Preface

"In the year 2000 we will travel in hypersonic airplanes, people will live on the moon and our vehicles will be fueled by atomic energy." As young children in the 1960s, this is how we imagined this symbolic milestone.

We believed that the 21st century would open a bright future brought about by beneficial technology, technology which had already been introduced to us at the time.

Yet, the year 2000 has now passed. The 21st century is here but this vision, which seemed to be shared by many people, almost belongs to kitsch iconography. Things have not changed in numerous areas: we still drive vehicles equipped with internal combustion engines, whose technology is more than 110 years old, airplanes travel once again at more economical speeds, there are energy crises, and the fear which nuclear energy raises has restricted any initiative for new applications – although high-speed trains draw their energy from nuclear fission.

The end of the 30 year boom period after World War II marked the end of major innovative and exploratory programs: the conquest of space was limited to the nearby planets, while Aerotrain, Concorde and other vertical take-off and landing airplanes were sacrificed for profitability. It became difficult to distinguish between scientific and technical vocations. Would technological perspectives become blocked? Would our research laboratories and departments become short of productive and profitable ideas in order to exclusively invest in quantative hyper-productivity that some people are already interpreting as destined to compensate for a lack in innovations?

However, ignoring the technological progress of the last 40 years would be iniquitous: the evolution of computing and of digital technology is conclusive evidence of the progress which has been made. From a few dozen reliable machines and with relative progress, we have entered into a market which is made up of billions of units. Components of machines have been reduced in size by a factor of 10,000 and their cost has decreased by the same proportions (a gigabit of memory is 5,000 times less expensive today than it was in 1970). Computers are everywhere nowadays, to the point where we no longer notice them when they are present.

Progress (the most envious industrialists will talk of simple industrial development) has continually been made by exploiting and perfecting the methods and processes of the most capitalist sector in history: the silicon industry. This is an industry whose evolution seems so predictable, so inevitable, that it has been characterized by a 40 year old exponential law, Moore's Law, which states that the number of transistors that make up microprocessors doubles every two years because these transistors become twice as small in the equivalent timescale.

However, this growth cannot go on forever and at this rate the limit of the performances of silicon components will be reached in 10-12 years at most. At that time, the current manufacturing processes will have arrived at the extremes of the world of traditional physics, the world of ordinary objects possessing mass, size, shape and contact properties. We will have arrived at a domain where the laws of quantum physics reign, laws which are so out of the ordinary and so different that they will call into question our industrial and technical know-how.

What will then be the perspectives for the development of our computers? What will the world of computing become in 15 years' time?

The anecdote about the year 2000 reminds us how dangerous it is to make this type of prediction. Nevertheless, this issue is far from being a simple puerile game. In numerous sectors of the economy and for many companies, 10, 12 or 15 years constitutes a significant time reference for the world of computing. Today, for example, the development process of the pharmaceutical industry considers information systems as the key to success in the development of new medicines, which is expected to have a project plan of between 10 and 15 years. This means that economic success will rest on the ability to understand and domesticate trends and innovations regarding technology, systems and organization. The aeronautical industry also considers project plans of 10 to 15 years and considers computing to play a vital role in this sector of the economy. We could also add the car industry and many other services such as banking and insurance for which information systems are no longer back-office production activities but rather real working partners. This timescale of 10 to 12 years also translates into more jobs available on the job market. We have only too often taken part in mass production campaigns in directing young people towards new industries, which five to seven years later proved to be too late in relation to the needs of the market.

As far as the next 10 years are concerned, by continuously pushing the limits of technology and the miniaturization of components further and further, it is the concept of the information system which changes: from processing, which is exclusively centered on the user, computing is becoming swarm intelligence. Since this technology currently makes it possible to produce tiny computers, it gives almost all objects from everyday life the capability of starting a spontaneous exchange of information without any interaction with the user.

In approximately 10 years computing will have become fundamentally different: it will not change gradually as has been the case for the last 15 years, but it will change dramatically for reasons which affect its deepest roots. Semi-conductors have been favored in the progress of computers over the last half-century. The simplest principle of thought is as follows: since it has been admitted that in 10-12 years, when hardware technology has evolved to its physical limits, then either our computers will have definitively reached their asymptotic power and future progress will be linked to innovative applications (this is the conservative or pessimistic view), or a replacement technology will emerge which will enable a joint continuation of hardware performance and progress in terms of application.

If the conservative point of view is acceptable on an intellectual and philosophical level, it will be difficult to accept for one of the most powerful sectors of the economy: to consider a ceiling in terms of the performance of components would mean entering into a market of hyper-competition where the only solution would be fatal price erosion. This is a situation similar to that of cathode-ray television screens and the textile industry, but with more serious consequences for the global economy given the volume of activity.

The hope therefore rests within replacement technology and the nanotechnology industry which will make the molecules itself. These molecules will be the base elements of future electronic circuits. For both economical and technical reasons, their development is considered as inevitable.

The first magnetic components (i.e. on the scale of the molecule where the rules of quantum physics reign) have already been created in laboratories. Conscious of the vital character of this technology, the large operators of the silicon industry are also amongst the leading pioneers of this domain. They are exploring carbon nanotubes in particular.

However, what can be created on the testing beds of laboratories on a unitary scale is still far from being applied to complex circuits and even less so as regards any possibility of industrial production. The main reason is the difficulty in the integration of several hundred million of these devices within the same chip like current microprocessors (remember that by 2015 there will be 15 billion transistors integrated onto one single chip).

Nanotechnology, in the historical sense of the term, does not simply consist of creating objects with molecular dimensions. The basic idea of the principle of self-organization into complex systems comes from life sciences. This means that the basic building blocks, according to the destination of the device, are capable of assembling themselves from just one simple external macroscopic instruction into a more complex device. This is the main challenge and the source of polemic debates[1] which scientists and technologists have to deal with today.

Given that nature can construct such machines and that molecular biology and genetic engineering have already investigated these principles, another path has opened for the computers of the future: that of organic molecular electronics which exploits a living material, such as a protein molecule, and reuses it in an artificial environment in order to ensure a processing or memory function.

The make-up of computers of the next decade is experiencing a transition period where everything is undergoing a process of change. New processors stemming from the conventional generation of semi-conductors are progressively going to be composed of structures coming from organic technology or from the first molecular components. Memory will follow the same path of miniaturization on a molecular scale. Mass storage devices will store information in three dimensions (in proteins or in crystals) which up until now has been stored in two dimensions, on the surface of an optical or magnetic disk. However, these magnetic disks, just like silicon components, will continue to be improved by exploiting quantum phenomena. Mobility has introduced another requirement: that of energetic autonomy. Chemical batteries will be produced flat, just like a sheet of paper, lighter and more powerful. The new generation of swarm and communicating devices will explore new approaches: supplying information using ATP molecules[2] (similar to living things), micro-internal combustion engines, or even nuclear micro-batteries which are far removed from conventional batteries. These swarm micro-objects, which are present in the diversity of the real world, are capable of communicating amongst themselves and with their users in the most natural way possible. This means that the interfaces

1 This debate amongst scientists hides another emerging debate concerning the general public. Just like GMOs, nanotechnology can be part of another controversial subject between researchers and the general public. The idea of designing tiny entities capable of reproducing themselves and which can escape from the control of their designers has been installing fear amongst people for some time now. The most futuristic practical applications illustrated in this book, which are part of current research trends, are still far from posing this type of risk. However, efforts to popularize these future applications must be undertaken if we do not want society to condemn emerging science through sheer ignorance of the real stakes and risks.

2 A reversible molecular turbine.

between the user and the machine will no longer be limited to keyboards, mice and screens but will use our five senses. Certain interfaces will not use the five senses since the neural system and telepathic control are already a reality. It is not the eye that sees, but the brain.

The vast network of tiny and heterogenous objects which make up the new generation of distributed systems enforces a new way of thinking in relation to software. Jobs in the world of computing will have to adapt to this. The development and maintenance of applications are no longer restricted to a finished set of programs with long lifespans, but have to take into account a vast perimeter of microsystems interacting with one another as well as unbelievable diversity and all in a context where instability and evolution rule, just like in the real world.

This book is devoted to the ambitious question of imagining what computing will be like in 15 years. How will information systems evolve and how will jobs in the computing industry change throughout this transition period?

Introduction

We are on the brink of a huge milestone in the history of electronics and have just entered into a new digital age, that of distributed computing and networks of intelligent objects. This book analyzes the evolution of computing over the next 15 years, and is divided into six parts.

Chapter 1 looks at the reasons why we expect the next 10 to 15 years will be a split from conventional computing rather than a continuation of the evolutionary process. On the one hand, the chapter deals with the emergence of ubiquitous computing[1] and pervasive systems, and on the other hand it deals with the problem of the miniaturization of silicon components and its limits.

Chapter 2 offers a clear chronology of the industrial technology of silicon and explains the reason for the inevitable entry of nanodevices into the market: from Bardeen, Brattain and Shockley's transistor in 1948 to modern chips integrating tens of billions of transistors and the curse of Moore's Law.

For the reader who is not familiar with how a transistor works or who wants a brief reminder, there is an entire section which presents the main part of the theory of semi-conductors: elements of solid-state physics, the PN junction, the bipolar transistor and the CMOS transistor. The specialist does not have to read this section. This is also a section devoted to the current manufacturing processes of semi-conductor components. It is reserved for readers who wish to further their knowledge and is optional to read.

1 Ubiquitous means micro-organisms that are found everywhere. Adapted to computing, the term refers to an intelligent environment where extremely miniaturized computers and networks are integrated into a real environment. The user is surrounded by intelligent and distributed interfaces, relying on integrated technologies in familiar objects through which they have access to a set of services.

The main part of the second chapter resides in the factual demonstration of the fatality of Moore's Law and the transition from microelectronics to nanotechnology (see sections 2.1, 2.3 and 2.4 for more information).

Chapter 3 is devoted to the introduction of nanotechnology and its application as the base components of computers.

First of all, it introduces the atomic microscope and the atomic force microscope, and the first experiments of the positional control of an atom with the help of such a device. The impossibility of constructing such a basic macroscopic machine by directly manipulating atoms is also explained. This would involve assembling billions of billions of atoms amongst one another and would take billions of years to complete.

The solution could reside in the self-assembly of nanomachines capable of self-replication. This is the approach of Eric Drexler's molecular nanotechnology (MNT) which is the origin of the neologism nanotechnology. A section is devoted to the polemic concerning the reliability of molecular assemblers in the creation of self-replicating entities (section 3.3). This section stresses the precautions which still surround the most spectacular and also most unexplored industries. Nanomachines are part of a real interest, especially as far as institutional circles (universities, research laboratories) are concerned. More and more leaders from the business world have been interested in nanomachines since they were first considered as a strategic sector in the USA. Section 3.3 is supplementary and if the reader opts not to read this section it will not affect their understanding and preconceptions relating to MNT.

The construction of self-replicating and artificial nanomachines is a topic which is still very much discussed. However, an alternative already exists: the approach used by living organisms and which has already been largely explored by molecular biology and genetic engineering. In fact, the powerful device that is nature enables the cell mechanism to assemble, with the perfection[2] of atomic precision, all varieties of proteins; an organized system of mass production on a molecular scale. Section 3.4 explores the construction of self-replicating nanomachines which are used effectively by nature. This section also develops another approach to nanotechnology which is derived from genetic engineering.

2 It would be appropriate to talk about almost-perfection. It is the absence of perfection in the reproduction of biological molecular structures which enables nature to be innovative and to become everlasting. Without these random imperfections, most of which reveal themselves as being unstable and non-viable, no sort of evolution would have been possible, and man would probably have never appeared.

Section 3.5 introduces carbon nanotubes and their electronic properties. These extraordinary materials, which would make a car weigh about 50 lbs, are the first industrial products stemming from nanotechnology.

At the end of this chapter, section 3.6 is devoted to the introduction of some remarkable basic devices which function on a nanometric scale and which are likely to replace the semi-conductor components of current computers. The theoretical and experimental reliability of computing which is based on molecular components are also presented. The CFNET (Carbon Nanotube Field Effect Transistor), hybrid mono-molecular electronic circuits, an organic molecular electronic device using a living protein to store a large amount of information and finally spintronic semi-conductors will all be dealt within this section.

Finally, quantum boxes and the phenomenon of quantum confinement will be discussed. This quantum confinement approach is currently more a matter for fundamental physics rather than the development of industrial computers.

Chapters 4 and 5 are meant to be a summary of the major technologies which the computers and systems of the next decade will inherit. These two chapters can be read in full or according to the interest of the reader. As the sections are independent, they can be read in any order.

Chapter 4 is devoted to processors and their evolution. This chapter introduces two analytical views. First of all, we address the standard outlook of between one and five years (microprocessor structure: CISC, RISC, VLIW and Epic, the progress of photolithography, distributed computing as an alternative to supercomputers, etc.), i.e. the perspective which conditions traditional industrial investments.

The chapter then introduces a more ambitious perspective which sees a new generation of computers with radically different structures. This vision with more hypothetical outlines introduces systems which may (or may not) be created in the longer term, such as the quantum computer and DNA processing.

Chapter 5 widens the technological roadmap from the computer to the entire set of peripheral components which make up information systems. It is structured according to the hierarchy of the base components of a system. Other than processors, we are also interested in memory, mass storage devices, dominating energy supply devices with the notion of mobility or distributed computing, and in the man/machine interface. There is a section which is specifically devoted to microsystems whose contribution to ubiquitous computing is vital. The technologies which have been mentioned above can be applied to the industrial present (notably with new semi-conductor memories, Giant Magnetoresistance (GMR) hard disks, and Tunnel Magnetoresistance (TMR) hard disks, voice recognition and new visual display devices) as well as future possibilities (holographic memories, memories created from atomic force microscope (AFM) technology, molecular memories and telepathic interfaces, etc.).

Chapter 6 deals with the changes that these new resources will introduce in the business world and in our everyday life. It takes into consideration the issues at stake in the business world: a break or continuity of investments, the impact on activities using coding, and the implementation of information systems in companies, economic opportunities and changes in business and jobs, etc.

Section 6.1 introduces the historical evolution of computing from the first specialized, independent systems through to ubiquitous systems.

Section 6.2 shows how we move from ubiquitous computing to an ultimate model of dilute computing (i.e. becoming invisible): tiny resources communicate with one another and together they resolve the same type of problem as a large central mainframe. It also shows how the relationship between man and machine has evolved over three characteristic periods.

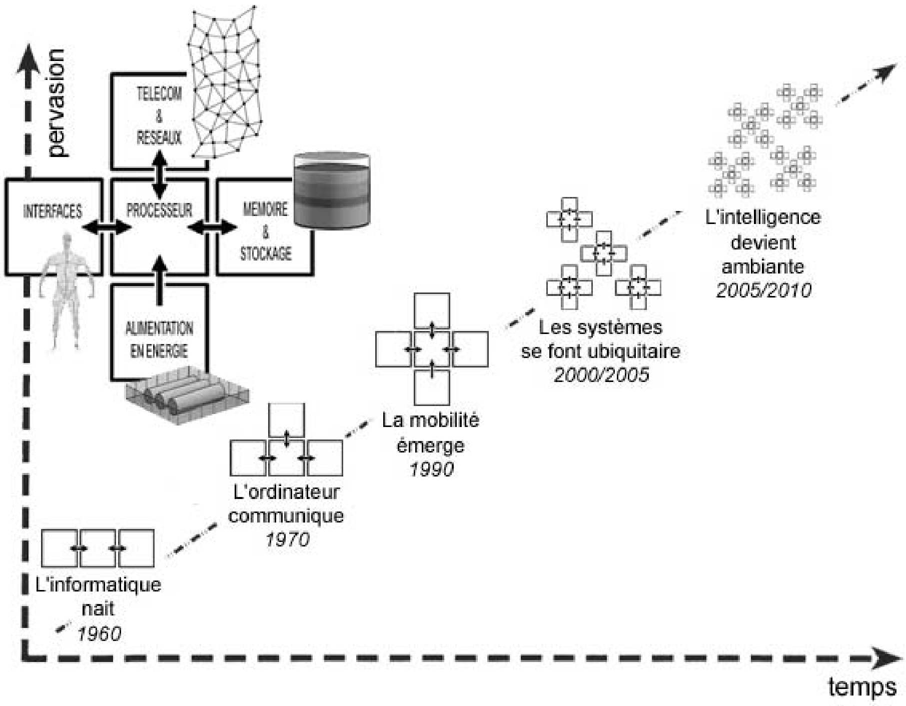
Section 6.3 introduces one of the first applications considered as pervasive, a precursor to dilute systems: Radio Frequency Identification Systems (RFID) and the Internet. We will also show how this global network could structure the supply chain of the future which would concern the Auto-ID initiative. The section concludes with the sensitive issue of the potential attack on a person's private life which this type of application could lead to.

Section 6.4 introduces the new challenges of a global network, i.e. how it is possible to make such complex and heterogenous networks function on a very large scale. Interconnected networks, which would have billions of nodes, and which would be associated with so many diverse applications, infrastructures and communication protocols, pose three fundamental problems. First of all, there is the problem of security, secondly the problem of the quality of service and finally, the size or the number of interconnected objects. However, such a structure would also consist of moving from a central system to what is known as swarm intelligence. In order to effectively use these swarm networks as new applications, the rules of software coding would have to be reinvented.

Section 6.5 mentions the unavoidable change in businesses and jobs in the computing industry, which the arrival of these new structures will lead to over the next decade. These new software structures will completely change the way in which we design, build and maintain complex applications. The following issues will also be mentioned in this section: the modern concepts of agile development, new opportunities regarding professions in the computing industry and the sensitive issue of off-shoring since distributed structures make it possible to operate these activities in regions where costs such as those of employment and manufacturing are more attractive.

After an analysis of the evolution of the business world in the computing industry, as well as an analysis of the evolution of structures in the computing world, section 6.5 deals with what the essential reforms in jobs relative to information systems should be; what will the new professional industries introduced by this technological evolution be like, and finally what jobs will no longer be viable?

The book concludes by reformulating the reasons behind the joint emergence of the material revolution (post-silicon and post-nanometric devices) and the concept of swarm intelligence, i.e. a complete and simultaneous change which is not only present at the center of materials technology, but also in algorithms which will unite this collective intelligence and in the perception that the users will have of these new systems. This conclusion introduces the real theme of the book: processing the next generation of computers which will enable us to understand the impact of change that these machines will have on methods used by humans and the manner in which humans manage these machines. We benefit from the understanding acquired from available technology in order to be able to debate the necessary change of the CIO (chief information officer)'s role: a job which from now on is no longer development and production oriented, but oriented towards anticipation, vision, mobilization and integration.


pervasion
TELECOM & RESEAUX
INTERFACES
PROCESSEUR
MEMOIRE & STOCKAGE
ALIMENTATION EN ENERGIE
L'informatique nait
1960
L'ordinateur communique
1970
La mobilité émerge
1990
Les systèmes se font ubiquitaire
2000/2005
L'intelligence devient ambiante
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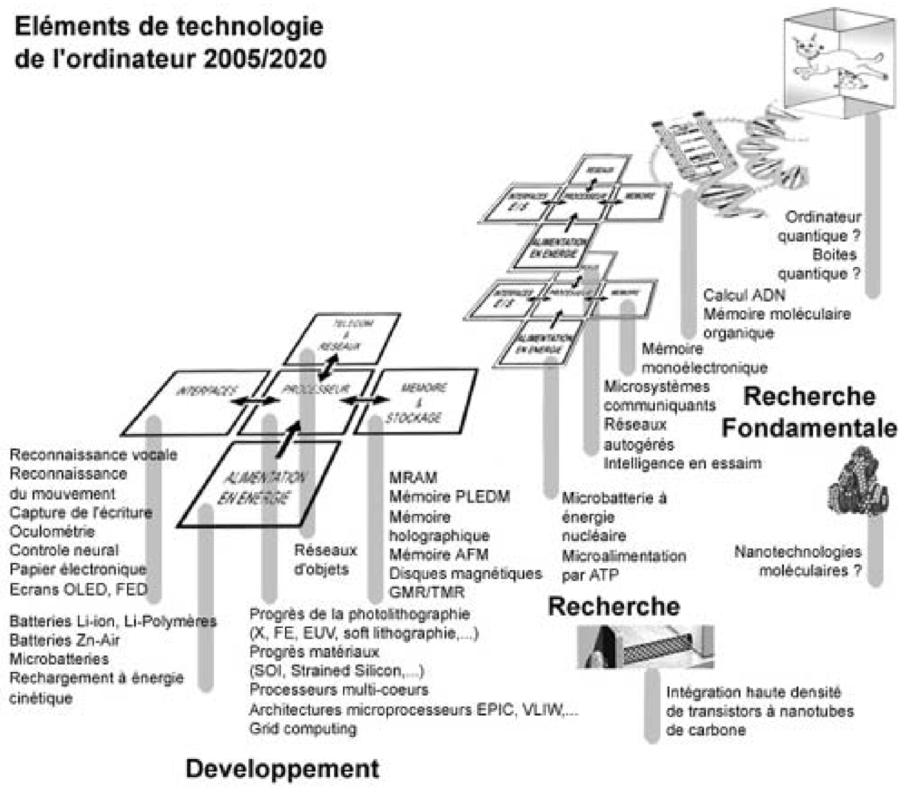
temps


Eléments de technologie de l'ordinateur 2005/2020
TELECOM & RESEAUX
INTERFACES
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ALIMENTATION EN ENERGIE
Reconnaissance vocale
Reconnaissance du mouvement
Capture de l'écriture
Oculométrie
Controle neural
Papier électronique
Ecrans OLED, FED
Batteries Li-ion, Li-Polymères
Batteries Zn-Air
Microbatteries
Rechargement à énergie cinétique
Réseaux d'objets
MRAM
Mémoire PLEDM
Mémoire holographique
Mémoire AFM
Disques magnétiques GMR/TMR
Progrès de la photolithographie (X, FE, EUV, soft lithographie,...)
Progrès matériaux (SOI, Strained Silicon,...)
Processeurs multi-coeurs
Architectures microprocesseurs EPIC, VLIW,...
Grid computing
Developpement
Microbatterie à énergie nucléaire
Microalimentation par ATP
Microsystèmes communiquants
Réseaux autogérés
Intelligence en essaim
Mémoire monoélectronique
Calcul ADN
Mémoire moléculaire organique
Ordinateur quantique ?
Boites quantique ?
Recherche Fondamentale
Nanotechnologies moléculaires ?
Recherche
Intégration haute densité de transistors à nanotubes de carbone