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A conceptual model and technological support for organizational knowledge management

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HIGHLIGHTS

- A KM background and a discussion of failure factors associated to KM are presented.
- A set of requirements that any KM model or initiative should met is defined.
- A comprehensive KM model based on the defined requirements is depicted.
- An architecture for distributed organizational memory is developed.
- Semantic treatment of knowledge sources by information retrieval strategies is proposed.

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ABSTRACT

Knowledge Management (KM) models proposed in the literature do not take into account all necessary aspects for effective knowledge management. First, to address this issue, this paper presents a set of requirements that any KM model or initiative should take into account to cover all aspects implied in knowing processes. These requirements were identified through a critical and evolutionary analysis of KM. Second; the paper presents a new distributed KM Conceptual Model whose building blocks are the knowledge activities involved in knowing processes. These activities are: knowledge creation, knowledge sharing, and knowledge representation and retrieval. This model provides a holistic view of KM whose purpose is helping managers understand the scope of this initiative, and supplying a guide for research and implementation in organizations. In this sense, the model presents KM as a highly social rather than technological process. Third; the paper briefly describes an architecture to provide a technological support for knowledge representation and retrieval activities of the proposed KM Conceptual Model. This architecture allows implementing a distributed organizational memory that helps to represent the knowledge context through an ontological model, providing a local perspective of each knowledge domain within the organization. Strategies for knowledge annotation, knowledge retrieval, and ontology evolution are briefly described and results of preliminary performance analysis are shown. Finally; based on the available literature, a comparative analysis of different KM models shows their adequacy for previously presented requirements.

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1. Introduction

Rapid changes in today's environment lead organizations to adjust and update the knowledge they have to maintain their competitive advantage [54]. Past research, however, has shown that this is not a simple task since most issues related to KM are multifaceted and require a holistic approach [37].

In this context, the concept of Knowledge Management System (KMS) emerged with the aim of supporting organizations in knowledge creation, distribution, and management [19]. A KMS can be defined as the practice of using prior knowledge to make decisions that affect current and future effectiveness of the organization [28]. There is plenty of literature in this field related to studies that focus on KMS rating and success evaluations of KMS implementations in organizations [4,35].

The emergence and use of different KMS have led many researchers to be interested in examining whether KMSs really work and finding out factors of their success. Ackerman [1] concluded that 80% of analyzed KMS initiatives failed due to overoptimistic expectations on their capabilities.

Jennex and Olfman [29] explored the use of KMS legacy by new employees in a number of U.S. companies and found that they would rather not use these systems just because they had poor understanding of their functioning. These authors suggested providing detailed guidance on the use of the system rather than theoretical descriptions of the system. In another study, Jennex et al. [30] examined the negative effect of the lack of a strategy associated with KMS in growing organizations.

Failed KMS initiatives have encouraged research into critical success factors for KMS implementations. Research findings by Alavi and Leidner [3], Barna [8], Davenport et al. [19], Chournazidis [16], and Yu et al. [80] suggest that a knowledge-friendly organizational culture is a key driver of successful KMS implementations. Wong and Aspinwall [78] identified and analyzed eleven critical success factors when adopting KM. Their studies indicate that culture and support for management leadership are main issues for successful KM implementation. On the other hand, findings by Chan and Chau [14] imply that leadership and commitment of top management are two of the most important factors. Studies by Barna [8], Dixon [20], Wenger et al. [75], and Yu et al. [80] support the existence of the KM strategy as a key success factor, while Sage and Rousse [56], Cross and Baird [18], and Chan and Chau [14] defend the importance of having the right technological infrastructure for successful KM implementation.

The analysis of the aforementioned literature leads to the conclusion that KM initiatives implemented in organizations often fail to manage the natural heterogeneity of organizational knowledge sources. Knowledge is usually regarded as something that can be managed as a physical asset. Their success was also affected by several reasons related to tacit knowledge capture and tacit-to-explicit knowledge conversion. Therefore, an approach with a new conceptual basis is necessary to emphasize semantics of organizational knowledge objects. Organizations need a more comprehensive conceptual model for KM and specific tools and policies to implement activities involved in KM. New issues arise to include knowledge storage and retrieval, and repositories creation and management.

In order to address these issues, this paper presents the following contributions: a set of requirements that any KM model or initiative should take into account to cover all aspects implied in a knowing process; a critical and evolutionary analysis of KM through which these requirements were identified; a new KM model that satisfies these requirements; a technological architecture for a distributed organizational memory designed by taking this KM model as a basis; a knowledge object annotation strategy and an information retrieval strategy developed for this architecture; an information system implemented to support this architecture; and a comparative analysis of different KM models to show their adequacy for the identified requirements.

The technological architecture is aimed at addressing two implementation problems related to KM: a) documentation overload, related to knowledge elicitation to feed knowledge repositories; and b) lack of context associated to tacit-to-explicit knowledge conversion. The annotation and information retrieval strategies were designed to enable the use of unstructured and semi-structured knowledge sources and natural language queries. The information system implemented to support this architecture was developed to allow an automatic semantic treatment of heterogeneous organizational knowledge sources and to facilitate knowledge sharing between domains by means of an interface that allows exchanging information through the propagation of natural language queries.

This paper is organized as follows: Section 2 provides a KM background followed by a discussion of most usual criticism and failure factors associated to KM. Section 3 proposes a set of requirements derived from the previous analysis. A comprehensive KM framework based on the defined requirements is depicted in Section 4. Section 5 presents the architecture of the distributed organizational memory, which is responsible for annotating and retrieving knowledge objects written in natural language. Section 6 presents an information system that implements this architecture; and its performance is evaluated in a case study related to a tourism company as a study case. A comparative analysis of current KM models is provided in Section 7. Finally, conclusions and future work are discussed in Section 8.

2. KM criticism and failure factors

According to Grant and Grant [24], the work done by many recognized experts in the field – both academics and practitioners – clearly show that the field of KM has significantly evolved over a very short period of time and it has been the focus of management attention. During this period, while there has been much debate about the nature of knowledge and the role of KM, there has been relatively less critical analysis of the foundational concepts underlying KM practices. Most of the outlined failure causes or criticism in relation to KM can be summarized in two main issues: KM as just a temporary fashion overfocused on IT, and the lack of understanding true usefulness of KM models and knowledge itself. Some authors have suggested that KM is indeed just another management fashion. For example, Wilson [77] largely describes KM as a management fashion mainly, promulgated by certain consultancy companies with the probability that it will fade away like previous fashions. Ponzi and Koenig [53] examine the degree to which KM can be seen as a fad (i.e. an intense but short-lived fashion). They provide empirical evidence based on a bibliographical count that suggests that management fads generally reach their highest level in five years, using the examples of Quality Circles, Total Quality Management and Business Process Re-engineering. Applying this rule, it is obvious that KM has exceeded the five-year mark and it might be included in management practices.

Although organizational culture is rarely taken into account when managing knowledge, it is one of the most influencing failure factors. Organizational politics, knowledge-hoarding attitude, and uncertain management commitment are some cultural failure factors [64].

In a survey based on KM papers published between 1990 and 2000, Swan and Scarbrough [67] found that more than 40% were written by and for IS/IT professionals. This seems to suggest that the IT community has become a referential point for KM. In many cases, this IT overfocus limits KM effectiveness. As highlighted by authors, the community's sole focus tends to be sub-optimal. In contrast, Harris [26] suggests that even though, strictly speaking, KM does not require the use of software, KM technology is necessary for a successful KM implementation. In a study of 28 KM-related projects, Grant and Qureshi [23] found that less than 50% were reported to be successful and most of them only involved explicit knowledge sharing. Failure factors related to technology include overemphasis on IT, low usability of systems [32], poor connectivity [46], and unchecked increase of IT maintenance costs [12,17].

Early models and knowledge classifications (for example, Nonaka's tacit/explicit conversion processes) have been useful in helping to understand the nature of knowledge in organizations but do not show how to make effective use of knowledge. McElroy [42] claims that early KM initiatives are very transactional, emphasizing capture and codification of the existing knowledge, which is not the key focus of a holistic KM view. Snowden [61] points out that the deficiencies of Nonaka model are becoming evident in practice. It should be noted, however, that each of these authors, in fact, proposes new models aimed at making up for the deficiencies of their predecessors.

As regards the questionable validity of the models that underlie KM practice, many alternative models and classification systems have been proposed for KM. With a major focus on Nonaka's cycle and the process of tacit into explicit knowledge conversion, most of them suffer from the above discussed overemphasis on IT. There are additional difficulties arising from the particular nature of the object to be managed: knowledge. For example, Styhre [65] pints out that the literature on KM suggests that there is little patience for an organizational resource that cannot be reduced into a number of categories and skills, and criticizes the codification or knowledge representation approach. Usually, knowledge explicitation process causes a loss of context that leads to an increased difficulty in interpreting explicit knowledge. Other authors [58] suggest that knowledge and management are contradictory concepts. Their grounds are based on the belief that tacit knowledge must be made explicit if it is to be managed. Marren [41] criticizes focus on knowledge as an end in itself without a link to the daily action or business strategy. Wilson [77] also discredits the concept of KM by pointing out that, in many cases, KM is merely being used as a synonym for information management. There are also additional difficulties related to activities carried out to manage organizational knowledge. New knowledge creation (or existing knowledge correction) requires interaction between organization and involved individuals. This interaction has many points of conflict: workload involved for workers to feed their knowledge into organizational repositories; loss of context that causes tacit knowledge explicitation, and the subsequent difficulty in interpreting knowledge pieces that have been decontextualized.

Knowledge storage also presents a number of associated challenges: kind of knowledge to be stored (declarative or procedural), and the need for semantic search processes that take into account context. Finally, as organizational knowledge depends on individual knowledge, mechanisms to encourage individuals to share their knowledge must be ensured, overcoming one of the most common fear: losing power by sharing what you know.

Nevertheless, the fundamental question remains: is the knowledge that is being created, captured, shared, or recorded really useful and relevant. This issue is especially important in the case of explicit knowledge (focus of most KMSs). Although much has been written about the challenge of capturing useful knowledge, there is not a unified opinion. Proposals' focuses range from quality of the knowledge being captured to challenges in making involved individuals actually contribute to knowledge repositories. A typical problem is that created KMS repositories are not seen as the best source of useful knowledge. For example, despite the existence of recommendation systems, informal networks are often the best way to find the right person. In addition, a rarely analyzed feature in the literature on KM is the obtention of the right knowledge and ensuring knowledge validity and relevance to each situation.

3. Requirements

The analysis of KM current situation and models has led to the identification of a set of requirements that should be met by a holistic KM model to become a reference framework for KM implementation and for the development of supporting information technologies.

3.1. Requirement I: KM initiatives alignment with organizational strategy

This is a key factor for organizations to achieve success in both internal management and KM initiatives. Knowledge workers must understand the nature of this relation so that their daily efforts are directed towards the organizational strategic goal.

This aspect is closely related to the quality of stored knowledge, and is mainly evidenced by the high rate of non-essential content presented by a knowledge repository. The problem arises when the knowledge base grows substantially and knowledge search requires too much time and effort. This problem has a negative impact on knowledge distribution and creation. It must be identified for storing those pieces of knowledge that may be valuable to workers. One of the most important concerns is identifying which KM process (knowledge creation, distribution, storage, or retrieval) contributes more to preserve the competitive advantage of an organization. This is related to the extent to which knowledge management efforts provide support to organizational strategies.

3.2. Requirement II: Organizational knowledge identification (consciousness)

Members of an organization are not usually conscious of critical knowledge assets of the organization. Some part of the organization often repeats the work of another part because members are not aware of the existence of the generated knowledge. Organizations need to know their corporative knowledge assets and how to manage and use them. The emerging challenge is to develop strategies and techniques to raise members' awareness of both the knowledge they need for their work and its possible availability in the organization.

3.3. Requirement III: KM activities structuring

KM must be understood as the management instance by which a set of resources for supporting knowledge development within the organization is obtained, unfolded, or used. For this reason, understanding how to structure KM initiatives will generate an advantage at the time of considering knowledge within the organization strategy. KM cannot be an initiative of a part of the organization; it must be conceived within the organizational strategic plan and driven by a model to guide the implementation of all necessary activities.

3.4. Requirement IV: Consideration of main activities related to KM

In this paper, KM activities are classified into three main categories: knowledge creation, knowledge distribution, and knowledge representation and retrieval. Each of them has a related requirement that is identified and described.

3.4.1. Requirement IV.1: In relation to knowledge creation

Sustainable creation through linkage with social processes: knowledge creation is a process of social nature that entails transformations between tacit and explicit forms of knowledge. These transformations (combination, externalization, internalization, and socialization) must be sustained within the organization for an effective knowledge creation. While knowledge activities include effective use of existing knowledge, it is more important to improve new knowledge acquisition, particularly in terms of business innovation.

3.4.2. Requirement IV.2: In relation to knowledge distribution

Knowledge contextualization: the context idea is associated with knowledge from its definition. Context is what distinguishes knowledge from data and information. When knowledge is distributed throughout the organization, it must be accompanied by the contextual situation that originated it so as to facilitate subsequent interpretation and reuse.

Identification of communities of practice and communities of knowledge: The importance of these communities lies in the fact that knowledge cannot be separated from its context. In every type of knowledge activities, those that contribute and those that look for knowledge require a common community to share experiences. Within a community, workers are informally and contextually bound by a common interest in sharing knowledge and common practices. This need comes from the nature of knowledge and the difficulty in institutionalizing this knowledge without taking into account a variety of group or social issues. Not only individuals but also organizations actually learn. That tension between knowledge held by individuals and knowledge collectively held by groups of individuals is a stimulating feature for innovation and creativity. Most knowledge is held collectively within communities and cannot be represented as the sum of individual knowledge.

Knowledge networks implementation: knowledge networks facilitate knowledge transfer between organizational domains and aid in canalizing workers efforts. Knowledge networks are basically the best vehicles for knowledge communicating and sharing within an organization.

3.4.3. Requirement IV.3: In relation to knowledge representation and retrieval

Knowledge contextualization: knowledge sharing requires a common mental framework between source and receiver. However, people with different backgrounds have different knowledge structures and perspectives. Knowledge is context-dependant, whereas an explicit representation generally tends to leave aside context. Without contextual information, workers neither understand nor trust the knowledge source completely and thus they do not adopt it. The need for providing support to context representation has to be taken into account in repositories design.

Transparency of mechanisms for knowledge representation and retrieval: knowledge contribution to repositories requires an extra documentation effort by workers who, unless they perceive an immediate benefit, do not find extra work worthy. Mechanisms used to feed and recover knowledge from repositories must be transparent for knowledge workers.

3.5. Requirement V: Distributed KM

Several reasons justify the need for knowledge management in a distributed way. There are reasons associated to difficulties in developing a centralized repository, such as impossibility of using the same formalism for all the organizational knowledge, duplication issues, versioning, permissions, etc. On the other hand, there are advantages related to a distributed management, such as the possibility of handling local manifold perspectives within the organization, which leverages understanding, learning, and innovation.

3.6. Requirement VI: Balance between social and technological KM aspects

Information technology is a critical, but not necessarily a key, element in KM. Information technology aims at the tacit to explicit conversion of knowledge, helping to capture, encode, and distribute organizational knowledge. Nevertheless, it is neither possible nor advisable to specify all the knowledge held by an individual. Therefore, the social component of knowledge-related activities (tacit knowledge transfer, teaching and learning processes, etc.) must be taken into account.

3.7. Requirement VII: Change in the organizational culture

Organizations must nourish a culture that facilitates knowledge creation, distribution, and use before underscoring information technologies as a means for accomplishing KM. A new thought recognizes greater complexity in knowledge challenges faced by organizations, and includes considering KM in the context of complex adaptive systems. Such concepts as nested knowledge domains and the role of individual knowledge agents combined to form collective or shared organizational knowledge are key examples.

4. Distributed KM conceptual model

4.1. Organizational knowledge

In this work, knowledge is intended as the process of knowing. A reflexive process that takes data and information in a social context mixes them with experiences, judgment, common sense, rules, emotions, and desires for generating new data, information, and/or knowledge [63].

Different types of knowledge have different KM implications and require different elements in a KM model. It is possible to distinguish between two types of knowledge: *tacit*, which is produced by information processing in an individual's mind and acquired by experience [52]; and *explicit*, which is produced by the articulation and communication of tacit knowledge and captured in a code or a language that facilitates its communication [47]. Since organizational knowledge is derived from individual knowledge, KM requires a suitable infrastructure for creating and managing tacit and explicit knowledge.

The building blocks of KM Conceptual Model proposed in this paper are the knowledge activities involved in a KM process. These activities are: *knowledge creation*, *knowledge sharing*, and *knowledge representation and retrieval*.

4.2. Knowledge creation

Organizational knowledge can be created through four conversion processes that involve tacit and explicit knowledge (Fig. 1): externalization, socialization, combination, and internalization [47].

Externalization refers to tacit to explicit knowledge conversion. In this process, individuals try to articulate their tacit knowledge by eliciting their experiences and beliefs. In the proposed KM Conceptual Model, this process is seen as a teaching process, thus becoming sustainable over time and easily launched.

Socialization refers to the creation of tacit knowledge from shared tacit knowledge. In KM Conceptual Model, individuals acquire knowledge through a coaching process where expert workers guide trainees in their learning process.

Combination refers to the creation of knowledge through the combination and exchange of explicit knowledge. In KM Conceptual Model, this process is supported by an organizational memory that lets workers sort, reuse, add, and recontextualize explicit knowledge.

Internalization takes place when explicit knowledge becomes tacit. KM Conceptual Model presents internalization as a learning process where individuals embody new knowledge updating their mental models. The interplay between individual and collective knowledge is an important aspect of organizational knowledge creation, amplification, and transfer.

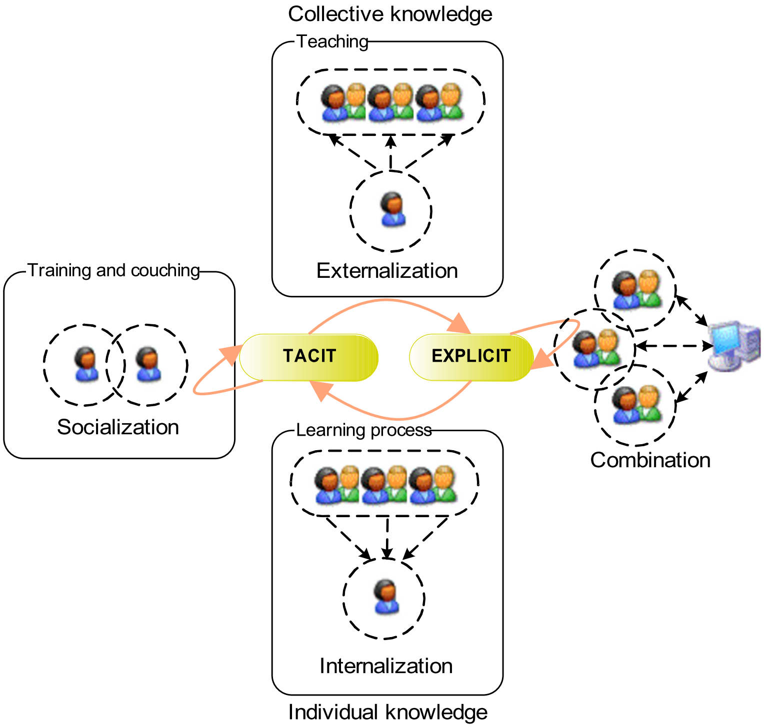

Fig. 1. Knowledge creation.

4.3. *Knowledge distribution*

Knowledge creation by itself cannot satisfy the strategic priority for most organizations that must continually learn and innovate to remain competitive. Organizations have to create value by using knowledge; and knowledge can be used only if shared [2,44,69]. Knowledge sharing can unfold through socialization, education, and/or learning processes and it may be challenging due to a number of factors, including type of knowledge, and inability to locate and access the required knowledge source.

KM Conceptual Model proposes that this sharing process should be fostered among knowledge domains within the organization from which individuals can obtain the needed knowledge. A community of practice is a social-technical system providing a means to develop and share knowledge among professionals. It is capable of providing individuals and organizations with a single-source solution for education, training, and performance support [33].

Two main characteristics distinguish communities of knowledge from communities of practice. Firstly, communities of knowledge are established and supported by the organization according to areas of interest, while communities of practice are formed spontaneously in response to professional interests. Secondly, communities of knowledge do not typically have well-defined goals other than the expansion of thinking along common areas of interest [39] while the main goal of a community of practice is learning. The importance of communities of practice stems from the fact that knowledge cannot be isolated from its context. In all types of knowledge activities, both knowledge contributors and seekers require a common community to share general conversation, experimentation, and experiences [70]. A challenge to KM initiatives is how to connect communities of knowledge and communities of practice to enable sharing across, not just within, communities. KM Conceptual Model proposes establishing a knowledge network among communities of different knowledge domains (Fig. 2). Knowledge networks facilitate knowledge transfer and sharing between knowledge domains and help to canalize/guide workers' efforts.

4.4. *Knowledge representation and retrieval*

Organizations must codify learned knowledge in order to preserve and reuse it. The approach to knowledge codification depends on its type (tacit or explicit). KM Conceptual Model proposes the use of an organizational memory as support for knowledge representation, use, handling, and conservation through time and space – to a possible extent – with limited human intervention. From the organizational perspective, organizational memory can act as a tool for KM on three types of learning in organizations: individual learning, learning through direct communication, and learning using a knowledge repository. As knowledge domains are distributed across the organization, it is necessary to represent and retrieve knowledge objects in the same way. KM Conceptual Model proposes to associate each organizational knowledge domain with

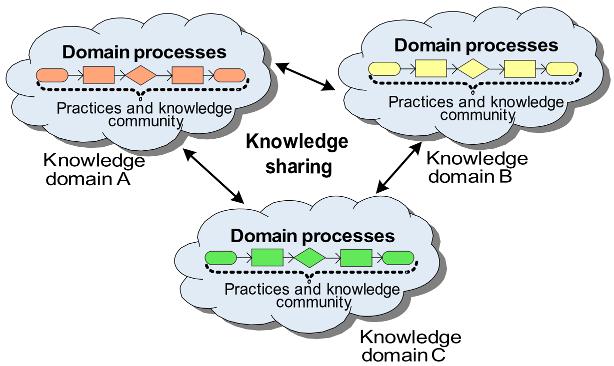

Fig. 2. Knowledge distribution.

its own memory and add mechanisms that enable knowledge retrieval from others domains. The result is a distributed organizational memory.

Characteristics, attributes, and semantics of knowledge objects of each domain, as well as relationships among them, are represented through domain ontology. Ontologies provide a domain model that allows representing the context in which knowledge objects fit [22,60]. This would allow both direct access to any knowledge object and making any relations between them explicit. The main role of the domain ontology in an organizational memory is to capture knowledge in a formal and generic way so as to allow knowledge sharing and reusing through software applications, communities of knowledge, and communities of practice.

Knowledge creates value only when it is applied by organizations to create capabilities and to take effective actions. Therefore, support and enhancement of knowledge use in organizations should be one of the major focuses of KM initiatives [81]. Since knowledge is generated and used in a distributed way, it is essential to facilitate knowledge retrieval by connecting seeker with the corresponding knowledge source. In KM Conceptual Model, knowledge retrieval activity is supported by the domain ontology that allows complex knowledge retrieval strategies. A detailed description of the proposed organizational memory architecture is presented in Section 5.

4.5. KM conceptual model

Based on the set of requirements defined in Section 3, a KM Conceptual Model is proposed. This model encompasses activities of knowledge creation, knowledge sharing, and knowledge representation and retrieval, which were identified as needed for KM implementations (Fig. 3). The model fuses two KM modeling approaches: network model and repository model [2]. *Network model* aims at using the power of information and communication technologies to support the flow of knowledge in organizational settings and among networks of knowledge domains. *Repository model* aims at knowledge codification (i.e. creation and maintenance of explicit knowledge). The result is a KMS that uses information and communication technologies to support knowledge sharing and knowledge creation activities, and a distributed organizational memory to support knowledge representation and retrieval activities.

The model aims at covering the set of requirements identified as necessary to neutralize most common failure factors in KM implementations. Specifically, this model was developed to support integration between KM technological and social aspects, linking activities that are commonly associated with such management to other organizational processes of highly social nature, e.g. learning, teaching, coaching, etc. (requirements IV.1 and VI).

Applying the proposed model involves a survey of organizational knowledge domains and thus the awareness of knowledge generated and possessed by the organization and communities (requirement II). This awareness allows the alignment of KM initiative with strategy and organizational culture (requirements I and VII).

The model core is an organizational structure made up of practice and communities of knowledge that enables creation, use, and distribution of knowledge (requirement VI). These KM processes are dealt with by management tasks that must be implemented by organizational decision levels with an appropriate use of technology (requirement III).

Technologies were exploited by the KM model for knowledge creation, distribution, and representation and retrieval processes. A distributed organizational memory technically supports these processes by implementing a KMS for each knowledge domain identified in the organization. This organizational memory constitutes support for several features of the KM model. The distributed scheme allows for the implementation of a knowledge network made up of knowledge domains within the organization, respecting the natural distribution of knowledge (requirement V).

The ontological model of each organizational domain knowledge provides proper representation and context for knowledge objects (requirement IV.2). The workload involved in eliciting knowledge to contribute to organizational memory is minimized by developing strategies that support the incorporation of knowledge objects into organizational memory.

Finally, by processing natural language queries, interaction with organizational memory is user-friendly and transparent, facilitating its use by workers (requirement IV.3).

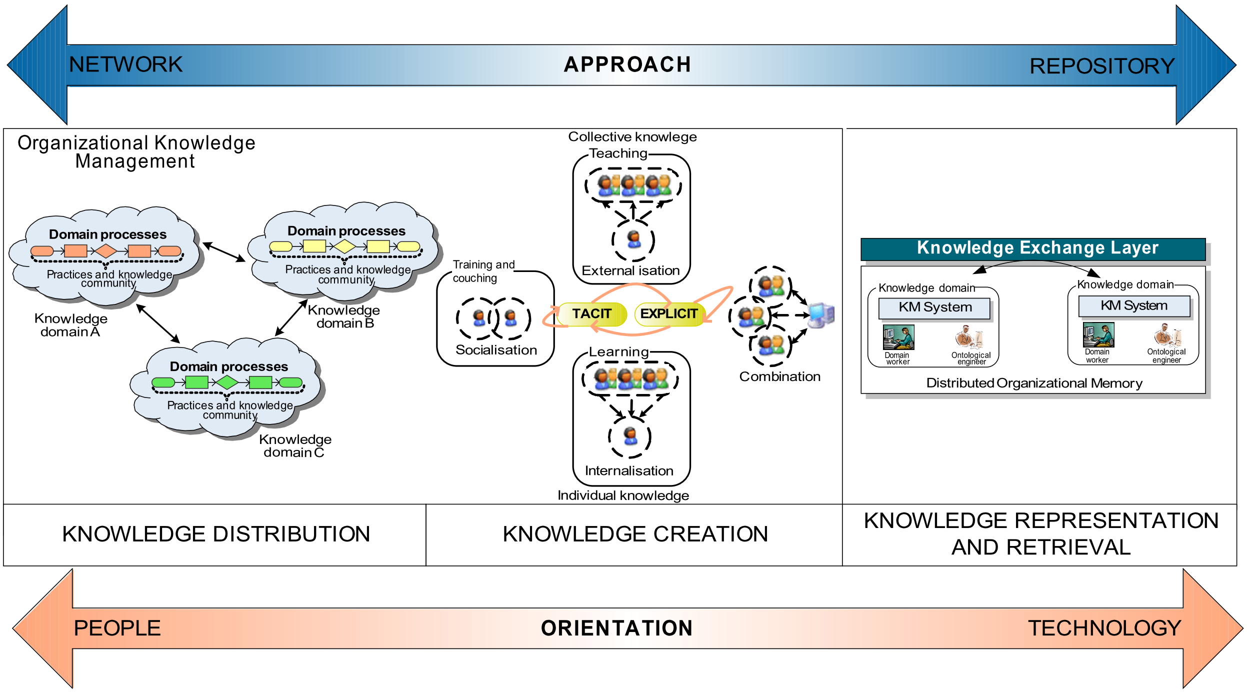

Fig. 3. Proposed model.

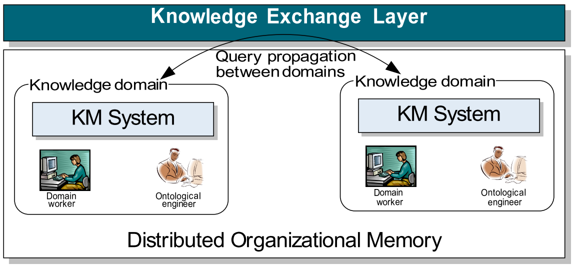

Fig. 4. KMS architecture.

5. A technological architecture for knowledge representation and retrieval

This section presents an architecture to provide technological support for knowledge representation and retrieval activities of the KM Conceptual Model proposed in Section 4. Current KM technological approaches tend to store all organizational knowledge into a single knowledge repository, disregarding different perspectives of each knowledge domain within the organization. In order to overcome this drawback and fulfill technological requirements of the proposed KM model, an architecture that satisfies principles of autonomy and coordination was developed. Autonomy enables each domain to choose appropriate perspectives, mechanisms, and politics to manage local knowledge. Coordination enables information exchange and knowledge sharing among organizational units [11]. The proposed architecture for distributed organizational memory comprises a knowledge exchange layer and several autonomous KMS, one for each identified knowledge domain (Fig. 4).

Distributed organizational memory helps to represent knowledge context providing a local perspective of different knowledge sources by knowledge domains. Organizational memory is divided taking into account organizational knowledge domains.

Knowledge domains are units formally defined in the organization (such as an organizational division) or informal (such as a group of interest). Knowledge domains are identified according to inspection and analysis of organizational activities. Each domain implements its KMS that uses semantic strategies based on domain ontologies to capture the domain knowledge in a generic form and represent the knowledge context.

Knowledge exchange layer provides mechanisms for exchanging knowledge among domains, keeping their autonomy. Domains store knowledge under their politics and context; and they can share knowledge with other domains through knowledge exchange interface, ensuring the principle of coordination.

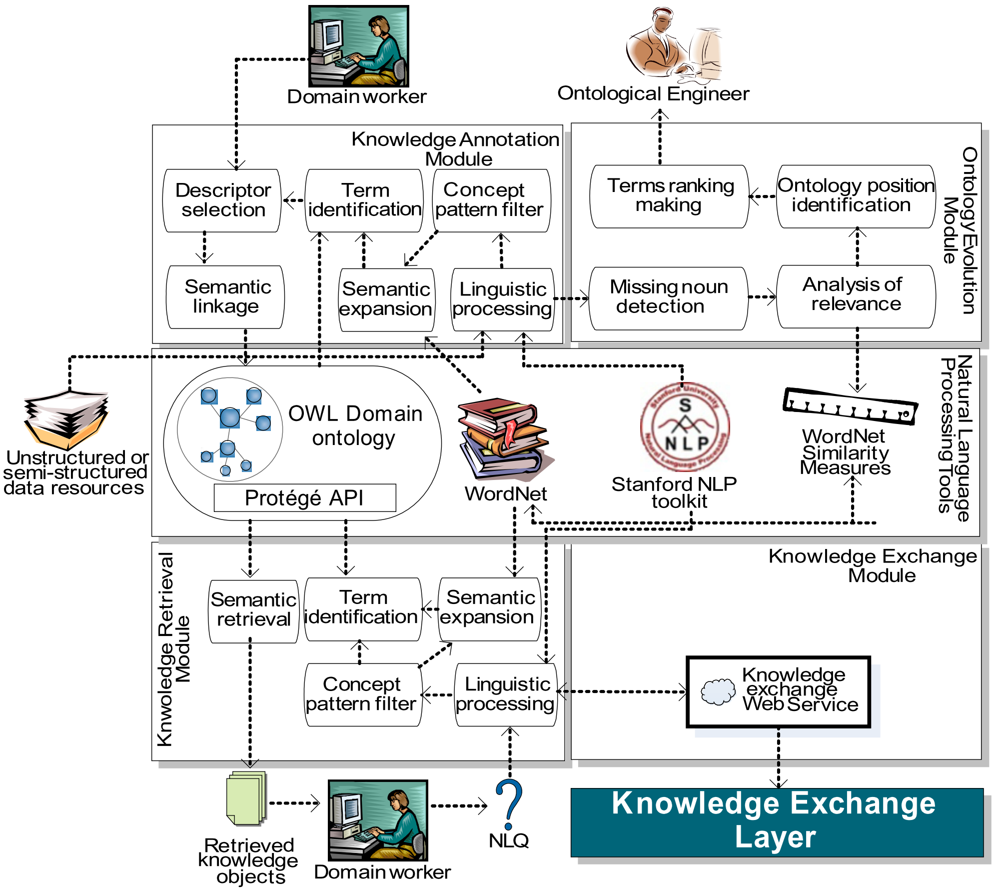

Fig. 5. Domain KMS.

5.1. Domain KMS

Each knowledge domain implements its own KMS that is composed of a set of tools for natural language processing and four modules: *Knowledge annotation*, *Knowledge retrieval*, *Ontology evolution*, and *Knowledge exchange* (Fig. 5).

5.1.1. Knowledge annotation module

This module is responsible for the semantic annotation of knowledge objects obtained from heterogeneous sources. It implements a classification strategy of knowledge objects based on domain ontologies with the aim of overcoming drawbacks of documentation overload and lack of context. Ideally, an organizational memory should be self-adaptive and self-organized, collecting relevant knowledge during usual business process operations. In practice, however, some kind of human intervention to keep knowledge semantics is often required. In this architecture, domain workers that generate knowledge objects perform this intervention by selecting appropriated descriptors. The architecture also incorporates the role of an ontological engineer, who is responsible for initially developing domain ontologies, updating them, and in some cases for collaborating on knowledge objects annotation.

Knowledge objects annotation strategy This strategy processes knowledge objects (documents, mails, memorandums, etc.) by using a domain ontology to capture relevant terms from them, and uses these terms to perform a semantic annotation [5]. It selects descriptors, which are ontological terms derived from nouns in a knowledge object. This approach, thus, selects only relevant domain terms and provides a homogeneous representation of structurally heterogeneous knowledge objects [72].

Each knowledge object to be annotated goes through a linguistic analysis process (tokenization, lemmatization, and Part-Of-Speech Tagging or POS Tagging). In this process, each grammatical element is assigned a tag with its syntactic nature (adjective, singular noun, verb, present time, third person singular, conjunction, etc.) [21]. Nouns are selected afterwards since they frequently carry more semantics than adjectives, adverbs, or verbs [7].

A searching process of exact occurrences begins, using nouns of the tagged knowledge object. Each noun is compared with terms of the domain ontology, which represents the knowledge in the domain. If a coincidence is found, the noun is selected as a descriptor and is linked to the ontological term. If there is no coincidence, such a noun is added to an unlinked nouns list. Depth parameters associated to ontological and semantic search are null since it was not necessary to make expansions by using the ontology or a lexical database such as WordNet.

From the unlinked nouns list, a process of semantic expansion that extends knowledge object representation begins. For each unlinked noun, its synonyms are retrieved from WordNet lexical database, and they are compared with the ontological terms. If coincidence is found between a synonym and an ontological term, such a synonym is selected as a descriptor and its noun is eliminated from the unlinked nouns list. Semantic depth is increased since an expansion was necessary.

Then, for each noun that remains in the unlinked nouns list, its hyperonyms in the WordNet are obtained; and again coincidences between its hyperonyms and ontological terms are searched for. Hyperonyms answer the question "What is it?" rising to the next level in WordNet taxonomy. If a coincidence between hyperonym and ontological term is found, such hyperonym is selected as a descriptor and its noun is deleted from the unlinked nouns list. Ontological depth parameter is increased since a level in the taxonomy of the domain ontology has been scaled.

Finally, if no coincidence can be found, nouns included in the unlinked nouns list are discarded as possible descriptors since no semantic correspondence with the domain ontology was found. Knowledge object generator should then select relevant descriptors obtained in the previous process, and should store them as knowledge object descriptors. Ontological and semantic depth parameters are helpful for deciding which descriptors should be selected for representing each knowledge object. High values indicate that it was necessary to move through WordNet structure (semantic depth) or in the ontology (ontological depth), so some semantics is probably lost.

5.1.2. Knowledge retrieval module

This module is responsible for processing natural language queries by using the domain ontology as a semantic tool to recover knowledge objects with high probability of containing the answer. To this aim, queries are transformed by eliminating natural language ambiguity; and similarities between query nouns and ontological terms are searched for.

Knowledge retrieval strategy At a first step, a user query goes through a linguistic analysis process (tokenization, lemmatization, and Part-Of-Speech Tagging) similar to the annotating strategy. Then, nouns, verbs, and wh-words are selected. Wh-words provide clues of the type of expected answer (time, location, person, etc.).

A searching process of occurrences (exact, semantic expansion by synonyms, and ontological expansion by hyperonyms) among ontological terms and nouns is carried out for each query noun within user query. This process is similar to that for annotating knowledge objects. Based on retrieved ontological terms, ontological relationships that relate these terms are obtained. Since the relationships of ontological terms are verbs, WordNet glosses are searched for their definitions. A linguistic analysis process of these definitions is carried out and nouns are selected.

For each query verb within user query, its definition in WordNet glosses is searched. A linguistic analysis process (tokenization, lemmatization, and Part-Of-Speech Tagging) of these definitions is made and nouns are selected.

Then, a comparison process among nouns obtained from query verbs and nouns obtained from ontological relationships is carried out. With the aim of discarding trivial nouns, the noun is verified to belong to the ontology for each coincidence. If it does not belong, it is discarded; otherwise, it is selected as a possible query descriptor. This comparison process between query verbs and verbs of ontological relations aims at expanding natural language query representation since its short length makes it impossible to obtain a large number of descriptors.

After obtaining descriptors that semantically represent the natural language query, the strategy proceeds to recover those knowledge objects whose descriptors match those obtained.

5.1.3. Ontology evolution module

Annotation and retrieval strategies depend on the domain ontology completeness. When a noun is retrieved from a knowledge object, the descriptor derived from that noun is lost unless it (or synonym or hyperonym) is found in the ontology. The whole semantics of a knowledge object is expected to be kept by storing most of its representative nouns. Domain knowledge changes and grows over time as the organization accumulates experiences. New terms emerge in the domain so that the domain ontology needs to evolve by adding them. Ontology evolution module implements an approach that allows adding new terms to the domain ontology. This approach allows domain ontology to evolve while new knowledge objects are annotated [71].

Ontology evolution strategy When a knowledge object is annotated, POS Tagger output is supervised. Nouns considered as relevant to domain which are not present in the ontology (missing nouns), are proposed to be included in the domain ontology. The compromised understanding of the domain knowledge represented by the ontology is to be kept unchanged, so this strategy just proposes the new terms to be added and their location in the ontology structure, but the ontological engineer is who makes the final decision.

Domain relevance of a noun w is defined according to the following three issues: usefulness of w for distinguishing knowledge object content in relation to domain corpus; its relevance for the domain knowledge represented by domain ontology terms; and the value judgment of the ontological engineer. Based on these issues, relevance of noun w in relation to all missing terms is generated by using Eq. (1).

$$relevance(w) = \underbrace{\max a_{wk} / a_{wk} \in TF\text{-}IKOF(w)}_{Relevance} \times \underbrace{\max sim_w / sim_w \in similarity(w, terms)}_{Similarity\text{-}Measure} \times \underbrace{judgment(w)}_{Expert\text{-}judgment} \quad (1)$$

The first factor in Eq. (1) is the biggest TF-IKOF (Term Frequency-Inverse Knowledge Object Frequency) value for noun w calculated among all current annotated knowledge objects [21]. This value quantifies the discriminatory power of noun w for future knowledge objects classification to answer users' queries (Eq. (2)).

$$TF-IKOF(w) = \left\{ a_{wk} \;\middle|\; \forall k \in corpus\colon\ a_{wk} = TF(w,k) \times \lg\left(\frac{|K|}{KOF(w,k)}\right)\right\} \quad (2)$$

where, *corpus* is the set of domain knowledge objects, $TF(w,k)$ is the term frequency of noun w in knowledge object k; $|K|$ is the number of knowledge objects annotated in the domain; and $KOF(w,k)$ is the number of knowledge objects in which noun w appears.

The second factor in Eq. (1) provides a value that quantifies the relatedness of noun w to domain vocabulary, i.e. ontological terms. It is calculated by the highest score obtained by comparing noun w with each ontological term. For this purpose, several similarity measures based on WordNet were evaluated [49], such as Leacock and Chodorow [34], Wu and Palmer [79], Resnik [55], Lin [38], Jiang and Conrath [31], Hirst and St-Onge [27], Patwardhan, Banerjee and Pedersen [48], and vector [48]. Among these measures, Wu and Palmer (Eq. (3)), Resnik (Eq. (4)), and Jiang and Conrath (Eq. (5)) measures were selected since they provided similar results but with better computational performance.

$$similarity(w, terms) = \left\{ sim_w \;\middle|\; \forall t \in terms\colon\ sim_w = log\frac{2 \times depth(lcs(w,t))}{depth(w) + depth(t)}\right\} \quad (3)$$

$$similarity(w, terms) = \left\{ sim_w \;\middle|\; \forall t \in terms\colon\ sim_w = IC\big(lcs(w,t)\big)\right\} \quad (4)$$

$$similarity(w, terms) = \left\{ sim_w \;\middle|\; \forall t \in terms\colon\ sim_w = \frac{1}{IC(w) + IC(t) - 2 \times IC(lcs(w,t))}\right\} \quad (5)$$

where, *terms* are WordNet terms, $lcs(w,t)$ is the lowest common subsumer between noun w and term t in WordNet taxonomy; $depth(c)$ is the ontological depth of c in WordNet synsets taxonomy, and $IC(c)$ means information content of c [55].

The third factor in Eq. (1) valuates expert judgment. It represents accumulative penalization due to previous rejections ($rejects_w$) of adding noun w as an ontological term. If the ontological engineer rejects the addition in the domain ontology, noun w is penalized in future proposals (Eq. (6)).

$$judgment(w) = \frac{1}{1 + rejects_w} \quad (6)$$

Based on Eq. (1), N-first ranked nouns are proposed to be added in the domain ontology. An ontology branch where to add the new term is suggested to the ontological engineer for each proposed noun. To this aim, the new term is compared with all ontological terms by using Resnik similarity measure (Eq. (4)). The branch with the highest similarity value is suggested. This information significantly bounds the search space, helping ontological engineers to decide on the precise ontological location of the new term.

5.1.4. Knowledge exchange module

This module allows domain workers to communicate with other domains in order to retrieve knowledge objects. A query not answered by KMS of the worker domain can be propagated to other domains so as to obtain the required answer.

To this aim, this module provides communication support with the knowledge exchange layer, which is responsible for propagating users' queries to appropriate domains. This module implements web services that allow users to ask for retrieving knowledge objects based on a natural language query from other domains.

5.2. Knowledge exchange layer

This layer is responsible for propagating queries towards other domains that can answer them. It was implemented by using software-agent technology. The developed multiagent system provides services to register and integrate organizational knowledge domains. Agent-oriented technology was used because KMS is an open and dynamic architecture in which knowledge domains comply with the principle of autonomy. They are not known in advance and they can automatically enter or leave the system. Multiagent system also provides a suitable framework in which recommendation techniques for helping users to identify proper domains can be easily added.

6. Architecture implementation

A prototype of Domain KMS, called Onto-DOM, was implemented on the basis of a client-server architecture. Each domain implements its own KMS server. Clients (i.e. domain users interfaces) were implemented by Java applets and JSP (Java

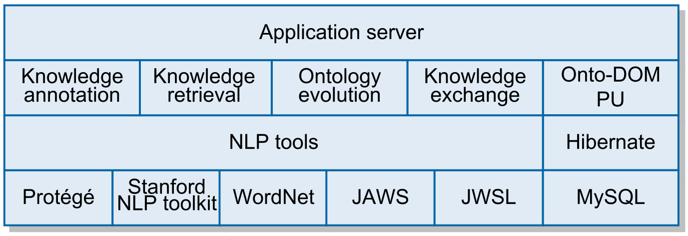

Fig. 6. Onto-DOM: server.

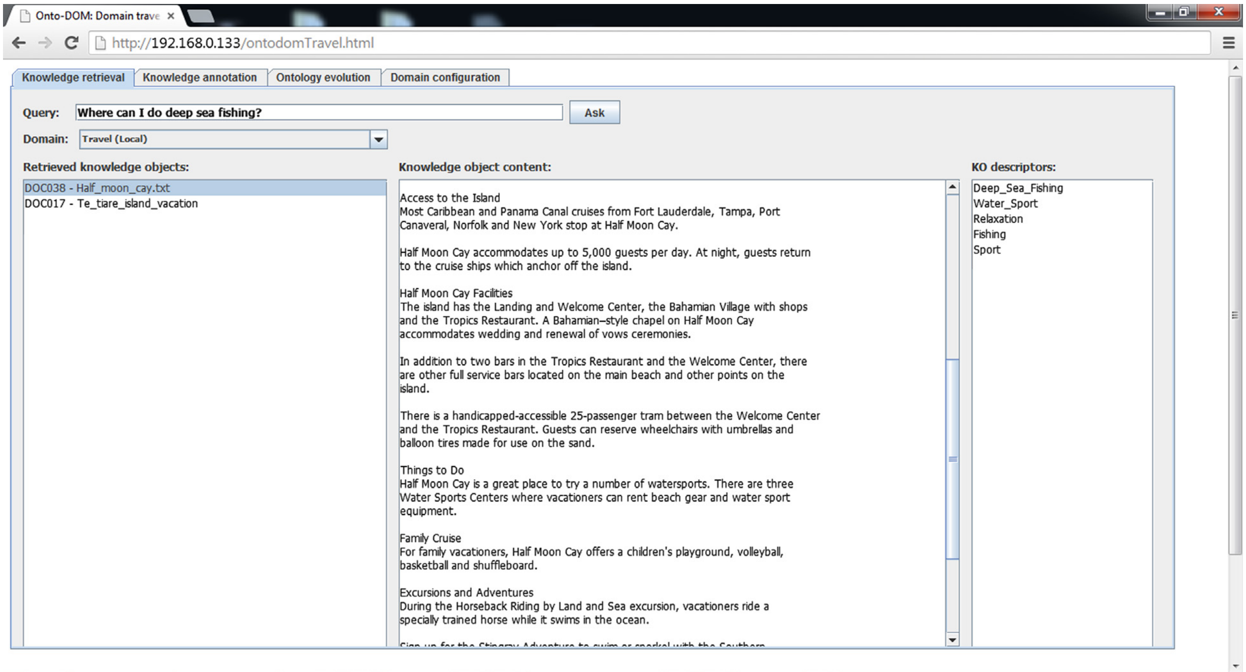

Fig. 7. Onto-DOM screenshot.

Server Pages), which can be run in web browsers. The server (Fig. 6) implements strategies described in Section 5 through modules: Knowledge representation, Knowledge retrieval, Ontology evolution, and Knowledge exchange.

For data persistence, the server implements OntoDOM PU module. Hibernate[1] module performs object relational mapping and query databases by using Hibernate Query Language and Structured Query Language for data persisting into a relational database. Annotation data are stored in MySQL.[2]

The server includes toolkits of Stanford NLP Group[3] for natural language processing. The OWL ontology is accessed using Protégé-OWL API.[4] WordNet lexical database is consulted by JAWS API.[5] Also, JWSL API[6] is used for computing purposes (Eqs. (1) to (5)).

Knowledge exchange layer was developed by using JaCaMo platform [10,73]. Web services are implemented using CArtAgO-WS [51] artifacts through web services description language specifications of provided services.

Fig. 7 shows the main interface of Onto-DOM prototype. It is used for knowledge retrieving, knowledge annotation, ontology evolution, and for configuring domain parameters such as domain ontology, corpus, other domains to propagate queries, etc.

1 http://www.hibernate.org/.
2 http://www.mysql.com/ database engine.
3 http://nlp.stanford.edu/.
4 http://protege.stanford.edu/.
5 http://lyle.smu.edu/~tspell/jaws/index.html.
6 http://grid.deis.unical.it/similarity/.

Table 1
Annotation strategy analysis.

ko	# desc	# asig	# non-asig	*tp*	*fp*	*tn*	*fn*	*r*	*p*	F_1	fall	*a*
1	103	41	62	33	8	60	2	0.9429	0.8049	0.8685	0.1176	0.9029
2	52	17	35	14	3	35	0	0.9714	0.8142	0.8859	0.0983	0.9226
3	62	23	39	16	7	37	2	0.9439	0.7747	0.8510	0.1186	0.9000
4	87	29	58	21	8	56	2	0.9362	0.7620	0.8402	0.1202	0.8963
5	48	17	31	12	5	31	0	0.9490	0.7508	0.8383	0.1239	0.8962
6	102	43	59	36	7	56	3	0.9446	0.7652	0.8455	0.1218	0.8972
7	90	28	62	21	7	56	6	0.9208	0.7630	0.8345	0.1203	0.8912
8	44	15	29	10	5	28	1	0.9193	0.7510	0.8267	0.1242	0.8878
9	53	11	42	3	8	41	1	0.9005	0.6979	0.7864	0.1285	0.8814
10	58	15	43	11	4	42	1	0.9021	0.7014	0.7892	0.1244	0.8846
11	48	17	31	10	7	29	2	0.8959	0.6911	0.7803	0.1307	0.8781
...	...	...	...	...	...	...	...	...	...	...	...	...
145	151	54	97	44	10	95	2	0.8655	0.6668	0.7533	0.1433	0.8600
146	63	27	36	21	6	36	0	0.8676	0.6685	0.7551	0.1433	0.8607
147	94	12	82	9	3	82	0	0.8695	0.6697	0.7566	0.1417	0.8623
148	109	34	75	21	13	71	4	0.8691	0.6689	0.7560	0.1419	0.8620
149	45	14	31	11	3	28	3	0.8679	0.6706	0.7566	0.1412	0.8621
Average								0.8679	0.6706	0.7699	0.1412	0.8621

6.1. Experimental results

To analyze the semantic capability of proposed strategies, a tourism company was selected as a case study. Three domains (organizational units) were identified: *Travel*, considered as local domain, is responsible for offering and selling trips around the world, except to Europe or Africa; and *Africa Travel* is specialized in offering and selling trips to Africa and thus knowledge objects generated in this domain are mostly related to Africa travels. And, *Europe Travel*, specialized in offering and selling trips to Europe. Each domain is responsible for managing the information related to its business activity.

For these cases, extensions of travel ontology were made[7] in order to provide an initial ontology for annotating knowledge objects. The ontology represents the vocabulary used in Travel domain and is made up of 184 ontological terms. In the same way, a specialization of this ontology was made for Europe Travel and Africa Travel,[8] including specific terms employed in these domains. The corpus is composed of 150 documents arbitrarily selected as knowledge objects, with a total of 35,091 words.

6.1.1. Knowledge annotation strategy

Based on Travel, Africa Travel, and Europe Travel domains, knowledge annotation strategy performance was analyzed through a comparison between results obtained by automatic identification of descriptors among nouns in knowledge objects, which is carried out with the proposed strategy, and results obtained from that identification by hand.

Each proposal made by the annotation strategy was compared with the descriptor annotated by hand, and they were classified as *true positive* (*tp*), *false positive* (*fp*), *true negative* (*tn*), or *false negative* (*fn*). A *tp* result represents a well-selected descriptor; an *fp* result represents a descriptor selected by the strategy that should be rejected; a *tn* result represents a descriptor well-rejected by the strategy; and an *fn* result represents a descriptor that was not selected but it should have been selected.

Each knowledge object of corpus was processed and their descriptors (noun in the knowledge object or nouns obtained from semantic expansion) obtained by both manual and automatic methods. Results were compared, and in order to perform a quantitative result analysis, *recall* $r = \frac{tp}{tp+fn}$, *precision* $p = \frac{tp}{tp+fp}$, *F-measure* $F_\alpha = \frac{\alpha^2 \times p \times r}{\alpha^2 \times p + r}$, *fallout* $fall = \frac{fp}{fp+tn}$, and *accuracy* $acc = \frac{tp+tn}{tp+tn+fp+fn}$ evaluation measures for information retrieval were used [40].

Evaluation measure evolution during annotation process experiment is shown in Table 1. Column ko represents the knowledge object being processed, # desc is the number of descriptors retrieved from the knowledge object, # asig is the number of descriptors assigned to an ontological term, # non-asig is the number of descriptors not assigned to an ontological term (i.e. # desc – # asig) and F_1 is the F-measure evaluated with $\alpha = 1$.

Results accomplished convergence around a value after processing 60 knowledge objects. Such statement implies that the selected number of knowledge objects has been enough to achieve mean values of the chosen evaluation measures. An exhaustive analysis proved that most non-selected nouns by the strategy correspond to tourist destinations; and such terms were not found in WordNet (example Caicos); neither were they found as ontological terms in the domain ontology. For this reason, the architecture includes an ontology evolution strategy that makes the domain ontology evolve. This strategy

[7] Travel ontology available at: http://protege.cim3.net/file/pub/ontologies/travel/travel.owl.
[8] Specializations of travel available at: http://www.kmgroup.santafe-conicet.gov.ar/.

Table 2
Natural language queries.

# Query	Query	# Query	Query
Q_1	Where can I find massage therapy?	Q_{47}	Where can I do bird watching?
Q_2	Where can I do a hut reservation?	Q_{48}	What river can I take rafting classes?
Q_3	What Island can I play volleyball?	Q_{49}	Where can I do gorge swing?
…	…	Q_{50}	What cities offer national park excursions?
Q_{43}	Where can I visit a museum?	Q_{51}	Where can I visit a cathedral?
Q_{44}	Where can I watch antelopes?	Q_{12}	What hotel has jacuzzi?
Q_{45}	What city has gardens?	Q_{53}	Where can I do a ballooning safari?
Q_{46}	Where can I watch cheetahs?	Q_{54}	What city offers shipwreck excursions?

Table 3
Query answers.

# Query	ko_1	ko_2	ko_3	ko_4	ko_5	ko_6	ko_7	ko_8	ko_9	ko_{10}	ko_{11}	ko_{12}	ko_{13}	ko_{14}	ko_{15}	ko_{16}	m_j
Q_1	C	C	C	C	N	C	C	C									8
Q_2	C	N	N	N	C												5
Q_3	C	N	N	N	C	C	C	C									8
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
Q_{43}	C	C	C	C	C	C	C	C									8
Q_{44}	C	C	C	C	C	C	C	C	N	C	C	C	C	C	C	C	16
Q_{45}	C	C	C	C	C	C	C										7
Q_{46}	N	C	C	C	C	C											6
Q_{47}	C	C	C	C	C	C	C	C									8
Q_{48}	N	N	C	C	C												5
Q_{49}	C	N	N	C													4
Q_{50}	C	C															2
Q_{51}	C	C	C	C	C	C	C	C	C								9
Q_{52}	C																1
Q_{53}	C	C	C	C	C	N	N	N	C	C	C						11
Q_{54}	C	C	C	C	C	C	N	N	C	C	C	C	C				13

$Q_{\#}$: Query number #; ko_k: Knowledge object in position k, C: Contain answer; N: Non-contain answer.

allows adding domain terms that are not represented by the ontology, thus ensuring high performance of the annotation strategy.

The evaluation measures value obtained in the experiments implies that most relevant terms of knowledge objects (86.79%) are retrieved and that most retrieved terms (67.06%) are relevant for semantic representation of knowledge objects. Providing recall and precision with equal importance (i.e. $\alpha = 1$), the F-measure, which allows evaluating both measures in just one, took a value of 0.7699. The proportion of non-relevant terms being retrieved in relation to the total of retrieved terms (i.e. fallout) was 14.12%, whereas the proportion of correctly retrieved terms in relation to the total of retrieved terms (accuracy) was 86.21%.

These values reflect a sound strategy for annotating knowledge objects able to retrieve most of the relevant terms and to avoid to recovery terms irrelevant for representing the knowledge object semantic.

6.1.2. Knowledge retrieval strategy

Fifty-four questions were analyzed to evaluate knowledge retrieval strategy performance (Table 2). Retrieved knowledge objects were classified as: Correct (C) or Non-correct (N). This classification was made by a domain expert. Results are shown in Table 3.

Since the position in which each knowledge object is retrieved is an important issue, results are shown according to the order in which they were presented to the query's author. This order implies ko_1 is the first retrieved knowledge object, presented at the top of the answer, followed by ko_2, ko_3 and so on. m_j indicates the number of knowledge objects retrieved for each query.

For each query, a semantic corpus analysis was performed to identify the knowledge objects that should be retrieved for a specific query. Mean Average Precision (MAP) [40] measure was used to evaluate results obtained by the proposed information retrieval strategy. MAP is a standard measure among TREC community,[9] which determines the relation between recall and precision measures (Eq. (7))

$$MAP(Q) = \frac{1}{|Q|}\sum_{j=1}^{|Q|}\frac{1}{m_j}\sum_{k=1}^{m_j} Precision(R_{jk}) \tag{7}$$

[9] http://trec.nist.gov/.

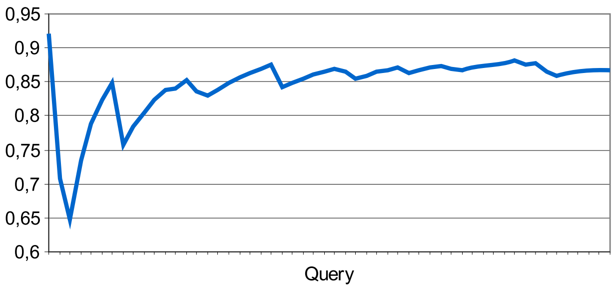

Fig. 8. Mean average precision.

Table 4
25-first ranked nouns proposed to be added.

Ranking	TF-IKOF Wu and Palmer	TF-IKOF Jiang and Conrath	TF-IKOF Resnik
1	maputo (C)	lodge (C)	maputo (C)
2	luanda (C)	terrace (C)	concession (N)
3	pound (N)	thrill (N)	pound (N)
4	assistance (C)	transfer (C)	luanda (C)
5	concession (N)	trip (C)	assistance (C)
6	wilderness (C)	address (N)	wilderness (C)
7	assistant (C)	hunt (C)	victoria (C)
8	tip (C)	pirogue (C)	tip (N)
9	harare (C)	cake (C)	kalahari (C)
10	falls (C)	dive (C)	lodge (C)
11	victoria (N)	hike (C)	center (N)
12	lighthouse (C)	decline (N)	beetle (C)
13	kalahari (N)	descent (C)	gemsbok (C)
14	membership (N)	sign (N)	falls (C)
15	olive (C)	field (C)	livingstone (C)
16	lodge (C)	theater (C)	seal (C)
17	rand (N)	tumble (C)	harare (C)
18	foundation (N)	bloom (N)	explorer (C)
19	gemsbok (C)	peak (C)	assistant (C)
20	landrover (N)	play (N)	olive (C)
21	grove (C)	timber (C)	grove (C)
22	beetle (C)	woodland (C)	cruise (C)
23	center (N)	transport (C)	bridge (C)
24	conduct (N)	search (N)	dune (C)
25	explorer (C)	dance (C)	kayak (C)
	Precision: 0.60	Precision: 0.72	Precision: 0.80

where, $q_j \in Q$ is query j, $Q = \{q_1, q_2, \ldots, q_n\}$ is a set of queries; $|Q|$ is the number of queries included in Q, m_j is the number of retrieval results to query q_j; ko_k is the retrieved knowledge object in position k; R_{jk} is the set of ranked retrieval result from the top result until getting to knowledge object ko_k, $R_{jk} = \{ko_1, ko_2, \ldots, ko_k\}$.

Fig. 8 shows the evolution of MAP value depending on the number of processed queries. As can be seen, MAP values show a convergence that is consolidated as the number of objects increases. This convergence is stable from 60 processed knowledge objects and remained invariant over the next 90 knowledge objects, completing the total of 150 processed knowledge objects. Such statement implies that the selected number of knowledge objects has been enough to achieve mean values of the measures used to evaluate the strategy.

Final MAP convergence value was 0.86. This value indicates that in most cases relevant knowledge objects were correctly ranked at the top of the list.

6.1.3. Ontology evolution strategy

Africa Travel domain was selected to evaluate the ontology evolution strategy. After applying the annotation strategy to 35 knowledge objects, 1900 missing nouns were detected. These missing nouns were ranked according to a relevance index (Eq. (1)), using Wu and Palmer (Eq. (3)), Resnik (Eq. (4)), and Jiang and Conrath (Eq. (5)) similarity measures.

Table 4 shows an extract of 25-first ranked nouns proposed to be added to the domain ontology in each case. In order to try out the strategy performance, nouns were manually sorted as Correct (C) (those nouns that should be added to domain ontology) and Non-correct (N) (those nouns that should not be added to domain ontology).

Results show TF-IKOF-Resnik combination brought about the best results with a precision of 0.80, compared with 0.72 and 0.60 provided by the other combinations. This result indicates that the 80% of nouns recommended by the strategy to be added to the domain ontology were correctly proposed for their incorporation.

Table 5
Ontological terms associated to the new terms.

Noun	Ontological term	C/N
maputo	Capital	C
luanda	Capital	C
assistance	Resort	C
wilderness	Forest	C
victoria	Emperor	N
kalahari	Desert	C
lodge	House	C
beetle	Insect	C
gemsbok	Oryx	C
falls	Drink	N
livingstone	Park	C
seal	Seahorse	C
harare	Capital	C
explorer	Park	C
assistant	Fish	N
olive	Coffee	C
grove	Garden	C
cruise	Boating	C
bridge	Casino	N
dune	Bar	N
kayak	Canoe	C

From the 21 nouns proposed by TF-IKOF-Resnik combination (Table 4), the ontology evolution strategy proposed an ontology branch in which each new term should be added. The ontological term proposed for each noun manually sorted as correct is shown in Table 5.

Results show that 76% of ontology branches recommended by the strategy for adding nouns were correctly proposed. These recommendations facilitate the ontology evolution process by reducing the time spent by the ontological engineer in locating the correct place where new terms must be added.

This strategy is a domain-independent approach for ontology evolution during the process of annotating knowledge objects. It makes the domain ontology evolve by adding domain semantics with high precision levels (80%). It does not need a domain learning stage and contains all essential components to extract specific terms used by domain workers from structured and unstructured knowledge sources. Additional linguistic analysis methods, such as collocation patterns and linguistic patterns, are not required for capturing domain-relevant terms, contrarily to approaches for creating domain ontology from scratch.

7. Comparative analysis of KM models

Several KM models with different focuses were proposed. Most known KM models were developed in the 90's. These model focuses reveal their emphasized requirement orientation (Table 6). The model proposed by Leonard-Barton [36] suggests that organizational knowledge building occurs by combining individualities with a particular set of activities enabling organizational innovation. The model focuses on managing interaction between organizations' technological capabilities and knowledge development activities (requirements I, IV.1, IV.2, and IV.3).

Arthur Andersen and APQC [6] propose a KM model that comprises two parts: KM processes and enablers. KM processes include creation, identification, collection, adaptation, organization, application, and sharing, while enablers are technology, measure, leadership, and culture (requirements II, IV.1, IV.2, and IV.3).

Wiig [76] focuses on managerial issues (requirement II) that affect KM behavior in an organization. In doing so, this model identifies several function components survey and categorizes knowledge: analyze knowledge and knowledge-related activities (requirements IV.1, IV.2 and IV.3), elicit, codify, and organize knowledge.

Nonaka [47] proposed a model that identifies four kinds of "knowledge conversion" that drive knowledge creation: socialization, externalization, internalization, and combination (requirement IV.1). These conversions are based on a dichotomy between tacit versus explicit modes of knowledge.

Choo [15] identifies knowledge manipulation activities that operate in a "knowing organization." According to Choo's model, an organization uses information strategically for sense making, knowledge creation, and decision making (requirements I and IV.1).

Van der Spek and Spijkervet [62] present a model that identifies a cycle of four KM stages: conceptualize, reflect, act, and retrospect (requirements IV.1, IV.2, and IV.3). KM stages configuration is oriented towards a problem solving cycle. Cycle stages are impacted by internal (culture, motivation of employees, organization, management, and information technology) and external developments (requirement VII).

Petrash [50] developed an intellectual asset vision and an implementation model, including approaches and tools to enable the company to maximize the value of its intellectual assets. The model focuses on identifying types of intellectual

Table 6
Adequacy of KM models to requirements.

Requirement	Wiig	Nonaka	Leonard-Barton	Arthur Andersen	Choo	Van der Spek Spijkervet	Sveiby	Petrash	Meyer and Zack	Szulanski	Alavi	Bukowitz and Williams	Weick	McElroy	Bennet and Bennet
I			✓		✓							✓			✓
II	✓			✓			✓	✓				✓	✓	✓	
III															
IV.1	✓	✓	✓	✓	✓	✓			✓		✓	✓	✓	✓	✓
IV.2	✓		✓	✓		✓			✓	✓	✓	✓	✓	✓	✓
IV.3	✓		✓	✓		✓			✓		✓	✓	✓	✓	✓
V															
VI															
VII				✓		✓									

capital. As such, it is oriented to characterizing an organization's knowledge resources: human capital, organizational capital, and customer capital (requirement II).

KM model proposed by Sveiby [66] focuses on understanding knowledge resources, but it is oriented to intangible assets (requirement II). The model is made up of three components: external structures, internal structures, and employee competence.

Szulanski [68] uses a communication metaphor to analyze intra-firm transfer of best practices (knowledge). Four barriers for best practices transfer were identified (requirement IV.2): characteristics of knowledge transfer (causal ambiguity and unproveness), characteristics of knowledge source (lack of motivation and perceived unreliability), characteristics of knowledge recipient (lack of motivation, lack of absorptive capacity, and lack of retentive capacity), and characteristics of context (barren organizational context and arduous relationship).

The model proposed by Alavi [3] focuses on a sequence of knowledge manipulation activities: acquisition, indexing, filtering, linking, distribution, and application that occur in a specific organization (requirements IV.1, IV.2, and IV.3). The model proposed by Meyer and Zack [45] derives from the work on information products design and development. A number of lessons learned from the cycle followed by physical products within an organization (acquisition, refinement, storage retrieval, distribution, and presentation) can be applied to knowledge assets management (requirements IV.1, IV.2, and IV.3). Bukowitz and Williams [13] describe a KM process model that outlines the way in which organizations generate, maintain, and deploy a strategically correct stock of knowledge to create value (requirements II, IV.1, IV.2, and IV.3). Some defined stages focus on more long-range processes of matching intellectual capital to strategic requirements (requirement I).

In the 2000s more comprehensive models have been developed. McElroy [43] describes a knowledge life cycle that consists of knowledge production and knowledge integration processes (requirements IV.1, IV.2, and IV.3) with a series of feedback loops to organizational memory, beliefs, and claims and business-processing environment (requirement II). Bennet and Bennet [9] describe a complex adaptive model to KM. The model is composed of living subsystems that combine, interact, and coevolve to provide the capabilities of an advanced, intelligent technological and sociological adaptive enterprise. Key processes of this intelligent complex adaptive model are understanding, new ideas creation, problem solving, decision making, and action taking (requirements I, II, IV.1, IV.2, and IV.3).

Weick [74] proposed a theory of sense making to describe how chaos is transformed into sensible and orderly processes in an organization through shared individual interpretation. The author proposes that sense making in organizations consists of four integrated processes: ecological change, enactment, selection, and retention (requirements II, IV.1, IV.2, and IV.3).

Each of these models, in its own way, contributes to understanding KM phenomena, as it is summarized in Table 6. Most of these models were developed under a special KM perspective or as a solution to a particular organization. This is why most of these models cannot be extrapolated or adapted to other organizational settings. This lack of a holistic perspective has lead many KM implementations to failure, contributing, at the same time, to managers' skepticism towards these initiatives. Later, and as a short-term solution, KM practitioners began to develop adaptations of these models for specific areas (education, consulting, etc.) that focus on technological solutions [25,35,57,59].

8. Conclusions and future work

The set of requirements that should be met by a KM model are identified in this work, which allowed generating a holistic KM Conceptual Model that defines a comprehensive framework for implementing organizational KM approaches.

This model application supports integration between technological and social aspects of KM, and allows an organization to take awareness of the knowledge it holds and the communities that generate it, bringing about the alignment of KM initiative with organizational strategy and culture. The core shifted from an overemphasis on information technologies, frequently found in current KM approaches, to an organizational structure made up of communities of practice and communities of knowledge.

The proposed architecture provides technological support for knowledge representation and retrieval activities involved in KM Conceptual Model. This architecture allows implementing a distributed organizational memory that helps to represent knowledge context through an ontological model, providing a local perspective of each knowledge domain within the organization. Domains can choose appropriate mechanisms and politics to manage local knowledge, and coordinate knowledge sharing among them while keeping their autonomy.

Experimental results showed that knowledge annotation strategy defines suitable support for workers to annotate the knowledge objects they generate, who may increase precision value through a manual process for selecting descriptors ranked by the strategy. MAP values resulting from the combined effect of knowledge annotation and knowledge retrieval strategies showed good performances. Ontology evolution strategy testing showed that this strategy can provide ontological engineers with suitable support for enlarging the domain ontology. This strategy assumes there is a previous domain ontology to be enlarged, and thus additional statistical techniques, machine learning algorithms, and linguistic analysis methods are not necessary to capture relevant terms, as in the case of those approaches that create domain ontologies from scratch.

The strategy that supports knowledge objects incorporation into organizational memory minimizes the workload, and the strategy for processing natural language queries facilitates interaction between workers and the organizational memory. Future work will be oriented to adding facility in sharing knowledge with partner organizations, to developing advanced recommender mechanisms to propagate users' queries between knowledge domains, and to including new annotation and retrieval strategies that allow representing knowledge objects with more complex semantics structure.

The technological architecture presented in this paper is focused on reactive knowledge supply using natural languages query processing for retrieving knowledge objects. As further future work, the technological architecture will be extended including recommendation techniques for retrieving knowledge objects so as to allow proactive knowledge supply to knowledge-intensive workflows [73]. In this way, the technological architecture will be able to provide organizations with knowledge in both a reactive and a proactive way.

Finally, future work will be also focused on providing the technological architecture with mechanisms to support the creation of groupware and to share tacit knowledge among workers in an organization.

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