BUILDING FET FLAGSHIPS

A WORLD-CLASS SCIENTIFIC ENDEAVOUR

FET FLAGSHIP PILOTS MIDTERM CONFERENCE

WARSAW, POLAND, 24-25 NOVEMBER 2011

European Commission
Information Society and Media

Foreword by Prof. Barbara Kudrycka
Minister of Science and Higher Education, Government of the Republic of Poland

Today's Europe is marked by many socio-economic challenges; to answer them we need bold researchers and societies. We need cutting-edge projects that will address ambitious problems and pushing science beyond its current boundaries will have a substantial impact in social, economical and environmental domains.

To implement such large scale, visionary projects, we need the concentrated efforts of scientists and governments to create supporting framework conditions, as well as targeted instruments combining international expertise, a multidisciplinary approach and effective management.

To address these aims the European Commission elaborated the FET Flagship concept, and in May 2011 launched six Pilot Projects that have been given one year to prepare proposals for full FET Flagship Initiatives. In 2013 two Consortia with the most promising ideas will be selected and will start their researches over ten years, with a total budget of around one billion Euros per Consortium.

Poland strongly supports the FET Flagship Programme. Several clusters of Polish researchers are involved in Consortia formed by the Pilot Projects. Our country plans to underpin Flagship Projects by providing appropriate funds for the participation of Polish researchers that should be able to apply for matching grants using corresponding calls of various national funding agencies.

FET Pilot projects touch upon various aspects of our life, from the human brain, new materials and techniques, to the simulation of socio-economical processes for global crisis management. FET Pilot Projects on the one hand improve our understanding of those issues, and on the other are the tool allowing stakeholders to focus their work.

The main objective of the FET FLAGSHIP PILOTS MIDTERM CONFERENCE is to present the progress made by all Pilot Projects on their visions, goals and expected impact on science, technology and society. Moreover, it will allow bilateral discussions between Flagship Pilots and European as well as national funding agencies. The conference is held under the patronage of the Polish Presidency of the EU Council at the Warsaw University of Technology and the University of Warsaw.

I believe that the Conference in Warsaw will create a forum for pushing forward the vision of FET Flagship Projects. I wish all participants a fruitful meeting.

Foreword by Neelie Kroes
Vice-President of the European Commission for the Digital Agenda

The FET Flagships Pilots midterm conference is a unique opportunity: to look ahead to the next decade of ground-breaking research, and to exchange views with funding organisations.

At the moment, many of us are very seriously discussing how to make Europe more competitive. Research is a vital component of any such strategy, and so it is a vital component of the Commission's Europe 2020 plan for smart, sustainable, inclusive growth. In particular, the Digital Agenda for Europe, which I launched last year, seeks to boost ICT research and development, through increases in both public and private spending. ICT is a technology which few sectors can do without; it enables progress in almost every industry. Many of our competitors recognise this and spend far more than we do on ICT research; it is vital for the future European economy that we increase our support too.

Of course, in times of financial uncertainty there is great pressure on every budget: so we must make sure that Europe works together to get the best results. Big science can be expensive: but we have seen how countries can cooperate on large projects of common interest such as

CERN or ITER to find answers to tough research challenges, even in the current financial crisis. We must do the same in ICT. The Commission and Member States have started to lay some of the foundations by developing world-class research infrastructure, and European scientists can now raise their level of ambition to take full advantage of them.

I want us to tackle the grand scientific challenges, and achieve world-class results. We have at our disposal the many talented, world-leading scientists that Europe has to offer. With the right political conditions, they can work together efficiently to reach common goals, and we will all benefit. That means we need to reinforce the coordination of ICT research, pool resources at EU and national levels, and create the critical mass needed to achieve our goal.

The Commission has challenged the scientific community to identify research goals appropriate to be implemented as FET Flagships: that is, research goals that can only succeed with a large-scale, federated effort, aligning programmes and resources from the EU and Member States. The response has been outstanding, as can be seen from the visions of the six FET Flagship Pilot actions described in this publication.

The Commission is committed to launching two FET Flagships in 2013, and the next few years promise to be an exciting period for FET research, with the potential to further strengthen Europe's research capability by embedding and integrating FET Flagships well in EU and national programmes.

I hope that these 'Big Science' initiatives will inspire both scientists and national policy makers to dream about what Europe can achieve, and that we can join together to make the dream a reality.

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FET Flagships Past, Present and Future

Origins of European ICT and FET research

The story of the European research funding programme for ICT started about 30 years ago, at a time when information technology development in America and Japan was accelerating and Europe's previously leading position in technology was starting to decline very rapidly. In late 1981 the directors of the 12 largest European IT companies were invited to a roundtable discussion by the EC and a few months later they presented a work plan for a collaborative research and development programme. In the same year, the European Commission created the "Information Technology and Telecommunications Task Force". In 1983, the pilot phase of the first European IT research programme was launched. In 1998 all ICT related research activities (the former ESPRIT (IT) research programme, the ACTS (Advanced Communications Technologies and Systems research programme and the Telematics Applications Programme) were merged into the 'Information Society Technology (IST)' programme (renamed 'Information and Communication Technology (ICT)' in 2007). This ICT research programme became part of the 5th Framework Programme for research and technological development (1998 – 2002) of the European Union.

The Future and Emerging Technologies (FET) programme itself traces its history back to 1989 when a specific sub-programme called BRA (Basic Research Actions) was launched in ESPRIT II (a former European information technologies research programme); BRA was renamed to FET in 1998.

The mission of FET

The European Future and Emerging Technologies Programme promotes long-term & high risk research that aims to advance scientific and technological knowledge and to lay new foundations for future Information and Communication Technologies (ICT). FET projects target research breakthroughs that have the potential to radically transform the scientific and technological tools used to build tomorrow's society. Some 165 projects are currently funded in FET research, which is now in its 22nd year.

The mission of FET is to promote long term high risk research, offset by potential breakthroughs with a high technological or societal impact. As such, FET aims to identify and develop future industry-relevant ICT frontier research agendas and to help relevant research communities to emerge and mature.

As inspiration for ground-breaking solutions often comes from disciplines outside the traditional IT sector, a prominent feature of the FET scheme is it's support of multidisciplinary research. FET funds, for example, long-term and high risk research activities in nanotechnologies at atomic or molecular scale, quantum physics, bio-chemistry, swarm robotics, brain inspired computing etc. The objective is to foster the emergence of new areas of research, to anticipate and set new trends and to build up collaborative teams and innovative skills across Europe.

The European FET research scheme is unique in the way it combines the following characteristics:

- Foundational. FET lays new foundations for future ICT by exploring new unconventional ideas and scientific paradigms that are too long-term or risky for industrial research.
- Transformative. FET is driven by ideas that challenge and can radically change our understanding of the scientific concepts behind existing information technologies.
- FET encourages high-risk research, but it balances these risks against high potential returns and possible revolutionary breakthroughs.
- Purpose-driven. FET aims to make an impact on future industrial ICT research agendas.
- Multidisciplinary. FET builds on synergies and cross-fertilisation between different disciplines such as biology, chemistry, nano-, neuro- and cognitive science, ethology, social science or economics.
- Collaborative. FET rallies the best teams in Europe and increasingly worldwide to collaborate on common new and emerging research topics.

FET is implemented by means of thematic research in emerging areas (FET Pro-active) and an open scheme (FET Open), involving the unconstrained exploration of novel ideas.

Europe's leading competitors have acknowledged the importance of foundational research for gaining and maintaining a leading position in ICT. In the US, rebalancing of the Federal Networking and Information Technology R&D Program was recommended in order to include more large-scale, long-term multidisciplinary activities and visionary research with a high potential pay-off. China has included information technology in its basic research programme to meet the nation's major strategic needs.

Partnerships for European Scientific Leadership: FET Flagships

More than ever in a difficult economic context, European industries' in-house investment is tending to focus on short-term market-driven research priorities rather than high-risk ICT research. This trend must be balanced by higher public and private investment in high-risk research.

Foundational ICT research in Europe today still remains fragmented in most domains, leading to duplication of effort, diverging priorities and untapped potential. Europe needs to develop joint research agendas based on a shared vision for foundational research and would benefit from applying the FET model in collaboration with Member States.

The European Commission's ICT Advisory Group (ISTAG) provides strategic advice and orientations on long term foundational research, in order to strengthen and broaden the science and technology basis of future ICTs. Based on ISTAG recommendations, the European Commission adopted in 2009 a Communication to the Council and European Parliament COM (2009) 184 'Moving the ICT frontiers' which included in its strategic action plan a proposal for "*launching two or three bold new FET research flagship initiatives which will drive larger multidisciplinary research community efforts towards foundational breakthroughs at the frontier of ICT, (…) on a scale too large to be addressed by current FET initiatives*". In response, the Competitiveness Council of the European Union in its December 2009 Conclusions "*invites the Commission to propose Europe-wide flagship initiatives in FET to tackle specific science and technology challenges at the crossover between ICT and other scientific disciplines*". The decision is underpinned by arguments stating that:

- "ICT is one of the main drivers of economic growth and social change and, as such, plays a vital role in the economic recovery, enabling Europe to emerge from the current crisis faster and stronger than before;"
- "fragmented European markets, a fragmented ICT research and innovation landscape, lack of human resources and under-investment in ICT research and innovation are major obstacles preventing Europe from taking full advantage of current and future ICT;
- "to reinforce future and emerging technologies (FET) in ICT, [the Council] RECOGNISES the strategic importance of high-risk, multidisciplinary research on new foundations for future ICT, to seed novel technologies and to open new research avenues that are essential for ensuring innovation and sustainable competitiveness of European enterprises".

FET Flagships are being developed using a bottom-up process. At the end of 2009 an open online consultation was set up to collect first grand ideas on FET Flagships from the scientific community. This was followed by several open workshops and information days to discuss and mature the scientific and technological ideas for FET Flagship candidates, and to catalyse the coordination of plans and community structuring. To channel the consultations throughout the initial phase of FET Flagships, two working groups were convened.

The first group, the External Advisory Group acts as an independent scientific advisory group to the EC during the FET Flagships preparation phase. The group is composed of about 10 top-level experts from science and research, with a significant representation from the FET-ICT research community as well as from other areas such as the Life Sciences, Social Sciences, Economics, Material Sciences, Energy, and Health.

The second group, the National ICT Directors' Working Group on FET Flagship Initiatives, was established to support the interaction between Member and Associated States' research and technological development authorities/funding agencies and the EC, and to investigate how FET Flagship Initiatives could be a means to align national research policies and programmes in long-term fundamental research.

Preparing the launch of the first FET Flagships

In 2010 the EC issued a Call for proposals for FET Flagship Initiative Preparatory Actions ("Flagship Pilots"), with the objective of promoting in a competitive bidding process the self-organisation of the scientific community, the preparation of a detailed research agenda, including the preparation of plans in terms of financial and operational feasibility. From the 23 proposals received, an expert panel, composed of renowned scientists, research programme leaders and industrialists, ranked the proposals according to their scientific excellence, their potential for realising scientific breakthroughs, and for their potential impact on Europe's social and industrial challenges. The top six contenders received around €1.5 million each to refine their proposal over a one-year period, targeting the complete design and description of consolidated candidate FET Flagship Initiatives by mid-2012.

The six Flagship Pilots were officially launched by EC Vice-President Neelie Kroes at the fet11 Conference: The European Future Technologies Conference and Exhibition, held under the auspices of the Hungarian presidency in Budapest in May 2011. Each of the Flagship Pilots is currently working on developing their strategic research plans, structuring a community that will be in a good position to implement their integrated research agenda, and on obtaining the involvement and commitment from key stakeholders.

A horizontal Support Action named FLEET started in April 2011 to assist the FET Flagship Pilots in addressing common, non-competitive issues, including aspects such as legal frameworks, civil society and ethical issues.

FET Flagships represent a new opportunity and a new approach to shape, build and realize a truly European Research Area. To implement a joint effort of such grand scale requires a great amount of preparation in terms of bringing together the best scientists with the brightest ideas, defining operational mechanisms, devising and putting in place a legal framework, and most of all, establishing the political and financial support of stakeholders.

While these are significant challenges, they also constitute clear opportunities for all stakeholders to:

- Avoid spreading S&T basic research funding too thinly at national and EU levels by coordinating efforts, and benefiting from what others do, directly or indirectly.
- Place different scientific theories, ideas and technological challenges under an exciting umbrella that stimulates many scientists to position their work in a bigger picture.
- Reach higher awareness, impact and return on investment in upstream research.
- Extend the time-horizon of research towards emerging technologies and their applicability in an integrated and coherent way.
- Create a framework in which scientists and technologists of different disciplines can initiate dialogue and collaborate actively, look for new inspirations from other domains, and benefit from the possibilities offered by tackling problems in a multidisciplinary approach.
- Give basic S&T research a stronger position in the funding systems via the creation of legal instruments which foster enforced connections with more established disciplines.
- Help to link scientific and technological research to innovation, and eventually towards commercialisation.

Two of the six Flagship Pilots are expected to be selected for launch as full FET Flagship Initiatives in 2013, initially within the FP7 programme. This is expected to involve long-term commitment over a period of up to 10 years, with each FET Flagship working with a total budget of up to €100 million per year where appropriate.

FuturICT

What is FuturICT?

FuturICT is a visionary project that will deliver new science and technology to explore, understand and manage our connected world. This will create new information and communication systems that are socially adaptive and socially interactive, supporting collective awareness.

Revealing the hidden laws and processes underlying our complex, global, socially interactive systems constitutes one of the most pressing scientific challenges of the 21st Century. Integrating complexity science with information and communication technologies (ICT) and the social sciences, will allow us to design novel robust, trustworthy and adaptive technologies based on socially inspired paradigms. Data from a variety of sources will help us to develop models of techno-socio-economic systems. In turn, insights from these models will inspire a new generation of socially adaptive, self-organized ICT systems. This will create a paradigm shift and facilitate a symbiotic co-evolution of ICT and society. In response to the European Commission's call for a 'Big Science' project, FuturICT will build a large-scale, pan European, integrated programme of research which will extend for 10 years and beyond.

Why do we need it?

Today, society and technology are changing at a pace that often outstrips our capacity to understand and manage them. It seems that we know more about the universe than about our society. Therefore it is time to use the power of information to explore social and economic life on Earth and discover options for a sustainable future. As the recent financial crisis demonstrates, the systems built to organise our affairs now possess an unprecedented degree of complexity and interdependence among their technological, social and economic components. This complexity often results in counter-intuitive effects driven by positive feedbacks that lead to domino-like cascades of failures. Neither the precepts of traditional science, nor our collective experience from a simpler past, adequately prepare us for the future. It is simply impossible to understand and manage complex networks using conventional tools.

We need to put systems in place that highlight, or prevent, conceivable failures and allow us to quickly recover from those that we cannot predict. We need this insight to help manage our financial markets but also to tackle other risks, such as pandemics, social instabilities, or criminal networks. At the same time, policy-makers are currently faced with major decisions of how to plan the general infrastructure of services to cope with the demands of the future, and what is more, to do so in a sustainable manner. The same decisions are also posed to individuals who wish to improve their own lives.

Thus now is the time to create a paradigm shift moving from a focus on the system components and their properties towards evaluating their interactions. These interactions are often hard to measure but create collective, emergent dynamics which are characteristic of strongly coupled systems.

How will it work?

The FuturICT flagship project will align the research of hundreds of the best scientists in Europe through a 10 year, € 1 billion research programme to develop new methods which integrate different scientific models, data and concepts. To build capacity, regional support will be developed alongside educational programmes for young researchers.

FuturICT will build a sophisticated framework for simulation, visualisation and participation, called the FuturICT Platform. A suite of models forming the Living Earth Simulator will power Observatories, to detect and mitigate crises plus identify opportunities in specific areas. These models will be driven, and calibrated, by data aggregated in real-time, which are gathered by a digital Planetary Nervous System. Both models and data will support the decision-making of policy-makers, business people and citizens, through a Global Participatory Platform which is intended to facilitate better social, economic and political participation.

The FuturICT Platform consists of:

- the Planetary Nervous System
- the Living Earth Simulator
- the Global Participatory Platform.

The FuturICT Platform in detail

Planetary Nervous System

The Planetary Nervous System can be imagined as a global sensor network, where 'sensors' include anything able to provide static and dynamic data about socio-economic, environmental or technological systems which measure or sense the state and interactions of the components that make up our world. Such an infrastructure will enable real-time data mining - reality mining - using data from online surveys, web and lab experiments and the semantic web to provide aggregate information. FuturICT will closely collaborate with Sandy Pentland's team at MIT's Media Lab, to connect the sensors in today's smartphones (which comprise accelerometers, microphones, video functions, compasses, GPS, and more). One goal is to create better compasses than the gross national product (GDP), considering social, environmental and health factors. To encourage users to contribute data voluntarily, incentives and micropayment systems must be devised with privacy-respecting capabilities built into the data-mining, giving people control over their own data. This will facilitate collective and self-awareness of the implications of human decisions and actions. Two illustrative examples for smart-phone-based collective sensing applications are the open streetmap project and a collective earthquake sensing and warning concept.

Living Earth Simulator

The Living Earth Simulator will enable the exploration of future scenarios at different degrees of detail, integrating heterogeneous data and models and employing a variety of theoretical and modelling perspectives, such as sophisticated agent-based simulations, multi-level mathematical models, and new empirical and experimental approaches. Ideas from complexity science will be compared with graph theoretic approaches and other techniques based on concepts from statistical physics. Exploration will be supported via a 'World of Modelling' – an open software platform, comparable to an app-store, to which scientists and developers can upload theoretically informed and empirically validated modelling components that map parts of our real world. This will require the development of interactive, decentralised, scalable computing infrastructures, coupled with access to huge amounts of data. Large-scale simulations and hybrid modelling approaches will require supercomputing capabilities that will be delivered by several of Europe's leading supercomputing centres.

Global Participatory Platform

The Global Participatory Platform will be an open framework for citizens, businesses and organisations to be able to share and explore data and simulations, and debate the potential implications. It will democratise 'big data', promoting responsible use of information systems and opening up the modelling of complex systems to non-experts. Next generation decision arenas for policy-makers will be developed to evaluate the consequences of interventions, and then opened up and tuned to the needs of the diverse stakeholders. This will enable (1) software developers to add value, e.g. mobile apps that exploit specific datasets or upload data; (2) develop information visualisation tools for policy analysts and researchers; (3) create semantic web services for distributed processing (provide) tools to support and learn from online debates. This participation will harness and shape the emerging global, social computing infrastructure to tackle various problems. In addition it will equip different scales of collective agent to more effectively sense their environments, interpret signals, debate the assumptions and implications, and make better informed, more collectively owned decisions.

What will be the benefit?

The FuturICT project will produce benefits for science, technology and society by integrating previously separated approaches. ICT systems of the future will provide the social sciences with the datasets needed to make major breakthroughs in our understanding of the principles that make socially interactive systems work well. This, in turn, will inspire the design of future systems, made up of billions of interacting, intelligent components capable of partially autonomous decisions. One goal is the creation of a privacy-respecting, reputation-oriented, and self-regulating information ecosystem that promotes the co-evolution of ICT with society. The tremendous growth in social media, mobile applications, Open Data and Big Data will enable complexity science to tackle practical problems by uncovering laws of interaction and help us understand the implications of strong couplings, thereby forging a new science of global systems that are more resilient to disruptions.

Furthermore, FuturICT will produce outcomes that are relevant to society, creating systems that help decision-makers assess the implications of alternative strategies. FuturICT's Global Participatory Platform will thus provide something like a policy 'wind tunnel' where the consequences of decisions can be explored. Hence the project will create a focus on resilience and sustainability.

The interdisciplinary concept of FuturICT foresees the integration of expertise in information and communication technology (ICT), complexity and social sciences, to create outcomes in these three areas.

Exemplar, case studies will be performed in order to address major challenges such as smart cities or smart energy systems, but also build up our capacity to model systems and understand data. Additionally these studies will improve our understanding of over-arching, key concepts such as risk, trust, resilience and sustainability which are relevant to a wide range of systems, including ICT systems.

Having all this new information in place will allow FuturICT to study interactions among society, technology, environment and the economy through interconnected "Exploratories". This will allow us to create an Innovation Accelerator that will discover valuable knowledge in the flood of information, help to find the best experts for projects, and support the distributed generation of new knowledge, hence promoting innovation. FuturICT will start an era of social innovation, sparking off novel, socially-inspired technologies, spin-offs and whole new business areas.

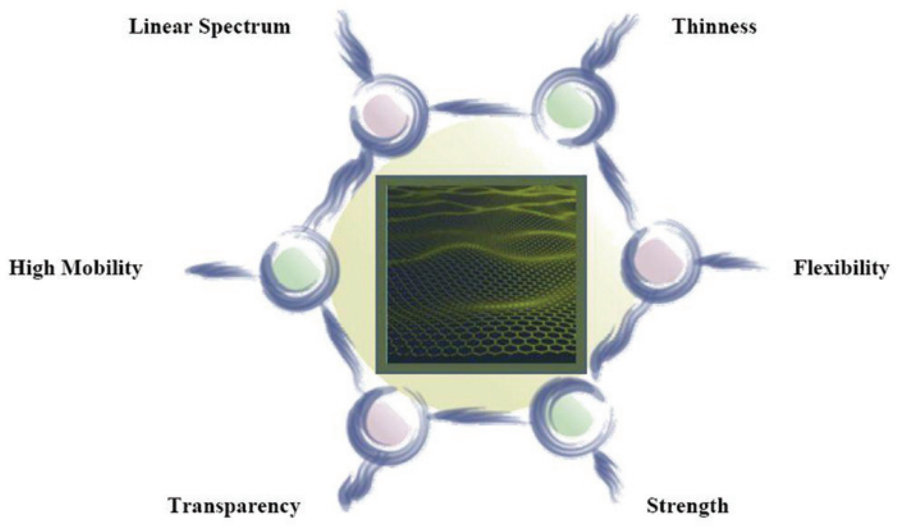
Who's involved?

Active collaborations are now taking place among Europe's top universities with hundreds of researchers engaged in the project. Hubs to support regional activities have been created in many European countries. FuturICT communities also exist in USA, Japan, China, and Australia. Individuals and a wide range of scientific organisations have expressed their explicit support, as have small and big businesses. Each supporter recognises the vital importance of securing funds for this area of research to build European expertise within an integrated project and create an innovation economy based on the digital revolution, while at the same time benefiting humanity. Affiliations with existing complementary projects are being established and new projects are being encouraged.

Regional hubs have been set up in many countries to coordinate activities. We also envisage different institutes joining the project as it develops. In addition, collaborations have started with Microsoft Research, IBM, Telecom Italia, Yahoo! Research, Disney Research, Telefonica, Mendeley, Springer Publishers, SAP and many others.

Graphene

The FET Flagship on graphene and related two-dimensional materials targets a revolution in information and communication technology, with impacts reaching into most areas of the society. Our mission is to take graphene and related layered materials from a state of raw potential to a point where they can revolutionize multiple industries - from flexible, wearable and transparent electronics to high performance computing and spintronics. This will bring a new dimension to future technology – a faster, thinner, stronger, flexible, and broadband revolution. Our program will put Europe firmly at the heart of the process, with a manifold return on the investment of one billion Euros, both in terms of technological innovation and economic exploitation.



The unique properties of graphene can be utilized, either separately or in combination, to create novel applications such as flexible transparent electronics, conducting light and strong composites, and many more.

The material with most superlatives

Graphene is single layer of carbon atoms arranged in a hexagonal lattice with a host of properties ideal for applications. One of the commonly occurring forms of carbon, graphite, is a stack of graphene layers, and has been used in a number of applications for hundreds of years, while monolayer graphene is still mainly confined to academic research. The overall goal of the FET Flagship is to change this and harness the potential of graphene and related materials to revolutionize information and communication technology (ICT) and find new applications in other areas.

The current focus on graphene followed the ground-breaking experiments by A.K. Geim and K. Novoselov in 2004 that were acknowledged with the Nobel Prize in Physics in 2010. The huge interest in graphene is driven by the considerable and tantalizing potential that this material offers in conventional as well as radically new fields of ICT applications. The electronic structure of graphene is very unusual, leading to higher device speeds and a potential for much faster electronics than what we know today. Graphene is almost transparent, absorbing only 2.3% of incident light, and very well suited for photovoltaic applications in optoelectronics, touch screens and solar cells. Due to its ultimate thinness, graphene is very flexible, but at the same time graphene is the strongest material we know (100-300 stronger than steel with the same weight), as well as the best conductor of heat, which enables not only flexible electronics but many applications outside ICT such as strong lightweight composites. Some of graphene's superlative properties are given in the figure above. Graphene is the first example of a new class of two-dimensional materials. Other members of this emerging materials group include boron nitride and different metal chalcogenides. Combining them with each other and with graphene in various sandwich structures has rapidly emerged as an interesting new materials palette for electronics. At this point, these materials have not been thoroughly explored, and their full potential has not yet been assessed.

Research challenges and technological potential associated with graphene and related materials

Since the start of the graphene revolution in 2004, numerous application concepts based on graphene have been demonstrated. In just a few years, high-frequency graphene transistors have reached performance levels that rival that of the best semiconductor devices that have over sixty years research effort behind them. Graphene electronics is still very much in its infancy and, extrapolating from recent progress, we expect graphene devices to break the 1 THz barrier in a matter of a few years.

In optoelectronics, the first graphene-based touch screen was recently demonstrated in Korea. The touch screen application is expected to be one of the first to be commercialized, partly because the materials choice is quite limited: the screens must exhibit both electrical and optical functionalities, and very few materials conduct both electricity (like metals) and light (like window glass). Presently, touch screens rely on limited resources such as indium that is only available from a few sources, predominantly in China, while graphene is essentially an unlimited resource – carbon is one of the most common elements on Earth. Graphene has been used to produce tunable lasers by exploiting the material's unusual electronic structure that guarantees a wide tuning range. Graphene's properties also imply that the percentage of light absorbed decreases when the incoming light intensity increases, which can be exploited to fabricate very fast pulsed lasers that have great potential in optical communication.

However, despite the great progress in graphene science and technology during the past six years, the field is still very young and many challenges remain. Some of them are fundamental: due to the unique structure of graphene, many of the possibilities it offers are still poorly understood, and their analysis requires highly sophisticated methods. To quote the Nobel Laureate Frank Wilczek from the Nobel Symposium on graphene held in Stockholm in May 2010, «graphene is probably the only system where ideas from quantum field theory can lead to patentable innovations». Among these fundamental challenges is the possibility to use spin rather than charge as the information carrier.

Many of the major experimental challenges have to do with materials supply. There are several methods to produce graphene – on the laboratory scale, mechanical exfoliation ("Scotch tape method") works well but is difficult to scale-up, while the techniques of chemical exfoliation, chemical vapor deposition and sublimation of silicon carbide are in principle all upscalable and have different strengths and weaknesses. Reliable and sufficiently large scale production of graphene with consistent quality is a crucial and necessary step before graphene science can evolve into a graphene technology. Further challenges are associated with the integration of graphene with other members of the family of monolayer materials to create heterostructures with tailored properties.

Different application areas have their own research challenges: for instance, the main hurdle that presently blocks the development of digital graphene electronics is the absence of an energy gap, which makes it very difficult to turn transistors off and limit leakage currents, while in analog electronics the related challenge is sufficient power amplification so that several graphene transistors can be connected in series. These engineering challenges spawn new innovative solutions such as the BiSFET (Bilayer Pseudospin Field Effect Transistor) that relies on the gapless nature of graphene to create a new type of transistor and regard ambipolarity as a new asset rather than a deficiency, or the tunnel FET where the bangap-tunable nature of bilayer graphene can allow efficient switching with no need to manufacture ribbons.

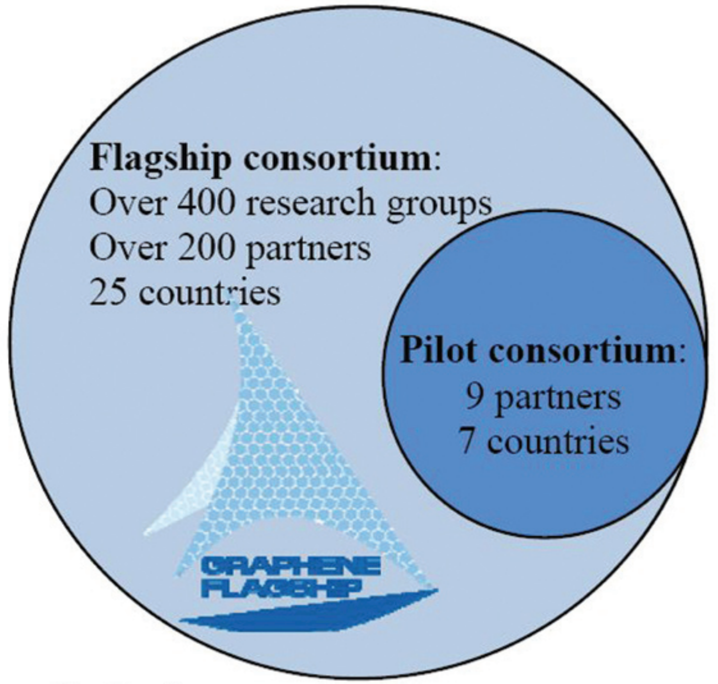
Industrialization of graphene technology

Graphene research is an example of an emerging "translational nanotechnology" where discoveries in academia are rapidly transferred to applications. The concept "translational nanotechnology" is typically associated with biomedicine where there is a well-established link between basic research and clinical studies, but the principle can be applied to ICT as well. The most striking example is giant magnetoresistance that moved from an academic discovery to a dominant information storage technology in a matter of a few years. Similarly, graphene has the potential to make a profound impact in ICT in the short and long term. Integrating graphene components with silicon-based electronics, and gradually replacing silicon in some applications, allows not only substantial performance improvements but, more importantly, enables completely new applications.

Graphene represents a disruptive technology shift, and, as such, faces great uncertainties and challenges. While we are convinced that graphene will make a revolutionary impact in ICT, it is much harder to pinpoint which applications will emerge first. In consumer electronics the volumes are so large – for instance, 44 mobile telephones are sold worldwide every second – that a reliable supply of materials and components is an absolute requirement. A systems manufacturer will not develop a new technology unless it can be assured of a safe component supply, while the component producer depends similarly on the materials supply and on the demand from the systems manufacturer. The strength of a concentrated effort, such as the FET-Flagship, is that it can address all parts of the value chain and catalyze the technology shift that no single player or branch would dare to undertake on their own. The branching of the value chain – usage of same materials or components in different applications – is another strength of such an approach. It allows the actors to pursue simultaneously both the low-hanging fruits, the first applications, and the larger strategic goal.

Implementation of the FET Flagship Pilot

The Pilot project prepares the road for the FET-Flagship initiative Graphene-Driven Revolutions in ICT and Beyond. The goal of the Flagship is to secure for Europe a key role in future ICTs based on graphene and related two-dimensional materials by providing a long term strategy of transferring knowledge and intellectual property into technological applications.



The Graphene consortia

The pilot consortium involves nine academic and industrial partners in seven EU member states. They carry the main responsibility for preparing the full flagship, and engaging the large European graphene community in the project. The large flagship consortium is still developing: presently over 400 research groups in over 25 European countries have expressed interest in joining the flagship. The prospective flagship partners represent a wide range of academic and industrial activities that come together to face the challenges of creating a major technology shift in ICT.

Despite being a very young research area, graphene research has already attracted substantial funding, both from national and European sources. Combined, the EC and the ERC have funded graphene research with about 40 million Euros in total and the member states with significantly more (tens of millions of Euro per year), both through national programs and transnational collaborations such as the ESF Eurocores program 'EuroGraphene'. These projects aim at advancing expertise in graphene devices, material characterization, or simulation, and at the development of functionalities such as composite materials and spintronic or photonic applications. However, the existing research effort is fragmentized in sub-critical small projects that end up duplicating each others' efforts, leading to reduced impacts and sub-optimal usage of national and EC resources.

The aim of the FET-Flagship is to improve coordination and create synergy effects that are necessary to realize the impact that we are convinced graphene and related materials will have. We will bring together a focused, interdisciplinary European research community that aims at a radical technology shift in ICT. We will develop graphene electronics that can sustain ICT devices and technologies evolution beyond the limits achievable with silicon. By exploiting the unique electrical and optical properties of graphene, we will develop novel electronics systems with ultra-high speed of operation and electronic devices with transparent and flexible form factors. We will advance methods to produce cheap graphene materials which combine structural functions with embedded electronics, in an environmentally sustainable manner. The flagship initiative will extend beyond mainstream ICT to incorporate novel sensor applications and composite materials that take advantage of the extraordinary chemical, biological and mechanical properties of graphene.

The EU member states have clearly recognized the potential of graphene. Several Member States have been setting up priority programs and networks to support graphene research and innovation. The FET Flagship offers a unique and timely opportunity to develop a unified strategy among European players in order to bring the potential of graphene-based technologies into reality for the benefit of all Europeans.

Guardian Angels

Overview

The "Guardian Angels for a Smarter Life" (GA) FET Flagship will create smart, energy-efficient electronic personal companions, which are ultra-small, and thus inconspicuous, and which will assist human beings in all situations of life from infancy to old age. They will be autonomous and thus easy to use, and they will be personalized, secure, and under full control of their users, and thus safe and trustworthy. These devices will be intelligent, autonomous systems-of-systems featuring sensing, computation, and communication beyond human capabilities. The project goal is to develop zero-power technologies for these electronic personal assistants, so that they will harvest all the energy they need rather than requiring an external power source. This flagship proposal is driven by the fundamental scientific challenges related to achieving energy efficiency in complex systems-of-systems, and will impact the development of ICT future and emerging technologies through multidisciplinary research targeting long-term goals.

The zero-power requirement of the project has two sides: the creation of energy through harvesting, and the development of ultra-low power systems, whose energy consumption is at an absolute minimum. The future devices will have the ability to scavenge for energy in very diverse environments and store the energy needed for the system functions. This will, however, require disruptive scientific progress in the field of novel concepts and technologies for energy harvesting, both for known types of energy harvesters such as solar, thermal, vibrational, and electromagnetic, as well as for new bio-inspired energy scavengers that are bio-chemical or synthetic photosynthesis-based. The target power density will be up to 10 mW per cm2 (or cm3), achieved by a combination of different types of harvesters. At the same time it is vital to ensure that minimal power is consumed by the rest of the system. The scientific and technological challenges of the project thus include developing a full ultra-low energy innovation chain: from materials and devices, to heterogeneous system integration, to software and communication techniques enabling the reduction of energy consumption by up to three orders of magnitude compared to existing state-of-the-art technologies. Compared to existing ENIAC, CATRENE and ICT initiatives, this FET Flagship will not be limited to segments of the nanoelectronics innovation chain, but will instead unify energy-efficient technologies and integrated energy scavengers within one long-term design and integration platform.

The objectives of the project are divided into three main categories: (i) scientific objectives centered on ultra-low power concepts, (ii) novel (nano)technology, materials and device integration solutions (utilizing advanced silicon platforms but including novel families of nanomaterials like graphene, carbon nanotubes and/or organic semiconductors on flexible substrates), and (iii) three generations of visionary zero-power autonomous systems demonstrators. These categories of objectives are interdependent and are designed to result in a platform of energy-efficient technologies for system integration, which will be applied to an unprecedented number of applications far beyond the GA demonstrators.

The impact of Guardian Angels on society and the economy will be enormous. On an individual level, anyone could benefit from a personal assistant acting as a modern day Guardian Angel, focusing on prevention in health and on personal safety, with the goal of maintaining or improving quality of life in a sustainable society. To achieve this, the GA consortium will work in close cooperation with different social stakeholders, interest groups and future users. Special attention will be paid to environmentally friendly, energy-efficient and economically feasible solutions. Undoubtedly, in the course of the project, further beneficial applications using GA technology will be explored to make our environment more interconnected and smart, more energy-efficient and safe.

The benefits of developing the enabling technologies for ultra-low energy consumption are indeed widespread and lie beyond the immediate application in smart devices. The novel electronic GA technologies developed in this project will reduce the energy consumption of systems-of-systems: the estimated reduction may be worth more than 7% of the worldwide GDP, as estimated by IBM analysts in 2010.

The project will strengthen the leading role of Europe in zero-power technologies by carrying out manufacturing in Europe and improving the competitiveness for leading communication, equipment and tools companies and service providers. Overall, the project will result in the creation of new employment in Europe in advanced Information and Communication Technology.

The Vision and Benefits of GA

GAs are foreseen as interconnected, smart, autonomous systems enabled by energy-efficient nanotechnology, constituting the outer circle of applications depicted in Fig. 1; they can be considered as the future of wireless sensors networks (WSN), and by their functionality they can include components of the internet of things. They will be interconnected, not only between themselves, but also through the gateway layer (mobile phones, PDAs, notebooks, tablets) to the inner circle of cloud (high-performance) computing. By their smartness and complexity they will enable personalized advice and assistance to humans, concerning their health and their interaction with the environment, far beyond what WSN and the internet of things can provide.

Figure 1: Positioning of GA zero-power technology and applications with respect to cloud computing and gateway (mobile communications and computing) technologies. Guardian Angels are smart, autonomous systems that are beyond wireless sensor networks in terms of functionality and powering, and include a higher complexity than the simple sensor nodes foreseen for the internet of things. GA will strongly interact with the gateway and cloud layers, and the project will create direct benefits for the future of mobile computing, and more energy-efficient architectures for high-performance computing.

GA technology will offer unique solutions for new generations of non-invasive biological monitoring, and for future smart apparel with embedded powering and sensing. They will enable unforeseen generations of autonomous robots. The supporting GA zero-power technology platform will impact development within other domains such as environmental, building and industrial monitoring, and efficient transportation. It will offer new progress paths for energy-efficient data processing in cloud computing, and change the way mobile computing interacts with humans' needs. In our project vision, GAs will give access to a huge variety of data, helping to extract relevant information for a smarter life: making life easier when you are well, helping to efficiently use energy sources, and maintaining or improving mobility and industrial processes without exhausting natural resources. GAs will also play a vital role for those of us who need increasing, or even continuous, support and services due to health problems or reduced mobility or sensory capabilities when we are advanced in years. Imagine today's mobile electronic systems being 1000x more energy-efficient so that they can be powered by the energy available in your environment without any power plugs. Imagine part of the energy savings transformed into sensing, communications and interface functions of an invisible system that becomes your day-to-day Guardian Angel. This project will address the grand scientific, technological and system engineering challenges in a time frame of 10 years to make this vision a reality.

Unifying goal: the science of zero power

Guardian Angels are defined as future zero-power, intelligent, autonomous systems-of-systems featuring sensing, computation and communication beyond human aptitudes. The science of zero-power involves exploratory research at the level of novel materials, devices, and system architecture that could enable energy savings by a factor of up to 1000 for the computation, communication and sensing functions. These will be combined with novel, smart, multi-harvesting interfaces able to detect and adapt to the most appropriate sources of energy, which will lead to an improvement of a factor of 100 in the harvesters' efficiency. Fig. 2 summarizes the integration of the main constituting functions into a single GA system, showing the driving force of the R&D, which is the improvement of the energy efficiency by orders of magnitude. As will be shown later, the GA consortium has identified the most credible technology principles and candidates to address these extraordinary challenges.

The zero-power GA is, therefore, the unifying goal of the project, and is defined as the systems-of-systems' ability to feed from the energy existing in dynamic environments, by harvesting various types of energy sources. The project will devise novel device concepts and material integration technologies for solar, thermal, vibration, and electromagnetic energy harvesters, and it will explore new bio-inspired, e.g. bio-chemical or synthetic photosynthesis-based energy scavengers, which will target power densities of 10 mW per cm2 (or per cm3) by a combination of different types of harvesters depending on the application context.. These battery-free, or in other words, zero-power systems will enable non-intrusive, independent and cost-efficient intelligent devices, which will communicate with each other and will support human beings by sensing biological signals and the environment.

Main objectives: enabling Guardian Angels autonomous personal assistants

The GA objectives are categorized into three groups:

(I) Scientific Objectives – These objectives concern fundamental research and involve the identification of underlying principles, devices, system architectures, algorithms and techniques that can advance the limits of today's energy consumption for each of the elementary functions composing the GAs, in order to achieve the required system autonomy.

- **Energy limits of computation:** reduce the energy per binary switching from 100,000 kBT down to 10-100 kBT (or from 100 aJ to 0.1 aJ per binary switching event). This research involves new switch concepts (like sub-thermal subthreshold switches), based on different physical mechanisms than conventional field effect transistors. The goal is to devise principles and technologies that allow the voltage supply of logic circuits to be scaled from 1V down to 0.2V, with negligible leakage current, which will offer a power gain larger than 100x.
- **Energy limits of sensing:** reduce the energy per integrated sensing event (including the first stage of the read-out interface) from 100 μW to 100 nW. Such energy savings combined with nanotechnology are foreseen as enablers of multi-sensing or sensor arrays in one smart system. The fusion of sensor data with ultra-low power will play a vital role in accomplishing the goals of the project.
- **Energy limits of communication:** to approach the limit of 1pJ/bit, candidate technologies are based on ultra-wideband systems, with a diversity of advanced techniques such as powerful low-rate error correcting codes and cooperative communication techniques. Other energy-saving solutions are foreseen at the architectural level.
- **Energy limits of man-machine interfaces:** the project will address the limits of zero-power man-machine interfaces and multi-modal sensing for affective state categorization approaching the ultimate energy limit of 1pJ/s. This includes scientific and technical energy challenges for brain-to-machine interfaces (including electroencephalography (EEG) and electrooculograhy (EOG)) based on non-verbal language, in which there is no need to speak, gesture, or type into a keyboard to communicate with machinery.
- **Energy limits of harvesting:** the project will explore and push the limits of energy scavengers, which should operate both in outdoor and indoor conditions and achieve levels of energy needed for GA systems 100x higher than the state-of-the-art. Various types of scavenger principles could be combined in a GA system, requiring disruptive materials and devices for solar, thermal, vibration, and electromagnetic, and significant advances in bio-chemical and synthetic photosynthesis scavengers. Research will include novel bio-degradable batteries that could be hybridized with the electronic systems to facilitate a realistic transition to the final zero-power autonomous systems.

Figure 2: Novel sensing, computation, communication and energy harvesting technologies are the basic blocks that will constitute the GA systems-of-systems. A dedicated operation system, communication and data security techniques will be combined with the hardware components to enable the GAs.

(II) Technology and Integration Objectives for implementing the zero-power technology platform supporting the GA demonstrator systems-of-systems.

One of the main goals of the project is to develop and implement a zero-power technology platform as a combination of future energy-efficient technologies and disruptive energy scavengers. The main components of the platform that together form the technology and integration objectives:

- **Energy-efficient technologies (computation, sensing, communication)**
- **Energy harvesting and green batteries**
- **Zero-power system design.**
- **Heterogeneous integration**
- **Software: operating system, communication and power management:** this objective also includes software-hardware interaction and all software-level components: operating system, power management, data security techniques and energy efficient algorithms and software codes.

(III) Zero-Power Systems-Of-Systems Objectives

Three (not purely chronological) generations of GAs are targeted, each constituting measurable objectives of the proposed systems-of-systems; progress on these generations will be reported in terms of full-hardware and virtual demonstrators in a well defined time frame (year 3, year 6, year 9). In this section we describe some of the main characteristics of the three GA generations that form the systems-of-systems objectives.

- **Physical Guardian Angels**

The Physical Guardian Angels are quasi-invisible, zero-power body area networks or, if appropriate, implantable devices, monitoring vital health signals and offering the necessary information for taking appropriate actions to preserve human health. They will acquire a well-defined view of the state of a person's health adapted to individual needs, by using a real-time, ultra-low-power, multi-parametric combination of non-intrusive, bio-signal sensors (ECG, accelerometers, gyroscopes, pulse oximetry, etc.) to allow for early warning and thus prevention. They can employ future GA technologies such as electronic skin or wearable networks of sensors with wireless interfaces. These systems will be compatible, from the communication point of view, with existing gateways (such as mobile phones) to serve as smart parts of a future vision of the internet of things.

- **Environmental Guardian Angels**

The Environmental Guardian Angels extend their abilities from the body to monitoring of the dynamic environment, featuring zero-power, bi-directional interfaces, full battery-free operation, disruptive scavengers (biochemical, thermoelectric, synthetic photosynthesis), personalized data communication, and algorithms permitting decisional processes. These devices will offer access to an augmented reality including alerts for hazards, e.g. electromagnetic or ionizing radiation, extended UV exposure, the concentration of allergens, pollens and gases. Moreover, they will be designed as real personal assistants to protect our children and maintain quality of life for elderly people. These sophisticated GAs will guard people from all sorts of environmental dangers, including pollution and catastrophic events, making our environment safer. These devices will feature complex, energy-efficient communication technologies (based on novel materials like graphene), both from GA to GA, and from GA to other gateways, offering complete networking capability. They will integrate the first disruptive energy harvesters developed in the project, and will demonstrate energy autonomy beyond any other existing technologies, at the hardware level. An extension of these GAs can be foreseen for other type of smart monitoring, for industrial, environmental and transportation applications.

- **Emotional Guardian Angels**

The Emotional Guardian Angels are intelligent personal companions with zero-power man-machine interfaces deployed at a very large scale. In addition to physical and environmental functions, they will be able to sense and communicate emotions and/or affective states by data fusion and human interfaces, and to categorize them in order to provide complex advice. They will play an important role in society, and will form a completely new generation of devices, not even imaginable today, based on human-technology interaction. They will assist people in capacities such as smart automobile driving assistants or air traffic controls, providing feedback if the user is too tired or emotional to control a vehicle, or using their inter-GA communication interface to avoid accidents. This could potentially aid the mobility of elderly people. They will extend human senses and reactions with beyond-human abilities, enabling increased security. They will enable social networking in real-time, in dynamic environments, under the full control of the individuals. In the medical field, they will provide quadriplegic sufferers with greater control of their environment, and will enable nonverbal decision-making and communication. These GAs could also help families and educators of those with autism spectrum disorders to understand and use alternative means of nonverbal communication. Emotional Guardian Angels may be the first intelligent systems of their kind for maintaining or even extending quality of life for patients who suffer from physical and mental health problems; they may interpret intentions and communicate with people in a completely new way, disruptive in comparison with existing technology.

The vision of Emotional GAs triggers a serious discussion about ethics, data security and privacy, both within the consortium and between the GA Flagship project and all the other stake holders, including those in medical professions, automotive companies, and the interested public. The GA project addresses these points explicitly and will include the respective stakeholders in the definition and implementation of the GA systems.

The GA Consortium: European and International Dimensions

The GA Consortium has the advantage of being based on a European-wide partnership, including more than two dozen universities, research institutions and industrial R&D labs in 13 countries. The consortium is coordinated by the two federal institutes of technology in Switzerland (EPFL and ETHZ), which have international recognition and the needed experience and infrastructure for this challenging endeavour. The consortium will be enlarged during the pilot phase with novel competences and partners, who will be identified following a detailed gap analysis, both in terms of scientific needs and impact. The competences are balanced in all the key fields of the proposed research, ranging from fundamental research to industrial applications and supported by technology transfer platforms, which not only shows the high involvement of all the research value chain actors in the project, but also maximizes the chances of success of the FET Flagship.

The proposed research topic, with a main focus on smart, autonomous systems enabled by energy-efficient (nano) technologies and their societal impact, is well synchronized with some starting or ongoing large, international programs such as One Mind (US), Smarter Planet (IBM) and Green Initiative (Intel). The GA consortium will have key collaborations at an international level in the US and south Asia, bringing complementary competences for success. The project goals and priorities are designed such as to reinforce and provide a new dimension of European leadership in autonomous smart systems and novel low-power technologies, and to position Europe at the top of research in these key ICT domains of the future.

The Human Brain Project

The HBP in a nutshell

The goal of the Human Brain Project (HBP) is to integrate neuroscience and clinical data from around the world into unifying computer models of the human brain, to simulate the behavior of these models, to develop applications for medicine and future computing, and to make these capabilities available to the world scientific community.

The HBP Consortium currently includes partner groups from 22 countries, including all major EU member states as well as Switzerland, the USA, Japan and China. When fully operational, it will employ a science and engineering workforce of approximately 550.

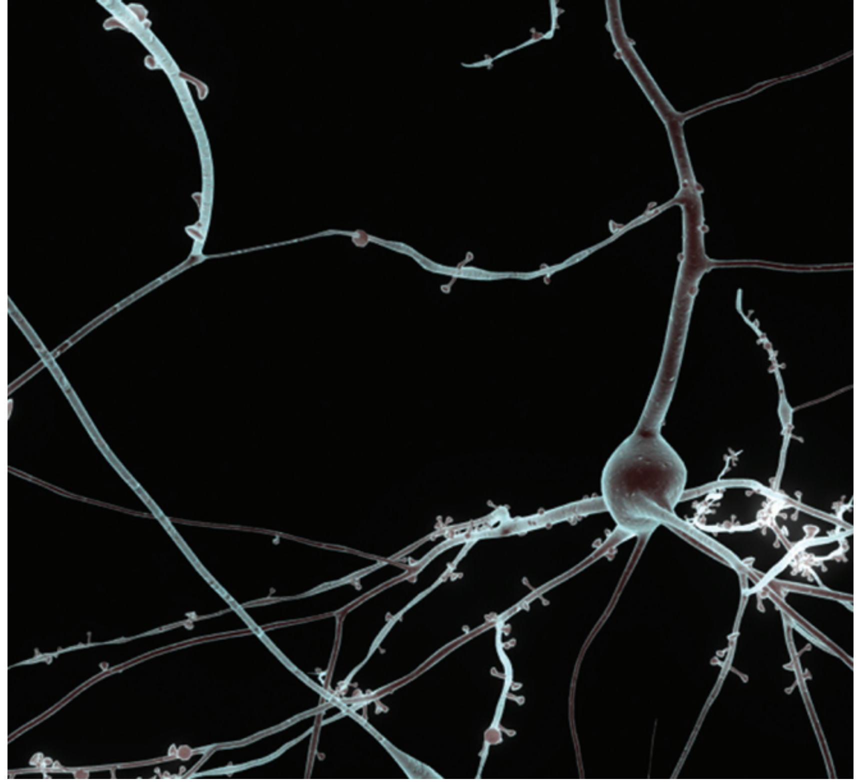
Rationale

In 2010, nearly a third of all European citizens suffered from some form of brain disease, with a cost to the European economy estimated at nearly 800 billion euros.* With few exceptions, research has yet to yield a causal understanding of the biological mechanisms underlying diseases and the way in which drugs affect the brain. Pharmaceutical companies are reducing their research into brain disease due to high risks and costs and low returns.

The situation in Information Technology is similar. There is broad consensus that IT needs to learn from the brain - a highly flexible, very fast, robust and massively parallel system with negligible power consumption (just 20-30 Watts) and unparalleled cognitive functionality. Yet attempts to implement brain-like designs in IT have not been very successful.

To respond to brain disease and to develop brain-like computing systems we clearly need a deeper understanding of the brain. A hundred years of neuroscience has accumulated a huge volume of highly fragmented data and knowledge, describing the brain on many different scales – from molecular interactions to cells and circuits through to cognition and behavior. What is completely missing is an integrative view of what we know and don't know. The new strategy proposed by the HBP is to systematically integrate all that is known into unifying models and to simulate the behavior of these models, allowing researchers to perform experiments impossible in animals or humans.

* Gustavsson, A., et al., Cost of disorders of the brain in Europe 2010, Eur. Neuropsychopharmacol. (2011),doi:10.1016/j.euroneuro.2011.08.008



The strategy exploits three key developments in technology and neuroscience:

1. The power of modern supercomputers is growing exponentially. Terascale computers have already allowed the project partners to move from simulations of single neurons to cellular level simulations of neuronal microcircuits. Existing petascale computers are powerful enough for cellular-level simulations of the whole rodent brain, or for molecular level simulations of small groups of neurons. Exascale computers, predicted for the end of the decade, will have enough computing power for cellular level simulations of the complete human brain and molecular-level simulations of areas of special interest.

2. New informatics and modeling approaches, already tested by the partners, allow scientists to integrate very large volumes of experimental and clinical data, to mine them for patterns and organizing principles of brain design valid within and across species. These principles can be used to guide and constrain models that predict hard-to-measure features of the brain from data that is more easily available, help to bridge knowledge gaps and make it feasible to build unifying models of the human brain without measuring every gene, protein, neuron, and synapse and without using ethically unacceptable invasive methods.

3. Large European and national research projects (FACETS, BrainScaleS, SpiNNaker) have developed "neuromorphic" technologies, implementing electronic models of neuronal circuitry in analog, digital and hybrid hardware. Systems resulting from this work offer massive parallelism, processing of high dimensional signals at speeds 10.000 times higher than biological nervous systems, support for plasticity and learning, low power consumption, and fault-tolerance. Nanoelectronics and new techniques of 3D circuit integration currently under laboratory study will bring further major improvements in integration density. Combined with biologically detailed brain models and better theoretical understanding the new technologies offer the prospect of novel computing systems, radically different from today's von Neumann machines.

Predictive Informatics

Informatics developed by the partners can already predict:

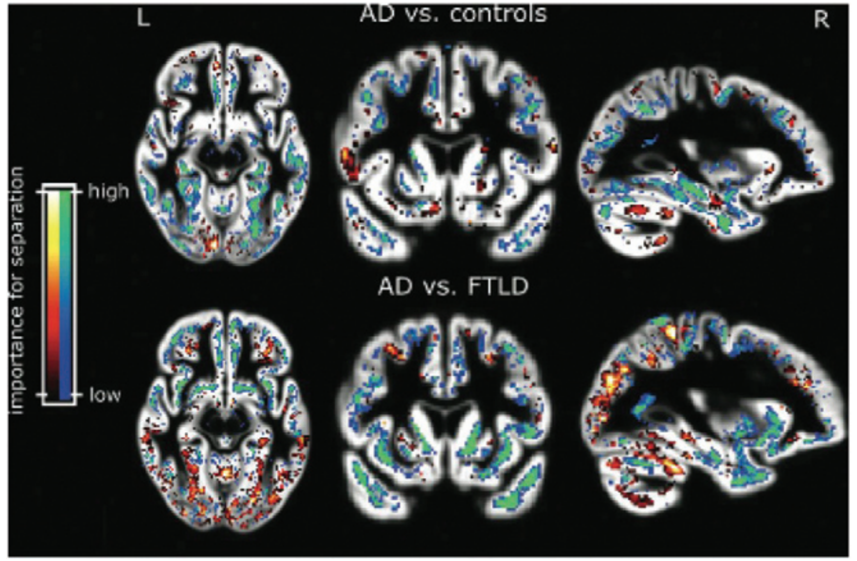
- Electrical behavior from gene expression patterns
- Larger patterns of gene expression from partial patterns
- Micro-circuit connectivity from neuron morphologies
- Cellular composition from brain maps of gene and protein expression

Goals

Data integration and Brain Simulation

The first objective of the HBP is to integrate neuroscience and clinical data in unifying models of the brain, and to simulate the behavior of the models. The Consortium will create the supercomputing capabilities necessary to enable simulations from the atomistic to the whole brain level. The HBP's simulation capabilities will scale up gradually. In the first years, the focus will be on the genetic make up of neurons, their morphologies, the distribution of cell types in the brain, and their micro and macro-connectivity. As the project enhances its generic brain building software and computing capabilities, it will adapt its models with species-specific parameters to build unifying models of mouse, rat, macaque, and ultimately human brains. Every fragment of new experimental data will add biological detail and accuracy, improving the predictive power of the models.

To implement this strategy, the HBP will develop a Facility for Brain Simulation, accessible to researchers over the Internet. The laboratory will offer researchers access to 3D brain atlases, software to build and simulate their own brain models, pre-tested workflows and tool chains, as well as "virtual instruments" equivalent to the physical instruments they already use in the lab. The Facility will contribute to scientists' productivity, ultimately allowing them to perform experiments that are not possible in humans or animals.



Brain Disease

The second goal is to contribute to understanding, diagnosing and treating diseases of the brain.

The project will create a new Facility for Medical Informatics offering an IT platform for federated mining and analysis of clinical data (genetic, biochemical, structural and functional brain imaging, clinical history, drug history etc.) from hospitals around the world. New informatics tools, developed by the Facility, will make it possible to identify biological signatures of specific brain diseases at different levels of biological organization from the genome to the whole brain. This strategy will allow clinicians to begin systematically mapping the similarities and differences between diseases providing a sound biological grounding for diagnostics and future personalized medicine. It will also point to possible causal mechanisms responsible for specific diseases, the relationships among them, and targets for treatment.

The data produced by this work will feed into unifying models and simulations of the human brain providing physicians and pharmaceutical companies with a completely new tool to test hypotheses of disease causation, search for drug targets, and perform in silico screening of drug candidates. Simulation will be equally useful for the design of novel medical devices and neuroprosthetics for diagnosing, monitoring and treating brain disease.

Future computing

The third goal of the HBP is to contribute to the development of future computing technologies, based on improved theoretical understanding and biologically detailed modeling of the brain.

The project will make a fundamental contribution to Neuromorphic Computing, bringing together existing European initiatives, developing principled methods to simplify brain models into artificial neural networks for implementation in "neuromorphic" devices and systems, and exploring relevant theoretical concepts, design tools and hardware (analog, digital and hybrid VLSI, non-CMOS technologies). The project will make these capabilities available to the community through a Facility for Neuromorphic Computing, allowing researchers and engineers to perform experiments with Neuromorphic Computing Systems of gradually increasing power and complexity. Researchers within the project will use these facilities to produce smaller prototype systems, which can form the basis for novel applications in industry, consumer electronics, medical devices, and vehicles as well as in future High Performance Computing and brain simulation.

Work in Brain Simulation and Neuromorphic Computing will feed research in Neurorobotics – the development of systems in which brain models are linked to robots in a "closed loop" with simulated and emulated brain models. Beginning with systems in which virtual robots interact with virtual environments – vital for experiments in behavior and cognition – the project will move toward physical systems in which brain models are implemented in neuromorphic hardware. The project will make these capabilities available to outside researchers through a new Facility for Neurorobotics.

The HBP will contribute to High Performance Computing. Simulating the human brain will require radical innovations in current techniques. In particular, exascale machines will generate more data than they can store or move to other machines. To meet this challenge, the HBP will develop new techniques to make supercomputers truly interactive, allowing scientists to use them as genuine scientific instruments, with the ability to perform simulation, visualization, data management, and analysis all on the same system. The project will create a new Facility for High Performance Computing in collaboration with all major HPC manufacturers. The techniques developed at the Facility will have broad applications, not just in brain simulation, but for the life sciences and simulation science in general.

Education

The 21st century is witnessing a data deluge driven by the industrialization of many aspects of the scientific process, especially in the life science and medicine. This poses major challenges for the way we prepare young researchers of the future. The HBP will be in a leading position to teach this new science and its applications in medicine and technology. The project will exploit its unique technology to build a novel educational program where the science, medicine and brain-derived technologies can be demonstrated through Internet-accessible hands-on interactions in virtual laboratories, lecture theaters, hospitals and factories. The project will use this Facility as the basis for unique programs of transdisciplinary education for the general public and for all levels of the education system.

Ethical and social issues

The HBP raises important ethical, social, political and philosophical issues and brushes on basic concepts of what makes us human. The HBP will thus adopt a strategy of responsible innovation, through programs dedicated to ethical and social issues. These programs will bring together scholars in the brain sciences, engineering, social sciences, and the humanities to study and discuss relevant issues and will use all available channels to encourage open, well-informed debate, address potential public concerns and build awareness of ethical and social issues among project participants.

Impact

Building new capabilities

It is impossible to plan scientific or technological breakthroughs and their long-term social and economic impact. What can be planned is the development of the data sets and research capabilities with the potential to make breakthroughs possible. In the case of the HBP this means:

- 3D atlases that provide access to the best currently available knowledge on the healthy and diseased brain in animals and humans, at different stages in their development
- A brain modeling and simulation facility that is capable of systematically integrating biological knowledge into unifying computer models of animal and human brains and performing in silico simulation experiments
- Unifying brain models that provide an integrated and quantitative view of what we know, what we can predict, and what we don't know at each stage of the project
- Tools to federate very large volumes of clinical data from hospitals around the world and to mine the data for biological markers of disease, at different levels of brain organization
- Techniques for interactive, visually-steered supercomputing and for management of very large repositories of heterogeneous biological data
- Neuromorphic computing systems derived from in silico models of the brain
- Closed loop environments in which brain models and neuromorphic systems are coupled to virtual robots supporting simulation experiments in cognition and behavior
- Radically new neurotechnologies for screening in the life sciences and for neuroprosthetics
- Large-scale research facilities open to the world scientific community.

Each of these outcomes creates opportunities to address deep questions in basic and clinical research and to develop new technologies, with a potentially large social and economic impact.

Using the capabilities

The capabilities developed in the HBP will make it possible to address fundamental challenges in neuroscience. In recent years, neuroscientists have gained a rapidly improving understanding of the structure and function of the brain at the molecular and cellular level and have characterized many important aspects of behavior and cognition. However, current knowledge is massively fragmented and researchers have great difficulty in tracing the causal mechanisms linking different levels. The HBP will provide researchers with a vital new tool to develop an integrated view of the brain and investigate these possible chains of causation. The first demonstration that simulation of biologically detailed models can support non-trivial cognition would be a major breakthrough for the project and for brain science. This achievement would make it possible, for the first time, to trace the roles of specific genes, molecules, cells, synapses, connections, and pathways in cognition unraveling the basic steps from genes to cognition and behavior.

A second major beneficiary will be medicine. Clinical data sets and informatics tools developed by the project are designed to identify biological markers for different brain diseases, opening the road to radical changes in the way diseases are diagnosed, classified and treated, preparing the way for an integrated view of brain disease. Disease simulation will allow researchers to test novel hypotheses of disease causation, creating the understanding needed for rational design of new treatments. Drug simulation can shorten and reduce the cost of pharmaceutical research, with major implications for the pharmaceutical industry, society and patients. More generally, simulation will vastly increase the value of animal studies and has the potential to reduce the use of animals in research, contributing to the EU's goal of Replacing, Reducing and Refining animal testing.

Finally the project will make a major contribution to future computing technologies. Neuromorphic systems, developed from the early stage in the project, will add intelligence to existing devices by enhancing image and feature processing, data analysis, information retrieval, while simultaneously offering drastic reductions in energy consumption and improvements in performance. The new systems will provide learning, adaptability, flexibility, goal-oriented behavior, and abstract action planning in novel real-world situations and act as basic building blocks for new types of information appliances and hand held devices, as well as genuinely intelligent robots with a huge range of applications in industry, health, education, research and the home. Techniques of interactive supercomputing developed by the HBP will allow users to visually explore vast volumes of data, build complex models, and observe and interact with simulations in real-time. These possibilities have broad applications not just for brain simulation, but throughout the life sciences and in simulation science in general.

IT Future of Medicine

The European Flagship Pilot formulating the ICT challenge posed by the future of indvidualized medicine

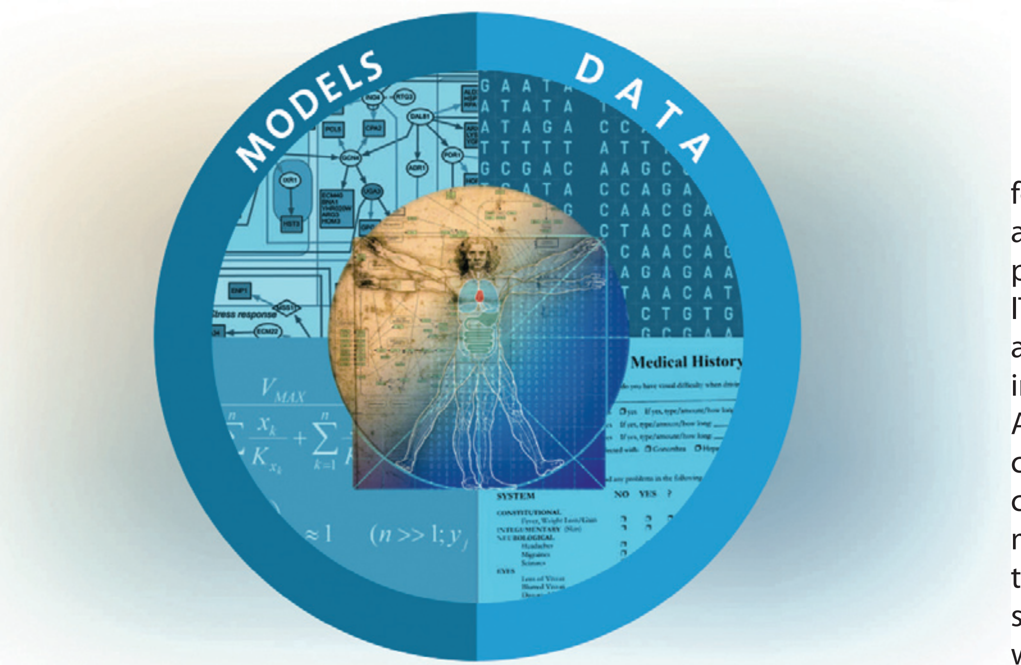
The flagship pilot "IT Future of Medicine" (ITFoM) organizes partners of academic institutions and industry with unparalleled expertise in ICT, life sciences, public health and medicine into an international consortium aiming to revolutionise medicine by constructing integrated molecular/physiological/anatomical models for individual patients in the healthcare system to form the basis of truly personalised therapy, disease prevention and lifestyle advice. This ICT revolution for medicine will have enormous benefits for the quality of health care (prevention, diagnosis and therapy), improved development and approval of new therapies (e.g. approval of 'fallen angels' for specific patient groups), a vast reduction of health care costs (through reduction of both the use of ineffective therapies and unwanted side effects of treatments) and increased well-being by increasing understanding of many un-diagnosed diseases. For this, the IT Future of Medicine consortium plans to first establish detailed 'reference' models of a limited number of individuals, which will then be 'individualised' for millions of individuals world-wide based on massive amounts of health related information for every individual. This data will be generated by -omics techniques, high resolution imaging techniques, and will also entail environmental information, as well as an enormous increase in the use of sensors able to monitor critical parameters for individual persons.

Acquisition and analysis of these data, generation and continual refinement of predictive models, and presentation of the results of model simulations in such a way that they can be routinely used in a clinical setting will generate unprecedented ICT challenges. As these challenges are assailed, benefits will be brought not only to the future of medicine but right across society. The next 10 years will see the vision of "Virtual Patients" become a reality and we will reap the multiple rewards afforded by this huge, and necessary, advances in technology.

Medicine – The future driver for ICT

Information technology and computing have, in the past, been primarily driven by requirements of "large" physics as well as by a broad spectrum of commercial applications including entertainment, while medicine has only played a minor role in the overall ICT development. This is going to change, due to the development of a new, data-rich, individualised medicine, likely to surpass the demands of all other fields of ICT development. As data-intensive analysis and computationally demanding modelling technologies become common clinical practice, ICT capacity and organization will become the key limiting factors in medicine, resulting in shifts of resources from personnel intensive to IT intensive applications.

The first sequencing of the human genome ten years ago has already marked the linkage between medicine and the computationally intensive applications of molecular biology. With the rapidly reducing costs of obtaining an individual human genome sequence, this technique will soon become affordable at the population level. A systematic and efficient integration of these data with data from physiological to metabolic and anatomic origins is yet to be implemented in health care systems.



ITFoM specifically addresses these issues. With the aim of establishing individual integrated biomedical models, the programme of work being designed will, for the first time, leverage the potential of these enormous data sets systematic approach. The relevant information will come from many areas, including medical data from the application of -omics techniques to individual tissue samples, high resolution imaging techniques, sensor techniques, and lifestyle information, personal characteristics and medication history of individual patients. Altogether, these data will be compiled into a single dataset for each patient organized in terms of a computationally integrated personalised model. The result will be a substantial innovation in clinical practice, as this personalised approach will be applied through specifically designed human computer interfaces that allow for a clear visualisation of the simulation and thus ensure a safe and high quality treatment or recommendation for patients. For the development of virtual patient models, ITFoM will unify quality standards for the collection and storage of biological material and clinical data sets in close cooperation with leading European activities. Additionally it will develop new standards for data capture and annotation where no appropriate standards currently exist. It will also integrate existing physiological models of the Virtual Physiological Human (VPH) projects, thereby integrating molecular systems biology with systems physiology. Already in its early phase, the project will establish a number of reference data sets, each with a broad collection of molecular data in addition to the medical and lifestyle history of each individual, all at an unprecedented level of detail. Effective governance and security for the storage and access to sensitive data such as this is still an unsolved issue in ICT and successfully tackling it will even bring benefits to areas that stretch far beyond ITFoM.

Already now, the resources required to analyse genome, epigenome, and transcriptome data rival those for producing the information in the first place. Extrapolating these developments to the future (an almost 10-fold drop in sequencing costs per year, versus a two-fold drop in computing costs every one to two years according to Moore's law), it is clear that advances in our understanding of the infrastructures necessary to deal with storing, transmitting and processing these data will be required.

Analytics – the ICT challenges in the –omics revolution

The enormous step forward in making predictive individualised patient models a possibility has been driven by the fantastic progress in nucleic acid sequencing techniques. While it has taken 10 years to sequence the first human genome at an estimated cost of 3 billion dollars we are now getting close to generating one genome per day on the newest generation of machines, at costs likely to drop in the next few years to below 1000 Euros per genome. This represents a million fold cost reduction in just over a decade.

The revolution in sequencing will be followed by the continual development of other lab technologies, such as such as mass spectroscopy and advanced imaging methodologies, which will enable the detection and characterization of all types of biomolecules. Determination of the whole scale complement of biomolecules present in individual samples will provide an in unprecedented insight into the functioning of a person's body fluids, cells, tissues, organs, and even the individual as a whole.

The ITFoM partners provide their expertise in cutting-edge -omics technologies including genomics, transcriptomics, epigenomics, proteomics from identification of single proteins to a high throughput proteome analysis including the kinetics of the protein activity, metabolomics employing mass spectrometry and NMR technology, analysis of the microbiome via metagenomics approaches and the use of novel techniques to produce personal stem cell cultures. The access to patient tissues will thus enable innovative therapeutic opportunities without the need to gain this type of information through biopsies.

ITFoM will put in place the platform that allows the data to flow directly from these analytical technologies into advanced mathematical models that will give an increasingly precise picture of the human body. Effective integration of disparate data types is a perennial problem that ITFoM will tackle, putting into place a flexible and extensible service layer capable of accepting and providing data of multitudinous types whilst ensuring adherence to existing and newly developed standards that will enable automated computation across them. Using advanced ICT the integration of environmental and life style data with physiological and molecular information will lead to a completely new perspective to understand health and disease in humans. Again, the expertise and technology developed through this process will have applications far beyond the remit of ITFoM.

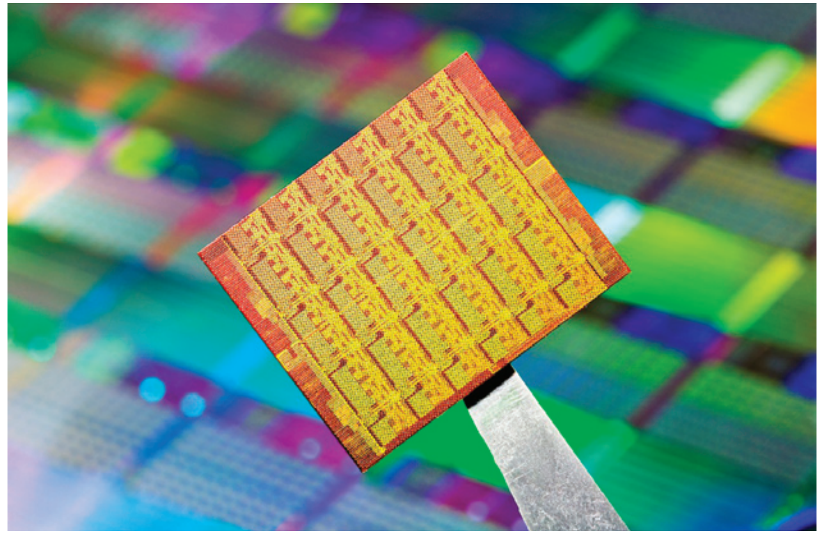
These technological developments will be balanced and complemented by the growth of knowledge of characteristic molecular events in health and disease. It will allow molecular analyses to be targeted rather than comprehensive, focusing on molecular events that can serve to identify disease processes, responses to therapy, or recurrences of disease.

The challenges that we face today are manifold and address technological developments in different aspects: in laboratory technology the efforts are focused on higher throughput and higher precision, but will also focus on more in vivo and non-invasive methods at lower costs. The next step will be the transfer of these novel lab technologies to the bedside and point of care approaches bringing the analytics close to the patient.

Modelling Health

The increases in the capacity of next-generation sequencing systems and the integration and analysis of -omics, physiological, and anatomical data provide a significant ICT challenge. Systems biology offers the methodologies and tools to analyse, integrate and interpret biological data, providing mathematical conceptualizations, or models, of biological processes that may then be simulated computationally. The "Virtual Patient" system generated by the ITFoM programme will integrate these data into a model system that will be personalised based on data from each individual. The model will allow predictions based on lifestyle choices and medical interventions on a tailored case-by-case basis. The patient model that will be developed in ITFoM will be based on a variety of data, from complete genome sequences of individuals to more detailed data about protein biochemistry and genes being used in specific cells and tissues. These will be integrated with physiological, anatomical and lifestyle data to build up a personal model of each patient.

The establishment and implementation of innovative developments in hardware and software infrastructures are needed. High performance computing systems and large data storage facilities need to be further exploited to manage the rapidly growing amounts of health information. New techniques will be developed in the rapid acquisition and evaluation of patient data, the respective dynamic storage and processing in real time, the building of a reference system by integrating data sets and mathematical models that are already existing and related data-mining and analysis.



Advanced statistical machine learning methods will be required for the extraction of patient specific information and the prediction of disease developments. Leading medical centres in Europe will assemble individual data sets for the development of a reference system that during the second phase will be evaluated for specific diseases.

Multiple approaches will be coordinated and combined to generate this virtual patient. Already we are able to create predictive models based on advanced genomic sequencing of samples from individual patients and make testable predictions about the individual cells or patient from which the samples came. In particular for cancer patients, it is anticipated that we will soon be able to predict in a semi-quantitative dose-dependent manner which cancer drugs or drug combinations could be effective and which will have little or no effect on a particular patient.

IT ethics, medical infrastructure, societies and engagement

The incorporated goals of ITFoM will have large implications for aspects related to ethics, the medical infrastructures in the health care setting, as well as all concerning areas from the fields of public health.

Regarding the need for innovative medical infrastructures, the ITFoM consortium comprises high-level expertise from different areas to establish and ensure access in any given setting. This includes the adequate access of professionals to diagnostic and treatment tools, as well as to resources such as biobanks for the interpretation of test results.

Around the research program of ITFoM the consortium will implement an education and training program comprising interdisciplinary PhD and Master Programs and dedicated courses for users in the clinical setting.

The development and implementation of ITFoM is likely to have some radical beneficial impacts on society. The increased transparency of patients due to their testing and analysis will influence the perceptions of (health) condition, risks, and responsibilities at the population level, ultimately even affecting the perception and assessment of diseases themselves. Especially patient organisations can contribute to this point, securing a harmonic transition to truly personalised medicine.

Consortium

The "IT Future of Medicine" consortium comprises distinguished academic and industrial partners from the ICT, clinical, analytical and biological fields all over Europe and worldwide. The partners integrate their expertise to develop the personalized patient model. Already ongoing and successful initiatives in Europe and worldwide represent an excellent basis for the foreseen achievements within ITFoM, providing knowledge, datasets, innovative technologies and infrastructure needed for the successful implementation of the "virtual patient". It will be an important issue for the consortium to develop methods for a systematic and efficient integration of information and know-how into the model-driven health care approach of ITFoM.

Robot Companions for Citizens

The challenge of sustainable welfare

Humans have moved beyond their evolutionary inheritance by progressively mastering nature through the use of tools, the development of culture and the harnessing of natural principles in technology. Indeed, the welfare of our industrialized societies is far removed from the conditions in which early human hunter-gatherers existed. However, this improved welfare, reflected in longer life expectancy, better health and greater prosperity, is not without challenges. Its sustainability is at stake in a number of domains—private, social, economic, urban and physical. Indeed, to maintain and improve the quality of life in a changing world is perhaps the hardest problem Europe will have to deal with in the coming decades. Our social and personal welfare systems, and our commitment to provide assistance and care to those who need it, are under threat due to the ageing of the European population. European economies are threatened by the imbalance of trade with other continents and increasing reliance on a narrow range of industries to maintain our global competitiveness. At the physical level we are faced with the challenges of man-made and natural disasters, over-exploitation of natural resources, pollution and environmental degradation.

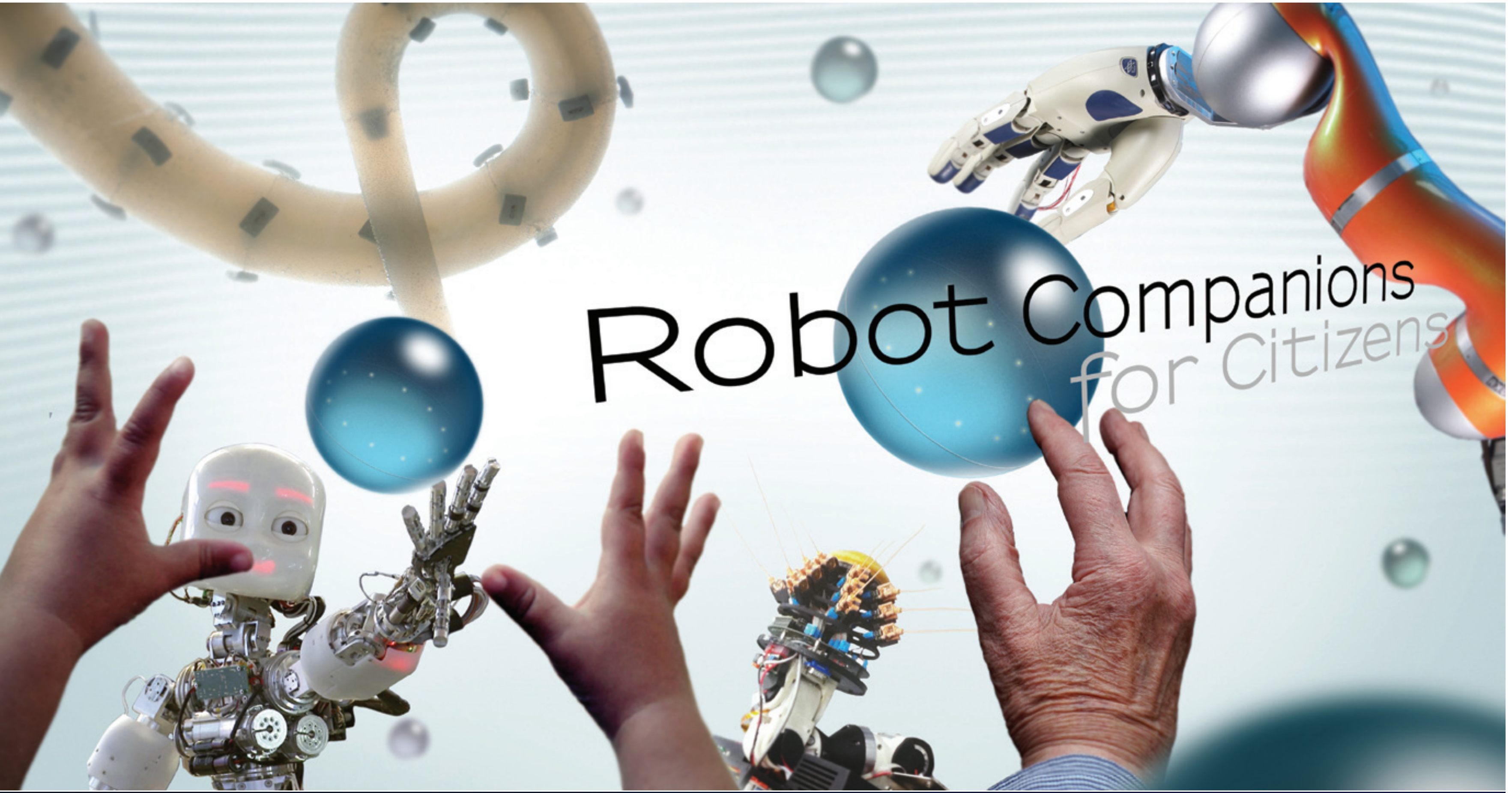
Just as science and engineering have played a central role in shaping the world we inhabit today, they will also be critical activities for addressing these urgent challenges. There, besides social and political endeavours, we believe that a new generation of robotic technologies, developed through European research in ICT, will be required to solve these real world problems. This need is urgent every day we listen to individual stories, or hear of dramatic world events, where robotics could make a substantial impact. We saw this during the Fukushima nuclear disaster, during the Deepwater Horizon oil spill in the Gulf of Mexico, and we see this in the everyday lives of millions of families caring for their elderly relatives. Paradoxically, increased life expectancy due to improved welfare, is one of the main sources of these new challenges. In 40 years time nearly 35 per cent of the European population will be at least 60 years old. In a world in which there will be relatively fewer young people to care for their elders, we will become increasingly reliant on technology to meet the aspirations of our older citizens to live active, fulfilling, and independent lives.

Our ambition: robots as enabling technology

To solve problems in the real-world one has to be physically instantiated and capable of action; information alone is not sufficient. Hence, we believe that a new class of machines and embodied information technologies, which we call the Robot Companions for Citizens (RCCs), is required to help us achieve sustainable welfare. RCCs will perform a multitude of assistive roles in our public services, enhance productivity and safety at work, and help us to cope more effectively with large-scale events such as natural disasters. Due to their ability to act and interact, physically and socially, with humans they will become ubiquitous yet safe; they will be unobtrusive, affordable and recyclable. This new generation of robots will extend the active independent lives of citizens, bolster the labour force, preserve and support human capabilities and experience, provide key services in our cities, and help us to maintain our planet.

Today we can find self-driving metros or trains, but their rails are a striking symbol of the limitations of current robotic systems - no existing robot or autonomous system is capable of operating without sharp boundaries that delimit its role and protect it from harming humans, the environment or itself. This is the reason why today no machine can behave as a personal assistant or caregiver, even though our society has an urgent need for better technologies for care. To solve this problem, and to develop dependable machines able to safely interact with humans, requires a fundamental rethink in how we conceptualize and construct robots. Human society and the global economy were transformed in the 20th century by the impact of computers and of computer-related technologies such as the Internet or the mobile phone. Here we envisage a new ICT-grounded robotic technology that will have a transformative impact on industry and society and lead us towards a new sustainable welfare for the 21st century.

These future robots will require a high number of degrees of freedom for movement, a high density of sensors, and a distributed computational architecture. For a traditionally-engineered system this would result in high demands for energy, computation and storage whilst, at the same time, controllability would become increasingly intractable. The RCC Flagship will overcome the limitations of existing approaches by following an alternative and biologically-grounded paradigm. A ground breaking example is the emerging biomimetic approach of "morphological computation" which considers motion patterns as naturally emerging and stabilized through the distributed and physical properties of compliant bodies coupled with low bandwidth control. This approach is in sharp contrast to current central, computationally-intensive control and planning algorithms. Morphological computation illustrates how fundamental sciences such as biology and neuroscience can have important impacts in engineering. Through evolution, nature has identified principles that together have given rise to all single-celled and multi-cellular organisms including the basic body plans for all extant animal phyla that emerged during the Cambrian explosion over 500 million years ago. Conservation of core principles is a fundamental law of evolution, indeed, our human body plan inherits many common principles from these early ancestors. In seeking to identify and exploit these biological principles to develop new robot bodies and brains, RCC is attempting something novel that is far from the naïve use of biological metaphors. By investigating suitable biological examples, and "reverse engineering" their core principles, we will create robots that share with animals the ability to deal with complex tasks in an elegant, quick and anticipatory manner. In other words, we will investigate and mimic the "simplexity" of biological systems to create efficient robot companion systems - using simplifying principles to deal with complexity in the real world.



The picture contains the following robotic platforms:

- *OCTOPUS: The prototype robot octopus arm. SSSA Pisa 'Soft-bodied robots' have no rigid architecture, so they can stretch, shrink, fit through holes and grasp odd-shaped objects. photo © Massimo Brega: The Lighthouse*
- *SCRATCHbot and SHREWbot: robots with whiskers that mimic rat-whisking behavior. Uni. Sheffield and Bristol Robotics Lab*
- *iCub: an open source cognitive humanoid robotic platform. icub.org. photo SPECS@UPF*
- *TUM-ROSIE robot: The Intelligent Autonomous System Intelligent Group at TU München (TUM) built TUM-Rosie with the goal of developing a robotics system with a high-degree of cognition.*

In order to answer the challenge of sustainable welfare we need to endow robots with new technologies for integrated forms of perception, emotion, cognition and action or, in other words, "sentience". On the basis of this fundamental insight the FET Flagship Candidate "Robot Companions for Citizens" (RCC) proposes a transformative initiative addressing a cross-domain grand scientific challenge:

to unveil the secrets underlying the embodied perception, cognition, and emotion of natural sentient systems that make them capable of acting, interacting and adapting effectively to their physical and social environment and of being cognizant and sentient of this relationship to the world.

The drive to answer this challenge will foster an advanced understanding of the principles underlying the relationship between mind and body, the role of "matter" in building the mind, the natural design principles underlying brains and bodies, the relationship between structure and function, and the principles that make living beings cognizant and sentient.

To achieve these radical scientific and technological goals, RCC will mobilize a densely-federated interdisciplinary effort that combines disciplines, concepts, methods and technologies that usually do not interact. RCC will create a fruitful dialog among roboticists, material scientists, neuroscientists, psychologists, social scientists and ethicists, in a contemporary renaissance aiming at creating embodied ICT solutions and tools required by society.

Europe should lead the way

The large-scale introduction of robots in society is already happening. From the lawn-mowing and vacuum-cleaning robots in our homes, to the industrial robots manufacturing our cars, the surgical robots operating in our hospitals, and the un-manned drones performing security operations in our skies, we are witnessing an industrial and societal revolution perhaps surpassing those brought about by the introduction of earlier enabling technologies such as the steam engine, electricity, the car or the computer. Robot Companions for Citizens is Europe's opportunity to shape this new drive towards self-controlled machines and move its thrust in the direction of sustainable welfare. To put Europe in the driver's seat of this revolution is critical to maintain our global lead in high-tech industry. As importantly, we believe that the development of future robots, and of their impacts upon European society, should be structured according to our humanistic traditions and values. Europe can lead the way in ensuring that robotic technologies have positive societal impacts and are developed for the benefit of all.

A new science of embodied sentience and simplexity

In realizing and deploying the sentient machines that will enable sustainable welfare, RCC is inherently science-driven. At the core of this initiative is the consideration that these next-generation real-world technologies will be grounded in the natural principles underlying embodied sentience and simplexity. This approach defines a new scientific paradigm that cuts across a range of disciplines ranging from material science, robotics and mechatronics to neuroscience, cognitive science, biomechanics, social sciences and the humanities. RCC combines these disciplines in a coherent framework around the core domains of Matter, Body, Brain, Mind and Society. Matter includes systems based on nanotechnology, material science, tissue engineering, and bioartificial hybrid systems supporting a new bodyware that uses nanofabrication technologies for energy storage, production and harvesting. Body includes sensing, actuation and the construction of new compliant, light-yet-strong morphologies. Brain addresses systems neuroscience, with the goal of understanding the design principles of biological nervous systems and the processes that allow their development, adaptation and maintenance in the real world. Mind includes the theoretical framework of sentience based upon a principled understanding of communication, perception, cognition, emotion and action, human-human, human-robot and robot-robot interaction, and knowledge accumulation and expression. Society pertains to approaches in the humanities, art and design, and social sciences that will keep the human perspective at the heart of the development of RCCs through a human-centered design methodology. This will be achieved through consultation with diverse stakeholder and user groups with due attention to the communities, common spaces and infrastructures in which people live and thrive.

The backbone of this federated effort will be the engineering disciplines that capture natural principles and transform them into real-world systems. In other words, we identify a new knowledge generation and validation synergy where science investigates the principles underlying natural embodied sentience and simplexity, and engineering validates these principles in real-world systems. This synergy will then give rise to powerful applications and new hypotheses requiring further scientific validation and exploration. Thus the vision of RCC defines and consolidates a new paradigm of analysing and synthesizing nature that makes a very concrete statement about how theories of body, brain and mind will be advanced.

RCCs will significantly impact upon society, thus we have to consider technological, psychological, ethical and legal implications. To investigate these issues and develop appropriate regulatory frameworks, RCC will realize initiatives in experimental ethics, semiotics and law to proactively identify the implications of RCC deployment, positive and negative, whilst taking into account human culture and the different ways in which people exist and interact in our shared world. Further, whilst engaging with a diverse range of experts we will also pursue an open science strategy, involving dialogue with the European public, that will allow an ongoing critical evaluation of the social, political, and cultural values of our work. Taken together, we believe that these initiatives will enable us to chart an ethically-robust and socially-relevant path to the development of RCCs that will improve the welfare and quality of life of European citizens. To test our scientific hypotheses and to demonstrate the effectiveness of our technologies RCC will develop experimental platforms of Robot Companions at multiple scales of morphology, simplexity and sentience. These in turn will drive the delivery of a selective and use-case-driven set of deployment platforms, tuned to the needs of identified user groups, that will be delivered during the ten years of the project and beyond. These deployment platforms will range from assistive systems for our homes - that will be useful to all but of particularly benefit to older or disabled citizens, to robust platforms that can operate in harsh and dangerous environments to perform tasks such as search-and-rescue and disaster recovery.

Impact and Stakeholders

Driven by its vision of sustainable welfare through sentient machines, RCC will involve pertinent stakeholders in science and technology, society, finance, politics and industry. To realize its goal, and in order to place Europe in the lead in future robotics, RCC envisions a Flagship as an incubator of advanced science and engineering involving thousands of researchers. Resources will be allocated in a competitive fashion to the best ideas that contribute to answering the RCC grand challenge. To assure the impact of this distributed research effort will require exceptional effort in project governance. A fundamental question for projects on this scale concerns the incentives for the communities involved to collectively delivery on their promises. Governance in the RCC project will therefore be built on four solid cornerstones: the concrete and well defined goal of sentient robots; our explicit science and technology roadmap; an uncompromising commitment to scientific excellence; and an insistence that, in order to realize ambitious goals, nobody can be above scrutiny.

The scientific momentum of the RCC Flagship will provide leverage for educational programmes at all stages from junior school to undergraduate and graduate teaching. Our vision for a new robotics, and its underlying science, is inclusive and provides integration from material sciences to sociology; this needs to be matched with an equally ambitious programme in training and education. RCC will realize new pan-European training programmes federating existing programmes and driving the development of new ones, in particular at the interfaces between disciplines. Through the immediacy of building life-like robots, and their clear application to realizing sustainable welfare, the Flagship will attract a large and diverse range of women and men to train for careers in science and technology. RCC will therefore promote a new educational spirit that reaches across the traditional boundaries especially those between science, social science, and engineering.

As with any large-scale research project, RCC will drive new business opportunities. However, RCC will also go beyond knowledge transfer and innovation, since it will realize a wholly new type of product: sentient robots. This raises fundamental questions of production and uptake. One scenario we envisage is to extend the reach of the automotive industries. RCCs are complex integrated systems similar to cars. As such, they could be assembled by large-scale integrated and automated manufacturing plants, assisted by networks of supply companies, and distributed and sold by dealerships including buy-back programs, loan mechanisms and long-term servicing and maintenance agreements. This production system is well understood, which should help to ensure the successful deployment of our Flagship's results. Added value of RCC will arise through broadening the horizon of these industries to include a range of sectors from health, education and security to transportation, manufacturing, and agriculture. Moreover, we can also foresee a complementary and more transformative model: RCCs as multi-scale communication systems. RCCs will communicate amongst themselves, and with other devices, using a unified protocol compatible with all our peripheral communication systems such as smart-phones, thus creating new opportunities for the telecoms industry and for content providers. As importantly, RCCs will also interface with people using forms of communication that are directly accessible, including spoken and written language, facial expression, gesture. Prostheses and wearable devices, based on RCC technology, could also have direct interfaces to the body and brain. Across of all these areas, RCC will instigate a dynamic and robust economic push that will reinvigorate the European economy and create new markets and opportunities for our manufacturing and service industries at home and across the world.

RCC provides more than research because it immediately ties all the relevant stakeholders into the project to define its transformative multi-disciplinary science and technology program and its translation towards society. RCC is beyond robotics as it pursues a new integrative paradigm, anchored in a grand scientific challenge, to deliver palpable outcomes for our sustainable future society.

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