Scientific Research Methods and Computer Science

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Abstract. The origins of the word "Science" are back from the Latin - *scientia* - (knowledge) -, nevertheless since the very beginnings the human being tries to apprehend his world and transmit that knowledge. Science is divided into several domains however they are related. This paper makes an historical and analyze overview about Science and scientific research methods. The scientific method is described, analyzed and related with Computer Science. For the specificities of Computer Science, three scientific approaches are presented - theoretical, experimental and simulation.

Key words: Science, Scientific Methodologies, Research, Research Methods, Computer Science

1 Introduction

The word "Science" has its origins in the Latin - *scientia* (knowledge). In more recent words it is said that Science is an organized or systematic body of knowledge [1]. Science embraces many different domains however those domains are related.

In ancient Greece, there were people know as philosophers that study the world that surround them trying to understand the phenomena. Some of them such as Socrates, Plato or Aristotle are considered the founders of the Western philosophy [2]. In that ancient world a *wise* or a philosopher studier might dominates different domains in science (logic, mathematics, philosophy, medicine, etc). With the passage of the centuries it came the specialization: scientists specialize in certain particular science or domain in order to study it and carry more profound researches in specific fields. That still remains as the current paradigm. However it is possible that in a near future we start to face a reality where a researcher might need to embrace various domains. From a very high point of view we might see this as the completion of the cycle.

Logic and mathematics sciences are the core of all science. From there and descending it emerge the natural sciences such as physic, chemistry and biology. At another level comes the social sciences (history, philosophy or linguistics for

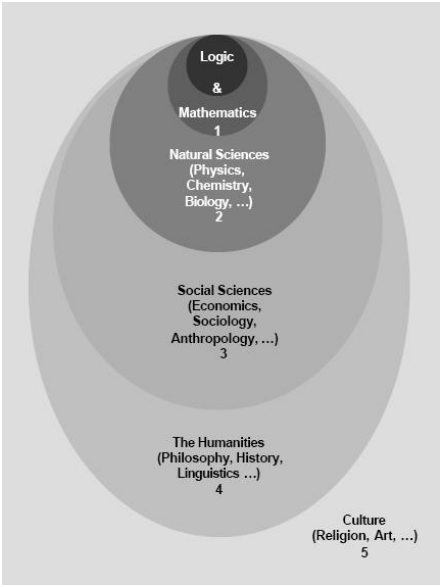

Fig. 1. Science, one possible view - Courtesy of [3]

example). Other level is possible to established for the cultural, religions and art domains. This is only a possible view that is given at [3] (Fig. 1).

Regarding Computer Science (CS) some said that it should not be called as a science [4]. Although CS is definitely a recent discipline, few will still argued that it is not provided with attributes to be qualified as a science. CS has its specificity and has its bases also in logic and mathematics. However, as we will see next, in nowadays CS is transversal to very different domains and is a large subject of scientific research.

The next section will focus on the scientific method for research in general. Section 3 overviews the scientific research methods concerning computer science specifically. Last section which concludes the paper will draw some conclusions and give some future perspectives on these subjects.

2 Scientific Research Method

Scientific research can be seen as the usage of a rigorous method or methodology for achieving new knowledge. Around this method or methodology implicit to scientific research there are few controversies but rather important.

According to Thomas Kuhn in [5], the process of scientific research has its bases in empirical (based in theoretical background) knowledge - observational-inductive science. When the research process reveals consistency with the actual paradigm Kuhn calls it "*normal science*". If the research outputs contradictions

to the actual paradigm the process must be carefully tested because it may leads to a paradigm shift - "*scientific revolution*" (Kuhn). This occurs very rarely.

At the other extreme Karl Popper argues in [6] that scientific research based in empirical methods can be refutable (*Falsifiability*). He rejects the classical empirical scientific research by stating that every scientific theory is conjectural and provisional only waiting to be contradicted by the facts. Popper defends that no theory should obtain its veracity only by facts corroboration; facts which were predicted based on the same theory.

Although Popper's rejection for induction methods, for some points of view, induction has proved to be very helpfully playing an important role in scientific research.

2.1 The Method

The scientific method consists on a series of stages with the purpose of providing answers to questions that emerge from science theories or observations. Aristotle in the ancient Greece or Ibn al-Haytham also known as Alhazen (965-1039) provide the initial contributes to the scientific method. Later, others such as Galileo Galilei or Francis Bacon also add contributions to improve scientific research.

Scientists use this method to obtain the answers they search within the science. The main goal is to produce scientific theories. We illustrate the different stages of the method as follows (Fig. 2).

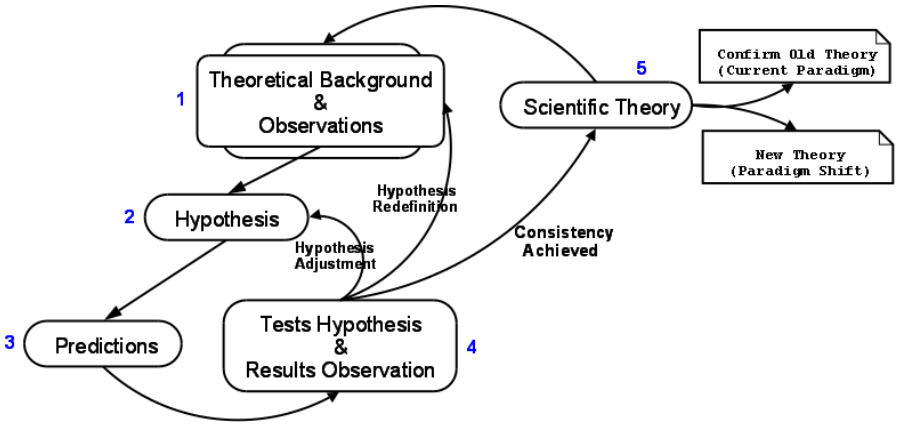

Fig. 2. The Scientific Method

1. From the theoretical background knowledge and observations questions may emerge in the domains of science. The answer to that new question may or may not be found on existing theories. If not found in old theories a new theory should be searched (researched).

2. First, a hypothesis must be formulated in order to provide the desirable answer.
3. Then, at this stage, and with the hypothesis in mind, we should be able to make some predictions.
4. After the initial phases, is now time to test the hypothesis and predictions. It is time to experiment and observe. In some cases it is needed to adjust the hypothesis, in others there may be the necessity of completely redefine hypothesis.
5. Getting to this stage means that the hypothesis proved to be consistent. If the scientific theory achieved is coherent with the current paradigm we are in the present of "*normal science*" (Kuhn); else if the new theory contradicts the current paradigm it means that we may be facing a paradigm shift - "*scientific revolution*" (Kuhn). As it was said before this occurs very rarely, but it is also important to note that in these cases the process must be very well verified. In both cases the new theory will also become a part of the theoretical background from where the whole process starts. This will certainly provide the scientific community with new questions and the need for new answers.

It is important to notice that scientific research is cyclic. As written in [3] the "logic of science is recursive". As a naive example we can look at papers, such as this, that after a literature review (theoretical background knowledge) the authors (researchers) present that review but adding a personal contribution. Of course the literature that was reviewed must be referenced.

With this superficial overview of the scientific research method, we must remark that there are more particular details that are ignored in this paper. An important aspect related to the method is the fact that it must be possible to reproduce the obtained results.

3 Scientific Research Method in Computer Science

There are many definitions about Computer Science, definitions that evolved over the years. CS is a recent discipline compared to others, but it is already divided into several specific areas within the entire domain. According to [8] the main fields of study in the discipline of computing are: Computer Engineering, Computer Science, Information Systems, Information Technology, Software Engineering.

To this different fields, different visions can be consider. If we consider CS as the study of algorithms that process information, or if we see CS as the study of information structures, we will be driven to a more mathematical approach - algorithms and structures are abstractions. Instead if we consider CS as the study of phenomena related to computers, we are in the presence of a more empirical approach.

Like in all science the first step will consist on modeling the problem or phenomenon to be studied - abstraction. This simplifies the subject of research

taking in consideration only the relevant aspects. After modeling the problem, we must endorse a methodology: Theoretical, Experimental and Simulation [3].

3.1 Theoretical Method

The theoretical approaches to CS are based on the classical methodology since they are related to logic and mathematics. Some ideas are the existence of conceptual and formal models (data models and algorithms), different levels of abstraction or efficiency [9]. Since theoretical CS inherit its bases from logic and mathematics, some of the main techniques when dealing with problems are iteration, recursion and induction.

Theory is important to build methodologies, to develop logic and semantic models and to reason about the programs in order to prove their correctness. Theoretical CS is dedicated to the design and algorithm analysis in order to find solutions or better solutions (performance issues, for example). Encompassing all fields in CS, the theoretical methodologies also tries to define (understand) the limits of computation and the computational paradigm [3].

3.2 Experimental Method

Experimental methods mean that experiments will occur in order extract results from real world implementations. Experiments can test the veracity of theories, or can simply do explorations trying to obtain new knowledge - empirical approach. However as defended by Edsger Dijkstra, "*an experiment can only show the presence of bugs (flaws) in a theory, not their absence*".

This method within CS is used in several different fields: artificial neural networks, automating theorem proving, natural languages, analyzing performances and behaviors, etc. It is important to restate that all the experiments and results should be reproducible.

Concerning, for example, network environments with several connection resources and users, the experiments are an important methodology (complexity) [3]. Also in CS fields that take in consideration the human factor (Human-Computer Interaction, for example), it is mandatory the usage of experimental approaches.

3.3 Simulation Method

Simulation in CS offers the possibility to investigate systems or regimes that are outside of the experimental domain. Normally complex phenomena that can not be implemented in laboratories [3] - evolution of the universe. Several domains in science which were not originally related to CS, are now taking advantage of these simulation methodologies meaning that scientific domains are being merged.

Some domains that adopt computer simulation methodologies are sciences such as astronomy, physics or economics; other areas more specialized such as the study of non-linear systems, virtual reality or artificial life also exploit these methodologies.

3.4 Summary

In short we can say that, due to its nature, CS can be seen or studied using these three main methodologies (theoretical, experimental and simulation). Each one more appropriated to specific areas within the domain of CS.

4 Conclusion and Future Perspectives

This survey indicates that science is transversal to several domains. Logic and mathematics are the core of all sciences such in Computer Science (CS). The scientific method is a tool for conducting a rigorous and systematic search of new theories or paradigms.

It is possible to find relations between different scientific domains and the prove of that is the fact that sciences such as astronomy or physics are becoming closer to CS. Another example is medicine, nowadays CS has increased its impact in several fields of medicine.

From the three methodologies presented for CS - theoretical, experimental and simulation - simulation is one that already is merged with several scientific domains. In the future we may find some changes in traditional scientific research methods. The recent discipline of CS as brought new possibilities. Paradigm shifts occur in the past and will possibly occur in the future.

References

1. R. K. Jain and H. C. Triandis: Management of Research and Development Organizations: Managing the Unmanageable. John Wiley & Sons, (1997)
2. Wikipedia The Free Encyclopedia, `http://en.wikipedia.org/wiki/Western_philosophy`
3. Gordana Dodig-Crnkovic: Scientific Methods in Computer Science. Conference for the Promotion of Research in IT at New Universities and at University Colleges in Sweden (2002)
4. Denning Peter J.: Is Computer Science Science?. COMMUNICATIONS OF THE ACM, Vol. 48, No. 4 (2005)
5. Kuhn, Thomas: The Structure of Scientific Revolutions. Chicago: Univ. Chicago Press (1962)
6. Popper, Karl: The Logic of Scientific Discover. Basic Books, (1959)
7. Computing Curricula 2005. The Overview Report. A cooperative project of The Association for Computing Machinery (ACM), The Association for Information Systems (AIS) and The Computer Society (IEEE-CS) (2005)
8. Computing Curricula 2005. The Overview Report. A cooperative project of The Association for Computing Machinery (ACM), The Association for Information Systems (AIS) and The Computer Society (IEEE-CS) (2005)
9. Denning Peter J.: Computing as a Discipline. COMMUNICATIONS OF THE ACM, Vol. 32, No. 1 (1989)