Part MMCCCXV

Future in the informatics era - Chapter 4

CHAPTER 4: NEW PERCEPTION of (SCIENTIFIC) INFORMATICS

CONTENTS

PROLOGUE

HOW CAN INFORMATICS MEET ITS CHALLENGES

In the first three chapters we tried to demonstrate that paradigms, laws, methods and tools of information processing and transmission are driving force of evolution that can be seen as coming (very) soon to a Singularity era in which a merge of biological and non-biological intelligence and creativity can have enormous, hard to imagine consequences.

To meet fully and fast its historical challenge, a new (visionary) perception of informatics, much broader and deeper, seems to be needed.

This is the subject of this and few next chapters.

DEEP THOUGHTS - I.

- Imagination is more important than knowledge.

  Albert Einstein

- The modern version of the grand question "Mind or Matter?" is "Information or physics?

  Frank Wilczek, 2004

- New scientific truth does not win because its adversaries get convinced and open their eyes. It wins because its adversaries die and a new generation of scientists comes who this truth already knows.

  Max Planck

- You have to know a lot to ask good questions.
- You have to know a lot to state new grand challenges before science and technology.

For development of science it is of large importance to know:

- What we know that we do not know;
- What we do not know that we do not know;
- What we think that we know but don't

BASIC QUESTIONS

- Should recent developments in science and technology be understood as giving rise of a need for a new, much broader and deeper, perception of Informatics?
- What are current Grand Challenges of "new" Informatics - from theory, technology and application points of view?
- Should recent developments in Informatics and other academic disciplines be seen as showing an emergence of a new, Informatics driven, general methodology of large importance for all sciences, technologies, and all major areas of functioning of society?
- Should new Informatics be seen as both a new Queen and new Servant of sciences, technologies and so on?

WHY IT IS VERY IMPORTANT FOR SOCIETY to PERCEIVE PROPERLY INFORMATICS?

- Wrong (too narrow and shallow) perception of a science/technology discipline usually leads to:
  - Wrong emphasis on main goals, methods and value systems within the given area of science.
  - Wrong/weak support of that science discipline by society and money granting agencies.
  - Wrong position of such a science discipline within the whole academic community.
  - Wrong orientation and low impact of the education.

BASIC OBSERVATIONS

- Old-fashioned view of any discipline usually hinders thoughts and intellectual progress in that discipline.
- Time came to clear up the philosophical and practical confusion of contemporary computer science.
- Central to the new perception of Informatics presented here are:
  - A series of discoveries concerning the key role and large potential of the information precessing in nature that are not much consistent with prevailing perception of Computer Science.
  - Discoveries showing enormous potential of new, informatics based methodology.
  - A series of discoveries indicating that such goals as a global computer, cell-, molecule- and brain-inspired computers seem to be realistic goals.
  - A series of events demonstrating that one can hardly have very significant innovations without employment of informatics thinking and tools.
  - Discoveries showing that all sciences converge to Informatics and all major technologies converge to ICT.

TWO MEGAGOALS and THEIR NEEDS

Expected exponential growth of performance and miniaturization of ICT, already for quite a long time, allows science, technology and medicine to see as perhaps their two main megagoals (what used to be seen as science fiction till recently):

- **To beat human intelligence.** To create superpowerful non-biological intelligence and its merge with biological intelligence.
- **To beat human death** - to beat as much as possible natural death.

These megagoals also require much broader and deeper perception of Informatics

- When you reach for stars you may not quite get one, but you won't come with a handful of mud either.

Leo Burnett

WHY a NEW PERCEPTION? - BASIC PHILOSOPHICAL MOTIVATION

- From time to time, in any area of knowledge, usually after a big progress, accumulated knowledge suggests that in order to make even bigger progress a new perception of some fundamentals of the field is needed.
- To make a revolution in a field one has usually to re-think fundamentals of the discipline.
- To make a revolution in an area of science/technology, usually an approach based on a new, deeper and broader philosophical standpoint is needed - in short, a visionary approach is what is much needed.

Observation from 17th century:

Men who fashioned modern science, mathematicians in their general method and concrete investigations, were primarily speculative thinkers and visionary scientists who expected to apprehend broad, deep, but simple, clear and immutable mathematical principles, either through intuition or through observations and experiments.

By John Herman Randall: Science was born of a faith in the mathematical interpretation of nature.

New vision: New science is being born of a faith in the information processing interpretation of nature.

OLD/CURRENT PERCEPTIONS of

INFORMATICS - COMPUTER SCIENCE

FIRST IMPORTANT VIEW

The first widely accepted and still dominating views of computer science were presented in a very cleverly written, and much influential, paper of Newel, Simon and Perlis, published in Science in 1967, that well captured the perception of the field at that time.

The basic ideas presented in their paper were:

"Whenever there are phenomena there can be a science dealing with these phenomena. Phenomena breed sciences. Since there are computers, there is computer science. The phenomena surrounding computers are varied, complex and rich."

SECOND EARLY and INFLUENTIAL VIEWS of COMPUTER SCIENCE

A citation from an article on ACM computer science educational curricula (1989) - still not seen as obsolete.

- **Old debate continue. Is computer science a science? An engineering discipline? Or merely a technology, an inventor and purveyor of computing commodities? Is it lasting or will it fade with a generation?**

BAD EDUCATIONAL IMPACTS of the name "COMPUTER SCIENCE"

- It leads to a too narrow, shallow, and technology-oriented interpretation of the field.
- It is reminiscent of the 19th century attempt to create ""microscope science" and the 20th century attempt to create "poultry science" (and to have a "science of robbering" as a part of the history science).
- The educational impact of the name "computer science" could perhaps be compared with those which the name "drill engineering" could have on the education of dentists.

OTHER VIEWS of COMPUTER SCIENCE - I.

- Computer science as a science is the study of scientific problems related to the design, behaviour and utilization of computers.

  Computer folklore

- Computer science is a science of the artificial that studies artifacts and contributes to the design theory and managing complexity.

  Simon, 1969

- Computer science as a science is, in the narrow sense, the study of symbolic representations and manipulations of these representations, and, in a broader sense, the study of representations and manipulations of knowledge.

  Hopcroft-Kennedy report, 1989

- Computer science is a discipline that deals with representation, implementation, processing and communication of information.

  Ullman report

- Computer science is the systematic study of computing systems and computations. The body of knowledge resulting from this discipline contains theories for understanding computing systems and methods, design methodologies, algorithms and tools, methods for testing concepts, for analysis and verification, and knowledge representation and implementation.

  US-Congress Report, 1992

OTHER VIEWS of COMPUTER SCIENCE - II.

- Computer science is the study of computers and what they can do.

  An influential publication of the National Research Council in USA, in 2004, namely *Computer science: reflections on and from the field*

- Computer science is the study of computers, including their designs (architecture) and their uses for computation, data processing and systems control. Its core disciplines are: architecture, software, operating systems, information systems and databases, theory (computation methods and numerical analysis, data structures and algorithms).

  Encyclopedia Britannica (2006)

ONE SPECIAL VIEW of COMPUTER SCIENCE

- Computer science is the study of computers and what they can do - the inherent power and limitations of abstract computers, the design and characteristics of real computers, and the innumerable applications of computers to solving problems.
- Computer hardware and software have been central to computer science since its origins.
- Computer scientists seek to understand how to represent and to reason about processes and information. They create languages for representing these phenomena and develop also methods to analyse and create such phenomena.
- They create abstractions, including abstractions that are themselves used to compose, manipulate and represent other abstractions.
- They study the symbolic representation, implementation, manipulation and communication of information.
- They create, study, experiment on, and improve real-world computation and communication systems as well as methods to operate such artifacts.

Reflections on the Field - reflections from the field, National Research Council, US, Mary show, 2004

Dijkstra: "Computing science is - and will always be - concerned with the interplay between mechanized and human symbol manipulation usually referred to as "computing", and "programming", respectively. It is located in the direction of formal mathematics and applied logic, but ultimately, far beyond where those are now,..."

Dijkstra: Computer science is as much about computers as astronomy is about telescopes.

Perhaps the most significant recent step in the correct direction has been that of P.J. Denning in the ACM Communications (July 2007), saying that science behind computing is a natural science.

Edgar Dijkstra

WHAT SUPPORTS CURRENT VIEWS of COMPUTER SCIENCE

1. General views of the underlying problems.
   - Computer science deals with **immense differences in the scale of phenomena**. From systems manipulating atoms and molecules, as well as individual bits in computers, to trillion operations per second and highly complex software systems and problems/solutions describing languages.
   - To deal with these problems computer science has to create **many levels of abstractions**. It has to create intellectual tools to conceive, design, control, verify, program and reason about the most complicated of the human creations.
   - All that has to be done with the **unprecedent precision** because the underlying hardware is a universal computer and therefore a chaotic system.
2. **Enormous power** of computation and communication systems.
3. **Enormous difficulties** with design complex, reliable and secure software.
4. Strong feelings that computer science is deeply intertwined with engineering concerns and considerations. That it concentrates much more on the **how**, than on **what**, which is more the focal point of physical sciences.
5. Computer science advances are often demonstrated by **dramatic demonstrations** and it is often that the (ides and concepts tested in the) dramatic demos influence the research agenda in computer science.

WHAT is MATHEMATICS? - OFFICIAL VIEWS

- Greek views and their developments.
  - Mathematics as a science centers around such concepts as number and magnitude.
  - Mathematics as a science centers around such concepts as number, magnitude and form.
  - Mathematics as a science centres around such concepts as number, magnitude, form and change.
- Encyclopedia Britannica: Mathematics is the science of structure, order and relations that has evolved from elementary practice 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.
- Mathematics is deductive study of numbers, geometry and various abstract constructs (the Longman Encyclopedia, 1989).
- Soviet encyclopedia: Mathematics is the science *to study spacial forms and quantitative relations of the real world.*

WHAT is MATHEMATICS? - PERSONAL VIEWS

- Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true.

  B. Russel (1917)
- Mathematics in general is fundamentally the science of self evident things.

  F. Klein - the leading German mathematicians at the end of 19th century.
- When mathematicians refer to reality, they are not certain; and as far as they are certain they do not refer to reality

  A. Einstein (19??).
- Mathematics is what mathematicians carry on and mathematicians carry on a highly sophisticated intellectual activity which is not easy to define. *Mathematical folklore*
- Mathematics is the science that draws necessary conclusions.

  B. Peirce(1809-1880)
- Pure mathematics is the class of all propositions of the form *p implies q*, where p, q are propositions.

  F. Klein
- Mathematics in general is the science of self-evident things.

  F. Klein (1849-1929)
- Mathematics is nothing more than a game played according to certain simple rules with meaningless marks on paper.

  D. Hilbert

WHAT IS PHYSICS? - OFFICIAL VIEWS

- Physics is the science that deals with the structure of matter and the interactions between the fundamental constituents of the observable universe.

  Encyclopedia Britannica

- Physics is the study of matter, energy and the relation between them. Physics today maybe loosely divided into classical and modern physics. Classical physics includes branches recognized and well developed before the beginning of 20th century: mechanics, acoustics, optics, thermodynamics and electricity and magnetism. Modern physics is concerned with behaviour of matter and energy under extreme conditions (small scale or rapidly moving objects).

  The Longman encyclopedia

- Physics involves the study of matter and its motion through space and time, along with related concepts such as energy and force.

  Wikipedia

- Physics is a general analysis of nature conducted in order to understand how the universe behaves.

  Wikipedia

- Physics is experience arranged in economical order.

  Ernst Mach

- One needs to realize that not only physics determines what computers can do, but what computers can do, in turn, will define the ultimate nature of the laws of physics.

  R. Landauer

WHY IS a NEW VIEW of INFORMATICS SO MUCH NEEDED? - I.

Recent results in the rapidly developing field of natural computing, have demonstrated that radically new and powerful information processing resources (for example quantum non-locality, superposition and parallelism), processes and devices exist in nature and, actually, existed abundantly far before the modern era of electronic computers.

Moreover, the nature made these resources and tools to play a very important role, especially for the functioning of living beings. Information processing is as crucial phenomenon of life as eating and breathing.

WHY IS a NEW VIEW of INFORMATICS SO MUCH NEEDED? - II.

The overall development of science and technology therefore naturally requires to explore such interesting and important phenomena and their power, potentials, laws, limitations and so on. To do that is also of the crucial importance for our understanding of the universe, evolution, life, brain, human bodies, functioning of society ....

- Two big discoveries led to an understanding that natural sciences are information processing driven.
- 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, how DNA computing could be performed and that it has a potential for remarkable efficiency.
- 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 results of Shor, in 1994-1996, that quantum computing could be

- These discoveries changed views on Physics and Biology that started to be seen and explored as being, to a significant extent, information processing driven sciences. From that it has been only a natural and logical step to see other natural sciences in this way, as being to an important degree information processing driven - and a new revolution in the study of natural and also other sciences has emerged.
- Of importance has been also an observation that there are primitive one cell organisms, like paramecium (from 50 to 350 μm in length), that do information processing par excellence in order to find foods, to avoid predators, to find a mate and to have sex - without having any synapses.
- All that resulted to a view that information processing

WHY IS a NEW VIEW of INFORMATICS SO MUCH NEEDED? - II.

There are also more pragmatic reasons why a new and more attractive perception of Informatics is much needed.

- With old view of the discipline, and to that adjusted education, the field stopped to be seen as much interesting and challenging for many very bright students.
- At the same time, for the overall progress of science, technology, medicine and almost all other areas of society, is of up most importance that the field develops as well and as fast as possible - and for that very bright students are needed.
- Not appropriate and even obsolete view of a discipline leads to the wrong overall orientation of the research and to creation of not sufficiently challenging challenges.
- Not attractive enough view of the field leads usually to a weak and wrongly oriented support of the field by society and money providing agencies.
- It is getting clear that in the future in all areas of human activities one can hardly have important developments in which ideas and tools of Informatics would not play one of the key roles - progress in most areas of society much depends on the progress in broadly seen Informatics.

CASE STUDY 1 – A PERSONAL VIEW

- The percentage of college freshmen planning to major in computer science dropped by 70% between 2000 and 2005.
- In an economy in which computing has become central to innovation in nearly every sector, this decline poses a serious threat to American competitiveness.
- Indeed, it would not be an exaggeration to say that every significant technological innovation of the 21st century will require to use some more or less sophisticated Informatics technology.

Bill Gates (2007)

CASE STUDY 2 - NEEDS OF TWO "MEGAGOALS"

Expected exponential growth of performance and miniaturization of ICT for quite a long time allows science, technology and medicine to see as perhaps their two main metagoals (what used to be seen as science fiction till recently):

- To beat human intelligence - to create superpowerful non-biological intelligence and its merge with biological intelligence.
- To fight natural death.

All that requires much broader and deeper developments of Informatics.

WHY IT IS NOT EASY TO SEE PROPERLY NATURE OF INFORMATICS?

Informatics is usually presented (wrongly) as a very new science/engineering discipline being only in the beginnings of its developments

The whole field is under enormous pressure to develop fast:

- Computing and communication systems of much better performance;
- Computing and communication systems of much smaller size and energy consumption;
- Faster, verifiable, reliable, secure and compatible software;
- More efficient methods to design reliable, secure and maintainable software.

It is therefore a big societal pressure to see scientific base of the field as serving short term goals of technology.

SOURCES of NEW PERCEPTION of INFORMATICS

- The recent attempts to develop scientific basis for modern computing and information processing and communication technology and their utilisation.
- Long term efforts to derive knowledge from information, to formalize knowledge and to formalize, as well as mechanize, reasoning.
- The slowly developing understanding that various science disciplines that were motivated originally by the design and utilisation of computing technology, liberated already themselves from seeing their main goals as serving technologies and developed, step by step, into areas of science with very broad impacts - as have done logic, automata and complexity theories, for example.
- Old and recent attempts to understand, match and beat performance of human intelligence and bodies.
- Recent discoveries that information processing is not only inherent, but often a driving force, in physical, biological, chemical, economical and social processes.
- The subsequent understanding that the discipline is the basis of a new and very powerful methodology and has enormous impacts in all areas of human activities, extending old methodologies to new heights.
- A realisation that the discipline could and should establish super-challenges dealing with which requires a very broad view of the field.

WHAT IS INFORMATICS? - NEW PERCEPTION OF INFORMATICS

NEW PERCEPTION of INFORMATICS

SHORT SUMMARY

Let us start with a very short summary of new perception of Informatics.

Informatics has four very closely related components:

- scientific,
- engineering,
- methodological,
- applied.

As discussed in the following, the new perception of informatics see informatics as having similar scientific aims as physics has and similar methodological impacts as mathematics has.

The main goal of **Informatics** is to study laws, limitations, paradigms and phenomena of the **information worlds**.

INFORMATICS as a FUNDAMENTAL SCIENTIFIC DISCIPLINE I

As a scientific discipline of a very broad scope and deep nature, Informatics has many goals. Its main task is to discover, explore and exploit in depth, the laws, limitations, paradigms, concepts, models, theories, phenomena, structures and processes of both natural and virtual information processing worlds.

To achieve its tasks, scientific Informatics concentrates on developing new, information processing based, understanding of the universe, evolution, nature, life (both natural and artificial), brain and mind processes, intelligence, creativity, information storing, processing and transmission systems and tools, complexity, security, and other basic phenomena of information processing worlds.

INFORMATICS as a FUNDAMENTAL SCIENTIFIC DISCIPLINE II

The development and analysis of a variety of formal, descriptional, specification, computation, programming, interaction, communication, security and reasoning models and modes, languages and systems; development and analysis of (deterministic, randomized, genetic, evolutionary, quantum, approximation, optimization, on-line, parallel, concurrent, distributed, continuous, ...) algorithms, heuristics, protocols, processes and games are some of the main tools of scientific Informatics.

Data, information, knowledge, formal languages and systems, logics, calculi, reasoning and proof systems, processes, resources, models and modes of information and knowledge processing, communication and interactions are some of the key concepts behind.

Computability, efficiency, complexity (computational, communication, interaction, descriptional,...) feasibility, universality, emergence, security, privacy, provability, learnability, validation and (formal) correctness, as well as secrecy, confidentiality, privacy and anonymity are some of the key issues.

Information and knowledge digitalization, mining, learning, analysis, sorting, comparing, searching, compression, representation, visualisation and transmission are some of the primitives of information processing.

INFORMATICS as a FUNDAMENTAL SCIENTIFIC DISCIPLINE IV

In order to meet its goals, the scientific Informatics develops close relations with other sciences and technology fields - currently especially with Physics, Biology and Chemistry, on one hand, and with electronics, optics, nano- and bio-technologies on the other hand.

The basis of the relationship between Informatics and the natural sciences rests first of all on the fact that **information carriers are always elements of the physical, biological or chemical worlds**, and consequently information processing is governed and constrained by their laws and limitations. Of large importance is also that information processes are an inherent part of the basic aspects of the nature and life.

Informatics as a science includes also numerous theories much needed for its development to depth and in broadness. Some theories are very abstract, others quite specific, and some theories are oriented on making better use of the outcomes of the scientific Informatics to create a scientific basis of engineering Informatics and Informatics-driven methodology.

INFORMATICS as a FUNDAMENTAL SCIENTIFIC DISCIPLINE VI

To meet its scientific goals, Informatics has to develop a whole variety of subareas. Some are deeply abstract and appear to be, at the first sight, quite remote from the main tasks and interest of the current engineering or applied Informatics, yet they serve to develop deep insights into the key problems and powerful conceptual tools.

In order to derive a deeper understanding of our real information processing world, Informatics has to create and explore a whole variety of other (virtual) information processing worlds. By broadening so much its scope in this way, Informatics can can also develop very powerful tools to deal with information processing related problems of our real world.

Observations, measurements, learning, analysis, modelling, simulation and visualisation, as well as postulation, generalization and decompositions, constitute some of the main methodologies to explore information processing worlds.

INFORMATICS as the leading SCIENCE

Informatics is, without doubts, currently the leading science and technology discipline with enormous impacts on all other sciences, technologies, industry, economics, health and environment care, liberal art and so on - guiding them and serving them.

There has ever been a "queen of science" with very broad impacts, also on all education. Some examples.

- Philosophy at the very beginning
- Medicine in Padua and at the same time theology in Paris in 17th century
- Philology at the Renaissance
- Mathematics after Galileo time due to its methodological impacts and Physics in the 20th century during its impacts on industrial revolution.
- By Ernest Rutherford (1912), In Science there is only Physics: all the rest is stamps collecting.

Observation: The leading science always had crucial impacts on ALL education.

Three big questions:

- Will science ends?
- Can science still expect such great discoveries as those of Darwin, Einstein and Watson-Crick?
- Will singularity be able to provide answers to both of previous questions?

INFORMATICS as the FIRST and LAST SCIENCE

- Informatics can be seen as the first, the oldest, are of science and technology.
- Are there parts of science that can be seen as having end? Anatomy of human body, geography, chemistry,...
- There are surely areas of science that have already practically died. For example, astrology; descriptive geometry.
- If an area of science becomes without big practical contributions, as well as become incomprehensible, it may lost support of society.
- Since many areas of science can be seen as converging to informatics, it is quite natural to explore the question whether Informatics could be seen as the last, all-sciences-embracing, science.
- Though it is true that not only information-processing phenomena are important in all sciences it is quite safe to say that other areas of science have diminishing returns.
- By far the greatest barrier to future progress in pure science is its past success.

INFORMATICS and PHILOSOPHY

- There are two major modes of human knowledge: science and philosophy. (A view of philosophers.)
- Most philosophers are deeply depressed because they cannot produce anything worthwhile.

  Each philosopher, by pushing his ideas too far, by taking them too seriously, ends up in an absurd, self-contradicting position.

  Karl Popper
- In *After philosophy: end of transformation*, published in 1987, fourteen prominent philosophers considered the question Has philosophy future?. The consensus was philosophical: Maybe, maybe not.

GRAND CHALLENGES of SCIENTIFIC INFORMATICS - I.

- To explore our world as a point in a space of potential information processing worlds.
- To explore laws and limitations of information processing that governs universe, evolution and life.
- To develop theoretical foundations for specification, design, analysis, verification, security, simulation, modeling and visualisation of huge information processing systems
- To understand mind, consciousness, learning, intelligence and creativity.
- To make foundations for science and engineering of the science making activities.
- To understand and manage all aspects of computation,

GRAND CHALLENGES of MATHEMATICS

To meet 21st century, The Clay Mathematical Institute in USA formulated in 2000 the following seven challenges solution of each is honored by one million dollar award.

- **P = NP**
- Poincaré conjecture (solved 2003 (Perelman) , solution verified 2006)
- Hodge conjecture
- Rieman hypothesis
- Yang-Mills existence and mass gap
- Navier-Stokes existence and smoothness
- Birch and Swinnerton-Dyer conjecture

Rieman hypothesis: All nontrivial zeros of the analytical continuation of the Rieman zeta function $\sum_{n=1}^{\infty} \frac{1}{n^s}$ have a real part $1/2$.

Hodge conjecture: For projective algebraic varieties, Hodge cycles are rational combinations of algebraic cycles.

GRAND CHALLENGES/PROBLEMS of THEORETICAL PHYSICS

- Problem of the origin of universe. Can we find out the initial conditions for Big Bang.
- Problem of very basic elements of universe. What is universe made of? What are black matter and black energy? Can we create them experimentally?
- Problem of the true nature of spacetime? What is their origin and structure? How many dimension has space? Is space an emerging phenomenon that can be derived from something? Are time and space an illusion?
- Problem of the validation of quantum theory. Is quantum theory universally valid? Also for large complex systems and for very small distances?
- 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. why they have values as they do?

Challenges are from the book of Lee Smolin: The trouble with physics. The rise of string theory, the fall of science and what comes next: 2006 and from the recent Nobel laureate David Gross talk (2012).

- To find out how Big Bang could occur is a new big challenge in physics. Till quite recently this problem has been seen as unscientific.
- Concerning the structure of universe, current understanding is that 5% is ordinary matter, 25% black matter and 70% black energy.
- David Gross considered as big challenges of physics also questions: Can evolution be quantized and predicted? Can we have theoretical biology? What is consciousness? How life has been created?
- In connection with such a broadening of the scope of physics it is natural that he defines Physics is what physicists do.

SOME of the GRAND CHALLENGES of INFORMATICS in MORE DETAILS - I.

- To work out ways how to see our world as "a point" in a huge space of other related (abstract) [virtual] words and to come up with new ways to understand and deal with the problems of our world through the investigation of and in this large space of worlds.
- To discover and understand laws, limitations, paradigms, processes and phenomena of the information processing that govern the evolution of the universe and life and play the key role in the development of nature in general and especially of living beings.

SOME of the GRAND CHALLENGES of INFORMATICS in MORE DETAILS - II.

- To create models, theories and (especially formal) tools to help engineering Informatics to specify, design, verify, analyze and maintain (especially enormously large), concurrent and distributed (software) systems as well as embedded systems.
- To create concepts models and theories for an understanding of intelligence and basics of intelligent behaviour, as well as consciousness (its origin, scope and functioning), and all that to such an extent that "highly intelligent information processing systems, devices and robots" become a reality.

SOME of the GRAND CHALLENGES of INFORMATICS in MORE DETAILS - III.

- To develop concepts, theories, models, methodologies and tools that would lead to the development of very powerful methods to search, mine, retrieve and derive information and knowledge as well as to make hypothesis and formulate theories in a way leading to *an engineering of the major science making activities*.
- To explore in depth inherent complexity of information processing, communication and interaction phenomena and to find ways for reasonable solutions of computationally very intensive, or even unfeasible, problems, in the current view of the issues, and of the problems requiring to process enormously huge data

CHALLENGE 1 - TO EXPLORE THE SPACE OF POTENTIAL INFORMATION WORLDS I.

History of science suggests that a deeper understanding of a phenomenon or of an object comes when a way is found to see properly that phenomenon or object as only a particular one in a very large, close and nicely smooth space of (quite) similar phenomena.

Three of the recently explored ways to see our physical world in a broader class of potential physical worlds are;

- To explore worlds with more powerful correlations than those of quantum correlations, but that still do not contradict general relativity.
- To explore worlds where various natural generalizations of quantum entanglement are valid.
- To explore worlds with the potential to beat Church-Turing barrier;

Case study I: HOW MUCH STUDIES of "STRANGE" PHYSICAL WORLDS HELP PHYSICS?

or, more technically,

HOW MANY GEOMETRIES

OF THE PHYSICAL WORLDS ARE USEFUL?

- The first important step was the development of Euclidean geometry that was actually a useful abstraction of our basic vision of our 3-dimensional physical world.
- Euclidean geometry can be seen as the most basic and the first perfect physics theory.
- Arithmetization of Euclidean geometry by Descarets (1596-1650) open the door to the study of much larger class of geometrical objects of the two and three-dimensional worlds and also paved the way for study of more (even infinite) dimensional worlds.

DEVELOPMENTS in GEOMETRY - II.

- The development of non-Euclidean geometries (1826-29) by Lobachevsky (and others showed that apparently very strange virtual worlds can represent features of very real world..
- Another big revolution in geometry started Rieman (1826-1866) by considering geometries as n-dimensional manifolds with a general quadratic differential form as its metric. This allowed to generalize much the concept of **curvature**, to show that there are different kinds of space of three-dimensions, what could soon be used by Einstein in his theory of relativity.

- Another big step in the area of virtualization and abstraction in geometry was initiated by F. Klein (1849-1929) who started to see the task of geometry as the study of geometrical objects as invariants of some virtual worlds (manifolds) with respect to special groups of transformations. The field developed as driven by the principles of the mathematical art and by an understanding that peculiar geometries may reflect features of some physical worlds.
- Klein's approach allowed to see dimensionality of a virtual world as depending of chosen class of elementary objects. As a consequence our physical world can be seen as three, four and even five dimensional.

SOME PROBLEMS SCIENTIFIC INFORMATICS DEALS WITH - I.

- What are the laws, limits, elements, structures, processes and methods of information world and what are their properties?
- What is **feasible**?
  - What is feasibly **constructable, solvable, computable, decidable**?
  - What has (and is) **a feasible evidence, a proof**?
  - What is feasibly **learnable, expressible, communicable?**
- To study space of information processing **problems**, its structure, hierarchies, reductions, equivalences, hardest problems,...
- To study the space of information processing **resources**. What are their properties and power? Which relations and trade-offs are among them? How powerful are such resources as **time, space, randomness, interactions, parallelism, concurrency, nondeterminism, alteration , reversibility, entanglement, non-local correlations?**

SOME PROBLEMS SCIENTIFIC INFORMATICS DEALS WITH - II.

- To study space of information processing **machines**, their power, mutual simulations. Models of machines that fit existing technologies, physical theories,....
- To study the space of **descriptional systems**: logics, languages, rewriting systems, automata,....
- To study **inherent complexity** of objects, processes (computational, communication, descriptional,...
- To study information, knowledge, reasoning, intellectual properties,...
- To develop learning methods and systems and of their properties (uncontrolled learning, deep learning,...)

SOME PROBLEMS SCIENTIFIC INFORMATICS DEALS WITH - III.

- To develop methods of design and analysis of deterministic, randomized, quantum and genetic algorithms.
- To develop theory and tools for management, analysis and processing huge (extremely large) data sets and streams.

COMMENTS I - INFORMATICS versus PHYSICS

The main goal of *Physics* can be seen as to study laws, limitations and phenomena of the *physical worlds*.

The main goal of *Informatics* can be seen as to study laws, limitations and phenomena of the *information worlds*.

Physics and Informatics can therefore be seen as representing two windows through which we try to perceive and understand the world around us.

In a similar way we can see life-sciences and Informatics as providing two windows and tools with which we try to understand, imitate and outperform the biological world and its highlights - human brain, mind, consciousness, and cognitive capabilities.

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 FIELDS

- Now I am in the grip of a new vision, that

  EVERYTHING IS INFORMATION

John Archibald Wheeler
Gems, Black Holes and Quantum Foam

- **"I have been led to think of analogies between the way a computer works and the way the universe works. The computer is built on yes-no logic. So, perhaps is the universe ... The universe and all that it contains ("it") may arose from the myriad yes-no choices of measurements (the "bits");**
- **By Wheeler, information has some connection to existence, a view he advertised with the slogan "It from bit" - or, in other words, that "Everything is information".**

IT FROM BIT symbolizes the idea that every item of the physical world has at the bottom - at the very bottom, in most instances - an immaterial source and explanation.

Namely, that which we call reality arises from posing of yes-no questions, and registering of equipment-invoked responses.

In short, that things physical are information theoretic in origin.

WHO WAS JOHN ARCHIBALD WHEELER (1912-2008)?

- A man who named black holes.
- A man who helped to explain nuclear fusion.
- A leading expert in quantum physics, relativity theory.
- Wheeler is considered among physicists as one of the greatest teachers of the last century.
- Richard Feynman was one of his students.

OTHER VIEWS on NATURE and SCIENCE

- Democritos; Nothing exists except atoms and empty space; everything else is opinion.
- Pythagoreans: Everything is number
- Philolaus: All things that can be known have number; for it is not possible that without number anything can be either conceived or known.
- Plato created a beautiful unified theory of matter according to which everything is constructed of the ideal right triangles.
- Cezanne: Everything in nature can be modeled from a sphere, a cone and a cylinder.
- Galileo: The book of universe was written in mathematical language and its alphabet consists of

- 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.

  W, Heisenberg

- Assumption that our world is a finite system does not just hint that information aspects of physics are important, it insists that *information aspects are all there is to physics at the most microscopic level*.

  E. Fredkin

RELATIONS of INFORMATICS to OTHER SCIENCES

There are several basic reasons why relations between Informatics and other sciences are getting stronger and stronger, deeper and deeper.

- **It starts to be understood that other sciences are in their fundamentals much information processing driven** and they converge to the state that studying their information processing aspects is becoming one of the main way to get a deeper insight into them. (Both physics and biology are perhaps main ones of that type.) For example, it starts to be understood that information processing is for life as important as eating and breathing.
- Because of strong impacts of informatics, especially of its methodology, on all sciences, one can talk about their convergence to and increasingly strong relation with Informatics.
- Informatics has been designing systems that are so huge and ever evolving in a not much coordinated distributive way, as internet, silicon compilers and so on, that they need to be studied by observational and experimental methods of natural and social sciences. As a consequence, that brings Informatics closer to these disciplines. All that also creates a space for influencing Informatics development on the basis of laws, limitations and findings of natural and social sciences.

WHAT CAN BE LEARNED

from the HISTORY of OTHER SCIENCES?

A GENERAL OBSERVATION

A success of a science depends much on how large and at the same time intellectually simple, smooth and dense space it is able to create and investigate in comparison to that observable by human senses and common sense.

LESSONS LEARNED from the HISTORY Of PHYSICS

- Physics was first named as *natural philosophy*.
- For a long time physics was seen as dealing with stuff we can handle between fingers.
- Quantum physics and relativity theory opened a new dimension to physics with big impacts on the stuff we can handle between fingers.
- Discoveries in cosmology shifted scientific interest to the study of black holes, Planck scale space and time, black matter and energy,....

Moral: Physics got a new dimension, regarding knowledge and usefulness, by extending VERY MUCH its scope and research space.

- In the 17th century physics solved the long standing problem of the understanding of the direct motion.
- In the process of doing this physics was able to replace a mysterious concept of impetus by the modern concept of inertia and to come to the modern theory of motion and by doing this to *drive out spirits from the scientific thoughts* and open the door to see the universe as running as a piece of clockwork.
- Physics did that by geometrizing the problem. That is by solving the problem in a virtual (geometric) frictionless, directionless, gravitationless and empty space.

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.

It has been rather curiosity and the need to extend our knowledge and understanding of the physical world that was behind its 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.

OTHER FUNDAMENTAL PROBLEMS of PHYSICS

- What is space? Has space a beginning, development, end, borders? What are and from where came space development driving forces?
- What is time? Has time a beginning, development, end? What are and from where come time development driving forces?
- What is (our) universe? What is in it? What we can say about its beginning, development, end, laws and limitations?
- Is something more fundamental than time and space? Are there some other universes?
- Why is our universe as it is? What can we know about our universe?
- Why we are in our universe?
- Does there exist a universal theory of our universe, of its structure, development, laws and limitations? Of all universes?

WHAT CAN BE LEARNED

from the HISTORY of MATHEMATICS

APPROACHES to the PERCEPTION of MATHEMATICS

There are several positions from which one can characterize mathematics.

1. By specifying subjects of mathematics
2. By specifying the essence of mathematics
3. By specifying methods of mathematics
4. By specifying goals of mathematics
5. Folklore views of mathematics
6. Peculiar views of mathematics

HOW TO PERCEIVE MATHEMATICS? I. Greek times developments

- Mathematics as a science centers around such concepts as number and magnitude.
- Mathematics as a science centers around such concepts as number, magnitude and form.
- Mathematics as a science centres around such concepts as number, magnitude, form and change.

HOW TO PERCEIVE MATHEMATICS? II

- Greek period: Mathematics used to be seen as the science centred around such concepts as quantity, structure, form and change.
- Encyclopedia Britannica: Mathematics is the science of structure, order and relations that has evolved from elementary practice 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.
- Soviet encyclopedia: Mathematics is the science *to study spacial forms and quantitative relations of the real world*
- Folklore: Mathematics is what mathematicians carry on and mathematicians carry on a highly sophisticated intellectual activity which is not easy to define
- Academia Europaea, 2010: Mathematics is centred around such concepts as quantity, structure, form and change.

- As far as laws of mathematics refer to reality, they are not certain; and as far as they are certain they do not refer to reality (Einstein).
- Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true (B. Russel - 1917).

DEFINITION of MATHEMATICS by its SUBJECTS

- Mathematics is science of quantities. (Otto Encyclopedia - 1930 - Czech).
- Mathematics is the body of knowledge centered on such concepts as quantity, structure, space and change, and also an academic discipline that studies them (Wikipedia, 2008).
- Major disciplines within mathematics fist arose out of the need to do calculations in commerce, to understand relationships between numbers, to measure land and to predict astronomical events.
- Mathematics is deductive study of numbers, geometry and various abstract constructs (the Longman Encyclopedia, 1989).
- 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. Nach traditioneller Einteilung gliedert sich die Mathematik in die Arithmetik, die Geometrie, die Algebra und die Analysis. (Meyers Grosses Taschen-Lexicon).
- Science qui étudie par le moyendu raisonnement déductif les propriétés d'êtres abstraits (nombres, figures geéométriques, fonctions,spaces, etc.) ainsi que les relations qui s'établissent entre eux (Le petit Larousse).
- Mathematics is science to study spacial forms and quantitative relations of the real world. (Soviet encyclopedia).

MATHEMATICS by its ESSENCE

- 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.
- Mathematics is a broad-ranging field of study in which the properties and interactions of idealized objects are examined (CRS Concise (3942 pages) Encyclopedia of Mathematics, 2003)
- This, therefore, is the mathematics: she remains you of the invisible form of soul; she gives life to her own discoveries; she awakens the mind and purifies the intellect; she brings light to our intrinsic ideas; she abolishes oblivion and ignorance which are our by birth. *Proclus (410-485 A.D.)*
- Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true. *B. Russel (1917)*
- Mathematics in general is fundamentally the science of self evident things.
  F. Klein - the leading German mathematicians at the end of 19th century.
- Mathematics is often seen as the science of numbers, quantities and measurements. These things are indeed an important part of materials to which mathematics has been applied. But they are no more mathematics than are the paints in an artist's tubes the masterpiece he is painting.
- As far as laws of mathematics refer to reality, they are not certain; and as far as they are certain they do not refer to reality *A. Einstein (19??)*.
- Mathematics is Queen of the Sciences and Arithmetic the Queen of mathematics

FOLKLORE VIEWS of MATHEMATICS

- Mathematics is what mathematicians carry on and mathematicians carry on a highly sophisticated intellectual activity which is not easy to define
- Creative mathematicians are inspired primarily by the art of mathematics, rather than by any prospect of immediate utility in sciences and technologies - they are guided only by their feeling for symmetry, simplicity, generality and an indefinable sense of fitness of things and mathematical beauty *Bell 1951*.

PECULIAR DEFINITIONS of MATHEMATICS

- Mathematics is the science that draws necessary conclusions. *B. Peirce(1809-1880)*
- Pure mathematics is the class of all propositions of the form *p implies q*, where p, q are propositions.
- Mathematics in general is the science of self-evident things *F. Klein (1849-1929)*
- These and scores of other definition of mathematics illustrate the hopelessness of trying to paint brilliant sunrise in one color. *Bell, 1953*
- The attempt to compress the free spirit of modern mathematics into an inch in a dictionary is as futile as trying to squeeze an ever-expanding thundercloud into a pint bottle.
- Mathematics is nothing more than a game played according to certain simple rules with meaningless marks on paper *D. Hilbert*
- In the pure mathematics we contemplate absolute truths, which existed in the Divine Mind before the morning stars sang together, and which will continue to exist there, when the last of their radiant host shall have fallen from heaven.

- It appears to me that the mine of mathematics is already very deep and unless one discovers new veins it will be necessary, sooner or later to abandon it.
  Lagrange, 1781
- I dare say that in less than century we shall not have three great mathematicians left in Europe,..
  Diderot, 1754

WHAT IS MATHEMATICS ABOUT?

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

LESSONS LEARNED from the DEVELOPMENT Of MATHEMATICS

Mathematics has made an enormous progress especially by extremely enlarging and completing its research space.

- **M** moved from dealing with integers to rationals, irrationals, complex numbers,..
- **M** moved to the study of arbitrarily large cardinality
- **M** moved from the study of 2D and 3D spaces to spaces of arbitrary dimensions and metrics.
- **M** moved from the study of 2d and 3D figures to the study of curves and bodies in any space.

LESSONS LEARNED from the DEVELOPMENT Of MATHEMATICS - I.

- It took centuries for **M** to move from considering a number as a fundamental object to seeing continuum as the fundamental object and set theory and logic as its building blocks.
- In all such cases extensions of the scope brought also new techniques to solve old problems, and that was actually the main underlying goal, inspired mainly by a centuries old experience with the power of generalisation and abstraction. Similarly we could analyse developments in other sciences.

LESSON LEARNED FROM

GOLDEN ERA of GREEK MATHEMATICS

GREEK MATHEMATICS - CLASSICAL PERIOD (Pythagoreans, 600-300 B.C.)

- Greek mathematics was based on and helped to develop a new doctrine of nature - namely that nature is orderly and develops according to a plan. Old doctrine, but in Greek society actually dominating at that time, was that gods manipulate nature and men according their whims.
- Its protagonists were Thales and Pythagorean and it was highlighted by works of Eudoxus, Euclid, Plato and Aristotle.
- Greeks created, for the first time, mathematics as an organized, independent and reasoned discipline.
- Greeks made mathematics abstract - to see mathematical entities, numbers and geometrical objects as abstractions, sharply distinguished from physical objects.
- Greek made mathematics deductive, deriving truth in theorems by deduction from axioms.

CONTINUATION

- Greeks came with the idea to prove existence by construction.
- Their mathematics was mainly (well founded) geometry, (actually motivated by astronomy).
- Main goal of Mathematics was seen as to understand functioning of universe - they believed that mathematics is the key to comprehension of universe, for mathematical laws are the essence of its design.
- Greeks made mathematics to be a liberal art closely related (and a preparation) to philosophy.
- For Greeks arithmetic, geometry and astronomy were considered as *the art of the mind and soul. It is believed that it was the aesthetic appeal of the subject that caused Greek mathematicians to carry the exploration of particular topics beyond their use in the understanding of the physical wo r1d.*
- *Greeks made enormous contributions to the philosophy of science.*
- *Their mathematics was much inspired by the fact that phenomena that are much diverse from qualitative point of view exhibit identical mathematical properties.*
- *Their position was based on a belief that mind is capable to recognize truth, observation of physical world is not needed. As a consequences their outcomes were a combination of ingenious ideas, bold speculations and shrewd guesses.*
- *Greek mathematicians mixed deep and serious thoughts with what we could consider as fanciful, useless, and unscientific doctrines.* sic for the soul.
- Greek mathematicians "reduced" astronomy and music to numbers and therefore astronomy and music was considered to be a part of mathematics.

PLATO's IDEAS

- He was the most influential propagator of the doctrine that the reality and intelligibility of the physical world can be comprehended only through mathematics.
- He was convinced that the world was mathematically designed, for God eternally geometrizes
- He believed that the world perceived by the senses is confused and deceptive and in any case imperfect and impermanent.
- He believed that physical knowledge is unimportant, because material objects change and decay; therefore direct study of nature and purely physical investigations are worthless.
- Plato believed that physical world is but an imperfect copy of the ideal world, the one mathematicians and philosophers should study.
- He believed that mathematical laws, eternal and unchanging, are the essence of reality.
- Plato encouraged devotion to a theoretical astronomy, whose problems please the mind not eye, and whose objects are apprehended by the mind, not visually.
- Plato not only tried to understand nature through mathematics, he actually tried to substitute mathematics for nature itself.

CONTINUATION

- Plato believed that there is an objective, universally valid reality consisting of the forms, or ideas.
- For Plato mathematics was also a methodology that helped to train the mind to see eternal ideas.
- For Plato nature was mathematically designed and this design was harmonious, aesthetically pleasing, and the inner truth.
- Platonic dialogue *Philebus* first gave expression to the thought that each science is a science only so far it contains mathematics.

Aristotle's IDEAS

- He believed in material things as the primary substance and source of reality.
- He believed that science must study the physical world to obtain truth.
- He believed that genuine knowledge is obtained from sense experience by intuition and abstraction.
- He believed that matter alone is not significant. It becomes significant when it is organized into various forms. Form and the changes in matter that give rise to new forms are the interesting features of reality and a real concern of science.
- He viewed matter as consisting of earth, water, air and fire.
- He believed that science has to study causes of changes.
- He believed that mathematics alone can never provide an adequate definition of substance.
- He distinguished sharply between physics and mathematics and assigned a minor role to mathematics.
- He gave 6 non-mathematical arguments why space is finite.

LIMITATIONS OF CLASSICAL GREEK MATHEMATICS

- They reduced mathematics to geometry dealing with simple curves, areas and bodies only.
- 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.
- They were not able to accept irrational numbers in arithmetic.
- Their concept of proof was too restrictive concerning creative mathematics, and so was their concept of constructability.
- They were not able to accept infinity. Neither infinity of large not of small objects and not infinite processes.
- They could not accept continuity because of their emphasis on atomism.
- They believed that mathematical facts are not created by men, that they exists and can only be discovered.
- They, including Aristotle, rejected practical utility as the purpose of inquiry and believed that philosophical investigations carry their own reward.

CONTINUATION

- All that happened in spite of considerable Greek achievement in engineering. For example, Archimedes designed various war-making machines - however, he thought so little of this as a subject of "philosophical discourse" that he included not a word about mechanics or engineering in the vast body of theoretical writing he left behind.
- Exception were Hippocratic physicians (5th century B.C.). Greek medicine of that time had inquire into a wide range of human anatomy and physiology to develop the medical and surgical means of dealing with wounds, fractures and diseases.

GREEK MATHEMATICS - ALEXANDRIAN PERIOD (300 B.C. - 600 A.C.)

- Mathematics produced was quite different in character from that of the classical period, there is an absence of deductive structure.
- Main protagonists were Archimedes, Diophantine and Ptolemy.
- From time of Nichomachus, who wrote a textbook on arithmetic used for 1000 years, arithmetic became the main subject of study.
- Geometers of that period concentrated on quantitative geometry, mainly on the computation of the lengths, areas and volumes.
- Philosophical differences in two periods of Greek mathematics - an example: Euclid was happy to prove that area of circle is proportional to the square of diameter, Archimedes concentrated on approximation of the constant π.
- Mathematics made many contributions to mechanics, optics, geodesy, canonic (science of musical harmony), ...
- Archimedes used ideas from mechanics to derive mathematical theorems.
- Big achievements - spherical trigonometry
- Main achievement - first truly quantitative astronomical theory (using trigonometry).
- Mathematicians of that period severe their relations with philosophy and allied themselves with engineering.

WHY WAS GREAT GREEK MATHEMATICS IGNORED FOR 2000

- One of the most puzzling things in history of science is why ingenious Greek mathematics of its classical period was then practically ignored for about 2000 years.
- It was actually already ignored in the Alexandrian period (300 B.C. - 600 A.C.)
- One reason is nicely put together 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.*
- Other reasons: it ignored computational needs of society; it was based on a wrong view of importance of observations and so it could hardly help other sciences;

CONTINUATION

- Christianity decreased interest in physical world, preparation of the soul for after-life in the heaven was the main concern.
- Christianity brought a new belief concerning ways one seek for truth.
- Theology was seen as embracing all knowledge.
- New revival of the Classical Greek period appeared after a new doctrine was developed that saw God as the one creating mathematical nature and as seeing search for mathematical laws of nature as religious quest. A discovery of a mathematical law was seen as a further discovery of the greatness of the God - and therefore God was to be praised after each discovery of

SUBAREAS OF GREEK and MEDIEVAL AGE MATHEMATICS

Classical period ; arithmetic, geometry, astronomy, music

Alexandrian period : arithmetic (number theory), geometry, mechanics, astronomy, optics, geodesy, canonic and logistic (applied arithmetic).

Medieval age: Astrology was considered as a subarea of mathematics

ASTROLOGY as a COMPANION of MATHEMATICS

- Astrology received new dimension in Alexandrian Greek period.
- Ptolemy wrote five books on astrology.
- Astrology nourished astronomy as much as alchemy nourished chemistry.
- Alexandrian astrology was personal. It predicted future and fate of individual on the basis of the computed position of the sun, moon and five planets in the zodiac at the moment of birth.
- Errors in astrological predictions used to be ascribed to errors in astronomic calculations, not in unreliability of astrological doctrines.
- The basic astrological doctrine was that heavenly bodies influence and controlled human bodies and fortunes.
- Galileo lectured to medical students on astronomy, but for the sake of astrology.
- Physicians of medieval time had to be more astrologers and mathematicians than experts in human bodies.
- Newton was also much involved in astrology.

SOME OTHER COMMENTS on MEDIEVAL SCIENCE and MATHEMATICS

- Medieval science was for long time concerned with understanding of the role of God in creation and running the world
- For example, Galileo expresses a widely spread view when he interpreted the difference between human and divine understanding: we proceed in step-by-step discussion from inference to inference, whereas He conceives through mere intuition.
- Some of important concepts of medieval science disappeared from modern scientific considerations. For example: ether, substance, Some other concepts disappeared as crucial. For example: left-to-right,
- In medieval time mathematics was much intertwined with physics.

This was during the scientific revolution in the 16th and 17th century. At that time:

- A very important starting steps was development of the analytical geometry by Descartes - as one of the greatest mathematical achievements of all times.
- As one of the outcomes metaphysics of space could be ignored. It is now never necessary to require what "space" is or whether it "exists". We need only to know how to manipulate equations whose variables denote outcomes of measurements or observations, As a consequence metaphysics of space is a luxury only few creative physicists can safely afford to bother about.
- The introduction of postulation/axiomatic method for

- Mathematical concepts started to be more and more purely intellectual constructs that were created by "the recesses" of human minds and they were no longer only, or mainly, an idealization of some immediate experience (irrational and complex numbers, integral,...).
- That was then accompanied by a complete change of the relation between geometry and algebra and the last one, and as its branch at first and very powerful child later, analysis, started to play a dominating role.
- Analysis then dominated for centuries and strated to play more and more the role of a servant of physics, to produce (computational concepts and tools) to deal with more and more involved problems of physics.

THIRD GOLDEN AGE of MATHEMATICS

- The third most prolific period in the history of mathematics started by 1830 and the end is not yet in side - this period can be seen as the third golden age of mathematics.
- Discovery of Non-Euclidean geometry around 830 by Lebesgue's, that gave rise to enormous development of various geometries with such strong impacts on whole mathematics and physics was one of the starting points.
- Mathematics during that period can be characterized as follows
  - Ever greater generality and abstraction and ever sharper self-criticism.
  - Ever stronger emphases on probability and approximation methods needed to solve huge and complex problems.
  - Ever growing use of randomness and probability tools.
  - A switch of emphases from solving particular problems to the development theories as tools to attack a class of problems.
- Another key tool developed by mathematics is the theory of differential equations because 99% of all important laws of physical sciences are in terms of differential equations or of their systems.
- In spite of the fact that during first 100 years of this period enormous successes have been obtained in mathematics, mathematics was not prepared enough to deal with a variety of complex problems war needed to deal with.
- For example, exact solution of various such problems were out of question and a variety of approximate methods have to be developed that in turn influenced also pure mathematics.

- In some departments of mathematics more was discovered in less than decade of war than it would be discovered in 50 years of piece.
- In spite of that around 1955 it was guessed that if mathematical physics be annexed as a province of mathematics, a detailed, professional mastery of the whole domain of modern mathematics , would require life long toil of 20 or more richly gifted men.
- Successes of mathematics in WW2 so much speed development of mathematics that today an order or two more mathematicians would be needed to achieve the same.

HIGHLIGHTS in HISTORY of MATHEMATICS

- Position number systems
- Euclid geometry as abstract deductive theory
- Heliocentric theory of heavenly bodies which at that time had only mathematical advantages
- Analytic geometry
- Analysis
- Differential equations
- Differential geometry
- Non-euclidean geometry
- Topology
- Linear algebra
- Abstract algebra
- Number theory
- Discrete mathematics
- Set theory and mathematical logic
- Probability theory and statistics
- Game theory and
- Category theory

TRUE ENDS od MATHEMATICS

Before 17th century mathematics brought large amount of still valid knowledge, beautiful and scientifically powerful, but its impact on the development of society has been next to zero.

17th century True end of mathematics is the greater glory of God.

18th century True end of mathematics is the greater glory of human mind.

19th century True end of mathematics is to be the queen of sciences

20th century True end of mathematics is to be main servant of natural sciences and technology fields

20th century Through outcomes of industrial revolution mathematics, at that time very closed inter vined with physics, stated to have large impact on society.

21th century True end of mathematics is to be the queen of informatics and one of its main servants.

20th century WW 2 demonstrated enormous potential of physics and mathematics to influence development of society.

- Abstractions - to study problem of physical world by transforming them into the (idealized) problems of the informatio processing world. By Plato: the world perceived by the senses is confused and deceptive and in any case imperfect and impermanent; He believed that physical knowledge is unimportant, because material objects change and decay; therefore a direct study of nature and purely physical investigations are worthless.
- Greek deductive mathematics based on qualitative axioms as a way to understand nature, They tried to understand why things happened - to unearth the cause of the phenomena.
- Descartes and especially Galileo's deductive mathematics based on quantitative axioms as an essence of science and a systematic way to develop science. The goal was to describe (using simple quantitative laws) how things happen, to describe some properties of phenomena (and not why they are as they are). Using this methodology scientists produced during next two centuries deep and sweeping laws of nature on the basis of very few, almost trivial, experiments and observations. One can say that Galileo's idea was the most fruitful idea that anyone has had about scientific methodology. Newton's quantitative characterization how gravitation acted, whose action could not be explained in physical terms, was an excellent (and much convincing) example of the power of new methodology.
- Generalisation (abstract algebras, mathematical logic, topology, metric spaces, category theory).
- Analytical geometry can be seen as a start of algebraist and quantification of

- Chemistry has actually a longer continuous history than physics.
- Already in the 16th century, there had been remarkable advances in the field that might nowadays be called chemical technology.
- In spite of that, chemistry, as a modern science, can be sen as being born only in the second half of the 17th century.
- Moreover, only at the end of the 19th century can chemistry actually be seen as having changed from being a servant and adviser of industry to the new position of being a creator of industry.
- The history of chemistry seems to teach us that

APPENDIX I

WHAT ARE (ULTIMATE) COMPUTERS?

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

- In the golden era of Greek mathematics slaves, and not free men, were considered as those to perform computations.
- In the 18-19th century the term *computer* was used for girls doing computations in manufactures.
- After the clock superparadigm got a momentum, computers started to be seen and developed as physical devices.
- Turing and others liberated, and very successfully, the concept of computer from its physical substance. (This

WHAT ARE (ULTIMATE) COMPUTERS? - II.

- By doing that Turing, Church and others were also able to set up a bound/barrier, called Turing or Church-Turing barrier, concerning the power of all potential computers.
- Development of modern computers and a need to get deeper insides into computation processes and their potentials and limitations brought an understanding that a variety of models of (universal) computers is needed - all were liberated from the physical substance though the laws of classical physics were kept in mind when evaluating their potentials.

- Liberation of fundamental concepts of computation from its physical origin has later been followed by the hardware-independence (and later also by the software- and model-independence) of the key concepts of computation.
- Discovery that quantum computers could be more powerful than classical brought back a need to pay attention to the physical substance of computers.
- At the same time the emergence of a global computer (network) that can be seen as never terminating and filled constantly with non-uniform inputs brought still another ideas how an "ultimate computer" can be seen.
- All that brought back old quest to find model of

WHAT ARE (ULTIMATE) COMPUTERS? - IV.

- S. Lloyd calculated that an *ultimate laptop* could not perform more than 10^{51} very elementary operations per second.
- 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?

APPENDIX II.

GLOBAL TASKS of PHYSICS AND INFORMATICS

- To develop a proper understanding of spacetime as well as of the universe and its evolution.
- How to transfer to physics such concepts us universality, complexity, computability and feasibility?
- To find out what is an ultimate computer?
- To search for minimal universal physical information processing phenomena.
- To design powerful quantum computers
- To make perfect security society in a way that undetected physical crime is practically impossible.

GLOBAL TASKS of PHYSICS, BIOLOGY and INFORMATICS

- To get deeper insights into biological phenomena through their simulation.
- To get deeper insight into natural life phenomena by designing and exploring artificial life phenomena.
- To understand cells information processing
- To understand the role information processing plays for life and for evolution.
- To understand life and evolution.
- To develop a model of the brain and mind as well as of conscious activities.
- To develop individual patients models of human body and its processes.

CHEMISTRY and BIOLOGY

- Chemistry is the study of the composition, properties and behaviours of matter. Chemistry is concerned with atoms and their interactions with other atoms and particular with the property of chemical bounds.
- Chemistry is also seen as the central science bridging physics and biology.
- Biology is the study of life and living organisms, including their structures, functions growth, evolution, distribution and taxonomy.