The Future of Information Technology – an interdisciplinary, scenario-based approach

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Abstract

The last decade has seen the most formidable technological advances in information and communication technology ranging from fibre optics to micro electronics, computers, and of course the Internet - the fastest growing consumer service the world has experienced so far. Global information super-highways have been developed and because of them decisions are now being made quicker than ever before.

As we enter the new millennium, the prospect of a global village supported by a wide information infrastructure will provide new chances but also risks. To benefit from the chances and to cope with the risks the market needs to prepare for and react on changes. Therefore, this paper presents some prediction techniques to forecast the future of information technology within the next five to ten years. Possible scenarios illustrate some exemplary applications in the business and private life, leading to a discussion of the impacts on economy and society in the large scale.

Keywords: Technology Trends, Software Engineering, Networks, Standards, User-Developed Applications, Information Management, Home Computing, Economic Impacts, Production, Organizational Impacts, Social Impacts

1 Introduction

Since its origins, information technology has continously extended into new areas, making its way from mathematical computation and data processing via office automation to electronic commerce. During its expansion and transformation, existing technologies like telecommunication and manufacturing have been reshaped, and new ones like mechatronics and virtual reality were created. In today's society, information has become one of the essential goods, and information technology is rapidly becoming an integral part of modern society and everyday life. Obviously,

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being able to predict mid-term and long-term technology trends, innovations, and user requirements early is an important competitive advantage.
On this background, the following questions arise: Are there ways to predict the future development of information technology? How will information technology evolve? How will information technology influence our way of living and working?
The rest of the paper tries to provide some answers to these questions. It is structured as follows: Section 2 collects and discusses existing approaches for analyzing and predicting future technology trends and user requirements. Section 3 assesses future technology trends in the medium term, and Section 4 outlines some application scenarios. The last section sketches the global impacts of technology evolution and innovation on society in the long term.
Note that the predictions and scenarios were not made exclusively by computer scientists, but originate from an interdisciplinary group of academic and industrial experts from various software application areas, among them mechanical engineering, managerial economics, and electrical engineering.

2 How to Predict the Future

Predicting the future is a difficult job, as not only meteorologists can tell you. In general, most prediction methods have a high potential of failure, due to the complexity of the real world, which cannot be modeled and understood fully and may change discontinuously and in unexpected ways. Furthermore, predictions themselves may influence the future because people try to make them come true or to avert them.
The future of information technology seems especially hard to predict, as past developments have shown. If asked whether there would be any revolutions in the area of application programming languages, hardly anybody would have expected fundamental changes four years before. However, one year later, the Java language came up, becoming a major market force in the following. A similar example is the internet: even though everybody was aware of the growing importance of networks and computer connectivity, nobody was able to predict the rapid growth of the internet and, in particular, the world wide web.
Hence, the approaches presented in the following have to be used with caution:

Extrapolation: The extrapolation approach is based on assuming the continuity of current and past trends in the future. In the context of information technology, this is a very suitable approach for the next ten to twenty years, mostly due to the steady evolution in the hardware area, which may be predicted rather exactly using Moore's law, for example. However, extrapolation is a quantitative approach and has its limits. Even if we are able to put the computing power needed for speech recognition into a wrist watch within the next ten years—does this mean that these devices will be built and used?

Crossover: The crossover approach is based on the observation that many successful technologies are combinations of existing technologies. A good example is the computer tomograph, a combination of a computer and an X-ray device. The crossover approach may be used to predict or generate small changes or improvements of products [Wil99], but also to predict long-term trends, like the combination of computers and telecommunication.

Demand-Driven: The demand-driven prediction approach assumes that people will invent and build the things they need and want. An example for this thesis is the development of flat screen monitors. They have been dreamt of since the invention of television, and are finally getting real now. The demand-driven approach has its difficulties, however, as various failures prove—think of the perpetuum mobile or the stone of wisdom. It is also difficult to anticipate future demands and needs of society. The rather short-term predictions of fugacious fashion trends by so-called "trend scouts" at least seem to prove this.

Embryo Technologies: Predicting the future based on embryo technologies assumes that most successful technologies have been invented, researched, and developed for some time at universities or other research institutes. In the context of computer science, this is evident and has been shown by many examples (data structures, relational databases, compiler technology, the internet, and many more). However, the embryo technology approach may be difficult to apply because it is not clear which technologies will survive and mature, and which will never grow up, or even die.

Analogy: Another, related method predicts the time a new technology needs to mature based on analogous technologies in the past. This seems to apply, for example, to object-oriented databases, whose history and development roughly repeats the history of relational databases.

Periodical Waves: Prediction based on periodical waves is based on the observation that many processes have a cyclic nature. An example is Kondratieff's model of long-term economy waves due to new technologies [Kon35]. In this model, information technology as a whole is seen as causing a wave, like mechanical engineering was in the 19th century [Mar80]. It is, however, doubtful whether a cyclic model is a suitable prediction method. Even if we were able to identify waves (like machine programming in the 50ies, high-level languages in the 60ies, structured programming in the 70ies, object-orientation in the 80ies, componentware in the 90ies), we can hardly use it to predict the future: there will be a new wave in the decade after the year 2000, but what will it bring?

3 Main Future Trends

This section provides a forecast about the main possible technological trends in the next five to ten years. All presented prognoses are based on the prediction techniques proposed in the previous section.

Faster, more powerful and cheaper: Hardware, networks, and software will become faster, more powerful and cheaper in the next couple of years. This prediction can basically be found by *extrapolation.* For instance, hardware is providing more and more power at decreasing prices. This observation was precised by Gordon Moore of Intel who showed that the cost-effectiveness of microchip technology doubles every 18 months. Within our prediction scope of five to ten years, Moore's law will continue to hold, although development will slow down to some extent [Kan97]. Based on this extrapolation, microprocessors as powerful as a Cray-2 are expected around the year 2005.
Networks as well as software show similar progress: Currently, the available bandwidth quadruples approximately every 1.5 years [Mül98]. However, software improvements are rather difficult to quantify. But regardless the kind of software you consider, you can notice an enormous progress in the last decades. For instance, consider the history of databases, starting out with hierarchical and network-based databases and ending up with relational and object-oriented databases. Or the development of office software bundles, beginning with simple text editors and ending up with very complex multi-user editors for text, presentations, databases, calculations, and so on.

Smaller and more mobility: The exploration of the American West serves to illustrate the role of mobility in history. Nowadays, the decades of planetary exploration involved spacecraft which flew past, orbited, or probed the planets as means of initial reconnaissances. In some

instances, limited mobility was provided by foot or rovers (manned and robotic) on the Moon, and on Mars by the short-range rover Sojourner. For that reason—mobility of men—all systems used by men have to become smaller and more mobile, especially computer-based systems. This trend to smaller and more mobile systems is mostly *demand-driven*.
Hardware has to become smaller and smaller, networks and software have to support the mobility of the hardware. Miniaturization is currently one of the most demanded hardware trends, enabling new applications like mobile computing, electronic commerce, and advanced medical applications. An example are smartcards, which are expected to contain a keyboard as well as a display within the next five years, thus becoming equivalent to personal computers of the mid-eighties [Hen97].
Another example are movies on television which will be delivered on-demand, or mobile phones that will be combined with Personal Digital Assistants (PDA) for mobile video conferencing and sharing of information on-the-fly. Necessary technologies like DSL [Eri99] or mobile IP [IM93] emerge these days, and standards are set to ensure interoperability on the global market. This forcast is related to the prediction techniques *demand-driven* and *cross-over*.

Higher degree of interoperability, integration and standardization: Years ago a common practice resulted in new technologies reflected by a variety of solutions proprietary to single companies. The better a company could deploy its own solution the higher its share of the market until maybe some day a single product got widely accepted as de-facto standard. This procedure took place, for instance, in the scope of network solution providers where different network protocols competed and TCP/IP made the race after many years. Another example from many others is the invention of Video Cassette Recorders (VCRs). Sony´s proprietary technology called ”Beta” lost against ”VHS” which is now de-facto standard in the whole world (or at least those parts watching TV).
These days, people learned that standards help their companies to preserve investments and enhance quality, and that proprietary solutions strengthen the dependency from a single provider. Even ”global players” cooperate in a coordinated effort to strive for standard solutions for new or existing technologies. These activities are also driven by the strong impact of standards to enhanced interoperability. As more and more business processes are supported by software solutions, more and more departments of a company work with computers and tight coordination along the value chain becomes of vast importance, interoperability is the answer and standards part of the solution.
Many observations let us conclude that this trend will continue in the following years (*extrapolation*). The reduction of size and costs in microelectronics led away from specialized circuits towards universal, programmable, embedded systems. Next to ”historical” groups creating standards (ISO, ANSI, etc.) large cooperations, like the Object Management Group (OMG), cooperatively and successfully work on standardized technologies (e.g. the Unified Modeling Language [OMG99b]).

More intelligent and applicable: Descending price-value ratios of data storage and data processing systems leads to the habit of keeping information in the system or store it on backup devices. Moreover, the variety of information kinds is steadily growing as an increasing part of everyday´s life is modeled, captured, processed, and stored. It is a rather young trend towards extracting valuable information from this — often tremendously large — data-pool (also called data-mining). However, due to immense processing power, modern systems are able to include a much larger variety and amount of information and thus demonstrate increasing levels of ”intelligence”. Interesting enough, this brute force method outraced other approaches focusing on teaching computers ”real” intelligence.

As computers are involved in an increasing amount of application domains, the necessity for sophisticated human/computer interfaces arises (*demand-driven*). Easy-to-use interaction is required to bring down education time and raise acceptance within the group of possible users. A good example are the steady improvements in the field of virtual reality equipment which enhances the look and feel of computer-generated worlds. However, interaction via head-mounted displays and data gloves is still cumbersome and new ways to intensify the immersion in virtual worlds are required. Examples of current developments in this field are haptic interfaces or speech generation and recognition. A complementary approach is called “ubiquitous computing” and results in seamless, almost invisible interfaces. A typical example is a pen recording the writer´s stroke, uploading the data to a computer for further processing.

4 Future Application Scenarios

The predicted technology trends described above have great impact on consumers and businesses in several application fields. Broadband networking enables applications to be performed independent from the location. Teleworking, teleeducation, telemedicine, and teleshopping are some examples. More powerful processors, advances in software and virtual reality improve business processes as well as everyday life.
To illustrate the effects on the different application fields of information technology, we will present four case studies in the following and relate them to the methods applied for predicting them.

4.1 Intelligent Home

Future information technology not only will impact big business domains but also influence the everyday life at home. Mainly advances in communication technology will characterize modern homes of the future. Whereas nowadays conventional television and telephony are the main parts of the communication equipment, the increasing use of computers and networks will form the household in future [EVZ98].
Advances in technology contribute to the demand for new media and the combined use of media (multimedia) in every home [SN95]. Additionally, interactivity will play a major role in using information resources like TV. Driven by a market demand traditional broadcast media will not only go digital but also evolve from a passive *lean-back* position to an active control-and-lean-back position (Movie-on-Demand) [EVZ98]. An increased individual demand on information requires of broadband connections for the last mile home. By extrapolating the current capabilities for broadband access we can see that powerful *lean forward* equipment with all their communication and information capabilities like personal computers will be used in near future. Competition among providers and increasing user demand for personalized services and applications will bring new application scenarios [HKS97]. Networking will not end at the front door at home but will also connect every electronic equipment inhouse (HomeBus) [Wic97]. Every electronic equipment will be addressable like nowadays internet-sites by their own identification (standardized IP-address). The computerization and networking of the complete home is called ”intelligent home”. Additionally, the miniaturization of electronic devices will impact the integration of different functions within one device. By crossing over these two trends we can see that increasing functionality and networking capability of all inhouse equipment raises the percentage of software in all devices.
To illustrate the role of information technology for homes in future we present a sample day of an employee in near future.

At 6.32am the alarm clock of Mr. White rings. The digiman (an integrated handheld mobile device of telephone, internet services, keycard, remote control and handheld PC) has set this time automatically based on the first date in the company noted in the appointment calendar and the usual time between waking up and getting to work. He puts his arm inside his health watcher. Based on the state of health and the daily dietary requirements the health watcher puts together the breakfast of Mr. White. While the connected coffee machine is producing a coffein free coffee, Mr. White starts the fitness workout guided by an interactive video, which also was preselected by his health watcher.
After workout, Mr. White looks at his virtual mirror (a large flat computer-screen). Today the clothing-assistant suggests a black suit, because there is an important business meeting in the company. The electronic weather forecast informed the clothing-assistant that today it will become hot. However, all short-sleeved shirts matching the suit are dirty so that the clothing-assistant selected a long sleeved one.
During breakfast the digiman suggests a shopping list for today. The list was set up by gathering information from all devices in the household. While accepting most of the list, Mr. White sets back some items to be taken care of later. The goods will be delivered by the shopping agent. After having read the contents of the electronic newspaper, which always preselects articles with respect to Mr. White's preferences, he leaves home to go to work.
When Mr. White returns home in the evening, he decides to buy some new short sleeved shirts. He leans forward to his computer terminal, which is connected via an optical internet broadband connection, the standard fixed communication interface of every household, and searches a shirt that matches the suit. Again he looks at the virtual mirror for the combination of different shirts with his suit [Gra98]. He selects two of them and orders them via the digiman.
Later he decides to watch the soccer match between Bayern München and Barcelona. To have more fun he calls his friend in Barcelona to make a video conference during the match. The image of the friend is displayed in the upper left corner of the multimedia screen, which also shows the match. Since he is weak in speaking Spanish his digiman translates synchronously from German to Spanish and back. The day ends with a hot soccer discussion between Barcelona and Munich from the lean back position.
The sample scenario described above bases on the technology trends and predictions of Section 3 concerning advances in hardware and software, and especially in communication technology. Of course not all information technology advances were taken into account when constructing the future day. Indeed it is not easy to predict the user's behavior at home. Decisions about future applications within the intelligent home will depend on the users themselves and of course on the ability of the company's marketing experts in respect with service content, user interface (appearance and usability), technology (quality, speed, presentation, brilliance) and last but not least the costs.

4.2 Management and Business Support

Today, companies more and more focus on customer orientation in all of their business processes. Customers want their products in less time and higher quality. Only on basis of summarizing know how, capacity and flexibility through a strong cooperation between different companies, it is achievable to manage this pressure of customers' desires [Wil96]. Driven by this customer demand, radical changes in business processes leading to virtual companies and electronic markets are indispensable. These new cooperation forms and the tied impacts in management and business are sketched below.
Crossing over internet technologies and the traditional business economics, one trend, which can already be observed today and which can also be extrapolated to the next at least ten years, is

the establishment of electronic (e) - commerce [FB99]. E-commerce describes all forms of economic cooperations based on electronic connections [Pic96]. This includes not only electronic markets but also enterprise networks and enterprise cooperations. One result from e-commerce will be the support of distribution. Intelligent information systems, which make the data-transfer between companies possible, facilitate the administration and enable the reduction to acquisition. Obviously, a prerequisite will be clearly defined and standardized technological and organizational interfaces as already mentioned in section 3. Another result from e-commerce will be the establishment of customized markets. This development will lead to a drastic change of the value adding process. Especially, the distribution chain will be shortened enormously up to the optimum of one step from producer to customer. This simplifies quick responses on market changes.

The modular design of products allows product configurations that fulfill customer requirements on different markets based on reuse of standard modules. The growing modularity of products leads to a specialization in companies by concentrating on one specific module. To configure a new product, special forms of organization like virtual companies are necessary.

Analogous to virtualization in computer science, virtual organizations abstract from given physical restrictions and thus become independent of size and business area. They consist of real companies that come together to carry out only one common project. Each company contributes parts of the whole product in terms of components or services. Conceivable forms of organizations are static-, broker- and decentralized-dynamic networks (cf. [Ins99]). Concerning these organizational structures, the differentiation criteria are the coordination and structuring aspects. While static networks are contractual regulated, broker- and decentralized-dynamic networks are structured by market principles. Generally, virtualization offers a possibility to enhance capacity and flexibility. Enterprises can reduce their activities to their core business [Wil98]. Thus, virtual companies become "Best-of-Everything-Organizations".

We give an example to illustrate the impacts of the mentioned trends in management and business. We examine what happens, if Mr. White is asked to organize a new device called Sheila for his employer. Sheila is a **s**peec**h** *driv***e***n env***i***ronment simu***la***tor that enables the employees to create their own working environment via speech. This device is an extremely thin colored display that can be applied on the wall similar to a wallpaper. An application scenario could be that Mr. White wants to work in a relaxed atmosphere and therefore he calls on the wall to simulate the sea or a mountain range.*

To find out if Sheila exists or even is capable of being manufactured, Mr. White enters the electronic market through his personal internet-portal which is a web-page offered by the company "search and find" (cf. [Tel99]). The portal guidelines him in an intelligent and effective way through the internet and he gets the information that the required product does not exist but knowledge to produce each necessary module is present.

However, Mr. White decides to send a demand to the electronic market to get Sheila; his message reaches all companies which have one of the necessary competencies. These companies themselves search for adequate partners to fulfill the needed requirements. Simultaneously, the production-conditions are already negotiated and an offer is sent back.

One possible enterprise network to produce Sheila is the cooperation of "Micro-Flat Display Technology" (Mitech) and "Phonetic Systems" (Phosys). Mitech is specialized on display technology and offers the needed hardware components. Phosys's core business is speech recognition and interpretation, so it brings in this required functionality.

Based on the received offer, Mr. White decides to send an order to Mitech and Phosys. In the following both companies constitute a static network based on a negotiated contractual obligation. Mitech is determined to represent this new company.

Now, Mr. White's detailed requirements are collated. Based on these, the interfaces between the software and hardware parts are defined. Because of new development paradigms as described *in section 4.3 and 4.4 and the application of process standards both software and hardware components can be developed simultaneously in an optimized way. The development process occurs in both cases according to the assembly concept. That means, the real effort lies in configuring the components adequately. Furthermore, software and hardware parts are fitted together and the ready-made product is delivered to Mr. White.*

The scenario sketched above has outlined some aspects that will come up by new trends getting through the economy. First, the intensive use of information technology enables a flexible reaction upon special customer wishes. Second, engineering processes will be optimized making the production of new products possible. Last but not least, value adding processes will be drastically changed, particularly in terms of shortening and automation.

4.3 Mechanical Engineering

Not only in the field of software products, but also in the context of the mechanical engineering customer orientation and short development terms are decisive for the market success of products. These demands have significant effects on the processes of design, construction and production as well as on the means and resources used here. They require technologies that enable fast design, early stage testing and simplified production of complex products. All these technologies profit from the increasing development of information technology:

- Product design: To simplify complex construction and development processes several CA-techniques like Computer Aided Design are used, strongly influenced by the developments of information technology. Thus the trend towards more applicability applied to the field of simulation techniques, as well as the trend towards a more wide-spread standardization of interfaces and interlinking of technical system has increasing effects on the construction process. As a result of *extrapolation*, in the future the meaning of digital mockup, VR technology (virtual reality) and RP technology (rapid prototyping by 3D-Plotting) [R+98] [KW97] will even increase.
- Design and Development of needed resources and facilities: To rapidly produce the customized products mentioned above, appropriate facilities in form of flexible production cells and production tools are needed. To develop, adjust, and configure these resources information technology plays a major and strongly increasing role. Here, the availability of more computational power and the thus obtained level of intelligence in terms of increased flexibility, as mentioned in section 3 combined with standardized interfaces between design and production systems will be the most influential trends. Using digital resource and product models, the layout and the control software for flexible production cells is generated automatically [RR98, RC98]. Further more, digital mockup is used to rapidly design and fabricate complex casting moulds for customized products [MF97].
- Production: PPC-systems (production planing and control) are used to control and monitor production flow, while flexible production cells form the basic units in highly automated production plants. Again, the trend towards more intelligent as well as integrated and standardized systems will shape production, as it already starts to emerge today: increased performance of computers, advancing platform standardization and the increasing interlinking of IT-systems improve the capabilities and the flexibility of PPC-systems, resulting in agents cooperating to efficiently distribute the work-load [RA97].

Using the possibilities of design and production as envisaged above, the following scenario describes the construction process of a new PDA (personal digital assistant) version:

DigiPal, a manufacturer of digital equipment decides to launch a new version of a portable personal digital assistant using cutting-edge technology including basic voice control. Therefore, Mrs

Green and her fellow members of the DigiPal development team revise the digital model of the PDA last version during design phase. In a first step, the new available technology for PDA production is reviewed. Mrs Green browses the component databases of different suppliers. Finally, she and her colleague engineers come up with several improved, smaller and more light-weight versions of components as replacements for formerly used components, like faster processors, more compact rechargeable batteries and thinner sensitive and even flexible displays. In a next step, the production team uses direct interactive VR techniques to visualize and manipulate the digital mockup. Mrs Green, in charge of the interface components, replaces the audio device, the microphone, and other components. Similarly, her colleagues place other new components and redesign the interior of the PDA. In addition, they use the digital model to develop a new PDA shell hosting the modified interior, placing the flexible touch-sensitive display outside the shell, attached to be wrapped around it for transport and unrolled for use.

After the end of the design phase, the PDA is tested by both in-house testers as well as pilot customers. In the inhouse-testing process mostly VR techniques are used to get feed-back as fast as possible. By handling a virtual model of the digial mockup, Mrs Green decides that a much bigger display is needed. After incorporating this and other changes in the digital mockup, RP-techniques are used to produce a prototype to make pilot customers experience the handling of the new version. Mr White, one of the pilot user, finds the new version very satisfying, however his experiences from everyday handling suggest that different proportions of the PDA are needed. For this reason, a second design cycle is initiated. Still using the digital mockup, components are rearranged and the PDA is tested virtually and physically again to see if it now meets the costumers demands. During the pilot phase, Mitech becomes aware of the availability of this new PDA with flexible display and shows interest in a specialized version for the realization of Sheila. Using a oversized display, improved storage capacities, and a faster processor, this version has the necessary hardware requirements for the realization of Sheila, including the processor performance for the improved speech recognition software to be supplied by Phosys.

After successful testing through the customers, Mrs Green uses the information from the digital model to generate the necessary production resources and establish an appropriate production plan. The automation support tools assist Mrs Green to supply, together with a production engineer from the team, the information necessary for the production and the assembly of the PDA hardware. Based on the digital model all the casting moulds needed for the PDA shell can be design and fabricate instantly. Furthermore control programs needed by the flexible production cells in manufacturing and assembly are automatically generated by Mrs Green and her colleague, ready for download into the production field.

Derived from assembly information of the model and with the help of a model of the flexible production field the necessary parameters for intelligent PPC-Systems are generated automatically for production flow control. These parameters contain appropriate information to minimize production time and production costs and to rebalance the imbalances of work-load introduced by simultaneous production of different versions of the PDA like the standard and the Sheila version.

To put the new product to market, the product information and parts of the digital mockup of new PDA are sent out to several electronic market places, announcing the product to its customers. Using this lean version of the digital mockup, the customers choose form a range of different product parameters defined for the digital model during the design phase. Due to the increased flexibility of modern production, DigiPal, the PDA producer, can easily offer a wide range of versions of the PDA differing in the levels of quality for processors, storage, interfaces, displays, and outer design, adjusting the production to the needs of the market. Based on the orders of the electronic warehouses, DigiPal uses the flexible production process to manufacture the new PDAs just in time to meet the demands of the warehouses.

The above sketched scenario focuses on the impacts of improved hardware, software programs, standardization, user-interfaces, and connectivity, as mentioned in section 3. Of course, for a complete scenario the impacts of the virtual market and the development of the operating software, as described in sections 4.2 and 4.4, respectively, should be considered.

4.4 Software Development

Compared to many application domains that employ software to create or enhance their products, software development itself is not likely to experience a revolutionary change in the immediate future. Although there have been substantial improvements which will influence also the near future, even proven existing concepts, technologies and development techniques like object-orientation, a clearly defined development process or continuously tool-supported development (CASE) have not been adopted by all of the software industry yet [DHP+98]. Struggling with increasingly demanding customer requirements, quickly evolving technical platforms, tightened project schedules and a shortage of skilled developers, the majority of software developers will not accept the risk of a revolutionary new approach to software engineering. Still, there are a number of current technology-driven trends in software development (Section 3) and other areas of information technology – relevant to both the company (Section 4.2) and the individual developer (Section 4.1) – that are likely to play an increasingly important role for software engineering in the years to come:

- Distributed Development: Using the improvements in high-capacity networking, communication devices and groupware tools, it is both possible and desirable to organize and conduct the software development process independently from the location of available development resources. This prediction is mainly *demand-driven* because the global shortage of skilled developers and the increasing emphasis on core competences of software companies require a more flexible distribution of workload. Also *extrapolation* of current trends in teleworking and outsourcing support this prediction [RMS+98, AMM99].
- Model-based Development: Sophisticated models of software structure and function are used to design and describe the increasingly complex systems of the future. The consequent use of abstract and semantically rich description techniques throughout the development process allows to generate less abstract development artifacts like code or component assembly plans. This principle is applied to shield the developer from a large part of technical complexity while concentrating on the problem-solving part of the developed software. This prediction is largely based on *extrapolation* of the long running trend towards more abstraction in software development. While early software had been written in machine language with almost no abstraction from the underlying hardware, growing complexity and platform diversity led to higher-order languages like C or Pascal which could be translated to machine code by compilers. The importance of problem domain analysis and customer communication made object-oriented approaches popular which are able to capture concepts and relations of the application domain very well. Currently, even more complex software is being developed for global use and heterogeneous interaction over networks. This requires even more abstraction from technical details and closer correspondence between elements of software and real-world concepts. The growing importance of *embryo technologies* like meta-modeling [OMG99a] or standardized exchange of descriptive meta-data over the internet [XML99, W3C99] also support this prediction.
- Componentware: The concept of developing software by composing reusable building blocks serves to integrate many aspects of future software engineering. The individual

software components represent the units of function, development, deployment and maintenance that are needed to structure and organize the development process [BRSV98]. This prediction may be seen as an *extrapolation* of the current trend towards object-orientation as explained in the previous section. Additionally, it also follows a *demand-driven* approach because efficient software development requires an increasing degree of reuse to stay competitive. However, the strongest support for this prediction comes from *analogy* with other disciplines like mechanical or electrical engineering. The widespread success in these areas is largely based on the assembly of finished products with components and the development of adequate supply chains. If we compare current software industry to the car industry around 1900 with its custom-made products, a complete vertical range of manufacture and numerous tiny companies, it is obvious that the maturation of software engineering will lead to a state which is similar to the current state of the car industry.

In the following, we will illustrate the mentioned ideas using the exemplary development project of the speech recognition part of Sheila by Phosys as introduced in Section 4.2.

After the relevant functional and non-functional requirements of the speech recognition engine have been identified and recorded with a suitable description technique, they are translated to a simplified, machine-readable form that is used by specialized software agents to search the internet for existing suitable software components.

Because speech recognition represents a rather well-established application domain, there already exist a number of them which fulfill part of the desired functionality. These components are used to rapidly build a first functional prototype which is then integrated with the digital mockup of the display as developed by DigiPal (cf. Section 4.3) and presented to the customer. This prototype serves to facilitate communication between the customer and Phosys regarding the exact requirements' specification. Analysis of these final requirements reveals that a number of the prototype's components may be reused for final development – possibly after extensive customization – whereas other components have to be developed from scratch.

After establishing a complete component-oriented design, again described in a suitable modeling language, Phosys has to reach a decision about components that are ordered from external partners and components that are developed in-house. This decision is based on economical as well as strategic aspects. Although Phosys has a record for building speech recognition engines, it has no expertise in those parts of the software that interact with the display hardware. Regarding the current shortage of skilled software developers and the resulting staff expenses, Phosys decides to order these less sophisticated components from FarAwaySoft, a dedicated developer of display interface components located in India. Phosys is well-prepared to perform this kind of distributed software development, using communication technology like virtual private networks, video conferencing or distributed CASE tools. Of course, each of Phosys's developers is also equipped with a powerful "digiman" (cf. Section 4.1) to coordinate meetings and other important development activities.

Still, to ensure that FarAwaySoft really understands the required functionality of the display interface components, it is necessary to specify the individual building blocks unambiguously, using appropriate intuitive description techniques with a clearly defined semantics. Moreover, rigorous test cases and procedures have to be defined in advance to determine the quality of delivered components. However, a considerable part of these test cases may be automatically generated from the existing specifications of the components' behavior.

The composition of all components forming the operating software of Sheila is obviously a vital step in the development process. A number of their interfaces and the interactions between them that are necessary to achieve a desired overall functionality are likely to be standardized by international organizations like the Object Management Group [OMG98], for example, once *the application domain has reached a certain level of maturity. Visual component assembly tools acknowledge these standards and use them to semi-automatically integrate the participating components as well as to test their conformance. This is possible because the relevant standards employ abstract yet precisely defined models and description techniques, which allow to generate the necessary integration and test code.*

However, despite the careful planning, specification, and testing process, a serious programming error in one of the speech interpretation components was not detected during development. Under certain circumstances it leads to a failure of the Sheila device, resulting in the display of a trash dump whenever a Caribbean sunset is requested by the user. Fortunately, Sheila's operating software includes a diagnosis component, which is able to detect this error (e.g. by analyzing the user's vocal reactions) and report it to Phosys using the networking capability of Sheila (cf. Section 4.1). Consequently, after correcting the error in the involved component, the updated version is sent to all the installed Sheila devices via the internet and automatically integrated to replace the original one.

The scenario outlined above is not very far-fetched and could be realized by mostly relying on current technologies. It is the short-term goal of software engineering to further improve and consolidate these technologies while integrating them tightly into the overall development process. Still, a large part of future success in software development relies not so much on technology but on human factors like organization, motivation or communication. These aspects have not been covered in this section as they are subject to a different kind of analysis.

5 Impacts on Business and Society

As outlined in the application scenarios in Section 4, we believe that information technology will elevate the degree of automation in many application domains. Advances in software engineering will allow to rapidly develop software and to support an increasing number of business processes. At the same time, more people will be capable and willing to use information technology due to improvements in human-computer interaction and user interfaces. Connectivity and standardization will facilitate the coordination and integration of different applications and systems on a large scale.

From a general point of view, the main contribution of information technology in the short and medium term is improved efficiency—truly novel applications are not predictable. Still, this does not preclude major impacts on business and society, as quantitative improvements in efficiency may surpass a threshold, resulting in fundamental qualitative changes. In the following, we try to outline some of these probable consequences, as well as some of the involved chances and risks:

Unemployment: The mentioned advances in information technology offer new business and employment possibilities, especially in respect to the combination of existing areas, as current business processes may be easily integrated and supported by software. At the same time, this poses dangers for many established businesses like banks, insurance companies, or retail shops, which are forced to adapt to this changing environment. The increased requirements for efficiency and flexibility are likely to eliminate a large number of less qualified jobs in service positions [Gro99]. Unemployment due to technological advances is mostly seen as a danger today, as it threatens the existing social structures. In the long term, the implications may be positive or negative, depending on whether the released forces are used for constructive or destructive goals.

Technology Dependence: The increasing use of information technology in many aspects of everyday life leads to an increasing dependence on this technology which in turn leads to an increased vulnerability to failure and sabotage. The infamous ”Year 2000” difficulties or the recent outbreak of the ”Melissa” computer virus emphasize these potential risks [Luc99]. On the other hand, virtually all technological advances in society in the past led to a certain degree of dependence. We feel that the involved dangers are a motivation to further improve security and dependability of future systems based on information technology.

Individualization: The advances in flexibility together with the reduction of overall development costs allow to customize products literally to a single customer. This results in higher diversity and the possibility of rather different lifestyles for each individual person. The individual may perceive this development as an increased ”quality of life”.

Global Surveillance: The increasing pervasion of everyday life with information technology allows to gather and analyze an unprecedented amount of data about each individual. While this data may be used to detect criminals, for example by creating a movement profile based on credit card transactions and mobile phone activity, there is also a growing potential for information misuse by governments and other organizations to establish a global surveillance system for its citizens. The advances in technologies like language or image interpretation will enable a limited semantical analysis of gathered data that was previously impossible. While this risk of misuse should definitely not be taken lightly, there is also a growing public concern for these developments as demonstrated by recent strong disapprovals about hidden global serial numbers in widespread hard- and software products. Although generally society as a whole is responsible to install and enforce stronger data protection laws, there are also means for the individual to protect its privacy by using strong encryption technology, for example.

Communication Behavior: Although permanent availability for communication is possible, it is generally not desirable. This leads to a growing importance of asynchronous communication as it allows to combine availability with the freedom to interact at a suitable point in time. As a consequence, it is no longer necessary to communicate in person at all times. While business has accepted this change in communication behavior (in some companies electronic mail has become more important than phone), it is not clear if this trend carries on to private communication. On the one hand, improved facilities allow communication on a global scale as well as interaction possibilities also for previously handicapped groups in society. On the other hand, susceptible individuals may substitute electronic for personal communication and subsequently lose contact with reality. It is the responsibility of the individual to balance the available modes of communication.

Note that most the trends and predictions mentioned above are not based on breakthroughs in technology or truly novel applications. However, information technology is prone to unpredictable changes, at least on a smaller scale—these changes may change the overall picture, especially if individual application areas are considered. Still, the previous predictions seem reasonable and likely, based on past experience and current knowledge.

From a general point of view, the improved integration and coordination of global business processes as realized by information technology reduces overall friction in the economy. It is estimated that as much as 60 percent of the gross national product of the USA is due to the cost of business transactions [Gro99]. These transactions are reduced or made cheaper by the mentioned advances in information technology, thus leading to higher efficiency and reduced global pollution. In principle, the involved energy and resources are free for other tasks. However, the exact nature of these tasks as well as the role of the individual in the process of achieving these task is not yet clear. Mere advances in technology are not enough to improve the subjective ”quality of life”. There is also a need for new goals for society and the individual as well as a common vision about a truly desirable future.

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