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Distributed Cognition Supported by Information Technology Can Help Solve the Knowledge Management Bottleneck

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ABSTRACT

Information theory describes three types of information: syntactic, semantic, and pragmatic. We argue that knowledge is pragmatically tested information. Validating syntactic and semantic information is easy and inexpensive, but pragmatic testing is more complicated and expensive since it deals not only with information but with matter, energy, and often people. Information Technology (IT) can be used to generate and validate new syntactic and semantic information, but its usage has been very limited at the pragmatic level. This asymmetric usage of IT has given rise to a Knowledge Management (KM) bottleneck. This article looks into new ways to apply IT to minimize it. Pragmatic Minimization is achievable with the help of Virtual Reality (VR) and Internet based Distributed Cognition (IDC). VR simulates energy and matter in computers, making the pragmatic test fully informational, and IDC leverages the massive testing capacity of a huge social pool of Internet users.

Keywords: Knowledge Management, Information Theory, Distributed Systems, Distributed Cognition, Artificial Intelligence, Virtual Reality, Conceptual study,

Introduction

Knowledge Management (KM) currently faces two major challenges: (1) the lack of clarity in defining and delimiting its concepts (for example, between the central concepts of “information” and “knowledge,” “distributed knowledge” and “distributed cognition”) and (2) the KM bottleneck (i.e. lack of capacity to process increasingly abundant information). Information Technologies (IT) can play a critical role in solving both problems. IT can help clarify the concepts by providing a model of artificial processing (versus natural or biological processing). IT can also support Distributed Cognition in solving the KM bottleneck by facilitating the generation, test, transfer, and storage of knowledge (Thompson, Levine, & Messick, 1999) thus making Distributed Cognition another important element of KM (Tsoukas, 1996).

This article first distinguishes and clarifies the concepts of distributed databases, distributed knowledge, distributed processing, and distributed cognition. Then, it presents the concept of *pragmatic minimization* as a critical component of the KM bottleneck and discusses how KM and other more traditional disciplines have unsuccessfully approached the problem. Subsequently, it discusses how IT –through simulated praxis and a more pragmatic artificial

intelligence— can improve KM, and concludes by explaining how Distributed Cognition (DC), aided by IT, can help solve the KM bottleneck.

The Knowledge Management Bottleneck

Over the Internet or through traditional media, huge amounts of information are offered for free or at a very low cost. It is generally accepted that a small portion of that information can be considered knowledge. The science and practice of KM has devoted itself to finding ways of extracting that knowledge.

KM's goal of obtaining knowledge from that huge base of information has remained elusive for two main reasons. First, it encounters a quantitative hurdle: there is a gigantic and continuously growing amount of information that needs to be processed. Second, it faces a qualitative obstacle: establishing the difference between information and knowledge. The quantitative hurdle could be solved by using increasing amounts of IT, but the qualitative obstacle is far more difficult to overcome. Until recently, KM has been using ad-hoc conceptual frameworks instead of borrowing more established ones developed by other scientific disciplines. Therefore, KM's current conceptual framework is a handicap in achieving the goal of acquiring and managing knowledge (Salim, 2010; Spender & Scherer, 2007).

Not all information is knowledge but all knowledge is information; therefore, larger information availability implies a larger workload to extract the knowledge (even if it is accompanied by larger knowledge availability). In other words, a higher workload is needed to find the proverbial needle in the larger haystack. Of course, it could also happen that some of the knowledge learned in the process deals with how to process information faster and more efficiently. Therefore, the ratio of information to work may change. For this reason, in order to analyze the current bottleneck, we have to consider both the quantitative and the qualitative aspects of KM.

Qualitative Aspect of the KM Bottleneck

Knowledge acquisition is thwarted for those who cannot distinguish between knowledge and information. KM tends to assume that information is a passive object located in books and in people's memories where it is waiting to be used, while knowledge, besides being able to stay "passive" in a book or in someone's memory, is also capable of "acting" from the brain, directing the movements of muscles or producing more knowledge (cf. Galup, Dattero, & Heeks, 2002). It is also common to read that information is "explicit knowledge" but not "implicit knowledge" (cf. Polanyi, 1966). However, this is not a formal, precise, or useful framework. KM might benefit from considering useful frameworks previously developed by other disciplines. For example, a generally accepted classification of information that comes from the disciplines of semiotics, philosophy, and information theory differentiates between information's syntactic, semantic, and pragmatic aspects (cf. Brier, 1995; Carnap & Bar-Hillel, 1952; Ferran & Salim, 2003; Morris, 1971; Nauta, 1972; van der Lubbe, 1997).

In accordance with this classification of information, syntactic information is a form, like noise or scribbles that no one recognizes. Semantic information is a form that is recognized by some,

in terms of other information, like a scribble that someone can recognize as instructions to operate a machine. Pragmatic information is a form that has meaning for some in terms of an action, like the actions accomplished by an individual who followed expert instructions on how to operate a machine. Clearly, knowledge is mainly pragmatic information. The ability to “act” over matter is inherent to the pragmatic dimension of information in contrast with the “passivity” of other types of information with a more syntactic or semantic dimension. Likewise, “implicit knowledge,” is manifested by “what it does” instead of “what it says.” It is mainly pragmatic information with a low semantic dimension while “explicit knowledge” is high in both, pragmatic and semantic dimensions. Since knowledge is highly pragmatic, we argue that knowledge is to organisms the equivalent of what software is to computers. In summary, semantic and syntactic information is the data or “passive information” that is stored in the memory of either organisms or computers.

Quantitative Aspect of the KM Bottleneck

The abundance of information does not satisfy the demand for knowledge. For example, the last decade alone has generated a huge amount of information on KM. As a sample, on July 28th 2011, a Google search for “Knowledge Management” yielded 23,600,000 hits, 16,300,000 of them being PDF files (PDF files are usually articles). Even if only 0.01% of those articles had relevant and non-redundant information on the subject matter, they amount to 1,630 articles.

Of course, the Internet or a traditional library is not where a CEO would look for solutions to a knowledge capitalization problem, nor would he/she would try to generate solutions on his/her own. Chances are that he/she will seek the help of specialists such as a business consultant or KM specialist, who has already studied the non-redundant and relevant information on the given subject and would be up-to-date on the latest innovations. At least for now, neither the Web nor traditional libraries are meant to replace proven knowledge –expert knowledge that has been validated and gradually acquired in an organized fashion throughout a professional career.

The cost of knowledge (whether it is in the form of services rendered by professionals, experts, or consultants; or in the form of licenses or goods that incorporate knowledge, such as patents, software, or high tech devices) is usually high. This is particularly true when compared to other inputs and supplies that both companies and countries require (Blankley, Scerri, Molotja, & Saloojee, 2005). In 1993 Drucker (1993) estimated that developed countries spent at least 20% of their Gross National Product on creating and disseminating knowledge (10% on education, 5% on on-the-job continuous education, and 5% on research and development). These numbers have not decreased.

Within organizations, knowledge formation costs translate to an expensive payroll for professionals and experts. The alternative to hiring these experts is to put aside the semantic heritage and go through trial and error; that is, to build the pragmatic dimension of information required out of their own experience. However, this presents a risk of even higher costs.

The costs of pragmatically testing (validating) the information –whether done beforehand by experts or in-house by the organizations themselves– is the bottleneck that keeps the abundant

supply of information from satisfying the demand for knowledge. In order to reduce the current KM bottleneck, it is critical to minimize these costs.

Pragmatic Minimization

The phase of knowledge generation and transfer that consumes the most time and resources is the pragmatic phase¹. This phase is where the KM bottleneck currently lies. This is the phase that needs to be minimized if we want to satisfy the ever increasing demand for knowledge. In consequence, we define *Pragmatic minimization* as the process of minimizing the cost of acquiring knowledge by testing newly generated information with real problems that require solutions. This concept can be illustrated by genetics.

Just as the genetic code evolves by natural selection of random mutations of macromolecular information, knowledge is generated and propagated by cultural selection of essentially random changes in neurological information (e.g. innovations and inventions). This process occurs in three phases: (a) a syntactic phase in which the information is altered and exclusively kept in the syntactic or formal dimension of information; (b) a pragmatic phase in which the new (or altered) information is contrasted with reality (e.g. field test; marketing test) and is culturally accepted or discarded (forgotten or placed in an archive for future potential retesting); and (c) a semantic phase in which the new information is incorporated and diffused into the information network that we call culture, in particular, that which we call knowledge.

Because the pragmatic phase is a critical one, we cannot simply disregard the testing phase. Untested information tagged as knowledge may be useless to solve a given problem if there is a discrepancy between what has been acquired and the realities of the problem. Knowledge acquisition could weaken its pragmatic anchors due to two idealistic perversions: voluntarism and combinatorial explosion. The first falls into voluntarism or the idealistic belief that the facts will conform or must conform to our chosen idea. The second lets the imagination fly into a prolific explosion of syntactic-semantic combinations, each as feasible as the next but with very little match with reality.

KM and Traditional Pedagogy

The discipline of KM has yet to produce an optimal solution for generating and transferring knowledge. Although it has produced important advances, the main problem shared by both phases has been left intact: the pragmatic proof of information so that it can be considered knowledge. In this aspect, KM has not surpassed the methods already developed by traditional pedagogy.

One of the most elaborated subjects in the KM literature is the distinction between tacit knowledge and explicit knowledge (Nonaka, 1991, 1994; Polanyi, 1966). We identify tacit knowledge with the pragmatic phase of the knowledge cycle and explicit knowledge with the

¹ The pragmatic phase is the phase in which we confront potential new knowledge with the real world. It is where we bring it to praxis.

complementary syntactic and semantic phases. Thus, the way in which a painter moves the brush is what we, in terms of Polanyi (1966) “know” but can hardly explain. It is pragmatic information that is hard to transform into semantic information. Transferring explicit knowledge is considered a relatively easy and quick task while transferring tacit knowledge is hard and slow.

KM has arrived at the same conclusion that traditional pedagogy reached very long ago: we need to reduce tacit knowledge as much as possible. In other words, it has concluded the need for the syntactic-semantic maximization and *pragmatic minimization*. If we do not explicitate tacit knowledge (convert it into words) then we: (1) cannot use logic (word processes like explicit conceptualization or definition, associations, and inferences) and (2) limit ourselves to gestural language and blindly imitating the actions of others.

For thousands of years pedagogy has developed the concepts and methods for teaching theory and practice. It has evolved towards teaching more theory and less practice. Using our terminology, pedagogy has evolved towards the maximization of the semantic transfer while minimizing the pragmatic transfer. Proof of this is the number of hours that formal education dedicates to theory in the classroom vis-à-vis what it dedicates to practice in laboratories, field tests, and internships. However, it is commonly accepted that during lectures only theoretical knowledge is taught and that the real learning takes place later, when we put into practice what we have learned. This is a very old discussion, entailed in the classical philosophical controversy between Plato’s and Aristotle’s conceptions of rationality, i.e., the episteme and the phronesis, respectively. And in “The Relation between Theory and Practice: Back to the Classics” we read:

Nowadays we can find many classifications in the literature that clarify different conceptions of knowledge: for example, public versus personal knowledge, molecular versus holistic knowledge, knowledge as given versus knowledge as problematic, knowledge by acquaintance versus knowledge by description, declarative versus procedural knowledge, knowing how versus knowing that. Haven’t we made too much progress in 2,500 years to return to the very beginning of the debate? As a matter of fact, it appears not. Centuries ago, the same type of problems now confronting teacher educators were thoroughly studied by philosophers, resulting in a fruitful theoretical framework of which most modern researchers are not aware. (Kessels & Korthagen, 2001)

KM, on the other hand, proposes that making knowledge tangible without explicitly stating it solves some management problems, but it is still a slow and incomplete form of knowledge transfer compared to its explicitation. The sales success of “practical teaching” videos is more a marketing than a KM success. What is sold in such videos is an incomplete knowledge set which is still slow to transfer to a person’s repertoire. Perhaps more appropriate examples are the KM attempts to transfer “best practices” through imitation. This is what we try to do in the “workshops”, “practical courses”, and books with titles such as *Ten Key Steps to Success*. They contain mostly pragmatic information made somewhat tangible, but they are generally more dramatic than effective. They only transfer parts or superficial aspects of the knowledge, such as appearances, poses, and jargon.

Lasnik (2003) presents the pros and cons and provides a rich bibliography of the different pedagogic methods that we have mentioned here under the concept of “tangibilization of pragmatic knowledge” (see also Demarest, 1997; Zucker, Darby, & Armstrong, 2002). In summary, in order to transfer knowledge successfully, we first need to make it explicit and only in the cases where it is irreducibly tacit, should we make it “tangible” without making it explicit. KM has not been able to accelerate the transfer of tacit knowledge that cannot be made explicit. Perhaps the problem was presented concisely for the first time by Polanyi (1966):

Discussions of KM begin by addressing the question, ‘What is knowledge?’ The most popular tenet here rests on the forms of knowledge that can be expressed for codification. The “robust” assumption is that tacit knowledge is difficult to extract from the human mind, thus limiting the manipulation and transfer of this type of knowledge.

Indeed, almost four decades after Polanyi explained the problem, many authors still claim that transferring knowledge from scientific discoveries to those who will develop it commercially requires its previous transformation into words, codes, and/or formulae (cf. Zucker et al., 2002). Thus, the speed of knowledge transfer is still limited by the time required for human interactions between teacher/master and pupils/apprentices.

Storytelling is a common practice that helps to communicate complex ideas, i.e. tacit knowledge, (Snowden, 2000). Generally, it occurs within the context of communal practices, since these provide a rich and fertile ground for storytelling and thus learning and knowledge transfer (Kurtz & Snowden, 2003). It is pervasive across organizations and communities; however, it is even more effective when appropriately managed (Snowden, 1999). Moreover, narrative storytelling has been found to be especially useful for transferring knowledge as long as the media used lends itself to the narrative format (Meyer, 2004). However, storytelling is both an art and a science. To assure its effectiveness for knowledge transfer both the sender and the receiver need to have a common context and good understanding of each other’s environment (Ellerman, Denning, & Hanna, 2001). Therefore, storytelling is a slow and imprecise method for transferring tacit knowledge.

Boiral (2002) describes how an environmental control organization was able to leverage the tacit knowledge contained in the experience of individuals; however, this article does not provide any substantial KM achievement that may be generalized. From Krogh et al. (2001), we infer that the achievements of KM in reference to knowledge transfer do not go much further than those of traditional pedagogy. In Nadler et al. (2003) we find a review of the learning and training literature showing that the methods for training people to become more effective negotiators can be grouped as: a) didactic learning, b) learning via information revelation, c) analogical learning, and d) observational learning. The authors acknowledge that observational learning reached “the largest increase in performance, but the least ability to articulate the learning principles that helped them improve, suggesting that they had acquired tacit knowledge that they were unable to articulate.” We can add that *didactic learning* and *information revelation* correspond to traditional learning through pedagogy or through the simple reading of explicit information. Respectively, *analogical* and *observational* methods refer to tacit knowledge. None of these findings are really new; thus, we have not really made new achievements in knowledge transfer.

While KM has been able to identify and explain in business terms the knowledge transfer problem, it has done very little to solve it. While writing this article, one of the authors received a promotion for a course which indicated: “*Much more than IT, KM overlaps project and relationship management. You can transfer information with a fax or email. You can transfer knowledge with effective training and you can transfer wisdom with coaching and mentorship.*” We can ask ourselves if there is any substantial difference between *effective training or coaching and mentorship* and the traditional activity of pedagogy. Are they different from the traditional interaction between the teacher, tutor, trainer, or professor and the students, trainee, intern, or apprentice? If there is a difference, it is not evident in the KM literature. Solutions like *coaching*—assisted or not by IT— simply provide new names to old methods already developed by traditional pedagogy

In summary, we can say the only real innovation of KM compared to traditional pedagogy is that the former acknowledges the existence of valuable knowledge in non-academic settings and applied IT more intensively than the latter. Brainstorming (de Bono, 1992), for example, is a business variation of the traditional forums, arenas, intellectual exchange campaigns, etc. The Intellectual Capital Multiplier Effect (Edvinsson, 2002) is an organizational variation of the multiplying effect of knowledge, common to traditional educational institutions, such as universities. Best Practices Benchmarking is a business version of old pedagogic seminars or workshops (Patton, 2001). Data mining exemplifies the use of IT by KM before traditional pedagogy (Cody, Kreulen, Krishna, & Spangler, 2002; Shaw , Subramaniam, Tan, & Welge, 2001).

Nonetheless, neither pedagogy nor KM can ignore the limits of *pragmatic minimization*. When they bump into those limits, they can offer nothing better than pragmatic knowledge which is difficult and slow to transfer. “Tangibilized” tacit knowledge is incomplete and slow to transfer. However, the tangibilization of tacit knowledge is currently the only solution available to tacit knowledge which resists explicitation (Boiral, 2002; T. H. Davenport & Prusak, 1998; Dixon, 2000; Nonaka & Noboru, 1998; Polanyi, 1966; Swart & Kinnie, 2003).

KM and Organizational Solutions

KM borrows intensively from IT and business science. Its premises generally resort to both, sometimes in a balanced fashion but sometimes relying more heavily on the former than the latter. The propositions that take business sciences as their main support, generally advocate the introduction of organizational changes. This organizational tendency, although mentioned and discussed using different terminologies, is particularly attributed to Ikujiro Nonaka who postulated it in writings like “The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation” (Nonaka & Takeuchi, 1995), “The Concept of “ba”: Building a Foundation for Knowledge Creation” (Nonaka & Noboru, 1998), and “A Theory of Organizational Knowledge Creation: Understanding the Dynamic Process of Creating Knowledge” (Nonaka, Toyama, & Byosière, 2001)

To a large extent, the appeal of Nonaka’s proposals’ lies in his implicit promise of explicating, or at least transferring, the notorious success of some Japanese organizations in knowledge

creation. It could be thought that the promise has been fulfilled, judging by some successes reached by certain western organizations that “copied” management methods from their rivals or equivalent Japanese organizations. Nonetheless, it cannot be said that all of that success is due to Nonaka’s revelations, or that it solely refers to knowledge creation. A good part of it comes from methods like *total quality*, *six sigma*, and other *best practices*, and it is not clear how much corresponds to knowledge generation. In any case, KM in general has not shown substantial advances in this sense.

According to Nonaka (1991, 1994; 2001) if we cannot convert tacit knowledge into explicit knowledge, the only way of transferring it is by the process of socialization and Zucker (2002) argues that explicitation is the only way of commercializing such knowledge. However, we already mentioned an alternative: turn it into a tangible asset that can be commoditized and commercialized. For example, we can develop a video course on painting that presents a painter moving his brush in a didactic fashion and sell it. This way we are converting the tacit knowledge of the painter (with more or less fidelity) into a tangible asset that can be reproduced and sold. For a very low cost, we can make as many copies of this course as needed by the market and thus mass transfer this tacit knowledge to as many people as we want. Explicitating tacit knowledge is the most efficient process to transfer it, but if that is not feasible from a business standpoint, we can tangibilize it and therefore still exploit it, sell it, and make it useful for others.

An industry where innovation and knowledge creation is critical is the pharmaceutical industry. They have invested heavily in improving these organizational processes. However, their innovation costs are still one of the key components of their cost structure and are the main reason for the high prices of their products. However, as Seeley (2004) says:

Drug companies need money to develop innovative products. Patients need innovative products whether they can pay for them or not. And a drug pricing policy that forgets either of these vital points is likely to be a disaster.

Therefore we cannot disqualify this cost justification as simple evil or capitalist greed (Reisman, 1980). Unfortunately, there are not many signs indicating that organizational changes have managed to substantially reduce the cost or time of innovation.

KM and Artificial Intelligence

KM contemplated using Artificial Intelligence (AI) as a way to apply IT to its field. According to Gärdenfors (1999), the first stages of cognitive science (in the 1940s and 1950s) were driven by the analogy of the brain functioning like a computer and the mechanical processing of symbols was viewed as artificial intelligence. Criticism of this symbol manipulation paradigm could be grouped in two families: (a) connectionism and (b) the theories of embodied and situated cognition. Connectionism modeled thinking as associations built inside artificial neural networks. Some of these models were tightly related to developments in the neurosciences while others, like concept formation, tended to be more general models of cognitive. Supported by Marr (1990) and using our terminology, we argue that connectionism stayed at the semantic and syntactic-semantic phases.

In the '70s and early '80s, AI focused mainly on explicating the knowledge implicit in the supplied information by applying computerized inference rules or “automatic test of theorems.” These rules helped to solve one of KM concerns: making explicit what was implicit. In the factset of “A is B” and “B is C,” it is implicit that “A is C,” and AI can make it explicit. But this explication remained mostly in the semantic dimension. Even if “A is B” and “B is C” has been pragmatically tested, “A is C” still requires a pragmatic test. However, that pragmatic test cannot be accomplished by the “automatic test of theorems” done by semantic AI.

Gärdenfors (1999) also argued that the theories of embodied and situated cognition saw cognition “as taking place not only in the brain but in interaction with the body and the surrounding world. In line with this, modern studies of robotics are based on so called reactive systems, the actions of which depend directly on the world instead of a symbolic model of it”. But what we can really call Pragmatic AI started with combining the use of Expert Systems, the digitalization of analogous information, and pattern recognition (where “A is B” is not only a logical proposition or a rule, but also the result of comparison of digitalized data from the real world). Later in this article we will see that Pragmatic AI can reduce the KM bottleneck as long as the Expert System grow in inference rules, the digitalization systems increase in speed, range, and precision, and the pattern databases grow in number, diversity and accessibility.

Information Technology As a Solution

Information Technology seems to be the only option available to advance *pragmatic minimization* further than what traditional pedagogy and KM has been able to do. In fact, developments like virtual reality² simulations are becoming the new test tubes for knowledge. It started with flight simulators for training pilots and has extended to training surgeons (Brown, 2006), simulating chemical reactions (Illman, 1994), and creating biochemical tests to develop medicines (Norris, 2003). Virtual reality is a way to overcome the current limits of *pragmatic minimization* by electronically simulating reality to test the ideas.

In comparison with the traditional, semantic inclination of artificial intelligence, we can speak of a more pragmatic artificial intelligence, oriented toward praxis and represented by developments in business intelligence systems applied to the Internet (Cody et al., 2002). Companies like Yahoo and Google provide examples of this in their attempts to develop Internet Intelligent Systems (Jhingran, Mattos, & Pirahesh, 2002).

Software that synthesizes music with the quality, quantity, and velocity of a Mozart are sold in stores or given for free on the Internet. Nowadays, the exceptionality of Mozart is reduced to the fact that he was exceptional from his time until the appearance of modern synthesizers. A computer can memorize a composition by “hearing” it just once, ostensibly as well as or even better than Mozart. It can abstract Mozart’s syntax, (rhythm, harmony, and instrumentation

² The expression “virtual reality” to name show-biz products or consumer electronics has distorted its original meaning. Indeed, before becoming a buzz-phrase, the use of the adjective “virtual” with the noun “reality” implied all that had the virtues and potentials of reality for a limited group of effects and purposes, for instance, for audiovisual purposes. However, today, instead of this, it implies an alternate and even opposed reality. Here we use it with the original meaning of the expression.

patterns); and, if the software identifies them with some preset conditions, it can detect formal – syntactic– imperfections and suggest how to correct them. It can generate new syntax with or without human feedback, and it can play it back using the sounds of the largest imaginable orchestra. It can perform the composition with strict fidelity or with variations. If given information on the potential tastes of a human audience, it can easily adapt to it and make innumerable semantic relations (at mind boggling speeds) with other scores, arrangements, and previously acclaimed performances. Software can find rhythmic, harmonic, melodic or instrumental similarities, compose “bridges,” references or musical combinations between them, change their rhythms and instruments and infer compositional projections. It can do all of these tasks with an additional advantage: if the human consumers do not like the result, they can simply erase them without inflicting a cruel disappointment on another human being. In summary, high quality computerized music compositions can be made in quantities and speeds which are several orders of magnitude higher than the capacity of any audience to enjoy and remember or to hate and forget them. The problem we face is not about generating potential innovations but about the ability to test those innovations.

Many argue that computers cannot test those innovations; that they can generate but not pragmatically process the syntactic-semantic innovations. From an ethical and economical point of view, it is unthinkable that we could give computers the ability to test the formulae they generated by combining energy and material supplies, using industrial processes and market tests as if they were musical notes. However, computers can process the innovations to the extent that they deepen the *pragmatic minimization*.

Now, leveraging the knowledge generated by all these disciplines and using the above conceptual framework, we propose the concepts of “simulated praxis” and “a more pragmatic artificial intelligence” as new avenues to optimally solve the problem of *pragmatic minimization*.

Simulated Praxis and its Limitations

Just like the combinatory speed of computers can be used to generate numerous potential innovations, their processing speed can also be used to simulate complex testing environments that have increased realism and therefore deepen the *pragmatic minimization*. Computers can be used to boost what the scientific community refers to as “mental experiments” and what we here call *pragmatic minimization*. Virtual reality is one way in which IT can be used to run those mental experiments. Flight simulators have been used widely to help pilots practice before taking a real plane into the air. MBA programs use business simulations (that go from the simple beer game to complex enterprise-wide simulation) to teach their students the complexities and nuances of the trade. Biochemists use in-silico experiments to accelerate the biological processes, try many more options, and be more humane.

However, computer simulations have their limitations in terms of the reality test. These limitations are given by the high possibility that one or more of the simulated components may differ from their real counterpart. An example of this problem is presented in the classical simulation of a stone that falls from a mast (for an in depth discussion see Galilei, 1632). This example highlights the ease with which a mental experiment or simulation could make a mistake

that a real life test would not make. Furthermore, in most cases the possibility of making such a mistake is less obvious, more subtle, and far more complex.

Nonetheless, it is generally more economical to refine the simulations than to test a whole array of possibilities with real matter and energy. Indeed, if we do not pursue this option, we would have to accept that whatever speed we currently have in advancing our body of knowledge will be the maximum speed ever; that knowledge will continue to advance at a human pace; that exceptional advances are only the result of a fortunate combination of people, circumstances, and opportunities. And if this were so, we would not be making good use of the increasing combinatory power of computer science to help solve the knowledge management bottleneck.

One avenue to overcome the limitations of computer simulations is, as usual, collaboration. Learning Sciences (Abrahamson, Berland, Shapiro, Unterman, & Wilensky, 2004; Laurillard, 1992), Life Sciences (Bubak et al., 2009), and Climate Science (Barberousse, Galinon, & Vorms, 2011) are now using collaborative computer simulations. This collaborative aspect is discussed in more detail in the section “Using IT for Collective Cognition” of this paper.

Furthermore, simulated praxis is a way of using a virtual simulation that is as real as possible to efficiently train not only people but also expert systems. Virtual reality provides artificial intelligence with its corresponding artificial reality and therefore minimizes the costly and slow interaction with the energetic-material world.

A More Pragmatic Artificial Intelligence

A more pragmatic AI is one that moves away from symbol manipulation, logical inference applications and automatic test of theorems to intelligent systems aimed to make sense of the overwhelmingly large, real live data that is being generated and stored in many databases inside organizations and across the Internet. Besides inferring that “ $A=C$ ” from the logical propositions “ $A=B$ ” and “ $B=C$ ”, a Pragmatic expert system can infer with some probability that two independently digitalized patterns of voices (A and C) belong to the same person if it can match both to the same voice record (B) previously stored in a voice pattern database. Moreover, the expert system can use this match as an initial filter to look for more stored patterns of that same person in other databases and confirm the identity match more efficiently than non AI systems.

Another common example of a pragmatic expert system is that used in automated credit systems. These systems need to authorize or reject credit request in a matter of seconds. They do that by applying many general and special credit rules and validations. But they also check if the transaction follows a pattern of authenticity given by prior transactions or of suspiciousness given a set of fraudulent ones. These systems are continuously evolving and interacting in real time with real data and making decisions that affect real lives. These systems made today’s electronic commerce and electronic credit systems viable by eliminating the bottleneck present at the credit and authenticity check.

In addition, the growing power and penetration of the Internet makes massive interaction with users viable and ethical. These users provide enough information (in terms of quantity and

variety) to substitute the artificial generation with a more current and “live” erratic information. Furthermore, Internet users, though not on purpose and with no special effort, are live and real-time selectors of the information that circulates on the Internet. Their preferences, interests, curiosities, approvals, disapprovals, and such, comprise a massive survey or statistic that may be considered a live census. They are the most agile and massive link with reality any intelligent system may have at its disposal. However, such an intelligent system must have the ability to interact with that huge flow of information and that discards the intelligence of a single human being acting alone. Artificial extensions of human intelligence are required given the limitations that human have in respect to processing massive amounts of information.

These types of intelligent systems need to be able to rapidly process the manifestations of millions of Internet users. For example, intelligence is needed to compare in relative –not absolute– values the popularity of a young music band measured in “clicks” on their webpage with the number of academic publications quoting certain authors or texts. A whole new high intelligence and sensitivity system is required to detect nuances, for instance, a sudden change in the manifestation of interest for certain information and its possible relationship with other variations or events reflected on the Internet.

This shifts the use of artificial intelligence from the syntactic and semantic phases to the phase of *pragmatic minimization*. Minimization would be accomplished by the ability to detect at an early stage and intelligently discriminate the variations in the reaction of the mass of users to the information circulating over the Internet. This minimization process is already being applied by Google in their PageRank algorithm and is being implemented more widely in many data mining applications.

Certain modern computer systems, such as those included under the denomination of Data Mining (Hand, Mannila, & Smyth, 2001), Business Intelligence Systems, Market Intelligence systems (Cody et al., 2002), and many others are oriented to the processing of indirect massive information, that is, information obtained not as “input” of a specific system, but as a summary of the “inputs” and even of the “outputs” of a very large variety of systems. The data they process does not necessarily reside in a single database but may be distributed in several databases or even inside a big Data Warehouse (Pyle, 2003). The search level of these systems is similar to that of Internet search engines like Yahoo and Google with a capacity to process the successive answers in a more automatic and systematic manner. They do not require as much interaction as the human user does in the process of reducing or widening the range of potential answers for selecting the most relevant answers. They use pattern recognition, statistical analysis, polls that interpret clicks as votes, and other techniques, some of them with a high complexity level.

Recent developments, such as Web based experiments (<http://www.wexlist.net/>), online research methods, Internet Science (<http://www.iscience.eu/>) and others, reckon the Internet potential of showing how certain cultures respond to stimuli like online questionnaires, ads, or the launching of new products or ideas. However, there is a need for cautiousness while these developments continue:

Testing large numbers of subjects takes large amounts of time and money, so we often avoid it. But if you can test 1000 subjects a week via the internet, suddenly a whole world of experiments opens up. That is, I believe, the great promise of web-based experiments. On the other hand, many scientists have reservations about the reliability of web-based experiments. How do you know, they ask, that your volunteers are really paying attention? How do you know they aren't pressing buttons randomly or even purposefully giving the wrong answers? I don't know. But that is also true for subjects tested in a brick-and-mortar lab. In fact, while my internet participants are volunteers that can quit whenever they want to, subjects who come to the lab are usually paid or are fulfilling a requirement for a psychology course. Who is likely to be more motivated? (Hartshorne, 2007)

Distributed Cognition Supported by Information Technology as a Solution

The concepts of distributed knowledge and distributed cognition have helped the development of solutions to the KM bottleneck (cf Heylighen, 2003; Malhotra & Majchrzak, 2004; Moreland, 1999). This has been done through concepts like "extended mind" (A. Clark & Chalmers, 1998) and "collective intelligence" (Heylighen, 2003; Lévy, 1997; Weick & Roberts, 1993) as well as ideas like "situatedness", the extension of cognitive processes into the physical environment (A. Clark, 1999; E. Hutchins, 1995; Steels & Brooks, 1995)–. They share assumptions like: a) groups of cognitive individuals self-organize to form a new system adapted to its environment (Heylighen, 2003); b) the system is or at least can be modeled as a connectionist network (Heylighen, 2003; Marr, 1990; McLeod, Plunkett, & Rolls, 1998); c) the system uses external media for propagating information internally (Heylighen, 1999; Susi & Ziemke, 2001); d) novel knowledge is "emergent" (Heylighen, 2003) and comes from recurrent, non-linear interactions between individuals.

An Analogy of Biological and Artificial Data Processing

In the field of IT, a database is defined as a structured collection of records stored in a computer system that can be updated, queried, and processed using software algorithms (Knuth, 1969). These programs are usually grouped into two categories: database management systems (DBMS) and data processing systems. The former directly interacts with the database and the latter interacts with the former, using them to make calculations, summarizations, and classifications among many other tasks.

We can establish an analogy between these computer systems and bio-cognitive systems. For example, knowledge is stored in a neural database that we call memory, and it is then processed by the "mind" or thought (neural capacity of processing information) as it calculates, summarizes and classifies. In a similar fashion, we can establish an analogy between computer systems and social systems. Cognitive informatics is an example of recent multidisciplinary studies that follow this analogy. It "acts as the bridge between natural science and information science. Specifically, it investigates the potential applications of information processing and natural intelligence to science and engineering disciplines" (Yingxu Wang, 2007; Yingxu Wang, 2011).

Distributed Database and Distributed Knowledge

Sociologists say that individuals share a similar culture when two individuals (A and B) that belong to the same social group share, for the most part, not only the information captured by each member, but also the way that they capture, communicate, structure, and process it. When individual A knows datum Y but not datum Z, and individual B knows Z but not Y, there exists the bio-social analogy to a distributed database. Such social group knows both, datum Y and Z. This knowledge is socially distributed and is what cognition and management sciences call distributed knowledge (Tsoukas, 1996).

Distributed Processing and Distributed Cognition

In the field of IT, distributed processing or distributed computing is defined as the simultaneous execution of different parts of a single process or program by more than one processing unit over a common database (Attiya & Welch, 2004). The data is stored across several storage devices that are controlled by separate computers (Ozsu & Valduriez, 1999), and the computers may be physically collocated or dispersed across different geographical locations as long as they stay interconnected.

In sociology, the corresponding processing unit is the individual (Giere & Moffatt, 2003; Edwin Hutchins, 1995). Distributed cognition may occur through the interactions of individual members in a conversation, discussion, brainstorming session, etc. While the comparison of human groups and databases cannot fully analogize the concept of distributed cognition, it is useful as an illustration, particularly when the definitions and delimitations between the concepts of *distributed knowledge* and *distributed cognition* are not particularly clear; nor are the limits in complementarities and interaction between biological and artificial brains (Hollan, Hutchins, & Kirsh, 2002). Nonetheless, we argue that *distributed knowledge* is the case where A and B know different facts and *distributed cognition* is where A and B need each other in order to process, summarize, conclude, or synthesize, in order to process datum Y and Z. We will attempt to demonstrate this distinction as an important element in solving the KM bottleneck.

All these concepts, including those of KM and distributed cognition, share a notion of collective knowledge or cognition. Collective cognition transcends individual cognition and proposes a different subject of cognition: a subject of cognition that “knows” more than what a single individual can know but whose cognitive outcome can be understood by an individual who could also benefit from it.

The solutions that resort to these concepts find in distributed cognition a framework for the knowledge that is created and transferred in organizations, a framework that includes organizations as an example of distributed cognition. These provide a new light to the KM bottleneck problem; however, while this new light is predominantly theoretical, it facilitates the application of practical advances in distributed cognition to the advancement of KM. Furthermore, there is already one practical contribution provided by distributed cognition: it encourages the search for solutions that are not limited by the cognitive capacity of an individual

but exploits the collective cognitive capacity that can collect and process much larger “mental content.”

Using IT for Collective Cognition

The formal analogy between the unit for distributed processing and the unit for distributed cognition (between a machine and a human being) does not imply any practical correspondence between a machine and a human being. In fact, it could be that a network of machines processes information that supports the knowledge of a single human being or that a single machine supports the knowledge of several human beings. Nonetheless, the notion of a Personal Computer (PC) and its connection through the Internet makes the practical correspondence between a unit of artificial processing and a unit of cognitive processing more viable. Even if by definition or any other reason, we assume that at least one critical part of cognition can only be performed by a human being, there is always another part which could be qualified as rote or mechanical which is better delegated to computers (for example the execution of numerous calculations or the search of a given sequence of symbols inside a much larger sequence). There are clear reasons and observations that lead us to believe that this practical correspondence makes the practice of distributed cognition more viable.

Wikipedia is just one among a huge proliferation of combinations of IT and distributed cognition, often called collective cognition (Cress & Kimmerle 2008). Every day we find new collaborative forms of knowledge reprocessing that thanks to the Internet have worldwide participation. These include recompilation, digitalization, reclassification, indexing, global access democratization, and –even though still incipient– collective generation of new knowledge.

reCaptcha is an example of IT and distributed cognition supported recompilation and digitalization. This project leverages ‘Captcha’ technology –used to prevent SPAM and BOT abuse– to help fix OCR failure problems in global digitalization projects like the Internet Archive. Other current examples of collaborative initiatives operating through the Web are digg.com, helium.com, ning.com, del.icio.us, imeem.com, and bluedot.us.

Recently the phrase “Semantic Internet” designates the stage of the network where the majority of its users is writing or producing content instead of just reading or consuming it. Sites like YouTube and social networks like Twitter or Facebook are popular supports for this popular knowledge distribution and collective cognition. And being popular (massive, barely selective, etc.) is their only difference from more exclusive professional networks –such as LinkedIn and Academia.edu– or the more traditional academic and scientific knowledge and cognition networks.

The proliferation of multiple forms of collective cognition is not new; there is a historical antecedent based on paper. Paper was the support for a large variety of compilations, recompilations, compendiums, renovations, anthologies, summarizations, and even creation of knowledge. Plato’s dialogues are a classical example and from the beginning of the modern age the collective project of the encyclopaedia (initiated during the French Enlightenment by Diderot

and D’Alambert) is another. Furthermore, the various periodic publications –like newspapers and magazines– have a content that is a mosaic of collective creation by editors, writers, illustrators, reporters, advertisers, collaborators, and even readers with their letters to the editors.

Distributed knowledge (and also distributed information) is not sufficient to accomplish distributed cognition. However, the more personal and interconnected computers become –as it increasingly occurs over the Internet– the easier it will be for information and knowledge to flow among individuals therefore facilitating the necessary precursor for distributed cognition. Of course, while a human individual is an obvious “knowledge unit” in a natural or social context, the PC is no longer its technological equivalent. As IT advances, the knowledge units are more complex and fuzzy. Is it a database, a network, or the whole Internet? But this is not important. The important concept here is that the collaboration or interactions of distinct and distributed supports of knowledge (natural or artificial) create the distributed cognition. When a child uses the Internet to do his/her homework, he/she usually has a window to Wikipedia or a similar site, another with an instant messaging application or social network that allows communication with his peers, probably another one with a spreadsheet, a word processor, or a presentation program, and finally one with either a game or a video clip. At this stage we cannot deny that a child learns more and faster with these information tools than without them.

IT based networks, especially the Internet and more particularly the Semantic Internet is the new support mechanism for distributed knowledge as well as a powerful accelerator for distributed cognition (cf. Boland, Tenkasi, & Te’eni, 1994; Heintz & Taraborelli, 2003). It seems now is the time for generating all possible combinations of IT and distributed cognition. Many such forms are still developing and can be questionable (T. Davenport, 2008). However, all this will probably end in the selection of a few forms that will become standard parts of our culture. This selection will be made during the pragmatic test of these technologies where some will be discarded and some others will be embraced by the masses of Internet users. The growing R&D investments on powerful computers and communication systems increase and complement the expectations that systems such as those mentioned earlier and, in general, artificial intelligent systems focused on *pragmatic minimization* may affirm the large distributed cognition systems and widen the KM bottleneck.

Conclusions

Our review of the literature has shown that several disciplines have looked into the phenomenon of KM and tried to find ways of improving it. However, most of these efforts have not been very successful. In general, each discipline has worked independently of the other and arrived at the same conclusion: knowledge can be tacit or explicit. Because tacit knowledge is very difficult to transfer, we need to make it as explicit as possible. Moreover, we have shown yet another option: tangibilizing tacit knowledge.

Another problem that KM faces is the creation of useful knowledge that is syntactically correct, semantically selected, and pragmatically tested information. We are already able to generate very large amounts of syntactically correct and semantically selected information, but only a very small fraction of it is useful and is hidden beneath a much larger pile of useless information. The

next step, pragmatically testing the information, is where the current KM bottleneck lies. In this paper, we defined pragmatic minimization as the process of minimizing the cost of acquiring knowledge by testing newly generated information with real problems that require solutions. Moreover, using the analogies developed at the beginning of the article as well as the proposed intelligent systems, this paper argued that IT –particularly the Internet– represents the new support mechanism for distributed knowledge and distributed cognition, which provides *pragmatic minimization* and, in turn, brings a solution to the KM bottleneck.

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About the Authors

Carlos Ferran earned a Doctor in Business Administration from Boston University. He is an assistant professor of Accounting and Management Information Systems at Governors State University. He has taught in Argentina, China, Colombia, Mexico, United States, and Venezuela. He started his professional career developing accounting applications for the Apple II and his last industry job before entering academia was as a CIO at a major financial institution in Venezuela. Dr Ferran is the President for the Latin American and Caribbean Association for Information Systems (LACAIS) and the editor-in-chief of RELCASI the first and only academic MIS journal written in Spanish.

Ricardo Salim earned his doctoral degree from Universidad Autónoma de Barcelona. For over 30 years he has worked as an entrepreneur (in Venezuela, Ecuador, Spain, USA and other countries) starting companies and personally developing IT products and services for the retail, service, and banking industries. He is the CEO of Software de Venezuela and the Chief Database Architect of Cautus Networks, Corp.

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