Building Artemis

Report by the High-level Group on Embedded Systems

ADVANCED RESEARCH and TECHNOLOGY for EMBEDDED INTELLIGENCE & SYSTEMS

Information Society

European Commission

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A R T E M I S

Foreword

Erkii Liikanen

Commissioner for Enterprise and Information Society
June 2004

We tend to take it for granted that our daily lives should be safe and comfortable, that the economy will grow and provide jobs, but we often overlook major underpinning technologies that make this possible.

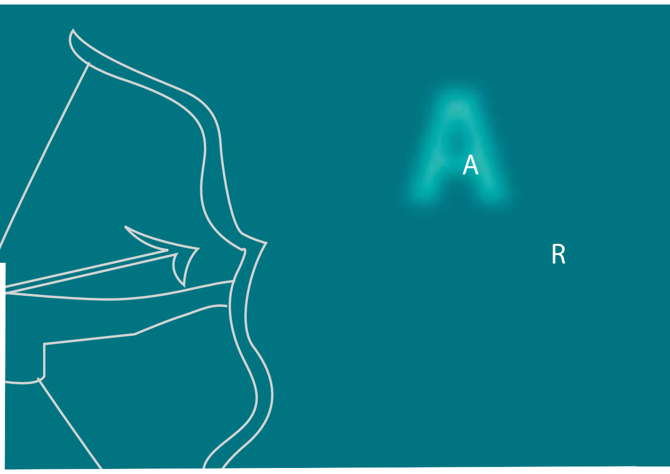
The convergence of low power computing with ubiquitous networking is leading to a major shift. Information and communication technology is embedded in an increasing range of products and processes, raising productivity and enabling new services and applications. Most product innovations today are based on embedded ICT.

Embedded systems underpin the competitiveness of important industry sectors where Europe is strong: from aerospace and automotive to consumer electronics, manufacturing and telecommunications. It is important that Europe consolidates this leading position. Contrary to desktop computing where a few major players dominate the scene, embedded systems is still an open field with enormous potential in the future markets of ambient intelligence. Europe must position itself as a major player, leading the development of intelligent and networked systems. Standards must be established to allow seamless connectivity and quality of service.

Addressing these ambitious objectives will require the mobilisation of resources on a large scale and the close collaboration of all stakeholders. This is why I called the first meeting of a High Level Group from leading companies and research institutions in January 2004. The participants committed to work together to define a joint vision and a strategic agenda to turn this vision into reality.

Significant progress has been made in the meantime. The High Level Group has defined a number of ambitious objectives and challenges that are discussed in this Report. It proposes to create ARTEMIS, the Embedded Systems Technology Platform: a coordination and integration framework where stakeholders from across the Union can join forces to ensure that the EU becomes a worldwide leader in embedded technologies and that this translates into strong economic and social benefits. ARTEMIS is a key initiative for building the European Research Area and realising the ambitious objectives that the Union set in Lisbon in March 2000. The commitment of all signatories in this Report is the best guarantee that our collective efforts will be successful.

I would like to take this opportunity to thank all contributors from industry, research and public authorities that worked so hard to make this initiative a reality.



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Introduction

Sustainable growth, industrial competitiveness and job creation depend heavily on productivity increase and innovation. Over the last decade, Europe's annual growth in productivity per employed person has fallen and is now lower than that of the US and Asia. It is important to reverse this trend.

Scientific research and technological development are among the key factors for productivity growth and innovation. This was recognised by the Lisbon European Council in March 2000[1] which adopted an agenda "to make Europe the most competitive and dynamic knowledge-based economy in the world". Furthermore, at the Barcelona European Council of March 2002[2] the EU set itself the goal of increasing European R&D investment to 3% of GDP by 2010.

It is now widely accepted that growth in productivity is largely driven by Information and Communication Technologies (ICT). In fact, more than half of the productivity gains in our economies today are attributed to ICT[3]. In the EU, for example, 0.71% of an overall 1.4% productivity growth per annum between 1995 and 2000 was due to ICT[4]. The gap in productivity between Europe and the US seems to be largely explained by Europe's weaker investment in ICT.

ICT already represents a substantial and increasing part of the added value of products, processes and services.

Furthermore, recent advances in miniaturisation and the pervasive use of communications and Internet-based connectivity are accelerating ICT-enabled growth. This is because ICT is becoming increasingly embedded in a broad range of objects, systems and processes, pervading everyday life as an integral and invisible component of the world we interact with.

It is important for Europe's economy and society to face the challenges of embedded ICT systems and to take advantage of the opportunities it is creating. This is an ambitious strategic objective that requires large-scale action at European level.

Technology Platforms form part of the wider policy decisions made by the European Council in Lisbon in March 2000 on establishing a European Research Area (ERA). ERA provides for the coordination of national research policies towards of shared objectives, expertise and resources, thus laying the foundation for a common science and technology policy across the European Union[5].

Technology Platforms are public-private partnerships that aim at developing and driving forward a coherent and integrated European research and deployment strategy in a number of strategic areas[6]. The creation of a Technology Platform may derive from one or more of the following needs:

[1] Lisbon European Council: Presidency Conclusions (24/03/2000 – No. 100/1/00)

[2] Barcelona European Council: Presidency Conclusion (16/03/2002 – SN100/1/02)

[3] "The Policy Agenda for Growth" and "The Sources of Economic Growth in OECD Countries", OECD, 2003

[4] "ICT and Economic Growth, EU Productivity and Competitiveness: An Industry Perspective", Mary O'Mahony and Bart van Ark, 2003

[5] ERA information leaflet – 20/09/2002 www.cordis.lu/era

[6] Communication from the Commission - "Investing in research: an action plan for Europe" – COM(2003) 226

- maintain or regain world leadership and enhance competitiveness in the face of stiff global competition through the generation of new RTD;
- develop and assimilate new scientific knowledge and technologies to evolve towards a paradigm shift;
- reconcile different policy objectives with a view to the sustainable development of a sector.

The concept of Technology Platforms was further reinforced by the Commission Communication on the future European Union policy to support research[7]. In this they feature as the instrument to realise European technological initiatives, which are one of the six major objectives put forward for increasing the impact of the European Union's actions. Technology Platforms are also described in the Commission Communication on the future financial framework of the Union that proposes to double the Union's research budget[8]. Technology platforms would "…bring together public and private stakeholders to set up and implement common research agendas in fields of industrial relevance…"

It is in this policy context that Commissioner Liikanen instigated, in January 2004, the first meeting of a High Level Group, whose industrial and academic members have collaborated to develop a vision and strategy for an Embedded Systems initiative. This Report is the interim result of their deliberations.

The report recognises the need to build a future around the opportunities offered by the rapid evolution of embedded systems. It acknowledges that the importance of embedded systems to the world economy makes it imperative for Europe to intensify its efforts in this area. European efforts must at least match, if not exceed, comparable investments being made in the US and Asia.

The overall aim is to ensure that Europe achieves leadership in intelligent, interconnected embedded systems. The High Level Group proposes to realise this aim by creating ARTEMIS, (Advanced Research and Technology for Embedded Intelligence and Systems), the Embedded Systems Technology Platform. The objectives, challenges and means to realise ARTEMIS are discussed in this Report.

[7] Communication from the Commission to the Council COM(2004)353 – 16.06.2004 "Science and Technology, the key to Europe's future. Guidelines for future European Union policy to support research"

[8] Building our common future – Policy changes and budgetary means of the enlarged Union 2007-2013, COM(2004) 101 of 10.2.2004

www.cordislu/ist/artemis

Embedding intelligence

SUMMARY

While embedded systems are the enabling components of invisible intelligence that provide comfort, safety and productivity growth, they are undergoing a revolution in becoming more intelligent and globally interconnected through a variety of communication links, including the internet.

This revolution will lead to the omnipresence of embedded intelli-gence. It is creating new opportunities but also new challenges, for example in terms of increased complexity and vulnerability to attacks.

Ambilight TV: Embedded systems enable exciting new applications such as Philips' Ambilight Ambient Lighting technology. Ambilight, in real-time, analyzes incoming television signals and produces background lighting that matches the images displayed on the screen.

Courtesy of Philips

Embedded In Everyday Life…

6:00 am… Your alarm wakes you up. You hit the snooze button and go back to sleep.
6:15 am … The alarm sounds again. You jump out of bed. Time to drive your child to school.
On the way there, you hit your brakes just in time to avoid a stray cat. Fortunately your car has the latest Driver Assistance System and you don't even skid.

After school, you drive on to the office, where you have just finalised a new manufacturing control system that directly links customer orders coming in through the Internet to the actual production lines. Orders should be processed automatically and the production lines would direct each order to the right boxes, which are stamped with a customer identification code.

After a few initial hitches, the system is working perfectly. Productivity is up. The number of accidents on the factory floor decreases dramatically, and if a problem occurs, the information is sent simultaneously by GSM and email to the right people, shortening the time elapsed between the occurrence of a problem and its solution.

On the way home from the office, you stop at the bakery to buy bread. Instead

Drive-by-wire technology in future cars will rely on fail-safe computer networks. Hydraulic mechanical sub-systems will be replaced by fault-tolerant electro-mechanical equivalents for steering, braking and gear shifting. The result is greater safety, reduced weight, so cutting fuel consumption and reducing emissions.

Courtesy of DaimlerChrysler

of loose change and coins, you pay using your electronic purse, stored on your bankcard.

Was this a special day? No, just an ordinary day, between home and office. Except that you spent your day **using embedded systems** to keep yourself **comfortable**, to keep yourself **safe**, to be **informed** and to improve **productivity**.

From the snooze function of your alarm that let you sleep that extra fifteen minutes, to the remote control that opened and closed your garage door and kept you dry, to your ABS braking system that kept you alive, to the Internet and the manufacturing control system that helped you improve safety and throughput in your company, to your bankcard that enabled you to avoid carrying loose change in your pocket, your day has been safe, comfortable and productive. You owe this to the existence of these embedded systems: systems that integrate hardware, software and interfaces into many of the objects and systems that are all around you in order to control them or provide additional functionality.

Although embedded systems have been extensively used throughout this ordinary day, they have only been used for very basic functions. They hardly provide a glimpse of the visionary applications that embedded systems will enable in the future.

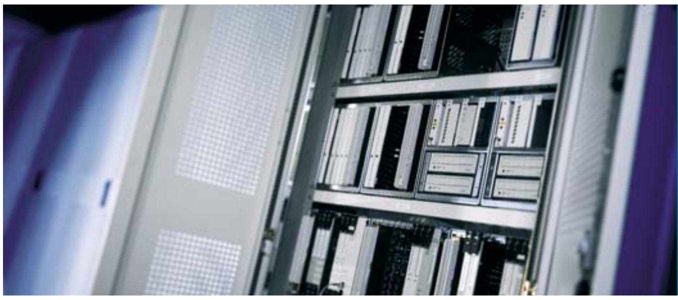
The embedded revolution

Embedded Systems include devices, middleware, software and tools for the construction of intelligent sub-systems capable of monitoring and controlling a broad range of domestic appliances and industrial systems. This includes the basic infrastructure of society such as roads, railways and communication or electricity networks. Embedded systems have a wide range of applicability into many market sectors and their importance is growing continuously. For example,

- In 2003, there was an average of 8 billion embedded programmable micro-components worldwide[9]. Conservative estimates foresee a doubling of this figure to 16 billion by 2010, or 3 embedded devices for every person on earth.
- The annual growth rate of embedded devices markets during the period 1999 – 2011 is estimated to be 10,3 %[10], above the forecast growth of the overall IT sector and well-above GDP growth.
- In the automotive industry, electronics are an increasing fraction of a vehicle's value, increasing from 22 % in 1997 to

[9] Gartner 2002: Microprocessor, Microcontroller and Digital Signal Processor Forecast Through 2005

[10] Automotive S/W and Electronics Briefing - IBM Automotive Industry Team, May, 2002



Courtesy of Nokia

33-40 % in 2010[11]. An estimated 70% of automotive innovations over the last 20 years are ICT-related whereas vehicles with stability control are 35% less likely to be involved in accidents.[11]

- Similarly in the avionics sector, embedded software now accounts for a significant portion of the development costs of a plane.
- The digitisation and networking of consumer electronics and home appliances and the convergence of PCs and home entertainment systems, are already giving rise to a new breed of intelligent consumer electronics devices. Analysts estimate the growth of the digital home in the US alone will generate 200+ billion in revenue up to 2010.

Embedded systems and software account for an ever larger fraction of the development costs of a modern plane.

Courtesy of AIRBUS

These trends will continue and intensify in the future. The "embedded everywhere" revolution is fuelled by device miniaturisation, where more and more functionality is available for less and less cost; by cheap and pervasive networking technologies; by digital convergence between formerly distinct technology families and industrial sectors; and by the need for companies to differentiate between, innovate and add value to their products. The leverage effect of embedded systems is enormous as the value added to the final product by embedded devices is often orders of magnitude higher than the cost of the embedded devices themselves.

Networking the embedded world

Whilst in the past, embedded systems has increasingly been an enabling technology providing safety, comfort and higher levels of productivity, these systems have mainly worked in isolation. Functions and services were usually derived by monitoring and acting locally upon physical environments.

The major revolution brought about by miniaturisation, ubiquitous communications and digital convergence is leading to a major shift in embedded systems which are moving beyond local interfacing to globally connected systems. This provides scope for increased levels of "collective intelligence" that in turn has the potential to lead to new levels of comfort, safety and productivity in all areas, from the individual to social and industrial environments.

The increasing level of connectivity, including connections to the Internet

[11] P. Hansen, "Electronic Stability Control Promoted in Japan", The Hansen Report on Automotive Electronics, vol. 17, No. 1, February 2004

and to public infrastructures, is leading to the increased availability of data and information, anywhere and in real-time. It offers a huge potential for product and service innovation, for increased productivity and better control of the large-scale systems our societies rely upon. It also presents great challenges in terms of system interoperability, complexity and vulnerability.

Networked Embedded Systems must be made safe and secure: it is important that increased complexity does not compromise their dependability and safety of use. Like virus attacks on desktop systems, it is imperative to prevent the infiltration by intruders of manufacturing plants, moving vehicles and environmental monitoring systems.

From air traffic control to the plane's onboard navigation system, embedded systems must get the job done safely and reliably

Courtesy of Thales

Fly by wire technology replaces mechanical linkages between moving components by electrical components and cables. Electronic flight control uses computers to operate the plane. Advantages include enhanced safety with fully monitored control, and development of a family of aircraft with similar cockpit designs and handling characteristics. Electronic control has now become an aviation industry standard.

Courtesy of AIRBUS

Strengthening
European leadership

SUMMARY

The High Level Group has identified three objectives as strategically important for Europe:

- *achieve **world leadership in those embedded technologies** that underpin European competitiveness in intelligent systems, products, services and processes;*
- *advance European solutions for the deployment of globally networked **interoperable** embedded systems that can connect to the internet and are open to third parties;*
- *favour the **creation of new markets** and enable **societal-scale applications** that enhance the safety, security and well-being of citizens*

Embedded Systems, a key technology for Europe

Embedded technologies are the fastest growing sector in Information Technology. They are key to the competitiveness of existing industrial sectors and are leading to the emergence of new markets and business opportunities.

Europe is currently leading the world in industrial sectors such as automotive, avionics, telecommunications, consumer electronics, manufacturing automation, rail transportation or energy. Embedded systems are at the core of competitiveness in these industries. European capacities and skills in the development, production, integration and use of embedded systems are of primary importance for reinforcing European leadership in the face of ever stiffer competition from Asia and the US.

Embedded systems allow product and service differentiation that give an edge over the international competition. Their extensive use creates the potential for a significant impact on productivity, driven by the immediate availability and intelligent usage of vast amounts of real-world data that is made available anywhere and at any time. The integration of embedded devices and controls in manufacturing systems underpins their efficiency, helping to maintain a strong manufacturing base in Europe.

Our strengths in these sectors should be the spring-board from which Europe engages in future new markets and develops new ways to support the well-being of its citizens.

Quality of life

The development of large-scale environments with embedded intelligence also has the potential to address a number of social challenges and priorities. Embedded systems can lead to new solutions which will enable the elderly to live independently as well as new solutions for monitoring and protecting the environment; for the security of citizens; for protecting large-scale infrastructures from accidents and threats; and for energy savings in buildings, transportation and energy distribution.

Embedded Systems – an Open Field

During the evolution of desktop computing, the underlying technologies originated mainly from non European companies. This resulted in polarisation around a few dominant players, which led to a lack of interoperability and open standards.

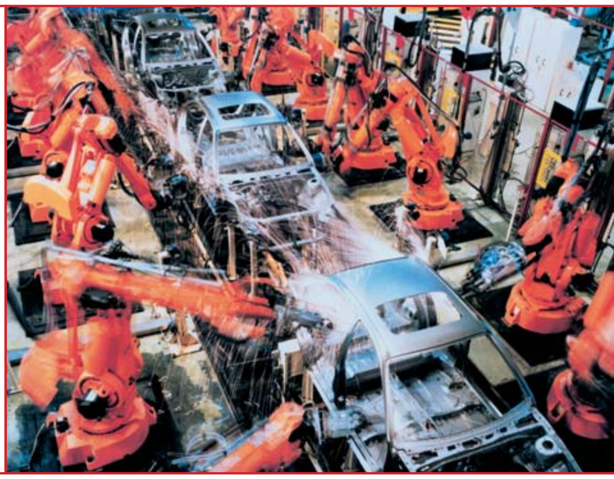
In contrast, the current evolution of embedded systems, that will be even more pervasive than desktop computing, is still an open field – a field of opportunity.

In this context, it is of the utmost importance that Europe builds on its current strong position in embedded systems, across many sectors, in order to expand into the future markets of

Orchestrating production processes

ABB's product portfolio includes several hundred thousand items used primarily to increase productivity and safety in electrical utilities and industrial processes in a sustainable way. The intelligence aspect of each product comes from at least one embedded processor. Harmonizing these into a well-orchestrated and carefully synchronized application requires complex communication on several levels between thousands of these embedded computers. Finding solutions to these challenging tasks will give the European industry a competitive edge.

Courtesy of ABB



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A revolution has taken place in radar systems. The heavy and complex radar systems of the early days have evolved to meet the needs of a wide range of users. Embedded digital technologies play a significant role in this change. Radar systems have a wide spread of applications, not only on land, on ships, aircraft and spacecraft. They can be installed aboard satellites and provide accurate images of the Earth. These radar images are used to protect Earth resources, control pollution and contribute to global security..

Courtesy of Finmeccanica

ever more intelligent, interoperable and environment-aware systems and services, multi-functional products and sustainable manufacturing.

The regulatory environment should ensure a level field for all players, stimulating innovation and competition and preventing undesirable dominant positions in the new markets enabled by embedded technologies.

Unmanned autonomous vehicles provide vital surveillance, e.g. for rescue workers in disaster areas

Courtesy of Thales

European skills

The evolution of embedded systems creates new needs in term of multi-disciplinary skills. System architects, engineers and designers are in short supply and many companies increasingly resort to outsourcing. Europe also suffers from a much lower proportion of researchers in the active population (5.7% compared to 8% in the US).

The emergence of new competitors in Asia increases pressure on companies to relocate, not only to take advantage of lower labour costs and gain access to local markets, but also to tap into the human resource potential and dynamism of emerging economies. Such relocation is gradually extending to research activities and to the high-tech sectors.

The recent enlargement of Europe to 25 countries is a major opportunity to extend the European base of skilled human resources. Countries in the immediate periphery of the EU may also provide an alternative solution to outsourcing to the Far East or to the US. Maintaining and reinforcing key skills and technological know-how within Europe's frontiers is, however, fundamental for

Vast networks of embedded sensors will enable efficient distribution and production of energy on demmand

© Photodisc

future growth in knowledge-intensive sectors. The research challenges posed by the future evolution of embedded systems can attract young talent to this area, from Europe and beyond, provided that we can develop a vibrant innovative environment for research, entrepreneurship and industrial development.

Application drivers

To explore the challenges for Europe that arise from the embedded systems revolution, the High Level Group has taken the approach of using a number of future application scenarios.

In this process, four classes of application contexts relevant to Embedded Systems have been identified:

- *Industrial systems* from the aerospace, automobile, medical and manufacturing sectors where *safety* and *dependability* are key considerations;
- *Nomadic environments* where people, *objects* and applications are constantly moving and changing;
- *Private spaces* such as homes and offices where comfort and security are key issues
- *Public infrastructure,* such as airports, cities and highways, including distributed infrastructures such as the electricity grid.

For each class, potential applications have been analysed to extract the major requirements that will need visionary work over the next decade, for Europe to be able to lead in Embedded Systems. The summary of the results of this work is provided in Annex III.

Towards Ambient Intelligence

The four classes of application drivers, from industrial systems to private spaces, all rely on embedded systems to provide new levels of safety, comfort and functionality.

What these four classes have in common is that they enable a vision of an environment in which intelligent objects work together towards these goals.

This is in line with the "Ambient Intelligence" vision developed by ISTAG[12], which defines an environment in which "humans will be surrounded by intelligent interfaces supported by computing and networking technology that is embedded in everyday objects, such as furniture, clothes, vehicles, road and smart materials." [13]

[12] Information Society Technologies Advisory Group (www.cordis.lu/ist/istag.htm)

[13] Ambient Intelligence – from vision to reality, ISTAG Draft Report (www.cordis.lu/ist/istag-reports.htm)

www.cordislu/ist/artemis

Snowboard Jacket with Integrated Infineon Electronics - Entry into Future Market of "Wearable Electronics"

Courtesy of Infineon Technologies

Embedded systems will transform Ambient Intelligent dreams into reality. A new industry will be born building products increasing our quality of life, providing more comfort for Europe's ageing population, alleviating the pressure on our environment by reducing pollution and increasing energy savings, by countering the growing insecurity.

Networking will be one of the keywords. Imagine a world where your PDA or mobile phone automatically connects into your car network when you are your car, in your home network when you are at home, transparently reaches your office, talks to the electronics watching your body health, or controls your physical environment.

By car and on foot, by train and bus, by plane and bicycle - the DaimlerChrysler researchers' software compiles personalized itineraries to accommodate the wishes of the individual user.

Courtesy of DaimlerChrysler

Challenges

in research and technology

SUMMARY

The evolution of Embedded Systems is being driven by new opportunities brought about by powerful, inexpensive computing, distributed components and networking. Increasingly, Embedded Systems will be designed to provide services to companies and people in collaborative environments, taking advantage of information, available through local and remote communication links.

This is leading to a considerable increase in the level of "intelligence" that will reside in Embedded Systems. This intelligence will be essentially dynamic, changing in time and in availability.

This Report identifies a number of major technological challenges that will need to be addressed to exploit the real potential of distributed embedded intelligence. Work on research and technology must be complemented by public-private initiatives to overcome the fragmentation of research, assemble the necessary financial resources, build the required multi-disciplinary skills and an innovation-friendly environment, and exploit the opportunities that arise from Europe's enlargement to 25 countries.

Embedded Systems are facing major changes at the economic, organisational and technological levels. In this section these changes are discussed in order to define what Europe needs to do to build competitive products 10 to 15 years from now.

1. Technology

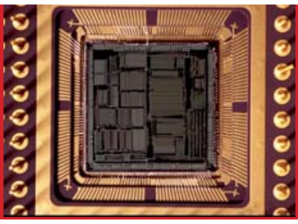
"… Software is Hard and Hardware is Soft…"

This statement[14] illustrates the increasingly critical role of software in the design and implementation of Embedded Systems and the blurring of the boundaries between hardware and software.

[14] made during a panel discussion at the International symposium on Systems Synthesis 2003

The distribution of intelligence across systems and dynamic access to external information increase the **complexity** of embedded systems, both in terms of design and in terms of the testing and validation of complete solutions.

The distribution of intelligence also leads to new **architectures**, in which large



Moore's law means that the ever-growing performance of chips provides exciting new prospects for embedded systems. Increased embedded functionality also lead to design challenges

numbers of heterogeneous Embedded Systems can collaborate, dynamically discovering each other's existence and capabilities and interacting through links whose capacities and availabilities cannot be guaranteed.

In becoming **"connected"**, Embedded Systems are growing in terms of both complexity and vulnerability. They require new definitions of open standards and interoperable interfaces.

To develop intelligent, inter-working and internet-enabled embedded systems Europe needs to build capabilities and industrial solutions in critical domains such as system design, distributed architectures, computing platforms, security, middleware and tools. The key objectives of this work are:

- derive **reference designs** for embedded platforms and software in a broad variety of application domains
- develop **middleware** layers for open seamless environments that support fast application development
- develop the basic **computing and communication** technologies that underpin future embedded systems
- develop software **tools** that support rapid design and prototyping

The technology challenges are discussed in more detail in Annex IV.

2. Education and skills

The shift towards connected and distributed Embedded Systems is creating new opportunities in existing markets and in emerging applications, but it is also leading to more complex designs.

Furthermore, Embedded Systems can no longer be designed using two separate threads of hardware and software that are merged at later stages. A systems approach is required that mixes functional and non functional requirements from the start. Central to this approach is the need to understand the interaction of the system with its physical and network environments.

These changes require engineering teams that possess skills in a wide range of disciplines such as: computer science, engineering, real-time computing, systems architecture, control, signal processing, security and privacy, networking, mathematics, hardware, sensors and actuators.

Engineering teams are currently unable to effectively consider fundamental design issues from all these perspectives at once, because they lack the common background and technical language to interact efficiently.

Creating these cross-disciplinary skills requires fundamental changes in engineering education and the organisation of academic research. New

Connected intelligent embedded systems on the move.

Courtesy of Infineon Technologies

models of cooperative industry-university system-oriented research and education must be studied and implemented. There is also a need for more intense and structured collaboration between research organisations such as universities and research institutes. The model of system-oriented Centres of Excellence[15] (CoEs) cooperating with specialised university teams (Centres of Competence) can be a good starting point.

The emphasis should be not only on traditional graduate training, but also post-graduate and training practising engineers in industry. The focus of such training and education should result from visionary, theme-driven projects formulated by mixed industry-academia teams within a restricted set of application domains that are strategic for Europe.

To match the vastly increased role of embedded systems in the European economy and the need for optimal solutions, the Embedded Systems platform should contribute to the emergence of Embedded Systems as a discipline. This will allow the formulation of European undergraduate and graduate degrees focusing specifically on Embedded Systems.

Europe's recent enlargement to 25 countries, possessing a highly qualified workforce, provides further potential to deepen and integrate the European repository of skills.

3 . Structural challenges

In order to harness the power of Embedded Systems effectively across all sectors, Europe faces a number of structural challenges.

As highlighted by the Commission in June 2004[16], these range from the fragmentation of European R&D funding, to the achievement of new levels of collaboration between companies and between industry and research.

At the level of research, European efforts are characterised by fragmentation, low reactivity and the lack of frameworks for the transfer of technology to industry (in terms both of legal provisions and incentives).

At the level of industry, the needs for design methodologies, middleware layers, interoperability, open standards, and platforms can only be effectively tackled through collaborative, industry-wide initiatives. This reality is emphasised throughout this High Level Group report.

Collaboration models, skills and expertise must be focused on particular industrial and social objectives. There is a need to build large research centres that are comparable to those in the USA (such as Carnegie-Mellon, MIT, Stanford and Berkeley). This requires novel research

[15] See draft ISTAG report on research infrastructures explaining these concepts (CoE and CoC).

[16] Communication from the commission to the Council COM (2004)353 – 16.06.2004 "Science and technology, the key to Europ's futire. Guidelines for future European Union policy to support research"

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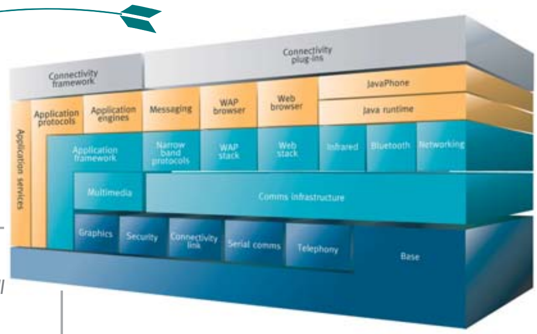

Operating systems, stacks and middleware are the intermediate software layers that pull embedded systems together and make them work with each other.

Courtesy of Symbian

infrastructure concepts (CoEs) allowing joint research through mixed industry-academia research teams, tackling system-level issues and cooperating with specialised university teams to address fundamental issues identified by the CoEs. This can be achieved through the integration of competences spread across many European institutions.

Setting up Networks of Excellence under the EU's Framework Programme can be a first step towards such integration. Nevertheless, geographic proximity provides incomparable advantages in terms of the cohesion, efficiency and reactivity, which are necessary to support world-class research. This has also been recently recognised by the European Commission[16] that makes the emergence of CoEs a condition for the realisation of the Lisbon agenda. The possibility for setting up such CoEs should be examined in order to bring together excellence, critical mass and mechanisms for transfer to industry.

Through mechanisms for mobility (such as Marie Curie), PhDs and post-docs will tap into the research infrastructure of CoEs, involving mixed teams of researchers and enhancing the whole process of scientific breakthroughs. Similarly, the mobility of researchers from industry towards CoEs is also crucial to gain early insight and feedback on the targeted vision and fine-tuning of the research programmes. This would make the best use of research skills and lead to greatly improved research efficiency.

Such networked research clusters should be organised within a restricted set of strategic European application domains. These networks can also form the breeding ground for the creation of the skills discussed above.

4. Outsourcing of jobs

Combined with growing system complexity and the resulting demand for software developers, the outsourcing of jobs to emerging economies in Asia can constitute a major disruptive factor. The argument that outsourcing can be used as an opportunity is dangerous, because the assumption that Europe can outsource while retaining the know-how at home is not necessarily credible. Furthermore, the outsourcing mechanism may lead to Europe actually supporting the creation of new competition, "*training its competitors of the future*". Job losses in the United States due to this effect give some cause for concern.
Outsourcing will continue as long as it provides a strong advantage to companies. The only credible European response implies a drastic improvement in the productivity and quality of design and software development in Europe. This can be achieved by better methods and tools based on higher levels of abstraction and by the development of a highly skilled workforce.

The way ahead

SUMMARY

Maintaining and reinforcing Europe's leadership in Embedded Systems is fundamental to growth.

The analysis shows that effectively addressing future challenges and opportunities in this field requires a broad partnership that would mobilise public and private resources and innovation on a massive scale. A major European technological initiative is needed with an ambitious vision and a coherent strategy.

The European Research Area (ERA) provides the appropriate political framework for such a technological initiative. The High Level Group supports the creation of ARTEMIS, the Embedded Systems Technology Platform. The Platform will provide a framework for defining and implementing a Strategic Agenda and for integrating research activities in Embedded Systems across the EU. The High Level Group also proposes a governance structure that is adapted to the ARTEMIS objectives and stakeholders.

This Report provides the foundations of the Platform. Further work will be needed to translate the initial vision to concrete actions, roadmaps and operational structures by the end of 2004.

1. The Artemis Technology Platform

The European Research Area, the decisions of the Lisbon and Barcelona European Councils and recent Communications from the Commission on strengthening European research provide the appropriate political framework for launching a European technological initiative on Embedded Systems.

The High Level Group therefore supports the creation of **ARTEMIS**, (**A**dvanced **R**esearch and **T**echnology for **Em**bedded **I**ntelligence and **S**ystems), the Embedded Systems Technology Platform. It reaffirms the commitment of the participating companies in pursuing the objectives of the Platform and in steering its development as a strategic European technological initiative.

The expected outcome of ARTEMIS is to reinforce the EU's position as a

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leading worldwide player in the design, integration and supply of Embedded Systems. ARTEMIS will pursue the following key objectives:

- definition of a common industrial vision and a Strategic Agenda to implement this vision. These will benefit the industrial sectors that rely on Embedded Systems technologies and the European economy and society at large;
- establishment of a coordination and integration framework where industry, research organisations, public authorities, financial institutions and other stakeholders across the EU join forces and coordinate their actions for implementing the Strategic Agenda.

ARTEMIS is a public-private partnership that will address the major challenges to allow European industry to benefit fully from the embedded systems revolution and position itself in the future markets of ambient intelligence. It will build on the basis provided by ongoing European (IST), Eureka (ITEA and MEDEA+) as well as national R&D programmes. ARTEMIS is neither "yet another" coordination or advisory body nor a public R&D programme.

2. Governance

To ensure that ARTEMIS realises its mission, its structure must be clearly defined and adapted to its objectives.

In establishing the governance structure, the High Level Group analysed similar initiatives such as other Technology Platforms and the Eureka cluster projects ITEA and MEDEA+. Experience and best practice in managing such initiatives has been used as a guide.

The ARTEMIS governance structure consists of:

- A **Steering Board**, to define, update and oversee the implementation of the Strategic Agenda. This Board involves decision makers from leading stakeholders from the private sector and academia, as well as representatives from the Mirror Group of Public Authorities. It is based on the current High Level Group.
- An **Executive Board**, as a smaller executive and operational representation of the Steering Board.
- A **Mirror Group**, ensuring the participation of Public Authorities at

The smart carpet can light-up and show you the way.

Courtesy of Infineon Technologies

national, regional and European levels in their function as policy makers, regulators and funding bodies. The aim of the Mirror Group is to develop synergies between national programmes and policies, pool resources to support the implementation of the Strategic Agenda and to promote a fertile innovation environment and a state-of-the-art research infrastructure in Europe.

- An **Office**, that provides permanent secretarial, operational and public relations support for ARTEMIS.
- **Working Groups** for specific pre-defined tasks, either permanent or on an ad-hoc temporary basis. The creation of the Working Groups is the responsibility of the Steering Board. Their operations and the follow-up and consistency of their activities and scope are the responsibility of the Office.

In addition, an annual **General Assembly** will provide the means to interact with all stakeholders in the platform and beyond.

This governance structure will be supported through public and private funding mechanisms and an eventual ERAnet activity. The Steering Board will also examine the possibility of establishing a joint undertaking as defined under Article 171 of the EU Treaty or a joint R&D programme undertaken by several member states with participation by the Community under article 169 of the EU Treaty.

3. Next steps

At the High Level meeting in January 2004, the Commission encouraged the creation of the High Level Group to develop a vision and scope for a Technology Platform on Embedded Systems. Between January and June 2004, a number of further meetings were held culminating in the adoption of the present report by the High Level Group meeting in Rome on 28 June 2004, under the chairmanship of Commissioner Liikanen.

The next important step is to build the Strategic Agenda, on the basis of this Report, by the end of 2004. The agenda should contain an action plan for addressing the major challenges and policies of the Platform in terms of research activities, human resources, research infrastructure, regulatory and standardisation issues, and financing. Roadmaps may need to be elaborated in particular technology areas.

At the same time, the Platform Office should be created and the rules of procedure for the functioning of the different Platform bodies should be decided. An overview of the recommendations of the High Level Group is provided in the next section.

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4. Recommendations

The High Level Group is committed to launching the ARTEMIS Technology Platform on the basis of the objectives, orientations and governance structures described in this Report. It recommends:

1. Establishing the ARTEMIS Office and rules of procedure for the various governance bodies as soon as possible.
2. A substantially increased research and development budget for embedded systems, from basic research to technology validation.
3. The coordination and integration of relevant European, national and intergovernmental public R&D programmes within the ARTEMIS framework.
4. The development and promotion of an educational programme that will establish embedded systems as a discipline
5. The development of collaboration models between industry and academia that allow a "systems approach" to research and favour the transfer of technology. The development of world-class Centres of Excellence in Europe, in particular application domains, is a central consideration.
6. An activity to enhance the innovation environment, producing a policy for standards and for open source and stimulating new ventures and markets.
7. A communication activity that will aim at ascertaining the key role of embedded systems in modern societies and economies.

The above recommendations are to be integrated in the ARTEMIS Strategic Agenda.

Annexe 1
Steering group

The vision for Embedded Systems has been developed by industry and academia, working together in establishing Artemis.

The members of the Steering Group that undertook producing this Report are listed below. The Report benefited from numerous additional contributions from experts from the various Working Groups[17], the Commission[18] and many others[19].

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[18] Javid Khan, Alkis Konstantellos; Véronique Pevtschin & Francis Wray (external rapporteurs)

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Gérard Mathéron	Director MEDEA+

Annexe 2
References

This report consolidates the work of the Steering Group and the three working groups that were formed to work on particular subjects. It also draws information from prior work, listed below.

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- ITEA programme – http://www.itea-office.org
- MEDEA+ programme - http://www.medea.org

Annexe 3
Applications Drivers

Potential applications have been analysed to extract the major requirements that will need visionary work over the next decade, for Europe to be able to lead in Embedded Systems. In this process, four classes of application "contexts" have been identified that are key to the future development of Embedded Systems.

Industrial Systems include all the major safety critical systems that rely on embedded systems to increase their value and efficiency.

In automotive and avionics, embedded systems provide the *capability for reaching new levels of safety and sustainability* that would otherwise not be feasible while adding functionality, improving comfort and increasing efficiency. Examples are driver assistance systems in cars that prevent accidents as well as advanced powertrain concepts that reduce fuel consumption and emissions.

In the health sector, medical diagnosis and treatment systems already rely heavily on advances in Embedded Systems. New solutions that mix embedded intelligence and body-sensing techniques are being developed.

Manufacturing is affected by embedded systems in terms of safety, efficiency and productivity. For example, embedded controls and process automation lead to flexible, efficient production, reduced environmental impact and a decrease in the number of factory-floor accidents.

Availability, reliability and continuous quality of service are fundamental requirements for industrial systems. These will be achieved through advanced control, redundancy, intelligent alarming, self-diagnosis and repair. The important issues are robustness and testing, holistic system design, the balance between openness and security, the integration of old and new hardware and of heterogeneous systems and the management of obsolescence.

Nomadic Environments allow people and moving objects to interact, dynamically and wirelessly, with services, resources and local and remote sources of information.

These environments provide both comfort and security and enable new forms of work organisation, increasing labour productivity by making information instantly available, when needed. They are applicable to virtually any form of human activity, from leisure to work and from the home to outdoors.

Nomadic devices will be able to connect to a range of environments such as the home, cars, trains, aeroplanes and wider-area networks. The devices will be able to reconfigure themselves autonomously depending on patterns of use and the

Seamless connectivity will become essential for networked embedded systems

Courtesy of Nokia

surrounding environment and will be able to download new services as they become available.

To develop such environments, the gap between large systems and embedded components will need to be bridged. Significant developments will be required in technology for low-power and high performance computing, networked operating systems, programming environments, energy management, networking and security.

Private spaces provide the ability to recognise individuals and adapt to their evolving requirements. Such systems will require significant computational, communication and data-storage capabilities. They will enhance the safety, security and comfort of individuals at home, at leisure and at work.
The mix of physical monitoring and data-based decision support by some form of distributed intelligence will rely on the existence of *seamlessly connected* embedded systems and the integration of sensors and actuators into intelligent environments.

Systems for Private spaces will be characterised by ubiquitous sensors and actuators and a high-bandwidth connection to the rest of the world. Technologies will need to be developed

Public safety rely on dependable infrastructures from communications to navigation.

Courtesy of Nokia

which support sensing and tracking, ergonomics and ease of use, security and comfort and multi-modal interaction. Key to this will be the development of both wireless and wired communications and of techniques for managing sensor information including data fusion and sensor overloading. The challenges are to make such systems intelligent, trustworthy, self-installing, self-maintaining, self-repairing and affordable.

Public infrastructures will be evolving towards intelligent infrastructures comprising a set of communicating, intelligent objects that can be used collectively. Examples include buildings, bridges, highways, undergrounds, railways and communication and energy networks.

Embedded systems have the potential to provide a dramatic *improvement* in these infrastructures in terms of their *safety and* ease *of use*, *maintenance and protection from threats.*

Usage of infrastructure is critical to everyday life. Systems must be robust to usage and resistant to malicious attack and fraud. They must also conform to legal frameworks with regard to security, trust, contracts and liability. They must be open to new services, usage patterns and rules. Privacy and health aspects are also central considerations. Furthermore, for such systems, it is the overall performance that is important, not the behaviour of individual components.

For intelligent infrastructures many technologies need to be developed. These include networks of intelligent sensors, hardware platforms which can dynamically adapt their processing to actual requirements and operate over years without service, new energy sources, component-based operating systems and many others.

Annexe 4
Technology Challenges

This annex describes in more detail the technology challenges identified by the Steering Group of the Platform. They will form the basis for deriving the research sections of the Strategic Agenda.

System design

Design is the process that takes a product specification to its final implementation. This includes the definition of intermediate layers of abstraction between the specification and the implementation in hardware and software, and involves tools for synthesis and verification. Complexity, in its many dimensions (functionality, communication among concurrent components, architecture) is perhaps the most significant challenge to be faced by design. A second challenge is to ensure that, for an embedded application, software can be easily ported from one platform to another. This is especially important since architectures for computing platforms are expected to evolve at a faster rate in the future.

Design methodologies are essential to create efficient implementations of new products quickly. To meet ever tighter time-to-market constraints, the implementations should be right first time. To improve quality, they should be reliable. To reduce costs, they should be highly optimised with respect to performance and power consumption. It is clear that without an effective methodology and a corresponding toolset, more designers will be needed to bring new products to market in a timely matter. The resultant burden on labour costs may become unsupportable by European enterprises. Even worse, due to the ever-increasing complexity of emerging products, the levels of quality and performance expected by users will become impossible to attain.

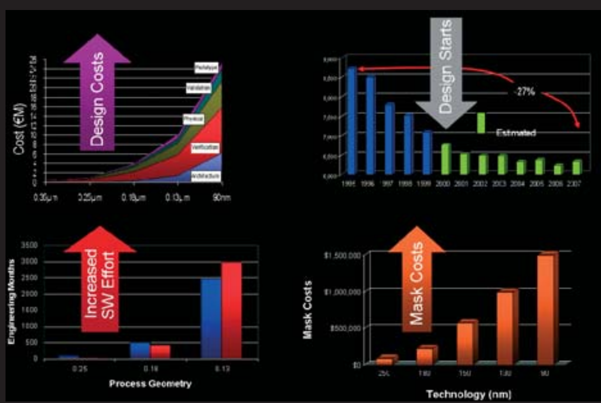
Core software building blocks

The development of Embedded Systems depends on a *small set of* core technologies for Real-Time and Embedded software (the embedded software stack comprising operating systems, middleware, the certification process and development tools). In these technologies, Europe needs to strengthen its level of knowledge and create a wider industrial base. Situations similar to that of the desktop computing sector, which is dominated by a few major players, should be avoided. Dominance hampers the potential for innovation, as dominant players do not readily support interoperability and open approaches.

When hardware meets software

The costs associated with chip design and implementation are prohibitively expensive for all but the highest volume applications. The role of software is increasingly important as Embedded Systems blur the boundaries between hardware and software. This leads to new challenges in design, including higher levels of abstraction, reuse, testing and validation.

Courtesy of Parades



Towards embedded computing networks

In the future virtually all embedded systems will be computing networks. Chip architectures will follow the Network-on-Chip paradigm. Devices, such as mobile terminals, will have a distributed communication-centric architecture as it will no longer be possible to separate functionality and control. Devices will be connected forming a yet higher level of network. Hardware and software development for such systems will be communication-centric. This will be a paradigm shift and a major challenge for the engineering community.

Systems will be composed of an integrated network of complex devices that share common resources. System architecture will be communication-centric with ad-hoc local networking, ambient sensors and actuators, and shared resources provided by an intelligent local infrastructure. Content production and data consumption, storage and sharing will be the typical functions performed. The architecture will be heterogeneous defined by communication capabilities depending, inter alia, on networks, protocols and services.

The architectures for Embedded Systems will experience a continued evolution from the physical space to the logical space, becoming distributed communication-centric networks of processing elements. The processing elements will range from simple microscopic motes, following the nano-technology curve, to high-performance microprocessors taking Moore's law to its limit. These clusters of processing elements will be heterogeneous by nature. While there will be a strong trend towards programmability and configurability, application-specific hardware accelerators will still be necessary.

Future embedded processors

It is becoming increasingly obvious that the von Neuman model does not fit well to Embedded Systems. Eventually, it will not fit at all. Future Embedded Systems will contain dedicated, domain-specific processing units. Their programming models will be widely different, ranging from reconfigurable hardware to massively parallel processors. The overall system architecture, including processing units and their inter-communication, will be optimised for critical, non-functional properties, such as energy consumption.

There is also a need to address the increasing demand for high-performance embedded computing in several market sectors such as multimedia, communications, aerospace, defence and medical imaging. This demand will need a major revolution in architectures for embedded computing, involving a move towards the concept of Flexible System Architecture including software programmable and reconfigurable platforms. This sets new challenges in terms of embedded software, including operating systems, middleware and compilation, and in terms of hardware architectures.

Supporting built-in security

Vulnerabilities must be avoided. The current economic impact of viruses and other threats to desktop systems is huge. It is, consequently, of the utmost importance to avoid any compromises to security in Embedded Systems.

These threats could be very serious. Communication is performed over low-power radio links that are easily intercepted, jammed or modified. Devices might be relatively easy to subvert and could be used as platforms for launching attacks. Standard solutions with firewalls, Network Address Translations, proxies etc. will not be available, so new methods for countering attacks and detecting intrusions will need to be developed. Indeed, "security" issues may ultimately affect the physical safety of those using or benefiting from such devices. Predictability and mitigation of system failure, due either to hardware or software failure or due to breaches in system security will therefore be highly important.

Security features will need to be supported through the provision of global, end-to-end management, configuration and security tools, and through the development of a trusted infrastructure. Networked embedded systems will, however, have different characteristics depending on the application sector such as aerospace, automation, automotive and mobile. Consequently the necessary security solutions will vary from application to application.

Integrated quality

Embedded Systems support mission critical systems with specific requirements in terms of Quality of Service (QoS) such as latency, reliability and safety. The Validation and Verification (V&V) of these properties are currently costly and time-consuming and are the main reason for the low productivity of embedded software development (V&V accounts for 40 to 50% of development cost). New approaches are needed to ensure that these properties can be specified, realised, verified and traced throughout the different development steps. Guaranteeing quality may result in increased complexity leading to the need for larger design teams.

Quality issues must be addressed both at the component and design-process levels. Components need to be certified according to industry-wide agreed procedures for the measurement of their quality. For the design process there need to be quality-based design methodologies and careful definition of the layers of abstraction.

Network enabled / network aware embedded systems

Increasingly, Embedded Systems are triggered or activated anytime, anywhere, through remote web access and other networking technologies. To support this capability, embedded systems will have to be "network enabled" and incorporate capabilities for self-management, self-supervision and mechanisms to auto-recover from failure.

From terminals to communication centric architectures

Distributed intelligence and ubiquitous broadband communications are leading to an evolution from device-centric to communication-centric architectures. Until now, system designs focused on new terminals and even the latest designs, such as smart phones, can still be considered to follow a "phone-centric" approach. In the move to digital convergence, the centre of gravity of solutions will move from phones to communication links, with a number of different products providing access to large amounts of data through ubiquitous networks.

Networked embedded devices create "smart spaces", enabling context-aware interaction. Remote control and configuration of embedded devices, and network management for embedded systems are important issues. The ad-hoc nature of the wireless network, when combined with smart communication protocols supporting self-configuration and self-organisation, enables easy and effective deployment with minimum external maintenance. The communication matrix is becoming a key element in achieving system performance at all levels, with communication dynamically established on an ad-hoc or opportunistic basis.

For distributed sensor networks it will be essential that public and enterprise networks of different kinds can be used in order to keep communication costs low. The sensor network should become a logical overlay to public and enterprise networks.

Communication protocols

The architecture must support a diverse set of protocols: those presently being used and those that can adapt to different situations at both the physical and logical levels. The layered approach fits the needs of current systems well, but will not be efficient in a future distributed world. Therefore, new models must be developed and verified.

Embedded systems will depend critically on efficient communication protocols, developed for its various subsystems and which support low power, flexibility, self-organisation and reconfigurability. A move to ID-less (semantic) addressing schemes will become an important factor in simplifying the management and commissioning issues in such a service-oriented architecture.

Intelligent Control

The actual quality and level of intelligence of Embedded Systems will be highly dependent on the control and decision-making algorithms that are embedded in the systems.

These algorithms will bridge the gap between the underlying real-time architectures and networking infrastructures, and the high level applications. Their efficient implementation is key to Embedded Systems and imposes special requirements on modelling, software and networking protocols.

Advances in control are necessary to realise new complex networked applications, such as air-traffic control, micro-satellite constellations, home ambient intelligence, DNA and brain modelling, networks of sensors and remote control via the Internet.

Sensor and actuator technologies

The envisioned application drivers will require huge amounts of input and output data. Cost-effective sensor nodes, low-power links and novel actuating technologies are the enablers for many application areas.

Technology must support the cost-effective implementation of sensors and actuators in mainstream CMOS. Local intelligence and protocols will require long battery life and autonomous power supplies. Support for fail-safe concepts including graceful degradation will be important, especially where safety is an important requirement.

Sensors and actuators will also support novel human interfaces. Such novel interfaces are likely to need ever increasing processing power.

Open systems, interoperability and standards

The increase in embedded intelligence will rely on the collaboration of heterogeneous systems in an ad-hoc manner. These will need to become dynamically "aware" of each other's existence and capabilities. Therefore, embedded systems will need to interoperate and to interface with other embedded systems of diverse origins. To achieve this interoperability, new standards will have to be defined. The main objective should be to avoid proprietary standards that restrict the social, business and innovation potential of embedded systems. Timely agreements are essential to enable advanced applications, e.g. frequency allocation for automotive radar systems.

For interoperability, it will be essential for an underlying open-standard framework to emerge allowing harmoniously co-existing 'devices' to communicate. Such a fabric should be minimalist, agnostic to the processing element and industry domain, with a simple protocol for message passing, allowing a hierarchy of self-organising networks to emerge. This will provide the basis for more complex and exotic industry standards to evolve. Such standards should not undermine or break the basic network fabric.

The ultimate goal should be an "Internet–equivalent" for embedded systems, where new devices can join the network, communicate with peers and share content (peer-to-peer) and resources.

Thus, at the abstract level, the focus should be on the development of a network definition that is agnostic to the processing element, independent of the application domain (such as mobile, consumer and automotive) and unconcerned about the network area.

In parallel with the need for interoperability when *using* embedded systems, there is a similar need for interoperability when *designing* embedded systems. With the goal of re-use and faster time to market, the user-supplier relationship is evolving and creating the need for an open architecture. In this evolution, COTS providers (Commercial Off The Shelf: for example software products such as real-time operating systems, compilers and development tools) must be involved to ensure that they fully subscribe to the implementation of an open architecture and support their tools and software within it.

Annexe 5
Glossary

ARTEMIS	Advanced Research and Technology for Embedded Intelligence & Systems
CoC	Centre of Competence, university teams specialised in a particular area
CoE	Centre of Excellence, joint research through mixed industry-academic research teams
COTS	Commercial off-the-shelf components or tools
ERA	European Research Area, a European internal market for research policy
Eureka	A European wide network for market-oriented research and development
GSM	Global System for Mobile Communications
ICT	Information and Communications Technologies
IST	Information Society Technologies, under the EU's Sixth Framework Programme for research and development
ISTAG	Information Society Technologies Advisory Group
ITEA	Information Technology for European Advancement, a Eureka strategic cluster programme
MEDEA+	Industry-led Microelectronics programme, a Eureka strategic cluster
QoS	Quality of Service
PDA	Personal Digital Assistant
R&D	Research and Development

European Commission

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