FROM SOLID STATE TO QUANTUM AND MOLECULAR ELECTRONICS, THE DEEPENING OF INFORMATION PROCESSING.

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I. INTRODUCTION

There is a global interest in semiconductor technology, in molecular electronics and molecular computers, in quantum electronics and quantum computers due to some new global events and ideas:

- The consolidation of the idea of a Global Information Society with the extension of the Internet and World-Wide-Web (WWW);
- The tendency towards virtual global plants for designing and manufacturing integrated circuits;
- The recognition of the relation between molecular electronics and the possibility to explain the nature of life;
- The new tendency, at a conceptual level, considering that a form of quantum physics might explain the nature and specificity of mind phenomena.

We are all concerned of these trends. All of them are expressing a part of an enlarged science and technology of information.

In information processing, with the perspective of a main-frame or a supercomputer on a chip, with the advent of molecular and quantum computing, and with the new ideas, even theories, concerning the processing of information by the human mind, we advance toward the deep roots of the nature and behaviour of information.

The domain of electronic devices, y compris semiconductor devices, aside power devices, becomes a great realm of informational devices, comprising the chips of today and of the following years, the molecular computers, among which the ADN computers seem very promising, and even the human brain. On this scale of informational devices, of course, many other types of devices will find their place.

II. ON THE NOTION OF INFORMATION PROCESSING

The notion of information processing is today larger than mere computation. Computations which are not algorithmic, that is effective, are possible. Still, any computation may be reduced at, or realized by an effective procedure.

Non-computational information processing was proved to exist, at least in the human brain, by some authors. The explanation of these authors may be unlike, may be right or not, nevertheless this type of information processing is present, and might be used, in general, by all living devices (organisms).

Another form of information processing to be considered is the structural-phenomenological information processing. It is a form combining computational and non-computational processing, the last one being a phenomenological process. The existence of the phenomenological (experiential) phenomenon was demonstrated.

Accordingly, the following forms of information processing might be taken into consideration [1]:

- computational, which is of two types, algorithmic and non-algorithmic;
- non-computational, which may be structural, structural-phenomenological or phenomenological.

Deliberating on all these types of information processing, in connection with the physical possibilities of realizing them, the following principles, relating information processing and physics, were formulated [1]:

For the structural realms of science and reality,

(A) Any structural computational process is submitted to the Turing-Church thesis;
(B) Any computation can be realized by a physical structural pro-cess;
(C) Any structural physical process is equivalent to a computation.

For the structural-phenomenological realms of science and reality,

(D) Any structural-phenomenological or phenomenological physi-cal process is equivalent with an information processing.

(E) Any information processing can be realized by a physical pro-cess (structural, structural-phenomenological or phenomenologi-cal, after the case).
(F) Any non-computational information processing cannot be strictly structural, it implies always phenomenological processes.

These fundamental principles do not mean a reduction of all physical reality to information, yet signify a strong link between physical and informational realities, their complementarity in the nature of things.

The electron devices together with the new quantum devices and some classes of molecular devices, and also living devices, that is all the types of informational devices, are submitted to the above principles. For any class of physical structure - submitted to the principles (A), (B) and (C) - , there are inherent limits for obtaining useful devices and systems for information processing. Nevertheless, the principles (D),(E) and (F) are showing that above such limits one encounters new physical phenomena that may be used for new information processing devices. It is difficult to say where is the end of the perspective for new devices.

III. THE SILICON'S EMPIRE

In 1967 I had to present an official report on the future of silicon technology. Then, in Romania only germanium diode and transistors were manufactured. I evaluated that silicon technology will predominate in the electronic industry for at least 15 years. At the beginning of the years' 80's, when Romania manufactured silicon integrated circuits, I reported that silicon will last at least still 15 years. We, Romanians, lost the step with VLSI and ULSI technologies, however the question of the future of silicon technology, now with a European and global interest, is still relevant for us.

Silicon has become the best known and characterised material. Its electronic properties are so remarkable that "silicon" becomes equivalent with "integrated circuit" or "system chip", and an entire period of the electronics technology may be named "silicon electronics" or "silicon microelectronics". Silicon is inefficient for many optoelectronics utilisations and allows a "niche" for semiconductor compounds, particularly GaAs, for these applications [2]. In the competition of materials, GaAs succeeded to have predominance over silicon in the domain of optoelectronics [3] and in some high speed areas.

In the dominant silicon empire, CMOS technology predominates over bipolar technology, the latter occupying a niche for analogue and high frequency applications, for instance up to 40 Gbit/s [3].
Why silicon will continue to dominate? Randall Isaac summarised recently [4] the reasons:

- The oxidation characteristics of silicon.
- For CMOS technology, GaAs lost the main competition with silicon because the hole mobility is too low in comparison with electron mobility.
- "The impressive economic base supporting silicon that is in place today" [4], making "highly unlikely that the present world-wide silicon infrastructure will be regenerated to support a silicon successor" [4].

- New possibility of progress in silicon technology and in silicon devices beyond previous predictions.

Concerning the future steps for the silicon technology, these were defined in an impressive roadmap for semiconductors [5] published by the National Semiconductor Industry Association (USA).
In the above study, the following generations, for Si CMOS technologies, are defined [6]:

1. 1995: 0,35 micrometers - already current generation, with optical lithography, 5,5 M transistors per microprocessor chip(1996), DRAM chip of 16 Mb uses now 20 millions transistors;
2. 1998: 0,25 micrometers - deep ultraviolet lithography, 12 M transistors per microprocessor chip(~ 2000);
3. 2001: 0,18 micrometers - x-ray lithography, 300 millions transistors for a capacity of 256 Mb DRAM chip;
4. 2004: 0,13 micrometers;
5. 2007: 0,10 micrometers, MOS transistors below 0.10 micron have been already demonstrated;
6. 2010: 0,07 micrometers.

Some data concerning the number of transistors per chip were taken from [7] and [8]).

Since the invention of the integrated circuit (1957) the Moor's Law remained applicable: the number of transistors on a semiconductor chip was doubling every year between 1958 and 1970, and since then until now (1997) is doubling every 18 months. The departure from the Moore law will happen about 2010, although this forecast is controversial [5].

The technology for the silicon advanced continuously and will continue to advance. And this can be done down to 0,07 micrometer length of channel (or gate) of a MOS transistor, and even near the limit of 0,02 micrometer = 20 nm imposed by the De Broglie wavelength of electrons (l=h/p). Below this limit, electrons cease to act like particles, and instead behaves like waves-essentially obeying the laws of quantum mechanics. Characteristic effects, such as tunneling, interference and discrete energy levels, occur under such conditions [9]. One observes also that "From the standpoint of basics physics, the dominant type of chip, the metaloxide semiconductor, might continue to operate down to dimensions of 0,03 micron (0,03 micrometers = 30 nm) [...].Below that scale it may be difficult to turn off the tiny switches called transistors. They would act less like switches than leaky faucets: an electron may move uncontrollably from one side of a transistor to another" [10].
If the domain of nanotechnology begins at 100 nm, then the Si CMOS technology will enter the year 2007 into this realm. For CMOS technology works a well-established scaling theory.
The effort in this direction is to maintain a high transconductance of the transistor with low supply voltage [11], which will be of ~1 V [12].

The problem of the fundamental limits is periodically reconsidered [13] [14] [15] [16]. The conclusion is that physical limits per se do not appear to put barriers over the next two decades [12] . We may observe that physical limits and scaling limits are separate problems, although, evidently, they are connected. Scaling will apply 10 years from now on [18].

Low power electronics becomes an essential objective and the new ideas of adiabatic computing technologies [19] [20] might be taken into consideration.

IV. TECHNOLOGY AND ECONOMICS

The silicon technology is depending on the possibilities of lithography. After the micron technology phase, today predominates the submicron technology (1 micrometer - 0,1 micrometer), and this will be followed by nanotechnology (under 100 nm definition lines). With ultraviolet light, dimensions of about 0,5 micrometer and even 0,35 micrometer with some special arrangements were reached [21]. Advanced ultraviolet techniques, from G-line steppers, to I-line steppers and to deep-UV steppers [22] were elaborated. Concerning x-ray lithography, "20 years of research [...] has produced only modest results. No commercially available chips have been made with x-rays" [23].

Concerning the silicon future, two factors are to be taken into consideration: technology and economics. The cost of building silicon plants is doubling every three years, reaching today values above 1 billion dollars and may increase to 2 billion dollars with increasing complexity of the chips. The companies began banding together into groups or into global virtual enterprises. A phenomenon of convergence manifests in the semiconductor industry under the form of multisite enterprises or virtual enterprises [24][25], because of shared investments for the high costs, a better use of equipments (improved with 30%), of human resources and of knowledge. In ten years, it is believed, that virtual enterprises at the global level will predominate. A virtual enterprise behaves "like a single company through strong coordination and cooperation toward mutual goals"[26]. A participating unit is a "node of production".

This represents a possibility for medium size countries like Romania to participate to semiconductor virtual enterprises with such nodes. This is another possibility, which supplements the "niche" strategy for small and medium size enterprises. Of course, if a European or a global company might consider to invest and build a main semiconductor factory in Romania this would be possible because of the scientific and technological expertise of our specialists, moreover because we had a semiconductor industry that for some niches, is still functioning.

What may happen in the future? One observes that "It may be long before the semiconductor industry plateaus. The pace of transistor integration will decline and manufacturing costs will begin to soar" [27]. This industry will continue to flourish because "growth will almost certainly come from refined products in more diversified lines" [28].

It is expected that in the year 2000 microelectronics sales value will reach 350 billion dollars becoming "probably the world largest industry" [29].

V. NICHE, EXOTIC AND INNOVATIVE DEVICES

The main line of semiconductor devices, circuits and systems remains for the silicon CMOS. Silicon bipolar and other semiconductor materials and devices will occupy only niches for specific subdomains.
A niche device has a viable and enough important economical use for some specific applications, being superior for these to Si CMOS.
An exotic device is not a device for the main line or a secondary line (like the niche devices), but it still might have a small niche or a future larger niche of applications, or it may remain only a scientific achievement.
An innovative device is a new device in a phase of research or development, which seems to be very promising.

Among niche materials and devices, excepting Si bipolar, without any doubt GaAs is the most important. GaAs will occupy most of the niche of optoelectronics [45]. GaAs obtains also a niche in the domain of VLSI chips, the faster growing segment being in the manipulation of high speed serial digital data for 1 Gb/s transfers of data [30].

Among the exotic devices may be mentioned,

- wide band gap SiC and GaN based devices [31]. Such mate-rials are convenient for high temperature transistors and are very efficient in the green, blue, and UV portions of the spectrum;
- indium gallium arsenide heterojunction FET (0,25 micrometers , fT = 340 GHz [32]) ;
- silicon germanium heterojunction bipolar devices (0,25 micrometers , 100 GHz). By low temperature (under 600 degrees C) chemical vapour deposition (CVD) epitaxy, heterojunctions of silicon-germanium and silicon [33] were realised and even manufactured. One considers that the silicon technology might continue with these devices, competing with GaAs for high speeds. The silicon-germanium technology is still in its infancy.

Concerning the innovative devices, these are classified by the "Roadmap" [34] in two categories:
1. evolutionary devices (using Si technology);
2. revolutionary devices.
Among the evolutionary devices may be mentioned:

- SOI technology that offers an evolutionary path for device innovations.
- Dual gate and vertical MOSFETs.

Regarding the revolutionary devices, a first idea is to use alternative devices and materials to discover new principles of operation.
A second idea is to use quantum devices concepts and quantum structures, if possible in silicon technology, or in another semiconductor material, but these are a part of the emerging nanotechnology (see VII).

VI. FUNCTIONAL AND ARCHITECTURAL ELECTRONICS

Not many years ago, when I was still active in the domain of electronics, in a book I published with two colleagues [35] we considered that one of the main ideas for the future of electronics is to conceive first functions, and then the structures that realise these functions. We observed, at the same time, that new structures may bring new functions, and we examined from this point of view the possibilities offered by quantum, molecular and even living devices.
The following main types of functions were defined [36]:

1. conventional f.: of communication, command and control, computation, image processing, graphics, telemetry, etc.
2. competence f.: of design, decision, molecular synthesis, genetical engineering, musical compositions, pictural compositions, etc.
3. robotics f.: informechanical (for mechanical movement), sensorial, of visual recognition, of speech, etc.
4. intelligence f.: expert systems, natural language understanding, machine learning, etc.
5. Functional architectures of complex technical objects : electronic home, electronic university, automated factories.
6. f. of coupling with living matter: biosensors, biochips, for coupling with the brain etc.
7. f. of coupling with informatter (hypothetical): of communications, antientropic functions.

Two main principles [37] are essential for functional electronics, and for a functional technology: (a) to replace, whenever possible, mechanical structures with microelectronic-informatic structures; (b) to replace human beings, whenever possible, totally or partially, with microelectronic-informatic structures.

Another principle, (c) to use the electronic-informatic synergetic capability of a technology [38], seems to be today very natural in the information society, both for old technologies, and new technologies. Quite new technologies are possible only due to microelectronic-informatic participation.

The principle (b) seems very technocratic. This may be compensated by a larger vision concerning the functional technology. This has a cultural role and has to participate at a high quality of life for all [39].

As an example, for the last period of the microelectronics era (until the 0,1 micrometers), one foresees that a general speech recognition system which needs a general purpose microprocessor, a DSP chip specialised for this function, SRAM, DRAM, and EPROM memories, A/D and D/A converters will be possible to be implemented with the next 0.25 micrometer Si CMOS generations, with two chips and even one chip [40]. This is, indeed, functional electronics.

Microelectronics will be followed by nanoelectronics (in the first decade of the following century). After the "classical" period, that is the Si CMOS technology, the information technology will enter into the quantum and molecular realms. The functional architectures of "complex" objects , described above, will become economically feasible. Intelligent materials, powerful intelligent agents, quantum computers to solve exponential problems in computing, and molecular systems to realise global inferences (by non-algorithmic computation) will be possible.

Moreover, the molecular period will have an evolution toward living devices (the so called organismic electronics) which will bring new functions like those of intuition and creativity.

VII. NANOTECHNOLOGY

The nanometric domain comprises transistors in this range of dimensions, quantum devices and molecular devices. The range of nanometric dimensions for nanotechnology is 0,1 nm - 100 nm. A few years ago this range was considered to be only from 1nm to 100 nm. Because manipulating atom with atom is still a nanometric operation, the domain of the dimensions of an atom (o,1 ÷ 1 nm = 1÷ 10 Å) is now considered in the range of nanotechnology.
Nanotechnology may be divided in two categories: lithographic and post-lithographic (non-lithographic).
The macromolecules have dimensions in the nanometric domain. Bacteria are in the micrometer domain. Viruses are nanometric and sometimes submicrometric.

There is more about nanotechnology: (a) nanotechnology for information processing and (b) nanotechnology for nanomachines, both at the molecular level [41]. A nanocomputer and a nanomachine may work together, becoming molecular nanorobots, to build microscopic and macroscopic materials and machines for the manipulation of atoms and molecules, and to work in the human body. The nanorobots might also self-replicate, making copies of themselves, to be able to work in great numbers for a definite objective. This nanotechnology, envisaged by K. Eric Drexler[42] and Ralph C. Merkle, may take 30 years to be realised.

For nanoelectronics, the following main classes of devices may be mentioned:

- nanometric transistors (100-20 nm, lithographic technology);
- quantum devices: with lithographic technology or non-lithographic technologies;
- molecular devices.

CMOS structures can be scaled down to 20 nm without functional sacrifice and some authors [43] believe that 30 nm transistors will be reached after 2010 (earlier than the forecast from the paragraph III). These transistors will work with only 10 electrons per transistor. Under 20 nm, CMOS transistors cease to function and will be replaced by quantum transistors like single-electron transistors. These will work with only one electron. Today, the CMOS transistors are working with about 100.000 electrons (holes). Under 80 nm the transport of electrons is ballistic.
Under 20 nm the electrons do no more behave like particles. Behaving like waves they are submitted to quantum tunneling , interference and discrete energy levels. The devices under 20 nm are called quantum devices. They will bring an increase of 10^6 of today integration density, with greater commutation speed and smaller energy dissipation: "Mastery of nanometric structures will become one of the 21st century's key technology "[44].
The main quantum silicon device that will continue silicon nanotechnology will be the single-electron transistor (SET). It seems "to be the most promising future switching element" [45] [46].

VIII. QUANTUM INFORMATION TECHNOLOGY

The new emerging field of quantum information technology comprises today quantum computing, quantum cryptography and quantum teleportation [47]. All these are forms of structural informational processing submitted to the principles (A), (B) and (C) presented in paragraph II.

On the one side, the quantum devices of the previous paragraph are also a part of the domain of quantum information technology; on the other side, quantum information processing may be even larger: non-computational structural information processing is envisaged by Roger Penrose [48] [49], and non-formal (non-computational) structural-phenomenological information processing was also considered [50] [51] [1] [52] [53].

Quantum computation ideas were advanced in the years 1980-1985 [54] by Paul Benioff, Richard Feynmann, David Albert and David Deutsch.

Quantum computers will use quantum logic gates for building quantum computing structures. An elementary quantum gate is a reversible gate, because it uses quantum phenomena respecting the reversible laws of quantum mechanics (Schrödinger equation). For the physical realisation of quantum gates may be used atoms, ions in a ionic crystal, quantum dots (an electron trapped in a quantum dot, along with its positive charge image, forms a dipole moment, and interacts with the moment of an adjacent dot; also quantum dot nanotechnology developed for quantum devices, as those mentioned in the previous paragraph, might be used). Candidates for quantum processing are also photons, quantum dots as artificial atoms (with discrete quantum states), spins a.o.

A quantum computer will be a quantum system built with quantum logic gates. For an isolated quantum system, that is not interacting with the environment, its evolution is governed by the Schrödinger equation (or by any other equivalent formalism of quantum mechanics), that is coherently and reversible, in a superposi-tional state. The inherent quantum superposition of states and the phenomenon of "entangled" states (which induced many discussions concerning various interpreta-tions of quantum mechanics) are essential useful features for quantum information processing:

"A classical computer processes its input according to its program to produce the output. Any classical system is always in one of a defined set of states. For exam-ple, a perfect classical bit is actually in state zero or state one at any time; the two possibilities are mutually exclusive. However, [...] , a quantum system can exist in [...] a superposition state. At all times during its existence, such a quantum state possesses components corresponding to each of (or at least some of) the different classical possibilities. For example, a superposition state of a quantum bit (qu-bit), would contain a component corresponding to the value zero and a component corresponding to one at the same time. The state is neither wholly zero nor wholly one, as must apply for a classical bit. This superposition phenomena means that if a computer is built which evolves according to quantum rules, it could be prepared in a superposition of the possible classical input states. In a sense it then processes the different inputs in parallel, to produce a superposition of outputs. It is known already that this parallelism would enable quantum computer to attack some problems which are intractable on any classical machine" [55].

A quantum system operates with many states simultaneously, its quantum state being a superposition of states. This part of the functioning of a quantum system was named by Roger Penrose the "**U** process".

There is also a second, inevitably process, the quantum reduction, which takes place when the quantum system interacts with a macroscopic system, either for a measurement, or for extracting an output of the computation. Roger Penrose named this "the **R** process". We adopted as very convenient these two denominations. Unfortunately the **R** process may take place in a non-controlled manner, when the quantum system cannot avoid the macroscopic "contact" which interrupts the **U** process. This may happen in the case of a very great number of quantum gates which approaches the macroscopic level. This is, otherwise, one of the big impediments for building quantum computers. The problem is how to isolate the quantum system from the macroscopic environment, excepting for the input and output of data.

A very difficult problem of a quantum computing system is the recuperation of output information.

Although experimental systems of a small number of quantum gates have been obtained, the realisation of a quantum computer is considered an open problem [56] and some consider that the hopes for building such computers are excessive[57].

The field of quantum computing is only at the beginning, and fundamental research in this domain may bring new possibilities for solving the mentioned difficulties.

The advantage of the quantum computer would be considerable for solving "exponential" problems [58] which are untractable for the classical computers. It is known that today's computers can solve "polynomial" problems, but not exponential problems[59].

Concerning the non-computational information processing, two fundamental remarks may be taken into consideration:

1. The human brain has the property of having non-computational activity (this was demonstrated by Roger Penrose [49]).
2. According to principles (A), (B) and (C), a structural system cannot have a non-computational activity.

The idea of Penrose that the brain might use some unknown principles of physics that extend the quantum physics exactly at the level of the **R** process, which becomes an **OR** process involving neurones, cytofibers in the neurones, embraced by, perhaps, a gravitational field, is contradictory to the above second remark.

The idea for a new extended physics is good in principle, because it is imposed by the first fundamental remark, which is a truth.

After the second remark, which is sustained by a fundamental principle inferred by the author [60] and by David Chalmers [61] that states that structural science is insufficient for explaining the entire reality (especially mind phenomena, but also living biological processes [62]), the idea of non-computational phenomena, in the frame of structural reality, under the form of an **OR** process does not seem plausible.

IX. MOLECULAR ELECTRONICS AND COMPUTING

The most important direction, which is in competition with quantum electronics, for the next century, will be the molecular electronics. This may prove to be complementary to the quantum electronics.

Regarding molecular electronics and molecular computers, some possibili-ties are envisaged:

- molecular logic circuits (Carter type) using electronic and/or optical processes in or between molecules [63];

- molecular logic circuits (Drexler type) using the mechanical movements of molecules [64];
- non-algorithmic computational molecular electronics proposed by Michel Conrad [65] based on the recognition of complementary conformational molecules.
- molecular cellular automata structures [66] [67] like those met in living cells under the form of the tubulin microtubules. Such structures have powerful computational power. They may self-organize in "neural" type networks, representing an intra-nervous system of the cell. This principle might be used in molecular electronics [67].
- DNA computers, initiated in 1994 by Leonard Adleman [68]. This discovery produced an enormous scientific and public interest [69] [70].

All these five types of molecular computing and computers remain in the frame of the Universal Turing Machine [1] and are respecting the principles (A), (B), and (C).

In the case of configurational molecular electronics (Conrad), the computation is not effective, is not proceeding step by step after a classical type of algorithm. Giving directly a result by a unique physical process, the recognition of molecules, such a computation is equivalent with a big program with a great number of instructions. If this is happening also in living cells, the existence of dedicated conformational informational molecules of proteins might have an important and surprising role.

Very promising way seems to be DNA computing. Molecules of DNA in a fluid environment play the role of input data, interact after a chemical "program" of computation that utilises standard methods of molecular biology and the final DNA molecules play the role of output data.
An important property of the DNA computer is the great parallelism of computation. ADN computers may be 1000 times faster than semiconductor computers.
One considers that with DNA and standard laboratory methods of molecular biology will be obtained associative memories of 10^20 words, every word having thousands of bits [71].
The theoretical impact of the ADN computer was tremendous. The problems of computability and complexity of computation are reexamined.
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What seems to be nearer practical application is the use of bacterial protein bacteriorhodopsin [72] [73], naturally found in the membrane of Halobacterium salinarium, but which can be fabricated in large quantities. This protein is switched, under a laser beam, from one state to another, with a structural change. Such switching "circuits" offer very good properties to be coupled either for memories, or for processing [74]. More advanced is the preparation of impressive memories (3D molecular optical memories) of very high density. Cubes of bacteriorhodopsin may have a capacity of 4 GB of memory, organised as an associative memory, but 9 such pieces may be placed on a card to obtain a memory of roughly 40 GB. It is hoped that in eight years [72] hybrid computers will be manufactured, using cards with semicon-ductor processor chips and cards with such molecular memories.
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If life is centred around DNA molecules, implying that these molecules are alive (it is known that viruses are considered alive by a part of biologists, but non-alive by the other part), their use in computing structures do not benefit of the possible phenomenological properties of living

organisms. If they are alive or not, in molecular electronics the use of biomolecules is structural. Molecular electronics is capable only of computations, and not of information processing that may bring intuition and creativity.

Living organisms, like biological cells and multicellular organisms, have a very important computational activity, and from this point of view the progress in molecular electronics may contribute to the elucidation of many structural informational properties of living organisms.

The biology may be seen as a "computer programming problem", and this point of view may be useful for biologists. This is a problem of the S-biology (structural biology).

The complete biology, dealing also with structural-phenomenological information processing, that is the SP-biology, may explain functions of organisms that cannot be explained by S-biology. And to the SP-biology will correspond the organismic electronics, a future possibility for the information processing that will combine computation and non-formal, non-computational forms of information processing. These are submitted to the principles (D), (E) and (F).

X. THE MAIN DEVICE: THE BRAIN

The deepening of information processing with the increased complexity of sub-micron device circuits, with quantum and molecular nanodevices, is going hand in hand with new functions and rich functional architectures. In the first decade of the next century will be manufactured and used 1Gb DRAM memory chips, 1Ghz microprocessors, compact intelligent agents, and many others. The greatest hope remains to build an artificial brain and to understand the functioning of the natural brain.

The brains may be classified in two categories:

1. brains without mind;
2. brains with mind;

What is a brain and what is a mind?

The brain is what we see as a biological hardware, or an electronic, quantum or molecular hardware that has an analogue construction to the natural brain, and fulfils an important number of similar functions.

These functions, for the brain without mind, are realised only with information structures. The artificial structural brain has still a psyche [53], although not a mental psyche, or a mind.

The mind is a complex of mental processors and mental processes [75].

A mental process is a structural-phenomenological event. The brain with mind listen to the principles (A), (B) and (C).

In Japan, Hugo de Garis heads the "Billion Neurone Artificial Brain Project" [76] with the aim to build an artificial brain with a billion artificial neurones, with evolved cellular automata based neural circuits, by the year 2001. This will be also a big scientific experiment. Will this artificial brain have a mind? If not, as we suppose to be the case, what will happen next?

Fortunately, in parallel, a great interest develops in the scientific study of natural brain, mind and consciousness. This research, but also other considerations from physics and even philosophy, will oblige us, I believe, to extend our contemporary S-science into an SP- science [77].

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77. S = structural, SP = structural-phenomenological.

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