A Knowledge-Construction Perspective on Human Computing, Collaborative Behavior and New Trends in System Interactions

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Abstract. This article presents an analysis of collaborative behavior within the historical process of the construction of scientific thought. We start from evidence that the origin of computing was immersed in a conceptual background heavily dominated by structuring thought, resulting in a mode of thinking organized around a centralized unit, strengthening categorization, disciplinarity and a predominant dichotomous logic. However, the new settings in which computer systems are involved, such as collaborative behavior and human computation, reveal a mode of thought and organization within an acentered model of realization. Sociology of knowledge helps us to understand this dynamic, allowing us to verify that the rhizomatic model of realization embraces not only what is traditionally viewed as the setting of computer systems, but also extends to the way of thinking, organization and operation of collective relations around computer systems.

Keywords: human computing, collaborative behavior, sociology of knowledge, hybrids, rhizome.

1 Aims and Organization of This Paper

This paper proposes an analysis, from a historical perspective, of the current settings of computational systems based on collaborative behavior and human computation. This approach operates outside of the usual disciplinary boundaries, since it borrows from the sociology of knowledge the practice of traduction (traduction<>trahison) [1] and adopts, from philosophy, the concept of rhizome [2] to address not only the collective relationships that are established around collaborative systems, but also the actual construction of these systems. Multiplicities, flux, materialities, heterogeneities and co-construction are features that are becoming increasingly evident within new configurations of computing. However, not only the mode of thought that supports the

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construction of computer systems, but also the usual ways of analyzing the relationships of these systems within the collective to which they belong are tied to structures and their centered organization, and thus, do not favor a broad understanding of this dynamic. We thus propose a traduction of the concept of rhizome [2], expanding a proposal already suggested by Deleuze and Guattari. We show how computation fits a rhizomatic model of realization and how this model goes beyond what is traditionally thought to be the setting of computer systems, extending this setting to include the mode of thought, organization and operation of collective relations.

We argue in this paper that the rhizomatic approach can contribute to our understanding of computation in at least three different ways. First, it provides a better understanding of situations that appear to be paradoxical. Paradoxes occur within a dichotomous mode of thinking when two visions that are understood as irreconcilable are put in confrontation. The adoption of a mode of thought supported by a network of relationships highlights the negotiation process among heterogeneous agents, consisting of a dynamic that leaves no room for the paralyzing feeling that stems from an apparent impossibility of reconciliation. Secondly, it brings a new comprehension of power configurations involving this scenario of multiplicities, flux, materialities, heterogeneities and co-construction. This new comprehension results from the shift from a structured conception where a single unit - under which everything is ruled - represents a mark of power and authority, to an acentered configuration where authority is negotiated. Thirdly, it helps to undermine the strict separation that takes place still today between what is said to be "technical", “exact”, “objective", “computable” and what is called "social", “humanistic”, “subjective”, “non-computable”, or “not computable in an acceptable amount of time”. This forces a revision in the understanding of knowledge construction. By highlighting the participation of computer systems in this negotiation network in which programs, machines, mathematics, humans, feelings, spontaneous actions and a variety of heterogeneous agents also take part, the three above-mentioned contributions directly affect the conception and construction of computer systems, as well as the comprehension of their (co)operation with/in the collectivity.

This paper is organized as follows. We start, in Section 2, from evidence that the origin of computing was immersed in a conceptual background heavily dominated by structuring thought, resulting in a mode of thinking organized around a centralized unit, strengthening categorization, disciplinarity and a predominant dichotomous logic. Section 3 argues that this model of realization no longer accounts for the new settings that computer systems have come to assume, such as collaborative behavior and human computation, which demand a way of thinking and organization in an acentered model of realization. In light of this, we analyze in Section 4 the evolutionary pathway from CAPTCHAs to reCAPTCHAs, which are current manifestations of collaborative behavior and human computation. We conclude in section 5 commenting some contributions of this approach for computer science.

2 The Primacy of Structures and the Emergence of Computation

Mathematicians, who embrace the idea of abstract theories, define abstract objects that are understood and thought of as forming *a shared body of knowledge*. They refer to these abstract objects as autonomous entities, and communicate and build new abstractions from them, which are increasingly disconnected from the entities in the world in which we live that initially served as inspiration for these objects. Fleck, a sociologist of knowledge in the 1930's, referring to knowledge in general, not specifically to mathematics, explained that when these links with the world in which we live are not perceived, one achieves so-called "objectivity", giving the impression of universality, neutrality and accuracy, exempt from any personal judgment [4].

In the first decades of the twentieth century, the scientific research conducted in Europe and the United States showed a strong tendency toward the quest for objectivity and categorization of knowledge. In mathematics, this trend became evident in the expression of mathematical thinking by representing relationships between entities in an abstract manner (as schemata or structures) with the aim of hiding the connections between such entities and any trace of "concrete reality". Rudolf Carnap was one of the philosophers of mathematics who strongly argued in favor of this approach. According to Daston and Galison [3], "[o]bjectivity, for Carnap, was deeply associated with this very particular way of abstaining from particularity while maintaining a commitment to the structural integrity of *shared knowledge*". Bertrand Russell, a British philosopher of mathematics, also argued in favor of structures which he saw as emerging from abstract representations of relations between entities. Once the structures are identified, the mathematician should abandon any correlation with the things in life that served as inspiration: "We may say, of two similar relations, that they have the same 'structure'. For mathematical purposes (though not for those of pure philosophy) the only thing of importance about a relation is the cases in which it holds, not its intrinsic nature." [5]

This was not, however, a consensus. The impatient resistance of the pragmatist William James is an example of the intense debate provoked by the proposal to decouple abstract representations from the world in which we live. William James defended maintaining the ties with the things in the world for the sake of clarity in the knowledge construction process: "Mr. Russell, and also Mr. Hawtrey, of whom I shall speak presently, seem to think that in our mouth also such terms as 'meaning,' 'truth,' 'belief,' 'object,' 'definition,' are self-sufficient with no context of varying relation that might be further asked about. What a word means is expressed by its definition, isn't it? The definition claims to be exact and adequate, doesn't it? Then it can be substituted for the word - since the two are identical - can't it? Then two words with the same definition can be substituted for one another, *n'est-ce pas*? Likewise two definitions of the same word, *nicht wahr*, etc., etc., 'till it will be indeed strange if you can't convict some one of self-contradiction and absurdity." [6]

Despite objections, in the mid-twentieth century the search for structural objectivity gained strength through the initiatives of the Vienna Circle: "(...) the search for a neutral system of formulae, for a symbolism freed from the slag of historical languages; and also the search for a total system of concepts. Neatness and clarity are striven for, and dark distances and unfathomable depths rejected."[7] A respectable group of scientists, amongst whom was Carnap, published the manifesto "The Scientific Conception of the World", which provided basic guidelines of what would be identified as "scientific practice". The Vienna Circle entered the scene with a double composition that placed logical analysis as a privileged component of scientific practice: a strict linguistic approach, combined with a formal logical system, whose accuracy would clarify the statements, eliminating ambiguities and inaccuracies of speech, and precisely determining their meaning. Logical analysis would then be combined with a decisive mechanism to ensure truth: empirical evidence obtained by breaking statements into their constituent parts until those parts are simple enough that they can be directly compared with concrete reality.

The Scientific Conception of the World settled comfortably on a foundation which has been strengthened in European culture since the seventeenth century in an effort to establish boundaries and disciplinarity as expressed in the four precepts of cartesian logic: evidence, analysis, order, classification [8]. Those percepts were respectable enough to minimize the echo of arguments against them, such as those proposed by William James. In this manner, mathematics, while suffering from a mistaken abstract, structured conception, was strengthened by appearing to be objective, neutral and universal.

As the second half of the twentieth century began, structure dominated thinking was still in vogue; within this milieu computers emerged. In 1936, mathematician Alan Turing imagined an abstract device, later to be named the Turing machine [9]. Attempting to mimic the processes that a human performs when computing a number, the Turing machine constitutes a formal counterpart to the intuitive notion of "computation". Turing's purpose at the time was to understand the extent of Hilbert's proposal, which consisted of a system (a structure) within which any statement would have a formal proof of its truth or falsity. The Turing machine, conceived using arborescent rationality, later came to be materialized in what are currently named computers.

As devices designed from formal systems, from structured symbolic representations, computers show in various different aspects the dynamic of control departing from a centralized unit. This is a consequence of the arborescent (structured) model in which they were conceived: languages grammatically organized from the start symbol, and whose operation is derived by repetition of rules forming the syntactic tree that has the start symbol as its root; automata correspondingly to grammars, also with a designated initial state, from which the process unfolds remaking patterns in repetition; and memory, a system unit on which all processing is done from successive storage retrievals and updates with new values. Computers are therefore systems organized around a strong central unit that dominates everything, a marker of power: "Regenerations, reproductions, returns, hydras, and medusas do not get us any further. Arborescent systems are hierarchical systems with centers of significance and subjectification, central automata like organized memories. In the corresponding models, an element only receives information from a higher unit, and only receives a subjective affection along preestablished paths. This is evident in current problems in information science and computer science, which still cling to the oldest modes of thought in that they grant all power to a memory or central organ." [2]

3 Computation, Dichotomies and the Rhizome

One of the legacies of the formation process of modern thought is a tendency to categorize knowledge into two distinct ontological zones. This dichotomy is a direct consequence of the totalizing (centralized) unit of the arborescent model, since it gives rise to characterizations of the kind “what is inside” and “what is outside”, “what is generated from the root” and “what is not generated from the root”, “the correct” and “the wrong”, “humans” and “nonhumans” [10], resulting in a conception of pure entities, that is, entities that fit comfortably in its structure.

Alongside with this goes the division between social and technical knowledge, a demarcation strongly supported on the assumption that a certain kind of knowledge (which is said to be technical) is objective, that is, independent from the fluctuations of human subjectivity. For many years, the field of sociology of knowledge reinforced this dichotomy by considering mathematics (the core of objective reasoning) as a kind of thinking that demanded a specific mode of understanding. Since the process of construction of mathematical entities was not adequately understood it was not uncommon to admit that these entities existed on their own, independently from human thought, a view shared by sociologists of knowledge as well as philosophers of mathematics. Therefore, mathematics remained outside the realm of study of the sociology of knowledge, protected from its key postulate: *the impossibility of properly understanding modes of thought without taking into account the corresponding context of collective action, or separately from their social origins* [11]. Only in the 1970s with the adoption of the principles proposed in the Strong Programme in Sociology of Science at the University of Edinburgh, did the sociology of knowledge community resolutely begin to consider that mathematics belongs to their field of study, providing evidence that mathematics - as well as all technical knowledge and, in fact, any other kind of knowledge - does not depend solely on what is considered to be "objective". Indeed, all kinds of knowledge require the collaboration of multiple heterogeneous agents [12]. As argued by Lévi-Strauss in his writings on anthropology: "Any system which treats individuation as classification (and I have tried to show that this is always so) risks having its structure called in question every time a new member is admitted." [13]

We see then that certain situations in life force us to deal with entities for which we cannot find a comfortable place in the usual classifications. For example, in the case of computers, the *rapprochement* between the logic of 0's and 1's and the materiality of digital circuits reduces the gap between abstraction and matter, between the idea and the thing. The computer combines mathematical rationality with materiality. Computers function the tension that results from the assemblage between rationality and materiality. As a result of this tension, computers and computation, as well as the mathematics which provides their conceptual foundation, are in a constant state of flux. Hence, even if this flux occasionally acquires a certain stability, such stability can only be provisional. Perhaps for this reason, the publication of Gödel's theorem in the 1930’s [14] was a severe surprise for those who advocated an approach to mathematics based solely on an arborescent mode of thought. Contrary to Hilbert’s expectations, sufficiently strong formal systems are capable of expressing statements about themselves, giving rise to the incompleteness theorem which demonstrates the existence of true statements that can be formulated within the system but cannot be proved. This exposed the inability of a formal system, even though it may be consistent, to decide every question that can be expressed mathematically within the system. The incompleteness theorem explicitly signals the impotence of totalizing systems for both mathematics and computing: formal systems require externalities in order to have some semblance of consistency and completeness. But these externalities come in a tensioned negotiation. Although incompleteness was exposed within the mathematical machinery itself, it was difficult for mathematicians to avoid extensions of these results outside of mathematics; even today most mathematicians reject with antipathy any associations between Gödel's results and other fields of knowledge. For accepting such associations would undermine the demarcation of borders between mathematics and other fields and consequently the unique prestige of mathematics as a form of purified thought: “Many references to the incompleteness theorem outside of the field of formal logic are rather obviously nonsensical and appear to be based on gross misunderstandings or some process of free associations.” [15] Gödel's theorems are a deleuzian “line of flight” enabling mathematics to escape from itself. As a consequence mathematics is renewed and strengthened. Therefore, incompleteness shows the flux in which mathematics, computers and computing are immersed by their constant need to reconstruct and to rebuild themselves.

However, computers as well as computer networks are also totalizing entities, arborescent systems, and therefore sometimes give a feeling of phagocytosis, as if machines were engulfing the world. Furthermore, just as mathematics is not completely captured by formal systems, the world escapes the machine, evidencing a kind of incompleteness of techniques for completely capturing the world. Computer and computer networks (as well as formal systems) require exteriorities, demanding human participation at some level. These human actions lead to a historical re-insertion of technical knowledge since they impose a link between the application of a technique and an individual situation where it is applied, possibly not the same situation for which this technique was designed. Hence, a rhizome arises in the line of flight of the collaboration between machines and humans. We are then forced to find explanations that cope with multiplicity, flux, materialities, heterogeneity and co-construction. In opposition to - but not excluding - the arborescent model, Deleuze and Guatarri [2] suggest a conception of a net of relationships, the rhizome, that helps us to see how this human-machine encounter both separates as it approximates humans and machines, at the same time undoing and redoing the human-machine dichotomy: “[U]nlike trees or their roots, the rhizome connects any point to any other point, and its traits are not necessarily linked to traits of the same nature; [...] It is composed not of units but of dimensions, or rather directions in motion. It has neither beginning nor end, but always a middle (*milieu*) from which it grows and which it overspills. [...] Unlike a structure [...] the rhizome is made only of lines: lines of segmentarity and stratification as its dimensions, and the line of flight or deterritorialization as the maximum dimension after which the multiplicity undergoes metamorphosis, changes in nature. [...] Unlike the tree, the rhizome is not the object of reproduction: neither external reproduction as image-tree nor internal reproduction as tree-structure. The rhizome is an antigenealogy. It is a short-term memory, or antimemory. The rhizome operates by variation, expansion, conquest, capture, offshoots. [...] In contrast to centered (even polycentric) systems with hierarchical modes of communication and preestablished paths, the rhizome is an acentered, nonhierarchical, nonsignifying system without a General and without an organizing memory or central automaton, defined solely by a circulation of states." [2]

In the following section we discuss a case involving computers, human computing, and collaborative behavior. The multiplicity, flux, heterogeneity, materiality and co-construction that become apparent in this case reject an analysis in terms of totality (unity), and therefore show the arborescent approach is incapable of providing, by itself, an adequate understanding of the configurations involved. This example shows the rhizome as a model of realization of the tensioned meeting between humans and computer networks. It also shows that the rhizome embraces the tree structures as it is remade from them. In other words the opposition with respect to the tree does not imply the exclusion of the tree model of realization from the rhizome, which would then amount to a tree-rhizome dichotomy.

4 Human Computing, Collaborative Behavior and New Trends in Systems Interaction

In this text "collaborative behavior" denotes an activity where individual human action, supported by information sharing and collective knowledge, contributes to the realization of a task in a process that may involve computers for the purpose of coordinating man-machine cooperation. Collaborative behavior appears to be an essentially human activity, but a more careful look at it reveals heterogeneity, the alignment of humans with machines, rationalities as well as emotions and subjectivities. It is a collective assemblage that involves negotiation and mutual trust among a diversity of agents that materializes, provides a body to, a hybrid entity. Apparently a negotiation is a binary link, but again a more careful look reveals multiplicity. Each agent is several, since it carries with it a history of previous negotiations. Even the machine carries in its architecture a multitude of agents and negotiations, as Latour [16] shows us in his analysis of Tom West's incursion in the DEC laboratory, a story told by T. Kidder [17]: “Looking into the VAX, West had imagined he saw a diagram of DEC's corporate organization. He felt that VAX was too complicated. He did not like, for instance, the system by which various parts of the machine communicated with each other, for his taste, there was too much protocol involved. *He decided that VAX embodied flaws in DEC's corporate organization.* The machine expressed that phenomenally successful company's cautious, bureaucratic style.” Furthermore, negotiation takes place in many directions, weaving a network of encounters, and therefore tending to an acentered configuration. This moves us away from structures in which connectivities start at a point and then proceed by dichotomy. However, structures recur insistently. They emerge unexpectedly from the network in a movement of reterritorialization of the network. Collaborative behavior takes place in a rhizome in which arborescent thought deterritorializes and reterritorializes.

The case study that we now consider starts on a strict separation between humans and machines, supported by an arborescent mode of thought. We consider the analysis of L. Ahn, who refers to a task involving induction which humans are capable of easily performing but which computers are either unable to perform or are unable to perform in a reasonable amount of time [18]. Thus the ability to perform such inductions is considered to be an essentially human trait. In addition to the enormous amount of time that is "wasted" by people in computational activities such as playing games (nine billion human-hours of solitaire in 2003, as reports L. Ahn[1]), the fact that the ability to perform certain inductive tasks is an essentially human trait has led to a new area of computer science research called "Human Computation". This emerging field seeks to harness human tasks involved in spontaneous activities such as playing games, for the purpose of benefiting society [19]. The following is an example given by L. Ahn: in search engines for images on the Internet it is currently very difficult to relate an image to the typed keyword. However, at a quick glance, a human being is able to suggest a word that permits the identification of the image and which thus could be used as a caption. In this manner, associating the action of inferring captions for images to a game-playing activity, a large number of images could be captioned, contributing not only to web searches, but also providing access for the visually impaired. Thus, the field of Human Computation proposes outsourcing to humans only those sub-tasks which machines cannot carry out on their own. Humans cooperate with the machine by performing a sub-task that the machine cannot do (or cannot do in a feasible amount of time). This joint, collaborative work creates a half human, half machine hybrid entity that can carry out the desired computational task.

In proposing a deleuzian analysis of the emergence of this new field of research in computing, this paper focuses on the evolutionary pathway from CAPTCHAs to reCAPTCHAS. The "Completely Automated Public Turing test to tell Computers and Humans Apart" (CAPTCHA) was proposed in an article published in the *Communications of the ACM* in February 2004 to describe a solution for a pressing contemporary problem: how to stop bots from invading websites. In other words, how can we control unauthorized access to computers or web pages by invasive computer programs. The proposal of Ahn *et al.* consists in displaying distorted characters so that in order to access a web page, the user must decipher and retype them, a demonstration that the accessing agent is human and not a robot. The use of this technique is now widespread in many popular websites such as Yahoo, Hotmail and PayPal, among others.

The dichotomous mode of thought, strictly separating as it does what it assumes to be opposites, has the effect of hindering the realization that entities act in co-construction, and consequently generates situations that seem to be paradoxical. Ahn remarks: "Notice the paradox: a CAPTCHA is a program that can generate and grade tests that it itself cannot pass (much like some professors)." [19]. There are other aspects which may also seem paradoxical when a dichotomous logic is maintained: although CAPTCHAS are based on a clear, sharp distinction between humans and machines, they were inspired by the Turing Test, which was intended to show the indistinguishability of machines and humans, as Turing claims in his 1950 paper where he presents the test: "I believe that at the end of the century the use of words

[1] http://www.youtube.com/watch?v=tx082gDwGcM

and general educated opinion will have altered so much that one will be able to speak of machines thinking without expecting to be contradicted." [20] Ahn does not comment on this strange turn of events. Instead, he claims that his proposal and the Turing test both distinguish humans from computers. Even though CAPTCHAs arose from a context dominated by a structuring mode of thought, paradoxically this proposal leads to a hybridization between humans and machines, interweaving an engine that offers a solution to a task that machine seems not able to perform by itself. Building upon this hybridization, we are then led to reCAPTCHAS, which are proposed as a mechanism for leveraging human action in collaboration with machines for the purpose of digitizing printed works with expired copyrights in order to make them freely available: "Although CAPTCHAs are effective at preventing large scale abuse of online services, the mental effort each person spends solving them is otherwise wasted. This mental effort is invaluable, because deciphering CAPTCHAs requires people to perform a task that computers cannot. We show how it is possible to use CAPTCHAs to help digitize typeset texts in nondigital form by enlisting humans to decipher the words that computers cannot recognize." [19]. Thus, CAPTCHAs and their subsequent evolution to reCAPTCHAs, simultaneously unmakes and remakes the distinction between humans and machines. Collaborative behavior deterritorializes and reterritorializes the arborescent thought processes throughout the human-machine dichotomy.

5 New Trends of System Interactions, the Need for Different Understandings of Collective Configurations

The rhizome allows us to perceive this movement of (de/re)territorialization. The endeavor to reestablish structures on acentered networks manifests itself, as we have seen, in paradoxes, unfolds in the reinstatement of the rhizome itself. As the rhizome slips and remakes itself, the structure deterritorializes and the acentered network restates itself. It no longer has the static image of a paradox, a typical paralyzing incompatibility which arises from a binary conception within the dichotomous mode of thought. It is the motion of reconstruction, the flux of a new conformation that results from a co-constructive negotiation.

This development also brings a new comprehension of the power of different configurations involving this scenario. These configurations result from the shift from a structured conception - where a single unit under which everything is ruled represents a mark of power and authority - to an acentered configuration where authority is negotiated. ReCAPTCHAS put in evidence a new scenario in which a multitude of human brains cooperate with the machine performing that part of the task of text decryption which scanners cannot. This creates a framework in which people perform a certain task but in most cases do not know the purpose of this action. Even when they know that it is to offer free digitalization, they certainly do not know of which text, nor which phrase they are helping to disseminate. When employing dichotomous modes of thought, people function like the pieces of a big engine. These pieces provide the machine with the ability to perform what is clearly recognized to be an exclusively human capability: namely, induction. This new configuration reverses the usual understanding that humans employ machines to solve their problems and not vice-versa - for example, a man with an artificial heart. It creates a situation in which machines employ humans to solve their problems, which makes humans confused about "Who is in command? Who owns the control?". The control no longer emanates from a unit of power, the root of a structure, but results from the continuous negotiation among of heterogeneous agents that participate in the network.

In addition, this configures a situation where social mechanisms act in a conformation which would normally be considered purely technical, placing humans and machines side by side in a symbiotic interaction. Computers changed the terms of the debate on the hybridization of knowledge to its current form. The directions that computing took in the 1980's, the widespread use of computers, and later the new forms of interaction provided by the Internet and by human computing and collaborative behavior, are forcing us to revise our understanding of knowledge construction. Computing is now seen to be a hybrid phenomenon, an area in which the human and the non-human are juxtaposed; hence the hybridization between "technical" and "social" becomes more readily visible, thus undermining the rigid and severely disciplined hierarchical, arborescent organization of modern thought.

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