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ICT Research
New perspectives

ICT and Future and Emerging Technologies

Embracing revolution

European Commission
Information Society and Media

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ISPL publications and other news are available via the website:
http://ec.europa.eu/information_society/activities/policy_link/

ICT Results is an online editorial service established on behalf of the Information Society and Media Directorate-General.

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

ICT Results website: http://cordis.europa.eu/ictresults

Trailblazing the future of ICT

In this report produced for the ICT Research New Perspectives series, we look at the EU's substantial investment in high-risk research. Europe balances its strategic research portfolio, focusing on solving industry and societal problems, with a programme dedicated to future and emerging technologies. The outcomes of this speculative research may be uncertain, but the returns hold tremendous promise for European growth and competitive strength.

When George de Mestral returned from a walk with his dog he observed how tenaciously the burrs of the mountain thistle clung to his trousers and his dog's fur. He was so curious that he pulled out a microscope and saw tiny hooks; the idea for Velcro® was sown.

Some of the best scientific discoveries, such as penicillin and Teflon®, are made almost by chance. Even in the high-tech world of ICT, many advances have been unexpected or the off-shoot of other research activities. The World Wide Web, for example, was not the outcome of a focused research programme. The Web had its origins in a CERN research project, but then developed into a technology that has revolutionised global society.

Classic tales of serendipitous discovery abound, and are usually quoted to show that risky and speculative research can yield significant results and spark unprecedented changes in society. But would de Mestral secure funding for a walk in the Alps today? Do scientists in Europe ever find money for highly speculative experiments? Do mavericks ever access EU RTD funding?

Science for the future

Where research grants come from public funds it is hard to find the balance between RTD that addresses the pressing needs of industry and society, and risky research that may, at best, extend the frontiers of scientific knowledge. **The EU's Research Framework Programme** (currently the Seventh Framework Programme, FP7) is no exception.

FP7 has a total budget of more than €9 billion for ICT-related activities. Calls for research proposals follow seven major themes, called 'challenges', which ICT must address. These challenges cover the main issues outlined in the **i2010 initiative**, the EU policy framework for the information society and media that promotes the positive contribution that ICT can make to the economy, society and personal quality of life.

Future and Emerging Technologies (FET) is a dedicated stream in the Union's ICT programmes which is divided into two main activities: FET-Open and FET Pro-active. Projects funded under FET are where scientists get to speculate, to push boundaries, to revolutionise science. These two activities together enable research that may take longer or an unexpected route to meet policy objectives.

Unfettered research

This speculative funding stream has been in place since the earliest days of the Framework Programme. It is well recognised and respected for its long-term potential. It promotes the exploration of radically new ideas and trends for future research and innovation, providing sustained support to emerging areas that require multi-disciplinary and long-term fundamental research.

FET's mission is to "promote research that is of a long-term nature or involves particularly high risks, compensated by the potential of a significant societal or industrial impact." As such, FET is not limited to priorities in the ICT programme per se, but rather aims to open new possibilities, set new trends for future research programmes and act as an agile pathfinder which reacts to new ideas and opportunities as they arise from within the scientific community or society.

Open to risk

FET-Open takes a bottom-up approach. Free from deadlines and demands for extensive documentation, scientists are invited to send in their proposals at any time. It is open, for example, to a broad spectrum of needs, opportunities and solutions; it avoids the risk of tunnel vision in ICT research and acts as an early indicator of new directions and opportunities for innovation in ICT.

Since the topics covered in supported projects are not predefined by the ICT Work Programme, but identified by the researchers themselves, FET-Open accommodates the exploration of new research horizons. Unconstrained by established approaches, it offers the opportunity to try out unproven ideas where the risk is too high for a larger RTD investment to be justified.

FET Pro-active operates in a top-down manner focusing resources towards visionary and challenging long-term goals that are timely and have strong potential for future impact. Pro-active initiatives are launched on topics with important potential, and where significant scientific or technological barriers and risk justify a concerted action at basic research level. FET Pro-active serves as a pathfinder that prepares for future directions in which the ICT programme, together with industry, may create the critical mass that can really make a difference to Europe's sustainable growth and the quality of life for its citizen's in the long run.

Pro-active initiatives are launched through calls for proposals. In the 2007-2008 ICT Work Programme, FET Pro-active has launched six initiatives that contribute to several ICT challenges, including the need for better performing computing systems and the wider and more integrated application of ICT in society and industry. FET Pro-active topics are selected through consultation, especially brainstorming events with high-level scientists across Europe and beyond.

Policy-driven 'play'

FET research may be long term and high risk but it is still purpose driven. It falls within the broader context of European policy and it explicitly contributes to the broader ICT issues set out in **i2010**.

In these ways, FET research responds directly to the **Lisbon Strategy for Growth and Jobs** – Europe's top-level policy for assuring the EU's sustained economic growth and a competitive global position. The strategy makes it clear that research is critical to achieving these aims, calling for greater investment in knowledge and innovation. By keeping Europe open to the most recent developments in ICT research and offering opportunities to discover new avenues of investigation, FET projects provide a foundation for Europe's future in ICT development and deployment.

FET also plays an important part in **unlocking the potential of SMEs**. Operating its grass-roots approach, FET-Open is particularly attractive to innovative SMEs that wish to collaborate and tackle issues that fall outside of mainstream research agendas. FET-Open projects supported under the STREP funding instrument are ideal for SMEs as they are limited in scope with concrete objectives to achieve over a defined period.

The simplified proposal process for FET-Open also encourages SMEs to get involved and has been highlighted by Esko Aho, former Finnish prime minister, in his evaluation report on the Sixth Framework Programme. The report sees the FET-Open process for evaluating proposals as a model for the entire Framework Programme. Aho argues that shorter early-stage proposals with fewer details of work packages should encourage the involvement

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of more appropriate and innovative participants and make all areas of research funding more accessible to SMEs.

Surprising science

"FET can change your life." Perhaps scientists should receive this warning before getting involved in FET because this kind of blue-skies research has the potential to change the way researchers see themselves and their field. FET paves the way to complex interdisciplinary investigations of far-reaching subject matter.

Scientists working on FET projects get a unique opportunity to work with the best people from other disciplines; this healthy mixing of disciplines frequently changes the researchers' perspective on what the problem is, how it can be tackled, and what the results could mean. It is not unusual to find computer scientists working with anthropologists, chemists, biologists, even with experts in ethics.

Of course, science has a habit of surprising us all; it is possible that the next big thing in ICT could still come from unexpected quarters. But the FET initiative is designed for inventors and researchers like George de Mestral (Velcro®), Alexander Fleming (penicillin) and Roy Plunkett (Teflon®); it ensures that curiosity is never quenched. And it puts Europe in the best possible position – surprises aside – to be at the leading edge of ICT innovation and an early adopter of new techniques and technologies for the benefit of the economy and society.

More information:

FP7 ICT Research Programme:
http://cordis.europa.eu/fp7/ict/home_en.html

Future and Emerging Technologies:
http://cordis.europa.eu/fp7/ict/programme/fet_en.html

Lisbon Strategy for Growth and Jobs:
http://ec.europa.eu/growthandjobs/

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

Aho Evaluation Report:
http://ec.europa.eu/dgs/information_society/evaluation/rtd/fp6_ist_expost

Meeting the challenges

A great many of the clear and present challenges for ICT research – short-term industrial bottlenecks and long-term societal issues – are covered by the seven themes of the mainstream FP7 ICT Work Programme.

Nevertheless, in its trailblazing role, FET supports burgeoning fields of uncertain, cutting-edge and groundbreaking research that are, as yet, unable to merit a presence within the main ICT research funding scheme or garner a critical mass of researchers at a European level.

Ten FET Pro-active initiatives were launched under FP6 and the list is growing under FP7. These initiatives – and the one-off projects funded by FET-Open – all fall under three broad ICT research themes:

Future systems

One of the biggest questions facing the ICT sector today is how to make computers more powerful and faster, yet smaller and more energy efficient. Significant mainstream research (mainly within Challenge 3 of the ICT Work Programme – Components, Systems and Engineering) is looking at how to maintain the relentless shrinking of microchips, but FET research broadens the horizon. While embracing nano-electronics, photonics and quantum computing, some projects in this area suggest a complete rethink about the way we do computing. They are looking at new materials and designs for components, new architectures for ICT systems, imaginative networking scenarios or communication pathways. They do not take today's ICT systems as a starting point, but ask the question "What if we did it like this?"

Humans and machines

ICT has become an integral part of our lives, but we must now embed it deep into society if we are to make the most of its benefits. The aim is not to replace humans with computers wherever possible, but to find the best and most efficient applications of ICT and develop new ways for humans and machines to interact. Whether through innovative interfaces or more seamless linkages, the boundary between the user and the technology is beginning to blur.

Paradigm shifts

FET research lets scientists explore uncharted territory. Some findings will be rejected, but some – sometimes at odds with scientific consensus – may eventually end up as mainstream. High risk and highly speculative projects may lay the foundations for entirely new models of ICT and revolutionise how we perceive and use the technology in the future.

Read on to learn how...

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To the micro-nano-world and beyond

One of the tenets of technological progress is that, over time, you can do the same thing with something much smaller. ICT is no exception, and microelectronics are now shrinking to the nano-scale. But FET research takes a macroscopic view and looks at entirely new architectures for ICT systems and components that could provide the basis for unprecedented computing power in the future.

Future systems at a glance

In our pursuit of smaller, more powerful, yet energy efficient microprocessors, the ICT industry is reaching the limits of its current capabilities. ICT needs a major overhaul, with new materials and techniques to manufacture components, innovative architectures for computing systems and fresh approaches to communication and networking.

Moore's Law has reached crisis point. For more than 40 years, the observation that it takes roughly 18 months for chip manufacturers to fit twice the processing power on a silicon wafer has held true. But manufacturing techniques are stretched to their limits; new approaches are needed if ICT components are to enter the world of nano-electronics.

However, manufacturing is only part of the problem. According to the International Technology Roadmap for Semiconductors (ITRS), the physics of silicon-only components may not hold at the nano-scale. The ITRS states that silicon-only technology will soon reach the limits of miniaturisation and power efficiency.

ICT has undoubtedly transformed European society and provided a massive fillip to its economy. In the late 1990s and early 2000s, ICT systems contributed to about half of European productivity gains. ICT plays a central role, helping Europe to remain competitive and offer products and services that can compete with cheaper options from fast-developing economies and manufacturing bases, such as India, China and other emerging nations.

Yet the competitive benefits of ICT will only be maintained if European ICT systems are among the best in the world – powerful, efficient, cheap and small. The ICT Work Programme recognises the importance of funding research into components, systems and ICT engineering. Challenge 3 of the main funding stream covers these issues.

However, the need for rapid developments in computing systems is so critical and urgent that the EU encourages research into future ICT systems from all possible angles. FET funding therefore also supports projects that rethink the current norms of computing systems.

The programme has launched several initiatives under FP7 that address the demand for novel approaches. The Nano-scale ICT Devices and Systems initiative complements projects funded through Challenge 3 of the ICT Work Programme, but they explore more unusual, less tested approaches to nano-electronics. Proposals for projects under this initiative look at highly speculative solutions, for example the use of single molecules, atoms or ions for computational purposes (e.g. storage, transfer and manipulation of information); the use of new materials for switches and memory; and the combining of molecules such as carbon nano-tubes or graphene with more traditional silicon structures.

Future ICT systems will not simply depend on nano-scale components. The entire architecture and ICT infrastructure needs a revamp. Two other FET Pro-active initiatives therefore look at Pervasive Adaptation and the Science of Complex Systems for Socially Intelligent ICT. FET Pro-active initiatives agreed for the ICT 2009-2010 Work Programme will also include Quantum Information Foundations and Technologies and Concurrent Tera-Device Computing. These topics and many FET-Open projects are all concerned with radically reshaping ICT systems for the future.

Europe must lead the way and literally find new ways of computing. The EU's investment in FET projects is its most promising avenue in finding revolutionary technologies. Each project may be a mini-revolution in the making and, when they are all combined, they could produce a new generation of ICT that looks nothing like the systems we know today.

Projects in action

MAGLOG
OCCULT
PICASSO
PHAT
I-SWARM
Pico-Inside

Although quantum computing attracts significant media attention, FET research is open to a variety of projects that reconsider ICT technology at any level. The **MAGLOG** project, for example, was the first to demonstrate functional components that exploit the magnetic properties of electrons to perform logic operations.

Compatible with existing silicon-based microelectronics, processors made from ferromagnetic materials promise to be faster, smaller and more efficient than conventional microchips. They exploit a phenomenon called magnetoresistance in which electrons in a magnetic field have a measurable property called spin (they point 'left' or 'right', which can represent bits of data, such as the binary digits 0 and 1).

The MAGLOG project developed techniques for etching logic gates from ferromagnetic material on a conventional complementary metal-oxide-semiconductor (CMOS) platform. These gates can be used for computation as well as data storage and memory. The project partners describe it as "memory that can think".

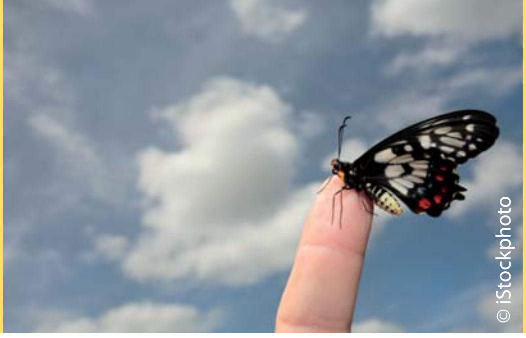
One form of magnetic logic gate uses structures called magnetic tunnelling junctions which make it possible to programme the gate itself, for example switching an 'AND' gate to an 'OR' function.

"The industry is crying out for reconfigurable computing to make microprocessors more efficient," says MAGLOG coordinator Guenter Reiss. "We have one of the best demonstrations of reprogramming logic gates 'on the fly' and could enhance the performance of a central processing unit by a factor of 10 to 100."

Magnetic logic has other advantages over conventional microprocessors. First, they retain their output state even when the current is switched off, which could greatly reduce the booting up time for devices. Second, magnetoelectronic components generally consume less power than their conventional counterparts, and components that are not being used can be temporarily switched off.

While the project has finished, the MAGLOG partners continue to work together and are working on various applications of the technology, including new low-power chips for mobile devices and secure smart cards with built-in processing capabilities.

Data security remains an important topic for ICT research and innovative approaches to encryption are critical to keep ahead of hackers and criminals. Members of the FET **OCCULT** project have demonstrated that secure messages can be hidden in chaotic waveforms, and transmitted at up to 10 gigabits per second on a standard fibre-optic



network with low error rates. Anyone tapping into the fibre-optic cable would have been unable to distinguish the message from the chaotic light noise that surrounded it.

A follow-on FET project, **PICASSO**, is now designing and testing two integrated and stable chaotic light sources. The first is a single chip about 1cm in length, which is being prototyped in a Berlin laboratory. The second is a hybrid device about 15cm long consisting of a laser and a small piece of fibre, using an oil coating to maintain temperature and feedback strength. Laboratory experiments have confirmed that the lasers could transmit light in patterns that were chaotic in time and space and would synchronise when they received light from one another through space or optical fibre. Synchronisation is key to making this system successful.

The security offered by chaotic waveforms does not match the complete security of quantum cryptography. But the rate of transmission is far higher – a security protection in itself. And attempts to break into the optical fibre and interpret the signal would be extremely difficult – if not impossible at the moment.

While light is now the medium of choice for the long-distance transmission of data, some FET research is looking at the potential of optical computers. Instead of using electronic components, optical devices perform their logic operations using photonic components, where light (photons), not electricity (electrons), represent information.

Materials known as photonic crystals could form the building blocks of future optical computers and micro-scale communications devices. European research has made important progress in the race to build all-optical chips for computers and communications systems. Scientists on the FET **PHAT** project have developed a relatively inexpensive way to make high-quality photonic crystals, and shown how these can be integrated into conventional silicon chips.

The PHAT project worked with complex structures made from an artificial opal whose optical properties vary in two and three dimensions (2D and 3D). Two-dimensional photonic crystals can act as waveguides, channelling light to where it is needed, and as filters to separate different wavelengths – a valuable property in optical communications. Three-dimensional photonic crystals can even trap light within their structures, potentially allowing them to act as optical switches.

By the time the project ended, in February 2007, it had two really big achievements under its belt: a spatially selective method of growing photonic crystals and the integration of 3D crystal with waveguides.

In the quest to miniaturise, some of the most exciting work being done is on tiny autonomous robots. Inspired by insect behaviour, work by FET's **I-SWARM** project to create self-assembling, interactive micro-bots has captured the attention of the world's media. A swarm of bots has been demonstrated working together, adjusting to obstacles and changes in their environment. Carrying out internal medical treatments or repairs to hard-to-access machinery, as well as planetary and deep-water exploration are some of the seemingly endless potential tasks that these mini-robots could one day perform.

Nanotechnology is about shrinking things to the smallest possible scale. It is usually a top-down process. But the **Pico-Inside** project is turning that upside down, starting from the atom, the molecule, and exploring if such a tiny bit of matter can be a logic gate (memory source) in computing, or more. The team of partners spread over Europe are taking a bottom-up or, as they call it, "bottom-bottom" approach because they do not want to reach the material scale. Work is focused on taking one individual molecule and building up computer components, with the goal of hosting a logic gate in a single molecule. They have already designed a simple logic gate with 30 atoms that perform the same task as 14 transistors, while also exploring the architecture, technology and chemistry needed to achieve computing inside a single molecule and to interconnect molecules. Though perhaps some time away, the commercial potential of this is huge.

More information:

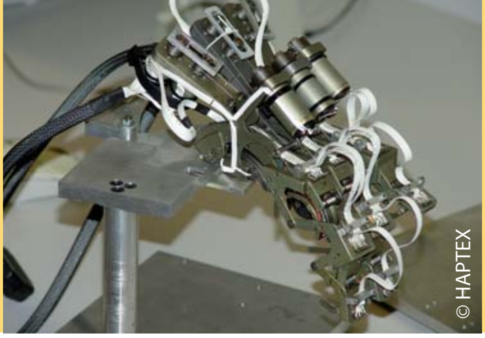
MAGLOG: http://maglog.ief.u-psud.fr/
OCCULT: http://ifisc.uib-csic.es/project/occult/
PICASSO: http://picasso.di.uoa.gr/
PHAT: www.tyndall.ie/phat/
I-SWARM: www.i-swarm.org
Pico-Inside: www.phantomsnet.net/Picoinside/

International Technology Roadmap for Semiconductors:
www.itrs.net

Autonomic Communication Forum:
www.autonomic-communication-forum.org

ICT and FET stories on ICT Results:
http://cordis.europa.eu/ictresults/ (enter search term 'FET')

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



Man meets chip

One of the biggest inefficiencies in the use of ICT occurs when humans have to interact with the technology. FET research is looking at ways to streamline interactions and the interface between ICT systems and users. The development of new technologies could begin to blur the boundaries between virtual and real environments, and between biology and electronics.

Humans and machines at a glance

To get the best out of ICT, people must be able to interact with the technology efficiently. New technologies that improve the human-machine interface will ensure that ICT is fully integrated into society and fulfils its potential to improve productivity and quality of life.

Despite almost half a century of advances in computing, it is astonishing that we still rely so heavily on the keyboard and mouse. Touch screen displays are still relatively rare and, while speech recognition and natural language software has improved dramatically in the last decade, we still tend to control computers through typed words and the movement of a cursor.

Some of the worst inefficiencies in the use of ICT often occur at the interface between a machine and its human operator. Perhaps software is difficult to understand or unintuitive to use. Operating systems may be hard to decipher and control. Some computer systems may even exclude members of society through the use of inappropriate hardware and input/feedback technologies (e.g. the reliance on visual displays and tactile input devices).

To compound these difficulties, most ICT is unable to really understand its operator. Even the smartest systems endowed with artificial intelligence still only reason at a very basic level. They are generally unable to spot behavioural nuances in operators, pick up on implied commands or predict what an operator might decide to do next.

In short, although ICT systems are capable of millions of logical operations per second, the power of computing plummets when humans have to get involved.

Scientists dream of ICT and people getting more intimate, where the boundary between the technology and the person begins to blur. European research is helping this dream to become reality for citizens.

FET research in this area tries to get more out of ICT systems by breaking down the barriers between 'us' (the users) and 'them' (the machines). ICT can be enhanced so that machines are not simply utilitarian, impersonal tools, but more like unobtrusive assistants in the manufacturing and services sectors and personal companions for everyday life. The potential market for such applications is almost limitless.

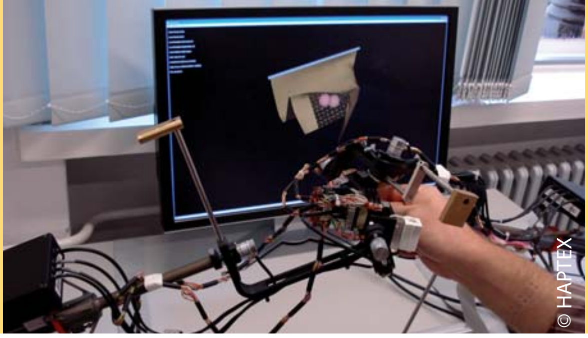
Starting in FP5, FET has successively funded three neuro-IT initiatives that took inspiration from the living sciences, mainly neurosciences, in order to derive new paradigms and technologies for information processing. Initiatives in FP6 continued this work with an objective to "explore new avenues in the design of intelligent information systems that attribute meaning to complex patterns of sensory stimuli and generate sequences of elementary actions that satisfy high-level goals." The systems developed had to show autonomous growth in perceptual, motor and cognitive abilities, and performance was assessed in realistic scenarios.

The merging of biosciences and ICT continues in FP7 with an initiative called Bio-ICT Convergence, which has a budget of €17 million. This initiative builds on earlier work to develop new technologies with demonstrable advantages in terms of functionality, operating conditions, resilience or adaptability. Bio-ICT also looks at how ICT systems can be naturally combined with biological systems (bio-hybrids), opening the way for novel applications, such as robust brain-machine interfacing, or for powerful sensory-motor capabilities. Seven projects were funded following the first call of this initiative.

Another related initiative, Human Computer Confluence, has been agreed for the 2009-2010 Work Programme.

Several FP6 and FP7 FET projects also focus on this area, exploring radically new approaches to human-machine and bio-ICT interfacing and integration (for example, the development of a non-invasive brain stimulation device to enable direct machine-to-brain communication).

FET research in this area supports several of the challenges in the mainstream ICT Work Programme, especially Challenge 2 (Cognitive systems, interaction and robotics) and Challenge 7 (Independent living and inclusion).



Projects in action

NACHIP
HAPTEX
CyberWalk
MAIA
TOBI
ECAgents

At the crossroads of where man meets chip is the work of the FET **NACHIP** project, which has created an interface between mammal brain cells and silicon chips. This was a crucial first step in what could one day lead to sophisticated new technologies, such as neural prostheses to combat neurological disorders, organic computers that use living neurons as their CPU, and even a genetically powered hard disk.

European researchers also pioneered a breakthrough interface that allows people to touch, stretch and pull virtual fabrics that feel like the real thing. The new multi-modal software linked to tactile hardware and haptics devices have enormous potential for shopping, design and human-machine interaction.

The system combines a specially designed glove, a sophisticated computer model and visual representation to reproduce the sensation of cloth with an impressive degree of realism. The new technology is a major breakthrough achieved through the highly focused work of the FET **HAPTEX** project. In just three years, the five partner research institutes created a pre-commercialisation prototype of the device and its related multi-modal software.

But it was not easy. Creating the realistic sensation of deformable textiles required a huge amount of modelling. The tactile sensations are recreated at a rate of 1000 samples per second, but have to be synchronised with a high-resolution visual system which can give a realistic impression of movement with just 20 frames a second.

This project is the first to combine a force-feedback device with a tactile one, developing a powered exoskeleton glove with a pair of pin arrays that provide tactile sensation to two fingers. The glove gives the sensation of bending and stretching the fabric, while the pin arrays convey texture. Then this integrated device is combined with the visual and tactile database to give an overall impression.

Obvious markets for the technology include the textile industry and online shopping, but applications of the technology in gaming are also possible as the glove could be used to make virtual worlds more realistic.

Virtual reality technology has advanced dramatically in recent years, but physically walking through large-scale virtual environments in a natural fashion has remained beyond our grasp. "In the virtual environment you have flight simulators, car simulators, but the most natural way of locomotion for humans is walking and this was practically impossible," says Marc Ernst, the coordinator of the FET **CyberWalk** project.

In April 2008, European researchers demonstrated that walking through virtual environments is set to be a reality. The project developed a 6m by 6m treadmill, called CyberCarpet, allowing unconstrained walking in all directions through large-scale virtual environments. To track the walker, the system uses cameras to pinpoint position and posture. This helps control the velocity of the treadmill and interactions with the virtual environment. Visualising the virtual environment is achieved courtesy of a commercial head-mounted display.

A software package, CityEngine, makes it relatively easy to create large-scale virtual environments in particular cities, in various degrees of detail. Combining the CityEngine with CyberWalk will allow people to go beyond strolling through the streets of ancient Pompeii and Rome. Architects, for example, could transport customers into the future, and allow them to walk through buildings even before they have been built. Talks with the gaming industry are already under way, but CyberWalk could also be used for emergency services training or for helping people with Parkinson's disease or needing medical rehabilitation after a stroke.

Meanwhile, the FET **MAIA** project has developed groundbreaking technology that uses brain signals (picked up with electrodes directly from the scalp) to control computers, artificial limbs and even wheelchairs. What sets MAIA's brain-computer interface (BCI) apart is that it does not rely on the human brain alone to do all the work, instead incorporating elements of artificial intelligence (AI). Not only will the wheelchair follow thought commands, but it also reacts to its environment, avoiding collisions even with another moving object.

The same technology could be applied to artificial limbs to allow quadriplegics to pick up objects or unlock a door. By using the BCI to interact with computer systems, meanwhile, they could control the lighting in their homes, surf the internet, or change the channels on the TV. Those simpler brain-computer interactions, which have the potential to become the basis for commercial systems sooner, will be the focus of a follow-up EU project called **TOBI**.

Most research into the artificial intelligence that underpins any form of intelligent machine-machine or machine-human interaction has centred on programming the machine with a set of predefined rules. But a team of European researchers has taken a new approach to the problem, developing 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 coordinator the **ECAgents** project.

The technology, dubbed Embedded and Communicating Agents, has allowed researchers at Sony's Computer Science Laboratory in France, for example, to add a new level of intelligence to the famous AIBO robotic dog. Initially programmed to merely recognise stimuli from their sensors, the AIBOs learnt to distinguish between objects and how to interact with them over the course of several hours or days. The 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 other trials. 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. Another project partner has developed a system called Push!Music that provides a new and innovative way to share music files over portable devices. Push!Music automatically shares files between users wirelessly using AI to decide what tracks to exchange based on the user's preferences and listening habits.

It is in portable devices and the internet where Nolfi sees the first applications for the technology arising, although he also believes it is probable it will lead to the first robots that are really able to learn, communicate and adapt to their environment within a few years.

More information:

NACHIP:
www.anatomiafisiologia.unipd.it/neurochip/Research/NaChip
HAPTEX: http://haptex.miralab.unige.ch
CyberWalk: www.cyberwalk-project.org
MAIA: www.maia-project.org
TOBI: www.tobi-project.org
ECAgents: www.ecagents.org

ICT and FET stories on ICT Results:
http://cordis.europa.eu/ictresults/ (enter search term 'FET')

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

From science fiction to science fact

Research must seek solutions to the immediate and foreseen problems facing society. FET research frees scientists to explore areas beyond mainstream ICT issues. The projects may be risky, but some could lead to revolution and dramatically change the way we perceive and use ICT in the future.

It is accepted that ICT is an enabling tool critical to improving the competitiveness of European industry and meeting the demands of its society and economy.

Today we know that ICT can contribute to improvements in productivity and innovation. It helps to modernise public services, such as health, education and transport, by making them more efficient and accessible. It even promotes advances in science and technology by supporting collaborative work and access to information.

ICT may be able to do much more – we just do not yet see how. But this is where FET research has an important role to play. FET is not just about discovering new science and developing next-generation technologies and ICT systems. Some of the most important results from FET projects are not in the delivery of technological outcomes, but in the project's contribution to high-level discussions and the organisation of the wider research effort.

In their pathfinder role, FET projects can shape society and scientific endeavour. In other words, a spin-off of FET projects can be an improvement in the scientific process.

FET stimulates change, at a personal and political level. Individual participants on FET projects, for example, often change their attitude toward their research. They have a greater appreciation for multi-disciplinary approaches and more awareness of the societal and political context of their work. At the political scale, FET research helps to inform debate, frequently providing a glimpse of a distant future that may otherwise go undetected.

Often a by-product of FET research, the pioneering interdisciplinary approach of FET projects may also be a catalyst for new research organisations and innovative restructuring of scientific institutions and collaborative programmes. FET calls for researchers to break away from consensus thinking and fosters cross-fertilisation between disciplines. For example, the European Centre for Living Technologies in Venice is a direct result from the PACE project under FP6 (building an artificial cell).

FET is also funding projects that could lead to radically new ways in which scientific knowledge is disseminated based on the latest Web technologies (e.g. LiquidPub).

FET research is as much about exploring new paradigms as solving specific problems. It is impossible to tell which projects will be successful or which will have the greatest impact. No-one knows which paradigms will become consensus and move into the mainstream.

Nevertheless, the size of the EU's investment in FET research creates a critical mass of projects covering a wide variety of issues. And who knows, a small project could ultimately have a huge impact on the economy of Europe and the quality of life of its citizens.

Paradigm shifts at a glance

FET can change the way that science is done. Speculative research may reveal novel concepts and suggest changes to research or the application of technology in unanticipated ways.

Projects in action

TYPES
$S2S^2$
EVERGROW
DIMES
NEW TIES
SENSEMAKER
FACETS

When you install software on your computer you are often pleasantly surprised when it works properly. It is a fact of life that software has bugs. But the **TYPES** project offers a new paradigm for software programmers. The project's work on the mathematical foundations of programming could one day revolutionise the software industry.

The current paradigm is that the bugs in software are inevitable and slowly get ironed out through patches, updates and upgrades. "The software industry is still very immature compared to other branches of engineering," says Dr Bengt Nordström, a computer scientist at Chalmers University in Göteborg. "We want to see programming as an engineering discipline but it's not there yet. It's not based on good theory and we don't have good design methods to make sure that, at each step, we produce something that's correct."

Nordström believes that the whole approach to software design needs to be rethought. The usual approach is to validate a program via a lengthy testing process. Instead, he would like to see a design philosophy that guarantees from first principles that a program will do what it says on the box.

The key lies in an esoteric reformulation of mathematics called 'type theory' based on the notion of computation. In this approach, the specification for a computational task is stated as a mathematical theorem. The program that performs the computation is equivalent to the proof of the theorem. By proving the theorem the program is guaranteed to be correct.

It is not that simple, of course, but so promising is type theory that, since 1989, the EU has been funding a string of projects to develop it under the FET programme. TYPES fosters co-operation on the topic among researchers at 15 European universities and research institutes, along with those at 19 associated academic and industrial organisations. The TYPES partners are also releasing open source software packages that anyone can download, use and modify. These packages include several proof editors that, in type theory, are the key to guaranteeing the correctness of programs.

"A lot of effort is now spent on testing software," Nordström says. "Very often programs are written quite quickly and then they are tested and changed and tested again, and so on. It's very unsystematic. This is not how we build bridges and highways. That style of working is going to change so that we spend more effort on actually writing programs than testing them."

Another FET coordinating action has helped to stimulate research in the burgeoning field of sound and music computing (SMC). SMC provides the core technologies for the electronic music industry and draws inspiration from hard sciences like physics and engineering, social sciences like psychology and musicology, and the creative arts.

Forget notions that sound and music computing is just nerds tweaking knobs in soundproof rooms. This fast-moving, multi-billion euro branch of the so-called 'creative sciences' looks set to be a major source of growth in Europe. That is if Europe follows the roadmap published by the **$S2S^2$** project.

"Music is growing in importance every day, especially in youth culture and for well-being, so it is vital we tied this all together – it's not only an economic lever but good for social cohesion," says Nicola Bernardini, the project's coordinator.

The roadmap identifies, characterises and proposes strategies for tackling the key research challenges facing this diverse field in the next ten to 15 years, overcoming the present fragmentation of effort and stamping out a common research agenda for future European output.

Using three scenarios, the roadmap paints a picture of how SMC research today will impact upon European society and economies tomorrow, and help bridge the semantic gap between abstraction and applicable human knowledge – the notion of 'sound to sense, sense to sound' ($S2S^2$). The scenarios show how our environment will change through advances in SMC technology, such as sonic environments, interactive music devices and expert music companions.

The FET **EVERGROW** project, meanwhile, is developing novel methods to map and model the internet, even visualising it as a jellyfish. The project is challenging conventional thinking and offering new insights into how best to route future network traffic.

EVERGROW relies on volunteers from around the world downloading and running a software agent – the **DIMES** Agent – on their PCs to help map the internet. The project team has used the DIMES data (three to six million measurements daily) to examine the high-level structure of the internet. At the time of reporting, in late 2006, their work showed that the internet contained over 20 thousand subnetworks managed by a single organisation (e.g. an internet service provider or ISP). Further mapping showed that the nucleus of the internet contained about 100 nodes, the highly connected mantle had about 15 thousand nodes, and the simple tendrils made up the remaining five thousand.

The EVERGROW team believes that this novel research approach could help to develop improved traffic routing schemes in the future. When internet users today request information via their browsers from a distant website, the data typically starts from a node in a tendril, travels along to a node in the nucleus, and then travels out to the node where the relevant information is held. A more efficient path for internet routing, and one which is less prone to bottlenecks, could be to send the information via nodes in the outer mantle, and avoid using the nucleus at all. Insights such as these could prove invaluable to companies such as Akamai and Google, which are regularly dealing with enormous volumes of web traffic.

From a brave new internet to a brave new world, the FET **NEW TIES** project has created a thoroughly 21st-century space populated by randomly generated software beings, capable of developing their own language and culture. The simulation engine runs across a grid of 60 computers. It will support about 1000 agents at first, building up to millions – each one a unique entity with its own characteristics, including gender, life expectancy, fertility, size, and metabolism. 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

The agents will have the ability to communicate, using what is called a 'native vocabulary' of a few simple words like, 'food', 'near', and 'agent'. Some basic rules will also be given, along the lines of 'if it's hot, it burns', but agents are expected to add to the rule set as they discover new laws of nature.

"It's a given of the NEW TIES project that we are not hardwiring agents," notes one of the partners. "We are not programming how they behave. Each entity has its own 'controller,' analogous to a brain. And because we want to create an interesting controller, we have to produce a challenging world – otherwise there would be no impetus for development."

The project previously discovered that aggressive behaviour, surprisingly, increases in agent-worlds as life becomes easier, while an ideal world (ideal meaning maximum survival) has two main attributes: flexibility and mobility.

Teaching a machine to sense its environment is a huge scientific problem, so researchers in the **SENSEMAKER** project turned to nature and the human brain for inspiration. They studied how human neural processes work to build sensory perception, and how removing one of the senses forces the brain to compensate by heightening others. Using tests on sight and touch, the project gained valuable insight into human responses to sensory loss and integration, which informed a new biologically inspired model that can be applied to any number of fields requiring artificial systems and intelligence, including robotics and computer systems.

The follow-up **FACETS** project concentrated on developing a neural computer that could emulate the brain. And a prototype "brain on a chip" – network of 300 neurons and half a million synapses on a single chip – is already working. The team used a unique combination of analogue electronics to represent the neurons and digital electronics for communications between them. Since neurons are so small, the system runs 100,000 times faster than the biological equivalent and 10 million times faster than a software simulation. Neural computing, with its low power demands and tolerance of faults, could help get components down to molecular size. The team says applications could be only five years away, setting off a revolution in information technology.

More information

TYPES: www.cs.chalmers.se/Cs/Research/Logic/Types/
S2S²: alternative site http://smcnetwork.org
EVERGROW: www.evergrow.org/
DIMES: www.netdimes.org
NEW TIES: www.cs.vu.nl/~gusz/newties/newties.html
SENSEMAKER: http://wwwasic.kip.uni-heidelberg.de/asicnew/vision/projects/recent_projects/the_sensemaker_project/
FACETS: http://facets.kip.uni-heidelberg.de

ICT and FET stories on ICT Results:
http://cordis.europa.eu/ictresults/ (enter search term 'FET')

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

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