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SOAF: Semantic Indexing System Based on Collaborative Tagging

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Abstract

The creation of Learning Objects and learning assets for e-Learning, as well as the development of more and more extensive repositories, is actually a generalized practice in all educational organizations. However, automatic tools for searching and locating learning content in these repositories based on semantic tags are not yet effective.

This article proposes a system architecture called SOAF for the semantic indexing of Learning Objects from a repository. It combines automatic techniques of information retrieval with collaborative tagging of documents made by users. In this way, the metadata of the Learning Objects provides real meaning derived from the learning practice in user communities able to share their experiences through specific annotation of the learning content, which will identify each Learning Object and will improve its reusability in new learning contexts.

Keywords: Semantic indexing, emergent semantic, semantic gap, Learning Objects, users annotations, social learning, social tags, folksonomy.

Introduction

There is a need for the design and development of information management systems based on semantics to guarantee the reusability of the Learning Objects and learning assets in different learning contexts. These systems have to be able to categorize extensive collections of Learning Objects and learning assets in the increasingly expanding repositories and to infer their real meaning, taking into account user's qualitative descriptions based on real learning experiences.

However, existing technologies for concept based description of web resources are still not very advanced. At the same time, the multiple and distinct media types used in the design of Learning Objects require specific techniques for each of these types.

The analysis of textual information is usually more affordable as the use of keywords for syntactic searches makes it possible to break the text into separate paragraphs and words. However, in the case of multimedia assets, the minimum unit is much more difficult to divide and there is still a great distance between high-level descriptions (or concept based descriptions) and low–level visual features that can be automatically ex-

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tracted from data, like color histograms, texture indexing, shape, or contours. The main challenge in this field has been quoted as automatically generated concept based description for multimedia information, and this problem is known as “bridging the semantic gap”. Currently, there is a lack of tools that can automatically manipulate the high-level concepts of an image or video.

There have been many attempts to solve the problem of the semantic description of multimedia assets (Moenne-Loccoz, Janvier, Marchand-Maillet, & Bruno, 2005; Stamou & Kollias, 2005). One of the first – using the MPEG-7 format to store multimedia metadata – was made by Hunter in 2001, who first developed a specific ontology using DAML-OIL. As part of the aceMedia Project (Bloehdorn et al., 2005), an ontology was created for visual description of multimedia content that has been incorporated in the MPEG-7 visual metadata. The MPEG-7 format provides detailed formatting information and fine-grained descriptions of the structural and low-level audiovisual features of multimedia content as follows: the Description Definition Language (the basic building blocks of MPEG-7), Audio (the descriptive elements for audio), Visual (those for video) and Multimedia Description Schemes (the descriptors for capturing the semantic aspects of contents, e.g. places, objects, events.)

Some of the proposed solutions for automatic semantic description include dividing the image into regions with similar visual features and assigning them semantic labels using statistical methods (Fan, Gao, Luo, & Xu, 2004; Pan, Yang, Duygulu, & Faloutsos,, 2004), EM algorithms (Duygulu, Barnard, Freitas, & Forsyth, 2002), or recent probabilistic models like the Cross Relevance Model (Jeon, Lavrenko, & Manmatha, 2003).

Recently, more and more websites allow their users to use collaborative tagging of different types of resources in order to annotate and categorize Web content. The result is known as folksonomy, social classification or social indexing of web content. In contrast with the traditional method of adding semantics, metadata is not created by experts but it is spontaneously generated by consumers (Cattuto, 2006; Marlow, Naaman, Davis, & Boyd, 2006). Other sites, like Amazon, have implemented social filtering algorithms based on the similarity among users’ profiles in order to offer better recommendations of their products (Linden, Smith, & York, 2003).

There are several websites that base their strategy on collaborative tagging, like del.icio.us, Tecnocrati, and Flickr (Marlow et al., 2006) which allow their users to annotate resources, like a web page, a blog post, or an image, normally using free sets of tags and enabling their sharing and reuse.

The integration of collaborative tagging and the emergent semantic has been recently proposed introducing the Navigation Map (Aurnhammer, Hanappe, & Steels, 2006a) concept that links users, tags, and data. This system is able to assign different meanings to the same tag using the visual features of an image.

This paper proposes a system architecture called SOAF (SOAF comes from Spanish “*Semántica de los Objetos de Aprendizaje basada en Folksonomías”* which could be translated as “*semantics of learning objects based on folksonomies”.)* that integrates collaborative tagging to improve emergent semantic descriptions for Learning Objects and learning assets. The SOAF system combines the information retrieval techniques based on emerging semantics with specific annotations resulting from real learning experiences of users in learning communities.

Social Networks on the Semantic Web

Social networks are representations of the relationships between individuals and groups of individuals in a community. The social links created in social network analysis have many applications in different scientific fields like sociology, psychology, informatics, etc.

The social network concept describes social relationships in terms of nodes and edges, where nodes are the individual actors within the networks, and the edges are the relationships between the actors, as shown in Figure 1 (Barnes, 1954).

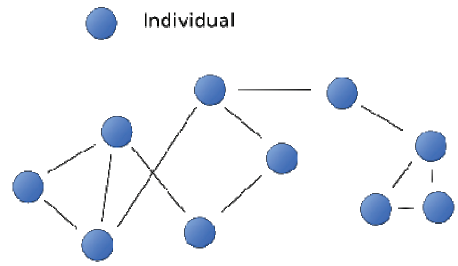

Figure 1. A social network diagram

Internet-based applications that use social networks – known as virtual social networks– provide new ways of socialization, finding friends, finding business partners, or simply connecting people who have common interests. This is the case of the Website Friendster, conceived as a social network based on the Circle of Friends (social network) and Web of Friends techniques for networking individuals in virtual communities and demonstrating the small world phenomenon applied to the human society characterized by shorter-than-expected path lengths.

Semantic Web Technologies

The semantic web has emerged as a vision of the future of the web with the publication of "machine understandable" data on the web that can be managed automatically by computers according to their content meaning. It can be read and used by software agents, thus permitting them to find, share, and integrate information from diverse sources (Berners-Lee, Hendler, & Lassila, 2001).

At the moment, most of the information published on the Internet is conceived for human understanding. Web browsers are limited to recognizing the mark-up language HTML that allows them to visualize the web pages content on a terminal screen. But the interpretation and manipulation of their content still remains a task that is very difficult to automate.

The development of the Semantic Web implies the creation of technologies to describe the data that appear inside web page, breaking a web page into smaller units to obtain finer granularity. One of the proposed vocabularies is the Resources Description Framework (RDF), which supports the description of resources and the relationships between them. In this way, it will be possible to describe resources in a finer granularity than a single web page or document.

Example: Semantic description in RDF code of a Learning Object about Fractal Geometry:

```
<rdf:RDF xmlns:rdf="..."
         ... >
<rdf:Description rdf:about="http://.../geofractal/estruFractal">
      <rdf:type rdf:resource="http://...#Introduction"/>
      <dc:title>Introducción a la Estructura Fractal</dc:title>
      <dc:creator>
      <lom:entity> <vCard:FN>J. Garrido</vCard:FN></lom:entity>
      </dc:creator>
</rdf:Description>
...
</rdf:RDF>
```

Another key technology in the development of the semantic web is the ability to define concepts and relationships between them and to represent in this way some specific domain of knowledge.

OWL was created to provide a common language for ontology description and is based on descriptive logics. The decentralized development of ontologies will facilitate the integration of data from different sources and different kinds of applications. Based on the previous example, using the OWL language, we could declare that an explanation (Introduction) is a type of lesson (Lecture) and may have various exercises:

```
http://...#Introduction ⊆ http://...#Lecture
```

```
http://...#Introduction ⊆ ∃ http://...#contains http://...#Exercise
```

Collaborative Tagging Systems: Folksonomies

Folksonomies are defined as Internet based collaborative systems for non hierarchical and spontaneous categorization and organization of web resources through shared tags (natural language terms) in a user's community or a social network (Vanderwal, 2007). Through a folksonomy, various users collaborate to describe web data and to create keywords lists or uncontrolled vocabularies.

Folksonomy systems enable users to freely add numerous descriptive keywords to content such as web pages, images, videos, etc, and also to learning assets and Learning Objects. The social tags assigned to the Learning Objects or web resources serve to classify and locate this content. At the same time, social tagging generates a navigation system based on the labels assigned to different web resources and on the existing links between the users that participate in a folksonomy.

From this point of view, the use of collaboratively generated tags improves the management of resources such as search, spam detection, reputation systems, and personal organization through the introduction of new forms of communication and new opportunities for data mining, due to the emergent social structure that underlies folksonomy systems.

Social tagging systems allow their users to share their tags of particular resources. Each tag serves as a link to additional resources tagged in the same way by other users (Marlow et al., 2006). Certain resources may be linked to each other; at the same time, there may be relationships between users according to their own social interests, so the shared tags of a folksonomy come to interconnect the three groups of protagonists in social labelling systems: Users, Resources, and Tags.

Figure 2 shows a conceptual model of a social tagging system where users and resources are connected through the tags they assign.

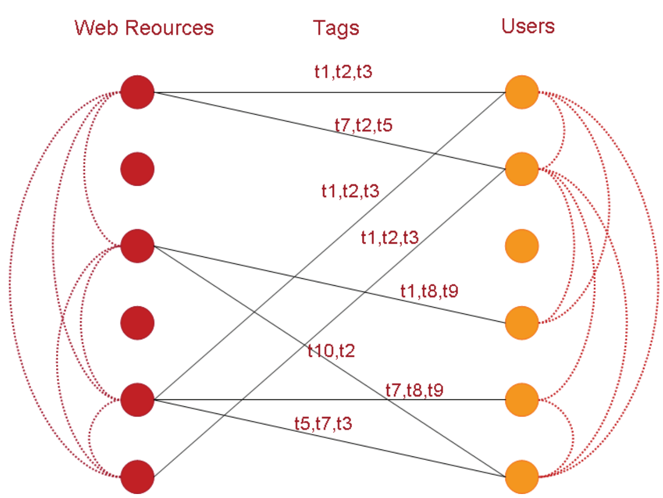

Figure 2. Conceptual model of a collaborative tagging system (Marlow et al., 2001)

Social tags, introduced by a specific person, are very different from expert tags which could be assumed to be more objective and consistent. In this way, social tags are mostly associative and subjective. They become social tags when they are shared over a users' community that creates an implicit feedback for both users and tags. It can be observed that over time, the relative frequency of the tags used to label a specific web resource tends to approach a constant value. This shows that collaborative tagging is able to coordinate users' actions to create coherent and consistent semantic annotations for the shared content. For a given tag chosen from one of the four popular tags on deli.cio.us, a power-law distribution between the number of tags and co-occurring tags has been shown by Cattuto (Cattuto et al., 2007; Szomszor et al., 2007), who predicted that "the most used tags are more likely to be used by other users since they are more likely to be seen."

There are three hypotheses about tags behavior over time (Halpin & Shepard, 2006):

- **Tags convergence**: the tags assigned to a certain Web resource tend to stabilize and to become the majority.
- **Tags divergence:** tag-sets that don't converge to a smaller group of more stable tags, and where the tag distribution continually changes.
- **Tags periodicity**, where after one group of users tag to some local optimal tag-set, another group uses a divergent set but, after a period of time the new group's set becomes the new local optimal tag-set. This process may repeat and so lead to convergence after a period of instability, or it may act like a chaotic attractor.

At the same time, from a pedagogical point of view, the use of social tagging systems in e-Learning proves to be a way of constructing personal context and a technology with a great potential to support self-steered learning. From a constructionist perspective, social tags become meaningful learning assets, where the learner himself is consciously involved in constructing a public entity.

The use of folksonomies, besides being a semantic mark-up collaborative method, is also an opportunity for learning because it generates social learning context. Social tags respond to the constructivist definition that evolution involves transformation from an interpersonal process into an intrapersonal one, and that learning takes place through communication among people in learning communities.

Collaborative Learning Promoted by the Web 2.0

Social software arises in the new context created by the Web 2.0 as a new paradigm of collaboration, with multiple applications such as social networks, wikis, and folksonomies that have been largely accepted by the e-Learning communities, promoting collaborative learning.

Every day there are more frequent virtual learning environments and virtual communities designed from a collaborative learning perspective, introducing new alternative ways of working with the social dimension of knowledge construction. That is why these communities promote an interaction process among students and problem solving in collaboration, becoming social spaces of learning, where the use of shared Learning Objects may contribute to contextualize and to add real meaning to the learning process.

Inside these virtual communities strong ties are established among the members, creating social learning networks whose value increases with each member‘s contribution to the common objective achievement (Owen, Grant, Sayers, & Facer, 2006).

This article proposes the integration of the collaborative tagging systems in the semantic marking-up of the Learning Objects in a repository. Users' collaborative tags are themselves learning resources, generating a social learning context. Students are motivated and involved in the construction of knowledge process through the creation of new personal meanings for the shared learning resources and are developing a new learning context in this way.

The emergent social interactions through the collaborative annotations of the shared resources in dynamic folksonomies force users to constantly reflect on the connections between items and tags which directly implicate the embodied social conceptualization of the learning assets.

Applying folksonomy systems to the learning environments, the reusability of Learning Objects in a repository relies on the collaborative user's annotations that will identify the learning resources. This is the philosophy behind the social tagging systems that we use in the design of our system architecture that we describe below.

Semantic Indexing of Learning Web Resources

The Semantic Web approach breaks the concept of a web page as an information unit, enabling the creation of resource descriptions with finer granularity. For example, from the semantic description of the Learning Object "Introduction to the Fractal Geometry", we could extract the definition of the fractal structure concept or the recurrence property. So, in the Semantic Web context, Learning Objects and learning resources have to be accompanied by the semantic descriptions of their content.

At the present time, Web resources mark-up process still requires manual annotations, especially multimedia resources such as images, videos, sound assets, etc., which need subjective interpretations. Managing large databases of images, for instance, is the well known problem of Image Retrieval (IR). The main challenge in this field is the automatic generation of concept-based descriptions that reflect the real meaning of the images.

Our solution defines a specific system that allows automating the Learning Objects semantic indexing process, combining the emergent semantic with the users' collaborative annotations.

Learning Objects on the Semantic Web

Learning Objects are defined as minimal units with self meaning, built by information assets interactive, represented in various digital formats and based on a single learning objective (Moral & Cernea, 2006). The most important property relating to Learning Objects is their reusability in new and different learning contexts, a consequence of their flexible and granular structure, as shown in Figure 3:

- At the first level of granularity: the lesson items (Information Objects)
- At the second level of granularity: the learning assets that compose the Information Objects (text assets, images, videos, audio assets, …)

While the automatic semantic description could be simpler in the case of text resources, and is based on the keywords extracted from the break up of text into small units, in the case of images, videos and audio assets, the information retrieval needs specific techniques for each type of multimedia resource.

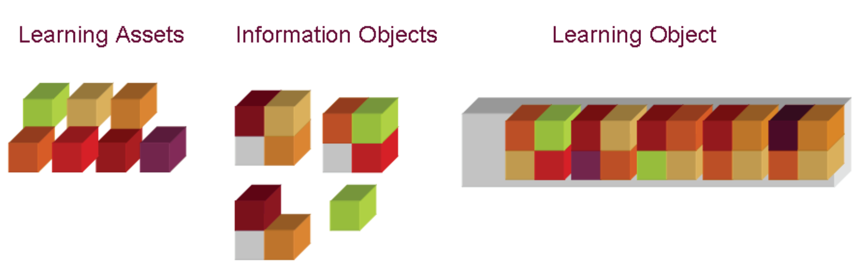

Figure 3: Granularity levels in a Learning Object (CISCO, 2003).

Generally, e-learning repositories are characterized by a high density of multimedia resources. That is why the SOAF architecture system provides three modules for the semantic indexing of these types of resources: image features extraction for semantic indexing, audio processing for semantic description and video analysis for semantic extraction.

However, in the case of multimedia assets the automatic methods for semantic indexing are still inefficient, and for that reason, we propose a system that integrates folksonomy techniques to complete and refine the emergent semantics for Learning Objects in a repository.

The Semantic Gap

There is a distance between the descriptions obtained by automatic methods for multimedia analysis and their real content, known as the semantic gap. The semantic gap is defined as the lack of coincidence between the information extracted automatically by computers and the human perception of the real content of multimedia resources, based on high-level concepts (Hare, Lewis, Enser, & Sandom, 2006), see Figure 4. The state of art of the automatic systems for multimedia analysis, particularly for image analysis, is still limited to low-level feature extraction, such as color attributes, texture parameters, borders, etc.

SOAF provides a representation of all Learning Objects and learning assets in a vector space of visual features that are processed using the Latent Semantic Indexing algorithm in order to extract the semantic definition for the media resources.

SOAF proposes a solution based on the integration of users' collaborative annotations to improve the automatic methods.

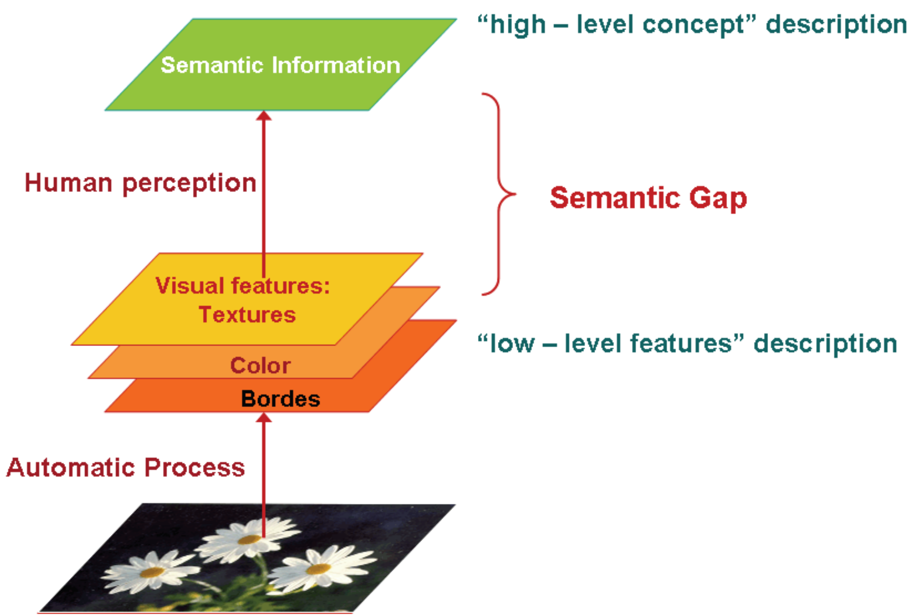

Figure 4. The Semantic Gap

SOAF Architecture: Integration of Collaborative Annotations with Emergent Semantics

The proposed architecture intends to classify Learning Objects in a repository by combining the emergent semantics with the users' collaborative tags. SOAF uses a folksonomy-based technique for the capture of users' annotations, testimonies of real learning experiences with a concrete learning resource. These tags are processed to obtain a set of terms connected with specific field ontology or an ontology network. This way, SOAF completes the semantic indexing obtained by automatic methods with the incorporation of users' collaborative contributions within a learning community.

From this point of view, social tags constitute an optimal solution for completing and refining the emergent semantic descriptions.

Automatic Semantic Extraction with SOAF

SOAF represents each type of media resource through its low-level features in a vector space and processes these vectors using matrix analysis algorithms in order to extract the concept based description. The features set is different for each type of leaning resource analyzed.

The representation of an image through a vector containing the visual characteristics is made using a set of low level features that might be relevant for image identification such as color analysis, textures and boundaries. For color process we chose the normalized histograms and color coherence vector that contribute to describing the distribution of color in the image. Color histograms are a popular method to compare images. Color histograms are computationally efficient, invariant to geometric transformations such as rotations or scaling, and sensitive to illumination changes and noise. But color histograms do not provide any information about the spatial distribution of the colors in the image, they indicate just what colors are present in the image and in what quantities. See Figure 5.

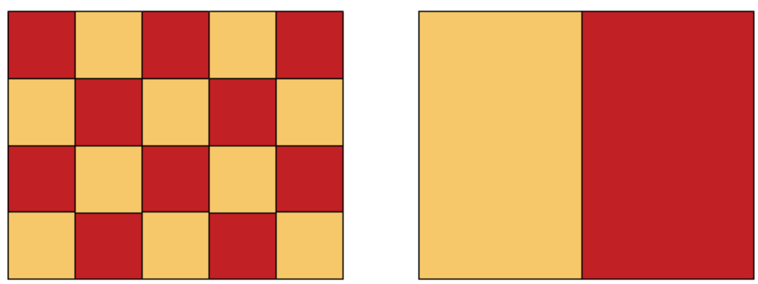

Figure 5. Two images with the same color histogram

In order to overcome this problem and to take into account the spatial distributions of each color present in the image, we consider the Color Coherence Vector (CCV) method proposed by Greg Pass, Zabih, and Miller (1996). The coherence measure defined classifies pixels as either coherent or incoherent. A coherent pixel is part of a large group of pixels of the same color, while an incoherent one is not. The CCV represents this classification for each color in the image. SOAF implements the Java libraries provided by the Discovir project. Another set of features computed in the case of images are the texture's descriptors, which are represented through the grey scale co-occurrence matrix. The final part of the low-level features vector that represents an image contains the invariant moments for shape and boundary.

Audio assets are represented through the Mel frequency cepstral coefficients (MFCCs) derived from the energy spectrum and are adequate for speech and non speech audio resources. MFCCs are obtained through a frame-based analysis of the signal. A Discrete Fourier Transform (DFT) is performed using a hamming window overlapping each frame to obtain an amplitude spectrum.

This spectrum is converted to a Mel scale spectrum using triangular filters emphasising frequencies according to their perceptual importance on this scale (Buchanan, 2005).

For semantic indexing of video content, SOAF uses the approach of Adams et al. (2003) that begin by assuming the *a priori* definition of a set of atomic semantic-concepts (objects, scenes, and events) which is broad enough to cover the semantic query space of interest and starting with a training set of videos. The low-level feature representation is made by a key-frames basis using color and texture descriptors such as in image processing (Guironnet, Pellerin, & Rombaut, 2005).

The SOAF system proposes an architecture for the automatic extraction of semantic descriptions of multimedia learning resources based on Latent Semantic Indexing (Pecenovic, 1997) using the representation of the resources in the $\mathbf{R}^n$ vector space through their visual features. This method uses linear algebra matrix computation to process the multimedia resources in a large data base. The goal of this method is to extract some sort of underlying semantic structure in a set of resources with respect of to the term occurrence in order to construct the index. A truncated singular value decomposition is applied to the features by documents matrix to estimate the structure of the visual features across resources within an observation set. The similarity of the analyzed resource with other resources that already possess a semantic description is calculated using a Euclidean measure. The output of the algorithm is a terms vector containing the weights of each term of preset vocabulary, which reflects the importance of that concept for the analysed multimedia asset. The extracted terms represent the automatic semantic index of the multimedia resource.

The Information Retrieval process in the case of text resources is associated with the complexity of the natural language analysis. For the semantic indexing of this type of e-learning resources, SOAF uses *Natural Language Processing* (NLP) techniques, very popular in the world of web searchers. Semantic indexing of text assets implies that the documents are classified using interpretable concepts described in a field ontology modeled. The main steps in the text analysis are text segmentation, word sense disambiguation, and normalization of the extracted concepts.

Despite all, automatic methods for semantic indexing do not guarantee the reliability of the extracted concepts because these algorithms usually introduce errors in the final information. That is why other complementary methods are needed to complete and correct the resulting semantic descriptions, especially in the case of multimedia resources.

From this point of view, SOAF considers three types of metadata that might describe Learning

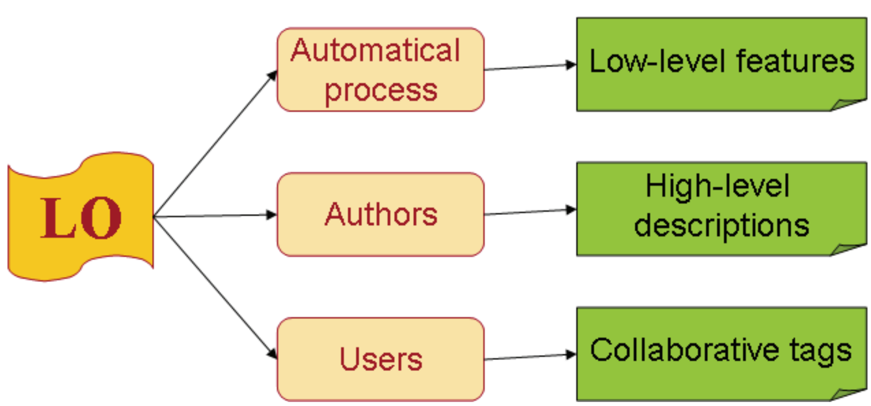

Figure 6: Three types of meta-information that might describe a Learning Object, according to their origin.

Objects or learning resources (Labra, Ordóñez, & Cueva, 2006), as shown in Figure 6:

- Automatic semantic indexing generated from the low-level features,
- High-level descriptors provided by authors (normally refered to the title, date of creation, names of the authors, learning objectives…)
- Collaborative annotations that are given by the end users.

Collaborative Tags

Without any doubt, collaborative tags given by the end users constitute a powerful source of semantic information for Learning Objects in a repository. Social tags bring new knowledge based on the real learning experiences of users. SOAF integrates these collaborative annotations in order to complete and refine automatic semantic indexing based on low-level features extraction.

The proposed SOAF arquitecture as shown in Figure 7, includes an initial vocabulary used in the automatic indexing by the Latent Semantic Indexing algorithm (LSI). After processing users' collaborative tags, the normalized set of new terms introduced by users is inserted into the vocabulary and the whole algorithm is recalculated. To complete the semantic indexing the concepts in the ontology must be linked. But collaborative tagging is different from ontology based approaches, where a group of experts develops an ontology and the resources are linked to that ontology. In the social tagging case, the approach is bottom-up, because the users develop their own tags without any coordination. A Spreading Activation algorithm is applied to the normalized set of terms in order to obtain related concepts in the ontology.

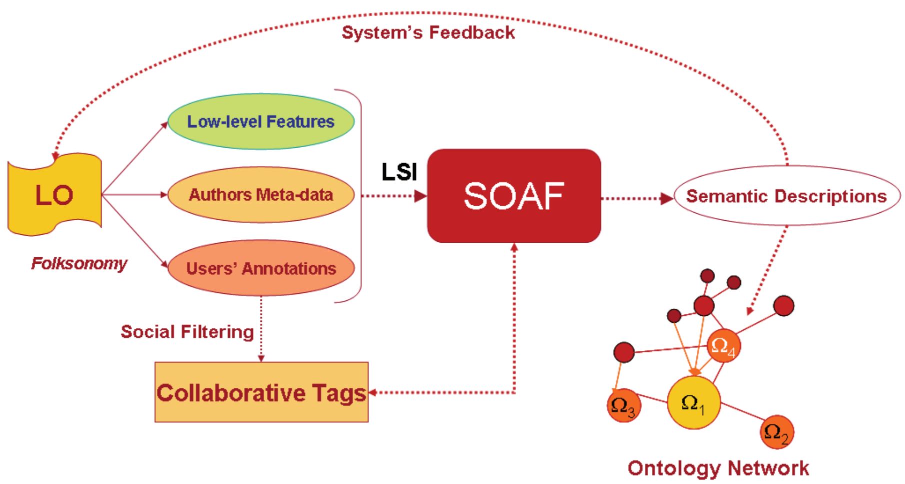

Figure 7. SOAF Architecture

Social Trust Filter for the Users' Collaborative Annotations

Finally, the tags of the users can be filtered applying a social trust test based on the similarity of users' profiles to guarantee their reliability and relevancy (Golbeck & Hendler 2006; Lerman, 2006; Shardanand & Maes, 1995). SOAF applies a Collaborative Filtering (CF) algorithm using the "Word of Mouth" principle used by the Ringo music recommendation system based on the similarity between users' profiles. A measure of similarity proposed by Sardanand and Maes is the Pearson Correlation Coefficients (PCCs) that aims to measure the degree of agreement between two users. PCCs are computed from the ratings $r_{a,i}$ and $r_{b,i}$ that the users a and b rate for the resource i and their user mean r_a and r_b:

$$w_{a,b} = \frac{\Sigma_{i=1}^{N}(r_{a,i} - \bar{r}_a)(r_{b,i} - \bar{r}_b)}{\sqrt{\Sigma_{i=1}^{N}(r_{a,i} - \bar{r}_a)^2 \Sigma_{i=1}^{N}(r_{b,i} - \bar{r}_b)^2}}$$

Through the social filtering, we pretend to give a greater probability to a tag taking into account if the users have similar profiles in order to assign the most relevant semantic information.

Conclusion

The automatic generation of semantic description for learning resources is still an open field. This article proposes an architecture of a system called SOAF for the semantic indexing of the Learning Objects in a repository. The system combines automatic techniques for information retrieval based on Latent Semantic Indexing algorithms with social tagging technologies. The tags assigned by the users in a learning community are filtered using a trust test based on the similarity of users' profiles.

Through the technology presented in this article, the metadata of the Learning Objects is itself a learning resource incorporating the meanings derived from the real learning experiences. Collaborative tagging contributes to a better identification of the learning resources and improves their reusability in new learning contexts. Currently, the SOAF system is part of our ongoing research and we are currently developing a prototype of the system in Java.

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