European Commission

Next Generation Computing Roadmap

NGC-R

EXECUTIVE SUMMARY

A study prepared for the European Commission
DG Communications Networks, Content & Technology
by:

eu|te|ma TECHNOLOGY MANAGEMENT optimat 451 Research

Digital Agenda for Europe

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1. Summary

1.1 Key Messages

Parallel hardware is now mainstream, but parallel software is not. While all consumer CPUs are now multi-core, software is still designed as mainly sequential. The "parallelisation" of legacy code is very expensive and requires developers with skills in both computer architecture and application domain. European industry needs a new generation of tools for writing software, backed by innovative programming models. New tools should be natively parallel and allow for optimisation of code at run-time across the multiple dimensions of performance, reliability, throughput, latency and energy consumption while presenting the appropriate level of abstraction to developers. Innovative business models may be needed in order to make the development of new generation tools economically viable.

High-performance computing meets cyber-physical systems. Applications in automation, aerospace, automotive and manufacturing require computing power which was typical of supercomputers a few years ago, but with constraints on size, power consumption and guaranteed response time which are typical of the embedded applications. This is a market opportunity to build upon the existing strength of European industry to develop a family of innovative and scalable technologies, powering computing devices ranging from the embedded micro-server to the large data centre.

Internet of Everything is developing fast. Computing applications merging automation, real-time processing of big data, autonomous behaviour and very low power consumption are changing the physical world we live in, and creating new areas of application like e.g. smart cities, smart homes, etc… Data locality is becoming an issue, driving the development of multi-level applications which see processing and data shared between local/mobile devices and cloud-based servers. European industry has the know-how and innovation capacity to be a leader in this area, where issues like interoperable interfaces, privacy and data sharing rules will play a very important role in the development of the market.

1.2 Scenarios for next generation computing

Over the years computing has evolved to 'nearly always on' web-based mobile computing devices. In the near future we can expect that hardware will become a commodity and the value will be in the software to drive it and the data it generates. The data deluge will require an infrastructure that can transfer and store the data, and computing systems that can analyse and extract value from data in real time. There are arguments suggesting that the computing sector will become increasingly polarised between small application-specific computing units that connect to provide system services, and larger more powerful units that will be required to analyse large volumes of data in real time.

This report presents a vision of next generation computing for the next 10-15 years. It does this by developing a number of visionary scenarios covering key areas of everyday's life. Starting from these scenarios, we present a series of technology roadmaps, associated research / development / innovation challenges and recommendations for Europe to exploit the opportunities offered by the next generation of computing.

Stakeholders throughout Europe were involved in the study through direct contacts and through two separate workshops providing a validation and refinement of the recommendations arising from this study.

Seven scenarios were carefully developed to address critical aspects of society and economy. Describing how computing will evolve in each of the scenarios has allowed us to describe a series of technology needs that, by considering Europe's current strengths and weaknesses in computing, we could translate into research and innovation challenges for Europe, and into value creation opportunities for the European industry.

Table: Overview of scenarios

Scenario	Focus
It's All About Me	Empowering the individual citizen
It's All About Us	Communities and how they collaborate
Trains and other Vehicles with Brains	Making transport more efficient
Connected Brains	Research, education and knowledge sharing
Health & Happiness	Health and social well being
Renewtopia	Sustainability, Energy and resource management
At a Factory Near You	Manufacturing in the future

A common theme across all scenarios is the need for small low-cost and low-power computing systems that are fully interconnected, self-aware, context-aware and self-optimising within application boundaries.

A key element of the value chain is in software and programming methodologies, and this builds on existing strengths in Europe. Moreover, with a particular know-how in industrial and embedded multicore systems, Europe is well placed to support the growth of the infrastructure needed to transfer, store and analyse large volumes of data in real time. This will form the backbone to support the growth of the 'Internet of Everything' and the next generation of Cloud Computing.

1.3 Areas of opportunity

In this context, we can identify several areas of opportunity for computing in Europe, where investment in research and development can generate significant economic value in terms of exploitation.

Cyber-physical systems

- Building on existing strengths in embedded / cyber physical systems and increasing research in this area will allow maintaining European leadership. Efforts will be focused on implementing a vision of smart networked cyber physical systems, based on manycore low-power architectures and powered by natively parallel software.

Software

- Research priorities should include autonomous systems together with dynamic and configurable computing including context-aware, self-optimising software and dependable systems. A strong effort is needed on programming models and tools for next-generation systems including native parallel programming and multi-dimensional optimisation (energy, throughput, response time, reliability, resilience). Productivity in parallel software

development should be greatly improved, while limiting the need for developers to be skilled in both low-level computer architecture and high-level application domain. Innovative programming models and tools should provide the right level of abstraction to make parallel programming less expensive and more agile. This area will potentially provide strong economic value.

Energy

- Europe is a global leader in energy efficiency and this will be a key requirement in next generation computing. Improvements will apply across the whole computing continuum, from the high performance data centres required to exploit the opportunities offered by big data to the small computing devices used in mobile and embedded applications powering the Internet of Things. High-performance computing will range from cyber-physical systems to industrial and scientific applications, with a variety of solutions scaling across different computing powers but sharing energy efficiency concerns. The economic value of energy efficient computing is potentially very high because it can enable applications which are otherwise not possible in very diverse fields like health, environment, and automation.

Computer interfaces

- Advanced human-computer interfaces will become increasingly important and will support natural and immersive interfaces such as mixed-reality devices. These interfaces will require adequate high performance and real time computing power, as well as research into health, behavioural and psychological issues to humanise our relationship with this new ubiquitous computing landscape. Similarly, advances in security will need computing power to analyse large quantities of data in real time in order to identify threats and provide mitigation actions, and to guarantee the appropriate level of data privacy in different usage scenarios.

In this world with large amounts of shared and open data easily available, there will be an increasing need for tools and methodologies to address privacy and security issues. Data and its openness, consistency and governance will become an area of increasing importance that will either be a key enabler or a high barrier for the effective exploitation of next generation computing. Another cross cutting area will be the need for industry wide interoperable interfaces for data and services, which will be needed for the effective development of the 'Internet of Everything'.

There are also several other areas that are arguably outside the timeframe considered in this report, but have nevertheless the potential to become disruptive forces for the next generation of computing.

- Quantum computing – although talked about for many years is still in its infancy but has the potential to solve large scale computational problems orders of magnitude faster than existing systems.

- New energy sources, computing architectures and energy harvesting and storage systems that allow cyber physical systems to works for years with no need for recharge; this will have revolutionary impact on computing, making "always on" devices economically feasible and opening the door to disruptive applications.

- Smart materials – beyond implantable and wearable computing, technologies such as printed electronics, biomaterials and graphene have the potential to radically change both the human-computer interface and the way in which computers interact with the physical world.

1.4 Policy support

At a policy level, work is needed to ensure that the infrastructure and legislative environment in Europe provides the right conditions for uptake of computing technologies.

- Easily understood policies on data openness, governance, privacy and sharing, especially across borders, will have to be developed with the collaboration of all involved stakeholders (citizens, local and national governments, industry, SMEs).

- The Internet of Everything requires a fully connected society and further work is required to develop faster and cheaper internet access, especially mobile access, across Europe. The high costs for large data transfers, the limited coverage of fast mobile networks, and the cost of cross-border data roaming are not compatible with the development of the market.

- European technology and service providers should be encouraged to cross sell and share technologies across multiple markets to maximise convergence and address common challenges.

- European governments should lead by example in the openness and sharing of data to stimulate innovation in areas such as public services, energy, environment and Health, by promoting interoperable interfaces and a sustainable market place for services.

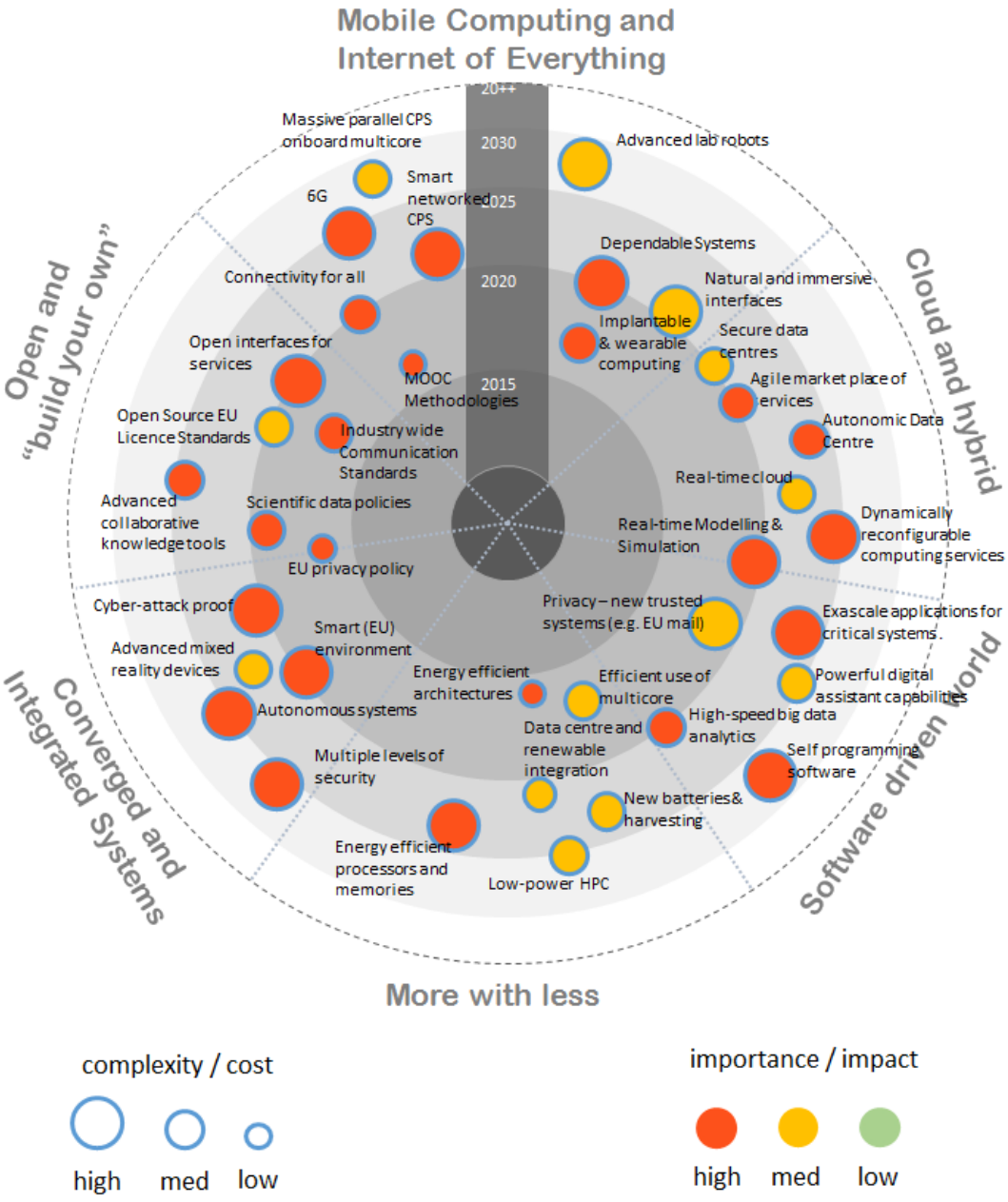
- Further work is still needed to build an innovation eco-system that brings together academia, industry, entrepreneurs and funding organisations, this should also consider cross sector / application collaboration.

Technological and societal changes will create opportunities for new business models, possibly based on open collaboration and on innovative ways of connecting the actors in the value chain. The infrastructure and legislative environment must be able to support and enable value creation both from traditional industrial actors and from new actors like citizens, non-profit organisations, local governments, prosumers, micro-enterprises.

Europe is well positioned to benefit from the opportunities that will arise as we move towards the next generation of computing and the society that it will enable. But there will be an increasing challenge for Europe to put in place common communication standards, a policy on open and shared data, seamless cross-border mobile telecommunications services and privacy and security measures that will create the environment for next generation computing and its applications to flourish.

1.5 Combined roadmap

As a summary, below you can find the combined roadmap for European research derived from the interviews, the desk research, the online-consultation and the experts' input at the workshops. It expands the concepts and ideas which are briefly described in this executive summary; the methodology to build it, and its contents, are fully explained in chapters "Research priorities" and "Roadmap" of this report.



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