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A Basis for IT Assessment

An overview
of the underlying technologies, their applications and
the implications for individuals, society and business

Report prepared for the Steering Committee of the Swiss Centre
for Technology Assessment

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Introduction

The search for pattern is the basis of all scientific investigation.
Where there is pattern there is significance ....

Watzlawick et al. [6], p. 36.

For some time already, the *Center for Technology Assessment* (for short: *TA-SWISS*)at the *Swiss Science and Technology Council (SSTC)*[i] and its Steering Group have recognized the importance of **Information Technology (IT)**[ii] as one of the key stimuli for the rapid changes visible in virtually all areas of public concern, ie. ranging from the global economy to issues regarding the safety and privacy of the individual. Several studies have been undertaken in rather specific areas as follows:

- The impact of IT on intermediary political organizations (eg. political parties) [1][iii].
- IT as an enabler for mobile work schemes [2].
- The implications of the systematic acquisition and analysis of customer data [3].
- Computer based patient records - advantages and risks [4].
- Deployment of telematics in transportation [5] (study in progress).

In the course of this work, it became quite apparent that these different application areas did not only have many commonalities in terms of the underlying technologies (eg. exploiting the astounding price/performance advances for digital electronics); also, recurrent issues were identified when the impacts of IT were assessed. Typical examples of such recurrent issues are *privacy* and the *dependability* of IT-based public infrastructures, or the well-known *digital divide*, ie. the possible emergence of a "two-class society". Evidently, these commonalities (as regards technologies) and recurrencies (as regards the effects of IT) may be interpreted as more general *patterns* associated with assessing IT in diverse application domains. As Watzlawick aptly put it in [6], such *patterns* may point to a more systematic approach. With this report, we attempt to do just that: Finding a systematic approach to IT assessment. The reader ought to be warned, however! This is just a first attempt, and its findings, guesses and proposals need to be validated through specific studies to be defined in the near future.

With the deployment of new technologies, new aspects in the assessment of IT may well emerge. Thus, it is foreseen that amended versions of this report will be produced at suitable instances.

Last but not least, another word of caution is deemed appropriate: We will see that all sorts of technologies (in a broad sense, ie. not necessarily meaning HighTech) accompanied mankind for many centuries in coping with information and in expanding its communication abilities. Assessing IT is therefore by the very nature of the subject a tightrope walk between identifying a process marked by radical changes (eg. papyrus, printing press, telegraph, television, Internet, ...) on the one hand, and a view focusing on the invariants of human behaviour. In that respect, the report will conclude that a lot still needs to be done to really understand the interactions between human behaviour and the tools used for information handling and communication. This calls for studies beyond just Technology Assessment – basic interdisciplinary research is a *must* in an era where electronics, informatics and biology come closer almost every day.

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[i] A list of abbreviations is provided at the end of this report in *Appendix A*.
[ii] *Information Technology (IT)* is understood here in a wide sense; specifically, it covers *Communication Technologies* as well. We are aware that alternatively the notion of *Information and Communication Technologies (ICT)* could be used, as recently decided by the Swiss Academy for Engineering Sciences (SATW).
[iii] Numbers in [] point to the bibliography in *Appendix B*.

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Appendices

1 A bold hypothesis: what's so new about the *Information Society*?

It has become almost undisputed that we are rapidly assuming the characteristics of what is called an *Information Society* or a *Knowledge Society*. The phenomenal growth of the *Internet* in the last eight years, the pervasiveness of mobile phones and the widespread control of even primitive appliances through microcomputers are ample proof of the fact that our daily life is indeed intimately tied with *Information Technology (IT)* and its applications. Many authors and politicians firmly believe that economic growth and the position of a country on the global market critically depend on mastering IT, with lasting consequences for eg. a nation's research and education policies[iv] (see eg. [7] or [8]).

We will argue, however, that terms like *Information Society* or *Knowledge Society*, if taken by their proper meaning, describe an inherent characteristic of the human society very much older than even eg. the printing press. Indeed, it can be argued that probably the only feature really distinguishing human beings and the human society from other living beings is the ability of humans to describe not only their environment, but also their feelings and their intentions in a *symbolic* way – ie. as "data" or "information" -, and that they have developed ever more sophisticated means to extract, process, store, distribute, communicate and interpret *information* on a *symbolic level*. Beyond that, decisions in private as well as professional life depend to a large extent on a massive body of *knowledge*, either shared and publicly available, or acquired privately through personal experience, individual learning or tradition. Seen that way, today's massive deployment of information technology does *not* justify to call us either an *information society* or a *knowledge society*. The question is rather whether our *behaviour* - as the knowledge society we always have been - is significantly changed through the new tools, and whether this process already lasting for many centuries is accelerating.

This view is judged to be the key to a more systematic approach to IT assessment. Its primary hypothesis lies in the assumption that most information-related processes (eg. information collection, processing, analysis and communication) and the applications relying on them have always been around in some form or another; it is the speed, accuracy, range, reliability, cost, etc. which may alter more or less drastically (and maybe almost unnoticed) with the introduction of a new technology, and in its wake, might change our *behaviour* and our *system of values* as well, even in a fundamental way. It should be noted that this view coincides in part with seeing information technology as a modification or "outside extension" of our sensory, articulatory and information handling organs. Increasingly, we might also be faced with all sorts of "inside extensions", ie. IT based implants for health care or even aimed at directly connecting our brain with external data handling systems. As such – ie. seen as a modification of the human nervous system and as blurring of how humans perceive their delimitations -, it also becomes clear that it is inherently difficult to predict the behaviour of a "rewired human" or a "rewired society" as a whole. On the other hand, it could mean a chance to formulate IT assessment questions in a more systematic way if the proper abstractions are found.

The reasoning just presented appears quite in line with the position of well known authors when critizing Artificial Intelligence (AI) [9, 10], when describing the paradigms behind computer science and its applications [10], or when discussing the issue of computers vs. cognition [11]. Our view also coincides with what has been described in [13] as a "middle ground" in a debate "whether any computer ethics issues are actually unique ... (or whether

[iv] Recently, this view has been questioned in so far as past investments into IT more often did not pay off [57]. However. the issue remains controversial [58].

they) can best be understood as a new species of existing generic moral problems". We will come back to this fundamental question in sections 2, 5 and 6.

In the field of study chosen here, some emphasis has been put on what is called *Pervasive Computin*g or *Ubiquitous Computing*, ie. the introduction of "intelligence" in the form of miniature computing and communication devices into virtually everything, and their linking as a *platform* for a host of new applications. On the other hand, we have (so far) somewhat neglected (but not forgotten) certain other application fields of advanced information technologies, eg. for entertainement or as modeling and design tools in various disciplines such as computational chemistry, computational fluid dynamics or even simulation of living cells [14] and the desktop systems for the "homebrew" type fabrication of micro- and nanosystems [15.6].

Our considerations will lead through the following steps:

- In section 2, we will more thoroughly substantiate our claim that the human society has been an information or knowledge based society esentially for all historic time. By purposely including in our analysis an *historical context*, we aim to put our work on better methodological ground. If the assumption is true that many conventional forms of information technology have already had – sometimes barely noticed – their impacts on society, culture and individual behaviour, pre-electronic forms of information handling should serve as a much better reference for our considerations than eg. critically assessing some non-technical issues still delaying some promising Internet applications (eg. the problems related to "digital signatures" for e-commerce).
- Examples of IT based applications will then be analyzed with a purposely science-fiction like flavour. By analysis, a comparison with pre-electronic systems of information handling is meant, aiming at unearthing possible impacts on our behaviour.
- In section 4, an overview is given of the underlying technologies necessary that such applications become feasible.
- Subsequently, some fundamental issues will be deducted which appear to be recurrent with many such systems – open questions related to basic human issues like trust, responsibility, values, mutual respect, coping with abnormity, etc.

As a preliminary conclusion, it may argued that the assessment of information technologies is, by their very nature, inherently more difficult compared to other technologies where cause and effect are much less tightly coupled with our own behaviour and our system of values. In essence, we will see that the assessment of information technologies can hardly be undertaken in a "per project" (eg. electronic ticketing) or "per application domain" (eg. medicine) type of approach, where the pros and cons are weighed against each other; the more, because most new IT applications rely on complex interactions of a host of cooperating subsystems. **Rather, our challenge will be how far humans let bypass themselves by mechanized means of information processing and decision making**.

2 Information and communication: terms, definitions and capabilities

2.1 Introductory remarks

It stands to reason that all scientific endeavours ought to take place within a consistent framework of terms and definitions. This is also true of *technology assessment (TA)*, and thus, we are called to convey our understanding of *information technology (IT)* and its *applications*. Given the specific features of this field (as already touched briefly in the previous section), the author is, however, of the opininon that *most terms used in this study should preferably be interpreted in a rather wide sense*. Thus, the popular social games should be avoided with endless arguments whether eg. mobile phones belong to the area of mobile computing or whether smart antennas are a subject for electrical engineers or computer scientists. Nevertheless, an attempt is made in the following paragraphs to convey our understanding of some often used terms. This will not be done with a very formal approach, but rather with an attempt to sketch the evolution of information handling capabilities.

As a supplement to the following sections, an alternative, more formal description of terms like *information*, *knowledge* and *communication* is provided in **Appendix C** (Concepts of information handling).

2.2 Basic information handling by living beings

All living beings lead their life in a permanent exchange of *signals* with their *environment*. Even very "primitive" beings are able to adapt or even optimize their behaviour according to "soundings" they take of their immediate environment through eg. sensors for temperature, water flow, acidity, brightness, etc., eventually coupled with processing capabilities allowing to identify characteristic patterns (eg. specific acoustical signals or particular contours or shapes within pictorial information[v]). This may be regarded as a ***first capability level*** of information handling in the sense that these beings are able, through their sensory organs, to collect data about both the living and dead environment and deduct therefrom information used to control some actuators, thus implementing or even "optimizing" a certain predetermined generic behaviour. Behavioural patterns could either be "built in", eg. be ultimately determined by genetic information, or have been acquired by some *learning process*. Learning - of course - implies that some form of *memory* must be available.

Although this first capability level may be regarded as "primitive", it is nevertheless a decisive component of the human information processing system, allowing us eg. to move easily (viz. unconsciously) in both our natural habitat and within the built environment (ie. without tumbling or colliding with obstacles on our way), and helping us in identifying specific objects or the timbre of a familiar voice. Last but not least, the first capability level provides "services" (ie. pre-processed raw information) to higher levels of information handling. In particular, it is an important basis for the many forms of non-verbal communication, also called "analogic" by Watzlawick et al. in [6], and thus is relevant for the *relationship* (in contrast to *content*) aspects of communication (see also **Appendix C** for more information on these terms).

[v] Spiders may serve as a nice illustration: Through sensing and interpreting the reverberations produced by an insect caught in their web, they are able to identify the type of insect and decide on further actions. This is, by the way, a form of one-way communication not really intended by the sender.

2.3 Intra-species communication

A ***second level** of information handling capabilities* pertains to signals exchanged between members of the same species, in order to implement certain preferred patterns of *collective behaviour* – in other words: to form the basic glue of a *society* (in a wide sense, ie. maybe even covering plant societies). This already presupposes two very important functions:

- Each being must be able to *identify other beings (and the messages produced by them) as belonging to the same species*, eg. by recognizing certain acoustical or visual patterns.
- Between living beings, some *communication channel* must exist, allowing for the transport of *data* produced by one being and received by one or many other beings, allowing these to interpret the data such that specific *information* can be extracted and the own behaviour can be controlled accordingly.

It is important to note that a distinction is made between *data* and *information*[vi]: *Data* stands for any (acoustical, optical, ...) *signal* with a certain *pattern* formed according to some *rules* (ie. an *alphabet* and a certain *syntax*), while information is "something" having a specific *meaning* for both the sender and the receiver when it comes to *interpret* the data with a view to implement a certain behaviour. It should be recognized that the meaning is not necessarily the same for a sender and a receiver; in fact, human communication is usually a *two-way* process (ie. a *dialog* according to some *protocol*) aimed at finding a common understanding beyond the "standard" meaning and to resolve ambiguities.

Another quite important insight at this stage is the fact that most living beings are not just simple automata with a fixed program for data interpretation and execution, but rather sophisticated systems being able to interpret the data according to the momentary *context*, possibly using memorized information acquired previously through some *learning* process. In fact, the reason why the information handling abilities of many living beings are still unmatched (and may probably never be reached) by conventional computer based systems lies in their superiority of considering context information and in *adapting* to new situations (see eg. references [9] ... [11]). A somewhat related issue emerges when a *society* is regarded as a sort of *distributed, loosely coupled nonlinear system* (to borrow a term used in the engineering sciences), thus having the characteristics of a *relativistic system* [12], and possibly exhibiting *non-determinism* or even *chaotic* behaviour.

2.4 Information handling and communication by humans

> *Language comes so naturally to us that it is easy to forget what a strange and miraculous gift it is.*
>
> Steven Pinker [16], p. 1.

So far in our considerations, human beings hardly differ from any other living beings in their ability to communicate both with the natural environment and members of the same species[vii]! What then distinguishes human beings from other living beings? We may think of a ***third level** of information handling capabilities* in the sense that humans have developed quite sophisticated systems to describe not only the environment, but also feelings, individual intentions as well as commonly accepted rules in a *symbolic* way – ie. as "data" or "information" or "instructions" -, and that mankind has found ever more powerful means to

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[vi] See also *Appendix C* for an additional discussion of terms like data, information, knowledge, semantics, etc.

[vii] This is even true for some misuses of communication capabilities. It is e.g. known that certain families of glow-worms modulate their light signals such that other species are mistakenly attracted, only to get killed and eaten.

store (eg. in libraries), sort, copy, distribute and communicate information on a symbolic level. Essentially, this level is synonymous with humans acquiring *language* in both its spoken and its written form. Whereas it is probably impossible to trace back the development of *oral* human communication to its very origins, it is generally accepted that the first *written* form of languages emerged more than 5'000 years ago almost simultaneously in Mesopotamia and Egypt [17, 18].

Two different types of languages may essentially be discerned:

(a) *Natural languages*, with their capability to describe virtually everything. A prize is paid, however, for this *general purpose* feature: Natural languages are somewhat imprecise, and despite huge efforts to define the meaning of its terms in lexica etc., there is usually some room when interpreting statements. This is especially true when we consider their *context sensitivity*: Usually, we are able to make succinct statements only because we can assume that our communication partners are aware of a specific *context* we did not explicitely state, and if we share with them some specific *world view* and *culture*.

(b) *Special purpose languages*, developed to describe specific facts and instructions, often in a well-defined *format* (using special *symbols* and a specific *syntax* and *semantics*) so that hopefully no room is left for interpretation. *Special purpose* implies that such a language is only used in a well-defined, *limited context*, where the *semantics* and maybe even the *pragmatics* are definded, allowing ultimately for some mechanization of *interpretation*, *simulation* or even *execution*. The following examples may serve as illustrations: programming languages, notations used in chemistry to describe chemical processes, formalisms used in mathematics to set up and manipulate algebraic equations, the sign languages used to guide people on roads and in airports, etc. There is a rich set of symbols and sign languages [19, 20], some of them dating back many thousand years. Usually, the older types of such languages (such as the signs painted on walls by gipsies) are much less formal than modern scientific notations.

There are a few outstanding *technologies* supporting such "third level" information handling activities:

(1) Both the invention of *paper* and later the *printing press* permit in principle everybody to share information - facts, feelings, insights, etc. - with everybody else.

(2) The establishment of a *postal system* allows for paper-based communication between people without the need to displace oneself.

(3) *Calculating devices* like the *abacus* and the *slide-rule* represent early tools for the mechanization of certain calculation procedures in disciplines like bookkeeping, engineering and some natural sciences.

(4) The combination of mechanical *keys* and *locks* embodies early forms of (physically implemented) *codes* for the protection of valuable properties.

(5) The *telegraph*[viii] - both in its early form using mechanical semaphors and later in its electrical implementation - enabled written *point-to-point communication* at the speed of light, with message transfer time in whole telegraph *networks* however determined by the working speed of the people operating the relay stations. The *telegraph* may be regarded as the forerunner of *digital communication* since messages were taken from a limited set and thus could well be regenerated at the relay stations as long as the signal impairments on a link were kept sufficiently low.

[viii] It should be noted that only the *transmission* aspects of telephony and telegraphy are considered when discussing the level 3 capabilities, i.e. the possibility to convey data or speech signals over large distances at the speed of light. The *switching* functionality, i.e. user controlled automatic routing, is regarded to belong to the next higher capability level.

(6) The *telephone*[7] is equivalent to giving our speech articulating organs and the related hearing senses a global reach.

(7) With *radio* and *television*, systems for rapid dissemination of information have been realized.

A common characteristic of all these "third level" technologies (and tools) is their strong reliance on *humans* still exercising the *cognitive functions*, *executing the crucial information processing steps* and taking *decisions* in case of conflicts. Nevertheless, these technologies (in conjunction with advances in the area of physical transportation, eg. shipping) were the key ingredients in establishing advanced systems of trade and science with a more than local scope. In particular, because of their almost instantaneous means for interpersonal communication, the telegraph and the telephone (followed later by radio and TV) represented a first step in having the world shrink to what *Mac Luhan* later termed the *global village*. Still, it should be stressed that the real *applications* - to borrow a term usually used with computers - were residing in human beings, logically combining different pieces of information and executing the crucial decisions, drawing heavily on context information they previously acquired.

Last but not least, as **figure 1** shows, one has to be aware that many decades before the dawn of the computer area, the members of civilized societies were already - so to speak - immersed in a sea of symbolic information: reading books, interpreting and implementing cooking recipes, writing or reading letters and contracts, obeying road signs, studying maps, consulting navigation instruments like compasses or sextants, etc etc.

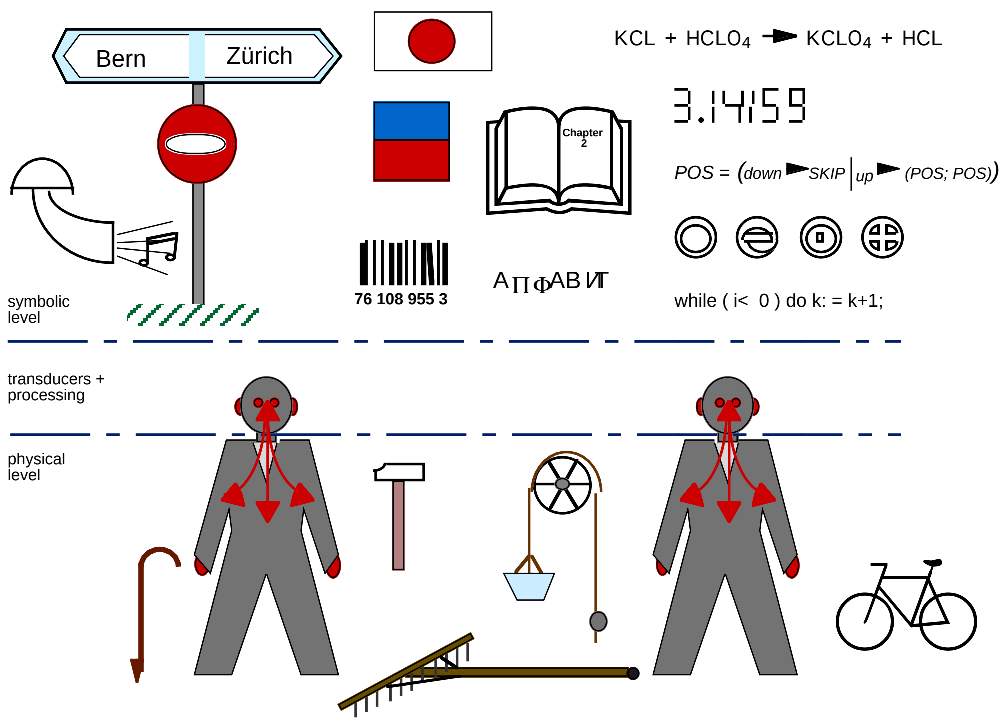

Figure 1 Humans immersed in a sea of symbolic information in the pre-electronic era

We may differentiate between data linked more or less directly (even physically) to some specific object (eg. a product label, a signpost, operating instructions, a patient record), and more generic data, appearing in many different guises like letters, books or a scientific report. This differentiation is important from the point of view of *interpreting* and *verifying* the data: In the first case, the direct relation to a specific object establishes a well-defined *context*, and verification is usually straightforward, whereas in the second case, the receiver relies much more on the hope that the originator of the data can be trusted, and that the context he/she has either implicitly or explicitly defined is not misleading. For both types of data, we may also distinguish between statements or documents using natural language, and those where rules beyond the grammar of natural languages have been defined (eg. in bookkeeping or in scientific disciplines).

The essential aspect of this capability level is that in many cases, information is assembled by a *human originator* for use by one or more recipients, allowing these to guide their own thinking and their actions in an "informed way", ie. making extensive use of insights, experience and *knowledge* gained by other people. Of course, data may also originate from simple sensing devices (like a thermometer) invented by humans in crude form possibly hundreds of years ago.

Beside the continuous, natural transfer of knowledge in everyday life, our society has built institutions like schools and universities to ensure passing on its knowledge to future generations in a well-organized way, and it has even established many different schemes to verify that a certain body of information is mastered by individuals as a prerequisite to practice some professions or eg. drive a car. Seen that way, it is neither the *computer* nor the *Internet* which made us to become an *information society* or a *knowledge society*! Rather, it could be debated whether the emergence of the information society is coupled with the emergence of language as such, or with the widespread circulation of written information made possible by the printing press.

All the *early (conventional) information technologies* quoted above already had a profound impact on behaviour, calling in their wake for a redefinition of values, for new laws to cope with new forms of crime, etc.[ix] This insight immediately leads to the conclusion that many of the ethical, social, moral and legal questions associated with modern information technologies have just as well been around for many centuries. For example, the four "fundamental issues of cyberethics" [13], ie. *(free) speech*, *(intellectual) property*, *privacy* and *security* have most probably had some meaning already in all ancient cultures.

Nevertheless, it would be very unwise to assume at this point that there is no need to assess the impact modern information technologies have, ie. just using the argument that the basic problems have always been around in some form or other! As we will see, the phenomenal *quantitative changes* related to modern information technologies (eg. processing and transmission *speed*, *storage* capabilities, *global reach*) and the *scope* of applications necessarily lead to a *reformulation of existing policies*, and some new IT concepts (discussed in the following two sections) might even lead to new, *unique issues* in ethics, politics and law.

2.5 Automation and control

The **fourth level** of information handling capabilities is very much tied to the industrialization which took place in the past two centuries. Its main characteristic may be seen as *taking the human out of control of industrial processes*, ie. conceiving specific processes such that they normally run without human intervention. In such systems, as seen on an

[ix] It might well be argued that many traditional tools and technologies (such as the procedures and forms associated with the tax system) could be the subject of TA.

abstract level, sensors measure the relevant characteristics of the process involved, the extracted data is analyzed by a controller and, through actuators, the process is influenced such that some objectives are met. It should be noted that these systems appear in a broad range of guises, involving both *analog* and *digital* forms of information handling, and various forms of *feedback loops* - sometimes clearly discernible and sometimes rather hidden. A large spectrum of examples could be given here - possibly ranging from the clever fly-wheel regulator of early steam engines via the programmable Jacquard loom up to today's sophisticated airplane control systems.

A second observation is even more important: Of course, this type of ***automation*** may not only be applied to all sorts of mechanical, chemical, etc. processes, but also to *data handling processes* typical for the *service industry*. In fact, this lead in a first phase to innovations such as the development of automatic telephone exchanges (as early as 1888[x]), relay-controlled punch card sorters (Hollerith machines, 1896) or electromechanical calculators. A crucial characteristic of this ***first phase*** of automation of data handling - and of automation in general - was the fact that automation usually encompassed a rather specific application, with more or less only the boring routine tasks being taken away from humans. The development and deployment of *programmable computers* together with a *unified (viz. digital) representation (viz. coding) of information* then marked the ***second phase*** of automation, its main characteristic being that a universal, programmable device could in principle be used to support a very broad range of applications through using application specific *software*. Thus, as the French term for software (logiciel) implies, the specific logic of an application (ie. the proper sequence of processing steps and decisions) is relegated to a stored program which might be modified or replaced if the application changes[xi]. As one of the computer ethics pioneers (James Moor) emphasizes, computer technology is, unlike previous technologies, "logically malleable" because it can be shaped and molded to perform a variety of functions [13].

Most of the first computer programs centered around *numerical* applications, ie. mechanizing and speeding up the execution of algorithms hithereto implemented manually or with the help of crude mechanical or electromechanical devices. Rather early (ie. in the second half of the fifties), however, it was recognized that the computer would lend itself to manipulating and processing other types of symbolic information (eg. texts, mathematical expressions, formal descriptions of electronic circuits, etc.), and - with a rather profound impact on the field - "information on information" or *metainformation,* eg. the formal definition of a data structure or the specification of a programming language. This ability of processing metainformation is one of the reasons why the IT field moves ahead so quickly: "Information Technology feeds on itself" in the sense that any advances (eg. a faster computer) may immediately be exploited to lead to other advances (eg. implementing a tool allowing to design a still faster computer), etc.

2.6 Pervasive computing and communication technology

We will now equate the **fifth level** of information handling capabilities roughly with the massive deployment and use of computer-based devices, data repositories and services, tied together in all sorts of networks, and possibly embodying *new approaches to information*

[x] Almon B. Strowger was an undertaker in Kansas City, USA. The story goes that there was a competing undertaker locally whose wife was an operator at the local (manual) telephone exchange. Whenever a caller asked to be put through to Strowger, calls were deliberately diverted to his competitor. This obviously frustrated Strowger greatly and he set about devising a system for doing away with the human operator (quoted from [21]). Thus, this is an early example where new technologies were introduced to combat intrusions of confidentiality!

[xi] The French term reflects much better the problems associated with changes: Usually, it is much more difficult to change the logic of an application than the underlying computer hardware!

processing (eg. artificial neural networks or cooperating agents) and new types of *human-computer interaction* (*HCI)*, with "computer" standing here generically for any IT based system. In addition, such systems may embody some *cognitive abilities* mimicking the cognitive functions of living beings (we will come back to this topic in sections 4.2, 4.6 and 4.13).

The capabilities of such systems go along with a significantly higher level of bypassing individuals through mechanized means of information processing and decision making - it is mainly this fifth capability level forming the subject of the next sections and possibly of future TA studies.

Most of the systems we consider here exhibit an enormous *complexity*. As we will show in more detail in section 4.13, traditional approaches to mastering this complexity (ie. ensuring that a system functions as specified, both in terms of functionality and dependability) are not too promising. The situation is somewhat similar to economic systems, where it is now almost generally believed that the concept of the so-called *market economy* (characterized by decentralized decision-making by private individuals) is superior to the so-called *command economy* (cf. eg. *imperative progarmming* style in computer science!) or *centrally planned economy* (see eg. [22]). The same is true for many of nature's organisms both on a microscopic and macroscopic level, where *self-organizing systems* play a crucial role [23, 24]. An important aspect of such systems is the ability of its subsystems to *adapt* and to *learn*, and it is no wonder that researchers in the IT field turn more and more to so-called *bio-inspired* concepts (we will come back to this issue in section 4.13). This, however, will certainly lead to a marked shift in emphasis for assessing IT; when - so to speak - the cognitive abilities of living beings are imitated, how can one differentiate between *virtual* and *real*? Who is ultimately responsible for the *virtual beings* someone has set free? This point will be taken up later in sections 3.8 and 5.3.

3 A sampler of advanced IT applications

3.1 Introduction and basic assumptions

In order to substantiate our claim that the analysis of rather diverse IT applications ultimately leads to similar results in terms of possible impacts on our behaviour and society at large, we will sketch a few selected applications, some with a seemingly science-fiction like flavour. Our choice (for the time being) is still more or less arbitrary, and we refrain from making any predictions about the commercial success or the importance of the applications in the future. It should be noted, however, that our assumptions and our imagination were guided by an extensive review of the available literature; in particular, we have used eg. [15] and ACM's electronic news service [25] as valuable sources of information.

Although we will discuss perspectives for the development of some key technologies only later, we may already safely assume that the real limits for the conception and deployment of new applications will hardly come from limitations of the underlying low-level technologies such as processing power, transmission bandwidth, data storage volume, etc., but rather from human-induced limitations (eg. sheer time limits in a time-to-market atmosphere) in mastering the inherent complexity of future systems. This is valid both on a microscopic level (eg. when designing a new family of microprocessors) as well as on a macroscopic scale (eg. when ensuring that the performance and availability of global networks is commensurate with their key role in the proper functioning of our economy and society).

For the following applications, we have furthermore assumed that these rely on technologies related to what has been called *Pervasive Computin*g or *Ubiquitous Computing*, ie. the introduction of "intelligence" in the form of miniature computing and communication devices into virtually everything - a term usually attributed to the late *Mark Weiser*, a scientist of the Xerox PARC research lab, pioneering visionary computer application scenarios [26]. In fact, in the spirit of what we have said in section 2.1, the author thinks that in the future, *Pervasive Computing* and *Ubiquitous Computing* could be regarded as almost synonymous to *IT* in the sense that future *applications* of information *technologies* often have an "all-embracing" scope, both in geographical and in functional terms. For a recent description of the state of the art in this field, see eg. [27] or [28].

3.2 The intelligent electronic butler

An intelligent *electronic butler* is a personalized system supporting an individual (his human "master") in coping with everyday problems of information handling much beyond agenda management. The electronic butler should be visualized as a piece of software running on a platform similar to a Palmtop or Laptop, always carried along (eg. attached to the belt or integrated into clothes) by its master, and being permanently connected to the next available network (e.g. a wireless LAN), thus being able to access whatever server worldwide at any time. This platform may also be connected via an "on-body-network" to other devices carried along (e.g. a microphone or video-goggles) or to sensors and actuators implanted for eg. medical or identification purposes. For a direct comparison with figure 1, we refer to **figure 2** for an illustration of the electronic butler, suggesting that some form of *agent* technology has been implied.

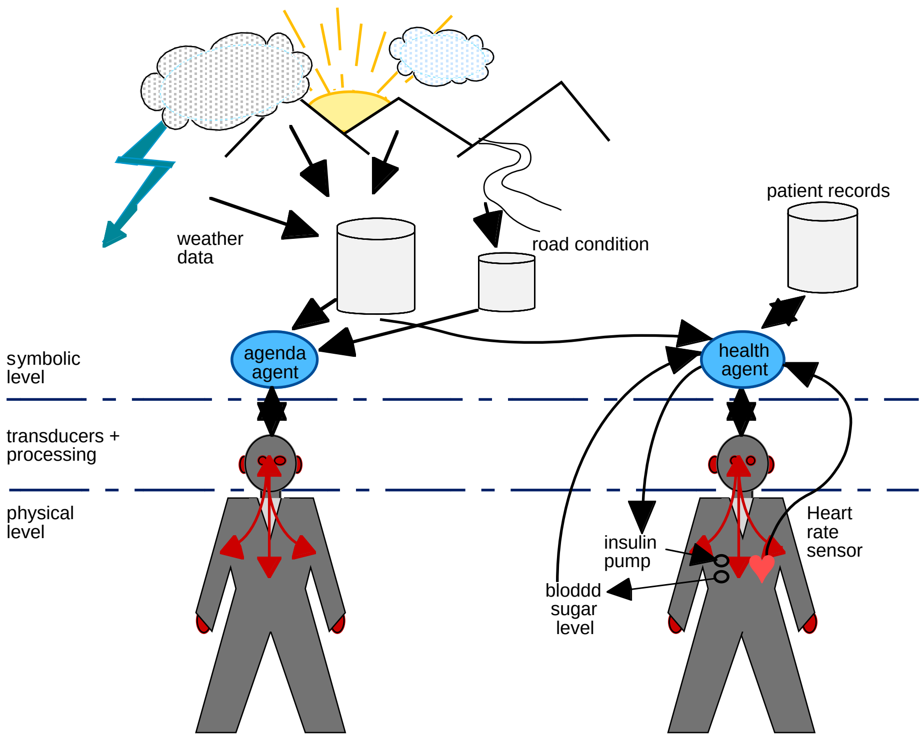

Figure 2 Pervasive computing & communication using agent technologies

A specific task - out of a broad range of conceivable functions - may serve as an illustration [29]: Instead of setting an alarm clock to wake the master up next morning at six o'clock so that he can reach a meeting in time, the butler is given the meeting time and preferences for travel modes. The butler than analyzes timetables of public transport systems, periodically checks weather and road conditions during night, waking up the master just in time to have a cup of coffee ready, prepared in advance by the butler-controlled coffee machine (via a wireless home-network). In addition, the butler presents a summary of events which took place during night and which might be relevant for next day's work, according to some profile previously defined. Moreover, the butler boasts a perfect acoustic memory since it is equipped with a device capable of recording everything his master hears for all his life. Thus, in replaying and analyzing the discussions which have taken place in previous meetings of the same kind, the electronic companion can make valuable suggestions during breakfast for arguments to be considered in the forthcoming meeting. In an even more science-fiction like version, the butler might have checked some implanted medical sensors (see section 3.4) to find out whether specific medication is to be recommended at breakfast time, or whether his master should rather have herbal tea instead of coffee (or cancel the meeting). Eventually, at the meeting, the personal electronic companion could check with the local air quality monitoring device [30] whether a break should be suggested to open the windows for a few minutes. Similarly, the e-butler could be equipped with sensors allowing to inspect quite inconspicuously whether the food served at the business lunch contains some unwanted ingredients .....

Although figure 2 is far from a sound technical description, it shows that applications of the type described before are based on the availability of a broad range of publicly available electronic information services, eg. weather information, road condition data, train and bus schedules, stock market news, etc. Of particular interest in this context may be the availablility of both *time* and *location information*, eg. through an integrated GPS (Global Positioning

System) receiver. Availability of these types of information might even be a must, since our butler can probably only reach useful conclusions if his reasoning is made *environment-dependent*, ie. considering the implications a specific date, time and location have[xii]. Moreover, if we imagine that the butler is communicating with other (remote) agents who in turn depend in their deliberations on information about the user's local environment, the electronic butler would have to incorporate a GPS *transponder*, ie. a device revealing the master's exact location to other people or any device having been authorized previously to receive this information.

3.3 The tailor-made professor

For a long time already, considerable efforts have been made to use various information technologies for educational purposes. One of the earliest uses of IT were probably the radio-based courses offered by institutions like the *Open University* in the UK, or the popular physical exercise ("Frühturnen") guidance given for the broad public by radio stations as early as the late fourties. Of course, we dispose today of a range of quite sophisticated electronic educational tools and systems, such as interactive CD-ROM-based learning packages, videotaped lectures, remote desktop-type multimedia access to outstanding lectures with the possibility of real-time feedback, all sorts of simulation packages allowing to create various virtual laboratories, eg. for the chemical engineering student, or so-called *Computer Supported Cooperative Work (CSCW)* packages for group work in dispersed seminars.

In the application we are about to describe, it is assumed that different motives meet in yielding a seemingly science-fiction like system:

- The growing competition between institutions of higher education, driving these institutions to be more market-aware and quality-aware.
- The possibility to reach a bigger educational market through networking, eg. in reaching students in distant regions or students not being able to attend local lectures.
- The growing pressure for quality control and accreditation, leading in its wake to some standards about contents and presentation.
- Political pressures to make the best use of costly resources in higher education.

In such a world of ideas, it might be argued that the least reliable components of the educational system are represented by the humble human beings in their roles as assistants, professors and lab technicians, with human shortcomings like fallibility, lazyness, inaccessibility, etc. Fortunately, a new technology could come to our rescue: computer-based so-called *avatars*, ie. virtual beings [15.3] generated photo-realistically on a computer. In the not-too-distant future, it may even be possible to tailor such an avatar to the individual preferences of its users, ie. clothe it (him or her?) with a preferred style, fit it out with a certain way of moving, lending it a pleasant timbre of the voice, etc. Thus, while the *content* mediated by the avatar professor would be of the highest possible quality (eg. obtained through a team-effort of the best institutions world-wide), the presentation *style* would be adapted to the preferences and the momentary mood of the individual client.

Although such a replacement of the classic lectures may look rather exaggerated, we have to be aware that first industrial avatar-type products appeared as early as 1996 [32], and that there are already educational projects embodying some of the features just described [33].

[xii] In fact, the US National Academy of Sciences recently organized a workshop to discuss the new paradigm of "location aware computing" [31].

In order to relate this application to our reference model of figure 1 (and also to the other applications described in this chapter), the avatar-based system is visualized in **figure 3**.

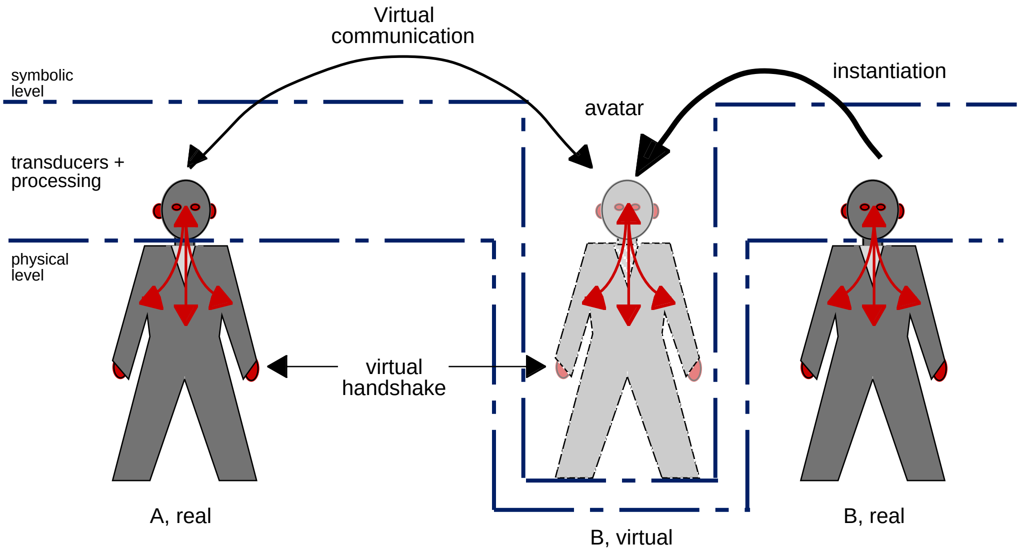

Figure 3 Avatar-based communication and mediation of information

Evidently, quite a host of non-technical questions arises with such a system, such as:

- How far does our "virtual realism" go: does an avatar exhibit feelings, can it be insulted, can it be punished, has it learning abilities itself, etc.? In fact, embodying affective capabilities in computers is regarded as a serious issue by surprisingly many researchers [34, 35].
- Who is responsible if the quality or performance is below expectations?
- How far do students feel obliged to follow an avatar's lecture? Does the system undermine student's discipline?
- Is the "perfect" teacher alo the best teacher? Or does imperfection further independence and self-confidence of students?
- etc.

3.4 Continuous wellness and health support

It may safely be assumed that even in prehistoric times, people tried to overcome physical deficiencies or health problems through the use of artefacts[xiii]. However, these artefacts were essentially restricted for a long time to devices such as orthopedic or dental prosthesis', or glasses to correct defective eyesight, etc. Probably the first tools involving *electronics* were hearing aids, and the first *implanted electronic devices* about 40 years ago were cardiac pacemakers.

In parallel to the sophistication of a broad range of prosthetic devices, for quite a long time as well, medicine has more and more tried to base the assessment of the state of health on all sorts of "objective" measurements, eg. ranging from simple things like taking the body temperature or blood pressure, through determining the concentration of characteristic

[xiii] It is eg. no wonder that the term *crutch* is used in some languages with a more generic meaning, ie. a sort of makeshift.

chemical compounds in bodily fluids or taking an ECG or EEG, up to sophisticated X-ray or MR scans allowing to "look" inside the body and even derive quantitative information from these scans (eg. the volume of a tumor).

If we look at these two developments through the eyes of a control engineer, we might argue that a phycician, depending on *multiple data taken from a patient*, administers *corrective measures* to overcome health problems – there is in principle a *feedback controlled system*. By *corrective measures*, a very broad range of actions is meant of course, eg. taking medication, performing surgery, etc. The crucial aspect of this view is that the *feedback loops* seen by the control engineer in all these "systems" passes via *people* (both professionals as well as the patient) taking the essential decisions for health care. With recent advances in IT, especially in the miniaturization of electronic, optical and electromechanical devices, and with rapid progress in the field of smart sensors, a tendency emerges to relegate more and more decisions originally taken by humans to some "intelligent" electronic system (eg. a microprocessor) – the physician (and the patient as well) is taken out of the control loop. Examples of this kind of automation are:

- implanted systems for diabetes patients, involving an insulin pump controlled by sensors which measure the blood sugar level
- robotic surgery controlled by body scans
- etc.

The technology of choice to connect sensors, processors and actors in many such situations will be RF wireless transmision over very short distances, leading to in-body or on-body "networks" very much like miniature wireless LANs. In many cases, it suggests itself to link these micro-networks to other networks, eg. to allow remote monitoring of a patient. The use of wireless transmission opens up possibilities for all sorts of EMC (electromagnetic compatibility) problems, if not properly engineered. Potentially, the health support systems have to be regarded both as sources of unwanted RF fields and also as the object of extenal interference. In the extreme, we might have to consider new sorts of "remote bodily injury" without bodily contacts.

In a next step of this evolution, it could well be that people with some health risks are invited by incurances etc. to become permanently monitored so that the right kind of help may be provided with minimum delay (people not accepting could be forced to pay higher premiums). Going even further, "improving" physical capabilities and "being in the hand of experts" may be demanded by otherwise healthy people, eg. starting with VIPs in sports, show business, politics and corporate management.

In terms of an illustration, the reader is referred to **figure 2** again. It should be noted that, on a conceptual level, the equivalent of the data bases containing road and weather information is found with databases containing patient records. Thus, a prerequisite for the establishment of integrated health care and health maintenance systems (as described above) is the standardization of these records and their linking so that they appear (ultimately on a global scale) as one homogeneous (although distributed) data base. The implications of such a scheme have already been studied extensively in the framework of the Swiss TA activities [4].

Furthermore, we could imagine that features of **figure 3** be incorporated: why not have avatar-based medical doctors helping with everyday health problems? In turn, features of the application described in section 3.2 might well be incorporated, above all geographical tracking (eg. to lead emergency services to the right location).

Again, a lot of non-technical questions arise, eg:

- How far does one trust his/her own feelings of well-being in contrast to the measurements provided by implanted sensors and the recommendations of some health agent?
- Who is responsible in the case of malfunctioning?
- Have insurance companies the moral and/or legal right to force medical IT systems upon us through premium discrimination?
- etc.

Last but not least, we recognize that a *mechanism common to all the applications* discussed so far emerges: It is seldom the individual being able to decide in complete freedom how far to make use of IT, even when there are drawbacks involved - *there can be all sorts of moral, institutional, societal or political pressures and even financial incentives to jump on the IT wagon*.

3.5 E-government

The use of all sorts of information technologies (including traditional technologies like paper forms or the telegraph) by government is probably as old as any political structures. In fact, one of the most successful IT companies of all times has its roots with the mechanization of the census in the US (i.e. the well-known tabulation machines named after its inventor, *Herman Hollerith*). As far as the use of IT for the so-called back office functions[xiv] is concerned, governments and state agencies have always been more or less in line with other prime IT users as eg. the service industry. This type of IT use is usually characterized by the fact that the *interface* between government agencies and the individual citizen (and also its corporate clients) is still of a *conventional* type, ie. through letters, hard copy forms, using phones or fax machines, or through spoken dialogues at a counter.

Of course, with the advent of electronic communication, notably the Internet, it is quite natural that most governments consider its use for various applications where an *electronic interface* to the citizens and the corporate customers is feasible. With the advanced penetration of Internet access into private households (not to speak of the high density of corporate access), an important precondition is met in many industrialized countries so that proposals like *electronic voting (e-voting)* must be seriously considered. As this has recently been done in Switzerland in a quite comprehensive manner [36], we refrain from a description of futuristic systems (although this was originally planned). The recent assessment of e-voting as presented in [37] has clearly shown that such advanced IT applications are not limited by purely technical problems - we might even imagine people casting their votes through gadgets like those depicted in figure 2! In fact, the most important problems encountered are the following:

- Making the systems secure and trustworthy.
- Ensuring privacy.
- As recently written in [38], "the toughest part of providing public services online is not the technology, but the need to recast the back-room procedures of government so that they can receive and supply digital information in an efficient manner" - eg. a standardization of the databases for administering the rights to vote is necessary.

Last but not least, some experts fear that the replacement of the traditional formal act of voting by mechanisms used many times everyday (like E-Mail) might jeopardize or *trivialize* the so far serious decision processes of the present *political life*.

[xiv] Often, such IT applications are described as *electronic data processing (Elektronische Datenverarbeitung, EDV)*.

3.6 The networked household

Switzerland appears to belong to the leading countries when it comes to home automation: The well-known *Haus der Zukunft* in Hünenberg ZG [39] comprises a range of features many people assume will be widespread in a not too distant future in industrialized countries.

The starting point to comprehensive *home automation* is the fact that today's modern households contain dozens of electrical appliances from simple light-bulbs via all sorts of machines (eg. for washing, deep freezing, heating, lawn mowing, etc.) up to sophisticated multimedia home entertainement systems. Many of the higher-end appliances already contain microprocessors for stand-alone control, and their functionality is increasingly determined by software. Quite interestingly, many of the very low-end systems in the form of lamps are in a way remotely controllable for many decades already, and primitive forms of "intelligence" have been hardwired into electrical installations (eg. a lamp can be switched on and off from two different switches[xv]). On the other hand, most higher-end appliances are still stand-alone systems, although the step towards embedding them into a network for remote supervision, parameter setting, control and maintenance is rather small in purely technical terms; in terms of equipment cost, the networking add-ons might well be negligible when the steadily increasing performance/price ratio of microelectronics is considered. What then are the prime hurdles which must be overcome if an all-electronic, networked home will be accepted by the big public?

- First of all, there must be some very obvious *added value* – eg. lower energy consumption for heating and air conditioning, no cabling mess around the HiFi system, possibility to detect malfunctioning equipment (eg. a deep freezer) when away, remotely assisted repair without the need that maintenance people come along, etc.
- An integrated home automation and communication system must be *extremely reliable* and be designed in a way that individual appliances continue to work properly if the common parts of the system fail. *Ease of use* will be of utmost importance.
- The electronic home should not allow any forms of *electronic intrusion*.
- Both an *economy of scope* and an *economy of scale* can only be realized if there are comprehensive *standardization* agreements among the developpers of very different kinds of appliances on the one hand and the developpers of home control software on the other hand.

Once these hurdles are overcome, there is – technically speaking – no reason to extend the scenario shown in figure 2 to include all sorts of "intelligent appliances", as foreseen by prominent market researchers (eg. [40]) or trade associations like [41]. Such appliances could not only contain primitive electronic controllers with the possibility of remote parameter setting and interrogation of operating states, but with sophisticated software so that the appliances might make their own "decisions" or even become active and make suggestions to their human owners or to the electronic butler helping his human master to manage household duties. In fact, one could depict such a networked household as a hierarchical system of electronic agents, with the more primitive agents residing on primitive appliances, and the electronic butler(s) described in section 3.2 orchestrating the work of their slaves. It should be born in mind that electronics could not only "creep" into traditional appliances, but – in the extreme - into everyday throw-away articles like bean cans (in the form of electronic tags containing product information and links to websites with cooking recipes) as well.

[xv] People familiar with house wiring in Switzerland will recognize this as a "Schema 3" approach, ie. a solution to bring primitive intelligence into the house probably a hundred years old.

One of the most prominent initiatives in this field is the so-called *Things That Think (TTT)* consortium of the MIT media Lab [42], named after the well-known book by Neil Gershenfeld [43]. The consortium's almost all-embracing vision is quoted here since it summarizes very well what many researchers and companies are after:

The Things That Think Consortium brings together about 50 companies and 10 research groups to explore the migration of computation and communications out of conventional computers and into everyday objects. From smart toys that let kids develop devices that are meaningful for them, to intelligent spaces that help seniors live independently, to new musical instruments for virtuosic artists, to ultra-low-cost computers that provide rural market access in developing countries, this effort is moving computing off of the desktop and into the world, in order to make it relevant to the rest of the world. As this once-quirky vision matures into a commercial reality, the work of TTT is growing to encompass the integration of the bits of the digital world with the atoms of the physical world, on length scales from atomic nuclei to global networks.

3.7 A posthuman world?

The title of this section is borrowed from a book [44] where a fascinating, albeit – for the taste of this author – alarming future is described. In a way, such a world could be described as a merger of the scenarios described above. In addition to the technologies assumed more or less implicitly so far, we would have to consider new types of human/machine interaction, eg. through *haptic interfaces* (haptic interfaces are devices that allow human-machine interaction through force and touch), or using *gesture recognition* and machine-based *speech recognition/speech synthesis*. Another feature of this IT-soaked world is that the demarcation between times (and spaces) of work and those of leisure are much more blurred than today – a process, that probably started already many years ago, as exemplified by the mingling of show business and politics.

Since is completely beyond the possibilities of this report to describe various forms of "living in a virtual world", we restrict ourselves to a quote from [44] where the characteristics of posthuman beings are listed:

First, the posthuman view priviliges informational pattern over material instantiation, so that embodiment in a biological substrate is seen as an accident of history rather than an inevitability of life.

Second, the posthuman view considers consciousness, regarded as the seat of human identity in the Western tradition long before Descartes thought he was a mind thinking, as an epiphenomenon, as an evolutionary upstart trying to claim that it is the whole show when in actuality it is only a minor sideshow.

Third, the posthuman view thinks of the body as the original prosthesis we all learn to manipulate, so that extending or replacing the body with other prostheses becomes continuation of a process that began before we were born.

Fourth and most important, by these and other means, the posthuman view configures human being so that it can seamlessly articulated with intelligent machines. In the posthuman, there are no essential differences or absolute demarcation lines between bodily existence and computer simulation, cybernetic mechanism and biological organism, robot teleology and human goals.

Any more questions?

It remains to be seen whether this is a long term vision of our future – certainly, it is thought-provoking.

3.8 Commonalities and preliminary conclusions

In the introduction to this report, we foresaw common characteristics for the advanced IT applications presented above. In the following, we restrict ourselves to a *list of issues* not yet regarded comprehensive; also, the order does not necessarily indicate a sign of importance.

(1) We face ***two rather fundamental paradoxes*** that go along with an IT dominated human environment:

- Although politics and industry suggests that we are so-to-speak elevated to higher levels of personal and societal fulfillment, **individuals are** more and more **taken out of the control loops** associated with their life.
- Although many speak of a *digital* era, this attribute rather belongs to the low-level technologies underlying modern IT systems. On the other hand, on the application level, we get more and more away from symbolic – i.e. digital – communication (cf. sections 2.2 - 2.4!); there is a **return to an analog world** dominated by visual and possibly haptic information types often presented in a quite baroque style (as exemplified by many Web pages).

  There could be quite far-reaching consequences, for example in the education system, where Neil Postman argues as follows [45]: "...In introducing the personal computer to the classroom, we shall be breaking a four-hundred-year-old truce between the gregariousness and openness fostered by orality and the introspection and isolation fostered by the printed word.... Now comes the computer, carrying with it the banner of private learning and individual problem-solving. Will the widespread use of computers in the classroom defeat once and for all the claims of communal speech? Will the computer raise egocentrism to the status of a virtue? ..."

(2) *Human behaviour* and our *system of values* are influenced by the tools we use and the importance we attribute to them, or, as Neil Postman said in [45]: "...embedded in every tool is an ideological bias ...". With the increasing importance of PC-like appliances, people may eg. acquire a "cut and paste" and "undo / redo" mentality, thereby negatively impacting their sense of responsibility for nature, society and other human beings.

Generally speaking, both *cultural issues* and *gender issues* are at stake: Do eg. developpers unconciously "code" gender-specific features into their software, or is there a cultural bias in the design of a system? A related issue concerns *handicapped people*: How far are people with physical or mental problems excluded from receiving IT services?

(3) *Real and Virtual get more and more indistiguishable*, and in the extreme, our traditional understanding of personal identity being intimately tied to our body seems to disappear. In a way, there is a frankensteinian convergence of some trends in medicine (regarding the human body as a collection of replaceable component parts) on the one hand and fields like robotics and neuroinformatics implementing android-like artificial beings. Some experts even think of becoming immortal [15.1], a view not too far away from the visions presented in [44].

(4) We have to face quite *paradoxical effects* of unlimited electronic storage and instant communication: While the individual can be confronted anytime with a complete record of all his /her actions in the past, *history* is becoming an endangered species since (1) much more decisions are made on a day-to-day basis, without traces of strategic thinking, and (2) virtually all electronic media are subject to fast (as measured on

historic scales) decay both physically and logically (through sheer lack of access software).

(5) It is more and more recognized that many failures of conventional IT systems were due to a lack of grasping the specific characteristics and boundary conditions of a given application *domain*[xvi]. This issue gains considerably in importance when it comes to develop pervasive computing systems, since subsystems (agents) developed and installed by different authorities will cooperate on an ad-hoc basis. For such ad-hoc cooperation to be successfull, the cooperating subsystems must agree on a common *understanding beyond the syntactical level*, ie. they must rely on either previously established standards for the *semantics* and *pragmatics* involved, or else establish agreement on the fly (based on some meta-standards for semantics and pragmatics). All in all, there are now widespread efforts to establish standards for so-called *ontologies* (see eg. the overview given in www.semanticweb.org), to realize what has been termed by the WWW consortium the so-called *Semantic Web* (" the idea of having data on the web defined and linked in a way, that it can be used by machines - not just for display purposes, but for using it in various applications"). Of course, these efforts are undertaken predominantly in an Anglo-Saxon context, and there is some real danger that through these standardization efforts, we are faced with a dramatic *impoverishment in terms of culture and languages* moving into our increasingly mechanized world so to speak through the back door.

(6) Many new IT applications aim at providing services which are *personalized* and *situation dependent*. This calls for proper *identification of users* and identification of context, including *user location*. To achieve this, standardized technical means of (1) user identification and (2) determination of user location must be provided. Although no real standards exist so far for (1), there is already a host of possibilities beyond the well-known username/password approach, eg. smart cards in combination with some biometric features. Also, for a few years already, experiments have been undertaken with implanting electronic transponders for identification purposes[xvii]. For (2), use of the *GPS* or the planned European *Galileo* system [58] is obvious. The backside of these developments is the *traceability of virtually all human activities* on a personalized basis, with potentially a considerable *loss of privacy*.

(7) Individuals very often are not entirely free in their decisions whether to make use of IT systems or not. There can be *social and institutional pressures* to become a user, and in some cases, traditional ways of dealing with information are simply no longer available. As an illustration, we might consider the potential abolition of road signs if cars get equipped with electronic guidance systems.

(8) There is a marked increase in *dependence on IT systems* in everyday life. The *dependability* required from the *IT infrastructure* (ie. networks, servers, etc.) must be markedly improved.

(9) New types of *liability* questions emerge.

(10) New forms of *unwanted intrusion, forgery and other criminal acts* will occur. For example, the forced destruction of bodily implants through powerful RF radiation presents a new type of "bodily injury".

[xvi] Essentially, this contributed to very costly incidencies like eg. the well-publized failures of the Ariane rocket or the Mars explorer.
[xvii] This is already quite widespread for domestic animals.

(11) Wherever mobility is a prerequisite, or where cabling is not economically feasible, RF-based networks prevail. *New forms of very short range wireless communication* will be introduced, including links between in-body entities and external devices. Implicitly, it is assumed that many of the appliances operate on a 24 hour / 7 days a week basis, or to use a catchword, they are "always on".

Wherever wireless networks are involved, this results in a continuous "irrigation" by *RF fields*, and where human users are involved, there is the potential of interruption on a 24 hour basis.

(12) Beside the EMC problems already mentioned above, various *other environmental side effects exist*, for example:

- Many IT gadgets will be conceived as "give-aways" or "throw-aways" in the future, since one cannot primarily make money with the hardware, but rather with the software and the services. Since these gadgets are embedded in everyday objects deemed uncritical, unwanted substances could enter the environment if *disposal* is not controlled.
- Potentially, the "always on" nature of the operation of IT systems could pose *energy* supply problems unless much mor emphasis is put on the development of low power devices.
- Mobile devices are usually powered by *batteries*. With the pervasiveness of electronic systems, the ordered recycling could face new problems. Whether problems of this type are resolved through the introduction of alternative sources of power supply (such as miniature fuel cells) remains to be seen.

4 Key IT technologies

4.1 Introduction

There is no reason to assume that the phenomenal growth both in processing power and network bandwidth could not continue for another 2-3 decades[xviii], because new types of electronic and optical devices are already on the horizon (eg. molecular electronics, optical MEMS, etc). For digital electronic systems, Moore formulated his famous "law" in 1965 that their performance would roughly double evry 18 months. It is surprising for how long a time Moore's prediction (in fact a form of an "educated guess" [46]) is already valid, as shown in **figure 4**. The reason for this may certainly not be found with some law in the natural sciences; rather, Moore's law became the yardstick of the designers of advanced electronic systems (a sort of self-fulfilling prophecy).

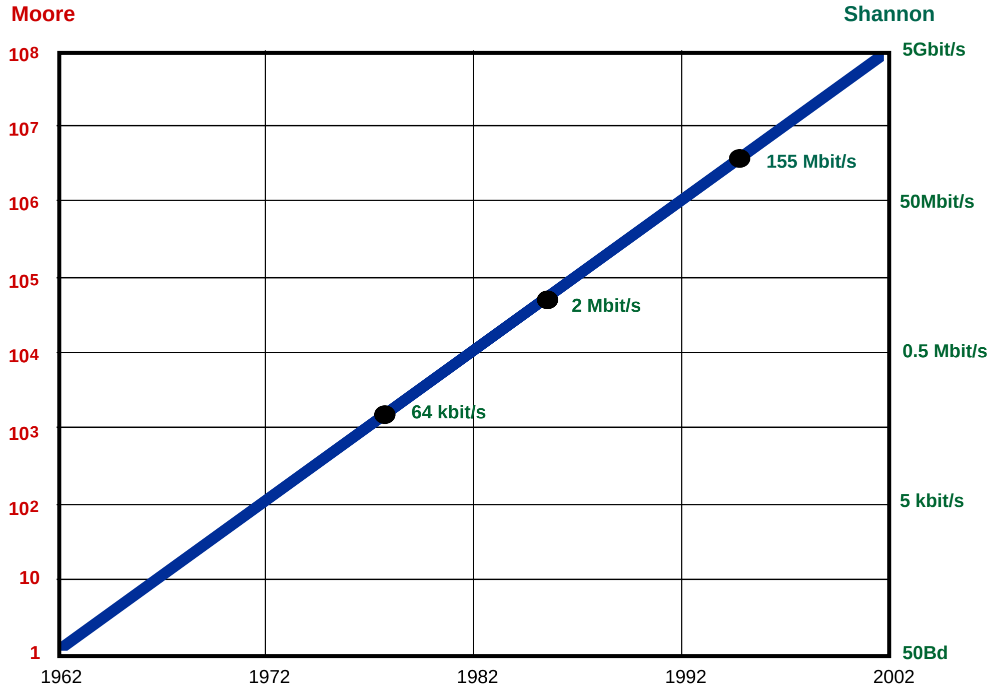

Figure 4 Performance of digital electronics (computer speed and storage density, scale denoted by "Moore") and digital transmission (bit rate on typical long-haul links, scale denoted by "Shannon").

Although *Moore* never considered digital transmission, it is another surprise that his law roughly reflects the advances made for digital transmission as well, when the last four decades are taken as a basis. While progress in the first two decades was somewhat slower for transmission, this was compensated through more recent developments with optical systems (see also figure 7). We have used the name *Shannon* in figure 4 because his well-known findings about channel capacity serves as a sort of yardstick for transmission engineers just as Moore's law does for computer engineers.

These (quantitative) developments are truly impressive and hardly matched by any other technological field; nevertheless, it should not be forgotten that figure 4 just relates to the *base*

[xviii] This hypothesis is valid for technologies deployed in commercial products, since there is usually a lead-time between the first demonstration of a new technological approach in a research lab and the massive deployment of this technology on a commercial scale. This lead time may range anywhere between, say, 5 years for improvements in standard electronic circuits, and 20 years for radically new technologies like hybrid electronic/biological structures.

technologies and the primitive building blocks, and not to the complex *platforms* built with these *components* and the applications supported by the platforms. By *platform*, technical systems like a PC (ie. its hardware and operating system) or the data transfer core of the Internet are meant. As **figure 5** shows, this reduced development and diffusion speed is due to the relevance of non-technical aspects on the higher layers of a system, notably in relation to the functionality and human-computer-interaction issues. In the extreme, it may take a whole generation to "digest" the blessings of new IT applications.

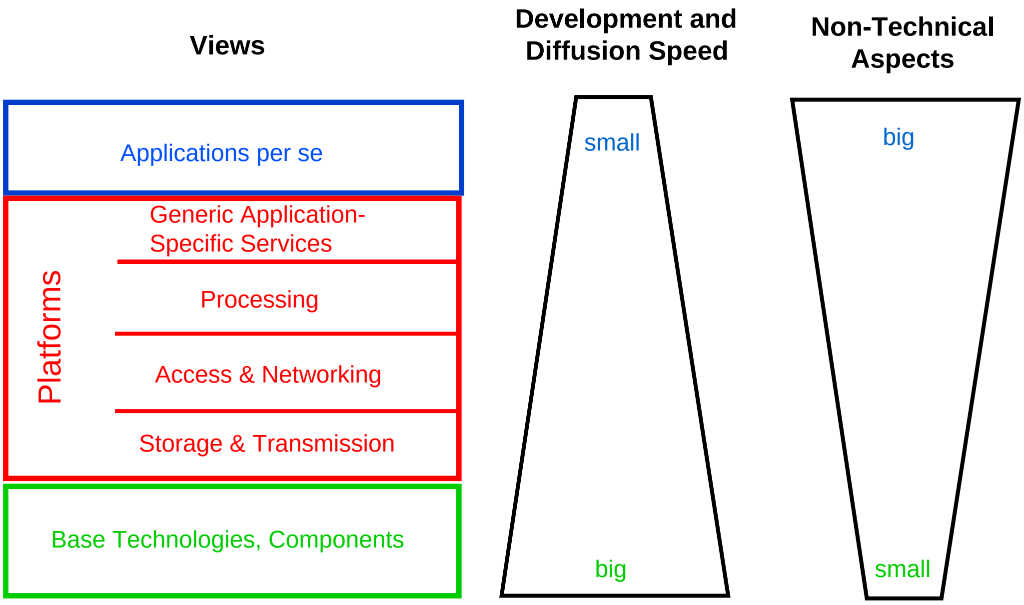

Figure 5 Different views on a technical system in relation to non-technical aspects and the development and diffusion speed.

Moreover, even most laypersons know very well that the "progress" really *perceived by users* does by no means exhibit such an astounding rate as shown in figure 4. The author presumes that the well-known law by *Weber* and *Fechner* for psychphysics applies here as well, in that the *perceived progress* is proportional to the *logarithm* of some physical measure - originally sound pressure and applied here to eg. no. of transistors on a chip.

Illustrations like figure 4 with their log-scale, in conjunction with the prediction that the performance of the base technologies continues to increase for another 10-20 years, may seduce us into thinking that the next two decades could just be some sort of replica of the eighties and nineties: steadily improving price/performance for PCs, decreasing cost for communication, larger bandwiths, etc. This neglects the fact that engineers and entrepreneurs are faced today with prospects radically different from those of the sixties and seventies, as illustrated in **figure 6**.

Evidently, this figure sheds new light on the importance of *Technology Assessment* for IT: If there are indeed IT applications which are both technically and economically feasible but would nevertheless be neither useful nor desirable (for whatever reason) - who should decide on whether such applications should be put on the market? This is probably one of the key questions to be discussed before further studies are initiated!

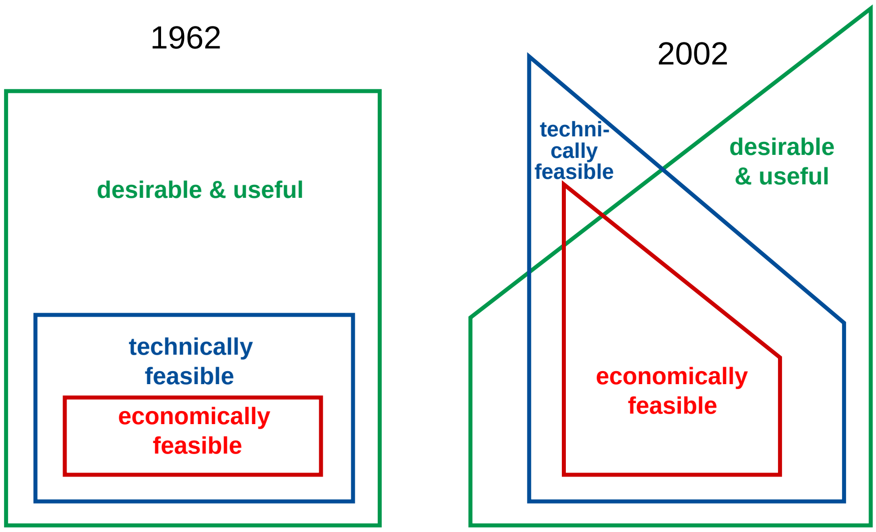

Figure 6 Engineers and enterpreneurs face entirely different prospects in 1962 and 2002.

In the following treatment of specific technology sectors, some of these sectors will (for the time being) be described in a very cursory manner only.

4.2 Information caption and reproduction

We start with summarizing the state of the art in an area which has by no means a prominent position when achievements in technology are made public (in contrast to eg. the sustained publicity for supercomputing). It should have become clear from the descriptions in chapter 3 that a broad range of *sensors* and *actuators* is necessary to embed computers in the different environments. We use the terms *sensors* and *actuators* in a broad, generic sense, so that traditional *input/output devices* are covered as well.

The *sensor/actuator technology sector* has seen spectacular developments in the last 10-20 years. These developments can be characterized with the following points:

- Miniaturization and integration with signal processing electronics on the same chip, yielding so-called *smart sensors*.
- Much broader scope in terms of physical/chemical quantities involved.
- Mass production, coupled with significant prize reductions for certain devices.

Some examples should suffice to illustrate these developments:

- Miniature as well as very large flat screens [47].
- Various haptic interfaces.
- Chemical environmental sensing arrays for drinking water analysis, size 25 mm2, measuring 9 different indicators for ater quality (Siemens Environmental Systems, UK).
- Face recognition and various other biometric identification approaches.
- Output device for odors developed by one of the leading companies producing aromatic substances

4.3 Processing

- Processing power: extrapolate from figure 4!
- New design paradigms to cope with growing complexity (eg. genetic programming); see also section 4.13.
- Biotechnologies and hybrid (bio/electro) technologies.
- New processing paradigms (eg. self-learning systems, based on new insights about perception and information processing in living beings - ie. learning from physiology and neurology).

4.4 Storage

1 Terabyte storage should be available in some years at about 300 SFr.

4.5 Compression

- Speech: down to 8 kbit/s. going even lower is feasible, but some features like speaker recognition may get lost.
- Video: High resolution may be obtained at approx. 2 ... 8 Mbit/s, while "head and shoulder" type moving images (eg. for a videophone) may be transmitted at 64 kbit/s.

4.6 Recognition, transformation, synthesis

- Speech synthesis (TTS): Well advanced, commercially available. A lot of work still needs to be done in "personalizing" artificial voices.
- Speech recognition: Commercially successfull only for very limited contexts. A lot of research is still necessary to analyze fluent spoken languages without training the recognizer for particular speakers.
- Speaker recognition: Not too much progress lately.
- Image analysis (eg. for medical applications)
- etc.

4.7 Transmission

In stark contrast to the sixties and seventies, transmission cost today (as long as we restrict ourselbes to bit rates up to eg. 2 Mbit/s per connection) is almost free! Dense Wavelength Divison Multiplexing (DWDM) is the technology of choice for the backbone network.

- see figure 4 and **figure 7**.

4.8 Switching and networking

- Trend towards all-optical networks.
- Aiming at Terabit/s throughputs.
- Whether IP is the technology of choice at very high speeds remains to be seen.

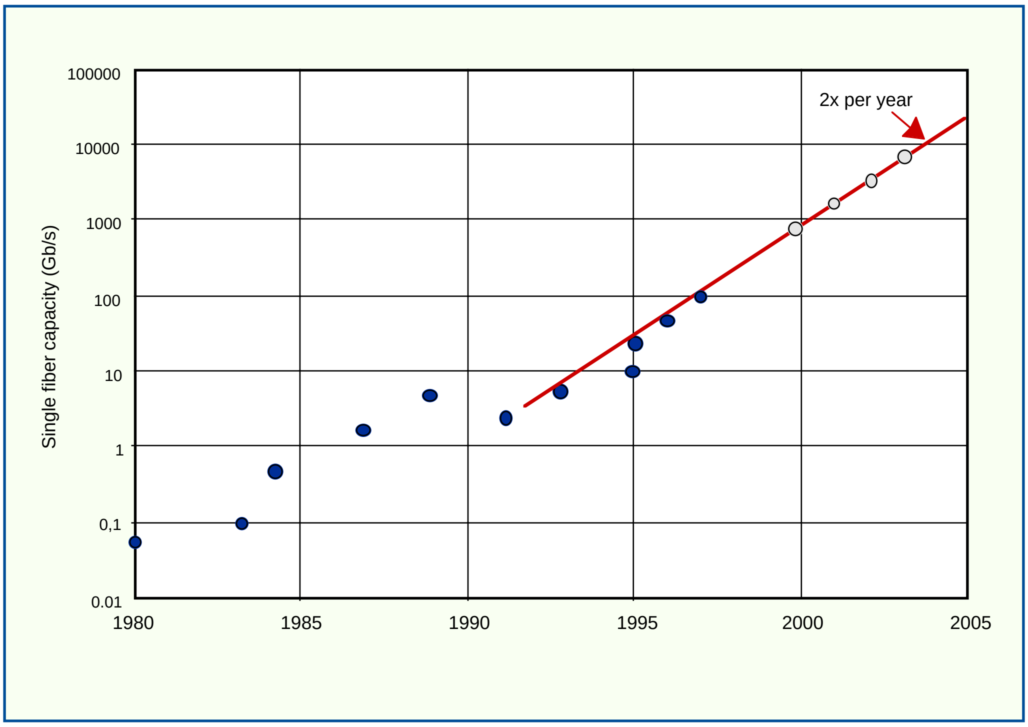

Figure 7 Recent advances in optical transmission.

4.9 Security technologies

- Many technologies in principle readily available.
- However, legal & organizational problems must be overcome for broad penetration.

4.10 Information retrieval and data mining

- Search technologies for individual users
- Data mining
- The *Semantic Web* [49].

4.11 Location finding

- The present mobile phone systems allow for rather crude location finding (down to the cell level, ie. with an accuracy of some km).
- GPS presently provides very precise location finding services. One limitation, however, is its indoor use; also, due to its US military origin, availability in crisis times may be at risk.
- The EU has decided to implement the so-called Galileo system similar to GPS [59].

4.12 Packaging

- wearable devices
- implantable devices
- "throw-away" technologies

4.13 Mastering complexity

Engineers are facing today the problem of mastering an enormous complexity on all levels of the systems they build, ie. at the level of individual components and subsystems and also at system or application level. This may be very well illustrated by what an expert of the Intel CAD laboratories (Manpreet S. Khaira) told an MIT audience about 4 years ago:

Is a processor with a billion transistors that executes 100 BIPS (Billion Instructions Per Sec) possible? This talk describes what the Micro-2010 would be like and the challenges involved in its design.

We expect all aspects of life to be impacted by Micro-2010. Applications like tele-presence, augmented reality, and reality animation indicate that such microprocessor performance will be a critical enabling technology. ......

Micro-2010 will run at a frequency in excess of 4 GigaHertz. Getting to that level of performance while meeting the power budget (<100 Watts) and area budget (<$500 cost) will require breakthroughs in circuit design methodologies, CAD tools and technologies, and process technology. If current design methodology trends were to continue, the design team for Micro-2010 would need to include every single VLSI design engineer graduating after 2005! ***So major breakthroughs in design methodology, enabled by a new generation of CAD tools, are essential if such designs are to become a reality.***

The semiconductor process in 2010 will have a minimum feature size less than 0.1 micron and the transistors a gate oxide thickness of less than 10 layers of Silicon Dioxide molecules. These dimensions are smaller than the wavelength of visible light and will require major breakthroughs in process technology. And new error control ideas are needed: given the expected volume of shipment of Micro-2010, major design errors cannot be tolerated, but avoiding errata in a 1 Billion Transistor design is practically impossible.

It is no wonder that engineers have started to seriously consider *alternatives to the classical computer architectures*. Some of them, notably *artificial neural networks*, are already deployed in many commercial products (eg. in speech synthesis and speech recognition); other approaches may still be of a speculative nature. However, many of the new concepts have in common that "engineers are learning from nature", ie. their *bio-inspired systems* start to mimick the adaptive and cognitive capabilities found for information processing in living beings. Such approaches are not only used at the lower (eg. electronic circuit) levels, but by software engineers at higher system levels as well, eg. in the form of so-called *autonomous agents*. Research is even going into concepts of *social order in multiagent systems* [48].

In a way, there appear two seemingly disparate processes leading to the construction of intelligent, affective, emotional, ..., machines:

(1) The very old urge of human beings to construct artificial entitities exhibiting their own capabilities, perhaps to be used as the ultimate tool (i.e. to expand one's own power). A very well-known example is given by the *Homunculus* as found in *Goethe's Faust II*.

(2) The very new insight of engineers that the IT devices they are supposed to develop cannot be properly designed by traditional engineering methodes because of their enormous complexity (i.e. engineers resort to construct self-organizing (autopietic) systems; they restrict themselves to develop the metadesign).

4.14 Market issues, standardization and other imponderabilities

The very nature of most IT applications – ie. their property that usually many machines, possibly provided by different manufacturers, cooperate in realizing certain services - that a host of *standards* is necessary. Standards are eg. needed to define the *data* involved in terms of syntax and semantics, to specify *protocols* for data exchange, to describe the *representation* of data (eg. video, audio, graphics) when offered to the human user, for *naming* and *addressing*, etc. As described very well in [60], there is an almost perpetual struggle between the insight of manufacturers that their products should agree to some international standard, and the selfish behaviour of the same people when it comes to grasp a potentially large market share by enforcing their own "industry standard" on customers. Also, there is the legitimate fear that standards may prevent the use of more advanced technologies and thus render products too expensive.

Decades of experience in the IT field have shown over and over again that these standardization and market issues make it extremely difficult to predict developments beyond a time frame of eg. 5 years, although this is fairly well possible for the underlying technologies as shown in previous sections. In addition, success or failure of new products depends critically on timing, price and even some fashion trends.

5 Basic IT impacts

5.1 Overview, taxonomy

As we have shown in chapters 2 and 3, and partly in chapter 4 as well, modern information technologies have the potential to permeate not only our professional and business world rather thoroughly, but our personal life as well. Since our way of communication and information handling is **the** outstanding characteristic distinguishing us from other beings, significant changes in the apparatus (viz. organs) and the mechanisms of perception, thinking, feeling, memory and communication are bound to have a profound impact on our civilization and culture. Some of these effects can readily be perceived or imagined, be it with a positive flavour (in the sense that many people think of "progress" has been made, eg. when profiting from the widespread availability of e-mail services) or with a negative scent (eg. when we consider possible intrusions of privacy). In many cases, the assessment of information technologies will, however, show *ambivalent* characteristics, and a need emerges to channel future developments such that the positive effects prevail (ie. through establishing appropriate laws). This situation is well known almost since the first commercial applications of electronic data processing, as eg. an early piece of fiction [51] shows, or the publications by Karl Steinbuch[xix]. As a consequence, a wealth of publications on such more or less straightforward issues exists, and there are many activities to get people more aware of the issues, eg. through courses at higher education levels or through professional activities (eg. the Special Interest Group on Computers and Society of ACM, SIGCAS).

Nevertheless, the author is convinced that subtle mechanisms exist whereby possibly more profound and far-reaching changes could result for society and culture, essentially because the behaviour of the individual is gradually changing under the influence of the newly acquired tools. This is well illustrated by an intriguing remark made by Kissinger in his memoirs [52] when he remarked that the advent of reliable, secure long-distance communication is seducing politicians and diplomats into neglecting strategic thinking ("whenever a problem in the deliberations arises, call the President")[xx].

Last but not least, we should not forget that IT is ultimately based on physical devices and plants, where neither the production nor the ultimate disposal are necessarily *environment*-friendly. Also, many IT systems depend more and more on RF-type data transmission, a field already hotly debated between the interested industry and people feeling uneasy about the effects of *non-ionizing radiation*. Finally, we have to consider that *usage patterns* might be drastically changing (eg. the "always on" assumption of pervasive computing), with consequences for energy consumption, battery recycling, duration of RF exposure, etc.

Thus, we will differentiate between

(a) The "classic" study field found in what has recently been termed *Cyberethics* [13], eg. grouped in fields like IT vs. democracy, free speech and content control, intellectual property, privacy, security, dependability of the IT infrastructure, codes of conduct for IT professionals, the digital divide, etc. This field will be described in somewhat more detail in section 5.2.

(b) *New insights* gained by explicitly considering IT when re-investigating the established (or adequately modified) models so far used by philosophers or sociologists in their analysis of *human communication, knowledge handling* and *behaviour in general*. We will try to sketch such issues in section 5.3.

[xix] Eg. Steinbuch, Karl: *Automat und Mensch: auf dem Weg zu einer kybernetischen Anthropologie, Berlin 1971*; *Masslos informiert: die Enteignung unseres Denkens,* München 1978.

[xx] As a consequence, history is threatened as well, since no records of defining a strategy are produced.

(c) *Environmental side effects* associated with the ubiquity of IT, ie. in relation to production, deployment, operation and recycling of IT devices and installations, as detailed in section 5.4.

5.2 *Cyberethics*: classical ethical and legal issues associated with IT

As we have seen in sections 2.4 and 2.5, many aspects of our civilization and our culture are closely related to information handling. Thus, it is no wonder that many laws contain rules about information handling, prescribing eg. specific contractual forms or defining deadlines. Some of these rules are even directly influenced by technicalities, eg. when demanding that an envelope be sealed or each page of a document be initialled by the contractual parties. Thus, it is rather obvious that the introduction of new media for documents and new mechanisms for communication is calling for changes in the legal framework. In turn, the use of IT in business and in legal proceedings is calling for additional technical means to meet established requirements like protection of privacy, authentication, etc. While many of these problems can be tackled in a rather straightforward manner, there are also more subtle issues, eg. where unwanted side-effects of a new technology only become apparent with the widespread deployment of some applications. Very often, there is also considerable leeway how far the use of new tools should be regulated by laws or directions[xxi].

All in all, however, considerable work has already been undertaken in various countries and by many institutions, and there exist even international organizations dealing with these issues. The most notable activities are found as follows:

International organizations

- IFIP (International Federation for Information Processing), a sub-unit of the UN, mainly with its Technical Committee (TC) 9: *Relationship between Computers and Society*[xxii] (there are woking groups on Computers and Work, Social Accountability, Home Oriented Informatics and Telematics, Social Implications of Computers in Developing Countries, Applications and Social Implications of Virtual Worlds, Information Technology: Misuse and The Law, and History of Computing).

Professional societies

- ACM (Association for Computing Machinery), especially with its Special Interest Group *Computers and Society* (SIGCAS)[xxiii].
- IEEE (Institute of Electrical and Electronics Engineers), where in particular the Society on *Social Implications of Technology*[xxiv] is active in our field. For example, this society organizes an international conference on the topic treated in this report (2002 International Symposium on Technology and Society (ISTAS'02): Social Implications of Information and Communication Technology. Raleigh, North Carolina, USA, June 6-8, 2002).

Both societies have periodic publications (i.e. *Computers & Society* by ACM SIGCAS and the IEEE *Technology and Society* Magazine).

Technology assessment and research institutions

See the comprehensive list available at:

http://www.itas.fzk.de/tadb/dbase/tainst/list.asp?lang=e&geo_id=1

[xxi] The recent animated discussion about the silent compartments on trains (Ruhewagen) may serve as an illustration.
[xxii] See http://www.ifip.or.at/tcs.htm#tc9
[xxiii] See http://www.acm.org/sigcas/
[xxiv] See http://radburn.rutgers.edu/andrews/projects/ssit/default.htm

In the framework of these activities, a more or less generally accepted taxonomy of legal, social and ethical issues has emerged as follows [13]:

(1) Ethical Values and Conceptual Frameworks.

(2) Free Speech and Content Control.

(3) Intellectual Property.

(4) Privacy.

(5) Security.

(6) Professional Ethics and Codes of Conduct.

The author would like to add the following points:

(7) The so-called Digital Divide, both within a country or a region, and seen globally.

(8) Education.

(9) Gender (see eg. [53]).

(10) Culture.

(11) Handicapped people.

(12) Dependability and Trustworthyness of the IT Infrastructure.

Thus, there is a wealth of information already available regarding the classical ethical and legal issues associated with IT – a mine to be exploited when it comes to undertake specific studies for the Swiss context, eg. when TA-Swiss aims to trigger or contribute to specific law-making activities.

5.3 Philosophical and social issues in an IT-dominated world

In chapter 2, we have essentially shown that our way of handling information and how humans communicate is intimately tied to our civilization and our culture. We may argue *that Information Technologies* profoundly alter the *language* we are using when *communicating* with other people and with our environment. Seen that way, the question arises how the many well established theories and models (exemplified by eg. [6], [54] and the works of Luhmann) about human communication and human behaviour in society and nature would have to be reshaped and re-analyzed, possibly leading to new behavioural patterns and even new pathologies.

5.4 Environmental side-effects

As described in section 2.6 and illustrated with some applications in chapter 3, we may well be at the verge of a massive proliferation of electronic gadgets, attached to all sorts of things, worn by people wherever they move, and "always on". Since many of these gadgets will purposely be hidden in their physical surroundings, and because their low cost could give rise to a throw-away attitude, we may be faced with massive environmental problems and new hazards related to non-ionizing radiation. Therefore, in section 6.4, a TA study is proposed aiming at a comprehensive compilation of environmental side-effects.

6 Proposals for a systematic assessment of Information Technologies

6.1 Introduction, aims

Although we have questioned notions like *information society* and *knowledge society*, it has become clear in the present study that many issues related to the massive deployment of IT merit attention. It is certainly true what has been stated in [55]:

> *We are entering a generation marked by globalization and ubiquitous computing. The second generation of computer ethics, therefore, must be an era of 'global information ethics'. The stakes are much higher, and consequently considerations and applications of Information Ethics must be broader, more profound and above all effective in helping to realize a democratic and empowering technology rather than an enslaving and debilitating one.*

As we have seen in chapter 5, we may essentially discern between three different fields of IT assessment:

6.2 Ethical and legal issues

It appears worthwile to scan the vast available literature first before going on with specific projects. Based on this analysis, ***we propose to develop a generic TA checklist for IT systems***, possibly along the structures shown in section 5.2. Such a checklist would have essentially to contain the following elements:

- A list of issues to be probed in IT projects, in order to assess the potential risks and impacts before substantial investments are made.
- References to the available literature so that studies already made for similar contexts can be used and there is no unnecessary duplication of work.

The author of this study is convinced that such a checklist would not only be very helpful for the various IT project bodies and the related investors, it would also allow TA-SWISS to establish well-structured relations with the field.

Priority could be given to TA-studies for areas where new IT-based approaches and their impact are of broad public interest, and where considerable financial involvement of the public sector is at stake:

- Education sector, with projects like *Schulen ans Netz* and *Virtueller Campus Schweiz*
- E-Government, with initiatives like *E-Voting* and *Guichet Virtuel*.

Of course, the abovementioned checklist would guide us in giving these studies a more or less standard structure.

6.3 Philosophy and social sciences

A study following the initial thoughts presented in sections 2.5, 5.1 (b) and 5.2 is proposed. The focal point of such a study should be what has already been stated in chapter 1: **Our challenge will be how far humans let bypass themselves by mechanized means of information processing and decision making**!

The plan of the Schweizerische Akademie für Geisteswissenschaften to devote its 2003 research seminar to issues related to the information society might be a good starting point for a focused research program in our country.

6.4 Environmental issues

It is becoming fairly clear what "shape" Pervasive Computing could take, ie. in terms of the number of "gadgets" carried along by people, how these gadgets would be powered, what their lifetime could be, and how the many devices would be networked. Thus, it would be very interesting to study what has been described above as *environmental side-effects for Pervasive Computing*, ie.:

- RF radiation and its impact on living beings (it should be noted that some new effects have to be investigated, since very-short-range RF communication is involved where eg. near-field antenna patterns have to be considered, etc.).
- RF radiation and its impact on electronic systems (EMC problems).
- Energy consumption, environmental problems related with batteries or new types of power supplies (eg. miniature fuel cells).
- Environmental problems related to manufacturing of new types of IT devices.
- Environmental problems related to the recycling or disposal of new types of IT devices.
- Hazards specifically associated with implanted IT devices.
- Health risks associated with the manufacturing and deployment of bioelectronic devices.

Beyond listing, defining and describing these problems with their qualitative and quantitative aspects, an assessment of the legal situation in Switzerland is necessary, with a view to make politicians aware of regulatory actions needed. In fact, such a study is already under way[xxv]; its results are expected for the first half of 2003.

[xxv] Its title is: Le principe de précaution dans la societé de l'information.

7 Conclusions

We have shown that the present rapid development and deployment of IT based systems and applications has the potential to change our system of values and our behaviour in a fundamental way. Although this is in principle a process reaching back in time well beyond the invention of the computer and the introduction of the Internet, both the speed and the pervasiveness of the deployment of Information Technologies may well overtax our abilities to digest the changes culturally and to draw the appropriate conclusions for law-making initiatives. Nevertheless, using a narrative approach in describing possible developments and analyzing these in a historical context has allowed us to make several proposals for the future activities of TA-Swiss. Beyond that, we have identified some fundamental issues which cannot be resolved by the usual TA studies. Rather, we are convinced that the philosophical and social sciences are challenged to establish a concerted effort in analyzing the IT impacts[xxvi].

[xxvi] This could eg. be the topic of a future NCCR program.

Appendix A: Abbreviations

ACM	Association for Computing Machinery
AI	Artificial Intelligence
CASS	Conférence des acdémies scientifiques suisses
CD-ROM	Compact Disk (based) Random Access Memory
CSCW	Computer Supported Cooperative Work
DWDM	Dense Wavelength Division Multiplexing
ECG	Electrocardiogram
EDV	Elektronische Datenverarbeitung
EEG	Electroencephalogram
EMC	Electromagnetic Compatibility
EMV	Elektromagnetische Verträglichkeit (see also EMC)
GPS	Global Positioning System
HCI	Human-Computer Interaction
ICT	Information & Communication Technologies
IEEE	Institute of Electrical and Electronics Engineers
IFIP	International Federation for Information Processing
IT	Information Technology
MEMS	Micro-ElectroMechanical Systems
MIT	Massachusetts Institute of Technology
MRI	Magnetic Resonance Imaging
PARC	Palo Alto Research Center
PC	Personal Computer
RF	Radio Frequency
SAGW	Schweizerische Akademie der Geisteswissenschaften
SATW	Schweizerische Akademie der Technischen Wissenschaften
SSTC	Swiss Science and Technology Council (in German: SWTR)
SWTR	Schweizerischer Wissenschafts- und Technologierat (in English: SSTC)
TA	Technology Assessment
TC	Technical Committee
TTS	Text-to-Speech Systems
TTT	THings That Think
TV	Televison

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Appendix C: Concepts for Human Information Handling

Figure C.1 and **C.2** put the discussion of chapter 2 in a more general context. **Figure C.1** takes the view that different *process steps* are involved from capturing signals from the environment down to putting the extracted information into a personal context and taking appropriate action.

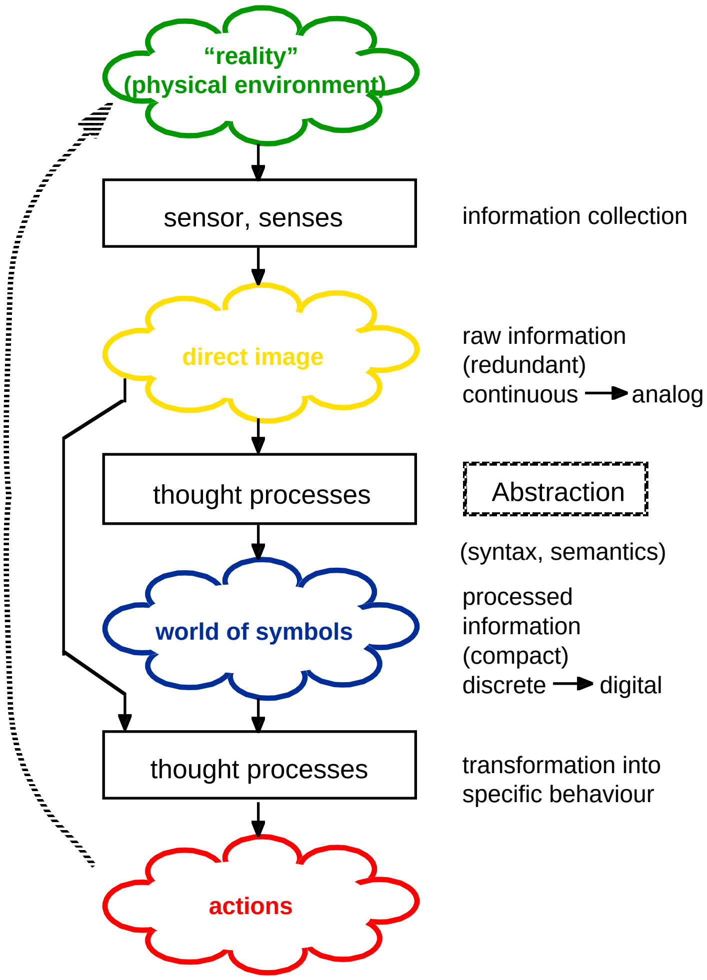

Figure C.1 Human cognition and information processing

In **figure C.2**, we use a hierarchical, layered model to summarize our descriptions presented in chapter 2.

Data ⇒ Information ⇒ Knowledge ⇒ Action

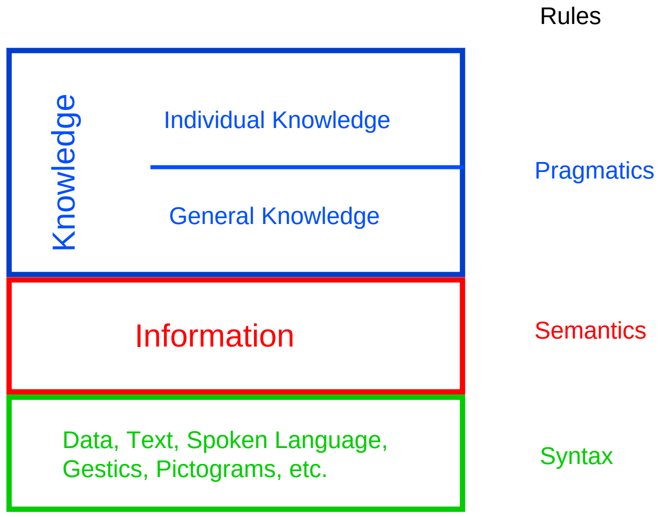

Figure C.2 A layered hierarchical model for information