ROOTS and IMPULSES of a new PERCEPTION of INFORMATICS

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Imagination is more important than knowledge.
Albert Einstein

1 Abstract

In the recent paper, "A perception of Informatics" [Gr10], a new, visionary and philosophical in essence, view of Informatics has been presented in quite general terms and ways.[1] This view has been then in [Gr10] illustrated and put more "down to the earth" through the presentation of some of the grand challenges of "new Informatics".

In the present paper some of the main impulses/needs or drives for and roads towards such a new perception of Informatics are summarized and discussed in more details. To see them well is also of the large importance for a full understanding and acceptance of such a view of Informatics. All of them are closely related to some of the major problems of current science and technology.

[1]One should note that new perception of Informatics, as presented and discussed in [Gr10[, could have been developed already many years ago because it is in some sense a quite natural minimal roof (minimal upper bound) of various views already indicated, mostly very cautiously, during last 50 years, here and there, by various visionaries of the field. However, until quite recently there have not been really sufficiently strong reasons explicitly visible to see well that such a maximal (total) upper bound on the perception of Informatics could be not only proper one but also much needed and prosperous one both for the discipline itself and also for society. Three events have started much to changed the situation. The first one has been an understanding that (quantum) information processing processes are and have always been the driving forces in our physical, biological and social worlds. The second one, due to the existence of so powerful internet and web, was an understanding that the field drives from a concentration on information processing (computation) through concentration on information transmission to a concentration on information management. The third one was an understanding that Informatics based methodology extends much in depth and scope mathematics based methodology. Therefore, it started to be inevitable to perceive the scope and aims of Informatics in much deeper and broader way.

2 A new Perception of Informatics

One of the basic standpoints leading to a new perception of Informatics, in [Gr10], has been that the overall development of science, technology, medicine, economy and practically of all major areas of the activities of mankind, much depends on the progress in Informatics, provided this field is sufficiently deeply and broadly understood. Therefore, it has to be much in the interest not only of the Informatics itself, but actually of the whole society, that this discipline is perceived, supported, developed, and also projected into all levels and forms of education, in a way that leads to its proper development, largest outcomes and broadest impacts.

New perception of Informatics, in [Gr10], see the Informatics as the oldest technology and science discipline consisting of the four very closely interrelated components: scientific, engineering, methodological and application.

As a scientific discipline, Informatics is seen as being both a deeply fundamental and also a broadly applied science. The most fundamental goals of the scientific Informatics are to discover and study the principles, laws, limitations, phenomena and processes of information processing worlds and, in particular, to develop information processing understanding of the universe, evolution, life, brain, mind, intelligence, complexity and security, as well as to develop a deep scientific understanding of the problems related to the specification, design, validation, reliability, security, structure, analysis and efficiency of huge and complex information managing, processing, communication and imaging tools and systems.

Current computer, computing, communication and imaging revolution is seen, at this perception, only as one of the very important milestones in the development of the both scientific and engineering Informatics, as well as of the Informatics-driven methodology. However, the scientific goals of Informatics go far beyond what this technology developments and its applications do and will motivate, imply and require.

As the scientific discipline, Informatics is seen as being currently the leading scientific discipline - due to ts enormous impacts on all other academic disciplines, as discussed below, and far beyond that.[2]

[2]Sciences used to have a "Queen of science", guiding and serving other sciences, with very broad impacts on the development of sciences and also on education at all levels. Some examples: This role was played by medicine in Padua and at the same time Theology in Paris in 17th century; Philology during the Renaissance; Mathematics after Galileo's time due to its methodological impacts and partly also Physics in the 20th century mainly due its impacts on the industrial revolution. Informatics is quite fast replacing (expanding/extending) mathematics (that is seen here as being one of the grounding stones of scientific Informatics, and the same holds for logic) in its Queen/servant role with respect to other scientific

To achieve its scientific goals, Informatics has to develop a huge variety of paradigms, principles, concepts, models, theories, methods and tools. Some of them are very abstract and may seem to be far from the needs of a narrowly seen computer science. However, most of them have very deep goals, though curiosity may be sometimes seen as the main or the only driving force of them. They are, however, in most of the cases actually much needed in order to develop powerful concepts, paradigms, theories and tools to deal with the basic problems of the understanding of principles, laws, limitations, phenomena and processes of the information processing worlds, as well as for the development of powerful information processing and transmitting systems designing and processing methods and tools.

As the engineering discipline, Informatics concentrates on the development of paradigms, principles, concepts, models, methods and tools for specification, design, validation, analysis and maintenance of the natural and especially human-made (hardware) devices and (software) systems used for acquiring, mining, retrieving, structuring, storing, processing, imaging and transmitting data, information and knowledge, as well as for the development of tools and methods (for example, specification and programming languages and corresponding methodologies) to make an efficient use of such devices and systems. To increase much storage capacity, computation power, communication performance, reliability, robustness and security of the information storing, processing, communication and imaging tools is one of the big tasks of engineering informatics. Low-energy systems and miniaturization - to move to nano- atto- and quantum-levels, is one way to go to make still long life for the Moore law and to have systems with more than petaflops performance and oxabytes data stores.

The engineering Informatics concentrates also much on the design of intelligent information processing systems and robots that could either simulate or even outperform those of the living beings and especially of humans in various (especially brain) activities. The goal is not only to have powerful and intelligent collaborators, but also to use designs and performance of such artifacts to get a deeper understanding of the nature and human/brain/mind activities. Cell-, bio- and brain-inspired computing is one of its grand challenges with already amazing achievements.

As an engineering discipline, Informatics is seen as the leading engineering discipline with enormous impacts on all other engineering disciplines, especially on their methodologies and tools.

Scientific and engineering Informatics create and develop also a basis for

disciplines.

a new and very powerful, Informatics-driven, methodology for science, engineering and mankind in general. The methodology that puts also two basic old methodologies, experimental and theoretical, to new heights. Informatics-driven methodology can also be seen as extending much mathematics-driven methodology and creating platforms for successful application of the holistic approach to science, as an alternative to the reductionism dominating so far. New methodology is based on, and leads to, a vision of the nature, society and virtual worlds as being written in the information processing terms, extending by that Galileo's view that nature is written in the mathematical language.[3]

Main components of this new methodology are: modeling, simulation (both being of another dimension than before), visualisation, virtualization, abstraction, algoritmisation, complexity considerations, tools to apply holistic approach to complex problems, mechanisation of reasoning and deduction, design of systems beating intellectual and other performance of humans and animals, information and knowledge mining tools, as well as mechanisation of learning and so on.

Informatics is also quite specific in taking a very special care to facilitate its applications by developing a variety of methods, tools and systems that allow to use easily its application potential in a variety of ways and to use information processing resources and tools by everyone, from everywhere and anytime. and often in no-time. The design of a global Internet, Web and computer (networks) and of the "intelligent dust" are some of the extreme highlights in this direction.

For a more detailed description and analysis of the four main components of "new Informatics" see [Gr10], where also several grand challenges of the scientific and engineering informatics have been listed and discussed.

3 Roots of a new Perception

There are several main reasons why a new perception of Informatics, as presented in [Gr10], is badly needed. A perception that is much broader and deeper than the current view of the computer science - as of the science dealing with *a broad range of phenomena related to computers and their use.* These reasons are actually closely related to some of the most basic global problems of the current academic disciplines.

[3]Observe that the use of mathematics and deduction can be seen as a very old methodology for science. However, it has actually been only after the scientific revolution in th 17th century, after a new and very powerful mathematics has been developed, especially through mathematical analysis, that mathematics has indeed started to play, as methodology, a really very important role.

1. It starts to be understood that in the foreseeable future, in 21th century at least, most, if not almost all, of the major technological innovations and big innovative projects in science, economy, finances, health and environmental care and in almost other areas of societal activities, will require to use, and in an essential way, more or less sophisticated Informatics paradigms, principles, methodologies or/and information storing, structuring, processing, communication and presentation tools. The overall development of society, science, technology, health and environmental care, economy, finances, but also of politics, care for our cultural heritage and also art developments and its impacts, will therefore much depend on the character and pace of the progress in Informatics, in all of its four components. This can hardly be achieved unless Informatics develops with a very broad and deep view of the disciplines and of its grand challenges and to all this the research agendas, creation of the institutional settings for research, as well as channeling of the research support, are fully adjusted.

2. Society starts to understand, or at least to believe, that one, perhaps the main, of the ways to go is to drive, and fast, toward so-called *knowledge society* at which knowledge, its production, dissemination, and utilisation are peacemakers and remote dynamos of the progress. Informatics-based tools and Informatics-driven methodology clearly play at these knowledge production, dissemination and application a very important and many sided role and all that requires again a very broad and deep development of informatics.

3. Informatics is helping to bridge various areas of science and technology, as well as to cross-fertilize them, and therefore it is of large importance for society that it develops as broadly and deeply as possible.

Indeed, it is getting understood that the science and technology, as the main producers and consumers of knowledge, are to play the key role in our transformation of society to a knowledge society. However, it starts to be also understood that to achieve all that is far from trivial and a simple idea of putting more money into science in order to get proportionally more practical dividends out of it does not work. In order to achieve the above goals a deeper understanding and a better view of the relation between fundamental (basic or pure) or knowledge oriented science on one side, and a use or application (national goals or grand-challenges) oriented science on the other side, is much needed. A new understanding is also needed of the relation between the potential of the science and technology to produce new knowledge and to put this knowledge to use. In addition, it starts to be also understood, and much emphasised, that the goal of the basic research is not only (a) *to produce knowledge*, but also (b) *to disseminate knowledge* and, what is quite a recent wisdom, (3) *to put knowledge into use*. It also starts to be understood that relations between pure- or basic- or fundamental-research on one side and applied- or engineering- or technology-oriented research are very complex and strong influences go in all directions.

A closer look to the features of Informatics-driven methodology reveals that this methodology contains a variety of very important features to bridge, in both directions, and very significantly, these two areas of research. The areas that used to be seen, for good reasons, in the pre-modern-Informatics era, as being far from each other and actually so far, and as so antagonistic, that one of the most basic position of Vanevar Bush in his so immensely influential report "Science, the endless frontiers", from 1945, was that "applied research invariably drives out pure".

The old view of the relation between knowledge and use oriented pure and applied science was much related to the well observed understanding, corresponding to the goals, methods and tools these two areas of science used, that not only goals of the pure and applied research, but also of the science and engineering, are so different, but that to work in these different areas require actually very different type of skills and therefore also of people. However, nowadays when all these areas of science and technology are done by researchers who starts to master main features of the Informatics-driven methodology and the outcomes of science and technology are to a significant degree and in the limit manifested through various informatics-oriented products,[4] differences between these, seen as so different, or even antagonistic, before, disciplines slowly starts to blur out. That is a phenomenon society has to be very pleased with. There are therefore nowadays again, as many times in the history, good reasons to assume that there is only one science, very closely related to technology, and that science should be divided only to a good and bad one. In order to support even much more this new phenomenon in the development of science and technology - that makes also science to be engineering driven, to a certain degree, and engineering to be science driven, again to a certain scale - it is much needed that Informatics, as the basis of Informatics-driven methodology, develops really in full broadness and sufficient depth.

Moreover, the fundamental science, equipped, supported and guided by Informatics paradigms, concepts, systems and methodology, has now tools and know-how how to put knowledge in use in the way that makes also the fun-

[4]For example, results of science and technology are often presented through methods transferred to algorithms that are implemented through software products. Moreover, it is getting understood that the attempts to come with best, most efficient algorithms and software can bring a deeper understanding of the underlying problems and therefore to have an important discovery value. In a similar way one can illustrate the bridging role of other features of the Informatics-driven methodology.

damental science richer and can much profit out of it. For example, through the design, analysis and optimization algorithms and protocols, through the design of models and their exploitation through analysis, simulations, visualisation, through an adoption of holistic approach and so on. On the other side, the use-oriented and technology research can nowadays much faster and better make use of the basic-research outcomes because they come in more ready to use form. Bridges, due to the powerful Informatics concepts, models and tools, play again the key role by that. All that implies that progress in the development of all basic branches of science and technology and their mutual fertilisation and impacts, what seems to be of so large importance for society, much depends on the overall progress in Informatics on the depth and wideness of its scope and aims.[5]

4. Iy is much needed, for the overall proper development of both individuals and of the whole society, that education concerning an informatics thinking and development of life-long capability to master ever more sophisticated information processing, communication and imaging technology and methodology, should penetrate, in an adequate way, all stages and orientations of all (life long) education processes. To introduce and to develop such new paradigm deeply into the education process, requires to see, by the whole society, challenges, goals and tools of Informatics in an appropriate and challenging way that would be expected to stand the scrutiny of time - to see Informatics as a very important, deep, broad and lasting discipline.[6]

5. Two of the recent and closely related paradigms of the current science and technology, that are believed/hoped to have magic impacts, are *multidisciplinarity* and *collaboration*. It is getting strongly believed, and there are good reasons for that, that one of the ways to increase the progress in science and technology is through a better and faster transfer of the concepts, models, ideas, methods and tools from one academic discipline to another and to deal with problems that require multidisciplinary expertise. These ideas are in

[5]At this point it is perhaps good to note that two big failures, in practically all major documents of IT, are continuously made. (1) Too narrow view of the field, as driven mainly by the progress in technology, that are soon broken by new developments that extend the scope and deepen investigations in the field; (2) Underestimation, and very much, of the problems related to the efficient design of correct, reliable, secure and efficient software - due to too matter-technology view of the software-technology.

[6]A significant change in the whole education process, that is conservative in principle and have always been - for good reasons - can hardly get really through unless it is fully understood by society that such a change will well meets societal needs and that what is behind is of the really lasting, broad and deep importance. This can hardly be achieved with computer-centered view of the field, but more likely in case Informatics is seen as the leading discipline of sciences and technologies and even of a broader importance.

some way not really new, but only nowadays there are ways and tools to make these two paradigms to be the ones really to focus on. The main reason behind is the fact that Informatics as the area of science, technology and Informatics driven methodology offers a variety of concepts, models, theories, methods and especially tools to facilitate much interdisciplinarity and collaboration.

There are many reasons and ways modern Informatics should be seen as facilitating multidisciplinarity and collaboration in science and technology. These reasons are as the whole such that much deeper and broader development of Informatics is much desirable to support its contributions to multidisciplinarity and collaboration: (a) Information processing processes are in the heart of many important phenomena and problems of a variety of academic disciplines and therefore similar, informatics thinking motivated, approaches can be a basis of their solutions; (b) Informatics thinking leads to asking new type of fundamental questions concerning fundamental phenomena of a variety of academic disciplines - questions that motivate approaches to lead to new deep insights into the problems; (c) Informatics concepts, languages and reasoning create a common framework to express problems and their (algorithmic) solutions from a variety disciplines in a way that allows to see similarities between them and makes transfer of tools and outcomes from one discipline to another much more easy.

In case of collaboration an important additional fact is the existence of powerful communication worldwide networks and possibilities, due to digitalization, to have real-time communication and transfer of many for research and development so crucial tools and products. This makes feasible the task to create efficiently working and geographically much distributed virtual collaboratories.

Let us observe in this connection that the founders of modern science, in 17th century, used to be mostly multidisciplinary scientists par excellence. One reason for that was their strong background in mathematics and a belief that laws of nature are written in the language of mathematics. Their important methodology was to transfer problems from different sciences into a common mathematical language and then to use a common pool of knowledge in mathematics to solve them. That allowed them to work successfully in several areas of science. Such a situation was actually till the beginning of the 20th century. Afterwards situation has started to change and specialisation started to dominate. Methodologies have developed so fast and so far and their applications required so much of resources and not only intellectual, but also computational, that it was no longer in a competence even of the brightest minds to embrace several areas of science.[7] The existence of Informatics-driven methodology and

[7]In spite of the fact that it used to be believed almost to the Second World War that

mechanisation of various intellectual, creative and computational processes and science making activities in general starts again to change the situation. To bring this development to new heights with big impacts requires much progress in the understanding of Informatics developments and challenges in all their depth and breadth as well as Informatics-driven methodology and in its education. At the same time progress in the development of Informatics-driven methodology requires progress in the scientific and engineering informatics and in the development of tools to facilitate application of this methodology.

6. It starts to be understood that information processing plays so important role in nature, and especially in living beings, that we can say that one of the ways to understand universe, evolution, life, brain, mind, intelligence, complexity and so on is through the study of the underlying information processes, their principles, laws and limitations. In short, one can say that natural, earth, behavioral and social sciences are, in their fundamentals, information processing driven.[8]

For example, there are good reasons to consider Informatics and Physics as two windows to see, explore and understand the world(s). Physics can be seen as dealing with the laws, limitations, phenomena and processes of the physical worlds - Informatics, in turn, as dealing with the laws, limitations, phenomena and processes of the information processing worlds. To explore relation between the physical worlds and information processing worlds is one

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for few top scientists it was enough at that time to have close contacts to about 10-20 top scientists in other fields to have a reasonable good understanding of all major scientific developments.

[8]This of course does not mean that by studying information driven processes one can get the whole interesting and important scientific truth in all areas of science. For example, in spite of the fact that on the most basic level molecular biology can be seen as the most fundamental one with the largest potential for far reaching discoveries for life sciences, this does not mean that it is not of importance, from a very different point of view, to explore other problems of life sciences, As one of many examples, let us mention the study of the behaviour of various species such as ants and whiles are, or species that are in the danger of extinction.

of the grand challenges of science in general.[9]

The existence of powerful information processing in nature, and also a natural idea to explore its primitives and fundamentals in order to develop new information storing and processing technologies that could far overcome current technologies requires that Informatics takes much broader view of the field and see it also as the one that is very deep and fundamental.

7. History of science and technology teaches us that it is very important to search for a proper perception and fundamentals of a scientific discipline and that the outcomes of such a search lead usually to a much broader view of the discipline with far reaching consequences. History also teaches us that a discovery/development of a new perception of a discipline, if correct, can change almost everything in the discipline. History of physics is an excellent example how important is to challenge an "obvious, or common sense, views of the field". Einstein's challenge of the vision of space as creating a fixed background for whole physics has changed physics for ever and led to extremely important discoveries with far reaching practical impacts. Attempts to develop *theory of everything* may lead still one step further than current quantum mechanics and relativity theory for physical world.

8. A need to formulate and pursue such grand challenges that even a partial successes in dealing with them may be very important for the development of a discipline. If an area of science and technology does not have really grand challenges that need huge research force to deal with, then it can loos a momentum and an interest of the brightest minds in science and technology as well as of potential students.[10] Really grand challenges require very deep

[9] The question which of these two types of worlds is more basic maybe one of those eternal questions that can give long life to philosophy as it is the *mind versus matter puzzle*. In this context of interest are the following two quotations of famous physicists. The first one is from W. Heissenberg, one of the founders of quantum mechanics:

- I think that modern physics has definitely decided in favour of Plato. In fact the smallest units of matter are not physical objects in the ordinary sense: they are forms, ideas which can be expressed unambiguously only in mathematical language.

and second one from John Archibald Wheeler, one of the founders of modern cosmology:

- I think of my lifetime in physics as divided into three periods. In the first period I was in the grip of the idea that *everything is particle*. I call my second period" *everything is field*. Now I am in the grip of a new vision, that *everything is information*

who named black holes and created slogan *It from bit* summarizing his previous thoughts, which has been later updated by David Deutch as *It from qubit.*

[10] Mathematics seems to be currently in such a stage. One can see it from its grand challenges, or 5 big problems/challenges, as formulated by the Clay institute. This is a list of very interesting and old problems that so far resisted all efforts to solve them. However,

and broad view of the very broad and deep discipline. Physics could hardly develop some grand challenges when seeing its goal as to deal with *things one can handle between fingers* as physics was seen in the 17th century. To understand the essence of time and space is really a grand challenge for physics, as well as to develop a *theory of everything*.

9. Development of the (meta)science and engineering of science making tools and activities is one of the grand challenges of Informatics and to meet this challenge again requires to perceive and develop Informatics very broadly and deeply.

There have already been developments that justify consideration of such a grand challenge. Results in the artificial intelligence have already indicated that the border line between creativity and mechanised reasoning is much thinner that we would think not long time ago.

For example, theorem proving used to be seen as one of the highlights of creative thinking and as a technical basis of the theoretical methodology. There are already results in theorem proving that overcame human mind, and all that with theorem provers that work in a very simple and general way. Once a million times faster computers are available, theorem proving could be, to a large extend mechanized. At least to such an extend that it would reduce the task of mathematicians, at least to significant extend, to making hypothesis.

Also in the area of engineering numerous highly intellectual activities, at least as we could see them not so many years ago, have been mechanized to a remarkable degree and often a level was obtained that is hardly achievable by humans in a reasonable time. Developing an engineering of the science making activities, at least to a remarkable degree, and, of the corresponding meta-science and engineering is therefore a reasonable and really grand challenge that will sooner or later be met one or another way.

10. One can observe a convergence of many academic disciplines to Informatics and their mutual fertilization n what requires again to have very broadly and deeply developed informatics to meet al l needs and potentials.

The fact that natural, behavioural and social science are, in their fundamentals, much information processing driven is far from the main reason why these areas of science, and not only they, start to be more and more (inter)connected with informatics. Another important facts are that informatics concepts, paradigms, methods, results and tools provide a new quality microscopes and also telescopes for mind and lead to new deep questions and new ways of approaching deep old questions, as well as to new ways of understand-

all of them can be, potentially solved in such a way that this may have actually not too much impact of mathematics and its potential to come to really grand discoveries.

ing of deep problems of these sciences. Moreover, informatics concepts, models and tools allow also to bring into new heights for these sciences the holistic approach and in this way to get deep insights into their complex phenomena and to complement this way the reductionist approach to them and to overcome its limitations. Because of such strong impacts of informatics, especially of its methodology, on all academic disciplines, one can talk about their convergence to and increasingly strong relation with Informatics. As a consequence, a significantly new perception of Informatics, of its wideness and depth, would likely have strong general impact on all academic disciplines, scholarship, art, technologies concerning research agenda, and influence the creation of the institutional settings for research and also for channeling of the research support, as well as on the education at all its levels and targets. All that may lead to a new framing of the science, technology and education policies.

4 Main Impulses of a new Perception

The first main impulse came from the observations that several areas of (computer) science, that were to a large extend originally motivated by computer technology or computing methodology, started to liberate themselves from the role of serving mainly computer and computing technologies, and that they actually needed that liberalisation for their healthy and vigorous development and outcomes of new quality and generality. For example, formal language and automata theory, combinatorics on worlds, computational, communication and descriptional complexity theories, semantics, concurrency, various logical systems and so on. It started also to be therefore quite clear that more powerful computing systems we have and more complex problem can be solved with them, more general, deep and broad theories are needed to help to develop useful concepts, insights and tools to deal with the underlying problems of these systems and their applications. For example, larger and more important software systems are being design, much better, more sophisticated and deeper and broader science of designing correct software and of the verification of the correctness of software is needed.

Moreover, the rapid increasing of the performance and decrease in the cost and size of computing systems, as well as their increasing reliability and enormous consequences of all that, are fully in accord with the old wisdom that a new technology can develop rapidly only in the case an intellectual framework has been already available for its development and that one of the major impacts of the new technology is a to bring the original intellectual framework to new heights. This applies in this case especially to the development of formal and logical systems, but actually to all other areas the origin of which can be traced to the pre-computer era.

The second main impulse came from three basic discoveries in natural sciences.

The first one was the discovery, by Francis Crick and James Watson, in 1953, of the twin-corkscrew structure of DNA and how genetic information is encoded into DNA - followed by a demonstration, due to Adleman first (?????? [??]), how DNA computing could be indeed performed and that such a computing has a potential for remarkable efficiency. Both of these discoveries created huge and important areas of research.

The second one was the discovery of quantum teleportation and of the unconditionally secure quantum generation of shared random classical key, by Charles Bennett et al. in 1984-1993 - followed by the demonstration by Peter Shor, in 1994-1996, that quantum computing could be performed and has a potential for remarkable efficiency. That led also to a huge increase in the research in quantum information processing and communication.

Both of these basic discoveries changed the views on physics and biology that started to be seen and explored as being, to a significant extent at least, in their fundamentals, information processing driven sciences. From that it has been only a natural and logical step to see other natural sciences, especially chemistry, in this way, as being, to an important degree again, information processing driven - and a new revolution in the study of natural and also other, especially behavioural and social, sciences has emerged. All that, supported by an immense development of the power and miniaturization of information processing technology, has initiated various new attempts to deal with perhaps the main frontier of science - mind - and the attempts to understand it through a "reverse engineering of the brain" - what could, perhaps, lead also to dealing with such phenomena as consciousness that have been for so far considered as being out of the reach of (current) science.

The third major discovery was that there are one or very few cells organisms, as paramecium (from 50 to 350 μm in length), that do information processing par excellence in order to find foods, to avoid predators, to learn to find a mate and to have sex - without having any synapses. Cells are therefore information processing devices per excellence. All that led to a deep observation that information processing is of such an importance for life as eating and breathing. In this way it got clear that in order to search for the beginning of the history of powerful information processing systems we need to go to the very beginning of the history of life.

The third main impulse came from the emerging observations that new, very broadly applicable and successful methodology, based on the development of the discipline, has been emerging and its proper essence, foundation and potential developments and applications started to be explored. Al that led to a need to back this new methodology by a proper development of the discipline.

Another impulse came from the observation that paradigms, theories and technologies behind the field have applications practically in all fields and areas of activities of the society and by that a need arose to find the "largest common denominator" of the field and to come with a perception of the field that would match perceptions of the fundamental sciences in its deepness, clarity and intellectual simplicity. A perception that would, likely, stand scrutiny of time and new discoveries would likely only enforce its validity.

In particular, one should realise that that discipline actually brings new dimension to centuries old efforts to derive knowledge from information, to formalize knowledge and to formalize as well as to mechanize reasoning. It is also to bring new dimension to centuries old attempts to understand, match and beat performance of bodies and minds of living beings.

Also on a more philosophical level, it started to be realised that information processing superparadigm is the one dominating in the current science, technology and so on, replacing machine/clock paradigm, and that such a powerful paradigm needs, for its successful application, likely, support of a science that is deeper and broader in the scope than what has been offered with computer-centered view of the field.

It started to be also realised that the old vision of the field makes it increasingly difficult to get proper financial support for the most the attractive but visionary challenges. Other areas of science and technology started to be in that more successful also by "taking the cream" of the Informatics as a discipline.

Finally, decreasing enrollment of students in some countries and increasing problems to incorporate the field in a proper form into the high school education, finally forced informatics community "to open the eyes" and to start to search why the field stopped to attract best student minds.

5 What to learn from Physics?

Physics is a natural science per excellence. Deepness and broadness of its laws and limitations; understanding of the phenomena and processes and impacts of all that knowledge led a famous physicists, E. Rutherford, to say (in 1912) that *In Science there is only Physics: all the rest is stamps collecting.* a well known exaggeration having its deep point.

What is actually physics about? Some say, physics is about matter and energy; others that it is about space and time and the rest is stamps collecting. Exaggerations that have again their points.

There have been, of course, other views of physics. Originally, physics used to be developed within *Natural philosophy*. In the 17th century physics was seen as "dealing with the stuff one can handle between fingers". At the end of the 19th centuries it was believed that the laws pf Newton and Maxwell were correct and complete laws of physics. Lord Kelvin got infamously famous for his prediction: *There is nothing new to discover in Physics* short time before two main discoveries in physics: quantum physics and relativity theory.

However, the discovery of quantum physics and relativity theories have shown how deeply wrong previous views were and new discoveries changed the physics radically. Moreover, they put it into another depth and breadth - all that with enormous impacts on our understanding also of the "stuff we can handle between fingers". For example, quantum theory is nowadays needed for understanding properties of superfluids, functioning of laser, the substance of chemistry, the structure and function of DNA, the existence and behaviour of solid bodies, color of stars, ...

In addition, Physics, as the fundamental science, started to explore space, time, black holes, matter and energy, and so on. It started to explore the universe from the Big Bang to the ever expanding horizons. Plank scale and superstrings are some of the hot problems on the agenda. Large Hadron Collider is currently the main experimental tool to explore deep nature and related to that is the LCD grid network of more than 100 000 computers. The idea of the Internet was also born from the needs to improve communication in order to better explore nature in its deepness.

By L. Smolin [Sm06], five main problems (grand challenges) of the current physics are:

- (*Problem of the theory of everything.*) To unify general relativity theory and quantum theory into a single theory (that could be then seen as a complete theory of nature).

- (*Problem of the interpretation of quantum theory.*) To solve the problem of foundation of quantum theory either by finding a clear interpretation of current theory or by finding a new theory without current inconsistencies.

- (*Problem of the unification of particles and forces.*) To find out whether all particles and forces could be described by a single theory that could explain all of them as following from a single fundamental entity.

- (*Problem of the constants.*) To explain how nature chooses values of constants in the standard model of nature.

- (*Problem of the black matter and energy*) Explain the nature of black matter and black energy or, if they do not exist, explain how and why is gravitation modified for huge sizes.

It is also of interest to look into methodologies physics has been used to deal with its problems. In short, one can say that Physics has been used all available methodologies that turned out to be useful. Let us mention two particular cases.

In the 17th century physics solved the long standing and key problem of the understanding of the direct motion by geometrizing the problem. That is by going into a (virtual) mathematical/geometrical friction-less space. In the process of doing this, physics was able to replace a mysterious concept of *impetus*, that assumed the existence of some (mysterious) spirit behind each motion, by the modern concept of the *inertia* and to come this way to the modern theory of motion. By achieving this physics *drove spirits out from the scientific thoughts* and opened the door to see the universe as running as a piece of clockwork.

Current highlight of the physics - superstrings theory - operates with the objects in 10 dimensional space. This theory has very high standing, in spite of the fact that it does not seem to be a testable theory - what used to be seen as a must feature of any theory to be accepted as a physical theory.

There are many other things Informatics can and should learn from the development of physics. Here are some of them.

Physics as the science has had so far practical applications exceeding that of any science before. In spite of that, the need to deal with immediate problems of the practice can hardly be seen as the main, or as the only, driving force of its development.[11] It has been rather curiosity and the need to extend our knowledge and understanding of the physical world, far beyond the one our senses can capture, that was behind Physics main discoveries and contributions.

Physics has made big progress even by exploring properties of particles that are not sure to exist (in some reasonable sense) or to develop theories we see no way to verify experimentally. Beauty, compactness, simplicity and surprising conclusions have been often enough in case no conflict with experiments have been recorded or predictable.

[11] In this connection of interest is the following position of J. Robert Oppenheimer, who directed Los Alamos Scientific Laboratory (see [St97]), *The things we learned [during the war] are not very important. The real things were learned in 1890 and 1905 and 1920, in every year leading up to the war, and we took this tree with a lot of ripe fruit on it and shook it hard and out came radar and atomic bomb.....*

It has been to a very large extend due to the capability of Physics to keep making its research space broader and broader, deeper and deeper and to look for its most fundamental elements that made not only knowledge physics produced, but also the impacts this new knowledge had, so remarkable.

5.1 How Physics and Informatics interact?

Interactions of physics and Informatics are of increasing interest. Let us mention two such areas.

5.1.1 Case study I What is an ultimate computer?

History of the attempts to have a full understanding of what a *computer* is is a nice illustration of the ways Physics and Informatics look at the world and on the interactions between them.

In the golden era of Greek mathematics, slaves, and not free men, were considered as only those to perform (tedious) calculations. In the 18-19th century the term *computer* was used for young ladies that were doing calculations in manufactures. After the clock superparadigm got a momentum, computers started to be seen and developed as physical devices. The first computer revolution came when uring and others liberated, and very successfully, the concept of computer from its physical substance. By doing that Turing, Church and others were also able to set up a bound/barrier, called nowadays *Turing or Church-Turing barrier*, concerning the power of all potential computers.

Development of modern computers that started second computer revolution and a need to get deeper insides into the computation processes and their potentials as well as limitations, brought an understanding that a variety of the models of (universal) computers is needed - but all of them were liberated from the physical substance though the laws of classical physics were kept implicitly in mind when evaluating their potentials.

Discovery of the Landauer's principle that related information and energy in a deep way was an important step on the realisation that physical laws may influence those of information processing. Discovery that quantum computers could be more powerful than classical brought definitely back a need to pay attention to the physical substance of computers. Moreover, the emergence of Internet demonstrated as realistic the idea of a global computer (network) that can be seen as an endless computer that never terminates and is filled constantly with non-uniform inputs . That brought still another surprising ideas how an "ultimate computer" could be seen. All that brought back also the old quest to discover and design a model of computers that would be able to beat Turing barrier.

Current understanding is that *computer is a physical device that helps us to proceed information by executing algorithms.*

The idea that universe is a sort of quantum computer brought up another approach to a search for limitation of the computation potential of nature. Seth Lloyd calculated that an *ultimate laptop*, with one litter of volume, could not perform more than 10^{51} very elementary operations per second. Moreover, universe started to be considered as a (quantum) information processing systems that has been able so far to store, from its big bang, not more than 10^{92} bits and perform not more than 10^{122} of elementary physical operations (again by S. Lloyd).

How about computing at the Planck scale level? Next challenge concerning limitations for computation.

A variety of approaches have recently been worked out to come up with more powerful models of computers. One approach is based on a generalisation of so called internet computer. (A computer that never stops working and continuously evolves in an uncontrolled way). Various other approaches are based on new physical theories that do not seem to contradict our current understanding of the physical world. One of the main subgoal is to find out whether there can be a model of computer on which one could solve efficiently **NP**-complete problems in the physical universe. There have been proposals for amorphous computing, wetware computing, time-travel computing, quantum non-linearities computing; soap bubbles, protein folding, black holes computing, Malament-Hogarth space time,.... However, it is believed by many that **NP**-complete problems cannot be solved in polynomial time, but it can be useful for physics to explore various ideas for so powerful computers. In connection with that Scott Aaronson suggested as a physical principle: **NP**-complete problems are intractable in physical world.[12]

Of a particular interest are cellular automata as a model of universal computers. Cellular automata have been originally introduced to give a solution of one of the main scientific questions of Turing time: *Can machines reproduce themselves?*, by S. Ulam and A. Turing. Cellular automata can be seen as physics based model of information processing world and at the same time as information processing based model of the physical world. As such they can be a good platform to study both worlds. Moreover, cellular automata can be seen as the simplest systems interactions in which can produce very complex and even chaotic phenomena. In addition, cellular automata can be

[12]Observe that **NP**-completeness is one of the most useful concepts in sciences. According to Google scholar there has been more than 4700 (3200) [500] papers in physics/chemistry (economics) [music] referring to **NP**-completeness.

seen also as a discrete variant of partial differential equations and as such to express and study complex continuous physical processes. Physically, they are the most appropriate and interesting model of computation.

5.1.2 Case study II - Impacts of Quantum Information Processing

There are four major impacts of the discoveries in quantum information processing that led to an understanding that a much broader a deeper view of informatics is needed not only in order to discover the laws and limitations of information processing world, but also, at least very likely, to develop more powerful information processing, transmission and security technology.

The first one is the discovery that if quantum effects are used some information processing tasks are possible that are not possible in case only phenomena of the classical world are employed. Quantum teleportation is the most famous example of this type.

The second one is the discovery that using quantum resources some classical information processing tasks can be solved in much more efficient way than it is (or at least it seems to be) the case if only classical processes are used and some communication problem can be solved with exponential speedup.

The third one is the discovery that some theorems of information processing, dealing with the classical data only, stop to be (fully) valid in case classical data are represented quantumly.

The forth one is the discovery that the knowledge of limitations of information processing in a more general physical setting than the classical physics is, for example of the so-called quantum no-cloning theorem, allows to create unconditionally safe cryptographic processes for some tasks, as it is the case of the quantum generation of the classical shared random keys.

All that required that a much broader view of the physical and information processing worlds is needed in order to get a proper understanding of the laws and limitations of the information processing and communication and to develop theories that could lead to full harvesting of the power which has not been recognized so far.

Still another important discovery is that one can consider physical worlds that has not been experimentally confirmed but that do not contradict relativity theories though they are more powerful than quantum physics is. This, and other developments in and around quantum information processing strongly imply that what is needed in order to understand fully our physical world and information processing worlds is to explore a whole (huge) family of the potential information processing worlds.

Of interest is also that results in quantum information processing led not only to a new view of Informatics, but also of Physics - of its quantum world and its potential. For example, it has been mainly through the outcomes of quantum complexity theory that it got reasonably clear that quantum computers could pay of. And it has been mainly due to the ideas from the coding theory and theory of fault-tolerant computation that it got reasonably clear that apparently devastating effects of quantum decoherence, that can destroy quantum information processing evolution of pure states exponentially fast, can be fought with successfully in polynomial time and therefore unlimited, in time and space, quantum information processing is feasible under quite reasonable conditions (due to so-called *thresholds theorems*). All that demonstrates close relations between laws and limitations of the physical and information worlds.

6 What to learn from Chemistry

Some consider chemistry as the science that deals with substances and some as an applied physics.

Chemistry has actually a longer history than physics. For a long time it was strongly tied to technology. Chemistry needed long time to obtain the freedom to have development independent from the technology behind.

Already in the 16th century there were remarkable advances in the field that might be called nowadays chemical technology.[13] In spite of that the Chemistry, as a modern science, can be seen as being born only in the second half of the 18th century. However, only at the end of 19th century chemistry can be seen as being changed from being a servant and adviser of the industry to the new role of being a creator of industries. The history of Chemistry seems to teach us also that experimentation and even technological progress are insufficient by themselves to provide a basis for establishing a modern science. Their achievements need to be correlated by an adequate intellectual framework which embraces the observable data and knowledge obtained, and, on the other side, it helps to decide at any moment the directions for the next developments, see [Butterfield].

Chemistry is also a good example that a significant progress can be made in a science when it overcomes intellectual obstructions that are checking its progress and directing it into wrong directions.[14] In case of chemistry these

[13] The smelting and refining of metals, production of glass-ware, pottery, development of explosives, medical substances, artist's material,...

[14] It took chemistry many centuries to free itself of the "atom" theory of ancient Greek science and philosophy, of similar simple ancient theories, and of the intellectual power of alchemy. Physics and astronomy had to deal with similar obstructions.

obstructions included outdated, but powerful, (pseudo)-scientific traditions as well as restrictive religious teachings - referred to as "God complex" in the sequel.[15]

Chemistry can be also seen, especially molecular chemistry, nowadays, as an information processing science. Molecules interact in such a way that they recognize other molecules, process this information and apply it. For example, some molecules can recognize cancer molecules and then destroy them. An understanding of such information processes should also be an inherent part of properly perceived Informatics.

7 What to learn from Biology

Concerning biology, and life sciences in general, the first special approach, during the first scientific revolution, was influenced by the 17th century attempts to explain everything by mechanical processes. The most significant success of this approach seems to be Harvey's explanation of the circulation of the blood. Leibniz went even so far to claim that everything which take place in the body of a man or an animal is as mechanical as the things that happen inside the clock. Descartes considered a man and also the universe as automatic machines.[16]

It is of interest to observe that, in a way, thanks to the DNA and genetic code, the information processing superparadigm entered the life sciences sooner than computers and quantum information processing brought it to the physical sciences. One should also note that virtually all forms of life, including humans, are descendants from their ancestors by the transmission of DNA and therefore the DNA information storage function alone is the reason enough to regard life as, in essence, an information processing process. One can therefore say that, in a deep biological sense, information processing is as much a part of the life as eating and breathing.

One should also observe that cells of the living beings are actually tiny computers and that, comparing to the even best of human made computers, living cell are information processor of extraordinarily efficient design and performance. The DNA in a cell contains enough information not only to make

[15]Big progress in chemistry was initiated when it started to focus on objective facts and (quantitative) characteristics of the field - surprisingly enough, for sa long time results of weighting and measuring were no decisive factors in the formation of chemical doctrines and principles.

[16]It is of some interest to note that Newton felt that though the system of Descartes necessitated a Creator who had set a clockwork into motion in the first place, the system was in danger of making the God superfluous once the universe had been given a start.

human (animal) body, but also to operate it for lifetime. Step by step it started to be understood that biology is nowadays an information processing science.[17]

DNA computing has been developed already for quite a while as a form of computing that uses DNA, biochemistry and molecular biology to do computation. For example, in 2002 a programmable molecular computer composed of enzymes and DNA molecules was announced (by scientists from the Weizmann Institute of Science in Rehovot); in 2004 a DNA computer was announced by, E. Shapiro et al., that was coupled with an input and output module which would theoretically be capable of diagnosing cancerous activity within a cell, and releasing an anticancer drug upon diagnosis; In 2009 bio-computing systems were coupled, by scientists from Clarkson University, with standard silicon based chips for the first time.[18] In December 2009 a working transistor was announced that was made of a single (benzene) molecule (attached to gold contacts) by a team from Yale University and from South Korea.

It is also of interest and importance to realize that the development in biology got into the point that one can see as one of its main challenges to understand cells - an important information processing devices - at least to such an extent that would allow to diagnose their malfunctioning and then to cure or repair them. Cells, and biological systems in general, can be seen as well-organized autonomous systems of many discrete interacting components and biology accumulated already huge amounts of knowledge about their basic components. This is especially true for the main components/macromolecules of cells: nucleic acids polymers - DNA and RNA - proteins and membranes. However, all that provides still very little insights into how cells indeed work as a whole and how they process information. What is therefore much needed, and actually of the crucial importance for biology, is to understand cells and their main components, and also other biological elements, as systems of interacting components - by models that abstract from the underlying chemistry. To do that through continuous mathematical models would require to simulate too huge amounts of differential equations what is unfeasible. A way out seems to be to create more automata-like models of the cell behaviour in the form of (several) discrete, concurrent, asynchronous and heterogeneous models of interacting elements, to study its behaviour and the emerging properties and to

[17]Potential of DNA for computing is very large. Indeed, DNA in each cell contains 3 to 5 millions of base pairs; it can be seen as 2m long and 2nm thick and with 750 MegaBytes. In a human body we have 3 billions of cells, DNA as 5×10^9 km long and with 7.5 OctaBytes.

Nature uses DNA in certain ways, mainly using proteins. However, there is no reason not to assume that we can try to use DNA/RNA in different ways than nature and to build on their bases nano-devises including nano-computers.

[18]L. Cardelli's web site is one of the best places for informaticians to look for papers and talks on molecular computing.

try to improve the models on the base of new discoveries of biology and also to put this way before biology, on the bases of simulation outcomes, new questions to answer by a classical biological research. The interaction models of the above type seem to be some of the most complex ones in Informatics and therefore in order to meet needs of biology and to be able to help biology, Informatics has to develop much further some of its most intriguing theory concerning specification, design, analysis, verification, validation and simulation of very complex concurrent systems.

We can also see that some of the most important questions biology is to answer are such that they require involvment of Informatics, and on many levels. In particular these are the following questions:

- How a single fertilized cell develops into a multicellar organism?
- How the central nervous system process information?
- What is life?
- How much is life characterized by what it does, especially how it process information, and how much by what it is made from?
- Is an understanding of conscious in or beyond the reach of current science?

8 What to learn from Mathematics

Let us first try to see what mathematics is about.

During the Golden era of Greek science mathematics was seen as an area of knowledge centered about such concepts as numbers, magnitudes, structures (and space) [and change]. Interesting enough current server of the Academia Europaea, its Mathematics section, presents mathematics again as dealing with quantities, structures, space and change.

Encyclopedia Britannica specifies mathematics as *the science of structure, order and relations that has evolved from elementary practices of counting, measuring and describing shapes of objects - it deals with logical reasoning and quantitative calculations, and its development has involved on an increasing degree of deduction and abstraction of its subject matter*. German *Meyers Grosses Taschen-Lexicon* writes: *Die moderne Mathematik sieht ihre Aaufgabe v.a. in der Untersuchung sogenante Strukturen, die durch die in einervorgegebenen Menge beliebiger Objekte definierten Relationen und Verknüpfungen bestimt sind.* French *Le petit Larousse* see mathematics s follows: *Science qui étudie* *par le moyendu raisonnement déductif les propriétés d'êtres abstraits (nombres, figures geéométriques, fonctions,espaces, etc.) ainsi que les relations qui s'établissent entre eux.* In T. Gowers' popular book "Mathematics", mathematics is presented as the science studying abstract (mathematical) models. CRS Concise (3942 pages) Encyclopedia of Mathematics, 2003' writes: *Mathematics is a broad-ranging field of study in which the properties and interactions of idealized objects are examined. Whereas mathematics began merely as a calculation tool for computation and tabulation of quantities, it has blossomed into an extremely rich and diverse set of tools, terminologies, and approaches which range from the purely abstract to the utilitarian.* Folklore says: *Mathematics is what mathematicians carry on* and that *mathematicians carry on a highly sophisticated intellectual activity which is not easy to define.*[19]

Observe now that mathematics gained very much by extending the concept of number. At first by adding unit fractions, then all rational numbers (already in Mesopotamia), later irrational numbers (through magnitudes at first), complex numbers, quaternions and so on. In addition, the related concept of cardinality was extended from natural numbers to several types of infinity. Mathematics moved from the study of computability to the study of incomputability in the theory of recursive functions, which was also very fruitful. It moved from the study of two- and three- dimensional spaces, and their curves, areas and bodies, as well as the relations between them, with Euclidean metrics, to the study of many-dimensional, and even infinitely-dimensional, spaces with very general notions of curves, areas, bodies, metric, topology and continuity. Even the concept of dimension was extended to non-integers. Mathematics moved from the study of Euclidean geometry to projective, analytic, differential, algebraic and non-Euclidean geometry. It moved from emphasis on absolute truth to the development of truth in terms of probability, statistics, fuzziness, approximation and so on. Mathematics moved from finding mathematical concepts and relations to describe phenomena of nature to mathematisation of thoughts processes through formal generation, deduction and proof systems.

It took centuries for mathematics to move from considering numbers as fundamental objects to seeing continuum as the fundamental object and set theory and logic as its basic building blocks. In all such cases, the extensions of the scope brought also new techniques to solve old problems, and that was actually the main underlying goal, based on and inspired mainly by centuries

[19] All that fits with our view that mathematics can and should be seen as an important part of informatics - as science that deals with abstract object specified by information (axioms) about their properties. However, all that would require much more elaboration and to go deeper into the history of mathematics.

old experience with the power of generalisation and abstraction.

In order to see even better grounds for our fundamental position concerning the relation between Informatics and mathematics (seeing mathematics as a very important of informatics - for benefit of both) let us look, at least briefly, on the development of views on subject, essence and goals of mathematics. To do that let us start at first with a brief summary of the research space of mathematics.

- Up to 1550 the concepts of mathematics were mainly immediate idealizations of or abstractions from experience.
- After 1550 mathematics started to be dominated by intellectual constructs derived from the recesses of the human mind. (One can say that for genesis of her ideas mathematics gradually turned from the sensory to intellectual faculties.)
- As a result mathematicians started to realise that mathematics is not a body of the truth about nature.[20]
- Around 1900 mathematics broke away not only from philosophy, but also from nature and science.

All that naturally gave rise to the following fundamental question. To which world belong the subjects of mathematical study. Of course, there can be many positions on such a philosophical issue. Here are some from the recent times:

- Hermite: *I believe that the numbers and functions of analysis are not the arbitrary products of our minds; I believe they exist outside of us with the same character of necessity as the objects of objective reality, and we find or discover them and study them as done by the physicists, chemists and zoologists.*
- Hardy (1928): *Mathematical theorems are either true or false; their truth or falsity is absolutely independent of our knowledge of them. In some sense mathematical truth is a part of objective reality.*[21]

[20] H. Poincare, considered as one the last universal mathematicians, was a conventionalist. He saw scientific laws as conventions whose establishment is driven by experience that is not driven by their correctness, but by suitability with respect to prevailing convention.

[21] Observe that originally it was Plato who believed that: (1) there is an objective, universally valid reality consisting of the forms, or ideas; (2) mathematical laws, eternal and unchanging, are the essence of reality; (3) physical world is but an imperfect copy of the ideal world, the one mathematicians and philosophers should study; (4) the world perceived by the senses is confused and deceptive and in any case imperfect and impermanent.

To summarize what was presented and discussed above, we can say that at the very beginning mathematics tried to concentrate on the study of problems of the physical world by transforming them to the mathematical/information worlds and later, and now, she has realized, that it is actually her main task/intention to study the laws and limitations of various information processing worlds (in a good belief that this will, or at least could, pay of also for the study of the physical world).

In this connection of interests are thoughts of John von Neumann:

- The sciences do not try to explain, they hardly try to interpret, they mainly make models. By a model is meant a mathematical construct which, with the addition of certain verbal interpretations, de scribes observed phenomena. The justification of such a mathematical construct is solely and precisely that is expected to work.

that could be modernised by replacing the word "mathematical" by "informatics".

There are other things Informatics can learn from the history of mathematics:

During the great period of the Greek science, 600-300 BC, mathematics was borned as abstract, independent and deductive science, actually as a liberal art closely related to philosophy, and also the concept of proof was borned. In spite of an enormous intellectual achievements of that period all that was practically abandon for almost two thousands years. There have been several reasons for that that are worth to notice and remember here. The perception of mathematics of that period was too narrow (concentration on geometry of simple geometrical objects, incapability to accept irrational numbers, infinity and continuity and too strong requirements on proofs. By insisting on a unity, completeness and simplicity, and by separating speculative thoughts from utility, they narrowed people's vision and closed their minds to new thoughts and methods. Their insistence on exact concepts and proofs was also a defect so far as creative mathematics is concerned. Another reason was nicely expressed by Cicero: *The Greeks held the geometers in the highest honour; accordingly, nothing made more brilliant progress among them than mathematics. But we have established as the limit of this art its usefulness in measuring and counting.* Moreover, celebrated Greek mathematics/geometry ignored computational needs of society; it was also based on a wrong view of the importance of observations and so it could hardly help other sciences and society in general.

Observe also that the concept of proof did not play very important role in mathematics from 200 BC till about 1870. At the end of 17th century mathematicians had virtually dropped the idea of clearly defined concepts and deductive proofs. Mathematics was so inspired by the developments of science and vice verse that a fusion of mathematics and vast areas of science was detectable and mathematics started to rely more and more on scientific results to justify its own procedures. In the 18th century mathematics and physics virtually merged, and the physical meaning of the mathematics guided the mathematical steps and often supplied partial arguments to fill in non-mathematical steps. The above period of mathematics, in which mathematicians did not care about foundations of their work is sometimes called *heroic age of mathematics*.

A view of that time: *Why to go to the trouble of proving by complicated reasoning things which one never doubts in the first place, or of demonstrating what is more evident by means of what is less evident.* Descartes, one of founders of modern science, believed that axioms of mathematics are true and mathematical reasoning is sound on the conviction that God would not deceive us and that to deny the truth and clarity of mathematics would be to deny God.

9 General lessons from the history of science

There are many other things Informatics can learn from the history of science. let us discuss few of them.

- Greek science, especially mathematics, made enormous contribution to science. In spite of that her main outcomes and messages used to be forgotten almost for two thousands years. For several reasons: (1) Mathematics was not able to make several natural steps to extend its scope and to deal with a broader range of scientific problems; (2) Mathematics ignored too much actual needs of other sciences and society; (3) Mathematics started to be too rigid and due to that put strong restriction on its potentials of creativity.

- From time to time, in any area of knowledge, usually after a big progress, new accumulated knowledge suggests that in order to make even bigger progress a radically new perception of some fundamentals of the field is needed. To make such a revolution in a field, one has usually to rethink very fundamental beliefs and assumptions and to develop a new, deeper and broader philosophical standpoint. In short, a new and visionary approach to the perception of the field is what is needed in such situations.

- It is often emphasized that great success of the science in 20th century has been to a large extend a triumph of mathematics and the most successful sciences of that period, physics, astronomy and chemistry are seen as being formulae and equations driven. Behind that one usually see two facts; the key underlying phenomena of these sciences exhibited conceptual simplicity, regularity, symmetry, periodicity and that reductionism as research paradigm was a way to get sufficiently important and precise predictions about phenomena of the nature. This is however, not the whole truth. Enormous success of 20th century science came when power of mathematics as a methodology to understand nature started to be combined or extended with the power of informatics-driven methodology and tools before the end of the second world war. Without that there would hardly be great success of cryptography, of the atomic bomb and never an attempt to get men to moon. New methodology and its tool brought a proper marriage of tools to understand WHAT is going on in nature and HOW to make use of it.

  A shift of emphases of society, due to its main needs, to life-, earth-, behavioural and social-sciences brought a new understanding that mathematical approach, formula- and equation-driven, is unlikely to work to deal with not only HOW but also WHAT in these areas of science with very complex phenomena that exhibit little of regularity, symmetry and periodicity, and in putting knowledge to use. One can see also limits of reductionist approach. Though in principle one could describe complex systems in these areas of science by enormous number of differential equations that could be practically unfeasible and of such a use as the idea to use set theory to deal with a potential to-put-men-to-Mars project.

10 General lessons from Technology

There is a lot Informatics can learn also from the development of technology.

- The overall and long term impacts of a radically new technology are often far broader and more significant that than contemporaries, exposed to its continuous developments and impacts, are able to conceive.

- The most important overall impacts the developments a new technology keep initiating are often of a much more profound type than the technology can directly bring - new technology can result in a new scientific view, methodology and an understanding of the world.[22]

[22] Inventions of telescope and microscope (without using theory of optics) changed several

- A new technology can lead to the creation of a new superparadigm not only for technology and science, but for the whole society. Important examples of this type are clock, steam engine and electricity.

- The history of mankind teaches us that no matter how radically new a technology has been, it could have an immense impact on science, technology and society at large, only when a very new way of thinking and seeing the world had already been emerging for quite a while in the science and society that could make then fast a full use and rapid development of this technology. The history of mankind also demonstrates that the main long run contribution of such a technology has been to help to develop much further this new way of seeing, understanding and managing the world, and to help to make this new view of the world more coherent and more powerful.[23]

  From the historical perspective, the development of powerful electronic computers can be seen as an inevitable, though radically new, achievement of the technology and science that have been needed to speed up the development of this new view and understanding of the world. This understanding has been slowly developing for centuries and was accelerated by the developments in science, especially in mathematics and logics, at the turn of century. It placed more emphasis on information processing, formalization and reasoning than on processes of the "physical world" - the ones that used to be emphasized during the periods in which physics was considered the queen of science and the backbone of modern philosophy. From this point of view, it is only quite natural that those areas of science which were initiated by new technology started sooner or later to shift their attention from the problems of the development of this new technology and of its utilization to the more general and, on the long run, far more important problems of developing a radically new understanding of the world. That could bring to the mankind not only new knowledge but also, inevitably, new powerful tools. Such a development of impacts of an area of science much revitalised by a new technology is natural, important and necessary. Such a development has also back impact on the new underlying technology. Indeed, it provides

areas of science. Almost all mathematicians of 17th century worked on optics, light and lenses.

[23]This is, for example, how one can see the impact of telescopes and microscopes. A new way of of the universe started to be developed long before the invention of telescope. The telescopes only helped to make these new views to develop into a coherent theory. In a similar way one can see the role the microscopes played in science. Computers can be seen as being both microscopes and telescopes of almost unlimited power.

this technology with significantly new motivation, concepts, insights and guidance how technology should develop.[24]

- History also teaches us that huge progress in technology is not always based by significant new discoveries in basic science, Step by step improvements in technology, based on the progress in understanding and mastering technology, can derive a new quality technology and that in turn can allow science to open new lines of inquires and to attempt to deal with very fundamental problems that were out of rich before.

- New technology can also allow to study better fundamental phenomena in nature (and society). This is mainly due to the fact that those natural processes that a man-made technology induces, or utilizes, are often much simpler than the most complex ones that occur in nature (or society), and may follow simpler, more transparent, and therefore more easy to discover and comprehend, laws and limitations, than those that may occur in nature in general.[25]

11 Epilogue

What has been discussed in this paper are roots and impulses that lead to a new perception of Informatics and not the ways and possibilities to making this perception to get fully accepted. This is, of course, another and a very complicated problem with many aspects as summarized, at least partially, in [Gr10a].

[24]Observe, that once such a turn of emphasis in a new area of science happens then, inevitably, a conflict of interest arises. It is the conflict between the immediate interest of society and technology, to keep the technology to improve itself and to have the underlying science to keep concentrating on serving technology developments on one side and, on the other side, the conflict is between the interests and needs of this new area of science to liberate itself to a larger and larger degree from serving technology only, or even mainly, and to concentrate on its own development towards its main, bigger, goals on the basis that technology is for this science mainly an important motivation area and one of the main application domains. It is also natural that the size of such a conflict, that is actually the conflict between the interests of science and technology and between the short and long term goals of society, depends on the amount of money involved much more than on other issues. It is also natural that new orientation of the "underlying science", that has been so much related to technology, namely targeting towards its main long term goals, can be seen, from technology point of view, as a departure to the areas of too little relevance to the technology/practice.

[25]This is also one of the main reasons why it is so important to try to build quantum computers - the process of building them, and also managing them, can reveal a lot about the mysteries of the quantum world.

In this connection it is of worth to realize that it is naturally quite hard to free Informatics from the views imposed and self-imposed by the magic power of the information precessing and communication technology (as well as from the pressure of funding agencies expecting almost immediate applications).[26]

There are, and have always been, many other obstacles for a new view of a scientific discipline to get through. Some scientists will never accept views that put them either "out of business", or at least on the "side road". However, nowadays there are also good reasons to assume that the resistance cannot be so strong as in the past when an area of science could be under a strong and almost full control by few powerful (due to outcomes and/or positions) authorities. The needs of society and science and the existence of authorities, especially institutional, with big goals, and needs to maximise the outputs and contributions of science and technology, also in long terms, and with money can much help to overcome obstacles caused by traditional scientific conservatism.[27]

[26] It is also amazing how long astronomy could not get rid of the influences of Ptolemaic and Copernican views, no matter how strong were the needs and how persuading was the evidence.

[27] Would it depend only on science and technology people, mankind would hardly already reached the moon and to benefit enormously from the side effects of this mission, such as mobiles, Internet and so on.