Abstract—In open information systems, users can act as consumers and producers of meaningful content. They can have an active role in capturing the semantics that they use within their communities. This approach uses the notion of web blackboards, which provide a playground for participants to reach better agreements about a some topic. Multiple blackboards can be connected, forming networks where the content within a blackboards automatically spread. In this approach, the blackboards might converge or diverge in distinct variants, providing a model where distinct local agreements or ontology views can co-exist within a system. The social construction dynamics benefit from mapping analysis and pattern observation, aiming to increase the underlying community awareness. In the same way, these dynamics are persisted, aiming to capture the community shared understanding across time.

I. INTRODUCTION

Today we face an big opportunity regarding the elicitation of meaning from the crowds. In the open information systems, users are no longer passive users of online resources, instead they now can act as consumers and producers of meaningful content and have an active role in the enrichment of resources. This content can be used by these communities to collectively construct local views of their world. The interplay between those views enable a scenario where interoperability emerges from heterogeneous semantic playgrounds, facilitating the users mechanisms to share meaningful information and communication means.

Currently, we make use of ontologies, which are artifacts that facilitate information sharing and “understanding” between agents. In IT related domains, an ontology is understood as a shared, computer stored conceptualization in a formal language agreed upon a group of stakeholders that enables system interoperability [9]. To facilitate the construction of these artifacts, we propose what we call web blackboards, which are data spaces where a group of participants can share descriptions about some observation subject. The participants are free to create and join to arbitrary number of blackboards, seeking peer-to-peer collaboration to fulfill their sharing needs. Within a blackboard, the participants contribute descriptions using distinct representations, incrementally seeking effective ways to express their conceptualizations. Those description artifacts can be for example texts or web resources gathered and shared within the blackboard. Additionally, several blackboards can be connected through mappings for description sharing, following the notion of “meaning network”.

The objective of having such networks, is to provide a “playground” where participants can incrementally seek an acceptable degree of agreement about their understanding of some topic of interest. In this interplay, local agreements or “ontology views” are constructed organically. When the participants cannot agree about some conceptualization, they are free to create autonomous variants of some blackboards. In the same way, if two blackboards are “talking about” two “similar” things, they can be marked for merging.

Additionally, the history of changes for each blackboard is traced, expecting to better capture the shared community understanding across the time. Such a history will allow the community to learn more about itself based on a concrete knowledge artifact. This knowledge can be used to improve the community capacity to perform high level interactions, such as making collective decisions.

This paper is organized as follows. Section II describes current work. Section III describes with more detail the notion of a web blackboard. In section IV we explain how users can interact within a blackboard. Section V shows a reference about how these artifacts can be represented in the web. Section VI explain how these ontology views evolve locally. Section VII introduces the notion of a semantic neighborhood. Finally, Section VIII presents our conclusions and future work.

II. RELATED WORK

Social elicitation of semantics has been addressed through multiple approaches. Currently, social annotation is the most commonly used method to enrich semantically the content in large-scale open systems [15]. Here, the communities annotate the published resources using tags or social bookmarking, usually assisted by community driven mechanisms such as recommendations that promote copy, transform and combine behaviors. In this way, social bookmarking evolves towards patterns of common terminology usage, called folksonomies that are commonly used for content exploration via terminology driven navigation systems. The use of folksonomies with formal languages and ontologies have been summarized and compared in [13], showing methods that vary from graph transformations Mika (2005) [14] to mapping clusters of tags into web ontologies [1].

Another approach is to use ontology engineering methodologies within a community of users, where the users usually must understand very well the domain. Those methodologies
can vary in the level of detail used to specify activities, techniques and representation formalisms. In the same way, methodologies can adopt distinct strategies for identifying concepts (bottom-up, top-down or a combination), etc. We can count several ontology-engineering methodologies that have been discussed and compared in numerous surveys [8], [10], [18]. These methodologies essentially address the inherent difficulty of managing an ontology, which in most of the cases cannot be considered to be static, whereas an ontology is an artifact that reflect our gradual understanding about reality. If this understanding must meet the community requirements, then it should evolve collectively.

Alternatively to traditional ontology engineering techniques, Cudr-Maurux [5] presents a relevant work about how semantics can emerge from agents in the wild. He considers global interoperability as emerging from collections of dynamic agreements between autonomous self-interested agents. Those agents interact following a Peer-to-Peer paradigm, where the agents interact via mappings. These mappings allow the formation of semantic neighborhoods of agents. These useful notions of mapping and neighborhood have been adopted in this paper to better support this blackboard based approach.

Of special interest are the approaches that doesn’t aim to reach global interoperability. This can be the case of Frisco report [7] where constructivist’s notions are considered essential for the construction of information systems. Here, ontology views are used to enable a inter-subjective annotation spaces, where knowledge artifacts are categorized into shared and private spaces. Shared knowledge is seen here as the sum of all individual conceptions of the community, whereas personal knowledge is the individual’s inner reflections about their conceptions. Similar notions were found in contested collective intelligence [6], which states that is not necessary or possible to reach context-independent ontologies. Taking this into consideration, we can say ontologies need to co-evolve along with their communities of use, disclosing multiple perspectives.

III. WEB BLACKBOARD MODEL

People naturally refer to their observed reality using a wide variety of languages and notations that allow them to say things about their perceived world and finally share information with others. For example, if someone wants to describe and communicate a music theme, he or she can use a handwritten sheet following some music notation or provide examples through a recording or just interpret the music. Furthermore, when received, those descriptions are subject to be copied, modified and combined by other people, usually composing distinct description artifacts. One example of a composed artifact could be a video that shows an animated musical notation system playing the same interpreted music as background.

When multiple persons want to agree about some representation of a particular observed subject, they may decide to interact via sharing partial descriptions, collectively trying to converge into the best representation possible. Through this paper a notion of shared ‘blackboard’ is adopted to refer to the dataspace where this interplay occur. Blackboard systems have a long research history [4], they are artifacts intended to facilitate the incremental construction of a knowledge base to be used by artificial intelligence applications. In a web application context, a blackboard can be seen as a simple extension of a ‘web document’ that allows the interaction of multiple participants within a network, in order to reach agreements. For reasons of scalability this web based blackboards are universally identified using standard mechanisms such an URL.

To characterize this blackboard we use semantics. Semantics classically concerns a triadic structure comprising a symbol (how some idea is expressed), a conceptualization (what is abstracted by someone from reality) and a referent (the observed thing or concept).

In the Fig. 1, we can see how two participants share their representations of a certain referent (observation subject), trying to approximate their own conceptualizations using a blackboard. Its important to note that in this approach, conceptualizations cannot be separable from the observer, and each time that a person contributes with a partial description, a link between the person and its contribution will be traced in the blackboard. This mechanism allows to distinguish distinct personal perspectives to explore the descriptions. In this diagram we can also observe that the ‘symbol’ vertex is split in multiple alternatives, showing that a symbol can be expressed through distinct representation mechanisms such as languages, measurements or models. Those representations are just examples since the possible representations of symbols may be infinite.

Following this notion, we will allow distinct description representations within a blackboard. Several representations may be combined according to the distinct degrees of “precision” or “expressiveness” required. In the same way, when its possible, one can construct translation mechanisms or “mappings” in order to transform one description representation into another. Those directed mappings are intended to improve our sharing capabilities, although they may incur in information losses depending on the expressiveness of the description mechanisms involved. A mapping can be characterized as an ordered sequence of operations capable of transform one representation into another. If a directed mapping exists between two distinct blackboards, we will say that they are connected for some representation.

IV. INCREMENTAL INTERPLAY

Whether a set of participants interact within a certain blackboard, representations of their internal conceptualizations will be put at disposition to others. These processes of information sharing can be characterized by Nonaka’s [16] in four modes of knowledge conversion: socialization, externalization, combination and internalization. These processes have been previously adopted into ontology evolution methodologies [12], where distinct stakeholders iteratively interpret and model their
Fig. 1. Two observants trying to reach agreements about certain observation subject. In this interplay, observants contribute distinct representations of their own conceptualizations to generate feedback for their community.

During the incremental interplay within a blackboard, there will be cases where some participants disagree with others regarding some representation for an observation subject. Thus, agreement mechanisms will be used in order to reach agreement, examples of such mechanisms can be dialogues or voting systems. Also, there will be cases where distinct participant’s views will become irreconcilable within a certain blackboard. Think for example about participants saying that unicorns are real in contrast with others saying that they are fictitious. In those cases the blackboard itself may diverge into distinct variants, intended to capture distinct semantics. The participants are free then to commit to the new variants if they prefer. Additionally, and if is possible, a mapping is created for the new derived blackboards, intended to share information between them.

In the same way, participants may realize that they are describing the same observation subject in two or more blackboards. In this case they can choose whether to create mappings between the distinct representation mechanisms or just merge distinct blackboards into a new one.

This model of diverging and converging, provides a strong support for non-linear development, following an approach that currently is used in large scale scenarios such as collaborative software coding sites that use distributed version control systems (DVCS)\(^1\). In these sites, users are able to work in parallel on distinct versions of code repositories, making use of cloning and merging functionality. These repositories are not centrally controlled. We count with several distributed control versioning mechanisms such as Git\(^2\) and Mercurial\(^3\) among others.

These mechanisms allow us to persist each divergence and convergence, maintaining a complete traceability of the connectivity dynamics between the blackboards, allowing us to visualize interesting phenomena such as neighborhood evolution. This follows the notion of remembrance (act of remembering), and provides a powerful mechanism to learn from the community shared understanding across time.

Although to achieve this we can directly adopt the current DVCS models, we still need to take into account some considerations. First we need to keep a consistent history of the blackboard participants and their contributions, such as descriptions artifacts for observed subjects. Secondly we need to keep track on changes of representation of each description artifact. For example keeping a link between a PDF file and the latex file that was used to generate it, or linking a excel file with an alternative representation of its data that is more suitable for querying.

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\(^1\)http://en.wikipedia.org/wiki/Distributed_revision_control  
\(^2\)http://git-scm.com  
\(^3\)http://mercurial.selenic.com
V. Representation model

To support this incremental interplay and to express the community interactions, this approach adopts the representation model presented in [17]. Here, notions like annotation space and domain context (blackboard) are explicitly represented using multiple RDF\(^4\) graphs. RDF is merely a data model; namely subject-predicate-object “triple”. RDF allows us to of “break down” knowledge into discrete pieces that can be linked via dereferenceable identifiers, providing a extremely powerful mechanism to connect disparate data items across the web.

Within the community interaction, the participants will use applications to register their contributions. In this representation model, these contributions are represented using distinct shared vocabularies, which in turn use the RDF data model underneath. For the sake of clarity these vocabularies can be categorized in distinct levels: (i) pragmatical level, which are vocabularies that support communication between users like the representation of dialogues (ii) empirical level, that refer to vocabularies about high precision artifacts used to observe the subjects, for example a photograph or a music recording (iii) semantic level, which refer to the models or schemes created via human abstraction, such as an ontology.

In the same way it is convenient to make a distinction between a shared space which refers to the descriptions contributed via one web blackboard and a personal space, which is used by the participants to support their own understanding, for example persisting data such as description drafts or private annotations. We can say that a personal space would represent a participant’s internalization space.

Additionally, the RDF model is also used to represent the blackboard branching and merging dynamics, where a directed acyclic graphs (DAG) is used to persist the evolution of the distinct blackboard states, keeping track of the following: i) branching of a blackboard ii) merging two blackboards with a common ancestor. iii) generic metadata about each blackboard state, such as subscribed participants.

VI. Ontology view evolution

We have seen how we can divide an annotation space in three levels, pragmatic, empirical and semantic, where portions of those levels can be either public or private. In this section we will focus on the “public semantic space” level, that is composed by ontology views.

We can say that an ontology view is not just a portion of a complete ontology. Rather is a collection of concepts and relationships that allows a unique interpretation by the participants of a certain domain, in this case the blackboard. In the same way as ontologies, ontology views may be described using metadata representation languages such as RDF, RDFS\(^5\), OWL\(^6\) among others. To better support this model, we adopt the definition presented by Chang et al [3] that allows us to include the notion of change operators in order to support coherent ontology view mutations. These ontology views may hold explicit references to any descriptions within the blackboard.

If we characterize these ontology views in terms of their dynamics, we can say that an ontology view will be the result of a change with respect to the previous one. These changes are performed using distinct change operators, which are applied by the participants directly at the public semantic space level of a blackboard.

These change operators can be constructed following varying degrees of abstraction, which can range from very granular such as add concept and delete concept, to more domain specific ones such as link MP3 file to song type, which can be constructed via composition of more granular ones via layered operator frameworks [11]. The change operators that will be used in each interplay will depend on factors such as application complexity and should be chosen or constructed by the participants themselves.

The importance of the notion of change operators relies on maintaining the consistency of each ontology view [2] and on the possibility of mapping them into update segments to be used appropriately to transform representations. In other words, this helps us to create the mappings between ontology views.

In each ontology view mutation, the sequence of operators that conform the change is persisted. Also, this sequence is augmented with the dialogues\(^7\) which have supported the agreement between the members. In this way we keep a more precise change history, that allows us to track the ’good reasons’ that motivated the ontology view mutation at a certain moment.

VII. Semantic neighborhoods

We have seen how distinct blackboards can expand into distinct derivations, and how they can collapse into new blackboards. We also use the notion of mapping, that provide a mechanism of translation between “connected” blackboards. Those mappings might be created manually or derived from a blackboard divergences, with the help of recorded operators.

In this approach, we will call neighborhood to a connected set of blackboards which can translate some representations without loosing information. We can say that within a neighborhood, some descriptions can be shared through directed mapping paths, transforming transitively their representations. Additionally, we will call semantic neighborhood to a neighborhood that is connected at the semantic level, or in other words, a neighborhood that counts with explicit correspondences between their underlying ontology views.

We expect that through the incremental interplay of communities, the amount of mappings should increase. If this is the case, at a certain point these mapping paths will form cycles with respect to some representation translation. Then, we can

\(^4\)http://www.w3.org/TR/rdf-syntax-grammar  
\(^5\)http://www.w3.org/TR/rdf-schema  
\(^6\)http://www.w3.org/TR/owl-ref  
\(^7\)These dialogues can be persisted and categorized in the public pragmatic layer of a blackboard
say that some descriptions can be shared from one blackboard to any other blackboard within the same cycle. When this occurs, descriptions from each blackboard can be subject to inspection by the participants of other blackboards, potentially using other representations.

A more interesting case occurs when a cycle is found at the level of ontology views, because we can suspect that distinct blackboards share very similar semantics. If this is the case, the involved ontology views can be marked as candidates for semantic reconciliation, potentially leading to inter-blackboard meaning convergences. This convergence process is facilitated through inspection\(^8\) of descriptions from the involved blackboards. If this interplay finally result in a convergence, the participants may decide to (i) merge the involved blackboards (ii) or create a new blackboard devoted to a new observation subject, which can be for example an abstraction of the candidates for semantic reconciliation.

On the other hand, if the convergence process fails, then we can suspect about sub-optimal mappings or the coexistence of very distinct conceptualizations within the same semantic neighborhood. If this is the case, some blackboards may be selected to diverge.

This notion of marking candidates for semantic reconciliation can be applied in additional setups. One practical example is to relate blackboards using explicit relationships such as causality, location, function etc. In this case, we may want to find patterns instead of just cycles. For example, checking for multiple incoming “part-of” relationships, in order to provide useful feedback to the participants regarding composition.

\(^8\)Note that some of the descriptions might be perceived as emergent by the participants, since they come from other blackboards via representation translation.

**REFERENCES**


