surroundings under varied lighting conditions and for self-location in known, self-taught and/or unknown surroundings.

*Robot technology for varied one-off production*
Danish industry is characterised by highly varied production processes that produce small series. Danish companies have a general need for fast product renewal and high flexibility. In future, it should be possible to meet these requirements by developing adaptive robots that can quickly be changed to match different situations and surroundings and have a fast change-over process using relocation, adaptive control or actual reconfiguration.

*Cognitive robots*
A significant wish is to develop robots that can understand spatial structures and temporal variations and phenomena. This will involve the development of robot technology that can collect and holistically interpret volumes of data. A critical issue will be the development of a robust, functional architecture, especially in relation to the development of (semi) autonomous robots that can both act on their own and be steered by humans.

*Multimodal user interfaces*
A major challenge is speech and gesticulation recognition for natural communication with a robot. There is a need for research into how a user interface can exploit all human senses – hearing, sight, smell, feelings and physical sensation – and which senses the robot should be equipped with to achieve a socially, emotionally and aesthetically satisfactory interaction between robots and humans.

*Role division between user and robot*
Decision-making tasks can be divided into a number of sub-tasks. Analysis of the tasks that robots are to perform can contribute to identifying the knowledge content that robots and users, respectively, should base their actions on.

*Robots in organisational interaction*
The interaction and division of responsibilities between humans and robots are critical for the overall functionality and efficiency of the system. Important questions are how to construct interfaces between humans and robots through the

creation of socio-technical networks, how to configure the division of responsibilities in this hybrid system through design processes and how to reconfigure them in practice.

## Interdisciplinary basic research

In the long-term, the steering committee proposes interdisciplinary basic research into complex cognitive capabilities and their potential for robot technology. A number of basic research topics are presented below which are essential in the long term for developing robots that can evolve, are flexible and interact naturally with their surroundings.

The steering committee proposes the following long-term interdisciplinary basic research areas:

*New materials*
Robots made using new designs with soft materials that ensure increased safety in connection with inter-robot interaction and robot-human interaction. Performing new tasks in which robots are optimised in relation to materials, elasticity, design, surroundings and control.

*Shape-changing and self-repairing robots*
Robots that can change their physical shape. For instance, robots can be modular in design, with components that move around in relation to each other in order to create different shaped robots. Robots that can register errors and carry out their own repairs through various types of redundancy, e.g. by allowing automatic replacement of malfunctioning modules.

*Adaptability, stability and dynamics*
Robots that can acquire new capabilities and change to suit individual users, use situations or surroundings. The flexible robot that is flexible enough, under its own control, to perform a series of tasks in its surroundings.

*The robot as a system component*
Development of adaptive and self-organising robots requires a dynamic link between the robot and its surroundings based on bonds and degrees of freedom. A system-theoretical modelling of objectives and functions in dynamic cognitive interaction between the robot and its surroundings can contribute to an understanding and development within robotics research of autonomous and adaptive robots.

*System integration*
In the area of system integration, research is carried out on the brain and the body as locations of intelligence as well as on how primitive and advanced behaviour can be implemented in robots across both the brain and the body. The point of departure is to couple the research to the various levels of functions of a robot, from physical components to the abstract control-related level. The results of this research could be, among other things, hybrid robots.

*Intelligent user interfaces*
Development of user interfaces that can interpret and employ the user's behaviour, expectations, experience and competencies. Therefore, there is a need for research in intelligent user interfaces that can be operated by experts, laymen and novices.

*Organic cognition*
What kinds of cognitive systems can we experiment at a general level with equipping robots with? The answer is to be found in natural cognitive systems that result from organisms regularly changing to suit their surrounding environments subject to limitations of a universal nature, because a given task can only be performed in certain ways, e.g. as the result of absolute laws of nature.

*Embodied cognition*
Cognition is always present in a body (host) in activity, and it therefore has significant corporeal components which manifest themselves in the form of silent learning, knowledge and memory. Research in the significance of natural hosts' sensory organs, morphology and actions in the world for meaningful perceptions, learning and cognitive categorisation at both the individual and species levels can therefore contribute constructively to the design of future robots.

*Contributions to cognition by robotics research*
Robotics research makes it possible to investigate the principles of interaction between cognitive load, body design, materials, scale, surrounding 'naturally' and artificially created environments in new and pioneering ways. Cognitive research is traditionally limited to studies of cognition in natural systems, but robots present entirely new opportunities to test cognitive theories on systems that do not have a previously fixed cognitive configuration.

*Cognitive taxonomy*
Can natural cognitive systems be divided up into a finite number of categories according to which tasks they are suited for? Does a "taxonomy of intelligences" exist and are there, for instance, general characteristics associated with the different solution models that can advantageously be transferred to artificial systems such as robots? Can a taxonomy be developed for the different categories of cognitive tasks that are performed by humans in natural decision-making processes? Can cognitive taxonomies act as inspiration for robotics research?

# 7. Research, education and innovation policy recommendations

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It is the recommendation of the steering committee that the perspective that should form the basis for an interdisciplinary initiative in the field of cognition and robots should be a balanced interaction between user and research-driven innovation. Instead of the highly ambitious “man-on-the-moon” focus we see in many international robot technology initiatives, a Danish initiative should rather focus on the problems users experience in the practical use of robots and on the needs of research to be able to regularly define its research agendas and redefine its critical problems in this light.

Therefore, the steering committee has the following recommendations for a Danish initiative:

- Improve opportunities for free interdisciplinary research
- Strengthen interdisciplinary strategic research
- Incorporate cognitive robotics as an element in the Danish High Technology Foundation’s strategy in the field of ICT
- Improve opportunities for networking and innovation
- Exploit funding options, build networks and formulate specific interdisciplinary research projects
- Debate possibilities within cognitive robotics and consider educational initiatives
- Establish a separate research and development programme in the slightly longer term

### Improve opportunities for independent interdisciplinary research

It is problematic that projects of an interdisciplinary nature often have more difficulty achieving funding within independent research than projects with a limited framework that fall under the individual research councils. The steering committee, therefore, recommends that:

- The Board of the Danish Councils for Independent Research utilise the Board’s pool for Visionary Research Projects to invest in interdisciplinary research-initiated projects. In terms of such an investment, research in the field of cognition and robots may be one of those areas that contributes proposals, in competition with researchers from other interdisciplinary areas, for visionary interdisciplinary projects on cognition and robots.
- The Research Councils for Nature and the Universe, the Humanities, Technology and Production as well as Society and Business combine forces to finance interdisciplinary research-initiated projects that transcend the individual research councils’ areas of responsibility. This would improve the funding opportunities for interdisciplinary projects in general, and for research-initiated projects on cognition and robots in particular.

### Strengthen interdisciplinary strategic research

Within strategic research, opportunities for obtaining funding for research in robots are generally associated with ICT-oriented research programmes.

At the moment, the Programme Commission on Nanoscience and Technology, Biotechnology and IT, under the Danish Council for Strategic Research, awards funding for strategic research in the field of ICT. This takes place within the framework of two research programmes on IT research and interdisciplinary use of nanotechnology, biotechnology and IT and communications technology, respectively.

The IT research programme, which expired at the end of 2005, contained certain opportunities for obtaining funding for interdisciplinary projects on research-related issues that affect cognition and robots. However, this is not the case with the programme for interdisciplinary use of nanotechnology, biotechnology, IT and communications technology.

Consequently, as things stand today the opportunities for obtaining support for strategic interdisciplinary research in the field of cognition and robots are very limited. The steering committee, therefore, recommends that:

- Policy-makers, the Ministry of Science, Technology and Innovation and the research councils take care, in connection with future grants for ICT-related strategic research programmes, to formulate budgetary allocations, funding notices and programmes in such a way as to include interdisciplinary projects on cognition and robots. The steering committee recommends that future ICT-related strategic research programmes should be open for interdisciplinary projects on cognition and robots, which are inspired by technological, health-science, biology, humanities and sociology research, to obtain funding in competition with other ICT-oriented research projects.
- The Danish Council for Strategic Research incorporates cognitive robots thematically into the Council's Innovation Accelerating Research Platforms. It is the steering committee's assessment that there is particular potential and perspective in cognitive robots in the following platforms:
    - User-driven innovation and business development in the knowledge economy
    - Global design-oriented manufacturing platforms
    - Healthy and safe foods
    - The individual perspective in the healthcare services of the future

**Incorporate cognitive robotics as an element in the Danish High Technology Foundation's strategy in the field of ICT**

The objective of the Danish High Technology Foundation is to promote Denmark's further development as a high-tech society. The Foundation funds strategic investments in research and innovation focusing of the areas of biotechnology, nanotechnology, IT and communications technology, as well as the overlapping areas in-between. In 2005, the foundation awarded funding to, among other things, a project that combines biotechnological plant production with robotics and visualisation technology. The steering committee recommends that:

- The Danish High Technology Foundation includes cognitive robotics as an element in the Foundation's ICT strategy.

### Improve opportunities for networking and innovation

The financing of promising interdisciplinary research in the field of cognition and robotics cannot stand on its own. There is also a need to strengthen the formation of networks among researchers, users and producers of robot technology solutions within and across the five areas where cognitive robots can help promote innovation. Furthermore, the foresight study highlights several specific innovation initiatives that could contribute in the short term to solving known and well-described problems in relation to the development and implementation of robots in specific applications. The steering committee recommends that:

- The Danish Council for Technology and Innovation considers how the Council can help promote networking and innovation relating to the development and utilisation of cognitive robots, including how specific grant types, such as the regional IT initiative and any future free innovation grants, can be made available for the needs of the innovation initiatives identified in the foresight study.

### Exploit funding options, build networks and formulate specific interdisciplinary research projects

Better funding frameworks for interdisciplinary research and innovation initiatives within cognition and robots are not a guarantee that the potential in cognitive robots will be realised. It is crucial that players interested in the area combine forces to exploit the funding opportunities that exist and that someone leads the way in mobilising further networking. The steering committee, therefore, recommends that:

- Industry, agricultural, service and local authority organisations as well as those for patients and the physically disabled consider how they can help promote networking among users, researchers and producers of robot technology solutions within the various application areas.
- Such networks be used to keep all parties informed of the funding opportunities that exist. Such networks should also act as a forum for specific partners to work together to apply to the Danish Council for Technology and Innovation for funding, e.g. for an innovation consortium, or to the Danish High Technology Foundation for funding a specific research and innovation project.
- Such networks be used prior to specific innovation projects, to establish a dialogue with important customer groups on creating early markets for the technologies that are developed. These might be customer groups from the public sector, such as hospitals, local governments and local authorities, or they might be private-sector customer groups such as farmers or suppliers of logistics services.
- Researchers in the areas of cognition and robotics combine forces to formulate interdisciplinary research projects for the research financing system. This forecast study presents the first ideas in a series of interdisciplinary research themes that can form a point of departure for further dialogue in the research community on specific research projects.

### Debate possibilities within cognitive robotics and consider educational initiatives

With this forecast study, a first step has been taken towards revealing the perspectives and opportunities that robots with more advance cognitive capabilities present. However, it is crucial that the debate does not stop with this study.

The study emphasises that there is a need for more debate on the ethical and social aspects associated with the way robot technology will affect our daily lives – at home and at work.

There is also a need for more dialogue within research and educational institutions with activities in the areas of cognition and robots on the possibilities and perspectives of a closer collaboration between the two areas.

There is a need for more dialogue on the specific opportunities for research collaboration as well as for more dialogue locally and cross-institutionally on the needs for possibly launching educational initiatives in the area.

An example might be a graduate-level programme in cognition geared towards industrial application that is established as a collaboration between cognition research environments at universities and the more application-oriented programmes, e.g. engineering programmes. Another possibility is to establish a joint PhD programme in the overlapping areas between the different disciplines.

Within the framework of the foresight study, it has not been possible to conduct a more detailed assessment of the prospective needs for educational initiatives, including ensuring that graduates will be able to find jobs after completing their studies. The steering committee, therefore, recommends that:

- Relevant heads of departments, researchers and staff-student study committees discuss their respective research and educational environments’ possible interests in this area. They should establish a dialogue across departments and institutions on the prospects of cognition and robotics researchers working more closely together.
- The Danish Board of Technology carries out a project on the ethical and societal aspects associated with the development and propagation of robots with more and more advanced cognitive capabilities.
- Managing bodies at universities with significant activity in this area consider whether there is a basis for proposing a major long-term research project in this area. It is expected that the Danish Government’s Globalisation Strategy will pave the way for the managing bodies of research institutions to compete with each other once a year for the opportunity to apply for such major and significant research initiatives and that the proposals submitted will be assessed on the basis of their quality and relevance.

**Establish a separate research and development programme in the slightly longer term**

It would be possible to implement the above-mentioned recommendations under the existing schemes and thus promote an immediate effort. However, this is an effort that stretches across many different schemes and presupposes complex interactions among many different authorities, councils and programmes within research and innovation as well as research and development environments and players at the user and industry level. In the slightly longer term there will be a need for a more comprehensive and coordinated effort.

The steering committee, thus, recommends that:

- Funding be earmarked, in connection with a general increase in allocations for research as proposed in the Danish Government’s Globalisation Strategy, for a separate research and development programme in the field of robot technology and cognition.
- A programme commission be formed in connection with a separate research and development programme with a view to ensuring further development of the proposed research and innovation agenda, including stimulating and coordinating the creation of interdisciplinary networks among research environments within robotics, cognition and user researcher and between research and user groups at company and industry levels.

# Appendix 1. The foresight study – methodology

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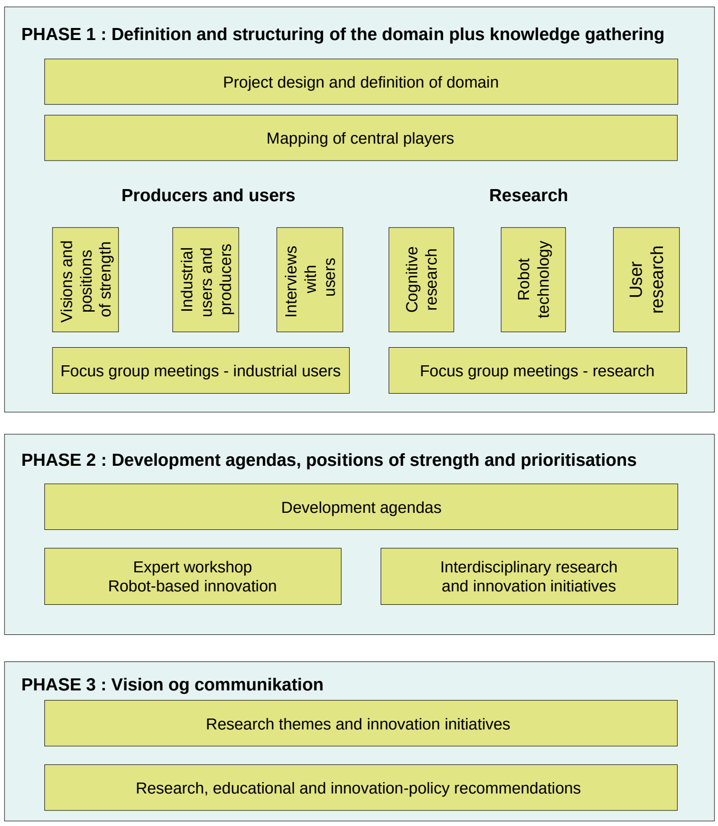
The foresight study on cognition and robot technology can be seen as part of a trend that has prevailed in recent decades in research policy in the Western world, making research and innovation across scientific disciplines a key part of research and innovation policy.

The overlap between cognition and robot technology is a relatively untouched area. This means that the present foresight study was of a more exploratory nature compared to other Danish technological foresight studies carried out in recent years. The perspective of the study has been promising application and business-oriented potentials within a timeframe of ten years. The study has not attempted to set out agendas for research and innovation in robot technology, but has focused solely on the possibilities in the crossroads, where robot technology research, cognitive research and user research meet. In terms of methodology, the process has been conducted as a broad dialogue between users and makers of robot technology solutions as well as researchers and experts in cognitive and robotics research. The goal has been to lay down a robust and broadly accepted foundation that can be used to identify promising prospects for innovation associated with the development of robot technology. The dialogue has included, among other things, surveys of players, expert reports, interviews, focus group meetings, workshops and company visits. In all approximately 100 people participated in the process in one way or another.

The individual sub-elements of the study are described in the following, and their relation and order of importance are indicated in the flow chart below.




*Flow chart – technological foresight study on cognition and robot technology*

**PHASE1: Definition and structuring of the domain plus knowledge gathering**

***Project design and definition of domain:*** Initially, an overall project plan was prepared that was subsequently adjusted in relation to the experience and knowledge gathered. The first step in the project plan was to define and structure the domain so it could form a basis for the steering committee's work.

***Survey of players – Initial mapping of researchers, companies and users:*** Information on Danish research and companies in the areas of cognition and robot technology was collected via a survey of Danish research environments and companies with activities or interests in cognition and robot technology. The information was collected via questionnaires sent out to institutions and companies in the spring of 2005. The institutions and companies were asked to briefly describe their own activities or interests in the field of cognition and robot technology as well as to provide a contact person and, in the case of research institutions, state the size of their staff.

***Expert report on visions and positions of strength in robot-based innovation:*** The report covers both production and utilisation of robots and provides an assessment of robot-based innovation prospects and specific Danish positions of strength with regard to both production and application. A distinction is made between industrial robots and service robots. The report contains descriptions of: i) the technological field and players; ii) application and business-related prospects that are realistic within a timeframe of ten years; iii) Danish positions of strength; iv) research and innovation-related needs.

***Exploratory interviews with users:*** Current and future user needs are identified through qualitative interviews with selected current and future users of robot technology. The interviews specifically focus on the users' own experiences and future requirements/needs for robots.

***Industrial users and producers of visions for robot-based innovation:*** Current and future needs are identified through presentations and visits to companies that are industrial users or producers of robot technology. The company visits and presentations focus specifically on the companies' or organisations' points of view in terms of utilisation of robots and their requirements and wishes for the robots of the future.

***Focus group meeting – industrial users of robot technology:*** The focus group meeting was held on 8 June 2005 at the Maersk Mc-Kinney Moller Institute for Production Technology, University of Southern Denmark. Experts from companies with various experiences and scientific backgrounds in robot technology participated in the focus group meeting. The actual objective of the meeting was, first, to comment on and discuss the expert report "Virksomheders visioner og styrkepositioner i robotbaseret innovation" (Companies' visions and positions of strength in terms of robot-based innovation) and its conclusions, and, second, to discuss ideas and suggestions for new initiatives, also including visions for future development and utilisation of advanced robot technology.

***Expert reports – Danish and international research, visions and positions of strength in robot-based innovation:*** Three areas of research are highlighted as being of particular significance for innovations based on robot technology applications. a) Technologies that can contribute to developing future advanced robots; b) Sociology, psychology and health-related cognition research; c) Socio-cognitive research in the work stations and processes of robot users. For each of these three main areas, expert reports have been produced by persons with special expertise in the areas in question. Each expert report contains a description of: i) the scientific field; ii) application and business-related prospects; iii) Danish positions of strength; iv) research and innovation-related needs.

***Focus group meeting with selected experts from within the three areas of research:*** The focus group meeting was held on 6 June 2005 at the Technical University of Denmark (DTU). Researchers from each of the three areas of research participated in the meeting. The actual objective of the focus group meeting was, first, to comment on and discuss the expert reports produced for the three key areas of research and, second, to discuss particularly promising interdisciplinary research that can be part of a research and development agenda for a research and innovation initiative in the field of robot technology.

### PHASE 2: Development agendas, positions of strength and prioritisations

***Development agendas:*** One of the objectives of this technological foresight study is to identify and motivate development agendas that appear to be particularly promising for Denmark within a timeframe of ten years. Development agendas are long-term visions within selected application areas in which cognitive robots will promote innovation.

***Expert workshop – issues for robot-based innovation:*** The expert workshop was held on 2 November 2005 at the Danish Ministry of Science, Technology and Innovation. Users and experts covering the most important research areas as well users and business interests participated in the workshop. The actual objective of the expert workshop was, first, to establish a dialogue between users and researchers on research-related issues based on user needs and wishes for robots within a timeframe of ten years and, second, to discuss how cognitive research and user research can contribute to robot technology research and innovation.

***Working report – interdisciplinary research and innovation:*** The field of cognition and robot technology is characterised by interdisciplinary development and entirely new interdisciplinary constellations and networks are expected to arise. This report briefly describes the mechanisms, processes and dynamics that characterise interdisciplinary research, development environments, networks and collaboration between research and businesses.

### PHASE 3: Vision and communication

***Research themes and innovation initiatives:*** One of the foresight study's main results is the selection and formulation of research themes and innovation initiatives. The objective is to formulate and develop an arena that can enable the identification of promising centres for future technological development prospects in the overlap area between cognition and robots.

***Research, education and innovation-policy recommendations:*** Another of the foresight study's main results is a series of recommendations for a Danish initiative.

***Final report:*** The results of the foresight study are presented in the main report, while the individual sub-analyses are reported separately on the enclosed CD-ROM.

# Appendix 2: Contents of CD-ROM

In connection with the foresight study on cognition and robots, the following sub-analyses were conducted. Their findings can be found on the enclosed CD-ROM:

- Expert report: “Virksomheders visioner og styrkepositioner i robotbaseret innovation” (Companies’ visions and positions of strength in robot-based innovation), Henrik Hautop Lund (University of Southern Denmark), Rune Larsen (RoboCluster), Michael Wehner Rasmussen (RoboCluster), Bjarke Nielsen (RoboCluster), Claus Risager (Danish Technological Institute)
- Expert report: “Robotteknologisk forskning” (Robot technology research), Henrik Gordon Petersen (University of Southern Denmark)
- Expert report: “Kognitionsforskning” (Cognitive research), Hans H.K. Andersen (Risø National Laboratory)
- Expert report: “Kognitiv og sociologisk forskning i arbejde, brugere og robot design” (Cognitive and sociology research in work, users and robot design), Annelise Mark Pejtersen (Risø National Laboratory) and Christian Clausen (Technical University of Denmark)
- Presentation: “Industriautomation” (Industrial automation), Leif Dalum (ProInvent A/S and Dansk Robot Forening)
- Presentation: “Landbrug, skovbrug og gartneri” (Agriculture, forestry and horticulture), Svend Christensen (Danish Institute of Agricultural Science)
- Presentation: “Leg og læring” (Play and learning), Karin Müller (KOMPAN A/S)
- Presentation: “Personlig service og omsorg” (Personal service and care), Inger Kirk Jordansen (Danish Centre for Assistive Technology)
- Presentation: “Sygehuse og sundhed” (Hospitals and health), Peder Jest (Sygehus Fyn Hospital)
- Working report: “Dansk forskning og virksomheder indenfor kognition og robotteknologi” (Danish research and companies in the areas of cognition and robot technology), Birgitte Rasmussen, Anne Skjerning, Per Dannemand Andersen (Risø National Laboratory)
- Working report: “Eksplorative interviews med brugere – visioner for robotbaseret innovation” (Exploratory interviews with users – visions for robot-based innovation), Birgitte Rasmussen, Per Dannemand Andersen (Risø National Laboratory)
- Working report: “Fokusgruppemøde – industrielle brugere af robotteknologi” (Focus group meeting – industrial users of robot technology), Birgitte Rasmussen, Per Dannemand Andersen (Risø National Laboratory)
- Working report: “Fokusgruppemøde – forskning i kognition og robotteknologi” (Focus group meeting – research in cognition and robot technology), Birgitte Rasmussen, Per Dannemand Andersen (Risø National Laboratory)
- Working report: “Virksomheder – visioner for robotbaseret innovation” (Companies – visions for robot-based innovation), Birgitte Rasmussen, Per Dannemand Andersen (Risø National Laboratory)

- Working report: “Ekspertworkshop – problemstillinger for robotbaseret innovation” (Expert workshop – issues for robot-based innovation), Birgitte Rasmussen, Per Dannemand Andersen (Risø National Laboratory)
- Working report: “Tværgående forskning og innovation” (Interdisciplinary research and innovation), Birgitte Rasmussen, Per Dannemand Andersen (Risø National Laboratory)

**Technology Foresight on Cognition and Robotics**

Recent years have seen major investments, at international level, in the development of increasingly advance robots. These robots can perform more and more advanced tasks and functions, either independently or in interaction with humans.

Robots are often called intelligent, but compared to humans and animals, technological intelligence still leaves a lot to be desired. Even the most advanced robots today are a far cry from the level of humans and animals, and some would even claim that robots are not yet intelligent and even not intelligent at all in human terms.

This is the background for this foresight study, which takes an in-depth look at the topics of cognition and robots. *Cognition* stems from the Latin *cognoscere*, which means to know, to recognise, to understand. This study takes a close look at the perspectives, possibilities and consequences for the development and utilisation of cognitively advanced robots.

This study concludes that interdisciplinary research and innovation in this area will make it possible in future to develop robots with more and more advanced cognitive attributes and that there is great potential ins such robots in connection with alleviating crucial issues and promoting innovation in areas of importance to society.