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ICT Research
The policy perspective

European robots
getting smarter, safer, and more sensitive

European Commission
Information Society and Media

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The service's main aim is to:
- raise the visibility of ICT-funded research results
- support projects' access to markets and encourage uptake of innovations
- raise awareness of European ICT programmes and activities

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Thinking machines, computerised companions

In this report produced for the publication series ICT Research: The Policy Perspective, we examine how the application of robotics and cognition research is creating a new generation of smart machines. Tomorrow's robots will not be confined to industry, but work in the 'real world', providing solutions for many societal issues.

C-3PO may be a likeable enough character in ***Star Wars***, but most real robots are quite unlike the well-spoken (sometimes irritating) cyborg. While the popular image of a robot is a walking, talking humanoid, most of the one million robots installed around the world today are little more than fast and efficient industrial workers.

Many hands may make light work, but in factories robots are ideal for high-volume and high-precision manufacturing industries. Robotics is a key 'enabling technology' for industrial productivity as it automates physical, repetitive and potentially dangerous tasks.

Industrial robots are most prevalent in the automotive sector, where they have been used since the 1960s on production lines for tasks including welding, painting, assembly and handling materials. In Europe, 50 years of automation and the widespread application of robotics have helped European carmakers remain competitive in the global marketplace, despite higher costs of manual labour.

Is there anything I can do?

The successful application of robotics in the automotive sector highlights how such technology has an important part to play as Europe works out the **Lisbon Strategy for Growth and Jobs.**

First, robotics makes industry more competitive and allows manufacturing to continue in high-wage regions like Europe. Linked to this, robotics also helps to drive industry growth and maintain strong employment.

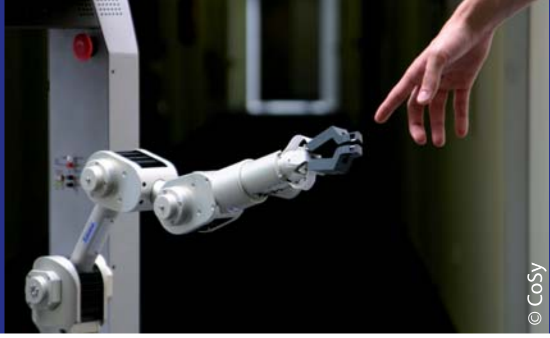
Traditionally, robots have been blamed for taking jobs away from manual workers – the cause of layoffs and unemployment. But a look back over the past 50 years casts doubt on this. While the installation of robots may result in immediate redundancies, the long-term benefits to employment cannot be denied. By limiting the amount of repetitive, manual labour for employees, robots allow the workforce to be deployed on tasks that are cleaner, safer and more rewarding. Employees can be engaged on higher value, more profitable activities that help to grow a business, not just fulfilling orders.

As companies fall under increasing environmental scrutiny, robotics can also improve a manufacturer's green credentials. Robots work fast and efficiently (reducing energy usage and carbon footprints), more accurately (consuming less raw material) and produce higher quality products (fewer rejects means less waste).

Finally, robotics provide a solution to Europe's declining labour force. A recent McKinsey study suggests, for example, that by 2020 Germany may be experiencing a six-million shortfall in skilled labourers. Soon European manufacturers will struggle to both recruit workers and meet their increasing wage demands. Robots can fill the labour gap.

I'm programmed for etiquette...

The **i2010 Initiative** is the EU policy framework that promotes the positive contribution that information and communication technologies (ICT), including robotics, can make to the economy, society and personal quality of life.



The economic benefits of robotics in industry are already clear; they have proven themselves as key tools for competitive growth. But they also have the potential to improve other aspects of European society. For example, healthcare robots could assist hospital staff. More accurate operations and the possibility for patients to receive attention from the best surgeons via a combination of robotics and telemedicine, could greatly improve outcomes. Robots capable of domestic chores could dramatically improve the quality of life for elderly people and enable them to retain greater independence. Robotics also play a growing role in dangerous rescues, cleaning up industrial accidents and, of course, space exploration.

The vision of the **European Robotics Platform** (EUROP) is for robotics technology to become more widespread in society. EUROP calls for robots to be transformed from industrial slaves to human assistants. As assistants, robots will be co-workers in the workplace, companions at home, servants, playmates, delivering professional services and acting as agents for security.

Echoing this vision, robotics research funded under the EU's **Sixth Framework Programme** (FP6) answered the call for an evolution in robotic equipment from specific industrial applications to a wide range of 'enabling' technologies, products and services for the consumer, home and entertainment markets. More intelligent, flexible, cost-effective, modular, safe, dependable, robust and user-driven robot systems would, in the words of the call, "pave the way to the future, massive introduction of robots in everyday human environments and their close co-operation with people".

But this vision of a collaborative or symbiotic relationship with humans is beyond the scope of what can be achieved technically today. Robots still have limited capacity to consider their environmental context and assess how external factors could affect their actions. They still struggle to learn from experience or apply what they have been taught.

EUROP brings together representatives of all stakeholders within the robotics sector to coordinate R&D that will meet some of these challenges. As a **Technology Platform**, established in 2005 under FP6, EUROP is part of the action outlined in i2010 to promote ICT R&D and leadership in innovation. To this end, EUROP published its first Strategic Research Agenda (SRA) in 2006. The SRA, agreed by the platform's 80 members, should enable industrial and academic research communities in Europe to coordinate their activities and work towards the economic, social and personal goals outlined in i2010.

EUROP's SRA is supplemented by another SRA published by the **Coordination Action for Robotics in Europe** (CARE), an activity funded under FP6 specifically to streamline initiatives in the field of robotics in Europe for the first three years of **FP7**. Its own SRA is based on EUROP's, but aggregates wider stakeholder consultations.

More than machines

These SRAs have shaped and guided the direction of research now being funded under FP7. For example, EUROP's SRA identifies two major challenges: first, to develop robotic systems that can sense and interact with the human world in useful ways; second, to design robotic systems able to perform complex tasks with a high degree of autonomy.

Challenge 2 of the FP7 ICT Work Programme is dedicated to 'Cognitive systems, interaction and robotics' and encompasses robotics research projects that "help them to carry out tasks intelligently with people, and in the service of people". The ICT Work Programme 2007-08 outlines the first steps towards realising this ambitious vision.

Smart robotics is still a nascent discipline, so the first two years of robotics research under FP7 is dedicated, in part, to basic research to understand how "the mechanisms underlying artificial and natural cognition, in particular learning and the development of competences requiring goal-setting, reasoning, decision-making, language, communication and co-operation." Only such knowledge will enable robotics engineers to "build machines that can understand, learn and generate concepts and translate them across languages with degrees of robustness and versatility not possible today".

Two calls for proposals under the 2007-08 ICT Work Programme have provided almost €200 million for robotics research addressing cognitive systems, interaction and robotics (Challenge 2). This level of funding is double that made available under FP6 and reflects the EU's growing realisation that robotics offers solutions to sustainable growth and improving the quality of life for citizens.

A total of 27 projects were funded following the first call. Key themes covered by these projects include robotic grasping, manipulation, robot "swarms", the detection and understanding of human and animal behaviour, natural language, cognitive development and machine learning.

Some cutting-edge robotics research may also be funded through the **Future and Emerging Technologies** (FET) theme of the ICT Work Programme or fall outside the FP7 ICT theme entirely (e.g. co-operative research projects within the nanosciences, nanotechnologies, materials and new production technologies theme which are managed by the European Commission's Research Directorate-General).

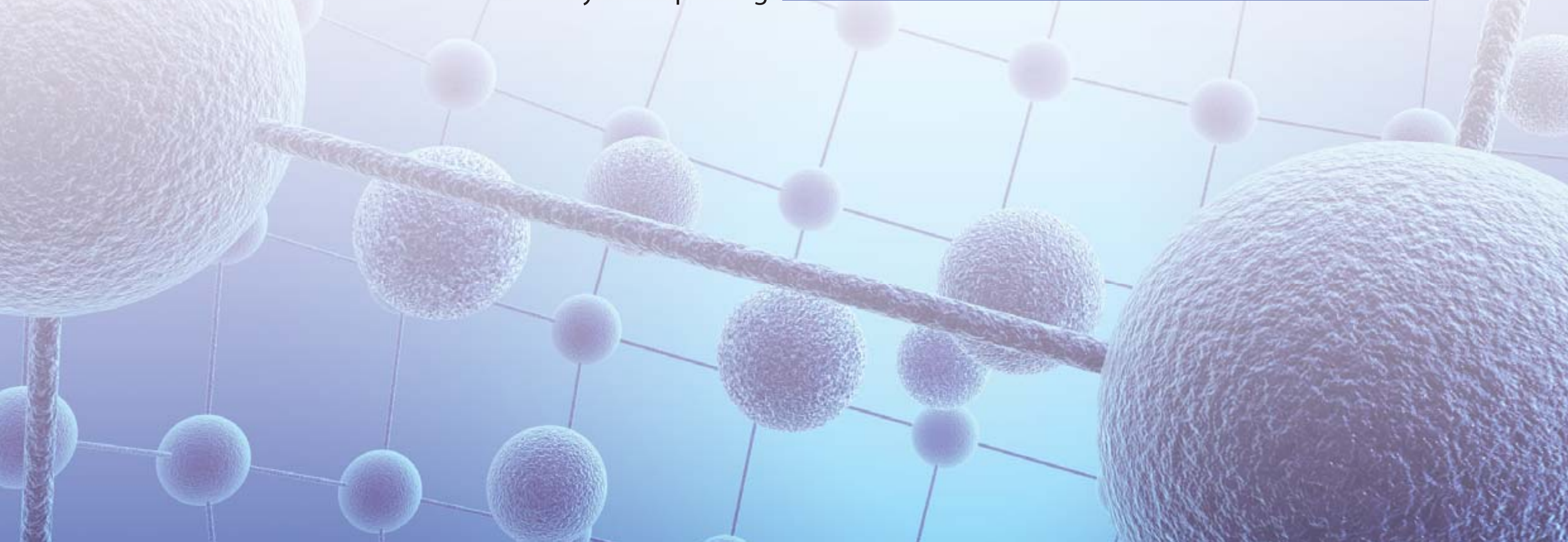
Europe has an impressive heritage in robotics research with a well-acknowledged, world-class scientific and technical base in many underpinning technologies. The EU's commitment to further fundamental and applied research in the areas of sensing, cognition and control will ensure that robotics keeps industry competitive and – directly and indirectly – provides European citizen's with a better quality of life.

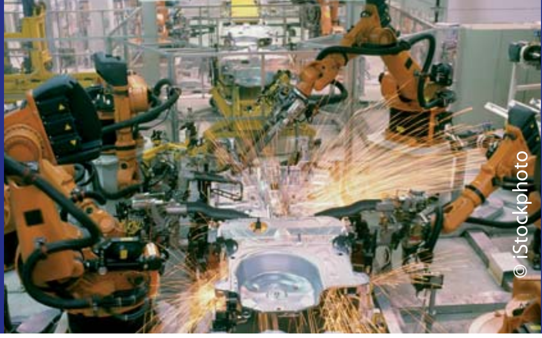
Common vision for future 'cognitive' robots

While the main emphasis of FP7 research looks towards the wider application of robotics in society, the importance of greater automation within industry must not be overlooked. It is estimated that only around 15% of possible industrial processes are currently automated, and more can be done to improve the transfer of technology to industrial applications.

Opportunities for growth lie in the service robotics markets and it is clear that they will be driven by technology. In this respect, there is a consensus that future robot systems will need to integrate sensor technology and be 'cognitive', and that academic and industrial research efforts will need to share a more common vision to achieve this.

Today, industry is more willing to support the widespread introduction of industrial-strength platforms into academic labs, while academic groups are collaborating to agree on what kinds of experiments should be carried out on these platforms. EU-funded initiatives aim to facilitate this industry-academic dialogue and improve technology transfer and commercialisation.





Meeting the challenges

Contrary to the popular belief that robots replace people and cause unemployment, industrial automation is a pillar of sustainable economic growth. History has shown that, while the introduction of automation technologies may result in short-term job losses, in the longer-term it creates wealth as employees focus less on manual, low value-added tasks and more on company growth.

The challenge that European researchers face is to make robots even more useful than they already are – and not just in industry. It is time that robotics technology moved out of the manufacturing sphere and evolved into versatile, 'assistive' technology, capable of working alongside and learning from humans in specialist and everyday tasks.

But the technology is a long way from this ideal. Significant investment is required to improve every aspect of a robot's function, from how it monitors and senses the environment and its context, the way it processes information and makes decisions, to its control systems that ensure it responds appropriately and works efficiently and reliably.

Perception

On standard production lines in use today, robots need some sensing technology as items are presented to them. But this is a uniform action responding to uniform input. But what if robots could perceive changes and act accordingly? To make robotics more versatile and functional outside of manufacturing, this is what is needed. High-tech sensing systems are required so this next generation of robots can carefully assess their surrounding environment. Ongoing research is required to give robots perhaps more human-like qualities, including the sense of sight, hearing and touch.

Advanced behaviours

Automation works as long as everything stays exactly the same. When something changes that means a robot will have to alter its task, even slightly, smarter technology is definitely needed. To help (rather than hinder) humans, robots must develop intelligence. It is essential that they can process information and make reasoned responses. The mechanisms of cognition, learning and reasoning are still poorly understood. Significant fundamental and applied research in cognition science and artificial intelligence are essential before robots can be expected to play any significant role other than as industrial slaves.

Response

Armed with all the information they need, and improved reasoning powers, robots must then respond accurately and efficiently. Continued research is necessary to improve control systems and versatile hardware, particularly for robots designed to move around different environments. Grasping is probably the most common robotic response, and research continues to improve the mechanics and control of robotic limbs. Another interesting avenue for investigation is the ability of robots to co-operate, not responding as individuals, but working together for greater efficiency and better results.

Perceptive robots make more sense

Robots and automation technologies must collect information about their environment so they can respond appropriately and more efficiently. A number of EU-funded projects focus on sensing technologies and new ways for robots to explore and better understand context and their environment.

Europe needs to adjust to fast-changing economic realities. It must achieve higher economic growth through more innovation and higher productivity, while creating more jobs. The Union's i2010 Initiative recognises that robotics can contribute to meeting these challenges.

The use of industrial robots is increasing steadily, in sectors such as food and packaging, plastics, and other areas of manufacturing like household appliances and furniture. Indeed, outside the automotive and electronics industries, European manufacturers use more robot systems than anywhere else in the world, including Japan and the USA.

The Strategic Research Agenda (SRA) published by the Coordination Action for Robotics in Europe (CARE), analyses 23 so-called "product visions" for robotics in Europe, many of which are not traditional industrial robotics. This vision of robotics beyond the traditional production line requires robots to become more versatile, flexible and aware.

In other words, robots must become more 'sensitive', achieved by the integration of sensing technologies. This is an essential first step in meeting the call for robotics to "get real" and move from constrained (i.e. factory) to real-world environments.

The objectives outlined in the FP7 ICT Work Programme 2007-08 place emphasis on sensing networks. Instead of relying on what it terms a single "eye" – for example, a digital camera – future robots could receive data from a diverse array of sensors.

Perception at a glance

Most industrial robots, performing repetitive actions on a production line, have limited sensing capacities. However, if robots are to evolve into human assistants, they must integrate more sophisticated, advanced optical, aural and tactile sensing systems so that they can monitor complex changes to their immediate environment.

Indeed, co-operative robots could use wireless communications technology to share environmental data between them and thus give team members access to a much better range of information.

Conversely, a community of co-operative robots mounted with sensors could themselves form an intelligent and potentially mobile sensor network. Such an application of robotic sensing and environmental monitoring could have important applications for real-time information gathering and interpretation in emergency or hazardous situations.

Eyes with brains

The frontier between perception, data handling and cognition is beginning to blur because of the growing number of 'smart' sensors. Europe has particularly developed expertise in the area of cognitive vision, whereby the visual hardware can immediately recognise and categorise objects without central data processing. Cognitive vision finds important applications in object tracking.

European policy demands that robotics technology is adapted for real-world, everyday applications so that they can fulfil their potential to solve societal issues and improve the quality of life of citizens. A robot's ability to work in open-ended, uncharacterised environments, where they may have no prior knowledge about their context, demands significant progress in smart sensing technologies and their integration into robotics.

Projects in action

SPARK
MACS
CHIL
CAVIAR
HUMAINE

One of the challenges facing European researchers is to develop mobile robots that are capable of several different behaviours, that are able to sense or perceive external signals and, most importantly, are able to 'learn' and react appropriately to changing conditions.

SPARK has provided a new paradigm for active robot perception, based on research into insect brains and principles borrowed from psychology, synergetics, artificial intelligence and non-linear dynamical systems theory. Perception is enhanced by the robot's ability to use information derived from visual, audio and tactile sensors to form a dynamically evolving pattern. The pattern is, in turn, used to determine the movements of the device.

The robot works out how best to carry out its mission in a particular external context. The robot behaves initially using basic inherited behaviours, for example moving towards a specific sound source. But higher, acquired knowledge is then built up incrementally as the robot detects the consequences of its 'instinctive' actions.

The improvements achieved by the researchers have already been integrated into products made by some of the project's partners, including a software package based on some of SPARK's cognitive visual algorithms.

The **MACS** project takes a radically different approach to a robot's visual perception. Instead of getting robots to perceive what something is, the project has enabled a robot to understand how it can be used.

This is an application of the cognitive theory of 'affordances'. Computer vision might identify an object as a chair, but a system of affordances will instruct the robot that it can be used for sitting. This means that, once an affordance-perceiving robot 'sees' a flat object of a certain height and rigidity, it knows that the object can be used for sitting.

In a test, a robot successfully used affordance-based perception to find an object, pick it up, and put it on a pressure-activated switch that controlled a door. The robot detected the passage and moved through the door. This remarkable achievement is one of the best demonstrations to date that robots can be programmed with a capacity for improvisation to perform real-world tasks.

Taken in another direction, sensing technology can be applied to traditional settings, such as business applications, where humans need help. Researchers on the **CHIL** project set out to make the technology used in meeting rooms and lecture halls more responsive to human needs. The team developed systems that could understand the context of meetings and proactively help the participants by controlling the meeting environment. For example, during a meeting such a system can filter and respond to incoming mobile phone calls to each participant, secretly remind participants of facts, such as other participants' names, and provide a virtual shared workspace for all.

The project has proven to be remarkably successful, with many spin-off applications and activities.

One application is being developed by a start-up company, Videmo Intelligent Video Analysis. Its software will focus on customer monitoring in retail situations. The system can automatically analyse customer behaviour to show, for instance, which displays are attracting attention and which are not. On the security side, the system can provide video-based monitoring and analysis of point-of-sale systems, including automatic fraud detection.

The **CAVIAR** project, meanwhile, has also made significant improvements to digital visual perception. It has developed a frame-free vision system that uses so-called 'spike events', produced whenever there is movement in the scene. "Instead of using frames, each pixel decides when it wants to send information, and that is dependent on changes in brightness," says Tobi Delbruck, the project's spokesman "This is a nice property because if nothing changes there is no output."

By outputting spike events, the silicon retina, or DVS as it is known, allows for processing of novel visual information at the moment it occurs, resulting in greatly reduced power consumption and response time. Traditional cameras operate at a rate of about 50 frames per second, but CAVIAR is about 200 times faster. As a pure hardware solution this remarkable speed is possible without a single line of computer code.

Delbruck sees the greatest potential for its application in robotics. Examples demonstrating this application include a car that drives itself along a track. The car uses the sensor to follow a line on the track. The application could be used for driver assistance.

Not all perception involves straightforward visual analysis. To help machines work better alongside people, the **HUMAINE** project is helping them to recognise emotion. Complex research by an interdisciplinary team of philosophers, psychologists and computer animators has looked at all the clues people give to their emotional state: the words they say, the tone, facial expressions, and smaller signals like eye gaze, hand gestures and posture. In trials in Scotland and Israel, museum guides – in the form of handheld PDAs with earpieces and microphones – monitor visitors' levels of interest in different types of display and react accordingly

More information:

SPARK: www.spark.diees.unict.it
MACS: www.macs-eu.org
CHIL: http://chil.server.de/servlet/is/101
CAVIAR: www.imse.cnm.es/caviar
HUMAINE: http://emotion-research.net
EUROP: www.robotics-platform.eu.com
CARE: www.robotics-care.eu

ICT and robotics and cognition stories on ICT Results: http://cordis.europa.eu/ictresults (enter search terms 'robotics and cognition')

ISTweb: http://cordis.europa.eu/ist/

IST and cognition research: http://cordis.europa.eu/ist/cognition

i2010: http://ec.europa.eu/information_society/eeurope/i2010

I think therefore I am... a robot?

The vast majority of industrial robots are honed for the artificial environment of manufacturing plants. They are unable to deal with unusual circumstances. It takes smart technology to reason through possible responses, learn from past experiences – and understand the complexities of human behaviour.

From the earliest days of school through to university graduation and beyond, teachers and mentors try to show their pupils how to think for themselves. They equip us with the tools and skills to find out answers on our own.

Scientists are still trying to fully understand how humans think and learn, and how this knowledge can be applied to machines. But if robots are to become more versatile, adapt to new or changing environments and function effectively in the real world, they must be equipped with cognitive capacities that can consider and control responses in real time.

Most importantly, robots must be capable of dealing with the uncertainty that is inherent in sensory data. Uncertainty takes the form of unexpected events, novel situations and interactions with other complex agents (namely humans) whose behaviour or influence on a scenario is difficult to predict.

Off the factory floor, environments can be too nuanced, too complicated and too unpredictable to be summarised within a limited set of specifications or rules. Cognition is a way of overcoming uncertainty in a world that is not pre-specified. A robot must be programmed with higher-level principles that describe the processes it must follow – exploiting memory, forecasting and learning – to discern the best response when faced with gaps, conflicts and ambiguities in its knowledge.

Advanced behaviours at a glance

For the past 50 years, robots have been little more that faster, more efficient and more accurate industrial machines. But endowed with thinking skills, they are finding applications in real-world environments. Cognitive sciences and artificial intelligence are key to meeting Europe's demand for wider application of advanced robotics solutions.

Research into cognitive systems is highly multidisciplinary in nature, with input from, among others, computer scientists, psychologists, behaviour analysts, neurologists, philosophy and biology.

EUROP and CARE's Strategic Research Agendas make it clear that advanced behaviours – cognition, autonomy and co-operation – should be a primary feature in future robotics solutions. In producing its SRA, EUROP evaluated 120 challenges facing robotics development in Europe and found that 41% involved the need for further research in advanced behaviours. Whether robots are co-working with people in industrial or domestic settings or patrolling borders, they are all but useless unless they can make decisions for themselves and work together where necessary.

Cognition adds value to what robots can do and more than 40 projects have been funded under the Union's Sixth Framework Programme to explore the fundamentals and applications of cognitive and advanced systems.

From elementary pattern recognition, research is now providing the knowledge for the next generation of robots with a higher level of smart technology that can infer and reason, plan ahead, set goals, learn and be made self-aware within a co-operative community. Perhaps the day of *I, Robot* reasoning is now not too distant.

Projects in action

COSPAL
DIPLECS
CoSy
NEW TIES

Designers of artificial cognitive systems (ACS) have tended to adopt one of two approaches to building robots that can think for themselves: classical rule-based artificial intelligence (AI) or artificial neural networks (ANN). But combining the two offers the best of both worlds. European research has this in hand.

The **COSPAL** project has developed a new breed of cognitive, learning robot that goes beyond the state of the art. "Developing systems in classical AI is essentially a top-down approach, whereas in ANN it is a bottom-up approach," explains Michael Felsberg, a researcher at the Computer Vision Laboratory of Linköping University in Sweden. "The problem is that, used individually, these systems have major shortcomings when it comes to developing advanced cognitive architectures. ANN is too trivial to solve complex tasks, while classical AI cannot solve them if it has not been pre-programmed to do so."

In what the researchers believe to be the most advanced example of such a system developed anywhere in the world, COSPAL used ANN to handle the low-level functions based on the visual input their robots received and then employed classical AI on top of that in a supervisory function.

The COSPAL system is able to learn by itself and can solve increasingly complex tasks with no additional programming. The project partners are launching a follow-up project called **DIPLECS** to test their architecture in a car. It will be used to make the vehicle cognitive and aware of its surroundings, creating an artificial co-pilot to increase safety no matter the weather, road or traffic conditions.

While building robots with anything akin to human intelligence remains a far off vision, making them more responsive would allow them to be used in a greater variety of sophisticated tasks in the manufacturing and service sectors. The **CoSy** project has brought together a diverse group of cognition researchers to further advance the field. The team integrated many cognitive components to create robots that are more self-aware, understand their environment, and can better interact with humans. Making an open source toolkit for the architecture available, CoSy has already sparked several spin-off initiatives.

A demonstrator called the Explorer developed by the CoSy team has a human-like understanding of its environment. Explorer can even talk about its surroundings with a human. Instead of using just geometric data to create a map of its surroundings, the Explorer also incorporates qualitative, topographical information. Through interaction with humans it can then learn to recognise objects, spaces and their uses. For example, if it sees a coffee machine it may reason that it is in a kitchen. If it sees a sofa it may conclude it is in a living room. Another demonstrator, called the PlayMate, applied machine vision and spatial recognition in a different context. PlayMate uses a robotic arm to manipulate objects in response to human instructions.

The CoSy team foresee robots like those developed in the project becoming an everyday sight over the coming years. Already some robots with a lower level of intelligence are being used to bring medicines to patients in hospitals and could be used to transport documents around office buildings. Robotic vacuum cleaners and lawn mowers are becoming increasingly popular in homes, as too are toys that incorporate artificial intelligence. And the creation of robots that are able to interact with people opens the door to robotic home-helpers and caregivers.

A project funded under the EU's Future and Emerging Technologies (FET) initiative is creating a thoroughly 21st-century brave new world – one populated by randomly generated software beings, capable of developing their own language and culture. This kind of social interaction is a tantalising prospect for artificial intelligence (AI) experts, computer scientists, sociologists and linguists working on **NEW TIES**. "While individual (or machine) learning and evolutionary behaviour have been quite well studied, social learning is still an unknown quantity," says project coordinator Gusz Eiben, an AI professor at the Vrije Universiteit, Amsterdam.

The project has two main goals: to study natural processes (like language development), and to advance the construction of collective artificial intelligence.

"Robots in the home are only five to ten years away, and in the future we might be able to send robot rescue teams to disaster areas to search for survivors," says Eiben. "They could even one day travel to Mars. Obviously, it will be important for them to be able to co-operate with each other – especially if they are in a hostile environment."

The NEW TIES engine runs on a grid of computers and supports millions of agents, each one a unique entity with its own characteristics, including gender, life expectancy, fertility, size, and metabolism. The agents will not be labelled, but will have their own distinguishing characteristics to make them recognisable. Their traits will be inherited from their parents, and passed on to their offspring, but they will be able to learn from their own experiences and from each other. The agents have the ability to communicate, using a 'native vocabulary' of a few simple words like, 'food', 'near', and 'agent' and will be given some basic laws of nature although they are also able to form their own.

Output from experimentation with NEW TIES will help scientists understand the development of language and collective knowledge and could find application in new robots with advanced behaviours. But Eiben anticipates another way in which such simulations could be used: politicians could run simulations on computers to test scenarios (for new tax laws, for example) before carrying them out in real life. "Simulators now allow us to optimise car engines or train timetables," says Eiben. "But why shouldn't they help us optimise social decision-making?"

More information:

COSPAL: www.cospal.org
DIPLECS: www.diplecs.eu
CoSy: www.cognitivesystems.org
NEW TIES: www.new-ties.org/mambo
EUROP: www.robotics-platform.eu.com
CARE: www.robotics-care.eu

ICT and robotics and cognition stories on ICT Results: http://cordis.europa.eu/ictresults/ (enter search terms 'robotics and cognition')

ISTweb: http://cordis.europa.eu/ist/
IST and cognition research: http://cordis.europa.eu/ist/cognition

Future and Emerging Technologies – complex systems: http://cordis.europa.eu/ist/fet/co.htm

i2010: http://ec.europa.eu/information_society/eeurope/i2010

Getting the job done, robot-style

***A** 'good' robotic response depends greatly on its context. It may be moving successfully between objects, grasping an item, completing a task without human intervention, or simply smiling. Research in a wide range of disciplines is helping robots to respond more appropriately in their new role as human assistants.*

Robotic responses at a glance

The measure of a well-designed robot is one that responds well to whatever situations it encounters. European research focuses on a number of response systems and control technologies, covering everything from actuators and manipulation devices to human-machine interaction.

The EU's i2010 Initiative recognises that, as human assistants, tomorrow's robots have an important role to play in European society. In particular, they have the capacity to resolve many of the future economic and social challenges faced by European society, such as ageing and well-being.

But the state of the art is still not yet sufficiently advanced to unleash robotics solutions and implement them widely. Their cost is one drawback, but reliability is possibly the greatest barrier to acceptance. Rarely can robots be left to get on with potentially complex or changing jobs on their own.

To access new markets and be competitive, robots have to be dependable, smarter and able to work in closer collaboration with humans, according to the EUROP SRA. "Designing dependable robots is a major challenge for future robotic products in all application domains," it notes.

A dependable robot is one that gets everything 'right' – it responds appropriately and efficiently in different scenarios to achieve its set objective. Research into improving reliability therefore touches on all areas of robotics, including sensing and advanced behaviours. But it also covers other areas such as actuators, manipulation, grasping and emotional responses.

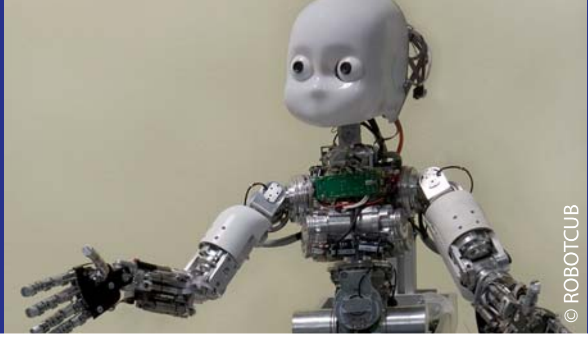
A roadmap for research in all of these areas is outlined in EUROP's SRA. The primary challenge for actuators, for example, is the "integration of sensing and control directly into actuators making them 'smart actuators'." Research into manipulation and grasping will try to increase the payload capability, precision, and speed of manipulation and grasping responses while decreasing the cost.

The FP7 ICT Work Programme 2007-08 places a strong emphasis on the need for research into these motion outputs. It calls for projects to involve "robots handling, individually or jointly, tangible objects of different shapes and sizes, and operating either fully autonomously (as for instance in difficult terrains with a need for robust locomotion, navigation and obstacle avoidance) or in co-operation with people in complex, dynamic spatial environments (e.g. domestic environments)".

But autonomy does not mean that robots can simply go off and do their work. If they are to work effectively alongside humans, they must also be good communicators. Future robots must be able to understand people and interact with them closely. The 2007-08 Work Programme also calls for more work to be conducted on "intuitive multi-modal interfaces and interpersonal communication systems."

Human-robot interactivity must allow robots to understand speech, gestures, recognise emotions and interpret all these within different contexts. Virtual programming tools and wireless data transmission, combined with low-cost interfaces that resemble current manual devices should also permit better diffusion of robotics into SME organisations and their proper use by untrained people.

If humans are given every opportunity to provide their robotic assistants with "the best possible start" (i.e. correctly trained and programmed) through well-designed interfaces, then robots will be best placed to "deliver the goods" – or dispense drugs, vacuum carpets or even help perform open-heart surgery.



Projects in action

ROBOTCUB
SWARM-BOTS
SWARMANOID
ECAGENTS
COGNIRON

Teaching robots to understand enough about the real world to allow them to act independently has proved to be much more difficult than first thought. The team of European researchers behind the iCub robot believes it, like children, will learn best from its own experiences.

The technologies developed by the **ROBOTCUB** project for iCub – such as grasping, locomotion, interaction, and even language-action association – are of great relevance to further advances in the field of industrial service robotics.

The iCub robots are about the size of three-year-old children, with highly dexterous hands and fully articulated heads and eyes. They have hearing and touch capabilities and are designed to be able to crawl on all fours and to sit up.

The first and key skill iCub needs for 'learning by doing' is an ability to reach towards a fixed point. By October 2008, the iCub developers plan to have developed the robot so it is able to analyse incoming information via its vision and feel 'senses'. The robot will then be able to use this information to perform at least some crude grasping behaviour – reaching outwards and closing its fingers around an object.

"Grasping is the first step in developing cognition as it is required to learn how to use tools and to understand that if you interact with an object it has consequences," says Giorgio Metta, one of iCub's developers. "From there the robot can develop more complex behaviours as it learns that particular objects are best manipulated in certain ways."

Not all robots have to be humanoid. The **SWARM-BOTS** project has developed highly unusual mini-robots, or swarm-bots, that work as a team to overcome challenges. While their co-operative behaviour is inspired by the actions of the tiny ant, their abilities could eventually take them to outer space.

Imitating insects such as ants, highly mobile small robots can accomplish physical tasks that no individual robot of the same size could manage. But if more sophisticated versions appear, then such machines could complete coordinated tasks in a way that could revolutionise the way we think about our world today.

Just 12cm in diameter, these mini-robots are packed with computing power, sensors and actuators. Each robot carries sophisticated technology, including a panoramic camera, sensors that detect sound, infra-red, light, temperature and humidity, motors for the grippers (or claws), and WiFi and USB connections. A unique feature of the s-bots is their ability to attach to one another using the grippers.

In one trial, the s-bots (the individual robots that make up a swarm) linked up to bridge and thus pass over a hole in the ground. In another, they jointly carried objects too weighty for a single robot to handle.

"Control was vital to the project," says its coordinator Marco Dorigo. "The robots autonomously attach to each other and move around in coordination. Their tracks and wheels guide their directional movement. Though the robots do not talk among themselves, they receive low-level signals – such as individual push and pull forces – allowing coordinated group movement."

SWARMANOID, a three-year follow-on project, is creating three different kinds of advanced robots. Featuring open-source software, these super s-bots will crawl, climb or fly, working alone or together.

Most research into artificial intelligence (AI) that underpins any form of intelligent machine-machine or machine-human interaction has centred on programming the machine with a set of predefined rules. Researchers have, in effect, attempted to build robots or devices with the communication skills of a human adult. That is a shortcut that ignores the evolution of language and the skills gained from social interaction. But the **ECAGENTS** project has developed technology to allow machines to evolve their own language from their experiences of interacting with their environment and co-operating with other devices.

"The result is machines that evolve and develop by themselves without human intervention," explains Stefano Nolfi, the project's coordinator. Initially programmed to merely recognise stimuli from their sensors, robotic dogs (AIBOs) learnt to distinguish between objects and how to interact with them over the course of several hours or days. A curiosity system, or 'metabrain,' continually forced the AIBOs to look for new and more challenging tasks, and to give up on activities that did not appear to lead anywhere. This, in turn, led them to learn how to perform more complex tasks – an indication of an open-ended learning capability much like that of human children.

And also like children, the AIBOs initially started babbling aimlessly until two or more settled on a sound to describe an object or aspect of their environment, thus gradually building a lexicon and grammatical rules through which to communicate.

The success of the evolutionary and social learning approach taken to developing AI by the project has also been demonstrated in a test in which hordes of small, wheeled robots learnt how to communicate, co-operate and self-organise to perform tasks that would be too complicated for a single robot. "This is a project with a big impact. We've managed to ground AI in reality, in the real world, solving one of the crucial problems to creating truly intelligent and co-operative systems," says Nofi.

The **COGNIRON** project, meanwhile, has focused on the possibility of companion robots, fulfilling personal needs. Just as it was impossible 30 years ago to imagine how PCs would change the world's economics, politics and society, no one foresees how the ability of a companion robot to mix you a drink could revolutionise society. But trivial actions could one day make a big difference.

COGNIRON's research was organised around seven key research themes: multi-modal dialogues, detection and understanding of human activity, social behaviour and embodied interaction, skill and task learning, spatial cognition and multi-modal situation awareness, as well as 'intentionality' and initiative. Finally, the seventh research theme, systems levels integration and evaluation, focused on integrating all the other themes into a cohesive whole.

Getting a robot to move around a human, without hurting them, and while making them feel comfortable, is a vital task. The robot must pick up subtle cues. If, for instance, a human leans forward to get up, the robot needs to understand the purpose of that movement. Furthermore, much human communication is non-verbal, and such cognitive machines need to pick up on that if they are to be useful, rather than irritating.

Even in verbal communication there are many habits robots need to acquire that are so second nature to humans that we never think of them. "For example, turn taking in conversation. Humans take turns [to talk], we need to find a way to make robots do the same," says Raja Chatila, the project coordinator. A robot that keeps interrupting would get on an owner's nerves.

To tackle the problems, the researchers took inspiration from natural cognition as it occurs in humans, which is one reason why a cognitive robot companion needs to be able to learn.

Despite its highly ambitious aims the project made enormous progress. One experiment featured a robot building a model of its environment in the course of a home tour, another involved a curious and proactive robot that was able to infer that a human needs something to be done. A third robot was able to learn by imitation and repetition.

More information

ROBOTCUB: www.robotcub.org
SWARM-BOTS: www.swarm-bots.org
SWARMANOID: www.swarmanoid.org
ECAGENTS: http://ecagents.istc.cnr.it
COGNIRON: www.cogniron.org
EUROP: www.robotics-platform.eu.com
CARE: www.robotics-care.eu

ICT and robotics and cognition stories on ICT Results: http://cordis.europa.eu/ictresults/ (enter search terms 'robotics and cognition')

ISTweb: http://cordis.europa.eu/ist/
IST and cognition research: http://cordis.europa.eu/ist/cognition

Future and Emerging Technologies – Beyond Robotics: http://cordis.europa.eu/ist/fet/ro-sy1.htm

i2010: http://ec.europa.eu/information_society/eeurope/i2010

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