The Scientific Role of Computer Science in the 21st Century

Dieter Fensel and Dieter Wolf

DERI Technical Report 2005-07-27

July 2005

DERI Ireland
University Road
Galway
IRELAND
www.deri.ie

DERI Austria
Technikerstrasse 21a
A-6020 Innsbruck
AUSTRIA
www.deri.at

The Scientific Role of Computer Science in the 21st Century

Dieter Fensel and Dieter Wolf
Digital Enterprise Research Institute (DERI)
DERI Galway, Ireland & DERI Innsbruck, Austria
{dieter.fensel, dieter.wolf}@deri.org

Abstract. This paper defines the future role of computer science in its scientific context. We will show that the future prospects of mathematics, physics, biology, and human brain research will greatly depend on understanding them as branches of applied computer science. Therefore, we will establish applied computer science as a unifying foundation of natural sciences.

Table of Contents

1 Introduction

As stated in the abstract, this paper investigates the future role of computer science in its academic environment. We will analyze related areas of science such as mathematics, physics, biology, and human brain research. We will ask whether these fields could be better understood by viewing them in terms of information representation, processing and reasoning. Some reader may find some of our statements (or possibly all of them) quite provocative or simply wrong. Regardless, this paper aims at facilitating a multi-disciplinary discourse between research areas that seldom seriously exchange their underlying philosophical principles and assumptions in an open discourse. This paper is a provocative step towards this direction. We purposely attempt to take novel views in hopes of stimulating points of discussions. And while we acknowledge that our proposed ideas may not be the final and correct answers, we excitedly anticipate what conclusions may evolve in such a process.

The structure of this paper is as follows: in section 2, 3, 4, and 5 we take a look at mathematics, physics, biology, and human brain research. Especially the order of the latter three sections reflects the increasing complexity of the research subject. Finally, in section 6, we provide some short conclusions.

2 Mathematics as a Branch of Applied Computer Science

In mathematics, theorems are deduced from assumptions by means of reasoning or, to put it differently, assumptions are found through gaps in the proof-finding process. As this process can be formalized, it can thus be done by a computer however, faster and more precisely. An example of this trend is the Theorema project (cf. [Jebelean & Buchberger, 2003]). „This system will provide a uniform framework in which a working mathematician, without leaving the system, can get computer-support while looping through all phases of the mathematical problem solving cycle:

- the phase of specifying a problem including the compilation of relevant knowledge and the definition of new concepts;
- the phase of exploring a given problem and creating ideas and conjectures by studying examples using the available knowledge and algorithms;
- the phase of proving or disproving conjectures and thereby increasing the relevant knowledge base;
- the phase of programming, i.e. transforming useful new and provenly correct mathematical knowledge into algorithms for solving the initial problem;
- the phase of writing up one's finding in interactive mathematical documents.“[1]

In Theorema, the computer is still only an assistant: however reality and experience have shown how quickly this can change.[2]

One could argue that since the middle of the last century, we have been aware of the limitations of logical formal reasoning. One of the most important proven theorems of

1. http://www.risc.uni-linz.ac.at/research/theorema/description/
2. Already only in the last decade we have seen the dominance of computers in areas such as checkers and chess.

that century is **Gödel's Incompleteness Theorem**. In 1931, Kurt Gödel demonstrated that within any given branch of mathematics there would always be some propositions that couldn't be proven either true or false using the rules and axioms of that mathematical branch itself. You might be able to prove every conceivable statement about numbers within a system by going outside the system in order to come up with new rules and axioms, but by doing so you will only create a larger system with its own unprovable statements. The implication is that all logical systems of any complexity are, by definition, incomplete; each of them contains, at any given time, more true statements than it can possibly prove according to its own defining set of rules.In layman's terms, there are more formulas in first-order logics than a theorem prover can enumerate. Turing’s fundamental document for this branch of mathematics, “On Computable Numbers, with an Application to the Entscheidungsproblem” was written in 1936 and defined the **Halting Problem for Turing machines**. In this document, Turing reformulated Gödel’s results from 1931. He replaced Gödel’s universal, arithmetic-based, formal language with a simple, formal device which is nowadays known as the Turing Machine. Turing demonstrated that this machine was indeed able to solve every conceivable mathematical problem as long as it was solvable by an algorithm. With the help of the Turing Machine, Turing was able to prove that the “Entscheidungsproblem” was unsolvable by showing that even with such a machine, the halting problem was undecidable. In conclusion, there exists no algorithm capable of deciding whether an arbitrary Turing Machine will in fact “halt” or not.

Gödel’s as well as Turing’s theorems have been used to argue that a computer can never be as smart as a human being because the extent of its knowledge is limited by a fixed set of axioms, whereas people can discover unexpected truths. However, if these limitations are true for computer-based reasoning they are surely also true for human reasoning. These boundaries are principles of nature and thereby they do not refer to specific underlying hardware. If this was not the case, we would have to assume that the human brain is in principle situated outside the boundaries of logic and nature. For example, Penrose [Penrose, 1996] presumes that the ability to go beyond the boundaries of the formal derivability is situated in hidden quantum dynamic activities. However, if this is indeed the case, then rest assured that our quantum physics colleagues will make sure that such a computer will soon be build and widely distributed and maybe this will actually facilitate the efficient solving of some difficult algorithmic problems.

3 Physics as a Branch of Applied Computer Science

After already introducing physics as providing services to computer science due to its provision of faster processors, allow us to take a closer look at it. In this section, we will analyze the amazing analogies between physics in the large, physics in the small, and the task of monitoring large and distributed computer networks.

Monitoring of large and distributed systems. The fundamental problem of monitoring large and distributed computer systems is to get accurate and concise descriptions[3] of the state of the system. In large systems, the state description is often too large and in distributed systems, due to delayed response times, the state description is often out-dated. This creates a contradicting situation for any system administrator. If the description is both correct and complete, then it will be significantly out-dated given the time it takes to accumulate, aggregate, organize, and analyze the required information. The system administrator may attempt to resolve various issues that have since been updated and/or changed. One the one hand, he may sacrifice accuracy and completeness in order to generate an up-to-date description closer to the current state. However, this description will be highly inaccurate and incomplete since there is no time left to gather, aggregate, and analyze it. This contradiction between either relatively complete and relatively timely descriptions of a system is a *principle nature*. Any actual system monitoring approach is an engineered compromise that may indeed work within the context defined by the applications of the system, however the inherent contradiction remains.[4] We will now sketch two interesting analogies in physics.

Physics in the large: he who travels through space has little time to lose time. Since Einstein, we know about the space-time continuum and the physical limit of speed of light for any movement in it. Strictly spoken, there are some quantum dynamics effects that seem to "travel" beyond light speed but they cannot be used to transmit any information with more than light speed. This limits all physical processes that can be used *to transmit information* between a sender and a receiver. Therefore, simply solving the dilemma of our system administrator by transmitting the information about the state of his system with infinite speed will most likely never work. A second consequence of Einsteins' insights is the fact that one can only choose between fast movement in space or in time, not both. Travelling at nearly light speed to Andromeda and back will bring us through large portions of space but will leave us almost no time to age. Back on earth, we would find a civilization that would have evolved over millions of years (i.e., they were "moving" much faster in the time dimension). We would face assimilation problems more severe than what a Neanderthal would face in our modern world. Any life path is just a compromise between fast movement through space or time direction and one is always done on the expense of the other. Or in layman words: Only the rolling stone gathers no moss.

Physics in the small. A second major revolution in the area of physics happened in the area of quantum physics. It turned out that particles can behave as waves and waves can be understood as particle streams. Actually it depends on the specific interaction of the observer with the observed object whether he will perceive it as a particle or as a wave. This resulted in principal boundaries in measuring the location (space) and movement (in time) of a certain particle. A precise spatial measurement (achieved through a high frequency interaction) limits temporal observation. A precise temporal measurement (achieved through a low frequency interaction) limits the accuracy of determined location. In conclusion, the more precisely we know about the location of a particle in space, the less we know about its movement in time and vice versa.

Why is this like it is? Why is there a principal boundary in the exact description of

---

3. These descriptions of a system will be called *meta* data in the remainder of the paper since they are data about data, i.e., data that describes a state of a system that is characterized through the data it has in its storage system.
4. Unfortunately, often it may **not** work, i.e., some of the underlying assumptions were chosen wrongly and the frustrated computer user blames the programmer or creator not realizing that all are victims of the limitations in accurately describing large and distributed systems in a timely fashion.

natural phenomena? Let us try to recall our discussion about the description of software systems. Descriptions of data by meta data or descriptions of programs by meta programs (programs that can predict the behavior of a program for any specific input) are either always larger than the artefact they are describing or they are always an approximation.[5] In order to thoroughly describe a computer we need an even larger computer. Two prime examples of this recurrent problem are software verification and service discovery.

Software verification is about a formal proof of correctness of an implemented software. Our colleagues from software engineering have good reasons for such an enterprise. Detonated rockets, lost satellites, and potentially exploding nuclear power stations caused by programming error cause or may cause severe damage to our society. Therefore, a program is formalized and its correctness in accord to the formal specification is proven. However, there is an intrinsic contradiction in this approach. Nearly none of the reasoners used for verification of software have ever been verified. The reasoners are usually a very complex piece of software, and rely on compilers, libraries, operating systems. Even worse, they rely on infinite user input and hardware (both, internally and externally in regard to the artefact they are verifying). In consequence, software verification can only provide a proof of correctness for a small piece of software relying on a bigger, non-proven piece of software and hardware. And this would lead towards another infinite regress if it is taken to its extreme (see Figure 1).[6]

We will use the problem of **service discovery** as a second illustration for our point (cf. [Fensel et al., 2005]). Web services provide automated access to web pages such as Amazon or Google. Due to such web services and programs, content access and processing is no longer limited to the human user. Web services are engines which automize the access to actual products and services such as books, travel arrangements, office supplies, etc. *Semantic* web services are about annotating such web services with meta data to help mechanizing discovery and usage of such web services. Therefore, semantic web services are means to discover web services which are engines to discover and access actual services. However, many research groups confuse the latter two concepts. They assume the existence of full-fledged meta data descriptions by a semantic web service that completely and accurately describe all the actual services that can be found and accessed via a web service. However, this has bizarre side effects. First of all, web services are no longer needed. An approach that was originally justified to support web service discovery has made the latter obsolete. Since it assumes all services that are discoverable and assessable via a web service are being fully described by its meta data description it is no longer necessary to access the web service. It is suddenly sufficient to reason about its meta data description. Unfortunately this approach will never scale since efficient database technology used to store trillions of facts is replaced by an inefficient representation in logics. This approach would not

5. Hegel already pointed out that a precise and complete description of one page of a book would require a second book larger than the Universe (cf. [Hegel, 1991]).

6. Notice that this is not at all meant as an argument against the efforts of our colleagues from formal software engineering. It just defines the principal boundaries of their approach in which their work is still needed and helpful.

work for mainly two reasons:

- All the potential content offered by a web service would need to be duplicated by its meta data description. However, no web service provider would be willing to spend this extra effort.
- Logical reasoning will break down if you need on-line reasoning over trillions of instances.

What is wrong with this is that the meta layer replaces the object layer and therefore everything becomes slow, unrealistic, and non-scalable.

Let's explore how the universe, the largest of all computers, behaves in this regard. After the idea of absolute space and time has been refuted by the Theory of Relativity, particles can only be defined through interaction with other particles. Therefore, each particle can only enter into a definite number of interactions with other particles. The idea of indefinitely accurately describing particles is therefore misleading. Since the particles cannot be any more or any less than the sum of all those interactions, we must anticipate that there is a definite boundary for the accuracy of its description. The universe can only be defined and described through itself. The universe is too small and too young to be able to thoroughly and accurately describe itself. It is lacking both time and space to do so. And since the universe, the describing entity, and the actual description of the universe are identical, the universe itself must be an approximation. Heisenberg's Uncertainty Principle and Planck's Quantum of Action (see Figure 2) are therefore not accidents but fundamental characteristic traits of physics. In other words, if the universe does not know the individual particle's precise location, how is the much less informed individual particle supposed to know? Without external help it is not even sure whether it is a particle or a wave.

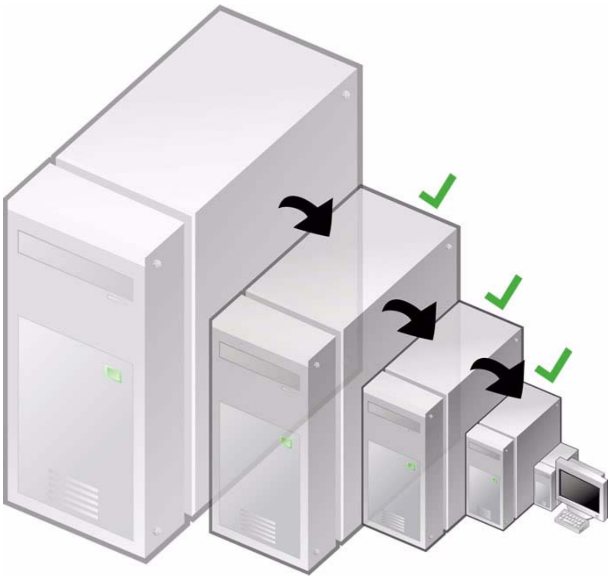

Figure 1 The infinite regress of computers accurately describing computers.

$$\Delta x \Delta p \geq \frac{h}{4\pi} = \frac{\hbar}{2}$$

$$h = 6{,}62607 \cdot 10^{-34}\,\mathrm{J\,s} = 4{,}13567 \cdot 10^{-15}\mathrm{eVs},$$

Figure 2 Heisenberg‘s Uncertainty Principle and Plank’s Quantum of Action.

The only way out of this necessarily approximative character of our Universe is the introduction of *infinity*. Like infinite speed in information transfer would help to resolve the dilemma of our system administrator, infinity would help to escape the approximate character of the universe. In consequence, there are three trials to escape this dilemma: Assuming an infinitely large universe, assuming an infinitely old universe, or assuming an (nearly) infinite number of universes.

An infinitely large universe could in fact exist with properties that would allow a structure that is able to carry an even larger structure in itself. Take as an example the surprising fact that there are as many natural numbers as there are even numbers. Simple mathematics can prove that there is a bijective mapping between both sets whereas any common sense would tell us that there are more natural than even numbers since the natural numbers are a proper super set of all even number also including odd numbers (see Figure 3). Unfortunately, the speed of light is finite, i.e., even an infinitely large

1	2	3	4	5	6	…
2	4	6	8	10	12	…

Figure 3 Mapping natural and even numbers.

universe would not have had the time to establish infinite many interactions in case it does not also exists infinitely long.[7]

Now what about an infinitely old universe? Already with Kant (cf. [Kant, 1994]) we know that an infinitely old universe is problematic since it would have taken infinitely long time for the current moment to arise. In other words, we would still (and forever) need to wait for its arrival. Also it seems to be common ground reached by modern physicists that the universe has finite age, born in what is called the Big Bang. The fact that the necessity for an approximate character of the universe (i.e., Heisenberg’s Uncertainty Principle) relies on the argument based on the Big Bang provides an interesting complementarity of physics in the small and physics in the large.

Finally, there are proposals that assume an infinite number of universes (cf. [Deutsch, 1998]) via parallel or mega universe. Whenever a decision in the quantum world is made a probability is turned into an actual state and for each of the potential

---

7. That is, we are back with this fascinating principle that information cannot be exchanged faster than light speed.

outcomes a new universe arises. This mega universe would quickly become quite large but would transfer the uncertainty in observations from the object back to the subject, i.e., the subject simply does not know at a certain moment in time which universe it will soon join.[8] However, in the end, this is just another form of infinity or simply theology twisted into physics. God, in His infinite omnipotence, could easily record all past, current and future events of the universe. But then why should He still execute the universe? In applied computer science, we mainly use prototyping because our specifications are incorrect and incomplete. Einstein was so frustrated by the approximate character of the universe that he stated: “God does not play dice.” Bohr countered that Einstein should stop dictating to God.

Systems which describe themselves are essentially approximations. Thus, the universe must be an approximation. Understanding physics as a branch of applied computer science will help us in comprehending many of its phenomena. To paraphrase Anton Zeilinger [Zeilinger, 2005]:

> *Tomorrow we will have learned how to understand and speak physics in the language of computer science. Laws of nature cannot make a difference or draw a line between reality and computer science, as computer science is the primary matter of the universe. Quantum physics is one consequence of the fact that the world is a representation of itself. Reality and information are the same!*

4 Biology as a Branch of Applied Computer Science

Again, we will start our discussion with another amazing analogy. Completed in 2003, the Human Genome Project (HGP)[9] was a 13-year project coordinated by the U.S. Department of Energy and the National Institute of Health. Project goals were to identify all the approximately 20,000-25,000 genes in human DNA and to determine the sequences of the 3 billion chemical base pairs that make up human DNA. An illustration of the result is provided in Figure 4. In analogy we provide an illustration of how the Microsoft Office system may look like at a binary level. Besides the fact that biology uses a more complex coding schema, no reader could really figure out the difference in functionality of the artefacts generated from these descriptions.

Originally, biology was the field of expertise of nitpickers. Are there 50,000 or 200,000 species? And is this due to the definition of a species or rather to the diversity of life itself? With the work of Darwin (cf. [Darwin, 1998]), the pathway for a more systematic approach was opened. The comprehension of species in relation to their environment was borne. Species adapt to their ecological systems and environmental changes cause species to change. Still, Darwin failed to provide an answer to a very simple question: How should this adaptation occur? It was Mendel (cf. [Mendel, 1965]) and his work on botany that opened the gate for answering this question by comprehending of species in terms of genetics. Individuals carry information which is inherited by their offspring. And if the environment is supportive to some of these individuals and their features, they will be reproduced by the next generations while other individuals together with their genetic information will disappear. The first step

8. We even dare to ask who should describe that meta universe.
9. http://www.ornl.gov/sci/techresources/Human_Genome/home.shtml

towards understanding biology as a branch of information processing had been taken. In comparison to physics, the field of biology as a branch of applied computer science is even more interesting. In biology, we not only have systems that describe themselves but systems that describe and *program* themselves! Genes are more than simple data. Genes include the program of their own interpretation and the process to produce new life. Genes are a static representation of a dynamic process.

The understanding of programs as data is something that happened very early in computer science. This allowed the theory and application of *programmable systems* to be implemented. The Von-Neumann-Architecture, named after John von Neumann, is a stored-program concept which consists of four main components: (1) Arithmetic-logic unit; (2) Memory unit (saves programs as well as data); (3) Control unit (decodes the

ACTATGAACAGGTATAACTAGTAACCTGACTGACCTAGATCTATGAATTC-
GATGCATGGATTACACTAGATTCGACTATGAACAGGTATAACTAGTAAC-
CTGACTGACCTAGATCTATGAATTCGATGCATGGATTACACTAGATTCGAT
GAACAGGTATAACTAGTAACCTGACTGACCTAGATCTATGAATTCGATGC
ATGGATTACACTAGATTCGACAGGTATAACTAGTAACCTGACTGACCTAG
ATCTATGAAGAACAAGGTATAACTAGTAACCTGACTGACCTAGATCTATG
AATTCGATCTATATAACTAGTAACCTGACTGACCTAGATCTATGAATTCGA
TGCAGGTATAACTAGTAACCTGACTGACCTAGATCTATGAATTCGATGCAT
GGATTACACTAGATTCGACAGGTATAACTAGTAACCTGACTTGAATTC-
GATGCATGGATTACACTAGATTCGACAGGTATAACTAGTAACCTGACTGACCTAGATCTAT-
GAAGAACAAGGTATAACTAGTACTAGATCTATGAATTCGATGCATGGATTACACTAGATTC
GACAGGTATCTAGTAACCTGACTGACCTAGATCTATGAAGAACAAGGTATAACTAGTAAC-
CTGACTGACCTAGATCTATGAATTCGATCTATATAACTATATAACTAGGACCTAGATCTAT-
GAATTCGATGCAGGTATAACTAGTAACCTGACTGACCTAGATCTATGAATTCGATGCATGG
ATTACACTAGATTCGACAGGTATAACTAGTAACCTGACTTGAATTTATAACTAGTAACCT-
GACTGACCTAGATCTATGAAGAACAAGGTATAACTAGTAACCTGACTGACCTAGATCTAT-
GAATTCGATCTATATAACTAGTAACCTGACTGACCTAGATCTATGAATTCGATGCAGGTATA
ACTAGTAACCTGACTGACCTAGATCTATGAATTCGATGCATGGATTACACTAGATTCGA-

1010101000101010000011111011010110011101010001100101
0001011101010000110010110101011001101010100011000110
0011010000101010110010101101010110101000101001011001
0101001010010100010001010000010010010000010000001001
0010100010001001001010010010010100100101001011100011010000101010110010101101010110
0010101101010110101000101001011001010100101001010001000101000000100010011111111110
0100100000100000010010010100010001001001010010010010100100101001011100011010000010
1010110010101100010100101100101010010100101000100010100000100100100000010000001001
0010100010001001001010010010010000001010110101011010100010100101100101010010100 10
1000100010100000001000100111111111001001000001000000100100101000101010101010110011
0101010001100011000110100001010101100101011010101101010010010100010001001001010 01
0010010100100101001011100011010000101010110010101100010100101100101010010100101 00
0100010100000010010010000001000000100100101000100010000001001001010001000100100101
0010010010100100101001011100011010000101010110010101100011111110010010000001000000
1001001010001010101010101100110101010001100011000110100001010101100101011010101 10
1010010010100010001001001010010010010100100101001011100011010000101010110010101 10
0101011000101001011001010100101001010001000101000000100100100000010000001001001010 0
0100010000000100100101000100010010010100100100101001001010010111000110100001010101

Figure 4 The sequences of the 3 billion chemical base pairs that make up human DNA and a binary presentation of Microsoft Office.

instructions of a program and commands the computer to perform some operation); and (4) Input/output unit (commands input and output of data). The Von-Neumann-Architecture was a revolutionary idea when it was first described in 1945.[10] Earlier computers had always been confined to a fixed program which was controlled by hardware. With the help of the Von-Neumann-Architecture, it was now possible to change programs very fast or to run different programs quickly one after another without having to change the hardware.

Still, this concept assumed an external entity, the human programmer that acts as God, generating programs. Unfortunately, our understanding of *self-programmable systems*, i.e. systems that are simultaneously its own program and programmer is still in its infancy. Our research in the field of Semantic Web Services is the first step towards realistic automatic programming scenarios. But it is rather child’s play than a serious contribution to these fundamental questions.

Otherwise, biology still has a long way to go, too. No computer scientist would ever try to understand purpose and functionality of the Microsoft operation system based on an arbitrary binary representation. There are several levels of higher abstraction necessary to understand the system since otherwise the complexity is much too high. In addition, the identical system can be represented by significantly different binary representations. Biology has to find these intermediate representation levels as if they were invented in applied computer science to describe their artefacts.

5 Human Brain Research as a Branch of Applied Computer Science

Modern brain research is the attempt to answer a four-thousand-year old question of philosophy by means of natural science. A human being seems to be composed of: a physical body, a spirit and soul (which we will treat interchangeably here), and a magical way of connecting them both. To answer this first and ultimate question of human existence is real rocket science. Let us take a look at this marvelous organ that manages the unification of this dualism, i.e., our *brain*. The important and (as we will see) wrong question of human brain research has always been: Does consciousness and free will exist or not? Are we mechanical devices or a “container” filled with spirit? Assuming determinism comes along in three lines of attack: (1) Everything is determined by genes. As we will see this has been proven to be wrong. (2) Everything is determined by biological hardware. This seems to be just a wrong point of view. (3) Spirit can be fully understood. Unfortunately, this is also most likely wrong.

Our arguments are based on the work of Wolf Singer (cf. [Singer, 2002], [Singer, 2003]) and on viewing the brain as a self-reflecting system since more than 80% of the reasoning of the brain is concerned with itself. Please note that we do not assume a physical separation of object and meta layer reasoning in the sense that we would expect to find Descartes' pineal gland. That is, we do not view this as an architectural model where we would try to find an object and a meta-level component. We view this rather

10. However, many of the ideas of the Von-Neumann-Architecture had been already elaborated in 1936 by Konrad Zuse.

as a conceptual model to understand the reasoning processes of our brains. We identify such an architecture as essential for flexible and efficient reasoning demanded by difficult computational problems such as the brain is faced with.

5.1 Everything is determined by genes

This can be contradicted by the fact that people who were blind during their first years of life are not able to see during the rest of their life even if their eyes are repaired (cf. [Singer, 2002]). The precise definition of proper 3D visualization depends heavily on the actual shape of the face which cannot be precisely determined by the genes. Therefore, the definition of the visual processing capability of the brain is not pre-defined by genes but results from an interactive process with the environment during the first years of life. The inheritance of properties by genes already anticipates the inclusion of external stimuli to define the actual shape of the brain. It is the interaction (some people would say the *dialectics* of both) of our genetic program and our environment that forms our personality - the brain implements it. “The program for all functions of the brain is determined by the architecture of the connections through which neurons communicate with each other. Since this functional architecture is modifiable by experience throughout the postnatal phase of brain development, the specific way in which we perceive and act can be *passed by imprinting and education from one generation* to the next.” [Singer, 2002] That is, there is a cultural inheritance process not present in the genes that materializes in the physical/biological structure of the brain.[11] This is a *necessity* since the rapid evolution of our species has required an inheritance process much faster than what is implementable by genetic inheritance. Such a process is *possible* through the fact that human babies are born much too early in general terms providing them with heavily undetermined and therefore flexible brains.[12] Information *must* and *can* be inherit via cultural processes that generation by generation reflect in the brain structures of the individuals beyond that which is determined and inherited by genes.

5.2 Everything is determined by biological hardware

Specific aspects of the spirit are not attached to single neurons but to their interaction patterns. Neurons can be active in various interaction patterns in which they play different roles at the same time. Such interaction patterns are composed of three elements: Neurons, connections (electrical and chemical), and a certain frequency of oscillations between the neurons established via their connections. Metaphorically speaking, a thought is a specific self-oscillation of a network of neurons. On the one hand, it is the topology of the network that determines its resonance. On the other hand, it is the resonance in the brain's interaction with the environment and with itself that creates, reinforces or decouples interaction patterns. Again, the brain is not a static device, but a device that is created through usage, or in the words of Singer „program and architecture are the same and it makes no sense to ask which side determines the

---

11. A late rehabilitation of Lamark!

12. There was a very critical phase in the evolution of our species where erected walk and its requirement for small pelvis aperture conflicted with the parallel request on increasing brain size. Only the extremely early birth of human babies could bypass this problem. Consider that a Chimpanzee female is usually two years pregnant with her baby.

other". It is again an interaction process where both sides concretize the other. The arguments that conscious decisions are accompanied by measurable brain activities and may not reflect the actual reason of a decision are not really arguments against their mutual relationship. This argument does not understand the nature of meta (or reflective) reasoning systems that are based on limited rationality - a prerequisite of efficient reasoning. Even if more than 80% of the reasoning of the brain is concerned with itself it can never guarantee a complete mental map of the other 20% nor of the 80% itself (reflecting the reflection). Complete consciousness would not only need to reason about external input but also about itself. Like the universe, it would need to be bigger than itself. If this was the case, the Cartesian pineal gland would need to be bigger than the entire brain to realize a fully conscious (and highly inefficient) approach and even worse, it would need to be bigger than itself to be aware of itself. Only the combination of partial consciousness (meta reasoning) and non-consciousness (object level reasoning) is what provides flexibility and efficiency and it is the only way to escape the infinite regress of assuming that things need to be bigger than they are by themselves.

Take modern Economics as an example. Classic economics naively assumes that all players possess complete information and therefore behave fully rational. Modern economics includes the costs of getting complete information – an action which actually would lead to irrational behavior when trying to get complete information. It realizes the need for *decisions based on limited rationality as a rational behavior*.[13]

Many problems tackled by computers are defined by intrinsic computational complexity. The size of the search space is too large to allow a complete search. If *NP* <> *P*, then it is even proven that for many classes of problems no efficient algorithm will ever exist.[14] Meta-layer architectures and reflection (reasoning about decisions, actions and knowledge) have been introduced to implement heuristic reasoners of limited rationality to find within a reasonable amount of time solutions of reasonable quality (see Figure 5). They are an example for reasoning with limited rationality. The meta layer should apply heuristics that may help to speed up the overall reasoning process and to increase its flexibility. Therefore, it needs to be incomplete in various aspects and resemble important aspects of our consciousness. It is incomplete in terms of Introspection and Reflection.

- **It is incomplete in terms of introspection** since the meta layer can only have an approximate view on the competence of the object layer in relation to the problem and the actual state of the object layer (otherwise both layers would collapse into

13. Just imagine to have to visit all the hundreds of thousands of CD shops all over the world to find the place where you can buy the cheapest CD.

14. The complexity class *P* is the set of decision problems that can be solved by a deterministic machine in polynomial time. This class corresponds to an intuitive idea of the problems which can be effectively solved in the worst case. The complexity class *NP* is the set of decision problems that can be solved by a non-deterministic machine in polynomial time. This class contains many problems that people would like to be able to solve effectively. All the problems in this class have the property that their solutions can be checked effectively. The question of whether *P* is the same set as *NP* is the most important open question in theoretical computer science. Most likely, they are not the same since *NP*-complete problems are a particular kind of problems for which all known deterministic algorithms have an exponential complexity.

one). However, it needs this abstraction to recognize potential paths in the reasoning process.

- **It is incomplete in terms of reflection** since the decisions made at the meta layer are of heuristic nature and may use rationales that do not accurately reflect the actual reason for a decision taken. In conclusion, it is predicted by the object layer beyond its knowledge and it influences the object layer beyond its awareness.

The reasoning at the meta layer is of limited rationality by definition (otherwise it would counter the efficiency achieved at the object layer). However, in most cases it is reasoning with several layers of limited rationality. Often, the object layer alone already implements a heuristic problem solver. A complete search including the meta layer may make no sense at the object layer. Therefore, the object layer already implements reasoning of limited rationality. It is usually at least second-order heuristic reasoning. This will produce false results but it is the only way to deal with difficult computational problems in limited amounts of time.

- **Object Layer**: Our perception provides us only with a partial picture of the world. It is often better to focus on the tiger than on the butterfly.
- **Meta Layer**: Our consciousness focuses only on a very small piece of the overall information provided in the cognitive process. Reasoning about whether the world is real and carefully evaluating all possibilities of moving the right or the left leg first is often not a good strategy for escaping the tiger.

Our consciousness can only be understood as heuristic meta reasoning over an heuristic object layer. For efficiency reasons it remains incomplete. For the same efficiency reason the object reasoning is already incomplete and heuristic. Very likely, this layered level of heuristic reasoning appears at various levels to have a decentralized architecture that can react more efficiently. Our consciousness is heuristic reasoning over heuristic problem solving with multiple (recursively appearing) layers.

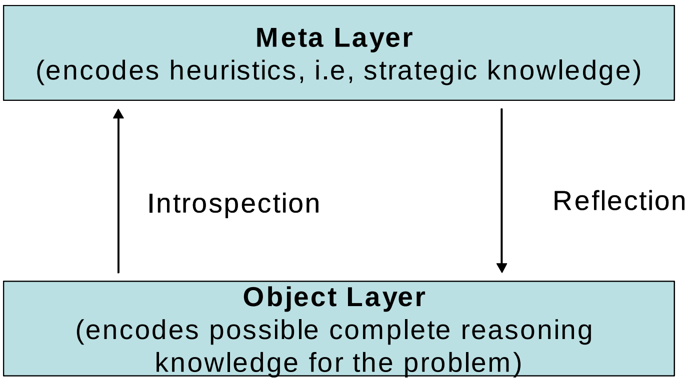

Figure 5 Meta reasoning and reflection

5.3 Spirit can be fully understood

The numerical complexity of our brain is frightening. Millions of neurons can have mega trillions of connections and hyper trillions of resonance patterns. A simple brain has more potential complexity than the universe has atoms. Finally, the ultimate, hidden material existence of reasoning is not the substantial, biological existence of the brain. It is more the rhythm of the music played by it that is the material existence of spirit: the patterns of self oscillation and resonance of the connected neurons. It is those oscillation patterns which, in the process of development of the individual brain, that create their own underlying network of links and connections. Only a branch of mathematics of stable oscillations in hyper-dimensional spaces could possibly formalize consciousness (a kind of "string theory" of consciousness). In general, it is more than surprising that such a super-hyper complex system can reach stable interaction patterns reflecting "intelligence". However, it may also precisely require such a hyper-complex and unpredictable system to create intelligence. Such systems are now, and maybe forever, beyond any analytical approach of understanding them. Faster computers may help to simulate – but not necessarily to understand.

6 Conclusions

Mathematics compensates shortcomings in current computer technology. Physics is an implementation of the theory of self-describing systems. Biology is an implementation of the theory of self-programming systems. Human brain research is an implementation of the theory of self-reflecting systems (meta-reasoning). Applied computer science will therefore be established as the standard foundation of all natural sciences.

Hereby, we are not pushing naïve dogmatism. We are indicating principal boundaries for the position of human kind in reality. Just as Galileo pushed mankind from the center of the universe, Darwin showed mankind evolved from Apes, and Kant established the fundamental boundaries of human knowledge, our thesis recognizes the true meaning of the boundaries of computability in a dual sense:

- **External boundaries of knowledge determined by the object**. We are not just perceiving the universe as approximation, instead the universe is an approximation. The boundary is not subjective but objective, i.e., the Kant's "Ding an sich" does not exist.
- **Internal boundaries of knowledge determined by the subject**. Intelligence requires a highly complex system which possibly (presumably) exists outside our conscious realm. We dare to say that we will never fully understand even ourselves. – At the very least, this also confirms our personal impression about ourselves and all people we have met in our life.

Or in the words of Sir Popper: "Science does not rest upon solid bedrock. The bold structure of its theories rises, as if it were above a swamp. It is like a building erected on piles. The piles are driven down from above into the swamp, but not down to any natural or 'given' ground; and if we stop driving the piles deeper, it is not because we have reached firm ground. We simply stop when we are satisfied that the piles are firm enough to carry the structure, at least for the time being."

We will continue our argument by investigating the role *semantics* will play in modern computer science.

Acknowledgement. Special thanks to Alice and Graham for transforming unreadable German notes into a readable text.

References

[Darwin, 1998] C. Darwin: *The Origin of Species*, Wordsworth Edition Lim., Hertfordshire, 1998.

[Deutsch, 1998] D. Deutsch: *The fabric of reality*, London, Penguin Books, 1998.

[Fensel et al., 2005] D. Fensel, U. Keller, H. Lausen, A. Polleres, and I. Toma: What is wrong with Web services Discovery. In *Proceedings of the W3C Workshop on Frameworks for Semantics in Web Services*, Innsbruck, Austria, June 9-10, 2005.

[Jebelean & Buchberger, 2003] T. Jebelean and B. Buchberger: Theorema: Computation and Deduction in Natural Style. In J. Grabmeier, E. Kaltofen, V. Weispfennig (eds.), *Computer Algebra Handbook*, Springer - Verlag Berlin, 2003.

[Hegel, 1991] G. W. F. Hegel: *The Encyclopeadia Logic*, Hackett Publ. Company, Inc., Indianapolis, 1991.

[Kant, 1994] I. Kant: *Critique of Pure Reason*, Everyman‘s Library, London, 1994.

[Mendel, 1965] G. Mendel: *Experiments in Plant Hybridisation*, Harvard University Press, Cambridge, 1965.

[Penrose, 1996] R. Penrose: S*hadows of the Mind: A Search for the Missing Science of Consciousness*, Oxford University Press; Reprint edition, 1996.

[Singer, 2002] W. Singer: *Der Beobachter im Gehirn*, Suhrkamp, Frankfurt am Main, 2002.

[Singer, 2003] W. Singer: *Ein neues Menschenbild?*, Suhrkamp, Frankfurt am Main, 2003.

[Zeilinger, 2005] A. Zeilinger: *Einsteins Schleier*, Goldmann, München 2005.