ITEA Technology Roadmap

for Software-Intensive Systems

2nd edition, May 2004

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INFORMATION TECHNOLOGY

FOR EUROPEAN ADVANCEMENT

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ITEA thanks the Roadmap Core Team and all those involved for their valuable input. We feel that their dedication and hard work have significantly strengthened the foundations of software development for European industry. We also thank the organisations that supported the work financially.

Executive summary

This is the second edition of ITEA's Technology Roadmap for Software-Intensive Systems.

This key strategy document, which is intended as a companion to the White Paper defining the ITEA Programme[1], develops the shared vision of the **technological direction** for the programme itself; it is ITEA's "*tool for monitoring the technology changes in and around ITEA's participants' core areas of interest and steering the direction of the programme (...)*." [2]

Since the first edition of ITEA's Technology Roadmap on Software Intensive Systems was published in March 2001, the pace at which society has been "going digital" has continued to accelerate. Because a key factor in this evolution is now software technology – whose own development is strongly influenced by feedback from changes in society – we have decided to revisit the technology challenges and perspectives, and to update the findings of the first edition.

However, the questions we attempt to answer in this new edition are just the same as those put forward in the first:

- *"Which of the problems and software technology challenges tackled in the ITEA Programme need to be solved?"*
- *"How do we think they are likely to develop in the years to come?"* [3]

Work started one year after the publication of the first Roadmap, and took two years to complete. We followed the same approach as before, deepening and broadening the topics discussed in the first edition.[4] The precise **process** we used is described below, followed by a classification of software-intensive systems designed to make the analysis **meaningful** and a list of the human and other resources needed to make this 2nd edition of the Roadmap **successful**.

The process of elaboration that proved successful in the first edition has been used again.

This second edition is driven by demand for a new generation of applications. It therefore describes not only the technological challenges that confront the European software industry, but also the steps that need to be taken to meet the needs of industry, government and the business community, as well as those of citizens and customers.

To achieve this, we adopted the following **process**:

- We started out by developing scenarios which describe the potential evolution of applications in the various domains of software-intensive systems, and which define the technological challenges that will have to be met if these transitions are to be successful.
- Because applications from different domains share technologies ("convergence"), we merged and clustered the results of the scenarios, outlining the likely evolution of software-intensive systems in the years ahead.

[1] *IRIS Book, which can be downloaded from www.itea-office.org*
[2] *From the IRIS Book section 2.1.1, page 19*
[3] *From Technology Roadmap on Software Intensive Systems, Edition 1, page 11, downloadable from www.itea-office.org*
[4] *In the first edition of the roadmap, some issues related to applications and technologies were less discussed than others and this imbalance needed to be addressed. Therefore, the development of this version started with a complete reworking of two so-called "application domains" and a deep review of the other three. All elements of this work are in the appendices to the main report.*

To make it **meaningful** and to structure the process, we used two classifications: five **Application Domains** [covered in Appendices 2 to 6] and four **Software Technologies Clusters** [covered in Chapters 2 to 5]. Together, these cover the field of software-intensive systems as completely as possible, keeping some distance both from specific products (so as to avoid potential conflicts regarding Intellectual Property Rights [IPR]) and also from current trends (e.g. in architecture or computer languages).

Both editions of the Roadmap use the same Application Domains, Technology Clusters and Technology Categories which are used to classify ITEA projects.[5] The main Technology Clusters are arranged around four basic questions:

1. *Which end-to-end technologies are required to acquire, process and store content?*
   The **CONTENT** cluster is articulated in three technology categories [see Table of Contents], and deals with signals, data, information, documents and knowledge from capture to complete processing.

2. *Which technologies are required to transport and distribute content?*
   The **INFRASTRUCTURES & BASIC SERVICES** cluster, articulated in four technology categories, deals with transport mechanisms and protocols, as well as with the management of networks (including security).

3. *Which technologies are required to build effective user-system interfaces?*
   The **HUMAN-SYSTEM INTERACTION** cluster contains a single technology category, which deals with the interaction between human beings and the appliances and systems that support the services.

4. *Which technologies are required to engineer software-intensive systems?*
   The **ENGINEERING** cluster is articulated in three technology categories. It explores the complexity of engineering processes and deals with the creation of end-to-end services.

To make it **successful**, the Roadmap 2 process needed the full support of the ITEA constituency.

- Members of the various ITEA bodies provided experts to join the Core Team in charge of elaborating working documents; 17 high-level individuals came together in 15 two-days meetings and contributed regularly to a dedicated website. To validate and enhance the documents, the Core Team held four workshops, meeting the ITEA Steering Group and other experts from industry – over sixty people in total.

- During two 2-days workshops, high-level experts from top European universities, research centres and similar national programmes reviewed and supplemented the intermediate and final results.

- Public Authorities in the Netherlands and France provided financial support over the two-year period.

Evaluation of a range of technologies identified the main issues and challenges for software-intensive systems.

The new Roadmap presents its findings in terms of four technology clusters. These are summarised in the following sections, first with a brief presentation of the cluster, followed by a table, which briefly recaps the main challenges. A final paragraph presents the main conclusions.

[5] *With some fine-tuning of names and definitions over time. For an introduction to these see the IRIS Book, which can be downloaded from www.itea-office.org.*

CONTENT

In general, content is whatever is exchanged within the environment of the system, or between systems. It is processed, stored, managed and transformed. Content ranges from analogue signals to huge multimedia data depositories.

Content categories	Category definition	Major challenges
Content Acquisition & Processing	Technologies that are relevant to acquiring, transforming and modifying content.	Digital sensory system; capturing and managing contexts; efficient analysis of data, integration of information.
Content Representation	Technologies for representing and structuring data while at the same time making the most appropriate and efficient use of resources.	Generic structuring of data; integrated multimedia streams; distinction between content and presentation of data; semantic data; semantic classification of content; virtual re presentation of real-world items; virtual/augmented reality; cyber representation of active entities.
Data & Content Management	Technologies for managing and retrieving content while ensuring data integrity in dispersed and heterogeneous environments.	Guaranteeing the integrity of data, intellectual property management and protection; certification of content; offering unique virtual identity capabilities and management of the context; personal or professional content management and intelligent search.

Major challenges for Content technologies / Table ES-1

The volume of digital content is growing rapidly. We are entering the era of high-quality, high-definition multimedia streams – the most challenging and resource-demanding kind of content we know. Overall, there are two reasons for this explosion of content: first, the infrastructure for capturing content is spreading [see Digital Sensory System]; second, storage is available at very low cost, while accessible bandwidth is continuously increasing.

Content is available at different levels of abstraction, i.e. signal, data, information, and knowledge. It should be easily accessible and needs to be managed with sophisticated technologies (e.g. efficient searching and consistency management) in distributed and heterogeneous environments.

Moreover, having more and more data and information in a digital format makes possible not only easier storage, but also advanced manipulation, analysis and automated feedback. This creates opportunities for new applications and services, especially when combined with advances in network technology. One important issue is converting raw data into information and making it available to a variety of applications and services by aggregation or integration from different sources.

The key to coping with this challenge is thought to lie with context awareness and meta-data, which guide the user through the massive amount of content that can be exploited by semi-automatic reasoning on a formally defined semantic basis (through a semantic web and ontologies). This supports the conclusion that content without context or meta-data is of little or no use, especially if sustainable content management is the aim.

Another major challenge that is being addressed – one, which will become increasingly important in the years ahead – is the security of content (i.e. ensuring that data is received only by those authorised to receive it) and also its trustworthiness (i.e. ensuring that people receive the correct data). Key in this area will be ease of use and acceptance of the technologies by end-users.

INFRASTRUCTURES & BASIC SERVICES

A solid, trusted networking and computing structure is essential for providing ubiquitous services. Such an infrastructure consists of protocols, transport mechanisms and basic services. The network needs to be managed (either in a traditional way or self-managed – e.g. through ad-hoc networks) and maintained, and network services middleware should make it transparent to the applications that are deployed.

To achieve this, all kinds of resources such as processors, bandwidth, display, time, energy, memory and storage, network resources (routers, proxies, etc.) need to be managed as well. The network infrastructure is moving on from its role as a mere infrastructure to one that provides network services, i.e. middleware that delivers virtualisation to networked, distributed applications such as accounting, storage and profiling.

One important set of services involves security, property management and privacy issues, which play a role in several places of the digital world, such as secure transport, authorised access, and conditional access etc.

There are a number of issues related to the use of technology for 'shared' services (e.g. quality of life, publicly used infrastructures, etc.). These touch on technological challenges such as:

- collection of large amounts of data (e.g. home-based health services with information distributed to doctors, pollution control)
- large-scale distributed modelling (such as those required by e.g. complex sensor fusion or weather models)
- large-scale computations
- context awareness.

Network technology is expected to evolve rapidly. Such technology will be necessary to provide ambient intelligence, combined with capabilities for seamless distributed interoperable networking. The way towards ubiquitous access and self-organising networks will be paved by wireless networks, increased bandwidth and

IBS categories	Category definition	Major challenges
Network Transport	Technologies carrying digital data from one place to another.	Heterogenous networks interoperability; increased bandwidth, range and mobility support; IP (Internet Protocol) in any device; optimised streaming and broadcasting; fully distributed environments.
Network Services	Technologies for managing the dynamically changing network infrastructure for roaming users and services.	Ambient intelligence; seamless distributed networking capabilities; service coordination; identity management and profiling network services; support for accountable events.
Resource Management	Implementation technologies that take account of resource constraints (physical, computing, time, spatial, radio frequency).	Small lightweight devices with long-lasting energy source; optimising between conflicting goals; dynamic management.
Security	Technologies that provide safe and secure access to data, user indentification, etc.	Creating secure network services, protecting privacy, protecting content and recognition of ownership of Intellectual Property, creating easy, reliable, safe personal identification.

Major challenges for Infrastructures & Basic Services technologies / Table ES-2

a reliable QoS Internet Protocol (which will be used by web services and P2P[6] protocols), service coordination, identity management and profiling services.

However, if an appliance, device or system is able to function optimally, constrained resources such as memory and storage, bandwidth, display size, time, power, and network resources will have to be properly managed. Terminal power management is critical to this. To share resources across organisations, complex distributed architectures will use new technologies such as grid technology. For critical applications, dynamic resource management is becoming more and more important (e.g. for self-healing or self-protecting).

In the background, the key challenge for security will be to get users to trust systems, giving them the assurance that “they are in control”. This is a major technical challenge, however, as the systems in use will become

[6] *Peer-to-Peer*

larger, more networked and more dynamic – whereby users may find them less predictable. To address this concern, security will become pervasive, and will be handled at all stages of the software life cycle.

HUMAN-SYSTEM INTERACTION

Software-intensive systems are becoming more and more complex and, at the same time, more and more people are using them. The interaction between the user and a system has a major impact on the acceptance and usefulness of these systems. The method of interaction depends on a number of factors, some of which themselves depend on the role of the user, the interaction device, the user's experience and their environment. A critical factor in the acceptance of information technology will be ease of access for non-technical users. Consumers in the mass market require easier interfaces than technology innovators and early adopters.

User interfaces need to support multilingual versions in distributed, collaborative, multicultural and multi-user environments, and must allow simple and quick authoring, navigation and access to multimedia data. Particularly important are multimodal (referring to modalities such as sound and vision), adaptive, personalised, scaleable user interfaces. New appliances, for example in intelligent Home and Nomadic devices and those used in industrial applications and systems (process control, air traffic control, medical systems etc.) require multimodal interaction.

In recent years, the games industry has also been particularly influential. Heavy competition and the demand for ever better versions in very short cycles have stimulated the development of Human-System Interaction (HSI), which comprises technologies that handle interaction with the user.

Even as people become increasingly familiar with complex systems, spending time coping with complexity is becoming less acceptable. HSIs should therefore hide underlying complexities from users and provide the best possible user experience, so that the user feels in control. A specific challenge here is to intelligently select appropriate modalities and provide "zero configurability" within multidimensional environments consisting of different networks and access technologies, devices, people and services. In addition, future user interfaces will need to be able to learn user preferences and to store, manage and disseminate this information to relevant related services and devices. This process needs to be secure and it must protect user privacy. However, acceptance of new HSIs that replace familiar, although complex, ones will take time unless the new HSIs can naturally support accepted modes of interaction.

In recent years, the various technologies have probably been overemphasised. For those who use them, it is the entire user experience that determines whether the new technologies provide real added value or not. It should also be noted that the added value usually comes indirectly through the services and applications that intelligently apply the new technologies – not from the technologies as such.

Therefore, in order to be able to fulfil users' needs and meet general requirements for future systems, the R&D in underlying technologies [see Chapter 2 on Content] and platforms [see Chapter 3 on Infrastructures & Basic Services] should be done in close cooperation with the R&D in user interface and interaction technologies [see Chapter 4 on Human-System Interaction], and vice versa. Moreover, other disciplines outside the area of software systems also need to be involved in the process so that software engineers can better understand user requirements, transfer them into software systems and improve the acceptability of outcomes; this includes, among others, behavioural science specialists and physiologists.

In short, the target for the new HSIs is that they should be:

- simple, self-explanatory and easy to use
- intelligent, context-aware and adaptive
- seamless and interoperable.

The whole process should largely be user-driven, which also poses new demands for software and systems design and engineering [see Chapter 5 on Engineering technologies and challenges].

ENGINEERING

Software-intensive systems are programmable systems based on one or more integrated controllers. Even today, less than 10% of the controllers produced are built into computers. Most of them can be found in systems such as cars, phones, washing machines, aircraft, robots, traffic systems, cameras and audio equipment. And this trend towards programmable systems is accelerating. Software not only increases the variability, configurability, extendibility and changeability of everyday systems, it will also soon allow for a greater variety of functions based on the advanced information processing capabilities built into these systems.

Future systems will be even more dominated by software. As a consequence, the engineering and maintenance process of software-intensive systems is undergoing dramatic changes because software is becoming not only a major part of the product but also a central aspect of system engineering.

Embedding software into systems increases the complexity of these systems as well as the complexity of the engineering process. Complexity becomes apparent whenever it becomes difficult to comprehend and manage all the aspects, requirements, consequences, interrelationships and relations associated with a specific product and the product creation process. It emerges from the combination of architecture decisions, restrictions on existing physical resources, integration of legacy functionality, required non-functional properties and the use of heterogeneous technologies.

In general, complexity increases the effort needed to develop products, services or infrastructure and increases the already high tension between time-to-market and general development cost on the one hand and the quality and adequacy of the product on the other. The effective engineering of efficient, reliable and safe systems is essential and needs support from appropriate technologies, such as methodologies, notation languages, design and implementation techniques, generation techniques, tools, knowledge, processes, guidelines and maintenance support.

Although the integration of hardware and software will present system engineers with new challenges, many of the engineering problems mentioned above are mostly software-related. This is partly due to the focus of this Roadmap but it also reflects the fact that software engineering is still a very young discipline.

Progress in software engineering support will depend on advances in methodologies, models, tools and implementation techniques that support the efficient implementation of embedded systems and services. Engineering technology will require techniques for mastering complexity and capturing high-level specifications of distributed systems. It will also require implementation tools that, firstly, support short time-to-market development cycles, and secondly, guarantee not only cost-efficient, resource-limited implementation on a wide variety of platforms, but also design flows that supports the development process in multi-disciplinary teams.

Engineering categories	Category definition	Major challenges
System Engineering	Techniques, methodologies and tools for the design and construction systems under constraints (time-to-market, technological, legal, economic and legacy).	Evolutionary systems; product line engineering; automation in verification and validation; system architecture trade-off analysis; hardware/software co-design.
Software Engineering	Techniques, methodologies and tools for the design and construction of architectures and adaptive technologies for implementation, deployment, execution, exploitation and maintenance of software systems.	Component markets and software suppliers; cross-cutting concern engineering; design pattern support; model-based development; self-organising software agents.
Engineering Process Support	Methodologies, techniques and tools that support an engineering and distributed engineering process.	Integration and interoperation of engineering tools; distributed and collaborative engineering; configurable methodologies and process standards; requirements-driven process management; knowledge-based engineering.

Major challenges for Engineering technologies / Table ES-3

However, we do not need totally new technologies for all problems. Experience has shown that integration, harmonisation and further development of existing ideas, techniques and corresponding tools can deliver significant progress. Moreover, software development is still often viewed and treated as an art rather than a mature engineering discipline that requires engineers to follow well-defined rules and guidelines. Progress can also be expected from the global exchange of best practice engineering experiences.

But it is not just technological challenges that we should be expecting. To a large extent, success will also depend on other factors, such as appropriate business models (e.g. for components), the way we deal with intellectual property for software, and the way in which the growing open source development scene influences the engineering of systems. To take just one example, the move to component-based systems will certainly impact the business model of industrial organisations and software technology and tool vendors. Component-based architectures will lead to sharing and exchange of common components between various applications. This will enable the development of new products and new technologies through the assembly of existing components.

It is still unclear how end-users will finally pay for components. Business models may range from “free” software and open source models, to licensing components and pay-per-use. With respect to the current situation, it is not inconceivable that most standard components will emerge from open source development, which may well prevent a classic component market appearing.

A simplified conclusion of the findings of this Roadmap

In years to come, *software-intensive systems* will incorporate four basic features (compared to their current status):

- They will be dynamic evolutionary systems.
- They will exhibit adaptive and anticipatory behaviour.
- They will process knowledge and not only data.
- They will allow the user to stay in control.

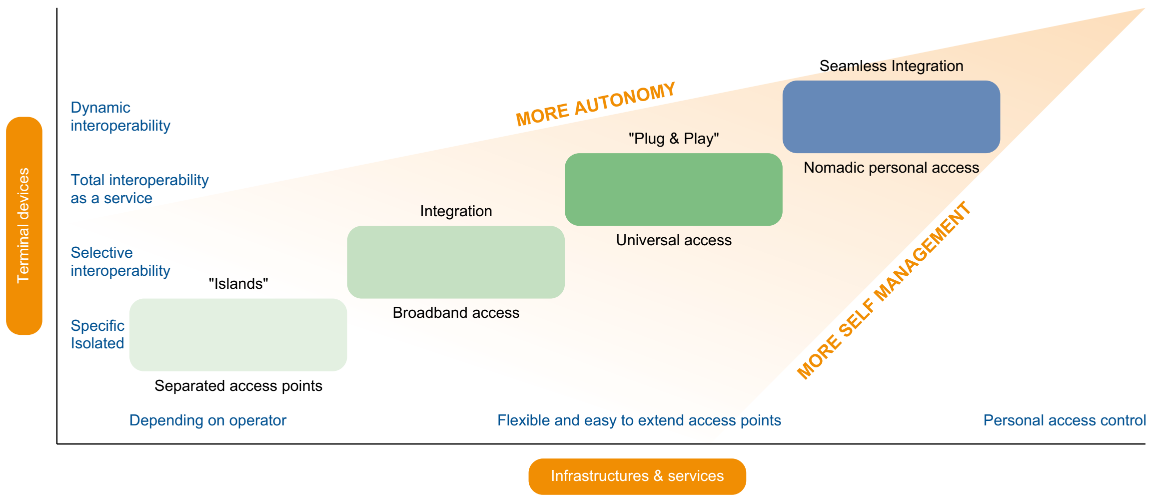
There are two kinds of keys to the development and deployment of these systems:

- Key drivers for *acceptance* are
  - interoperability of products, systems and applications
  - the "-ilities" – security, usability, testability, reliability – and safety

- Key issues for *implementation* are
  - mostly technical: mastering size, complexity and adaptiveness
  - mostly economic: middleware business models and costs

At the crossroads of technology and business: the challenge for the years ahead

Our work on this second edition of the ITEA Roadmap for Software-Intensive Systems has confirmed most of the findings of the first. It has been possible to validate the gradual evolution that we then described: *"Our technological environment will become, step by step, more and more networked and more and more autonomous and self organising […] From now on to this long-term vision, generally two stages may be foreseen […]: the self configurability and interoperability of the terminal devices and the integration of the different networks."* [7] The evolution of applications during the past three years has confirmed the projections made in the previous document [see Figure ES-1].



The road towards convergence / Figure ES-1

[7] *From page 4, Technology Roadmap on Software Intensive Systems, ITEA, March 2001*

These three years have also shed more light on some very important features related to software-intensive systems that will shape the fundamental challenges that the industrial community must address in the next few years.

The first feature concerns the very special nature of software (high cost of development and very low cost of reproduction) and its ubiquity: it pervades all kind of applications. The second is global worldwide networking with all systems collaborating with one another. Combined, these two characteristics present us with challenges which were not yet fully apparent in the first edition of the Roadmap, ones in which it is impossible to separate business, industrial and technical considerations. These can be stated in a very few words – but that does not make them easy to implement.

All parts of the network are entering a state of *continuous change*, with respect both to the services they provide, and to their number and capabilities. This is having a cascade effect, whereby changes made in any one part of the system may lead to the need for changes in other parts. Here, legacy is the key issue, one whose consequences will usually be unknown until they are tackled. To prevent chaos, we need brand-new ways of creating software systems that are self-configuring, self-adapting and self-healing, based on loosely coupled, independently evolving components from numerous suppliers around the world.

The very *nature* of what we are building has changed. We were trained to build rock-solid software-powered pyramids or cathedrals, with well-defined traditional, respectable organisations, employing one architect and one master contractor. We now have to deploy and use a thin web of players who are dynamically interconnected, extremely diverse, unrelated – and sometimes antagonistic. How can we combine the agile and cooperative development we need with four other vital factors: respect for Intellectual Property Rights, the acceptance and development of open standards, the acknowledgement of liability, and rapid access to the marketplace? This is where lessons from the Open Source Software movement may be useful as well.[8]

As we've proved over the last years, ITEA is actively taking up the gauntlet.

[8] *See the ITEA Report on Open Source Software, January 2004 (downloadable from www.itea-office.org)*

Chapter 1

Introduction

This document is the second edition of the ITEA Technology Roadmap for Software-Intensive Systems[9]. The work on this edition started one year after the publication of the first, and continued for two years. It develops the topics discussed in the first edition in greater depth and broadens their scope. The core questions, however, remain the same:

- *"Which of the problems and software technology challenges tackled in the ITEA Programme need to be solved?"*

- *"How do we expect them to develop in the years ahead?"*

In short, this Roadmap develops a shared vision of where the programme should be heading from a technological point of view; the ITEA Technology Roadmap is a "*tool for monitoring the technology changes in and around ITEA's participants' core areas of interest and to steer the direction of the programme without changing its industrial objectives*".[10]

There were two reasons for publishing the second edition so soon after the first. One is internal to ITEA; the other concerns the status of software itself within industry in general.

In the first edition of the Roadmap, some issues related to applications and technologies were discussed only briefly. Therefore, the development of this version started with a complete redevelopment of two "application domains" [11] and an extensive revision of the other three. The results of this are included in the appendices to the report.

Since the first release the adoption of digital technology by society has accelerated. Software technology is a key factor of this evolution, but at the same time, it is also greatly affected by these changes. For this reason, new technology challenges and perspectives had to be reconsidered, in order to update the findings of the first edition.

Some examples of these improvements: updating and fine-tuning of the domain definitions, introducing applications and technologies from the field of industrial automation, and a more extensive discussion of technology maturity.

In this chapter, we introduce the content of this 2nd edition of the Roadmap in three parts. The first [section 1.1] is a summary of the background. The second describes the methodology used and the basic classifications [sections 1.2 and 1.3]. The third, much shorter, part contains a guide to this document [section 1.4].

9 *The first edition of the ITEA Roadmap on Software Intensive Systems has been published in March 2001. It has been received as a milestone for shared appreciation of progress in the realm of software by National Authorities as well as by other participants to the European Research Area.*

10 *IRIS Book, Section 1.1.3, page 15*

11 *ITEA's definition of this term is given in section 1.3.1*

1.1 BACKGROUND

To ensure a clear understanding of the Roadmap results, a few points need to be clarified from the start. That is the purpose of this section. The subjects covered, which come from the first edition of the Technology Roadmap on Software Intensive Systems and from the Interim Report on ITEA's Status (the IRIS Book), are:

- a brief recapitulation of ITEA's vision
- a short explanation of the overall methodology used
- an explanation of the application domains and technology categories used in the report.

1.1.1 ITEA

The ITEA Programme (Σ! 2023) started in November 1998 as an eight-year EUREKA programme. "*The rationale for its launch was a response to the fact that the digital age is imminent and the digital transition is proceeding rapidly… Software is the key to this revolution… [and] the crucial invisible power behind new products, systems and services. Software is providing more and more **flexibility** and - through networking - increasing **interaction/connectivity**.*" [12]

This is translated into an industrial vision [Figure 1-1] and an overview of technical challenges [Figure 1-2]. Connecting to this infrastructure, the stakeholders – people or machines/systems – locally access to distributed multimedia data, which is processed by software embedded in hardware.

Vision / Figure 1-1

[12] *From IRIS Book, Introduction, page 9*

As shown in Figure 1-2, the resources that are accessed are distributed in a dynamic infrastructure. The overall system has three main features:

- a huge number of connected terminal appliances/devices
- a large range of connected entities (user profiles, enterprise VPNs, etc.)
- a wide diversity of network technology (e.g. wired or wireless, long-range or short-range, narrow-band or broadband) and protocols.

Software will be the principal driver of this environment: appropriate software technology is essential to the new functions and services and for seamless transparent security and control.

Underlying all this is the assumption that software is an enabler of **convergence** for different industries and that they all share a number of concerns:

- *“They must learn to share architectures and know-how/best practices and technologies as their customers will be increasingly expecting seamless services across industrial sectors such as home, car, office, body gateway.”*
- *”They need to be able to move from single products to product families.”*
- *”They must address legacy issues for their own products and for the products of others.”*[13]

Technical challenges raised by the key drivers / Figure 1-2

In this context ITEA’s aim has always been to make significant progress in a number of application fields by launching and implementing projects. The roadmapping effort was launched concurrently with the launch of the first projects. The aim was to create a better tool for monitoring the technology changes in and around ITEA participants’ core areas of interest and to steer the direction of the programme without changing its wider industrial objectives.[14]

[13] *IRIS Book, Section 1.1.3, page 15*

[14] *IRIS Book, Section 2.1.1, page 19*

1.1.2 A rapidly changing industrial environment

ICT seems to be changing more quickly every day. Together with the increasing importance of software, the two main technical underlying trends are hardware development (more and more computing power, memory, bandwidth, etc., at an ever lower cost) and ubiquitous connectivity. This connectivity is based on a convergence of networks and services, leading to self-configuring, self-healing distributed systems and services. While this was already true in 2000 (when the preceding edition of the ITEA Roadmap was written), the economic environment has dramatically changed since then: the demand for ICT equipment has not merely faltered; growth has completely stalled and prices (for consumer goods, professional equipment and infrastructure) have fallen rapidly.

The business models are also changing rapidly. There are many stakeholders, often with conflicting interests, active on the markets with quite different understandings and goals.

These new approaches result in players[15] that have a large influence on service offerings and on the functions of a product and, indirectly, also on the acceptance of a technology. Some examples in different fields:

- Younger European customers use SMS so widely that data messages are becoming more important than voice[16] connections much sooner than expected.
- Value-added service providers, content providers and content owners are still in turmoil: the ”AOL Time Warner” or ”Vivendi Universal” model (merging of content, access and service providers) praised at the end of the 1990s seems to be less in favour at the moment. At the same time, some players from the TV market are leaving the sector just as companies with a PC background are entering it.
- Access providers/operators’ business models are not yet stabilised: mobile network operators and fixed network operators still have different business models for the supply of similar services; cable operators provide access to TV and the Internet and new operators are around the corner
- Western equipment suppliers are drastically reshaping, e.g. by cutting down their microelectronics units (the latest, and by no means the smallest, being Motorola) or subcontracting or building alliances. Professional equipment manufacturers are quickly moving from their traditional role of hardware and software providers to being systems/solutions/services suppliers.
- From being ”a telephone that you carry with you”, mobile phones are becoming multipurpose electronic appliances, combining a host of different services and functions, including telecommunication.[17]
- The digitisation of content and peer-to-peer sharing technology, which allows anyone to become a content provider, puts us in the middle of the process to develop new business models and roles for content distribution.
- Since transactions will be based on *digital data*, existing business will be in great danger if they do not change drastically; ICT completely reshapes the way travel agencies, banks, etc. do business.

[15] *At the industry level, this is shown by the fact that new players appear and that traditional players change role. In both categories, some disappear or change their identity.*
[16] *Incidentally, young people are now transforming their mother tongues into new languages*
[17] *This personal appliance might evolve into the cyber representation of the owner*

- Selling and ordering products on the network will reduce wholesale and retail channels and will have a large impact on distribution. The distribution of *digital content* will also eliminate physical transport. For some physical goods, transport will increase, due to one-to-one transport across larger distances. Eventually this might lead to "production" at the consumer's site of products such as books, CDs or even "printed" electronics.

As important, at least, are a number of other disciplines, regulations and legislation as well as social and economic conditions and constraints that will influence these developments, sometimes acting in different directions. There has been significant progress in a number of these areas, for example:

- The semiconductor industry is making faster processors, larger memories, better audio and video processors, reducing the number of physical components, etc., available at lower cost and with reduced power usage.
- System integrators are improving and developing new products and appliances.
- The role of ICT in a number of areas will increase (e.g. Intelligent Transport Systems, Intelligent Production Systems, Intelligent Healthcare Systems, etc.).
- Infrastructure providers enable service access from and data exchange between these products and appliances. The availability of services is determined by market factors.

In contrast with this progress, during the years 2000-2003 there has been a dramatic slowdown of the growth of the bandwidth of backbone networks, due to lower investments in this field.[18] In access networks (wired as well as wireless) however, the speed has been increasing as technologies allowing the creation of new services appeared.

More generally, keeping OpEx (Operating expenses) at the lowest level is now the main driver in businesses.[19]

Other drivers, like the introduction of new high-end services, which require deployment flexibility and an ability to scale up, are also key considerations for software. Regulations, legislation and capital investment and marketing decisions have a large impact on whether or when certain infrastructures or services become available for public use. The overall political and social environment has a dramatic impact on investment decisions, quickening the pace in some fields, slowing it down in others.[20]

Finally, in this context, software plays a major role because it is the heart of the products and equipment, allowing e.g.:

- Equipment suppliers to implement the new functions and applications on their devices.
- Infrastructure providers and content providers to implement their products, services, billing and payment systems.
- Semiconductor industry and other manufacturers, through effective design environments, to handle the increasing complexity of the products and their designs, to support distributed teams, to use more complex simulation and testing tools, and manage the overall production process.

Any statement or forecast of future developments in software technology needs to take this context into account.

[18] *As a consequence of the collapse of the Internet bubble, the past over investment in backbone infrastructure led to excess capacity and consequently a reluctance to continue investing*

[19] *To illustrate this point, a significant challenge is to find solutions for migration to the next generation, despite the obsolescence of existing hardware*

[20] *As illustrated by the policy of USA over the last three years (injecting huge amounts of money into the development of network security technology) and by the decision of the China government to promote Linux*

Technical, legal, and business aspects: an example

The "always-on" broadband connection (supporting, e.g. instant messaging and presence applications) could be a good example of interactions between technical, legal, and business aspects. It has some interesting features:

- From a technological point of view, the lack of public IP addresses is a challenge. In the near future, we will get fixed IP addresses. First one per house or person, in a few years a dozen per house or person and then hundreds per house. Domestic wireless networking (Bluetooth™, Wifi, etc.) is related to this. It makes it possible to make calls at home with VoIP using a normal mobile phone.

- This would imply new devices for equipment suppliers and a new business model for operators.

- The home server could provide information about presence.[21] Information about presence in cyberspace will be shared with other people in the same community/tribe. This raises various legal challenges. Will this information really be limited to the community only? Where are the civil and social safeguards?

- The current strong demand for trustworthiness in the distribution infrastructure will probably be a major factor affecting acceptance as the "virtual cyber identity" develops.[22] It can be stored and set in the mobile trusted device, in the home server, or a similar appliance. A new business entity – the "trusted third party" – whose role it is to deal with these issues is also likely to develop.

1.2 THE ROADMAP PROCESS

This section summarises the process followed to develop this Roadmap. We will examine three aspects: contributors, environment and methods.

1.2.1 Contributors

The process to create this Roadmap was based on consensus. The ITEA companies nominated experts to the Core Team elaborating the document. Several working sessions resulted in a first draft. This first draft was presented to the members of the ITEA Steering Group. In addition, it was presented during two workshops to a panel of European industrial and academic experts, resulting in further improvements. Before publication of Roadmap 2, final approval was requested from the ITEA Board Support Group and the ITEA Board. All in all, more than 70 specialists in various industries and from major European universities and large research centres contributed to the development and validation of this document.[23]

There are different ways and means to construct a technological roadmap in a given field. The rest of this section provides details of the way this was done in this case. It is also important to note here that our Roadmap was developed in a context where a lot of efforts are being made in Europe to develop roadmaps on Information and Communication Technologies. Companies and/or people from the ITEA communities are also participating in these efforts. Information was exchanged with the other teams. The associated documents are listed in the general bibliography [Appendix 10]. Publications by and meetings with colleagues from MEDEA, the Dutch

[21] *Technological alternatives for sharing presence information can be SIP-based or Jabber®-type*
[22] *Increasing with the level of piracy and attacks against IP and all kind of protected content*
[23] *Appendix 8 lists all participants in the Roadmap development process*

Ministry of Economic Affairs, the IST Advisory Group (ISTAG), the European ICT Association (EICTA) and the French Réseau National des Technologies Logicielles (RNTL) were particularly helpful. Regular contacts with some other projects (e.g. ARTIST) were initiated to compare goals, methods and findings, for mutual benefit.

1.2.2 Environment

Before developing the detailed strategic application domains and core enabling technologies approach of Roadmap 2, it is important to have a global view of the future. Which are the main influences driving us towards the digital future?

Whether they are a professional user, an ordinary customer, an industrial process or a group of individuals, at the factory, at the office desk, moving around or at home, the "**User**"[24] will be faced with several types of infrastructures and services and will be using several types of terminal device.

Today the convergence between the computer, telecom and consumer industries is beginning to induce major changes in our environment and will also change a lot in every industry sector. Looking towards the future, this convergence suggests greater user autonomy, and therefore increasing self-management.

Bearing in mind that the key concept of EUREKA is pan-European cooperation, but also how cross-fertilisation between various business approaches can be highly effective, it was decided to break through the boundaries between industrial sectors and select the trans-business "strategic application domains model". This cross-fertilisation can occur within a domain, where all industrial partners coordinate their R&D efforts, but also between different domains, which may have matured at different times. As the time-to-market is the key to success, the R&D cross-fertilisation reduces time and effort.

1.2.3 Methodology

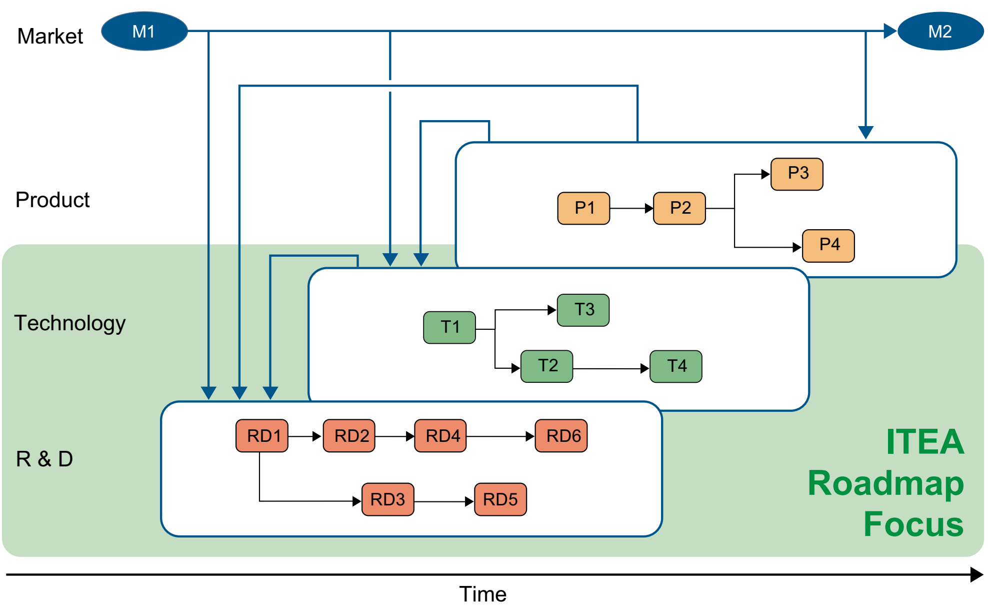
In industry, roadmapping uses a process approach that contributes to business technology integration and improves the technology strategy definition process by presenting the interaction between products and technologies over time. This is described by the upper part of Figure 1-3. We have adapted this process by concentrating on the technology and R&D aspects shown in the lower part of this figure.

As shown in Figure 1-4, we started from "application domains" [section 1.3.1] whose development potential is described in scenarios. Technologies that enable this development were identified for each domain. This large number of identified technologies, augmented by inputs from Roadmap edition 1 and several external workshops, is the basis upon which the next step was based (clustering and classification).

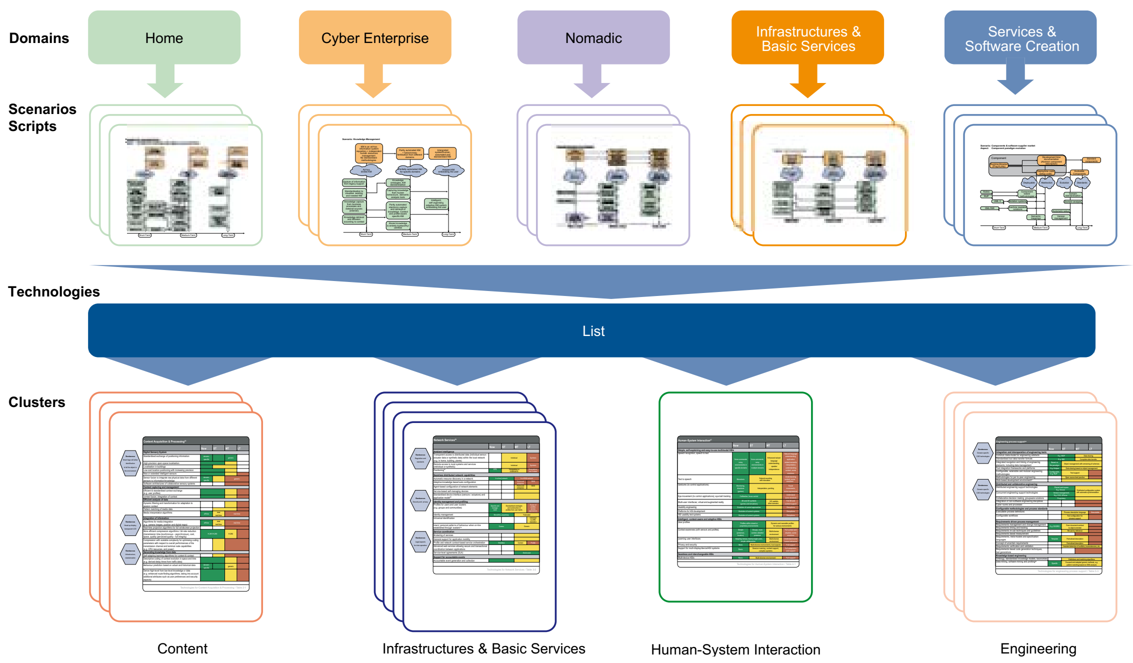
The goal of this second step was to regroup these technologies into a number of "technology clusters" and "technology categories" [section 1.3.2]. This was a highly iterative filtering process, during which the whole list of technologies was matched against each technology cluster. The goal was to extract and assign to the cluster the technologies and technological challenges which were relevant to it. Redundant technologies were deleted and those that do not obviously fit into any particular category were distributed among clusters. This filtering process was repeated inside each cluster, in order to assign the technologies and technological challenges to the technology categories.[25]

[24] *From now on, the term "user" will be used to indicate either a person or a machine/system, connected to any part of the network*

[25] *This process is illustrated – with an example – in Appendix 1.3*



The roadmapping process / Figure 1-3



Methodology / Figure 1-4

It is beyond ITEA's remit to feed the results of this Technology Roadmap back into market/product roadmaps, this being the responsibility of each industrial partner.

Before we discuss basic choices [section 1.3], we will first clarify one crucial concept used in this document: the "**rendezvous**".

Important events in the development and deployment of technologies form a **rendezvous**. In many cases, the implementation of a function does not depend only on ITEA or ITEA-related software technology. A rendezvous marks the emergence of several technologies and external conditions, the convergence of which enables a new generation of applications. Identification of rendezvous is an important aspect of the work on scenarios in applications.

In this document, we have considered and discussed three types of rendezvous, which are combined using the same graphical symbol, a hexagon:

- Technology rendezvous, which are only ITEA-related and largely under the control of the software area players.
- Technology rendezvous, which are a combination of ITEA and external technologies (e.g. hardware). For example, a rendezvous may require not only a software progress but also the availability of certain physical characteristics (e.g. bandwidth).
- Rendezvous that supplement the above through regulation or standardisation.

1.3 APPLICATION DOMAINS AND TECHNOLOGY CLUSTERS

The definition of application domains and technology clusters is essential to a good understanding of the findings of the Roadmap.

1.3.1 Application domains

Classification criteria

In order to consider the applications of software-intensive systems, an effective classification of the different activities was needed. This classification should also take into account the fact that software technologies may reach across classical marketing classifications (i.e. lead to convergence). The major advantage of breaking through the boundaries between market sectors is to have a wider approach for any proposed solution. In fact, and especially with the experience of the ITEA projects portfolio, cross-fertilisation between various technical communities and markets is one of the major benefits of the Roadmap approach (and of the ITEA Programme itself).

ITEA has identified five broad **Application Domains**.

HOME

All activities that may be required by actors/people/agents in their private environment in order to exchange information inside and outside the home (using all types of appliances) and perform the corresponding tasks.

Note: this does not include **nomadic** applications.

The Home domain covers the evolution of information technology in and around the home, driven by the deployment of a broad range of interactive and distributive electronic information services. This includes the introduction of new services due to the convergence of data formats and the use of personal wearable devices at home. These services are defined by considering the IT-needs of the people living in the home. Three forces are driving this:

- Multifunction devices (one device to control all appliances that support remote control features, phone handset as remote control, etc.).
- Universal content (content for a range of devices: e.g. an Internet page that can be rendered on a PC screen or a mobile phone screen).
- A range of media, where cross-exploitation enhances the overall service.

It is expected that this tendency towards convergence, sharing of networks and devices by multiple applications, will have a strong impact on the implementation of IT services in the home. This creates the concept of the “Intelligent Home”.

CYBER ENTERPRISE

All activities that may be required by a set of people or machines, which communicate and interact with each other as well as with the outside “environment”, in order to achieve a common goal (technical or economic) and/or perform a task together, independent of the organisational and/or geographical location of these people or machines.

In this definition, a Cyber Enterprise is not restricted to a company with social and legal status. The intention is that a Cyber Enterprise should also capture activities that span across company boundaries (joint ventures, consortia, supply networks, project-specific associations, etc.) as well as activities where various types of entities participate (governments, associations, individuals, etc.)

A Cyber Enterprise may have many different forms of organisation, management, and rules for interaction. Many different choices may be made, according to the goals, duration, nature of the tasks, etc. Furthermore, a Cyber Enterprise may evolve over time in terms of its members, their relationships, its organisation, etc.

Whatever the precise nature of a Cyber Enterprise, it always shares some knowledge and resources. A Cyber Enterprise therefore needs to protect these by appropriate means. Also, in this context, actors can be either people or machines. Machines are entering the scene when considering production/process control in Cyber Enterprise.

NOMADIC

All activities that may be required by nomadic actors/people/agents away from their home or workplace and on the move to exchange information and perform corresponding tasks. It also includes all mobile and transportation applications.

The Nomadic domain focuses on the evolution of information technology for devices, appliances and applications to be used by on-the-move end-users (or nomads for short). Nomads are the users of portable or mobile equipment. Most often they are people but they could also be moving entities, robots, intelligent cars, goods etc. The Nomadic domain focuses entirely on the impact of being mobile on the devices, appliances and applications of a nomad. Given the different aspects which mobility can have, this includes:

- Technologies to support the safe, fast and comfortable **transport** of people and goods from one place to another.
- Technologies to support the **location independence** of people, devices, applications and services, so that they can use the same applications, services and content at any time and any place with the same quality.
- Technologies to support **permanently moving and interconnected devices**, vehicles and applications, so that one can use them even whilst moving, driving, walking and from one place to another and possibly working at the same time.

INTERMEDIATION SERVICES & INFRASTRUCTURES

All kinds of activities that may be required to support the different actors/people/agents who need to access and manage networks and network services (incl. design, implementation, sales, maintenance and billing services).

This domain is defined as: distributed adaptive services, plus the generic support and framework services used to dynamically compose the adaptive services. In general the word service has several meanings, two obvious ones are: (1) sellable features offered to other stakeholders, in B2C[26] as well B2B[27] relationships, by means of a software application/product and (2) work done for others (e.g. outsourcing activities such as network operation and management or maintenance). We should be aware that the division between application/ product and services is often blurring in business models. In this context, however, we concentrate on the first meaning. Specifically, we concentrate on services which search and exchange digital information, which might be the goal in itself or a means to achieve some other goal (e.g. buying in e-commerce situations or negotiating service level agreements). Even automated decision-support systems – close control systems with a feedback loop (collect, analysis and react) can be considered as intermediation services. Looking in more detail we see that such services are often dynamically composed of network-based services, which together offer the real application functions to users or stakeholders such as network operators and content information service providers.

SERVICES & SOFTWARE CREATION

All activities that may be required to help the different actors/people/agents engaged in designing, implementing, verifying, maintaining and modifying software-intensive products, systems or services.

In this domain we deal with the **activities of the engineering process** for software-intensive systems, rather than with the technologies needed to enable a specific feature of the resulting products. As in other industries, IT engineers need and use a huge amount of techniques, notations, methods, tools, processes and knowledge to do their work. And to do their work efficiently, they need the *right* techniques, notations, methods, tools, processes, etc. There is a growing market and industry for the production, sale and distribution of software and system production technologies. Many companies (but also non-profit organisations and the wide open source community) provide engineers with a huge set of software production tools including compilers, profilers, debuggers, specification tools, code generators, test environments, run-time platforms, versioning tools, bug trackers, etc. These technologies need to evolve over time and cope with the ever-increasing complexity of the systems to be built and the corresponding complexity of the engineering process.

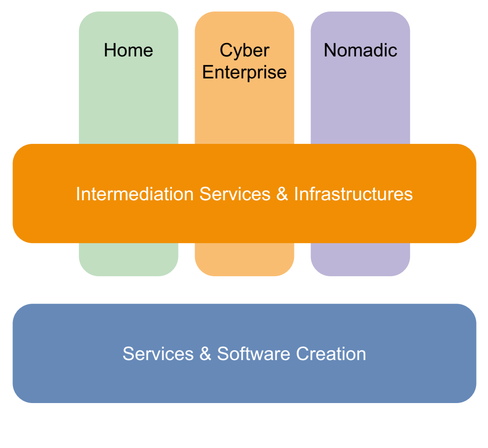
[26] *Business to Consumer*
[27] *Business to Business*

Domains versus markets

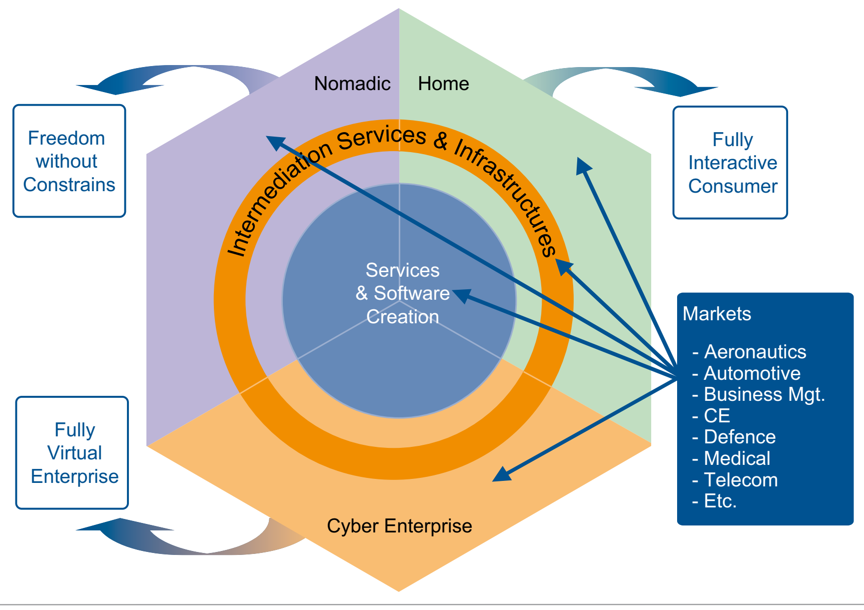
One should remember that these domains cover the market but do not represent market segments, instead they refer to fields where technology needs to be deployed. The reasons for this choice are twofold. On the one hand, reference to markets segments would have brought the ITEA roadmapping effort too close to product roadmapping (and prevent cooperation between companies). On the other hand, as business models are changing very quickly, taking a broader view transcends the perceived boundaries between markets.

Another important point is that deployment of a technology will depend on its maturity. This level is generally not the same in each domain (example: file compression technology was deployed first in Cyber Enterprise, before being adopted by Home and then by Nomadic). Home, Cyber Enterprise and Nomadic are associated with the end-use of the technology, while Intermediation Services & Infrastructures, and Services & Software Creation concern the interconnect and interact side of ITEA. Figure 1-5 illustrates the different application domains.

The five Application Domains approach was selected for the ITEA programme. However, as shown in Figure 1-6, behind the five domains one can easily identify the various industrial sectors. These include markets such as aeronautics, automotive, business management, consumer electronics, defence, medical, telecom, etc.



Application domains / Figure 1-5



Domains versus markets / Figure 1-6

1.3.2 Technology clusters

Classification criteria

The technology classification has to be simple enough to keep things clear, but at the same time, thorough enough to ensure that the coverage of technologies is both complete and unambiguous.

Software technologies are about processing content. This processing starts with signals (to and from the environment of software-intensive systems) and continues with data, information and knowledge. If all this content processing (including storage and management) was located in a single computer, then two more clusters would be necessary: one with the technologies to design and implement such systems (engineering) and another with the technologies to let the user (individual or machine) interact with the system. Presently, processing is increasingly implemented through networking and distribution. Hence a fourth cluster is needed, related to the technologies that make networking and distribution totally transparent.

This classification into clusters presents the main advantage that it is independent from any architectural design – since it deals with abstract operations – while covering the complete field of software technologies. Inside these clusters, technologies have been regrouped in categories with two goals:

- covering the complete field
- avoiding an inconveniently large number of categories.

Here also, it was important that the classification be as independent as possible from present market-related categorisations. Furthermore, the technology categories should preferably be at the same level of abstraction and independent one from the other (orthogonal). The main difficulty in this exercise is that the fast pace of evolution in the environment of software (CPUs, I/Os, networks, etc.) favours the invention of new technologies (e.g. representation, storage, management, interaction, etc.) that may, at any time, make this classification obsolete.

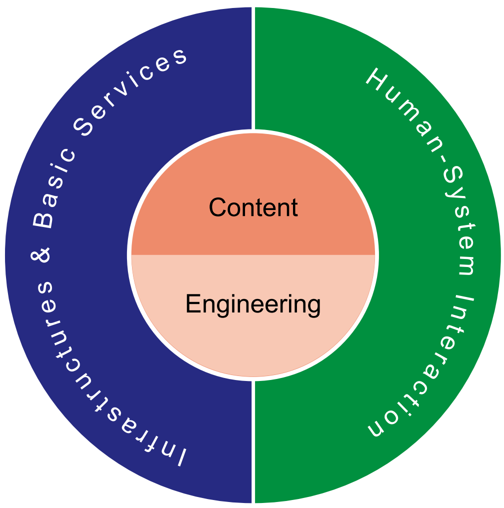
Practical classification

We have defined four main clusters of technology, based on four basic questions:

- What are the technologies required, from source to sink, to acquire, process and store content?
- What are the technologies required to transport and distribute content?
- What are the technologies required to engineer software-intensive systems?
- What are the technologies required to interface the system and the human user?

Note that, while the first three clusters are primarily concerned with software, the fourth one is only partially dependent upon software and mostly upon biology and psychology related sensors.

The technology clusters are illustrated in Figure 1-7. Table 1-1 lists the technology clusters with the corresponding technology categories.



Technology clusters / Figure 1-7

Content	
Content Acquisition & Processing	Technologies that are relevant to the acquisition, transformation and modification of content.
Content Representation	Technologies for representing and structuring data while making the most appropriate and efficient use of resources.
Data & Content Management	Technologies for managing and retrieving content while ensuring data integrity in dispersed and heterogeneous environments.
Infrastructures & Basic Services	
Network Transport	Technologies for carrying digital data from one place to another.
Network Services	Technologies for managing the dynamically changing network infrastructure for roaming users and services[28].
Resource Management	Implementation technologies that take into account resource constraints (physical, computing, time, spatial, radio frequency).
Security	Technologies that provide safe and secure access to data, user identification, etc.
Human-System Interaction	
HSI	Technologies that deal with interaction with the end-user.
Engineering	
System Engineering	Techniques, methodologies and tools for designing and constructing systems under a variety of constraints (time-to-market, technological, legal, economic and legacy).
Software Engineering	Techniques, methodologies and tools for designing and constructing architectures and effective technologies for the implementation, deployment, execution, exploitation and maintenance of software systems.
Engineering Process Support	Methodologies, techniques and tools that support centralised and distributed engineering processes.

Technology clusters & categories / Table 1-1

[28] *As this technology category does not include network level services only (i.e. transport level QoS, etc.) but also the management of complex information in the network, it could have been also called “Network-centric services”*

- The **CONTENT** cluster deals with signal, data, information, documents and knowledge from acquisition to the final processing. It is divided into three technology categories.
- The **INFRASTRUCTURES & BASIC SERVICES** cluster deals with transport mechanisms and protocols as well as with the management of the networks (incl. security, etc.). It is divided into four technology categories.
- The **HUMAN-SYSTEM INTERACTION** cluster deals with the interaction between the human and the appliances and systems that support the services. It consists of only one technology category.
- The **ENGINEERING** cluster deals with the product creation process of end-to-end services. It is divided into three technology categories.

1.4 HOW TO READ THIS DOCUMENT

1.4.1 Document structure

The structure of this edition of the ITEA Roadmap is similar to that of edition 1. The core of the report, following this introduction, is composed of four chapters, each of which is dedicated to one of the ITEA technology clusters. Based upon the scenarios designed for the different application domains, they consolidate the technical findings of the roadmapping work. As domains interface with one another, cross-references between the different chapters have been made, to help the reader see the different sides of neighbouring technologies. The last two chapters [Chapters 6 and 7] summarise the results of the preceding ones, from the ITEA perspective.

The appendices deliver information about the making of this Roadmap. Appendix 1 explains its development (Core Team meetings and workshops, both internal to ITEA and with the valued cooperation of external experts). Appendices 2 to 6 collect the scenarios for the five application domains. They allow the reader interested in specific aspects to study the details of the development of this Roadmap. Appendix 7 explains the semantics of the application domain graphs. Appendix 8 lists all participants in the Roadmap development process. Appendix 9 is a glossary of the most common terms in the document. Appendix 10 contains a general bibliography.

1.4.2 The semantics of the technology tables

Chapters 2 to 5 describe the four technology clusters. Each cluster is broken down into several technology categories which are explicitly described in the context of technological challenges – later referred to as **challenges**. Each **challenge** is then extrapolated into technologies, which are positioned according to time and development stage. To keep the document easy to read, yet reasonably short, the table cells are coloured and an indication of timescale is proposed. This section explains the colouring of the tables and abbreviations.

Based on current knowledge, the colours in the table cells indicate the maturity of the technology. The position of a coloured cell with respect to the table timescale (short, medium, long-term) is an indication of starting time of the deployment of the corresponding technology.

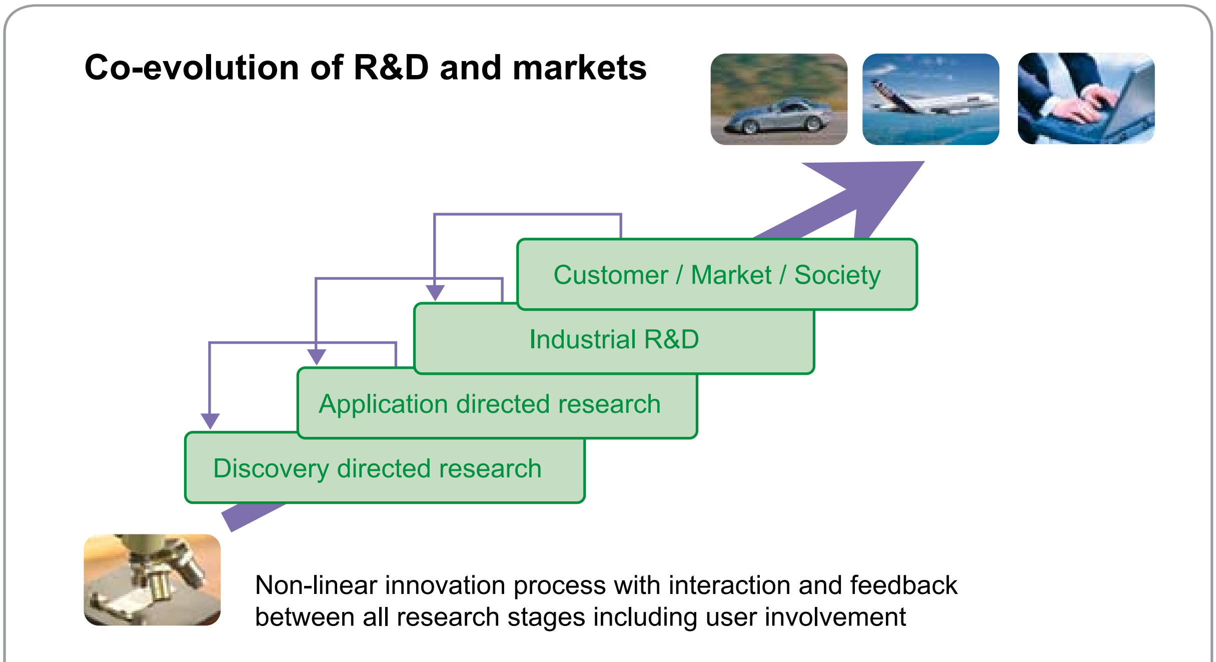
The following colours are used:

- *Green*: represents ongoing research and the **development** of specific technical solutions.
- *Yellow:* ideas, principles and proposals for a technical solution to the problem are just appearing.
- *Orange*: the technological problem has appeared, but ideas and principles for solutions are not yet known.

Note that the deployment of a technology does not mean that R&D on it is finished. Figure 1-8 illustrates this point: there is a permanent feedback between all research stages and markets.

The headings of the table columns indicate a timescale. Roughly, short-term (ST) is associated with the period 2004-2006, medium-term (MT) with 2007-2009, and long-term (LT) with 2010 and beyond. Please note that:

- Actual implementations depend upon rendezvous in many cases and always upon the acceptance of underlying technologies by users[29]. These elements must be considered, but they are impossible to predict.
- Not all application domains evolve at the same pace; therefore some deployments in some markets may be earlier or later than foreseen in a table. See also "Domains versus markets" on page 26.



Innovation processes today / Figure 1-8

1.4.3 A rough guide for the reader

The next four chapters contain detailed technical views on the perspectives and challenges for each of the four technology clusters. Chapter 6 takes a more synthetic look at these developments.

Finally, Chapter 7 summarises the findings of the Roadmap, which is primarily a technical document, rather than a report suggesting directions for policy. Policy indications are made in other strategic documents produced by ITEA (e.g. the IRIS Book[30]) and then decisions are taken by policy makers, for whom a technology roadmap is one of many inputs, albeit a key one.

[29] *Of course users don't care about technologies but about fulfilling non-functional requirements*

[30] *The IRIS Book is freely available at www.itea-office.org*

ITEA Technology Roadmap

for Software-Intensive Systems

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