Continuous Engineering of Information and Communication Infrastructures

Extended Abstract

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Abstract. Information and Communication Infrastructures (ICIs) are business, mission, project or product critical, long living and usually highly heterogeneous hardware/software systems. They represent a substantial investment and need to be adapted continuously to changing requirements for the protection of that investment. Their users critically depend on their permanent availability.

Continuous Engineering (CE) ensures an organized evolution of ICIs by providing guidelines, methods and tools for their construction and continuous change.

1 New Challenges

Radical changes are taking place throughout the economy. Efforts aimed at gaining a competitive edge in terms of price and quality are seldom limited to regional markets. Today's entrepreneurs face competition on a global scale, and this global change has put them under increasing pressure to review traditional products and organizational and work processes — including the underlying information technology.

Information has long since become a production factor. A smooth and steady flow of information, both within and between organisations, is now a strategic imperative. A competitive advantage will thus only be enjoyed by those who exploit to the full the potential benefits of modern information and communication technology.

Information highways, broadband communication, multimedia, video conferences, teleworking and telecooperation — these are just a few of the catchwords used to denote the possibilities seen in the years ahead. This development heralds the end of an era in which centralized company departments were made responsible to provide for the information technology requirements of all users.

The 1980s were characterized by dramatic advances in hardware development. Large mainframes were complemented by midrange computers which were in turn complemented by powerful personal computers and workstations.

Networked workstations have already brought about a decentralization of computer services in many corporations. These networks encourage the integration of independent data processing capabilities and isolated subsystems into larger configurations.

A further change in the structure of information technology has been taken place since the beginning of the 1990's. Individual information systems were being inter-connected to form coherent structures.

Such integrations lead to new configurations which — analogous to other basic structural forms — are referred to as Information and Communication Infrastructures.

Transforming independent information systems into integrated structures also changes their basic characteristics. Whereas previously such systems were developed to satisfy immediate needs, the principle aim pursued in the development of Information and Communication Infrastructures is to ensure that the systems' useful life can be prolonged indefinitely, in much the same way as this principle applies to comparable infrastructural entities, such as road networks and telephone systems.

2 New Applications

2.1 Business Applications

Private enterprises and public organizations continuously address themselves to the task of reorganization. Business concepts — such as lean management, lean production or business process reengineering — can only be put into practice successfully if supported by information technology. Companies with flat, customer-oriented management structures must be able to call upon high-performance communication systems that are readily adaptable to changing needs.

The organization of activities into work groups plays a key role in the decentralized management structures being adopted today. The effectiveness of such groups has a decisive influence on critical business performance factors such as costs, processing time, productivity, time to market and the quality of products and services.

Industry and public organizations are increasingly aware of the need to enhance the effectiveness of such work groups. They are now taking a critical look at their organizational structures and procedures, as well as at the corresponding business processes.

Computer supported process management provides organizations with far-reaching advantages:

- Explicit models enable cooperative processes to be more readily understood and critically examined.
- Teamwork is improved, and cooperation between team members is guided and comprehensively supported.
- Problems in communication, attributable to misunderstandings, misdirection etc., can be alleviated.

Changes in the business structures implemented in industry have intensified the demand for an effective exchange of information and improved efficiency in communication between collaborative work groups. The transitions from closed

DP “islands” to integrated distributed system solutions as well as the division of corporations into cooperative and flexible profit centers, the flattening of administrative hierarchies and the integration of outsourced external services have become an essential factor in responding to global markets.

2.2 Technical Application

Information and communication technologies are paving the way towards intelligent products of many different kinds. Therefore they are developed as an integral part of many engineering systems like

- automobiles
- aircraft and space vehicles, and
- last but not least, many household goods.

The infrastructures in demand here are expected to conform to especially high quality standards which in turn lead to demands for “safety-critical” or even “zero-defect” software in information and communication infrastructures.

Many new products like telephone sets, consumer electronic products, micro-electronic devices etc. are subject to permanent improvements and refinements and this demands for their continuous engineering. These improvements and refinements are wherever possible left to changes to software of the embedded information and communication infrastructures.

Manufacturing technologies undergo again dramatic changes. Early attempts to fully integrate different stages in the production of goods are reconsidered now and brought to a consolidation based on new integration technologies for information and communication infrastructures. As a consequence manufactured goods are brought to the market faster and global competition is largely based on “time-to-market” performance of corporations. By the same token the continuous improvement and refinement of goods demands for continuous adaptations of their manufacturing technologies. Once again many of these adaptations are meant to be achieved with changes in the supporting information and communication infrastructure.

Most visibly are at the moment dramatic changes in production technologies for the car manufacturing. These publicly debated revolutionary developments represent however just the tip of the iceberg. Both the production and disposal of almost all technical goods is being reconsidered, new production technologies based on new divisions of labor and on new information and communication technologies are implemented in almost all sectors of the industry.

Last but not least, information and communication technologies are replacing traditional technologies. The best known example is the replacement of hydraulic steering and control systems in aircrafts by “fly-by-wire” technologies, which are again based on highly complex information and communication infrastructures.

3 New Structures

Substantial productivity gains can be achieved in many domains with the amalgamation of previously autonomous computer applications. In this way, programs

and software systems do not remain separate but become linked via different kinds of integration and communication platforms into compounds that become critically important to the application. As a consequence, many of the programs and software systems installed in recent years have evolved into assets of an unexpected durability. We therefore refer to such durable and evolving systems as Information and Communication Infrastructures.

Like other kinds of infrastructures, Information and Communication Infrastructures are developed for continuous use and to enable adaptations and extensions through partial renewal, partial extension and partial replacement. The establishment of Information and Communication Infrastructures thus demands a wide range of skills:

- the skill of the business consultant for the analysis of business structures and practices which the infrastructures are meant to support,
- the skill of the engineer for the analysis of the engineering problem and for the specification of the requirements for the needed infrastructure,
- the skill of the technology advisor for the choice of the right concepts and systems for the infrastructure,
- the skill of the technology developer for the adaptation of existing products to their use in an infrastructure,
- the skill of the technology and systems integrator for the amalgamation of individual technologies and systems into a coherent overall infrastructure.

Information and communication infrastructures are meant to provide numerous decisive advantages when compared with traditional systems:

- ICIs are built to be improved in an evolutionary manner based on a fundamental concept that has been carefully planned and established.
- ICIs are built to be altered and extended at any time, allowing entrepreneurs essential flexibility in responding to changing requirements.
- ICIs make it possible to utilize new and improved components in conjunction with older existing systems.
- This capacity to develop infrastructures gradually over an extended period of time safeguards investments.

ICIs present a substantial change to software and systems engineering. The logical relationships between the components in software and systems are highly complex, and this complexity increases as these systems themselves are combined into a larger whole. That demands for modern architectures that are

modular: Components are constructed as independent, reusable entities.

open: Systems can be used and adapted over long times

compatible: Structures have to be established that are compatible to accepted principles, and the use of standardized interfaces, components and invariant platforms.

4 New Characteristics

Information and Communication Infrastructures are in most cases product, mission or even business critical. They must guarantee maximum safety and reliability. This is particularly true for systems used in high-risk applications, such as nuclear power stations and aircraft piloting, traffic control, banking and telephone networks.

The infrastructures currently used often do not fulfil this prerequisite. In many cases there are substantial shortcomings in their quality:

- Systems are often faulty and unreliable. This can often be attributed to such factors as unsystematic engineering techniques, a lack of theory and formalization, inadequate quality assurance, and bad systems management, among others.
- The architecture and functions of legacy systems are often not known in detail. In the majority of cases this is attributable to inadequate maintenance techniques, and to incomplete or non-existent documentation.

If these factors are present simultaneously, systems can become an incalculable risk. This presents corporate users with new challenges, particularly in view of their exposure to competition in international markets.

5 New Technologies

5.1 Computer Technologies

Various developments in information technology are currently paving the way for the inter-connection of independent applications:

- Client/server systems based on PCs and workstations complement centralized mainframe architectures.
- Computers are being transformed into working environments capable of supporting complex work processes.
- Substantial progress has been made in establishing international standards for protocols, platforms, and interfaces, such as TCP/IP, http, HTML, X.400, X.500, SQL, EuroISDN.
- Manufacturer alliances are being formed to enforce industrial standards, for example OMG with CORBA, OSF with MOTIF and DCE.
- Simple alphanumeric terminals are being replaced by others equipped with graphic interface systems, window technology and multimedia capabilities.
- High-speed broadband networks are advancing rapidly to replace slower conventional telecommunications lines.
- Groupware and workflow systems enable the coordination of teamwork in offices and even the coordination of work in large organisations.
- Multimedia systems allow for the visualization of complex information.
- Virtual reality systems allow the simulation of activities in 3D spaces etc.

All these new concepts and technologies contribute to the “re-vitalization” or even “re-invention” of many applications like

- in the banking business
- in the insurance business
- in commerce
- in the publication business
- in the logistics business
- in tourism
- in the service and maintenance business

etc.

5.2 Network Technologies

Network technologies facilitate the construction of integrated Information and Communication Infrastructures, offering several substantial benefits:

- They support geographically distributed organizations.
- They protect investments made in independent systems and user-specific software.
- They reduce the high cost of new developments through the integration of existing systems.
- They improve and accelerate work practices by providing reliable collaboration support to users.

Network technologies allow now the deployment of:

- heterogeneous communication systems
- heterogeneous information management systems, comprising file systems, relational and object-oriented databases
- different hardware and software within the same Information and Communication Infrastructure.

5.3 Information Management Technologies

Development of Information Modelling and Management Techniques increasingly support the implementation of comprehensive information systems.

These information systems:

- offer a uniform, global view on information maintained in an enterprise, and
- enable the documentation of relationships between the data compiled in different parts of an organization

They facilitate:

- a better understanding of complex organizational structures
- the application integration into Information and Communication Infrastructures

- the systematic design of software

New information systems are applied to

- document the semantic content of data at various levels of abstraction
- check on their syntactic and semantic consistency
- enable the development of domain and customer specific view on models
- enable their implementation by means of different kind of data management systems like data bases, object bases etc.
- enable the coexistence of different models in heterogeneous Information and Communication Infrastructures
- enable the re-engineering and migration of information systems.

6 Continuous Engineering

Software and systems that make up Information and Communication Infrastructures are different in nature from those that serve as products of a limited lifetime. Their development and evolution require practises other than those of classical software and systems engineering.

Continuous Engineering aims for a number of goals that are not yet in focus of software engineering. From a business perspectives ICIs are meant

- to be kept adequate with respect to their business function, up-to-date with respect to their technology base, reliable for their continuous functioning and robust against their unintended use
- to be continuously improved with respect to their functionality and user satisfaction, with respect to their cost, quality and performance
- to be continuously expanded to support new business functions as well as new and more users
- to be reorganized once in a while to mirror respective business reorganizations.

From a system perspective ICIs will need to have built-in provision for their later change. This in turn requires the denotation of the objects of interest of ICIs like

- material artefacts (i.e. computers, networks etc.)
- conceptual artefacts (i.e. programs, specifications, models etc.)
- data about material and conceptual artefacts
- information (i.e. data in context) about material and conceptual artefacts
- uncoded knowledge (i.e. interpreted information) about material and conceptual artefacts.

The change of ICIs will then be governed by a variety of dependencies existing between the different objects of interest and will be constrained by a number of chosen ICI invariants. It is argued here that ICIs should be built around four categories of invariants of different life times

- category 1 (indefinite life time) encompasses standards for formats of architectures and components
- category 2 (reduced life time) encompasses standard platforms, interfaces and protocols
- category 3 (further reduced life time) encompasses data and information structures maintained by an ICI as well as execution structures across components of an ICI (i.e. the intension of an ICI)
- category 4 (further reduced life time) encompasses data and operations themselves (i.e. the extension of an ICI).

Introducing and categorizing invariants gives raise to the development of continuous engineering processes for building, maintaining, changing and renovating ICIs.

Continuous Engineering of Information and Communication Infrastructures poses many questions and problems to software and systems engineers. Only vague ideas exist on how to tackle the involved technical problems like:

- the analysis of existing (legacy) software and to document its results
- the (re) integration of existing (legacy) systems into Information and Communication Infrastructures
- the conversion and transformation of existing (legacy) systems into renewed Information and Communication Infrastructure.

Everyone of these tasks can be performed only with a deep understanding of the meaning of the different appearances of ICIs as e.g. models, specifications, repositories, code, architectures etc. It would be hopeless to apply known semantic formalism to them. Instead a pragmatic semantics is sought that can help to pin-down some of the critical properties of ICIs and may be used to validate the changes made in the continuous engineering process.