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► To cite this version:

Fabien Ferri. From reduced artificial intelligence to semiotic engineering: a new project for artificial intelligence. 2021. hal-03450318

HAL Id: hal-03450318

<https://hal.science/hal-03450318>

Preprint submitted on 25 Nov 2021

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From reduced artificial intelligence to semiotic engineering: a new project for artificial intelligence

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Abstract. Following the reduced artificial intelligence programme carried out by Bruno Bachimont in the 1990s, we propose a new research programme: semiotic engineering. After having recalled in a first part the link of filiation which unites the first-generation reduced artificial intelligence programme to the semiotic engineering one, we return in a second part to the phenomenology of knowledge elaborated by C. S. Peirce to show in what way it constitutes a true methodological guide allowing the implementation of the semiotic engineering programme. Finally, in the third and last part, we show the limits of the first-generation reduced artificial intelligence programme and outline the principles for implementing semiotic engineering.

Keywords: Semiotic engineering, Artificial intelligence, Operational iconicity, Diagram, Phenomenology of knowledge.

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1. Reduced artificial intelligence and semiotic engineering	2
2. Peirce's phenomenology of knowledge: a methodological guide.....	4
2.1 Peirce's categories of being	5
2.2 Reduced AI: purpose, method, principles.....	6
3. Limits of reduced AI and principles of semiotic engineering	8
3.1 The example of the concept of function in the context of medical knowledge modelling	8
3.2 Principles of semiotic engineering	9

1. Reduced artificial intelligence and semiotic engineering

The discipline to which this article belongs is semiotic engineering: its objective is to design diagrammatic systems to help solve problems. The problem posed by such a discipline is the diversity of the knowledge it must involve, and the extent of its objects of study: all human activity is potentially concerned by its research programme. We will first define it as a technique of knowledge supports involving the sciences of culture to understand the problem-solving practices implemented in scientific, technical and ordinary practices. More precisely, this discipline develops graphic devices that allow problem solving mediated by the reading and interpretation of semiotic units of manipulation, graphic signs, and this through a type of reasoning that it gives rise to and allows for: diagrammatic reasoning.

Semiotic engineering is a descendant of reduced artificial intelligence (now abbreviated to reduced AI), an artificial intelligence research programme distinct from strong and weak artificial intelligence programmes, whose strategy was to instrument computer science in the automatic operationalisation of intelligent tasks [1]. But unlike weak AI, semiotic engineering does not aim to instrument computer science. It aims to instrument the resolution practices operated by human beings thanks to the directly manipulable semiotic artefacts that are diagrams. Is the reproduction of a mind task by means of a technical device a model of the activity of the mind performing such a task or is it a simulation of the behaviour it reveals? Is it a simulation of the actual process of the mind performing it?

The questions of the reduced AI and its issues were the following: what knowledge is used by a minded agent in the context of a problem resolution (gnoseological issue)? What temporal organization does such a resolution require to be accomplished (methodological issue)? What is the share of formalizable knowledge in the set of phenomenological knowledge allowing the construction of a model of the knowledge system exploitable by the computer tool (scientific issue)? What program can be built from the formal knowledge drawn from the phenomenological model of resolution to make

part of the problem resolution automatic, since a phenomenological content is not entirely reducible to a formal content (technological issue)? What are the phenomenological contents to be inferred from the result of the approximated resolution in order to make the resolution of the problem studied complete (hermeneutical issue)?

Reduced AI was engineering that set out to solve problems by computer by considering programs for what they do, i.e. solving problems by programming and operationalizing them within computing devices [1]. It did not deal with all problems, but only those of a certain class. What was that class of problems?

Reduced AI focused on the class of problems involving linguistically conveyed phenomenological knowledge. Since it set itself the task of exploiting phenomenological knowledge for solving problems through computer science, it used scientific knowledge to address problems posed in terms of phenomenological knowledge.

Consequently, reduced AI started from a certain understanding of the notion of problem, according to which a problem is not a difficulty that requires the use of a supposedly natural faculty to be solved (intelligence), but a situation that requires the implementation of knowledge. It is easy to understand such an understanding, if one keeps in mind the following precaution followed by reduced AI: to abstain from any prior, a priori, thesis on the nature of intelligence or mind.

Indeed, if reduced AI had not described problem solving in terms of knowledge, then it would have described it in terms of process. But to describe resolution in terms of process is to tacitly posit a thesis about the nature of knowledge. This thesis consists in asserting that knowledge is an object of scientific ontology, either reducible to physical states (according to the physicalist position) or reducible to computational states (according to the computationalist position). To describe resolutions in terms of processes was to tacitly reduce knowledge to cognitive operations, hence to automatic actions that could be formalized algorithmically. But then what is knowledge related to a problem?

The only way to avoid falling into the reductionist trap while maintaining a truthful approach to knowledge was to consider knowledge for what it is in our most familiar everyday life: phenomenological content conveyed by linguistic idioms. The additional step taken by semiotic engineering consists in adding to the knowledge conveyed by linguistic statements graphical representations carrying a cognitive content that complements it. In this perspective, reduced AI becomes, in our opinion, semiotic engineering when it aims to rigorously articulate the idioms of natural languages with the contents of non-linguistic graphical representations in order to provide access to the contents lost by the formalism used as a principle of knowledge modelling (as soon as this principle is implemented). The application of this principle consists in reducing knowledge to the contents and logical structures of linguistic statements.

2. Peirce's phenomenology of knowledge: a methodological guide

In order to free ourselves from any theoretical prejudice or dogmatic posture, we have no other choice, in order to describe immediate, familiar and everyday informal problems, than to go in search of a phenomenology of knowledge, in the attention to what the evidence of practice gives us to see as know-how mobilizing tacit knowledge (which gives itself to be seen in tricks of the hand and silent gestures) and explicit knowledge (which gives itself to be listened to in linguistic expressions). This practice of doing and saying, in its tacit and explicit expressions, i.e. its apparent, and therefore describable, externalizations, is therefore what authorizes a public phenomenology, which can be the subject of a common study submitted to collective deliberation.

In its quest for a phenomenology of knowledge, reduced AI found in the phenomenology of knowledge elaborated at the beginning of the 20th century by C. S. Peirce [2] a relevant research program that predicated a methodology that could also serve as a guide to semiotic engineering concerned with instrumenting the resolution of informal problems mobilizing phenomenological knowledge.

Semiotic engineering, as its name indicates, aims to place the problem of artificial intelligence within a semiotic framework, but without having recourse to computer artefacts. Intelligence is a multifaceted notion, which can be defined in many different ways, more or less arbitrarily, and loaded with presuppositions, even prejudices. In order to limit arbitrary decisions and presuppositions and question this behavioural manifestation, we need to start from the theoretical device that was set up by Peirce, enriching it with a technical understanding of the formats of graphic representations, in order to articulate linguistic representations to non-linguistic representations.

In response and reaction to the Kantian doctrine of categories, Peirce built a theoretical device at the foundation of a phenomenology of knowledge, called in his terminology *phaneroscopy* [2]. *Phaneroscopy* deals with *phanerons*, which designate the modalities of presence of reality to a mind. It does not presuppose anything about the nature of the mind in question or about the ontological basis of reality. In the context of semiotic engineering, the semiotic formatting of the intuitive content that carries meaning proceeds jointly through graphic schematization (i.e. non-linguistic graphic representations) and conceptual categorization (i.e. linguistic graphic representations).

Peirce's phenomenology of knowledge is a phenomenology of the sign without a presupposed subject (substance) or predefined object (thing-in-itself). According to this phenomenology, all ontological reality is reduced to a manipulable sign carrying meaning. Moreover, everything that is a manipulable semiotic unit is spiritual, from the moment that the sign becomes the relay of an interpreting activity. Peirce calls this dynamic, vectored by inferences and bouncing from sign to sign, "*semiosis*". *Semiosis* is the potentially indefinite dynamic that carries the mind from sign to sign.

The semiotic break in this process is marked by the act, insofar as the act is what stops the interpretative process of semiosis in order to bring the human interpreter into the pragmatic order of action and practice, which is the order of existential finitude. The indefinite movement of interpretation is thus opposed to the finitude of action. More precisely the finitude of the action is the actualization of the act of interpretation in an effective operation realized. Interpreting in the context of semiotic engineering therefore means performing one or more technical operations whose operating modes are schematized by sign systems. These operations are guided by conventions that control the reading of the schemas so that they are actualized analogically by the persons who manipulates these schemas by reading them.

The whole challenge of semiotic engineering consists of schematizing the non-computable operations of experience in order to model them, categorizing them linguistically in order to analyze them, and making them explicit discursively in order to characterize them, so that they can be implemented by intelligent semiotic agents. This is because it is a matter of transforming the content of these non-computable operations captured semiotically into cognitive tools that prescribe their correct manipulation. In other words, good semiotic manipulation is that which allows the reproduction of the operations of which the graphic symbols are the schemas, and which the interpreting subjects who manipulate them must implement. According to semiotic methodology, the association of ideas is no longer controlled by natural principles (resemblance, contiguity, causality) [3], but by inferences made between signs. What semiotic engineering proposes to make explicit are interpretive conventions that make it possible to systematize the relationships between knowledge and action through the manipulation of graphic signs that carry meaning.

2.1 Peirce's categories of being

Peirce thus distinguishes three ontological categories [2]: 1° the firstness or being of the fact in its qualitative particularity (e.g. red); 2° the secondness or being of the actual raw fact, which implies the reciprocal action between two beings in the order of a mechanical causality (e.g. the sound waves that make the tympanum vibrate); 3° the thirdness or being of the law determining a future fact, i.e. the being of a third that allows a first one to interact with a second. Thirdness is the category of final causality, therefore that of intelligence. Why is this so?

Because it is the implementation of a third (diversions, means, representation, instrumental mediation, method, etc.) by a first (subject) in relation to a second (object, obstacle, danger, goal to be reached, problem to be solved). Indeed, there is intelligence as soon as there is mediation of a means. Intelligence thus supposes: 1° the representation of an object or a more or less complex situation causing an obstacle (problem); 2° the representation of the means to be implemented to remove and overcome it (intermediaries); 3° the representation of the end to be reached (the representation of

the solution as a resolution of the problem). The representation of this end is, moreover, the bearer of information that retroacts in a recurrent causality on the intelligent being in the process of resolution: it continuously retroacts on the arrangement of the means implemented in the research process, in such a way that it adequately coincides with the content of the end aimed at by being fully adjusted to it. Any phenomenon that manifests thirdness behaviour, regardless of its degree of complexity, can therefore be described as intelligent.

Semiotic engineering is the construction of thirdness through the arrangement of semiotic units carrying meaning, which can be manipulated by human beings in semiotic systems whose functioning is activated by their operational reading. Thanks to their reading, these systems allow the implementation of the "diagramming" faculty [4]. Diagramming refers to the ability to coordinate perceptual, motor and inferential processes during the operational reading of diagrams. This is why diagrams are both material supports (as captioned graphic diagrams) and generative methods (as prescriptive cognitive tools).

In other words, thirdness is the category of controlled interdependence, and therefore that of knowledge, since a problem is that which requires knowledge to be solved. Authentic thirdness is the category of effective knowledge (on the side of the interpreting subject) and observed thirdness is the category of objective intelligence (on the side of the observed phenomena). Authentic thirdness is what allows an objectification of the mind through signs materializing knowledge. The observed thirdness is the condition of possibility of a phenomenology of intelligence, since it manifests the logic of semiotic relations. This is why Peirce saw, for example, in the behaviour of a frog subjected to a scientific experiment the concrete operativity of an embodied syllogism [1].

By identifying thought with a sign and intelligent operation with an inference between signs, we can therefore associate all semiotics with a dynamic material logic that allows for a phenomenology of knowledge and intelligence, from the moment a phenomenon (or phaneron in Peirce's language) meets the criterion of thirdness. It is this fact that semiotic engineering exploits as knowledge engineering, i.e. thirdness engineering.

2.2 Reduced AI: purpose, method, principles

The linguistic sign is the most commonly used in the expression and transmission of phenomenological knowledge because of its ease of manipulation and speed of transmission in intersubjective exchange. Therefore, the reduced AI was concerned with phenomenological knowledge as expressed through linguistic formulations. Its object was not the set of signs expressing knowledge, but the expression of knowledge as it is conveyed through the linguistic medium.

The project of semiotic engineering is to supplement reduced AI with non-linguistic manipulable semiotic units, in order to allow diagrammatic reasoning, so that information processing is no longer carried exclusively by virtual computational machines, but by the living semiotic machines that we are as interpreting beings of meaning-bearing manipulable signs.

The objective of reduced AI was in fact to create knowledge-based computer systems whose function is to operationalize linguistically expressed phenomenological knowledge by implementing a formalist methodology governed by two principles [5], the first of which was identified by the members of the Vienna Circle (the modelling principle) and the second by mathematical logic as it was accomplished in the mechanization of reasoning, thanks to the work of Turing (the effectivity principle). The principle of modelling indicated in what way the operational system of knowledge is a model of the problem treated; the principle of effectiveness specified in what way the model of the problem was operational, i.e. in what way the operationalization of the model in the computer device that implemented it referred to the effectiveness of the reality that the implemented model simulates.

Reduced AI, as the engineering of knowledge conveyed by linguistic representations, thus adopted a formalist method by resorting to a logicist conception of knowledge (formalism as a modelling principle) and a computational conception of logic (formalism as a principle of effectivity) [6]. To adopt a logicist conception of knowledge is in fact to consider that the gnoseological truthful content of a linguistic expression is equivalent to its formal structure. In this perspective, common sense concepts have the same status as scientific concepts. What makes them common is the fact that their content is reducible to a formal structure, to the formal relation that structures it. Therefore, in order to extract the knowledge conveyed by linguistic expressions from natural language, it was sufficient to identify the formal structure of these expressions. By concatenating these structures in the canonical language of knowledge, formal logic, one could then construct a formal system of representation of the gnoseological content conveyed by the linguistically expressed phenomenological knowledge, and thus build a model of the problem for which this phenomenological knowledge is the resolution knowledge. Now, as any formal system is mechanizable on a Turing machine, any formal system is operational insofar as all the operations of the system are executable by a Turing machine. This is why computational formalism gave knowledge engineering the principle of effectivity it needed.

If the principle of effectivity did not pose a problem, on the other hand the principle of modelling did. Indeed, operationalizing the formal model of the phenomenological knowledge system implied having identified primitive notions, which resulted from an interpretation of their meaning in the irreducibly singular phenomenological context from which they were extracted. This meant that the formalization of the knowledge system was not a modelling in the strong sense, but a construction proceeding from a prior modelling that had fixed the meaning of the

primitive notions of the model. In other words: what became invariable for the formal model became variable from the point of view of the resolution context, since each resolution context was recognized as an irreducibly singular interpretation context.

3. Limits of reduced AI and principles of semiotic engineering

3.1 The example of the concept of function in the context of medical knowledge modelling

For example [5], if we are in a medical setting and we need to model knowledge in the conceptual graph formalism from their linguistic expressions such as "Logroton contains chlortalidone" (a) and "chlortalidone has a diuretic function" (b):

[Logroton] – (contains) --> [chlortalidone] (a)
 [chlortalidone] – (has_the_function) --> [diuretic function] (b)

From the inference rule that a drug has the function of its active ingredient we would like to deduce that:

[Logroton] –
 (contains) --> [chlortalidone]
 (has_the_function) --> [diuretic function] (1)

But since we are in a logical formalism, and $A \text{ and } B \Rightarrow B$, we therefore deduce, assuming that the truth of (1) is transmitted to that of (2), that:

[Logroton] – (has_the_function) --> [diuretic function] (2)

However, this is not true in the modelled domain because in the context of (1) the notion of function refers to the biochemical function of the active ingredient whereas in the context of (2) its meaning refers to the therapeutic function of the drug Logroton. Indeed, Logroton is an antihypertensive drug that carries the biochemical diuretic function in order to perform its therapeutic function of lowering blood pressure. This example clearly shows that the terms used by the formal system are not primitive notions as formalism would impose, but linguistic terms whose meaning is contextual, i.e. overdetermined by a point of view. The notion of function means by default the therapeutic function, but in the context of the active principle, this function means the physiological effect of the principle in question.

Thus, since the meaning of the formulas induced by the generative syntax of the formal system is not adequate to the contextual meaning induced by the interpretative operations of the domain, while being interpretable (since the symbolism of the formal

systems is borrowed from natural language), the consequence is that the formal system, operationalized in a computer device whose computational capacities surpass those of our conscious cognitive operations, can lead to meaning formations corresponding to new knowledge in the domain that we could not anticipate, due to the inferiority of our conscious processor compared to the machine's.

The question thus became: how and in what way can a computing device produce meaning? By approaching this question from the point of view of cognitive technologies, this meant that the computational machine should no longer be considered as a means of modelling, but as a new type of support for the inscription of knowledge. Just as graphic writing is not a model of the world, and the world is not a book written in mathematical language (according to Galileo's beautiful metaphor), automatic formal systems revealed, thanks to the implementation of the reduced AI research programme, that they are not models of knowledge domains, but virtual operative and computational supports that convey knowledge and enable new knowledge to be constituted. It is this discovery that allowed the development of a critique of formalism in artificial intelligence [6], the research programme of knowledge engineering and the elaboration of a critique of computational reason [7].

3.2 Principles of semiotic engineering

What semiotic engineering seeks to specify is a principle of modelling that exploits the oblivion of logical formalism and a principle of effectivity that supplements the principle of computational effectivity [8]. We propose another principle of modelling, complementary to the principle of logical formalization, which we call the principle of phenomenographic representation. It should allow us to express the non-logical content of phenomenological knowledge, that is, the qualitative structure on which the non-logical intuitive faculty is based, which was already recognized by Turing, in §11 of his PhD thesis [9], as one of the two sources of mathematical reasoning.

Instead of having an abstraction of the linguistic content through logical formalization, we obtain an abstraction of the intuitive content through schematic representation. For this reason, semiotic engineering is not interested in the linguistic idiom as a vehicle of knowledge, but in the graphic symbol. The function of the graphic symbol is to compact this qualitative phenomenological structure in semiotic space so that it can be grasped synoptically by a human being who reads it.

Secondly, there must be a principle of effectivity. We call this principle the principle of operational iconicity. It is a principle of non-computational operational effectivity. Instead of exploiting a principle of computational effectivity, it is a matter of exploiting the mediation through which we access non-computational effectivity. This mediation is, in our view, operational iconicity [10]. Now, operational iconicity can be captured by a diagram insofar as a diagram is a semiotic machine, i.e. a machine that gives access to an operational content that is not reducible to a computational content.

From then on, the challenge of semiotic engineering is to develop a visual dictionary and grammar of practice, i.e. a visual semiotics of practical operations that cannot be reduced to computational operations [8].

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