Criteria for Computational Thinking in Information and Computational Technologies

Larisa Yusifovna Ismailova

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoye Shosse, 31, Moscow, 115409 Russian Federation
lyu.ismailova@gmail.com

Abstract: This paper is an attempt to generalization and development approaches to the interdisciplinary analysis of computer science, formed in the scientific school of NRNU MEPhI and Institute "JurInfoR-MSU". In interpreting the perspective of computing in modern literature there is no unity and the state of research and a region of the expanded understanding of information science is most clearly manifested in the separate analysis of concepts of computing and of notions of computer science. When comparing it becomes possible to find some deserving interest area, and its characterization is explored in this paper. As a result, it is able to come to an explanatory system, giving rise to an analysis of contemporary issues, and develop formulation and the approach to the problem of expansion and development of an improved understanding of the conceptual foundations of computer science. In this paper it is shown that this problem is decomposed to 4 main subtasks.
[Ismailova L Yu. **Criteria for Computational Thinking in Information and Computational Technologies**. *Life Sci J* 2014;11(9s):415-420]. (ISSN:1097-8135). http://www.lifesciencesite.com. 86

Keywords: Methodology of computing, computational thinking, natural and artificial information processes, processes interaction

1. Introduction

This paper argues that a relatively new phenomenon of *computational thinking* gives an interdisciplinary understanding of modern trends in computer science [1].

In interpreting the perspective of computing in modern literature there is no unity and the state of research and a region of the expanded understanding of information science is most clearly manifested in the separate analysis of concepts of computing and of notions of computer science [2]. When comparing it becomes possible to find some deserving interest area, and its characterization is explored in this paper. As a result, it is able to come to an explanatory system, giving rise to an analysis of contemporary issues, and develop formulation and the approach to the problem of expansion and development of an improved understanding of the conceptual foundations of computer science. In this paper it is shown that this problem is decomposed to 4 main subtasks.

First, in the system of foundations the problem of separating the bases of two components: the *basic principles* and *key actions*, or *practices*, is to be solved. *Basic principles* are the statements and descriptions of immutable laws and recurrence relations that shape and constrain all the computing technology. *Basic practices* are the skill field and abilities, in which specialists in the computations can show different levels of performance type: beginner, competent, and experienced.

Second, a degree of irreducibility of computing to a combination of notions on the basis of full or partial borrowing conceptual foundations of mathematics, science or engineering, and transferring it to the area of computing is under the estimation. Since computing as an area is in its infancy, then it requires the development of more private conceptual basis that is consistent with the observed facts and phenomena and having predictive power.

Third, the necessary extent expansion of known concepts, leading to the requirement for the formation of an improved and updated "computational thinking" is under analysis. Computational thinking can be regarded either as a style of thought organization, which encompasses known practices, or as independent practice. It is understood as the ability to interpret the world in the form of algorithmically driven transformations, which algorithmically controlled by the transformations of inputs into outputs.

Fourthly, an idea of objects, their interaction with environment, based on the new requirements for "computational thinking" is forming. Thus the explanatory system is formed and piloted for the study of both natural and artificial information processes.

The results of this interdisciplinary analysis are used in the educational practice in NRNU MEPhI and MIPT. Computational thinking has to be a fundamental part of the way not only specialists in Information Technologies but the people think and understand today's world [3].

2. An approach to computation modeling

There is a practical need in developing of methodology and characterization of the fundamental bases of computer science from the standpoint of ideas about the *computational process*. The computational process appears to be a basic building block of computing, and this is based on common principles and practices, as well as the dynamics of their relationship, which will express the area of computer science as a field of science, based on deep and enduring fundamental principles. In today's world computer science is increasingly beginning to play a key role, providing multiple and highly dynamic connection between science, technology and society.

2.1. Computing as activities

The most fundamental concept in computer science considered the computation performed on the computer -- computing. Computing is also considered as activities aimed at the development and application of computerized part of the information technology [1].

2.1.1 Area and discipline of computing

Computing area is assumed as generalized area of knowledge, which includes computer science, software engineering, design of hardware platforms and other disciplines, somehow related to information technology. The discipline of computing usually refers to systematic study of algorithmic processes of information descriptions and transformation.

2.1.2 Lack of a narrow understanding of computing

Such a standpoint, deliberately narrowed to frames of engineering, for observing the computing is clearly insufficient. Such a narrow interpretation currently leads to damage in the implementation of innovation, doing research in science and technology development. This is reflected not only in the development and financing of education and research, but also on the attitude of the society to computing, as well as on the choice of direction for young generation career growth.

2.2. The need for computing own grounds

There is an urgent need to develop own computing bases. The current situation highlights the apparent lack of full or partial borrowing conceptual foundations of mathematics, science or engineering, and transferring it to the area of computing [2]. Since the computing area itself is in its infancy, then it requires the development of more private conceptual basis that is consistent with the observed facts and phenomena and having predictive power [3]. For example, Web-science requires systematic application of partially defined functions, a special understanding of the domains on which variables range, intensive development of the descriptions apparatus, etc. Information processes require consideration of functions as processes regardless of prior ascertain their domains and/or ranges, as is customary in ordinary mathematical practice.

The accumulated to date results in the application of computing, confirm a necessity to establish its widespread expanded understanding and development of improved conceptual framework. An importance of computing in the structure of modern society, its essential interdisciplinarity, its key role in assessing the dynamics of the relationship of science, technology and society, poor drafting its logical and methodological bases indicate the urgency of establishing the expansion and development of an improved understanding of the conceptual foundations of computer science.

3. Proposed methods and approach

The proposed method of research computing with object**s** is as follows. The logical and philosophical concepts are selected and developed of: interaction of objects with each other; the interaction; the interaction of objects with the environment.

Each of these representations is understood as follows.

(1) *The interaction of objects with each other*. The very idea of the object is developed. This is studied in the framework of applicative computational systems, models and technologies with the least possible today formal constraints.

(1') *The interaction*. The representation of interaction as such is developed, that in the world practice today is essentially unstudied question.

(2) *The interaction of objects with the environment* (i.e., the environment of "computation", of result formation, and the like). Thus it is necessary to develop a representation of the environment itself. This is studied in the framework of semantics of applicative computational systems, in particular, in semantics of programming language constructs and, in a part, in semantic networks.

The proposed approach to the *construction of an explanatory system* for computations with objects is as follows. The principle of "natural explanation" is formulated and adopted. An idea to explain the objects and their behavior *naturally* requires the adoption of certain principles. Then, based on the principles, *explanatory system* is developed. It is necessary to select the central beliefs that will fully characterize the range of the effects, in this case the *computational* ones. So, there is the entity -- *object*, -- and another entity -- *environment*.

Object interacts with the environment so that the result of evaluation *is placed* in the environment. On the other hand object in the interaction with the environment receives from it the values and/or parameters.

The proposed approach to understanding the *structuring of environment* is as follows. The structure of the environment should cause quite comfortable feeling: this is the place where the values of the objects are stored. Hypothetically, the environment is a universe where there is a “deep” part and “peripheral” part. The details of the deep one are unknown, but its structure can make a reasonable assumption. Peripheral part, to the contrary, is good “seeing” and not only its structure is known, but also all of its components.

Expected results and overall work plan are following. Overall task is an ongoing project. Work on the project is broken down into three annual stages. In general, based on ideas about the interaction, the “process interpretation” of information processes is developed, reflecting the current understanding of implementation research.

The result of steps 1-3 is a series of articles, and the general result is the preparation of the monograph material and preparation of software allowing to assess modeling of object interaction and their interaction with the environment.

(Step 1) The first stage attempts to express computer science as a field of science which is based on deep and enduring fundamental principles. The system has two components: the *basic principles* and the *main actions*, or *practices*.

Basic principles are the statements and descriptions of immutable laws and recurrence relations that shape and constrain all the computational technology. They can be summarized in seven categories: - computation, - communication, - coordination, - reorganization, - automation, - evaluation, - designing (Table 1).

Table 1. Basic categories for a science of computer science.

Category No	Category Formulation
1	Computation
2	Communication
3	Coordination
4	Reorganization
5	Automation
6	Evaluation
7	Designing

This is not necessarily mutually exclusive groups of principles, but windows that give specific perspectives relating to the computation. For example, the Internet is a technology that derives its operating principles, above all, from communication, coordination and reorganization, and its architecture is derived from design and evaluation.

*Basic practice*s give the field of skills and abilities, in which specialists in the computations can show different type levels of their performance: the beginner, competent, and experienced ones. There are four basic practices: - programming, - development of systems, - modeling, - application.

Computational thinking can be regarded either as a style of thought organization, which encompasses known practice or as a fifth practice. It is understood as the ability to interpret the world in the form of algorithmically driven transformations, which algorithmically controlled by transformations of inputs into outputs.

(Step 2) In the second stage, the answer to the question why the computation, -- computing, -- is much wider than programming. This is in connection with the analysis of a kind of movement that became known as “computational thinking”.

By its supporters the computational thinking is assumed as a new way to characterize what is the core research direction, the lever to reduce the number of studying the computer science and argument in favor of the adoption of computer science as a legitimate field of science. This movement is controlled in accordance with a plan to implement the four main objectives, listed in Table 2:

- the inclusion of computer science in the science (as a partner on equal terms, rather than as software);

- finding out the ways to make computer science more attractive in the eyes of students specializing in it, and in the eyes of others, located in adjacent scientific fields;

- revival of ongoing research deeper issues inherent in computer science [8,9,10];

- displaying fundamentality of computation that often in most cases cannot be eliminated, the efforts made to turn this understanding into faith.

(Step 3) The third step is working on the formulation of general principles, using which one can try to respond to the still unresolved question: “What is computer science?”.

Table 2. Main directions of evolving the computational thinking.

Direction No	Direction Formulation
1	The inclusion of computer science in the science (as a partner on equal terms, rather than as software)
2	Finding out the ways to make computer science more attractive in the eyes of students specializing in it, and in the eyes of others, located in adjacent scientific fields
3	Revival of ongoing research deeper issues inherent in computer science
4	Displaying fundamentality of computation that often in most cases cannot be eliminated, the efforts made to turn this understanding into faith

Experts take care of that movement for computing thinking movement is not engaged solely in the minds of people fixing a narrow understanding of this trend, but to emerging needs in such thinking, coming from other disciplines or from people to be raised. There is concern that there is no going beyond a predetermined package, and very understanding is just wrapped in new paper and a new bandage tape.

In this regard, of particular interest are two *key questions*:

- whether computing thinking is a unique and distinctive characteristic of science,
- whether computational thinking is an adequate characteristic of science.

Apparently, both of these questions need to give a negative answer. But in structures, surrounding the basic principles of science, when trying to answer them, everything is vice versa, and these questions have to give a positive response. This is sufficient reason for the deep divisions accompanied by discussions. This is due to the inadequacy of the name itself.

4. Expanded understanding of computer science and related works

The subtasks above, in couple, can give solving the problems. Each of them, separately, is important for science, technology and society, seen in conjunction. Their importance, relevance and novelty are confirmed by the latest discoveries. Over the last decade in studies in other fields of knowledge the *natural information processes* have been discovered, confirming the independent status of computing/computer science as a science.

Older definition of science as “the study of phenomena surrounding computers”, which was given by A. Perlis , G. Forsythe and A. Newell, and dates back to around the year 1970, gives “the study of information processes, natural and artificial”. Shift in the direction of the computer as an object of research on the computer as a tool enables us to re-engage deep questions of our knowledge, presented in a new light when the computation is considered a lens through which one examines the world [4].

Another aspect of novelty is in detecting irreducibility of computing/computer science to mathematics or engineering. This stemmed from the recognition that computing is a unique combination of paradigms of mathematics, science and engineering. It is a combination of a compound and, since none of these paradigms is not individually explaining and did not cover the entire field of computing [2].

In the foundations of mathematics and theoretical computer science for a long-established tradition of objects treated as abstract entities, endowed with certain properties. Among the most profound attempts to analyze objects and ways to manipulate them, determining their fundamental role for logic and philosophy is especially important for modern science to recognize the contribution of M. Schoenfinkel, H. Curry and D. Scott. As part of the research program H. Curry [5] received justification of logic and philosophy approach of operating objects based on a single metaoperator of *application* allowing the action of one object to another. Objects, occurring in the systems, form the *applicative computational system* (ASC) and the direction of research spawned in the 1940s -- 1960s a whole range of scientific schools worldwide. As is known, a direct attempt to build the logic on this basis leads to contradictions, the most famous of which is the Curry’s paradox.

The most successful attempt to overcome this difficulty were methodological conceptions of D. Scott, who proposed in the 1970s build a system of objects in continuous lattices endowed with a special topology [6,7]. The *theory of computation* built on this basis gave growth to scientific discipline called *semantics of programs*, and D. Scott for his contribution to the development of logical and methodological foundations of computer science was awarded the Turing Award.

Appearance and, in particular, the development of computer science in modern times with special urgency is raising the question about the objects, but in the context of the avalanche growth of information technologies and their achievements, and their impact on science and society in general. In the field of computer science, applicative computing systems, or ASC, play a great role, which is relatively new phenomenon to science and technology. It has been proved in ASC [8,9] that the objects behave as functional entities, having the following features: (1) arity, or number of argument places for object is not fixed in advance, but displays itself gradually, in interactions with other objects; (2) in combining of a composite object, one of the original objects – function, -- is applied to the other one -- the argument, -- and in other contexts, they can turn their roles, that is, functions and arguments are treated as objects on equal rights; (3) self-applicability of functions is permitted, that is the function can be applied to itself.

Such methodological setting helps producing a unified view of artificial and natural information processes, which gives an element of novelty. As can be shown, with the approach overcomes the disadvantages of Schoenfinkel-Curry's system, contributing to the development of "computational thinking'" for the extended area of knowledge.

Finally, the analysis and accommodation of computational thinking to modern conditions also characterizes the novelty of perspective project. Already in 1975 the Nobel Prize in Physics Ken Wilson put forward the idea that the modeling and computation became a full way of doing research that was previously unavailable. K. Wilson discoveries were made on the basis of computational models, the use of which led to a radical change in the understanding of phase transitions in materials. At the beginning of the 1980s he teamed up with other leading scientists from other fields of knowledge, who believed that the major scientific problems can be solved on the basis of computations and asked the government to expedite the process of creating a network of supercomputer centers [4]. They argued that the computation was the third pillar of science, along with the traditional theory and experiment. In their deliberations, the term "computational thinking" was used. The observed motion of computer science (computational science), eventually grew into a huge interagency initiative of high performance computations (HPC), culminating in the US Congress bill funding initiatives HPC in 1991.

This movement has confirmed that both the ideas of computation and computational thinking are essential for the development of science. This gave rise to a powerful political movement, which included this performance, e.g., in US federal law. In our country, such initiatives are also known, some of which are included in the priority list of areas of science and technology of RF.

Conclusion

This is a review paper on ongoing project aimed to expanding the range of understanding the computer science.

1. As was shown, the observed motion of computer science (computational science), eventually grew into a huge interagency initiatives of governmental level. To succeed the modern computer science people need using the computational thinking as a means to turn computer science to a full scope science. This could be achieved using the ideas of natural computation where data objects can be observed as the information processes.

2. This general task can be easier achieved when decomposing the problem to 4 main subtasks. Briefly, they are: basic principles as a couple of basic principles and basic practices; self standing conceptual foundations; improved understanding of computational thinking; understanding data objects as information processes.

The question for future study was earlier debated as whether the computing assigns to the field of engineering or science. There is a need to overcome the limitations of narrow understanding of computing.

Acknowledgements:

This work is a generalization of the results, which are associated with the construction of conceptual and computational model obtained at different times during the projects, partially supported by RBRF grants 14-07-00119-a, 12-07-00661-a, 14-07-00072-a, 12-07-00646-a, 13-07-00716-a, 12-07-00554-a, 14-07-00054-a.

Corresponding Author:
Dr. Larisa Ismailova
Department of Cybernetics
National Research Nuclear University MEPhI
(Moscow Engineering Physics Institute)
Kashirskoye shosse, 31, Moscow, 115409, Russian Federation
E-mail: lyu.ismailova@gmail.com

References

1. Carnegie Mellon University Center for Computational Thinking. http://www.cs.cmu.edu/~CompThink (Date View 22.04.2014)
2. Great Principles of Computing Web site. http://cs.gmu.edu/cne/pjd/GP/GP-site/welcome.html (Date View 22.04.2014)
3. Wing J. Five deep questions in computing, Commun. ACM Jan. 2008; 51(1): 58-60,

4. Wilson KG. Grand challenges to computational science, *Future Generation Computer Systems*, Elsevier, 1989; 171-189.
5. Seldin J.P. Curry's program, To H. B. Curry: Essays on Combinatory Logic, Lambda Calculus and Formalism, J. P. Seldin and J. R. Hindley (Eds.), Academic Press, London, 1980;3-33.
6. Scott DS. Outline of a mathematical theory of computation. *Technical Monograph PRG-2*, Oxford University Computing Laboratory, Oxford, England, November 1970.
7. Scott DS. Lambda calculus: Some models, some philosophy, *The Kleene Symposium*, J. Barwise, H. J. Keisler, and K. Kunen (Eds.), North-Holland Publishing Company, 1980; 223-265.
8. Wolfengagen VE. Applicative computing. Its quarks, atoms and molecules, Ed., Dr. Ismailova L. Yu. Moscow: Center JurInfoR, 2010;62.
9. Wolfengagen VE. Semantic modeling: computational models of the concepts. The Proceedings of the 2010 International Conference on Computational Intelligence and Security, CIS 2010, Sponsors: Xidian University, Beijing Normal University, CPS of IEEE. Nanning, 2010; 42-46. doi: 10.1109/CIS.2010.16
10. Wolfengagen VE. Combinatory logic in programming. Edited by Dr. L. Yu. Ismailova. Moscow: Center JurInfoR, 2003;336.

6/28/2014