Agent-Oriented Knowledge Management

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Abstract

Recent approaches to management acknowledge the central role of organizational knowledge evolution in a firm's ability to obtain sustained competitive advantage. A notion similar to knowledge evolution has been studied extensively in the area of Belief Revision. In this area, formal models have been developed for analyzing the process by which an agent changes her beliefs in the light of new information. In this article we examine the use of techniques and results from Belief Revision to formally describe and analyze organizational knowledge evolution. Moreover, we will argue that a main routine which leads to a firm's long term performance, is the one that supports the extraction and transformation of the maximum articulable knowledge into articulated and codified knowledge, technical or organizational, through systematic and intensive efforts.

Keywords: Knowledge Evolution, Belief Revision.

1 Introduction

The issue of sustained competitive advantage has been widely discussed in the management literature. Recent approaches have argued for a knowledge-based view of the firm, where much of the firm's success to obtain sustained competitive advantage is attributed to its skills in managing effectively organizational knowledge, and more precisely to its ability to keep this knowledge up-to-date via a process of continuous knowledge evolution.

The notion of knowledge evolution also appears in *Belief Revision*, an area in the intersection of Formal Philosophy and Computer Science. The concept at focus in this area is the process by which an agent changes her beliefs in the light of new information. Formal models have

been developed for describing this process, and a number of results have been established shedding light on the different aspects of belief revision and the relationships between them.

In this paper we argue for the use of techniques from Belief Revision in studying organizational knowledge evolution. We focus on the fragment of an organization's knowledge known as codified knowledge and we show how the evolution of this knowledge can be formally captured within the framework developed by Alchourron, Gardenfors, and Makinson (1985) for Belief Revision. Having expressed (codified) organizational knowledge evolution as a belief revision process, we then examine the possibilities that open up in using formal tools from Belief Revision to study some well-known phenomena in Knowledge Management.

The article is structured as follows. In the following section we discuss the difference between data, information, and knowledge, as well as the structure that knowledge has in an organization. In particular, four layers of knowledge are identified, differing in the content of the knowledge they contain, which ranges from "crude knowledge" (first layer), to "knowledge about how to manage knowledge" (fourth layer). At an orthogonal direction, there exists a second categorization of knowledge consisting of three categories – tacit, articulated, and codified knowledge – all of which are discussed in section 3. In section 4 we consider the knowledge-based view of a firm, while in section 5 we examine organizational learning and the way it contributes to a sustained competitive advantage. Section 6 reviews the main ideas and results from Belief Revision. In section 7, we show how knowledge evolution can be encoded within the formal framework developed for Belief Revision, and finally in section 8 we make some concluding remarks.

2 Knowledge in the Business World

In today's world of information technology and the Internet, finding data is easy and cheap. The same is true for information. Is this enough however? One can easily find the answer by observing that the explosive growth in available information in the last few years was accompanied by an acknowledgement of the significance of knowledge as a means of adding value to all the available information. Therefore, it would be misleading to equate information with knowledge.

More generally, one needs to distinguish between data, information, and knowledge. "Data are what come directly from sensors or other sources, reporting on the measured level of some variable. Information is structured data that is placed in a context (Bohn, 1994)". Hence information is generated only after an appropriate processing of the data. For example, having access only to the prices of the stocks in the stock market exchange at a given day, is not very useful in itself. Once however these values are viewed *in context*, for example, once the companies associated to each stock are known, and/or once the rate of change in relation with the previous session of the stock market is brought in the picture, the useless data become valuable information. Loosely speaking, data can be viewed as "raw material" that needs further processing before it can acquire meaning and added value.

Knowledge in turn is not just the accumulation of information; instead it is a complex structure whose individual components are inter-related in many different ways with varying degrees of strength. New information can be elevated to knowledge, but it can also pass unnoticed.

Knowledge is context specific, humanistic and related to action. Moreover, knowledge is to a large extent subjective; for that reason the term "belief" might be more appropriate. According to Nonaka et al (2000), knowledge is "a dynamic process of justifying personal belief towards the truth" (p. 7). For the above reasons, new information can be either accepted or rejected to the existing body of knowledge, depending on whether it is relevant or not to the context, or whether it is in agreement or against the accepted beliefs: "information is acquired by being told, whereas knowledge can be acquired by thinking" (Ancori et al, 2000, p. 262). Consequently knowledge enables the inferring of predictions, causal associations, and decisions, based on the existing beliefs and theories.

We mentioned above that knowledge has structure. In particular, knowledge is structured into four different but interrelated layers. The first layer, which also happens to be the most elementary, is crude knowledge. At this layer, evidence is accumulated, which at some point in the future will be elevated to the next layer of knowledge, where the agent is aware of how to use the facts. This layer is related to the agent's ability of selection, processing and integration of crude knowledge to the previous stock of accumulated knowledge (for example, consider the information "company X will have a growth in revenue in relation with last year". This information belongs to the first layer, but after some processing it will be elevated to the next layer where it will lead to decision-making like "the value of company's X stocks will increase", and eventually it will lead to the action "I will buy stocks from company X").

The third layer relates to the exchanges and interactions between agents in terms of knowledge. Hence it relates to knowledge about how to transmit knowledge. Finally, the forth layer, which is also the most complex, relates to knowledge about how to manage knowledge. It includes, "knowledge about when, where, and how to find crude knowledge, how to use knowledge and how to communicate knowledge" (Ancori et al 2000). It can be compared to a brain, which processes stimuli and issues orders that direct the other parts of the body.

Hence, knowledge is a structure that become increasingly more complex with time, generating more connections and relationships between the factors related to a particular concept, thus enabling the derivation of statements/propositions, predictions and judgments, leading eventually to decision making. This is in fact the essential difference between knowledge on one hand and information and data on the other. It generated value through decision making. The greater the knowledge of a domain, the better the decision making related to that domain.

3 Categorization of Knowledge

There are different kinds of knowledge depending on (a) the consciousness of this knowledge by the agent (b) the degree to which the agent can describe explicitly this knowledge:

Codified knowledge (Know-How and Know-Why):
The agent is fully conscious of the knowledge she possesses and she can also describe her knowledge to other (verbally or in writing) with accuracy and clarity (for example, mathematical samples, manuals, blueprints, etc), and total consciousness of the relationships between cause and effect. Hence, in this case there is no *causal ambiguity* (Lippman & Rumelt, 1982) since each process and its corresponding outcome can be controlled and

analyzed. The agent knows not only how to perform a task (know-how), but also the reasons she is performing the task the way she does (know-why).

Articulated knowledge (Know-How and Know-Why):
The agent is again conscious of the possession of knowledge, but to a lesser degree than at the previous category, and she can express this knowledge mostly verbally with some clarify, having made however considerable effort and possibly having used more that one ways (for example, speech, body movements, analogies, drawings, etc). The agent in this cases seems to possess a mental model, which however she can not describe with clarity since she can never be certain that she has included all the relevant parameters, their correlations, and the range of permissible values. As a result there is some degree of causal ambiguity between the process and the outcome.

Tacit knowledge (Know-How):
The agent is conscious only at a small degree about her knowledge, and moreover it is very difficult for her to express this knowledge in any way. The most common way of describing this knowledge is by using it (via illustration). While the agent has the know-how for performing a task, she can neither describe how she does it or why she does it that way (know-why). As a result, there is a large degree of causal ambiguity between the process and the outcome.

	Codified Knowledge	Articulated Knowledge	Tacit Knowledge
Know-How	2	2	2
Know-Why	2	1	0

* 0-2 is a scale on know-how/know-why, where 0 stands for "no knowledge" and 2 for "a lot of knowledge"

Table 1

Table 1 shows the relationship of Know-How & Know-Why for each of the three categories. For example, Know-How is related to codified knowledge, tacit knowledge and to articulated knowledge, while Know-Why is related mainly to codified knowledge to a lesser extent to articulated knowledge, while it is missing altogether from tacit knowledge. The most controversial category is articulated knowledge. One can not claim that is has a rigorous scientific foundation, but at the same time it is not quite a "personal asset" of the one who possesses it. Moreover it shows that at least part of tacit knowledge can be transformed into codified knowledge, after having gone through the intermediate (hybrid) stage of articulated knowledge (see Figure 1).

In describing the transformation process of tacit knowledge to be codified, Cowan & Foray (1997) distinguish between three stages. In the first stage, tacit knowledge takes the form of mental models of a task, coupled with a primitive vocabulary in which these models are expressed. Gradually a stable language is developed, which provides the foundations for the exchange of ideas between members of a group, eventually leading to learning (Brown & Duguid, 1991; Tsoukas, 1996). This constitutes the second stage. At the third stage both the language and the models are mature enough for the knowledge to be codified into

propositions. These three phases are comparable with the structuring of knowledge into layers described earlier, as proposed by Ancori et al. In particular, the creation of the models correspond to the layer "how-to-manage-knowledge", the generation of the language corresponds to the layer "how-to-communicate-and-transmit-knowledge" while propositions correspond to the layer "how-to-use-knowledge".
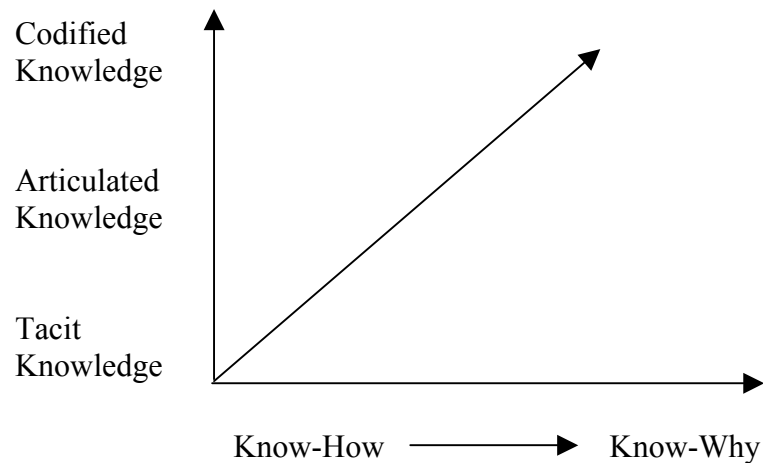

Figure 1

The question that rises naturally is whether tacit knowledge is at all transformable to articulated and codified, and if so, how much of it can be transformed.

Hakanson (2001) distinguishes between three categories of tacit knowledge:

a) *Unarticulated knowledge*. This category includes skills which are mostly acquired through experience (like swimming or riding a bicycle). In the world of economics, the most important form of such tacit knowledge is creativity. In Science for example, there is a difference between discovery and demonstration. A demonstration is the outcome of some scientific research which can be articulated and codified. A discovery on the other hand requires creativity which can only be taught through a master-apprentice relationship.

b) *Articulable knowledge*. This category includes the kinds of tacit knowledge that is at least potentially articulable. The transmission of knowledge in this category can be achieved through observation, demonstration, reverse engineering, and the existence of communities of practice that may extend beyond the boundaries of the organization possessing the knowledge.

c) *Internalized tacit knowledge*. This category includes the set of rules or routines which have been internalized by the organization over time, when the theoretical insight that led to them have been long forgotten.

The above shows that there is a small portion of tacit knowledge that cannot be properly articulated and codified.

It should be noted that the part of tacit knowledge which can not be articulated, is the only kind of knowledge that Polyani considered and called "tacit". Tacit knowledge according to Polyani, is related directly to expertise acquired through action. Therefore is can not be expressed in any way other than through action. Although, for the sake of consistency, in the rest of this paper we shall continue to use the term "tacit knowledge" for all three categories of knowledge mentioned above, it should nevertheless be noted that Polyani's notion of "tacit knowledge" relates only to the first category.

In summary, we have seen that knowledge is much more than just information. It has structure gradually evolving, and it can be classified into codified knowledge, articulated knowledge and tacit knowledge. Tacit knowledge, in contrast to codified knowledge, constitutes internalized knowledge which is not observable, cannot be externalized, and therefore it cannot be easily transmitted. On the other hand, a good portion of tact knowledge can be converted, through appropriate processing, to articulated and then codified knowledge. The transformation of tacit knowledge to be codified is very important for an organization, since codified knowledge is the only kind that can be easily manipulated, transmitted, exploited, and become an organizational rather than a personal asset.

4 Knowledge – Based View of the Firm

What makes certain organizations display a sustained competitive advantage? In an effort to answer this question, many recent approaches to management reconsider the notion of a "firm". Questions like, what is a firm, what are its components, which of these components can account for the long-term differences in performance that are in contradiction with the "suggestions" of the neoclassical theory, are just some of the issues that have recently attracted a lot of attention.

An important result of this research is a gradual appreciation of the impact that resource accumulation decisions can have on firm performance levels. The importance of firm-specific capabilities and resources was demonstrated by Cool and Schendel (1988) who found that firms in the same environmental settings, pursuing the same strategies, had widely varying levels of performance. Lawless, Bergh, and Wilsted (1989) argued that these performance differences resulted from differences in organizational capabilities. In a sample of manufacturing firms, they found significant differences in capabilities and resources across firms pursuing the same strategies, and they also found a significant relationship between these capabilities and firm performance.

One way to explore the performance implications of firm-specific capabilities is through the resource-based view of the firm (Barney, 1991; Wernerfelt, 1984). This perspective is rooted in the seminal work of Penrose (1959), who suggested that firms could be viewed as collections of productive resources. In examining the implications of this perspective, the most important observation to emerge is a recognition that firms will enjoy a competitive advantage only if their resources and capabilities are unique. In an important contribution to this research dialogue, Dierickx and Cool (1989) emphasized that competitive advantage is most likely to result from the development of unique asset stocks that are built up through an ongoing process of critical resource accumulation.

One kind of unique asset stocks especially contributing to the sustainable competitive advantage of firms follows from the creation, ownership, protection and use of difficult-to-imitate knowledge assets (Teece, 2000). Such assets include tacit and codified know-how, both technical and organizational. However, while explicit knowledge can escape the organizational boundaries and be copied, tacit knowledge is very difficult to be re-produced by competitors.

The notion of sustainable competitive advantage however places the question at a *dynamic* rather than a *static* basis. In other words, for the overall success of an organization, its well being at a certain point in time is not enough; whatever skills the organization possesses need to be maintained and developed over time (Teece et al, 1997). Consequently, organizations with a sustainable competitive advantage are the once with dynamic capabilities. Given that knowledge (both tacit and explicit) is one of the most important aspects of competitive advantage, we can then conclude that the organizations with a sustainable competitive advantage are the ones which have the capability of constant evolution and exploitation of their knowledge (in this process of evolution, tacit and explicit knowledge go hand-by-hand). This conclusion in turn leads us to a knowledge-based view of the firm, which constitutes a dynamic approach, as opposed to the resource-based view of the firm, which is static. According to the knowledge-based view, the capability to create and utilize knowledge is the most important source of a firm's sustainable competitive advantage. Consequently, a firm has a competitive advantage when it can create and maintain knowledge more effectively than its competitors (Nonaka et al, 2000).

5 Knowledge, Learning and Sustained Competitive Advantage

The constant evolution of knowledge leads to learning, which by nature is a dynamic process. Hence the above firms also display a greater learning capability than the rest. As Prusak said "If organizations can manage the learning process better – the most effective ways to pass on the often tacit understandings that form the basis of how they operate – they clearly can become more efficient. Developing these learning strategies has subsequently become an important knowledge management theme" (Prusak, 2001, p. 1004).

Hence the question posed in the beginning of this section can be rephrased as follows: what makes certain firms better in learning that others? According to Nonaka et al (2000, 1995), organizational knowledge is created by the interaction between tacit knowledge and codified knowledge. Moreover, the extension or reduction of organizational knowledge depends on the marginal propensity to knowledge conversion, which shows by how many units explicit knowledge increases when tacit knowledge increases marginally by one unit. If this rate exceeds 1, we have extension of knowledge. If this rate is below 1, we have reduction (Nonaka et al, 2000).

The next question that arises naturally is, what does marginal propensity of knowledge conversion depend on?

The answer to this question lies in the fact that some firms have the ability to convert personal knowledge into collective (organizational) knowledge, but more importantly, the ability to _maximize_ the degree of articulable tacit knowledge that becomes codified organizational

knowledge. The transformation of personal knowledge to collective knowledge is greatly facilitated by a preceding transformation of tacit knowledge into articulated and codified.

Therefore, we propose that the main component – routine that enables a firm to reconfigure and develop its resources is this very ability of knowledge acquisition and transformation of tacit knowledge into articulated and codified. In other words, the firm has the ability to manage knowledge and convert mental models into propositions, which as mentioned earlier, is a characteristic of the forth and final layer in the structure of knowledge, named "knowledge of how to manage knowledge".

The organizations that display sustained competitive advantage are therefore the ones that possess a meta-capability of transforming tacit knowledge into articulated and finally codified. Since however the intermediate step of articulated knowledge is essential, the above organizations have the ability of "mining" tacit knowledge to be articulated. This is in agreement with Winter's view that only a small proportion of articulable knowledge becomes articulated by the firm (Winter, 1987). The firms that convert into articulated a larger proportion of articulable knowledge, have greater chances of displaying better performance. Consequently, the greater the proportion of articulable knowledge that becomes articulated, the greater the marginal propensity of knowledge conversion.

To clarify the above statement/proposition, let us examine it a bit closer. Firstly, the articulation and codification of knowledge, not only reduces causal ambiguity and makes possible the transfer of knowledge (Zander & Kogut, 1995) and best practices (Szulanski, 1996) with minimum cost, but it also facilitates the maintenance of knowledge by the organization. An empirical study by Argote et al (1990) has shown that the depreciation of knowledge related to some activity, can be very high. In other words, firms tend to "forget". One way of avoiding this depreciation is to record knowledge into manuals, documents, etc. Consequently, knowledge needs to be extracted and codified at a collective – organizational level, if it is to have any chance of surviving the test of time.

Second, when we talk about "meta-capability" we mean that organizations provide a context that supports the efforts of articulation and codification of the tacit knowledge generated, for example, by the performance of a task. The process of articulation itself helps the agent to understand better her own tacit knowledge. A context that supports such efforts is one that provides appropriate motivation to the agent to describe and analyze the knowledge she possesses, to exchange ideas though contact and discussion with other interested parties, and finally, to test and validate her model. Such an approach could be described as a "scientific approach", since it follows the stages: question, investigation, theory formation, data collection for verifying the correctness of the theory (testing), and finally validation. In other words, it is a systematic, structured effort. Notice that a better understanding of the knowledge by the agent, through articulation, testing, and validation, is likely to lead to more effective ways of performing the task, which in turn could generate additional (tacit) knowledge. This is what is meant by the "interaction of tacit and codified knowledge".

Thirdly, the effort of transforming "the greatest possible" tacit knowledge into codified forms, or in other words, the search for "know-why", can (and should) lead a firm to re-examine its organizational routines that have become tacit knowledge over time (norms, habits, rules of behavior and conduct, etc), and which can be a major source of organizational rigidies and organizational inertia at times where radical organizational changes are required. In re-

examining these routines, one needs to understand the reasons that led to their creation. Such investigations, which challenge the assumption that current deeply embedded organizational routines and knowledge, are valid, may often reveal inconsistencies in the organizational structure and the models/theories that drive it. As already mentioned earlier, knowledge is a process to approximate the truth. If this is indeed the case, there is no reason to believe that current knowledge is necessarily true. Consider for example the perceptions of a top manager. These perceptions form the basis of the firm's actions and strategies. Are these perceptions correct however? Starbuck and Mezzias (1996) report significant deviations between such perceptions and some objective data. They present two indicative empirical studies (Tosi et al, 1973; Downey et al, 1975) which investigate the correlation between the perception of some managers on the segment of the market that their firm was involved, and some financial reports and industry statistics. In most cases the correlations' coefficients were zero or negative. Therefore, in our view, this process of re-examination of the firm's current theories and beliefs is equivalent to double – loop learning (Argyris & Schon, 1978), and plays a major role in understanding how organizational knowledge is created.

Such an understanding is the most important aspect of the forth knowledge layer (see earlier discussion) at an organizational level. Therefore, the improvement of an organization's learning abilities, will not come from a better use of information technology in collecting massive volumes of data and converting them into information. This process can only effect the first knowledge layer (crude knowledge). It is improvements in the forth knowledge layer that can effect all others. At this point however it should be noted that an organization that tries to manage the knowledge of its members, can be assisted by new technology in finding new ways of utilization. For example, the structuring of information is an important mechanism for the conversion of tacit knowledge to explicit (via knowledge exchange protocols for instance) and consequently for enabling effective knowledge transfer. "A knowledge exchange protocol is a process that structures information exchange in such a way that the provider of the information and/or the recipient of the information can systematically present/recall information in a focused manner" (Herschel et, 2001; p. 107).

In view of the above, our main thesis is the following: A firm that displays sustained competitive advantage possesses better learning abilities, which in turn are acquired by the firm's intensive, systematic, and structured efforts to extract, articulate and codify, (through testing and validation) the maximum proportion of articulable tacit knowledge that resides either at a personal or at an organizational level.

This process can lead to the highest level of learning, namely double-loop learning. In this way the firm can achieve maximum accumulation of knowledge at a collective-organizational level, and it can improve the management of this knowledge. In turn, this leads to the generation of new heuristics, mainly related to the process of strategic decision making.

Example: For the sake of argument, let us assume that knowledge can be quantified and can be easily distinguished into tacit and codified. Moreover, let us assume that at time point t = 0, two firms A and B, both have 10 units of knowledge on the same subject and with the same content (they both produce equally good microprocessors). The only difference between the two firms is in the distribution of their knowledge. In particular, A has 7 units of tacit knowledge and 3 units of codified knowledge, while in B's case it's the other way around, that is, 7 units of codified knowledge and 3 units of tacit knowledge.

Let us now consider the following question: which of the two firms will learn more easily in the future (i.e. at time-point t=1)?

Our thesis tells us that it would be firm B. The reason is that in firm A, the production of microprocessors is more of an art, and therefore it is rather hard to communicate the knowledge related to this process effectively. To take an extreme case, suppose that none of the members of the firms knows how any other member performs her task. All that each member knows is who does what (with practically no knowledge of the details involved). In such an environment, decision-making is very hard since there is very little common ground (for example, some common terminology to facilitate communication). The same is true for any efforts to identify and solve the problems in R&D.

In firm B on the other hand, there is a well understood language for communication, which makes decision making much easier, and moreover any questions or concerns can by readily expressed within a "scientifically founded" framework within which they can be investigated. Consequently the opportunities for further development of the existing knowledge are much greater. As a result, at time point t =1, firm B will have accumulated more knowledge than firm A, despite the fact that they have both started with the same knowledge.

6 Belief Revision

The area of *Belief Revision* studies the process by which a agent modifies her beliefs to accommodate new information (possibly *inconsitent* with the agent's original belief state). Much of the early work in the subject was produced by Alchourron, Gardenfors, and Makinson in the early '80s (see Alchourron, Gardenfors, and Makinson (1985), and Gardenfors (1988)), who have developed a framework for describing the process of belief revision, commonly referred to as the *AGM Paradigm* (after the initials of its creators).

Alchourron, Gardenfors, and Makinson, use *Propositional Logic* as the foundation of their framework.[1] In particular, the agent's beliefs are represented by sentences A of a propositional language L; A can be either a *propositional variable* p (representing a primitive statement like "inflation is low") or it can be a complex sentence, like $p \wedge (q \vee r)$, generated from propositional variables with the use of the classical propositional connectives $\wedge$ (conjunction), $\vee$ (disjunction), $\rightarrow$ (implication) and $\neg$ (negation). So for example, if p stands for "inflation is low", q for "demand is high", and r for "the new product is very successful", then the sentence $p \wedge (q \vee r)$ states that "inflation is low, and either demand is high or the new product is very sucessful".

The complete repertoire of the agent's beliefs is called a *belief state* and it is represented by a set T of propositional sentences. Alchourron, Gardenfors, and Makinson require that T is *closed* under logical implication, meaning that every sentence A that follows logically from T, is already in T. Such a closed set of sentences T is called a *theory*. This closure property of T,

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[1] To be precise, the AGM paradigm requires only certain structural properties from the underlying logic, which are satisfied not only by propositional calculus, but by many other logics as well. However, for the purposes of this paper, propositional calculus is sufficient.

essentially encodes the agent's ability to *reason*; that is, to derive (rational) conclusions from premises.[2]

Having established formal representations for the basic ingridiants of the belief revision process, namely belief states (represented by theories), and the new information (represented by propositional sentences), Alchourron, Gardenfors, and Makinson turned to formal models for the process itself. In particular, in the AGM framework, belief revision is modelled as a function * mapping a theory T (representing the agent's initial belief state) and a sentence A (representing the new information received by the agent) to the theory T*A (representing the agents new belief state resulting from the revision of T by A).

What does the revision function * look like? How is T*A related to the original belief state T? If A is consistent with T, that is, if the agent does not believe in the negation of A, then the answer is fairly simple: T*A is the theory resulting from the addition of A to T and the closure of the new set under logical implication; in symbols $T*A = Cn(T \cup \{A\})$, where for a set of sentences Γ, $Cn(\Gamma)$ represents the closure of Γ under logical implication. Things however are not as straightforward when the new information A is *inconsistent* with the agent's initial belief state T; that is, when $\neg A$ is in T. In this case, merely adding A to T and closing under logical implication is not good enough since the resulting belief state is *inconsistent*. To preserve consistency one needs to give up some of her inital beliefs before accepting A. Which ones? Clearly $\neg A$ should go, but this is still not enough since some of the remaining beliefs may *indirectly* contradict A. Suppose for example that the agent believes the sentences B and (B $\rightarrow \neg A$). Then although none of the two sentences are in direct conflict with A, their combination *is*, since it produces $\neg A$ as a consequence. Therefore, apart from $\neg A$, at least one of the above two sentences also needs to be withdrawn when revising with A. Choosing between the two, and indeed between many others that could also be in indirect conflict with A, is not an easy matter. The choice depends on many logical and extra-logical factors. Hence, the definition of the revision function * for the case where the new information A contradicts the initial belief state T, requires closer examination.

In what follows we briefly review two of the main proposals in the AGM paradigm for modelling the revision function *. The first approach is based on a set of *rationality postulates*, known as the AGM postulates. The second uses the notion of *epistemic entrenchment* to determine which beliefs should be surrendered during the revision process. The former is what is called an *axiomatic* approach to modelling belief revision, whereas the later is a *constructive* approach.

6.1 The AGM Postulates

In modelling a revision function *, one needs to determine the relationship between the initial belief state T and the resulting belief state T*A, which, as already mentioned, is not as simple when the input A is inconsistent with T. A guiding idea toward this aim is that any agent does not through away or accept beliefs with no good reason; therefore the new belief state T*A should differ from the initial state T *as little as possible* given the new information A. This is

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[2] In fact, the closure of T entails that the agent is more than just a reasoner; she is a *perfect* reasoner, since she is aware of *all* logical consequences of her beliefs. This is one of the strongest assumptions made by the AGM framework.

known as the *Principle of Minimal Change* and it is widely accepted among philosophers as one of the driving forces of rationality. Of course, the Principle of Minimal Change as stated above, leaves much to be desired since it does not give any hints about *how* the difference between two belief states is to be measured. Nevertheless, the Principle of Minimal Change played a central role in the development of Belief Revision. It was based on this principle that Alchourron, Gardenfors, and Makinson (1985) introduced their AGM postulates, listed below, to model a revision function *:

(K*1)   T*A is closed under logical implication.

(K*2)   A is in T*A.

(K*3) $T*A \subseteq Cn(T \cup \{A\})$.

(K*4)   If $\neg A$ is not in T then $Cn(T \cup \{A\}) \subseteq T*A$.

(K*5)   If A is consistent, then T*A is also consistent.

(K*6)   If A and B are logically equivalent, then T*A = T*B.

(K*7) $T*(A \wedge B) \subseteq Cn((T*A) \cup \{B\})$.

(K*8)   If $\neg B$ is not in T*A, then $Cn((T*A) \cup \{B\}) \subseteq T*(A \wedge B)$.

The first two postulates are straigthforward: (K*1) says that T*A is a theory, and (K*2) that the new information A in included at the resulting belief state. Postulates (K*3) and (K*4) essentially say than when the new information A does not contradict the initial belief state T, then there is no reason to though anything away, and therefore T*A is simply the closure under logical implication of $T \cup \{A\}$. Postulate (K*5) says that consistency is precious, and should be preserved at all costs, unless of course the new information A itself is self-contradictory (as for example is the sentence $(p \wedge \neg p)$). Postulate (K*6) renders the syntactic form of the input A irrelevent to the revision process - what matter is its meaning. Therefore two sentences A and B that are logically equivalent (for example, $\neg(p \wedge q)$ and $(\neg p \vee \neg q)$), change a belief state T in exactly the same way. Finally, postualtes (K*7) and (K*8) relate the revision by a conjunction to the revision by each of its conjuncts. In particular, (K*7) and (K*8) taken together, say that whenever B is consistent with T*A, then adding B to T*A (and closing under logical implication), gives us the same belief state as revising T by $(A \wedge B)$.

Alchourron, Gardenfors, and Makinson (1985) have argued convincingly that the AGM postulates should be satisfied by any revision function * (refer to Gardenfors (1988) for a detailed discussion on the AGM postulates, and their relation to the Principle of Minimal Change). Moreover, it appears that (K*1) - (K*8) are in a sense the only "universal" postulates for belief revision, since all other conditions that have been studied, while quite plausabile at first sight, give counterintuitive results in many cases. The "completeness" of the postulates (K*1) - (K*8) has been further supported by a number of formal theorems, called *representation results*; we will come accross one such result in the following section.

Interesting enough though, while strong evidence exists for the completeness of (K*1) - (K*8), at the same time these postulates fail to pinpoint a *single* revision function. In other words, there are more than one functions* that satisfy (K*1) - (K*8). This is as it should be, tells us Alchourron, Gardenfors and Makinson. The plurality of revision functions is due, not to the weakness of the AGM postulates, but to the fact that different agents change their minds in different ways, even when they receive the same input A and start from the same belief state T. Consequently, all that (K*1) - (K*8) do is to circumscribe the (large) territory of the different revision behaviours. What makes an agent choose a certain revision function * over another function * (both of which satisfy the AGM postulates) depends on a number of extra-logical factors. We will return to this point later in the paper.

6.2 Epistemic Entrenchment

The AGM postulates are essentially a list of properties that any revision function ought to satisfy. These postulates however do not give any hints about *how* the new belief state T*A can be constructed from the original belief state T and the input A.

Such a constructive approach to belief revision has been proposed by Gardenfors and Makinson (1988), and it is based on the notion of *epistemic entrenchment*. Loosely speaking, the basic idea can be described as follows: in a belief state T, not all beliefs have the same status. Some are more important than others, depanding on their explanatory power, their usefulness in inquiry and deliberation, and so on (see Gardenfors (1988) for a detailed discussion on the origins of epistemic entrenchment). Let us now suppose that we can order the beliefs in T according to their epistemic importance. Then this ordering can be used to determine the beliefs in T that should be surrendered during belief revision: they are the ones that are least entrenched (i.e. low in the ordering) among those that (directly or indirectly) contradict the input A.

Gardenfors and Makinson (1988) have developed formally the above ideas. In particular, they define an epistemic entrenchment related to a belief state T to be an ordering on sentences $\leq$ satisfying the axioms (EE1) - (EE5) listed below:

(EE1) For all A, B, C in L, if $A \leq B$ and $B \leq C$ then $A \leq C$.

(EE2) For all A, B in L, if A logically entails B then $A \leq B$.

(EE3) For all A, B in T, $A \leq A \wedge B$ or $B \leq A \wedge B$.

(EE4) When T is consistent, A is not in T iff $A \leq B$ for all B in L.

(EE5) If $A \leq B$ for all A in L, then B is a tautology.

Given an epistemic entrenchment $\leq$ the revision of the belief state T by a sentence A is determined by the following condition:

(E*) $B \in T*A$ iff either $(A \rightarrow \neg B) < (A \rightarrow B)$ or A is a contradiction.

In the principle case that A is not a contradiction, the above condition essentially says that B belongs to T*A if, in the presence of A, the sentence B is more entrenched than its negation ¬B.

Gardenfors and Makinson (1988) have proved the following representation result that connect the AGM postulates with epistemic entrenchment:

Theorem 1: If T is a theory and * a revision function satisfying the AGM postulates (K*1) – (K*8), then there exists an epistemic entrenchment ≤ related to T and satisfying the axioms (EE1) – (EE5), such that condition (E*) is true for all sentences A in L. Converesely, if T is a theory and ≤ an epistemic entrenchemnt related to T satisfying the axioms (EE1) – (EE5), then there is a revision function * satisfying the AGM postulates (K*1) – (K*8), and such that the condition (E*) is true for all sentences A in L.

The above theorem essentially shows that an epistemic entrenchment encompasses all the relevant factors that determine the dynamic behaviour of an agent's belief state.

7 Belief Revision in Knowledge Management

We have seen in section 4 that knowledge management, and more precisely effective *knowledge dynamics*, is one of the most important factors in obtaining sustained competitive advantage. In this section we shall examine the role of Belief Revision in modelling organizational knowledge dynamics.

As already discussed, organizational knowledge is divided into three categories: tacit, articulated, and codified. Let us denote tacit, articulated, and codified knowledge, by T, R, and C respectively. While a proper representation for T and R is still elusive, C can quite naturally be represented as a closed set of sentences of a propositional language L (alias a theory of L).

Consider now the changes occurring at C. These changes are initiated from two different sources. Firstly, there are changes to C due to an input A from the external environment (for example, some external consultants may inform the firm about a new production technique). We shall call this kind of input A *external codified input*, and we shall denote the body of codifed knowledge resulting from the incorrporation of A into C, by C∘A. Secondly, there is the input B that is generated *internally* by the transformation of tacit knowledge to codified, described in sections 3. We shall call this input B *internal codified input*, and we shall denote the body of codifed knowledge resulting from the incorrporation of B into C, by C•B. Figure 2 depicts the two kinds of change (see next page).

In view of figure 2, the role of Belief Revision in modelling the evolution of codifed knowledge should be evident: both the operators • and ∘, which we shall call *internal* and *external* revision respectively, can be modelled as AGM revision functions; in other words, AGM belief revision can be used to model the changes to codified knowledge due to both the internal input generated by the "codification" of tacit knowledge, as well as the input received from the external environment. This opens up a wealth of possibilities.

Firstly, the relationship between internal and external revision can be formally studied. Are the two functions identical, or will a sentence A generate different effects to codified knowledge depending on whether it is internal or external input? In case the two functions $^\bullet$ and $^\circ$ are different, are they orthogonal to each other or is there a relationship between the two?
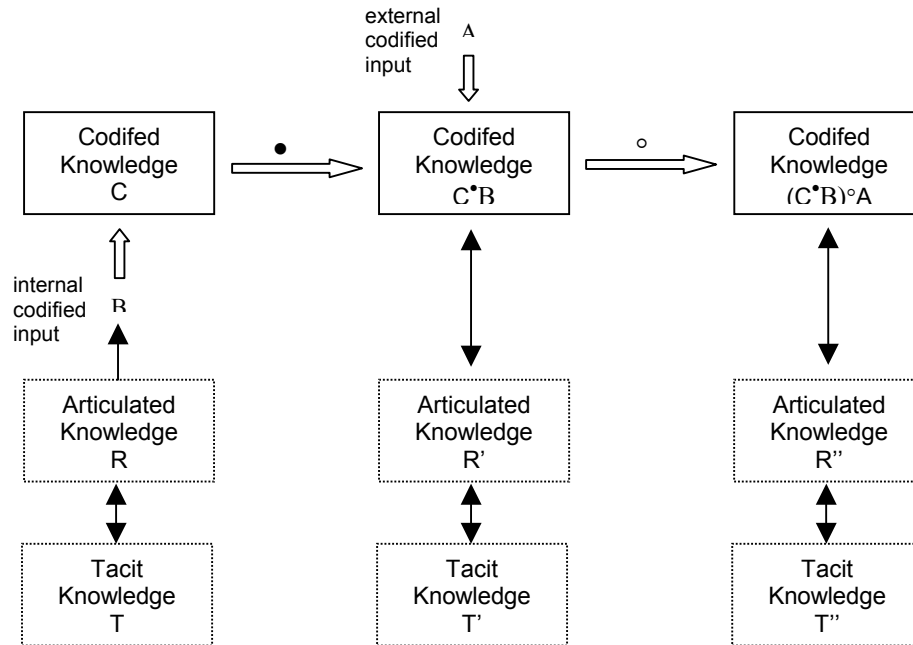

Figure 2

Secondly, each of the two revision functions $^\bullet$ and $^\circ$ can be studied independently in terms of their corresponding epistemic entrenchments. We shall focus on the external revision function $^\circ$ with the understanding that similar considertations apply to the internal function $^\bullet$ as well. Consider therefore two firms which, despite the fact that the have the same initial knowledge, they react differently to stimuli from the external environment. This phenomenon can be easily explained within the context of Belief Revision; it simply amounts to the two firms using different external revision functions $^\circ$ and $^{\circ'}$, which in view of Theorem 1 means that the epistemic entrenchments used by the two firms, let us denote them $\leq$ and $\leq'$ respectively, are also different. In other words, different learning patterns can now be encoded and analysed in terms of orderings on beliefs respesenting comperative significance.

Finally, and perhaps more importantly, we can formally describe double-loop learning as a revision of epistemic entrenchments. More precisely, consider a firm whose codifed knowledge is C, and which received an extrnal input A. If the firm has double-loop learning, it will not only change its body of codified knowledge to $C^\circ A$ as dictated by the associated epistemic entrenchment $\leq$, but it will also modify the epistemic entrenchment $\leq$ itself, thus producing a new epistemic entrenchment $\leq'$. In other words, the input A changes not only the body of codified knowledge but also the learning behaviour of the firm – this however is essentially what is meant by double-loop learning, and as we have seen it can by readily encoded and analysed in the framework of Belief Revision as a change of epistemic entrenchments.

Notice that in this section we have focus almost entirely on modeling changes in codified knowledge. This is not to say that tacit and articulated knowledge do not evolve in time. Codified knowledge was selected because it is the only kind of knowledge for which, by its very nature, it is reasonable to assume that it can be respresented in terms of propositional sentences. We do acknowledge however that both tacit and articulated knowledge need to be brought in the scene, and their changes be modelled either dierectly by appropriate representation devices, or indirectly in terms of the effects that they may have to the epistemic entrenchment associated with codified knowledge.

8 Conclusion

Contemporary approaches to management, acknowledge the central role of organizational knowledge in a firm's ability for sustained competitive advantage. In particular, it has been argued that one of the characteristic features of a successful firm is its skill in managing effectively organizational knowledge, and more precisely its ability to keep this knowledge up-to-date via a process of continuous knowledge evolution. This ability is strongly related to the firm's intensive and systematic/structured efforts to extract, articulate, and codify (through testing and validation) the maximum proportion of tacit knowledge, technical and organizational. This in turn means the creation of new organizational theories and beliefs which often challenge the old ones.

The process of knowledge evolution has also been studied in the area of Belief Revision where formal models have been developed for describing the process by which an agent changes her beliefs in the light of new information.

In this paper we have argued for the use of techniques from Belief Revision in studying organizational knowledge evolution. We have focused on codified knowledge and we have shown how the evolution of this kind of knowledge can be formally captured within the framework developed by Alchourron, Gardenfors, and Makinson (1985) for Belief Revision. Such a formal description of codified knowledge evolution, opens up opportunities for analyzing phenomena like differences in learning patterns, or double-loop learning capabilities, in terms of the formal tools already available and well understood in Belief Revision.

It should be noted that this work intends to initiate rather than to complete discussion on the use of Belief Revision in organization knowledge evolution; much more remains to be done. One of our immediate aims is to consider the interplay between tacit, articulated, and codified knowledge and the way that it may affect the organization's revision policy (alias, epistemic entrenchment). A second, more ambitious research avenue would be to investigate the possibility of applying ideas and results from conceptual spaces, as developed in Gardenfors (2000), in order to model the transformation of tacit knowledge to codified which to a large extent is generated through interaction between agents. Work on this is currently under way.

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