Nanotechnology as NanoTechnoScience

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Abstract

The new scientific-technological disciplines ("technoscience") are unique in that they emerge at the interface between the scientific and engineering activities and are supposed to ensure an effective interaction of the two aforementioned types of activity. Characteristic of the scientific-technological disciplines is a more close relationship with the engineering practice. These sciences also summarize R&D orientations and form a single R&D-establishment in the process of solving complex scientific and technical problems and tasks. To this type of the modern scientific-technological discipline belong nanoscience & nanotechnology. Nanotechnoscience has a systems orientation.

Nano Systems Engineering

Nanotechnology is at the same time a field of scientific knowledge and a sphere of engineering activity, in other words – NanoTechnoScience (Baird, D. et al. 2005) - similar with Systems Engineering as the analysis and design of large-scale, complex, man/machine systems but micro- and nanosystems. "Nanoscience is dealing with functional systems either based on the use of sub-units with specific size-dependent properties or of individual or combined functionalized subunits" (Schmid, G. et al. 2006, p. 11). Nano systems engineering is the aggregate of methods of the modeling and design of the different artifacts (fabrication of nanomaterials, assembling technology for construction of comprehensive micro and nano systems, micro processing technology for realizing micromachines etc.). "Microsystems engineering and nanotechnology are two disciplines of miniaturization in science and engineering, which complement each other. Nanotechnology provides access to so far unused, completely novel effects. Microsystems engineering allows for the development of complete systems solutions due to its highly systemic potentials" (The KIT). Nano systems engineering as well as Macro systems engineering includes not only systems design but also complex research. Design orientation has influence on the change of the priorities in the complex research and of the relation to the knowledge not only to "the knowledge about something", but also to the knowledge as the means of activity: from the beginning *control and restructuring of matter* at the nanoscale is a necessary element of nanoscience (fig. 1).

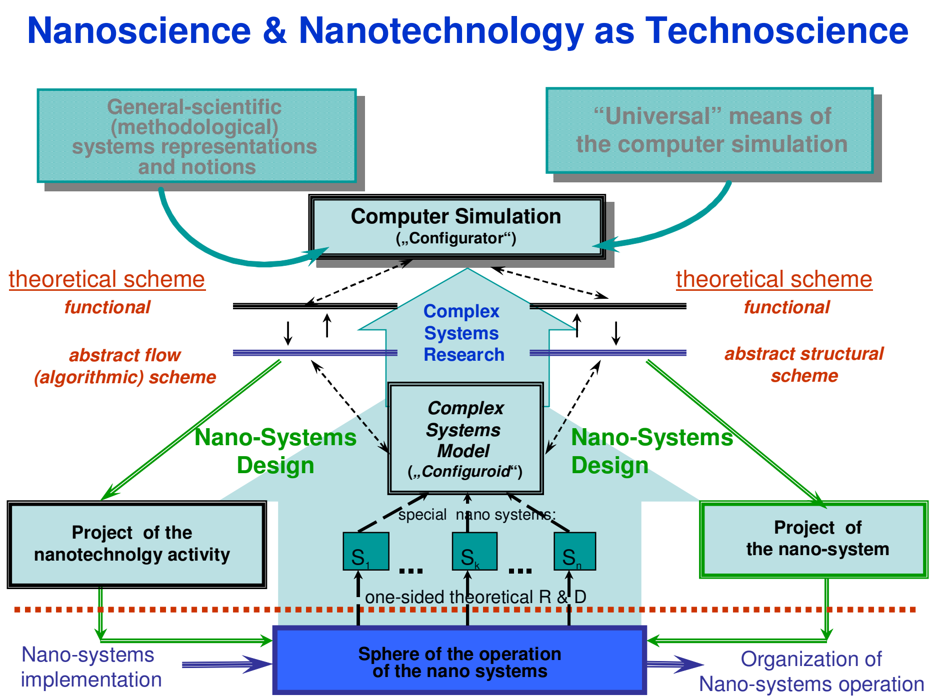


Fig. 1

Micro-Nano Systems Engineering is a quite new direction in Systems Engineering. Micro/Nano Systems Engineering or systems engineering for micro and nanotechnologies is assembling technology for construction of comprehensive micro/nano systems, micro processing technology for realizing micromachines, microelectromechanical systems (MEMS), and microsystems. "The microsystems field has expanded to embrace a host of technologies, and microelectronics has now been joined by micro-mechanics, micro-fluidics and micro-optics to allow the fabrication of complex, multi-functional integrated microsystems". Micro Systems Engineering is the technologies and capabilities available in this highly interdisciplinary and dynamically-growing engineering field: "including, design and materials, fabrication and packaging, optical systems, chemical and biological systems, physical sensors, actuation, electronics for MEMS and industrial applications" (Gianchandani et al. 2007).

The object of the nanoscience exists first of all only as computer model that simulates in the definite form the operation of the oncoming system that is to say designer's plan. Scientific investigation is always connected with the computer simulation und all, what we see in the display, is already determinate from the some theory and their mathematical representations that defined in the software of the simulation modeling.

Nanoonthology or nano scientific world of view has a function of the methodological orientation fort he choice the theoretical means and methods to a solution of the scientific and engineering problems. This is allows to change from one explanation and scientific world of view to another without any problems. For example, electron in one place is considered as spherical or point electron charge, could be rolled spherically symmetric over the nucleus or as "the freed electrons travel through an external circuit wire to the cathode" or in "various electron trajectories", in second - as «one can view the electron charge between the two atoms of a bond as the glue that holds the atoms together», in third – «the electrons in nanotube are not strongly localized, but rather are spatially extended over a large distance along the tube», and in forth electrons as in the quantum theory can be viewed as waves: «If the electron wavelength is not a multiple of the circumference of the tube, it will destructively interfere with itself, and therefore only electron wavelengths that are integer multiples of the circumference of the tubes are allowed» (Pool & Owens 2003, p. 98, 120-121, 128, 243). Systems ontology in contrast to the analytic, mechanistic, linear-causal paradigm of classical science is "the reorientation of thought and world view following the introduction of "systems" as a new scientific paradigm" (Bertalanffy 1972). It is in principle all the same for the systems approach to investigate the complex systems in the macro, meso, micro or nano levels.

Nano Systems Ontology

We can speak about the main different systems representations that are similar for all these types of the systems and also for nanosystems.

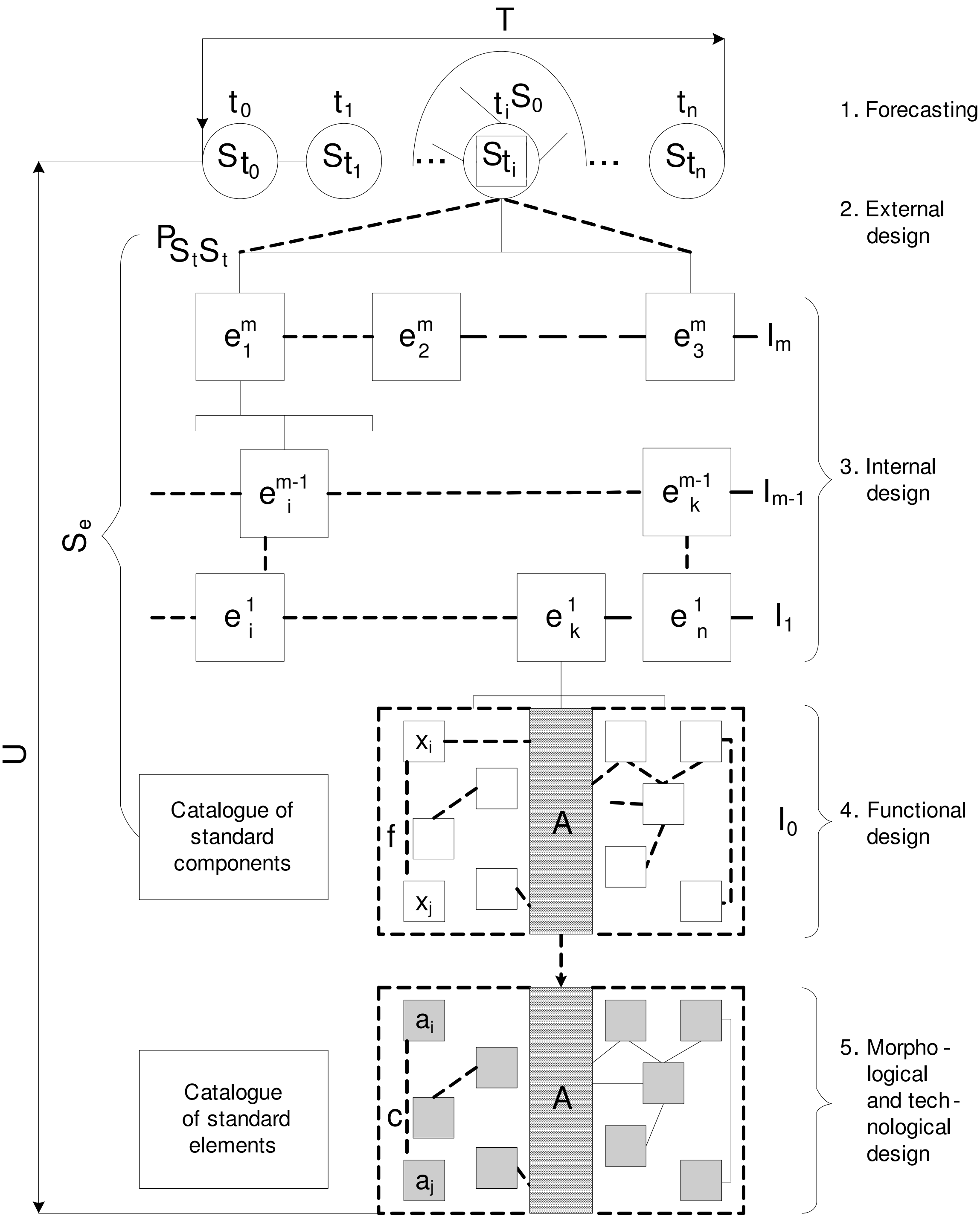


Fig. 2. Systems representations as the stage of the systems engineering activity: **T** – life cycle of the technical system; $\mathbf{t_0}$, $\mathbf{t_l}$ … $\mathbf{t_n}$ – internal system's time; $\mathbf{St_0}$, $\mathbf{St_l}$ …$\mathbf{St_n}$ – states of system; $\mathbf{S_0}$ – system's environment; $\mathbf{S_e}$ – system's hierarchy; $\mathbf{l_l}$…$\mathbf{l_m}$ – levels of hierarchy; **e** - unit of hierarchy; **u** – level of the analysis (sub-systems); $\mathbf{x_i}$ – functional element (first-order properties); $\mathbf{fx_jx_k}$ – fnctional connections (relations); $\mathbf{c(a_ia_j)}$ – connections; **a** – element (first-oder properties + second-order properties); **A** – component

The *first (1) stage* may be called *forecasting*, as the evolution of the system over its lifetime is analysed. Links between states must be established so as to view the sequence of states as an evolutionary process. Invariants and external goals of the system important for the engineering problem at hand are identified that must recognise the future system state in a changing environment.

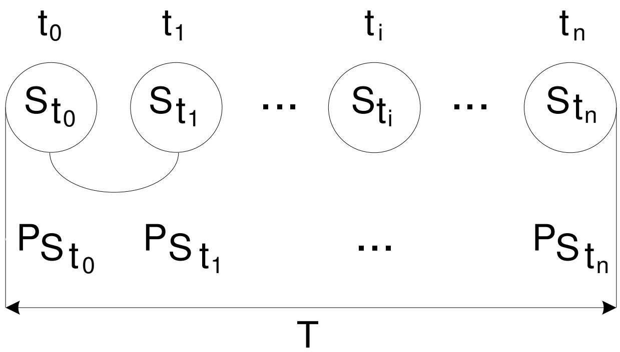


Fig. 3. Processual System Representation

Simultaneously, the basic internal system operation processes are outlined that must lead to the external goals. The needs in a system of this type are defined and forecast and initial requirements to the system formulated accordingly, for they can change as the systems growth. For this reason this forecast must be scientifically sound. Analysis of the needs now is becoming a major engineering tool, for unnecessary or obsolete systems waste human, economics and material resources, and under the circumstances of developing large technical projects requiring enormous financial expenses, may bring disastrous results. Analysis and forecast of the needs must, however, be supplemented with their scheduling for they are derivatives of scientific and technological achievements but are not yet recognised as needs.

Such processual nanosystem representation is for instance the self-assembly simulation of basic building blocks as internal nanosystem operation process: "The basic building blocks of microtubules are "tubulin monomers" (alpha tubulin and beta tubulin) with slightly different properties" (see fig. 4). Self-assembly process is the evolutionary design process of the nanosystem. "Self-assembly provides the basis for important new computational and manufacturing techniques and their development and prediction may play a significant role in advancing nanotechnology. Understanding the *self-assembly process* in nature might open up new and fundamental approaches to novel computational and informatics paradigms and also to the design and manufacturing of complex, threedimensional, and heterogeneous systems" (Pidapart).

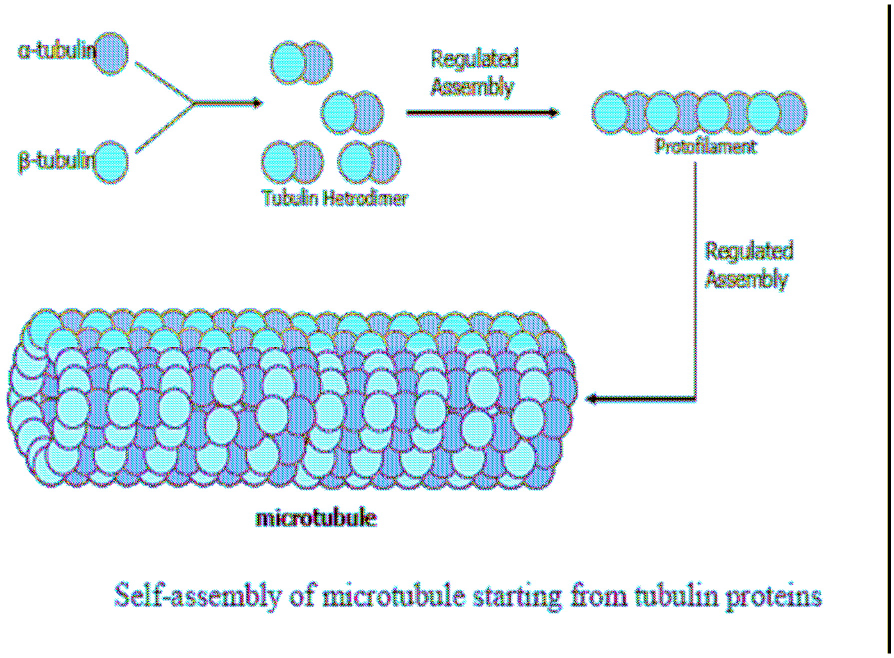
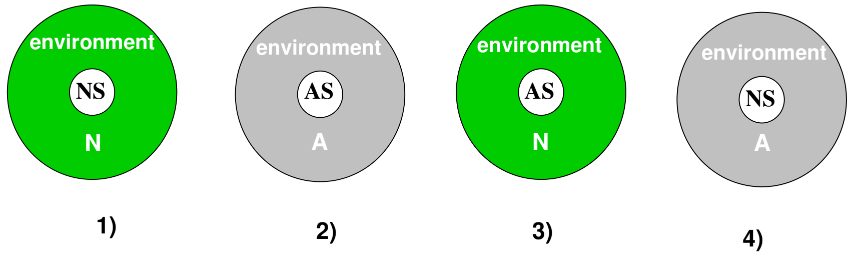


Fig. 4

The marked out outside links of the system are considered in detail at the *second (2) stage external design*. A technical system is described as a static totality of external links with the existing and expected objects in the environment. In this way the requirements to the system by the environment are formulated. Because the system must function in a certain natural, social and cultural environment, the external links largely dictate the goals of its existence. The representation is helpful in integrating the activities of developers of adjacent systems.

In the fig. 5 we can see the different possibilities in the relationships between system and his environment. For the nanotechnoscience are most interesting the third and the forth cases.

Different interconnections between Natural (N) and Artificial (A)



1) Natural system (NS) in the natural environment

2) Artificial system (AS) in the artificial environment

3) Artificial system (AS) in the natural environment

4) Natural system (NS) in the artificial environment

Fig. 5.

1) Natural system in the natural environment: vital activity of the livings organisms in the biosphere.

2) Artificial system in the artificial environment: operation of the technical components in large-scale technical system

3) Natural system in the artificial environment: "because of the lack of appropriate synthetic motors that perform well if loaded, in the past, ***biological motors*** *have been integrated into micro-fabricated environments*. Feasibility studies have demonstrated proof-of-principle for controlling the unidirectional movement of motor-driven transport along engineered tracks; adjusting the speed of the transport system on user demand by using light; and specifically attaching cargo from a solution … In this system specialized ***motor proteins*** *connect to small containers filled with proteins and transport them along the skeleton of the cell* ... Since motor proteins are a thousand times smaller than any man-made motor, we try to utilize them in *a synthetic environment* as the engines powering our nano-trains" (Garber). Hybrid vehicle is a combination of non-biological and biological elements, e.g. polymers as an artificial environment and biomolecules as natural system in this environment. "Development of artificial vehicles that carry a drug and are aimed for *in vivo* targeted drug delivery and controlled drug release is a key target of intensive research and very important for future medical science" (fig. 5) (Dudia 2007).

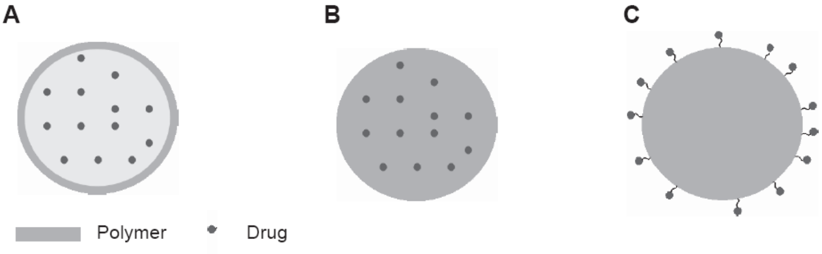


Fig. 6. Drug delivery systems: schematic representation of three basic DDVs consisting of (A) a hollow carrier loaded with a drug, (B) a matrix carrier having the payload distributed in the matrix or (C) attached on the matrix surface.

4) Artificial system in the natural environment: "Being incorpoaretd in an *artificial* nanovessel (serves as a *natural environment*), this system offers the controlled communication between the interior and exterior of the vesicle containers. … *Vesicles serve as a* ***biologically relevant*** *environment* … using nanoparticles as delivery agents … when injected into the body it transports itself to the correct target, such as a tumor, and delivers the required dose at this target" (see fig. 7) (Berger 2008).

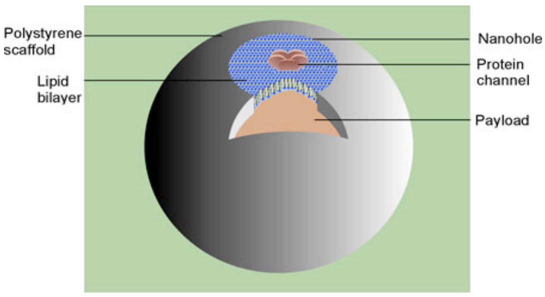


Fig. 7. "Schematic representation of a hybrid nanocontainer, consisting of an impermeable hollow polymeric scaffold with a single small opening and a payload inside the scaffold. Synthetic bilayer lipid membrane with embedded MscL channels seals the hole. … This system offers the controlled communication between the interior and exterior of the vesicle containers".

The most immediate dangers "may come from the uncontrollable interactions between the various nanomachines that are being designed and the environment. The relations between machines and their associated environments, between the technosphere and the biosphere have not been seriously investigated and should be paid more attention" (Bensaude-Vincent & Guchet 2007).

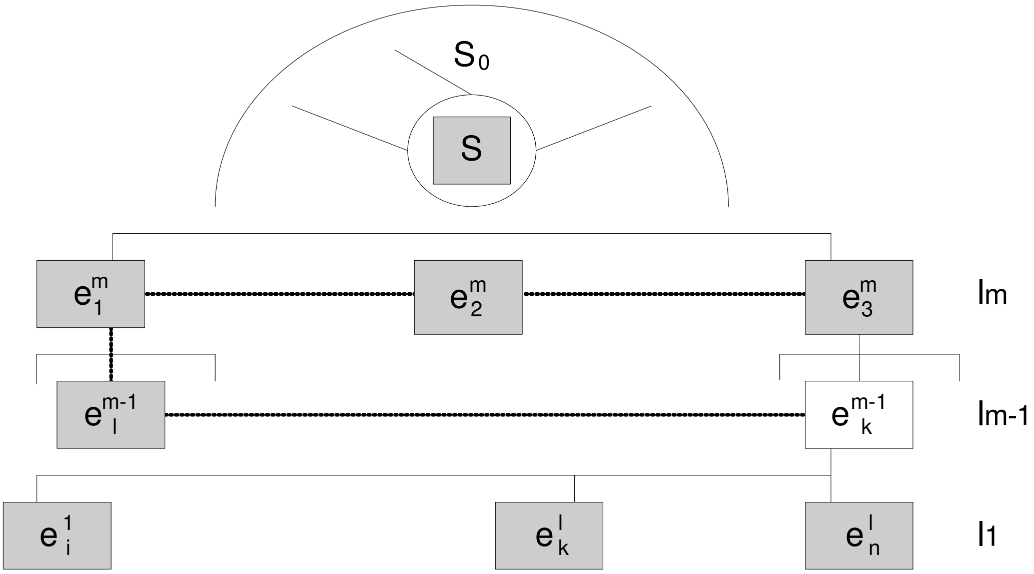


Fig. 8. Macro- and Hierarchical System Representation

The *internal design* is consistent with the hierarchical representation. The list of external links obtained at the preceding stage makes it possible to describe the system functionally as a unit of the top hierarchical level. Then the system is decomposed into hierarchy of units. It is decomposed into numerous parts for with the increasing complexity of the engineering tasks all its parts cannot be designed at once. It is only the structuring principles that are thoroughly analysed at this *third* ***(3)*** *stage*. This stage is essential in co-ordinating the developing activities and division of labour between the system developers. The system cannot be integrated unless it has been soundly decomposed.

For example quantum dots are tiny particles that behave as if they were individual atoms ("they can absorb light energy, kicking their internal electrons up to higher energy levels, then release the energy by emitting light"). But in the same time they are a cluster of atoms that is to say have a complex structure. One of the type of the quantum dots the Cornell Dots "are nanoparticles consisting of a core about 2.2 nanometers (nm) in diameter *containing several dye molecules*, surrounded by a protective silica shell, making the entire particle about 25 nm in diameter. The researchers call this a "core-shell architecture" (see fig. 9). Unlike quantum dots, they are mostly chemically inert. "For use as biological markers, quantum dots are encased in a polymer shell … Quantum dots also contain heavy metals like cadmium that can leach through the polymer shell and disrupt the chemistry being observed" (Steele).

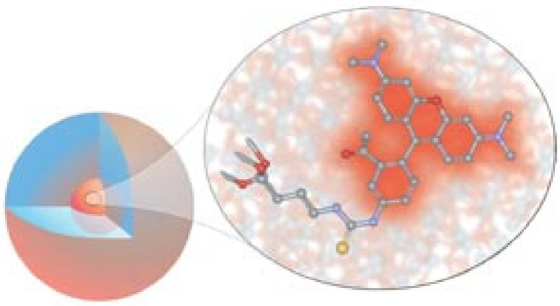


Fig. 9. Schematic representation of a Cornell Dot, with several molecules of a fluorescent rhodamine dye encapsulated in the center. The dye has been modified with a group that links to the encapsulating silicon.

Similarly in the modern biology "it does not posit a single basic explanatory level, it only says that for every level of phenomena (save possibly the lowest) there is a lower level in terms of which the focal level can be explained. As an ontological thesis, as a thesis about the fundamental entities and processes that make up our world, this thesis seems to presuppose that causation in our world always works in an inside-out (or *bottom-up*). fashion. That is, the parts of a whole and their interaction cause the behavior of the whole, but never vice versa. It never happens that properties of wholes cause the behavior of their parts. As a methodological maxim weak reduction ism prescribes always searching the component parts of a phenomenon to scientifically understand it. In what follows I hope to show that the ontological thesis is false and that the methodological maxim is a prescription for bad science" (Brandon 1996, p. 181-182).

If the units can be taken from a catalogue of standard components, the latter must be adapted to the actual system. But in most cases a dedicated development effort is needed at the *fourth* ***(4)*** *stage* of *functional design*. The system is viewed as a set of parts having a standard structure. The functional structure is the same as for the class of similar systems.

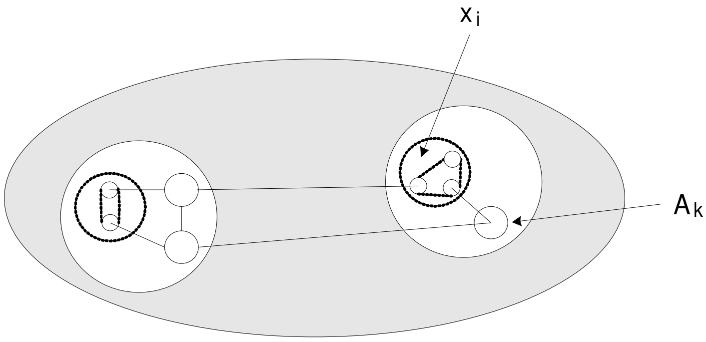


Fig. 10. Functional System Representation

Therefore, the possible redesign of parts does not change the functional nature of the system; other kinds of units such as consisting of more economical and easy to operate elements may replace the existing ones even during the functioning, while the functional structure remains invariable. In other words, as it modifies the system improves but remains essentially the same. At this stage, the work of system part developers is co-ordinated. The engineer must be able to think using the language of functions, not the ways to perform the functions by the components of the system. It facilitates the search of further decisions to implement the functions. In the nanotechnology there are different types of the functional elements: quantum wires, quantum dots, quantum bulks and quantum wells which are fabricate for the different nanostructures. «If one dimension is reduced to the nanorange while the other two dimensions remain large, then we obtain a structure known as a quantum well. If two dimensions are so reduced and one remains large, the resulting structure is referred to as a quantum wire. The extreme case of this process of size reduction in which all three dimensions reach the low nanometer range is called a quantum dot. The word *quantum* is associated with these three types of nanostructures because the changes in properties arise from the quantum-mechanical nature of physics in the domain of the ultrasmall» (Pool & Owens 2003, p. 226-227).

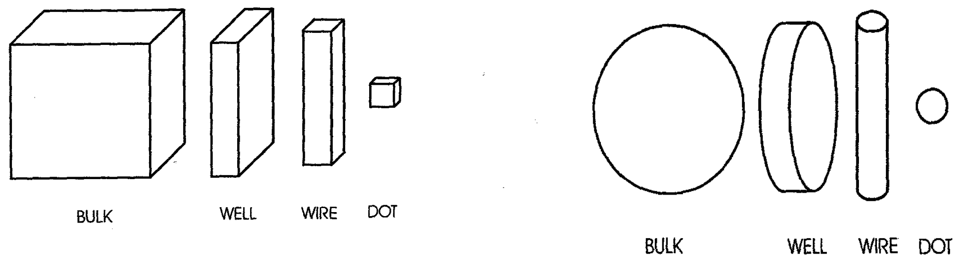


Fig. 11. a) Processes of diminishing the size for the case of rectilinear geometry; b) Progressive generation of curvilinear nanostructures

This is similar Descartes' reasoning: „To this class of objects seem to belong corporeal nature in general and its extension; the figure of extended things, their quantity or magnitude, and their number, as also the place in, and the time during, which they exist, and other things of the same sort." The main cognition instrument is for Descartes is geometry and mechanics (and "in general all the arts to which the knowledge of physics is of service") is the part of physics (Descartes).

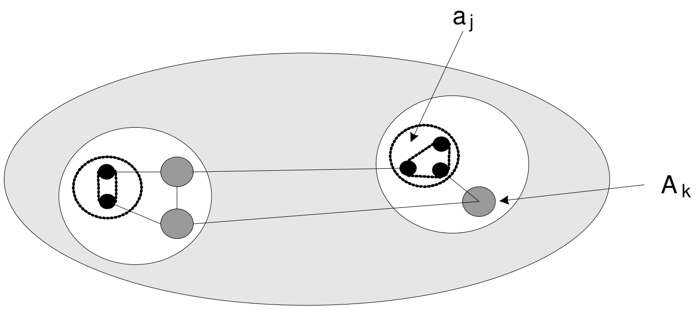


Fig. 12. Micro-System Representation

The functional sites are filled out from the catalogue of standard elements at the *fifth (5) stage* of *morphological and technological design*. If such parts are not available, the necessary parts are tailor-made for the specific system. The given functional structure (arrangement) is immersed to material; it is implemented.

The components and elements chosen from catalogues should have first-order characteristics, due to which they are included in the system, being as close as possible to the characteristics of units and functional sites, they fill. Second-order characteristics being undesirable shall not essentially change the ideal functioning of the system. Links between elements and components shall reflect operations of making the technical system, so such construction may be called technological. Such presentation of the system is required to co-ordinate experts in the course of its making and implementation. In the course of technical activity, all components and characteristics of the complicated system may be somewhat changed and adjusted. This is similar with the problem of the relationships between ***material, place and filling*** by Aristotle. He said: “Since anything which is produced is produced by something (and this I call the starting-point of the production) … we do not make the substratum … we make the form … we bring the form into this particular matter, and the result is” the concrete thing. The systems or their elements can be “different in virtue of their matter (for that is different), but the same in form” (in the first-order characteristics) (Aristotle *Metaphysics*). “First the term “form” frequently rides tandem with the term “matter”. Originally, indeed, matter and form are introduced as twins: substances are in a sense composite entities, their component “parts” being matter and form. And originally, matter and form are simply stuff and shape: a bronze sphere … is an item composed of a certain stuff, namely bronze and a certain shape, namely sphericality. (Of course, the bronze, and a certain sphericality are not literary *parts* of the bronze sphere, and the unity of the bronze sphere is not like the unity of, say, a table, which is put together from a top and four legs).” But later the interconnection between matter and form has by Aristotle nothing in common with the interconnection between stuff and shape (Barnes 1995, p. 97). In “Physics” Aristotle continued this theme: “we speak of 'a statue coming to be from bronze', not of the 'bronze becoming a statue'. The change, however, from an opposite which does not survive is described indifferently in both ways, 'becoming that from this' or 'this becoming that'”. Then he discusses a notion “place” (functional place of the elements): “The physicist must have a knowledge of Place, too, as well as of the infinite-namely, whether there is such a thing or not, and the manner of its existence and what it is-both because all suppose that things which exist are somewhere …, and because 'motion' in its most general and primary sense is change of place, which we call 'locomotion'. … The existence of place is held to be obvious from the fact of mutual replacement. Where water now is, there in turn, when the water has gone out as from a vessel, air is present. When therefore another body occupies this same place, the place is thought to be different from all the bodies which come to be in it and replace one another. What now contains air formerly contained water, so that clearly the place or space into which and out of which they passed was something different from both … The form and the matter are not separate from the thing, whereas the place can be separated. As we pointed out, where air was, water in turn comes to be, the one replacing the other; and similarly with other bodies. Hence the place of a thing is neither a part nor a state of it, but is separable from it" (Aristotle's *Physics* 208b-209b). This problem is new formulated in nanotechnology which tries "shaping and connecting carbon nanotubes like water pipes", multiwalled (a nested nanotube in which one tube is inside the another) or metal-atom-filled nanotubes (see fig. 13) (Cox 1999). In these cases is nanotube the Place.

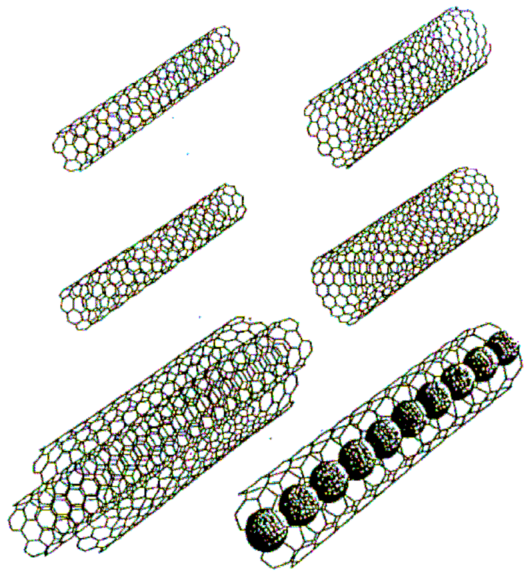


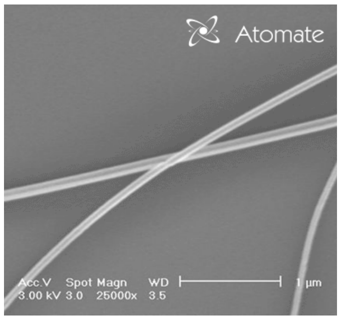
Fig. 13. Examles of carben nanotube structures, included multiwalled or metal-atom-filled nanotubes

Possible structures of carbon nanotubes depend on how graphite sheets are rolled. One of them is rolled up to form a seamless cylinder with axial symmetry and in general exhibiting a spiral conformation called chirality. With different chiral vectors carbon nanotubes have dissimilar properties such as optical activity, mechanical strength and electrical conductivity. Therefore carbon nanotubes can be semiconductor (making for exceptional transistors), a sensitive detector of vanous gases, conductor (metallic nanotube is highly conductive to electricity depending on the exact geometry of the carbon atoms) through which flows an electric current (fig. 16) or into carbon nanotubes can be injected hydrogen to store the hydrogen inside carbon nanotubes (similar as water in the Aristotle's vessel), etc., depending on the diameter and chirality of the tube. From the functional point of view it is indifferent what kind of realization have the functional elements in the nanosystem or from what kind of material are they produced. As metallic wires have the carbon tubes the high conductivity and a very low resistance. "In the metallic state the conductivity of the nanotubes is very high. High currents do not heat nanotubes in the same way that they heat copper wires. It is estimate that they can carry a billion amperes per square centimeter. Copper wire fails at one on amperes per square centimeter because resistive heating melts the wire (second-order characteristic). Nanotubes also have a very high thermal conductivity, almost a factor of 2 more than that of diamond. This means that they are also very good conductors of heat. One reason for the high conductivity of the carbon tubes is that they have very few defects to scatter electrons, and thus a very low resistance" (Pool & Owens 2003, p. 119). "The physical shape of nanotubes significantly influences their theoretical ability to carry an electric current. If the carbon atoms were simply kept in their two-dimensional array, electrons would be able to move in all directions. But once this array is wrapped into a tubular shape, quantum confinement will only allow electrons to move down the length of the tube and not around it. … Because of this, some types of nanotubes – depending on their diameter – can theoretically carry charges some 1,000 times greater than common conductive materials, such as copper or silver" (Ray. 2008).

But all function must be correlated to concrete material elements. In this case we can use a different material for the realization of the same function or realize form in another substrate. At the same time natubes can be self a *substrate* ("The bonds holding nanotubes together are stronger than those in diamond, effectively making the nanotube a stronger material than diamond … Still, exceptional strength is only one of the many unique properties that carbon nanotubes offer" (Ray 2008)) or *filling* for definite functional elements: for example *supercapacitors* or for *transistors* to make a computer out of nanotubes. "Conventional Faraday capacitors store electric charge between parallel charged plates that are separated by an insulating dielectric material. Instead of flat parallel plates, capacitors that come in tubes use two metallic foils separated by an electrolyte-impregnated paper in a "sandwich" that is rolled up into the tube. For these devices, nanotube thin films can increase the surface area of the conducting foil due to the nanotubes' very small size, orderly alignment and high conductivity. "Nanotubes provide a huge surface area on which to store and release energy-that is what makes the difference …" (Johnson 2005). The switching rate such devices is estimated to be about 100 times faster than that of the present chips (first-order characteristic) (Pool & Owens 2003, p. 121), which is why so much attention has been devoted to finding a way to use them in electronics.

Nanostructure Image Gallery

GaN: 20 nm diameter GaN nanowires form a cross with one of the nanowires originating from a nickel nanoparticle shown in the image.



http://www.atomate.com/gallery/gallery.php?img=a13

Fig. 14. Nanotubes as nanowires

Carbon nanotubes are widely being touted as what could be the next great advancement in circuit technology: "… carbon nanotubes could end up being the foundation for the integrated electric circuits of the future. They would make-up vastly smaller microchips than those in production today and, potentially, they would function several times more efficiently. … The age of the integrated nanochip circuit – made-up of composite carbon nanotubes – may have arrived" (Ray 2008). The researchers describe their method of using nanotubes - tiny tubes entirely composed of carbon atoms - to create a functional electronic circuit: "given their amazing electric properties, nanotubes have been a subject of keen interest for creating such things as chemical sensors, flexible electronics and high-speed, high-device-density microprocessors for computing" (fig. 15).

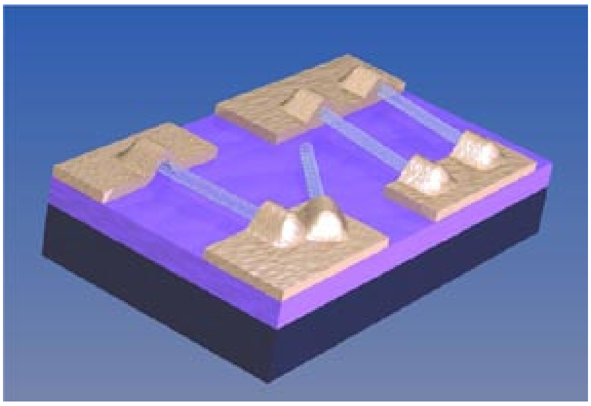


Fig. 15. An image showing a circuit made of nanotubes**.**
(Copyright © University of Pennsylvania)

"The resulting circuits take advantage of unique electrical properties of nanotubes and can be produced in bulk. Since the researchers can create nanotubes via processes separate from the chips, this process allows for a better control of the quality and diameter". Researchers believe there is a definite role for nanotechnology in the future of electronics (Nanotubes 2005).

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