Bits, Atoms and Genes Beyond the Horizon

by Dimitris Plexousakis

The 'Beyond the Horizon' Project: Anticipating Future and Emerging Information Society Technologies

In order to achieve the full potential of the Information Society and to ensure the long-term competitiveness of Europe, vigorous R&D activities in Information and Communication Technologies (ICTs) and related disciplines are essential. This is the key role of the Information Society Technologies (IST) programme within the forthcoming 7th Framework Programme. As part of IST, the Future and Emerging Technologies (FET) activity has the role of stimulating the emergence and development of new IST-related disciplines and technologies, which promise to have significant scientific, industrial and societal impact. In this perspective, FET is supporting long-term, visionary, high-risk research in advanced strategic research areas related to ICTs.

ICTs are now at a crossroads and prospects for further advances are increasingly relying upon synergies and cross-fertilisation with other scientific and technological fields. ICTs can no longer be seen in isolation, but increasingly as an area, which is both enabling and being enabled by other areas. This accelerated integration of many S&T fields is bound to be at the origin of the next revolution(s) in medicine, manufacturing, education, energy and many other application fields.

Beyond-The-Horizon (B-T-H) is a coordination action funded by IST-FET and coordinated by ERCIM. It is structured in six Thematic Groups (TGs), driven by the Scientific Steering Committee in close collaboration with FET and Infrastructures unit of the European Commission and administered by the ERCIM office. The purpose of the project is to provide input in ICT-related trends and strategic areas that require support, through a well-defined, extensive and systematic consultation of the relevant science and technology communities in Europe. The project will deliver roadmaps for the scientific and technological advancement and in order to meet the emerging grand challenges in the strategic fields of 'Pervasive Computing and Communications (TG1)', 'Nanoelectronics and Nanotechnologies (TG2)', 'Security, Dependability and Trust (TG3)', 'Bio-ICT Synergies (TG4)', 'Intelligent and Cognitive Systems (TG5)' and 'Software Intensive Systems (TG6)'.

Since the beginning of the project in January 2005, the six thematic groups have held brainstorming workshops for the purpose of identifying the emerging grand challenges for the next 15 years in the respective areas. The workshops brought together eminent researchers

From left: Gavriel Salvendy, Purdue University, USA and Tsinghua University, China; Claude Cohen-Tannoudji, Winner of the 1997 Nobel Prize in Physics, Keith Jeffery, Director for IT of CCLRC and ERCIM president; and Thierry van der Pyl, Head of Unit, European Commission.

from both academia and industry that embarked on drafting agendas for basic research in the six thematic areas. Summaries of the findings of the groups are reported in short articles in this issue. More detailed reports are available through the project's web site. The reports will be finalized in the next few months after a wider consultation with the European research community. Major milestones of the project include the mid-term assessment that took place in Brussels last October and the Plenary Workshop that was held in Paris, 12-13 December 2005.

Plenary Workshop

The Plenary Workshop brought together representatives of the six thematic groups for the purpose of examining the research themes that arise at the intersections of the different areas. A challenge in itself, the task provided the opportunity to rethink the already identified grand challenges of the individual thematic areas in light of the potential for synergy and cross-fertilization with other thematic areas. Research themes emerging at the cross-links of the thematic sessions are listed with the following TG reports. The debates were enriched with varying perspectives by notable invitees from the European research community, including members of the IST committee and representatives of the French Ministry for Research. Other workshop special guests included Ulf Dahlsten, Director of the EC's FET and Infrastructures Unit; Claude Cohen-Tannoudji, Winner of the 1997 Nobel Prize in Physics; Wendy Hall, representative of the future European Research Council; and Anne Cambon-Thomsen, member of the European Group on Ethics. Prof. Gavriel Salvendy (Purdue University, USA and Tsinghua University, China) shared an 'outsider's view' on the directions of basic research in ICTs. The workshop was very well-attended (80 delegates) and the discussion sessions were lively. The complete programme, presentation slides and photographic material are available through the project web site.

B-T-H is entering its second stage during which the finalized Thematic Group reports will be disseminated to the European research community at large

for feedback and consultation. The reports will be accessible through the web site by late January and the research community will be invited to provide their comments through the on-line consultation mechanism of the B-T-H workspace. In closing this short report on B-T-H, the Scientific Steering Committee extends an invitation to researchers in ERCIM Institutes, especially the participants to the relevant Working Groups, to participate in the consultation process and share their views on the current outcomes of this endeavor.

Thematic Group 1:
Pervasive Computing and Communications

by Alois Fersha

The vision impacting the evolution of Pervasive Computing and Communications is the claim for an intuitive, unobtrusive and distraction-free interaction with technology-rich environments. In an attempt to bring interaction 'back to the real world' after an era of keyboard and screen interaction, computers are being understood as secondary artefacts, embedded and operating in the background, whereas the set of all physical objects present in the environment are understood as the primary artefacts, the 'interface'. Instead of interacting with digital information via traditional computing means, Pervasive Computing aims at physical interaction with digital information, ie, interaction by manipulating physical artefacts via 'graspable' interfaces. It links the 'atoms of the physical world' with the 'bits of the digital world' in such a way, that every physical artefact is considered as being both

representation of and control for digital information.

The challenges of Pervasive Computing are dominated by the ubiquity of a vast manifold of heterogeneous, small, embedded and mobile devices, the evolvability of their population and interoperation, the ability of perceiving and interpreting their situation, the autonomy of their goal-oriented behaviour, the dynamicity and context-adaptation of services offered, the ad-hoc interoperability of services and the different modes of interaction with these services (see Figure).

In a workshop in June in Vienna, TG1 has identified and prioritised a list of technical challenges which are needed for enabling the vision of pervasive computing and communication. The objective of the plenary workshop held in Paris, was to present and discuss both this vision as well as, the associated challenges and to coordinate the potential research and work programme with the other TGs. At the plenary workshop, a presentation on the visionary areas of 'Societal Artefacts', 'Evolve-able Systems', 'Future Aware Behaviour', and 'Human Computer Confluence' was presented as well as the list of technical challenges, including Systems of Self-

Empowering people with a 'pervasive computing landscape', that is:
- aware of their presence
- sensitive, adaptive and responsive to the users' capabilities, needs, habits and emotions
- and ubiquitously, safely and securely accessible
- via natural interaction

Pervasive Computing – state of the art.

managing Artefacts, Aware Environments and Context Recognition, (Natural) Interaction and Usability, Bio-based Paradigms, Manageable Information, Measurements, Models and Benchmarks for Pervasive Computing Systems, Ambient Informatics, In-Body Pervasive Computing, and Search Challenges for Pervasive Computing and Communication Environments.

As an outcome of discussion sesions, links were identified with other TGs. Specifically, the topic of evolvable and adaptive systems was identified as a cross-TG thematic area, linking TG1 with TG4 (bring in the bio-inspired computing aspects) and TG6 (focussing on adaptivity in software).

In the thematic discussion of TG1, the participants agreed to structure the final research agenda along the three visions of 'Networked Societies of Artefacts', 'Evolve-able Systems', and 'Human Computer Confluence', which adequately reflect the priorities identified at the first workshop and which also put more emphasis on the network and communication aspect.

The key technical problems and milestones that must be solved towards achieving this vision are summarised as follows.

Networked Societies of Artefacts:
- deriving models for goal-orientedness and social behaviour,
- enhancing and enriching the communication fabric of societies, thus enabling opportunistic networks
- harnessing dispersed content and managing information,
- the design and development of space aware models.

'Evolve-able' Systems:
- the development of viable, evolve-able systems (hardware, software, communication fabric),
- enabling the adaptation to unforeseen situations, interpreting context, and creating future aware behaviour in support of both, long-term forward evolution as well as short-term adaptivity
- considering deterministic versus non-deterministic, stochastic approximation
- coping with the fundamental issue of scale.

Human Computer Confluence:
- supporting invisible, implicit, embodied, implanted interaction,
- considering qualitative aspects such as user experience and user behaviour.

Thematic Group 2:
Nanoelectronics and Nanotechnologies

by Colin Lambert

The thematic group recommends sustained investment in research to underpin the 'More of Moore', 'More than Moore' and 'Beyond Moore' technology drivers.

The 'More of Moore' approach is focused on delivering the 'International Technology Roadmap for Semiconductors' (ITRS) for late complementary metal oxide semiconductor (CMOS) and post-CMOS systems, and in particular, how to continue Moore's law beyond the predicted 22 nm node in 2011. The 'More than Moore' approach is focused on delivering greater functionality through heterogeneous integration of nanosystems with electronic, optical, magnetic, chemical, biological, mechanical and other functions. Research themes which extend 'Beyond Moore' in terms of their potential to deliver disruptive technologies include new paradigms such as intra-molecular computing and solid-state quantum information processing (SSQIP), addressing the emerging field of engineered coherent solid-state quantum systems.

It was generally recognised that future disruptive technologies and breakthroughs may come from progress in a range of rapidly-developing areas. It was also recognised that the medium-term impact of many of these technologies may initially occur in niche 'More than Moore' areas, which would provide economic benefits and stimuli before impacting on the 'More of Moore' challenge.

Recommended Areas
Recommended areas for research are as follows:

- Cooperative research on 'System-ability' of emerging ICT technologies and devices, involving multi-disciplinary teams of nano-technology researchers and system architects and the development of reliable, predictive and quantitative nanoscale-device simulation methods, which to interface to higher-level design tools comprehending extreme heterogeneity

- Interfacing nano-scale biology with nano-electronics, including bio-nano transduction and growable electronics. This would provide the hardware for research under TG5 and could lead to circuits and connections which grow, shrink or reconfigure according to demands on functionality, thereby impinging on activities in TG 2 involving evolvable hardware and emergent design.

- Future interconnects for heterogeneous system integration. Promising avenues include the use of nanotubes, recently-synthesised molecules non-linear wave propagation and 3d architectures (which allow higher integration density, less I/Os, shorter wires, less power and higher speed). Nerve bundles are an example of unidirectional, self-restored signal propagation, chemically assisted guided growth and life-long repair capability. To avoid problems associated with high-density interconnects, non-local processing in non-charge-based devices and interconnect-lean architectures such as cellular automata could be explored.

- Post-CMOS memory, storage and logic, aimed at identifying nanodevices that integrate gracefully with CMOS and architectures that exploit the advantages of both CMOS 'hosts' and nanotech blocks. This would include a range of information carriers such as electrons, spins, photons, phonons, atoms, molecules, mechanical state and material phase.

- Nanoelectromechanical systems (NEMS), including VLSI-like arrays of sensors, probes and sources and nano-object-based NEMS with potential applications to microwave signal processing, mechanically detecting magnetic resonance imaging, bio-sensors and bio-actuators, micro-nanofluidics, single molecule sensing-analysing, data storage and operation at the quantum limit.

- Nanotechnologies for quantum-coherent systems, aimed at investigating new types of solid-state qubits and scalable coherent systems to build large-scale coherent systems and practical quantum computers, and at addressing the enormous materials science challenges associated with the engineering of solid-state qubits and quantum coherent systems in solid-state environments

Please contact:
Colin Lambert (TG2 Coordinator)
University of Lancaster, U.K.
E-mail: c.lambert@lancaster.ac.uk

Thematic Group 3:
Security, Dependability and Trust

by Michel Riguidel

The evolution of digital society is characterized by ubiquitous computations, communications and storage, and by the development of services that are personalized and context-aware. Massively distributed, interoperable and interdependent complex ICT systems composed of billions of interacting components will soon be emerging along with new, unprecedented challenges for Security, Dependability and Trust.

ICT security balances the freedom and the will to protect tangible and intangible values, ensures the immunity of applications and system resilience, and instils and preserves confidence in digital, critical infrastructures. At the smallest level, nanotechnology, quantum communication and cryptography offer new opportunities to tackle ICT security. Embedded sensors and devices can form ad-hoc networks requiring new mechanisms for establishing trust when sharing information or resources. New paradigms come to the foreground, such as service architectures that compose services from lower level modules, peer-to-peer systems characterized by their remarkable robustness and resilience against attack, and biological defence mechanisms which may inspire new breakthrough technologies. At a larger

scale, the completion of the Galileo satellite navigation system around 2009 will create ever more sophisticated possibilities for positioning with implications for both security and privacy.

The following emerging research themes were identified during the meetings of Task Group 3 :

Ambient Trustworthiness

The mass diffusion of digital systems must be endorsed with built-in mechanisms for enhancing trust and confidence on their usage. Common security mechanisms mainly based on boundaries and firewall protection mechanisms do not scale with respect to new complex systems. We should imagine different mechanisms such as the ones inspired by the living world: immune and self-healing systems. We should consider autonomic, evolvable and adaptive security mechanisms, which will require new semantic models managing the complexity of ambient intelligence environments where humans and devices may jointly function and interact. Security systems and cryptographic mechanisms must be scaled down for inclusion in small devices (even at nano-scale) with specific requirements for energy consumption and computation power.

Dynamicity of Trust

Lack of trust either on the cyber-infrastructure (due to frequent attacks) or the difficulties to model trust relationships among different entities (human and digital ones) is one of the main barriers for the establishment of a true Information Society. In future ICT systems with billions of devices, the capability of managing and negotiating trust relationships that foster cooperation is crucial. The understanding on how trust emerges and evolves as well as, of the related notions of reputation formation, monitoring and evolution are mandatory. Security-based trust and trust-based security are two emerging areas of interest. A deeper understanding of trust needs the involvement of research expertise from several fields such as economy and sociology.

Quantum Technology and Cryptography

Nature can provide us with resources to secure our information and communication systems. The possibility provided by Quantum technology to offer secret bits of information among authenticated distant partners as well as, truly random values are building blocks of many protection mechanisms. Quantum technology and quantum computing might also represent a major threat for current cryptographic algorithms and mechanisms. We should also study the assumptions on which Quantum Computers (QC) may act and their consequences on current and future cryptographic methods, as well as, the development of new QC resisting techniques.

Assessability and Verifiability

Assessing and proving the trustworthiness of a complex system is a main issue. During the last years many techniques have been developed, especially in the dependability community. Yet, the scale of new ICT systems and the kind of threats and assumptions on their operational environment pose new challenges. Different metrics, modelling tools and observation mechanisms are needed. The capability of measuring the tolerance to attacks is crucial in new systems that due to their logical and physical diffusion are susceptible to 'attack'. We need to develop a discipline of system and software security based on high-level verifiably secure programming. We advocate an approach based on efficiently verifiable mathematical proofs showing compliance to policies (expressing safety, security, or functionality constraints).

These areas have connections with research themes in other Thematic Groups: eg, trust and confidence in pervasive systems (TG1); security and trust issues with scarce resources at nano-scale (TG2); self-healing systems and bio-inspired security mechanisms (TG4); knowledge-based security models (TG5), as well as, evolutionary and adaptive software security (TG6).

Please contact:
Michel Riguidel (TG3 Coordinator)
ENST-Paris, France
E-mail: riguidel@enst.fr

Thematic Group 4:
Bio-ICT Synergies

by Fernando Martin-Sanchez

Key advances in recent years have attributed particular relevance and promise to research in bio-inspired ICTs. The aim of this thematic group is to identify long-term research topics in the information processing field that are inspired from the biological domain and expected to have a significant impact.

It is widely recognised that research at the interface of biology and information technology may lead to important new progress in information systems and computer technologies. The question is what and how we can learn and understand from biological systems, and how we can exploit this knowledge to develop new technologies.

The TG4 workshop took place in Sophia-Antipolis, France, on 28-29 June 2005 with the goal of analysing future challenges in this field. The group agreed upon a vision based on the idea that higher living organisms contain at least two systems that can be interpreted as 'natural' information processors, namely neurons and genes. Advances in biological and neuro-sciences that have enhanced our understanding of aspects like development, action, perception, homeostasis and learning may be exploited for designing and implementing new ICTs. These are the 'building blocks' underlying our vision: 'genes, brain and chips'. Three main research themes were identified as pillars for exploiting the Bio-ICT synergies potential, namely 'New Modeling Paradigms', 'Bio-Inspired Strategies of Growth, Adaptation and Evolution' and 'Bio-ICT artifacts' (see Figure).

Proposed Research Themes
1. New Modelling Paradigms
A major research challenge relevant to predictive modelling is the formalization and development of paradigms that capture the different levels of complexity in biological entities - from the molecule to the cell, tissue, organ, system, individual, population and ecosystem - and that enable explaining observations and pre-

dicting and controlling behaviour. Main objectives addressed under this research challenge include: (a) devising robust, reusable, adaptable and properly validated models, (b) modelling the behaviour of the systems in response to stimuli, (c) unification of information from disparate sources (molecular, cellular, individual, population, images, etc.) and (d) using these models for personalized decision support. Some of the technical challenges involved are: (a) con-

3. Bio-ICT artefacts
The final goal of research in modelling both the organizational and phenomenological features of living systems is to seamlessly integrate artificial entities in order to augment or substitute capabilities (classical examples include artificial retinas or physiologically coupled artificial limbs). In this sense, main challenges include: (a) interfacing between the living and the artificial world, including enhancement or substitution of
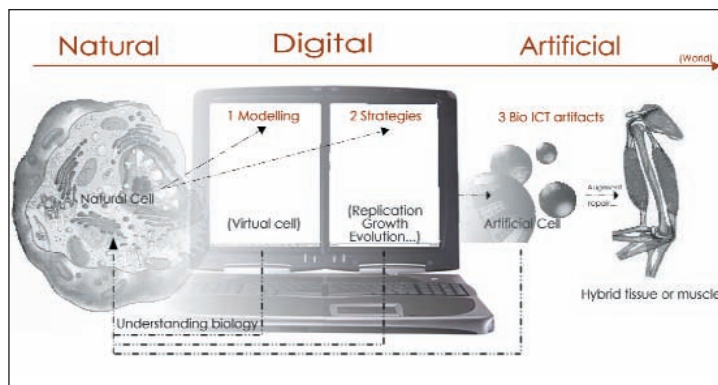
Connecting the natural, digital and artificial worlds: cell modelling, synthesis and hybrid systems.

necting models at different levels of connecting discrete with continuous models, (d) dealing with inconsistent, competing models and (e) fitting models to data (data driven modelling).

2. Bio-Inspired Strategies of Growth, Adaptation and Evolution
A second theme concerns capabilities (observations). Its main objective consists of advancing scientific understanding of the biological foundation of key capabilities of living systems, based on new modelling techniques. Such capabilities include adaptation, learning, sensing, self-organization, self-assembly, self-replication, growth, self-healing, self-protection, emergence and collective behaviour to name but a few. The main objectives addressed under this research challenge are: (a) developing new information theories and modelling techniques to capture how biological systems realise basic capabilities of living systems at different granularities, (b) developing ways to validate such theories with respect to real biological systems, (c) studying how such technologies can adapt and evolve to match, over long periods of time, evolving needs whilst being compatible with natural processes of change.

human capabilities (eg, using implants), (b) providing sensor/motor interface to the body, (c) extending the range of capacities beyond perception and action, including for instance memory, resistance to bacteria and viruses, or interfacing directly in metabolic processes ('cyber-drugs').

A number of possible interactions with other thematic areas were also identified:
• TG1: evolvable systems, bionets, interfacing with human sensory system
• TG2: molecular & DNA computing, self-assembly and bio-inspired fabrication, biomimetic interfaces, magnetic biomarkers
• TG3: bio-inspired immune systems, evolutionary strategies
• TG5: genotype-phenotype mapping, embodiment, growth
• TG6: adaptation and evolution, design for emergence.

Please contact:
Fernando Martin-Sanchez (TG4 Coordinator)
Institute of Health Carlos III, Madrid Spain
E-mail: fmartin@isciii.es

Thematic Group 5:
Intelligent and Cognitive Systems

by Rolf Pfeifer and Alois Knoll

The grand challenge to build truly intelligent and cognitive systems capable of acting in the real word and interacting with humans in natural ways is still far beyond the current state-of-the art and requires a long-term research effort. Because the basic research issues required in order to meet the challenge are still daunting, it is important to focus the current initiative in order not to spread the resources too thinly.

Vision and Grand Challenges
The most challenging long-term visionary goal of our research community has been the development of so-called complete agents, that is, agents that are embodied and self-sufficient (ie, they can sustain themselves over extended periods of time), situated (ie, the can acquire information about the environment through their own sensory systems), and autonomous (ie, they function independently of external control). For 'intelligent and cognitive systems', the expert group recommends the framework of embodiment. We understand intelligence and cognition as properties that emerge as an agent interacts with its environment. The notion of embodiment has many implications that form part of the theoretical framework.

In order to meet this long-term challenge, the following research themes need to be pursued:
• *mind-body co-development and co-evolution*: in order to maximally exploit the design power of evolution and development, controllers and robot morphologies have to evolve simultaneously. The permanent interaction of the body of an agent with the environment during growth enables its 'mind' to develop. This process, ultimately, requires materials that can grow (see the following point).

• *materials and growth technologies*: recent research strongly suggests that materials play an essential role in

behavior. Also, through growth, biological organisms can form highly complex morphological structures. Although there are promising starting points (eg, self-assembling materials, modular robotics), we do not expect to have growable materials that match biological capacities available any time soon.

- *morphological computation:* the morphology (shape) and the materials (eg, muscles) perform important functions for an agent in real time, an idea that completely differs from classical

Turing computation. Generally speaking, the term refers to processes based on shape (eg, molecules/DNA, modules of a modular robot) and material properties.

- *design for emergence*: as behavior is always the result of the interaction of an agent with the environment, behavior is emergent, meaning that it cannot be understood (and designed) on the basis of the internal control program (or 'brain') only. The question then is: how can we design purposive (goal-directed) agents without destroying the emergent nature of their behavior?

In each of these topic areas real physical embodiment plays an essential role. However, given the current state of the art, simulation work ('embodied agent simulations') will form an important part of the endeavor.

Cross-Links among the B-T-H themes

The strongest cross-links between intelligent and cognitive systems (TG5) and other proposed programmes are with TG4 (Bio-ICT) and TG2 (Nanotechnology).

- TG2: interfacing biology and electronics; generically growing electronics as a tool for building complex systems employing principles of emergence; self-assembled scalable interconnects
- TG4: interfacing between natural and artificial systems; design for emergence; bio-inspired strategies for

Task Group 5 workshop participants Giulio Sandini and Olaf Spoorns learn about the artificial whisker system developed by Miriam Fend of the Artificial Intelligence Laboratory in Zurich in the Artificial Mouse Project (AMouse, http://www.amouse.de/).

growth; sensory, morphological, DNA, and molecular computation in general; development of bio-ICT artifacts (sensors/actuators/ metabolism); bio-inspired processing architectures.

We feel that by tackling the proposed challenges in the current initiative, we can make substantial progress towards the long term goal of designing truly intelligent and cognitive systems, with potential for real breakthroughs.

Please contact:
Rolf Pfeifer (TG5 Coordinator)
University of Zurich, Switzerland
E-mail: pfeifer@ifi.unizh.ch

Thematic Group 6:
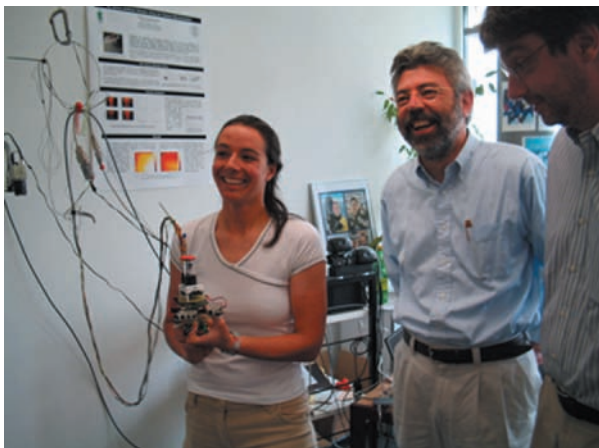# Software Intensive Systems

by Martin Wirsing

Software has become a central part of a rapidly growing range of products and services from all sectors of economic activity. These systems in which software interacts with other software, systems, devices, sensors and humans are called software-intensive systems. Examples include large-scale heterogeneous systems, embedded systems for automotive and avionics applications, telecommunications, wireless ad hoc systems, business applications with an emphasis on web services etc.

Our daily lives depend on complex software-intensive systems that are becoming increasingly distributed, heterogeneous, and decentralized. This trend will continue for most typical environments, while requirements for quality of service, security, and trust will increase. To work dependably under such difficult conditions, systems will have to exhibit adaptive and even anticipatory behaviour. Current engineering methods and tools are not powerful enough to build, deploy, and maintain such systems.

Today's grand challenge is to develop practically useful and theoretically well-founded principles, methods, algorithms and tools for programming and engineering future software intensive systems. To meet this challenge we have to advance beyond the 'engineering' metaphor for software development and augment our current engineering activities with scientific foundations, tools and methods that support change throughout the whole system life cycle.

Among the many promising areas for future research the participants in the Thematic Group have identified three crucial areas: Engineering adaptive software-intensive systems; managing diversity in knowledge by adaptation; and eternal software-intensive systems.

Engineering Adaptive Software-Intensive Systems

The current approach, where systems are mainly assembled at design time does not scale to pervasive, highly dynamic systems. The emergent behaviour of systems is an unavoidable fact that must be exploited during the system's life time, in order to scale to the level of complexity we are witnessing. Systems will no longer be produced ab initio, but more and more as adaptations of other, existing systems, often performed at run-time as a result of a process of evolution. The challenge is to develop methods, tools and theoretical foundations that enable effective design by harnessing, controlling and using the effects of emergent system properties.

Managing Diversity in Knowledge by Adaptation

We are facing an unforeseen growth of the complexity of the data, content and knowledge being produced. In knowledge engineering and management the 'usual' approach is to take into account, at design time, all the possible future dynamics, most commonly by designing a unique global representation schema. As applications become more and more open and complex this top-down approach shows its limits. The challenge is to develop design methods and tools that enable effective design by harnessing, controlling and using the effects of emergent knowledge properties.

Eternal Software-Intensive Systems

Information, and the tools to work with it, represent one of society's most important assets. From a cultural as well as economic point of view it is essential to enable continuous and up-to-date access to long-lived and trustworthy information systems, as well as to guarantee that the corresponding information systems don't age and break but are able to evolve. The challenge is to organize software-intensive systems so that they can survive in a constantly changing world.

Please contact:
Prof. Martin Wirsing
Universitat Munchen, Germany
E-mail:
wirsing@informatik.uni-muenchen.de

Quantum Information Processing and Communication
Preparation for FP7 in Future and Emerging Technologies Unit, DG INFSO, EC

In view of the forthcoming FP7, the Unit Future and Emerging Technologies (FET) of DG Information Society and Media is now carrying out a Europe-wide consultation process with the relevant S&T communities in a number of ICT fields. The objective is to define the major challenges and promising research directions that FET could support in FP7 (see B-T-H articles in this issue).

Quantum Information Processing and Communication (QIPC) is now a well established scientific field which opens unconventional perspectives for information processing. It exploits fundamentally new modes of computation and communication with the aim to understand the quantum nature of information and to learn how to formulate, manipulate, and process it using physical systems that operate on quantum mechanical principles (control of coherent superpositions of quantum degrees of freedom – qubits). Today, there is a significant world-wide effort to advance research in QIPC, which has led to a deeper and broader understanding of information theory, of computer science and of the fundamental laws of the quantum world. Advances in QIPC could soon lead to new technologies and devices that hold the promise to radically change the way we compute and communicate.

Since its early steps, European scientists have been at the forefront of QIPC research. So far, FET is the sole part of the IST Programme that has been supporting QIPC research and has been very successful in attracting the best research teams in Europe. While the field has now reached a certain degree of maturity and there is critical mass in Europe in the main sub-fields, it is still necessary to further expand and strengthen activities at the European level. In view of the forthcoming FP7, FET and the European QIPC research community have actively been working during the last year towards the elaboration of a common European research strategy in the field. These efforts have culminated in the publication of a technology roadmap on 'Quantum Information Processing and Communication: Strategic report on current status, visions and goals for research in Europe'. This report was written by the most prominent scientists in the field and, after a wide consultation within the QIPC research community, it is now published on the FET web site (http://www.cordis.lu/ist/fet/qipc.htm#prepfp7).

The QIPC roadmap presents in a comprehensive way the state-of-the-art, the medium and long term goals and the visions and challenges for the future. It includes an overview of FET activities, a description of national research programmes and the worldwide research position of Europe in QIPC. The main bulk of the document is devoted to a scientific assessment of current results and an outlook of future efforts. It covers three main research directions: quantum communication, quantum computing and quantum information science, as well as the interactions and interdependences between them. The document stipulates the need for further support in these three research directions, as well as to keep a diversity of experimental realizations and to look for synergies between them in order to reach concrete objectives. Integration across different disciplines and between different experimental approaches is considered crucial for the further advancement of QIPC in Europe. Prospects for applications and commercial exploitation are equally discussed. The roadmap is a living document, which will be periodically updated in order to serve as a guideline both to scientists and decision makers.

In parallel to the strategic report, the research community in collaboration with FET has produced the publication "QIPC in Europe". It is a collection of 30 articles in "Scientific American" style written by 58 of the most prominent experts in Europe. It gives a balanced overview of QIPC research in Europe and refers to work accomplished within FET and nationally funded projects. These two documents complement each other and are important milestones along the way towards elaborating a common European strategy in QIPC. They are both published in the FET QIPC proactive initiative web site and by the Publications Office of the European Commission.
Link: http://www.cordis.lu/ist/fet/qipc.htm