AI in Foundations of Computer Science

U. Ferreira

e-mail: ulisses@philosophers-fcs.org
Tr. Pirapora 36 (Ufba Escola Politécnica), CEP 41770-220, Salvador, Brazil

Abstract. Formal Deductive Logic has been traditionally seen as the Foundation of Computer Science, but, as mentioned here, that is not precisely correct, for Logic has been an inseparable branch of Philosophy since Aristotle. Then, this paper presents associations between Artificial Intelligence and Foundations of Computer Science.

1 Foundations of CS and AI

Taking knowledge as a requirement in sciences and hence in CS, more than other branches of CS, AI has a very strong scientific nature, in the sense of natural sciences or in the most general sense of *sciences*, in comparison to deduction[14], which, in a typical form, does not require knowledge. AI has to apply scientific methods, but not only scientific methods are applied in AI (for instance, the above synthetic concepts which will be cited here are applied in AI), but AI researchers also discover nature, while mathematics[11] is simply a matter of abstraction and a tool. However, philosophy[4] is also a fundamental subject inside the AI umbrella. An introduction with this approach is [2].

As an example, in order to work on AI, the concept of intelligence has to be explicitly defined, or clearly understood. Alan Turing defined his concept of *artificial* intelligence[19]. In contrast, so far, *intelligence* is not uniquely definable in psychology, which may lead to different views in AI. My opinion, or point here, is that views in computer science and AI ought to be explicit. From this, one obtains the conclusion that philosophy of CS also seems to be in AI, whereas branches of AI are also in the philosophical foundations of CS.

Belief can be defined as some weak knowledge, e.g. given a proposition p, expression $\bigcirc p$ sometimes represents "it is believed that p is true". [8] explains that belief is a notion somewhat bigger than knowledge and the nature of these notions are different, I would say. Given this, with some care, I would take belief as a primitive notion and would define knowledge as a strong belief up to the representation of this pair of important notions. However, if knowledge could be indeed defined in terms of belief, as opposed to the idea of the four orthogonal functions[8], I could ask myself whether or not knowledge exists, and hence whether science exists as something different from philosophy or religion. In the setting presented in [6], there is a scale of real numbers in $[-1, +1]$, where the absolute false is represented as -1 whereas the absolute true is represented as $+1$. This is equivalent to MYCIN[17] and compatible with probabilities although the latter traditionally uses the $[0, 1]$ interval. In this way, the negation of any knowledge is of knowledge nature over the same subject, whereas the negation of any belief on something is of belief nature over the same subject.

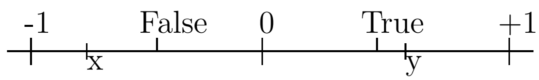
An important note: Except for otherwise stated, I simplify the used language by writing logic[18] to mean deductive logic.

2 Philosophy of CS and AI

By 'the foundation' in the abstract I mean that logic is used for supporting other subjects, i.e. logic is the root of computer science[9] (CS), metaphorically speaking. In this way, foundations of computer science have been seen as in the context of pure mathematics. However, more recent results[8] demonstrate that philosophy is in the root of CS. Logic was traditionally part of philosophy, and the paper shows that it still is. Briefly, in order to prove this, the referred to paper of mine initially builds a somewhat fuzzy classification, after having studied pieces of work on Kant. The two big classes are analysis and synthesis. The former divides in two analytical subclasses labelled ω and π, and the latter divides in two synthetic subclasses labelled ψ and ϕ. The synthetic class, roughly and conceptually, is linked to the greatest and the broadest (or the most general) while the analytical one, roughly, is linked to narrower or deeper. So, given the analytical nature of logic, it is placed in one of the analytical classes, while given the predominantly synthetic nature of philosophy, the latter subject is placed in one of the synthetic classes (many academic people probably observe that ψ suggests psychology, while ϕ suggests philosophy). Then, briefly speaking here, the proof consisted in finding and observing synthetic and important notions (pleasure and pain, for instance, are often dealt with in psychology) with which are often dealt in philosophy, more precisely analogy, belief and (non-mathematical) induction, inside a logical application. It is something like pointing out that there is some application greater than logic, while any application does not manage to form something greater than philosophy or what is commonly dealt with by this subject, and since logic is part of philosophy. In this way, we can talk about philosophy of computer science (PhCS) as a novel subject area inside foundations of CS. In accordance with the same paper of mine, the other representative subject areas are mathematics, physics and psychology, which seem to be rather obvious, and they are closely linked to AI.

For this paper, AI is seen as having three aspects: the technological AI such as in [15], the scientific AI, and finally the philosophical AI. The first one is essentially motivated by applications. Planning systems for instance. The scientific AI tries to discover the nature, in particular, the human one. For example, I regard cognitive sciences as a kind of intersection between psychology and AI, as well as one of the scientific aspects of AI. A few philosophical issues have been recently explained in AI books such as [16]. Finally, the philosophical AI is dealt with here in this paper, but essentially in the context of philosophy of (computer) science[13].

There are subtle issues in this brief classification, e.g. it is known that the Prolog programming language offers the closed world assumption, which is not only motivated by technological reasons but also has important philosophical aspects. One of them is that, for consulting a database, that assumption can be the appropriate one. However, the philosophical aspect is that if a person answers *no* because he or she cannot provide the answer *yes*, he or she misses an important opportunity to admit that he or she does not know something. Thus, partiality matters in AI. Briefly speaking, this can be understood as a conceptual requisite to a knowledge-belief base. In contrast with the Prolog approach, in [5], I introduce some conceptual connections between uncertainty and a defined seven-valued logic, whilst those variables, which is referred to here as big variables, include not only degrees of certainty and of completeness of information, as opposed to the ideas of incomplete information and absence of information (which in its turn I represent by uu), but also degrees of doubt and inconsistency. In [5], the uncertainty[12] model is nearly the same as presented in [6]. Incomplete information is of essential importance, not only in philosophical views and logics but also in practice, for computation and programming languages. The obvious proof of this is $0/0 = uu$. The computation of 0/0 programmed in a language without uu has resulted in "run-time error" instead, while mobile agents need to be robust, for example. A big variable is illustrated as in the following picture in the real interval:



The x and y variables represent the minimum and maximum values, respectively, whereas $False$ and $True$ are the false and true thresholds, respectively.

In *monotonic reasoning* such as in mathematics, x can grow and only as $x \in [-1, y]$, and $False$ can grow and only satisfying

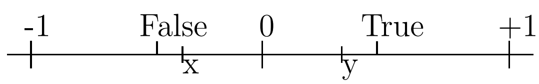
$$False \in [-1, min(x, True)].$$

Still in *monotonic reasoning*, symmetrically, y can shrink its value and only as $y \in [x, +1]$, and $True$ can shrink its value and only satisfying

$$True \in [max(False, y), +1].$$

In contrast, in *non-monotonic reasoning*[9], such constraints are not necessary.

An example of inconsistent big variable is the following:



The region between the thresholds $False$ and $True$ is interpreted as an overlapping area of $True$ and $False$, hence an inconsistent subregion in some sense, and, in case where $False \leq x \leq y < True$, a degree of doubt is

$$y - x,$$

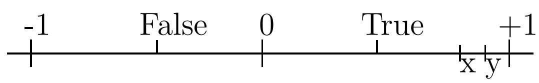
while

$$z = \frac{(True - y) + (x - False)}{2}$$

permits the calculation of a degree of inconsistency which is z in the above formula. In the denominator, 2 corresponds to the whole spectrum, $(1 - (-1))$. Accordingly, $(True - False)$ corresponds to how subjective a situation represented as big variable is. In case of a 100% objective situation, the suitable representation makes $False = True$, in such a way that there can be doubt given incomplete information but not for inconsistency. Another interpretation for inconsistency can happen if we permit $y < x$ or $True < False$, for instance. As an example of the expressiveness of some inference, taking D as a proposition which denotes some diagnostic, and taking s_i as a proposition which denotes some symptom, the implication

$$\psi([-0.2, +0.6]\ s_i) \rightarrow D\ ?\ [+0.8, +0.9]$$

has the meaning that if s_i ($i \in \mathbb{N}$) has its x minimum certainty degree greater than or equal to +0.6, the big variable D can be as in the following diagram:



where $x = +0.8$, $y = +0.9$. There may be other approaches. In any case, this subject is in the core of AI.

Another classical issue is 'Is there any difference between human being and machine?', which has also been discussed in the context of cognitive sciences[10]. Needless to say, such classical issues lead to endless discussions because there exist different philosophical views in there, although those philosophical views are implicit. Thus, PhCS has been present but spread out inside the branches of CS, whereas it could explicitly support mathematical foundations of CS. The philosophy of mathematics, in its turn, could support pure mathematics, but philosophy of computer science seems to be a richer area.

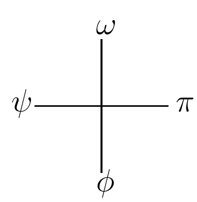


figure 1. The Four-class Conceptual Diagram in AI and PhCS

Generally, this somewhat speculative work (which can only be grasped by intuition or non-mathematical induction, for being related to ϕ in a meta level) suggests the following fundamental classification:

- (ω,vocabulary,knowledge,reasoning);
- (ϕ,semantics,intuition,induction);
- (π,syntax,perception,deduction);
- (ψ,context or pragmatics,feeling,belief).

Thus, if one wants to add the four functions due to Carl G. Jung to keywords from languages issues and others from AI, typically, *induction* and *intuition* lead to *belief*, whereas *deduction* and *perception* lead to *knowledge*. The above diagram is a convenient way of organizing these relevant key notions. Metaphorically, key questions that are made in sciences, and hence in computer science, may be the following: (ω,what), (ϕ,why), (π,how), (ψ,perhaps, for what/whom). Furthermore, from the classes I obtain four regions. See figure 1. The $\psi\phi$ (SW) region corresponds to synthesis while the $\omega\pi$ (NE) corresponds to analysis. Further, the $\psi\omega$ (NW) region may be linked to knowledge-belief representation while the $\phi\pi$ (SE) region may be linked to concepts such as machine learning and cognition.

According to the referred to paper of mine, synthetic concepts such as intuition; non-mathematical induction; perspective; distance; analogy and hence a sort of subjective pattern matching; truth, hence axiomatization; semantic web; link; generalization; synthesis; common sense; insight which is so mysterious and so important to sciences and philosophy, are placed in the ϕ class. With respect to key subjects in AI, there are philosophy; monotonic reasoning; nonclosed world assumption; neural networks; inductive logic programming and so forth.

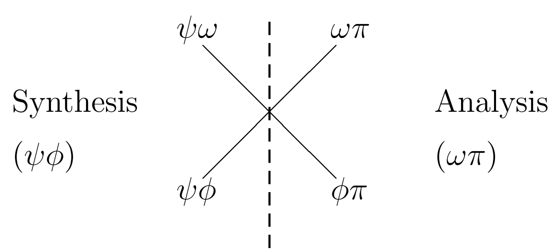


figure 2. The View of Synthesis and Analysis

Now, synthetic concepts are subjective and personal, whereas analytical concepts are objective and universal, in the sense that they are accepted by everyone. From this, the classical logic is universal because it is purely analytical.

Synthetic concepts such as synthesis; feeling; uncertainty; belief; transcendence; incompleteness; subjectivity; relativity and inconsistency are placed in the ψ class. With respect to key subjects in AI there are psychology; fuzzy logics; fuzzy sets, fuzzy systems; anything particularly related to image; partial information and so forth. What synthetic concepts have in common is that they require something more than what is known as computation (That characteristic, however, is not only in the foundations of AI but also in the foundations of CS). Therefore, this illustrative, informal and simplified theory assumes or believes that mankind and machines are of different natures. Furthermore, according to this view, apparently, a human being builds his or her analytical layer in mind over his or her synthetic layer, which is apparently a natural characteristic of animals. They learn by induction. In contrast, machines can build their synthetic layer from their analytical layer, invented by human beings. Other different philosophical theories in the foundations of computer science can appear soon, or perhaps will explicitly emerge.

The analytical concepts are very much like those applied to other branches of CS. The synthetic concepts form an important part of AI.

A general rule of thumb that I grasped during this work is that synthetic concepts cannot be proved over universally quantified variables by means of deductive logic, although, by a sample presentation, one can prove opposite (i.e. existentially quantified) propositions. In contrast, by a number of sample presentations sufficiently big, one may show in some way that some universal synthetic proposition is valid, but, since the subject is somewhat subjective, one has also to rely upon someone else's opinion. That is one of the reasons why explicit philosophical views are important. There is no point submitting an article based on the view that humans are naturally different from machines to a panel where the members think a contrasting way.

3 Theories of Computation

With respect to the traditional theory of computation, possibly except for my previous work, there has been a single and unique theory, as computation used to be uniquely defined and studied in the context of computability theory[3].

However, in the last few years, different concepts such "mobile computation" have appeared. In late 1999, prior to my philosophical work, I observed that from the moment that I conceived an older idea of moving computation, a *physical* semantics of computation came up[7]. Likewise, although every music score can *represent* a particular piece of music, in order to yield music indeed, one or more people or machines produce a number of notes in some interval of frequencies that can be captured by human hearings. Therefore, music is a physical process with some characteristics (inside the ψ class). From the physical point of view, computation is somewhat more complex. In this way, notions of computation have existed, namely the mathematical computation, and one or more physical ones, in addition to different philosophical views. However, the latter ones are related to mathematics but they are not mathematics itself, in the pure sense. There is the known notion of physical mathematics, but the theory *depends on* future discoveries in physics and that is not in the context of pure mathematics.

On the other hand, for some materialistic view of reality, an NP-complete graph can metaphorically show that 1 (*matter*), 2 (*space*), 3 (*time*) and 4 (*motion*) are orthogonal notions:

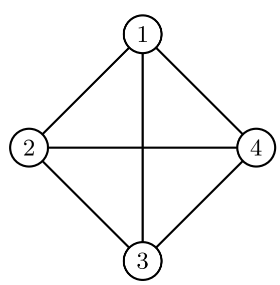


figure 3. An NP-Complete Conceptual Graph

Apparently, it can be seen that, like an equation, *motion* can be defined in terms of *matter*, *space* and *time*. And the other three notions can apparently, accordingly, individually, physically and philosophically be defined in terms of the remaining ones. Time has been conceived as a flow in computer science, including AI, where past, present and future are related key notions. Nonetheless, there can be different philosophical views of such notions. More generally, *space*, *Zeno's paradoxes*, *time*, *matter* and *philosophy of physics*, are some significant and related keywords in good dictionaries such as [1], whilst *mobility* as the quality of being *mobile* seems to be a related notion which came up mainly in the electronic engineering and technology.

Another aspect of AI in foundations of computer science which I observed some years ago are spatio-temporal logics. A space-time logic of mine has been defined for some years, for general purposes, such as mobile agents, Internet and semantics of programming languages. It makes use of synthetic notions such as induction, analogy, uncertainty and belief, including space and time. For example, given that p is a proposition, the proposition $@a \cdot t[p]$ denotes p at place a and time t.

In a similar way that Einstein's relativity theories have influenced philosophical theories, in particular (again) up to mobility, new physical notions of computation together with their corresponding theories can well emerge in the future. Computation now depends on physics (ω), and perhaps on astronomers, together with mathematicians. From each notion of computation informally presented, there may be one or more theories of computation that ought to be formal and use deductive logic.

In this way, mathematics is also used as a tool in physics as usual, whereas physics can be closely related to philosophy of computer science.

4 Conclusion

Computer Science as a human science: Apart from physics and psychology, the big picture of an organization of the subjects inside this CS view can be described as follows:

Philosophy of Computer Science. It is part of the foundations of computer science.

AI. It is both supported by philosophy of CS and partially overlapped by it. AI is partially part of the foundations of computer science.

Foundations of Computer Science. It includes philosophy of computer science, philosophical parts of AI, and mathematics as a tool. Here, a physical notion of computation (or intelligence) is also defined.

Theories of Computation. Every uses some natural language and mainly formal logic, and is supported by some foundation, and supports the application level. Here, a notion of computation is used.

Theories of AI. The same status as theories of computation. Here, it is used a notion of intelligence, which is defined in philosophical AI as part of some foundation. This one or the previous one supports the following.

Informatics. Informatics includes other areas of CS, in particular, applications as well as some parts of AI. It also includes computer science in the present sense.

As a sample, I gave some components of what I mean by philosophy of computer science.

References

1. S. Blackburn. *The Oxford Dictionary of Philosophy.* Oxford University Press, 1994.
2. B. J. Copeland. *Artificial Intelligence: a philosophical introduction.* Blackwell Publishers, 1993.
3. N. Cutland. *Computability: an introduction to recursive function theory.* Cambridge University Press, 1980. This book was reprinted.
4. W. Durant. *The story of Philosophy.* Will Durant, 1961. Published in Brazil by Editora Nova Cultural Ltda.
5. U. Ferreira. Uncertainty and a 7-valued logic. In P. P. Dey, M. N. Amin, and T. M. Gatton, editors, *Proceedings of The 2nd International Conference on Computer Science and its Applications*, pages 170–173, National University, San Diego, CA, USA, June 2004.
6. U. Ferreira. Uncertainty for programming languages. In V. Milutinovic, editor, *Proceedings of the VIP Scientific Forum, the int'l Symposium of Santa Caterina on Challenges in Internet and Interdisciplinary research, SSCCII-2004 Conference*, 2004.
7. U. Ferreira. Mobility and computation. In V. Milutinovic, editor, *Proceedigs of IPSI-2005 HAWAII Conference.* IPSI BgD, January 2005. To appear.
8. U. Ferreira. On the foundations of computing science. In D. L. Hicks, editor, *Proceedings of the Metainformatics Symposium MIS'03*, number 3002 in Lecture Notes in Computer Science, pages 46–65. Springer, September 2003, published in 2004.
9. M. R. Genesereth and N. J. Nilsson. *Logical Foundations of Artificial Intelligence.* Morgan Kaufmann Publishers, Inc., 1987. Reprinted with corrections.

10. D. Gillies. *Artificial Intelligence and Scientific Method*. Oxford University Press, 1996.
11. G. G. Granger. *L'irrationnel*. Éditions Odile Jacob, 1998.
12. H. Kyburgh Junior. *Handbook of Logic in Artificial Intelligence and Logic Programming*, volume 3: Nonmonotonic Reasoning and uncertain reasoning, chapter Uncertainty Logics, pages 397–438. Oxford University Press, 1994.
13. K. Popper. *The Logic of Scientific Discovery*. Karl Popper, 1972.
14. G. Restall. *An Introduction to Substructural Logics*. Routledge, 2000.
15. E. Rich and K. Knight. *Artificial Intelligence*. McGraw-Hill, Inc., second edition, 1991.
16. S. Russel and P. Norvig. *Artificial Intelligence*. Prentice Hall, second edition, 2003.
17. E. H. Shortlife. *Computer-Based Medical Consultations: MYCIN*. New York, 1976. Elsevier.
18. S. Toulmin. *The Uses of Argument*. Cambridge University Press, 1958.
19. A. Turing. Computing machinery and intelligence. *Mind*, 59:433–460, 1950.