Collaborative Metadata for Geographic Information

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Abstract: Retrieval of web-based geographic information (GI) for spatial decision-making processes can benefit from emerging semantic technologies. Ontology-supported metadata, collaboratively created by a social network of spatially-aware users, ensures efficient and precise discovery of maps published with the help of catalogs. The creation and maintenance of the metadata is driven by two forces: on the one hand experienced catalogers who ensure consistency and quality, on the other hand catalog users who continuously adapt and extend the metadata. We discuss the requirements for a catalog for GI which is able to capture the semantics emerging within a community and apply the results to the registered metadata.

1 Introduction

One of the definitions found in [Pic95] treats geographic information systems (GIS) as a set of technologies used to collect, manipulate and represent GI. A common application of GIS are spatial decision-making tasks, for example in the context of urban planning. Research on participatory GIS (PGIS) aims to open up GIS to involve the public into such processes [Ren06]. PGIS can include a variety of approaches to make "GIS and other spatial decision-making tools available and accessible to all those with a stake in official decisions" [SS05]. The public can be involved several times during the process, in the following we will focus on GI retrieval, evaluation and maintenance.

GI for PGIS is either created directly by the participating organizations or retrieved from external sources like the World Wide Web. Relying on web-based GI is particular: everyone interested is able to join the decision-making process [Tul07]. In addition, it ensures access to GI without the need of expensive, high-level equipment [LME$^+$02] commonly required for local GIS. The increasing availability of web mapping tools either used to browse maps (e.g. Google Maps, available at http://maps.google.com) or to create maps (e.g. Open Street Map, available at http://www.openstreetmap.org) is the reason that people are getting used to basic map interaction techniques formerly reserved for GIS specialists. And the ongoing transition of the user's role from content consumer to content producer [Kel05] accounts for the increasing availability of community-based GI. But it remains mostly unused for PGIS due to the lack of standardized APIs or sophisticated discovery tools. The problem of missing standards has been addressed by the Open Geospatial Consortium (OGC). Spatial data infrastructures (SDI) are proposed for the distributed supply of GI in the web, and how SDI and PGIS can be combined has been investigated in [KWR05].

The lack of sophisticated discovery tools has several reasons, one is the problem of varying possibilities to provide GI. Web services, conformal to the standards by the OGC, are the usual way to access GI in a SDI. But community-based GI is also often provided as downloadable files encoded in, for example, GeoRSS or Google's KML. Catalogs, which are the common approach for the discovery of GI available within a SDI, should support the different solutions for GI retrieval. Metadata needs to be published to make GI findable using a catalog. Such metadata can include information about the nature of the data, how to access the data or the service, who has created the data, and more. Catalogs also provide interfaces to query the repository of registered records and retrieve the matching entries. Searching GI requires to extend the common notion of keyword-based queries: spatial filters can be added to restrict the search results to a specific region of the world.

In this paper we discuss metadata registered in a catalog used to publish and search GI. Users send queries based on given vocabulary and a reasoner infers which entries in the repository match the query statements. But relying on sophisticated query processing algorithms alone can not provide better results, if the registered metadata lacks quantity and quality. Insufficient metadata is the main reason if search results suffer from low precision, poor rate of relevant entries, inconsistent search results, and many more [CJL$^+$06]. Searching, for example, the web for OGC-conformal Web Map Services (WMS) does return a long result list. But only a minority of the GI provider make use of the extensive capabilities suggested by the WMS standard. Sometimes not even a title or a short abstract are provided. This problem is common for web-based GI and makes searching suitable data a tedious and unsatisfactory task.

In the following section we further investigate the nature of metadata and discuss why elaborated metadata is crucial for the usability of GI. Making the data provider or professional catalogers responsible for the creation and maintenance of the metadata is the common approach and its drawbacks are discussed afterwards. At the end of this section, the idea of a collaborative creation of the metadata is introduced. Letting the community contribute to the existing metadata can help to ensure more comprehensive and consistent descriptions of the underlying data. Before we come to a conclusion, we try to put things together in the fourth section by applying the results from the preceding sections to the already introduced catalog for GI.

2 Metadata based on Ontologies

GI comprises two elements: data and a description of the data. Unlike metadata of information usually exchanged in the web, e.g. images or videos, an elaborated description of spatial data is crucial for a successful integration. A GIS depends on it to display the complex data correctly. GI can have a varying spatial dimension, can have a temporal extent, and is very variable concerning the thematic features. The thematic properties usually represent observed phenomena, e.g. the amount of precipitation at a certain location. In this case, metadata should include not only the unit of measurement, but also a description or the accuracy of the measurement process.

Metadata can be modeled as the triple $M_d = (FP_d, NFP_d, U)$ for a particular data set d. The non functional properties NFP are used to describe the externalities of the data and can include an open list of features a data provider might want to add. It might contain a title, a short description, information about licensing issues, usage fees, and more. The information about the data provider is represented by U. FP_d is a set of partly mandatory functional properties for d, which has to include at least details about accessing the data, for example the URL linking to the file containing the data. GI provided with the help of a web service requires more information, for example the protocol used to invoke it. In addition of such primary functional aspects, the structure and the semantics of the data itself should be described as well to achieve seamless integration. A description of the data structure ensures correct display of, for example, a map showing last month's precipitation. Describing the semantics is more challenging and subject of ongoing research efforts. But only if the meaning of the data has been captured in its metadata, we can ensure a sound interpretation of the GI. Some value hidden within the attributes is supposed to represent the measurement of precipitation, but this information is only reliable if this information is explicitly stated. Semantic annotations address this problem and are further explained below.

One important aspect influencing the usability of GI is its findability, which depends on elaborated metadata. It has to be extensible and adaptable to changes of the underlying data [SL06]. Schema-based metadata, for example encoded in XML, can fulfill this requirement only partially. Metadata based on ontologies is more flexible, enables modularization [DHSW02] and helps to prevent semantic conflicts. The latter exist due to semantic heterogeneities like homonyms and synonyms or due to different levels of detail of the conceptualization. Having, for example, a concept labeled *rain* would not match queries asking for *precipitation*. Ontology alignment in the form of semantic annotations provides a solution to relate concepts describing the nature of the data to concepts denoting real world phenomena [KFM07]. The latter are stored within domain ontologies, which also provide the vocabulary used for building semantic queries. A user selects the appropriate concept from the domain ontology, for example *precipitation*, and sends the semantic query to the catalog. Reasoning algorithms are able to infer that maps providing information about *rain* are relevant for this query, if their metadata has been annotated with the selected domain concept.

But even with a semantically-enhanced catalog, the user still lacks the possibility of evaluating the GI if the metadata contains only little information. Information asymmetry between the data provider and the data requester can make GI useless if quality is the crucial factor. In the context of spatial decision-making processes, the data requester will rather choose to buy data from companies known for high-quality data than rely on GI available in the web if he is not able to evaluate it. Next to the requirement to prevent semantic conflicts we therefore also have to ensure that metadata is comprehensive and contains sufficient information for the evaluation of the described data. Metadata creation is usually in the responsibility of the data creator or professional catalogers; the drawbacks of this approach are discussed in the next section.

3 Creating metadata

Publishing GI using a catalog relies on the data provider or a professional cataloger to create its metadata. A typical place facing the same challenge of searching and classifying information is the library, and *Library Research* has addressed many of the information retrieval problems which now have become an issue for GI retrieval. In libraries the book is the subject of interest for students, and professional catalogers are responsible for indexing the books to make them findable using a library catalog.

> ”The cataloger must envisage the needs of the reader, endeavoring in every way to make it a simple process for him to find books. He should, like the librarian, adopt a neutral stand between the reader and his books, giving emphasis to what the author intended to describe rather than to his own views”

This quote by Margaret Mann [Man30] elucidates the cataloger’s problem. He has to anticipate not only which keywords the creator would assign, but also which keywords the user would use to search the book in question. Library Research has always faced the problem of the information gap between the searching students and indexing cataloger due to differing backgrounds [Hey99]. Indexing is a subjective process which accounts for the problem that ”one person’s view on an item in a retrieval system my hinder retrieval by others” [Bat98]. Furthermore, to ensure consistency and simplified maintenance, the controlled vocabulary used for the classification has to be minimized. This results inevitably in incomplete metadata. Incorporating all the keywords students could possibly use to search the book in question is not an option.

A problem usually more apparent in the web is the requirement for a continuous adjustment of the metadata. As the underlying data, whether GI or online texts, is changing, the describing view on it has to change as well [APF06]. Member fluctuation renders web communities dynamic: users with additional knowledge providing new information might join. Metadata needs to be continuously updated within such environments. Letting professional catalogers create and maintain the catalogs ensures high-quality metadata, but can also be expensive and time-consuming [Mat04]. With the growing importance of the classification of resources made available through the web, this problem got even more urgent. At last, the responsibility of the data providers to create the metadata during the registration process is often the reason for low-quality metadata. The professional cataloger has an interest to keep the used vocabulary consistent and the quality of the metadata on a certain level. The data provider on the other hand has no motivation to provide elaborated and consistent information if he gains no benefit. This problem, also known as moral hazard [Del06], can have a significant impact on the usability of data.

One option to address the mentioned problems is to involve the user in the categorization. In [HR97], users have been made responsible for indexing items, in this case images. The user terms have then been aggregated to a generalized view on the resources, called the public index. This process is also called distributed classification and realizes a bottom-up consensus view of the world [Spe07] . Several examples exist where the user is involved in classification, mostly by letting them assign tags to the items in question. Citeulike (http://www.citeulike.org) implements a catalog of research articles, LibraryThing (http://www.librarything.org) lets users create personal libraries. Both solutions aggregate personal tags to create a public index for tag-based discovery. Exploiting the collective intelligence hidden within the community of catalog users to create and maintain more sophisticated metadata is the preferred option to avoid the drawbacks of the usual top-down approach. A collaborative approach helps to incorporate the varying user contexts in the metadata, is less costly in terms of money and time, makes metadata very adaptable to changes from outside, and is a way to ensure comprehensive metadata in general.

Contributions can come from GIS users applying the retrieved data in their own applications. They can, for example, add new non-functional properties or apply semantic annotations to enrich the functional data descriptions. Contributions can also be produced by semi-automatic mining algorithms, which examine the structure of the data to capture the semantics hidden within the maps. Geographical features in the database may imply information about the topological relations of the represented features [KL05]. Or the co-occurrence of keywords or words within the title or description of two maps might indicate similarity [SRT05]. Or user profiles can be analyzed and compared to reason about the degree of affiliation [LMD06]. All refer to a kind of semantics ”that is implicit from the patterns in data and that is not represented explicitly in any strict machine processable syntax” [SRT05]. All can be subsumed as implicit semantics which are, together with the powerful (soft) and the formal semantics [SRT05], an approach to include the community in the ontology building and maturing process [BSW+07].

Implicit semantics can be captured in different ways, one approach used for the catalog is discussed in the next session. The derived information can then be used as input for updating the powerful (soft) semantics encoded in the non-functional part of the metadata ontologies. They are called soft because they can be fuzzy, contain inconsistencies and uncertainties within the relations of the concepts. Formal semantics on the other hand are explicit, have to be consistent and decidable. They are represented by the functional part of the metadata, the semantic annotations and the domain ontologies. The fluctuation of the community and changing views on the world result in changing implicit semantics, and therefore powerful (soft) semantics as well. Capturing such emergent semantics [AMO+04] requires continuous synchronization between the implicit semantics hidden within the system and the interactions between the users and the powerful (soft) semantics.

Neither the bottom-up, the collaborative approach, nor the top-down approach with the data provider alone as creator of the metadata are able to succeed without the other [Kli03]. The data provider has much more information about the creation process and the nature of the data and is therefore responsible for most of the metadata. The top-down approach ensures consistency and therefore interoperability. But one imposed world view would never fit all participating parties, a bottom-up approach has to be part of the metadata creation process as well. Relying on a bottom-up approach does not necessarily result in higher rates of recall [GT06]. Incorporating many world views without having a controlling instance leads to inconsistent and fuzzy ontologies, which drives them unusable for many applications [Pet06]. In the next section we suggest a strategy for a GI catalog with a simple approach to capture the implicit semantics to exploit the collective intelligence and ensure high-quality metadata.

4 Bridging the information gap

Up until now, this paper has introduced the concept of ontology-supported metadata and explained two methods for its creation: either in form of a top-down approach by letting the data provider create the data descriptions or as bottom-up process letting the community build the metadata in collaboration. We also argued that both approaches should actually play a complementary role. In this section we propose a possible solution to bridge the gap between the implicit semantics coming from the user interacting with the catalog and the formal semantics used for the discovery.

But there is no straightforward way to exploit the implicit semantics. In the context of our catalog, we focus on the actions a user can perform with the catalog. Contributing actions have an effect on the implicit semantics, and should therefore have an impact on the metadata ontologies capturing the powerful (soft) semantics as well. The similarity between two metadata records is used as indicator for changing implicit semantics. Similarity has a threefold use. Searching the catalog can use it as indicator to assess the relevance of the search results. Browsing through the registered GI can be supported by similarities, equal to URLs linking to related documents in the web. And similar records can be used as clue for changing formal semantics, for example finding the appropriate domain concepts for the semantic annotations.

To capture the implicit semantics, we could either keep a log of all modifications within a certain time span and calculate the changes of the similarities all in one. The alternative which will be used for the catalog is to let the effects of every modification directly change the related values. All possible operations a user can perform on the catalog are classified, depending on their effect on similarities and the affiliation of the participating users. The actions, both implicit and explicit, can be confirming or contributing. A user might, for example, load specific GI into a local GIS system and confirm that a service providing the data works as expected. As next step, he might contribute to the metadata by rating the GI. *Tagging* and *Relevance Feedback* are two typical examples of an explicit and implicit action, their meaning and effects are described in the following.

Tagging A folksonomy is the compilation of terms members of the catalog community choose to tag specific GI with. One dataset providing coffee bars in Paris can have the tags {*coffeehouse, paris, coffee, bar*}. This short list already shows that tags are subjective and imprecise [GT06]. Only the first tag does really describe the nature of the represented location. Some like the the label "paris" give only contextual information. And tags are noisy and error-prone, only the combination "coffee bar" is correct, but bar only has multiple meanings in English. Tags can be used either to measure similarity of the information provided by two datasets, or act as input for semantic annotations.

Relevance Feedback Querying the catalog using keywords returns usually multiple results. To improve the overall precision of the discovery, relevance feedback mechanisms can be incorporated [BYRN99]. From the result set the searching user can select a set or records that appear to be relevant for the query. Future similar searches can exploit this information and put the formerly records marked as relevant to the top of the result. Information collected from the relevance feedbacks can be exploited, like the tags, to modify the similarity between the marked entries.

Metadata for a particular dataset d is defined as the triple $M_d = (FP_d, NFP_d, U)$. Two metadata entries are similar, if some of their content overlaps, for example if one or more keywords are equal or if the two described services provide information about the same area. Metadata and the similarities are formalized as weighted, directed graph $G_M = \{M, S, W_S\}$. M is a set of nodes representing the metadata entries registered at the catalog. $S \subset M \times M$ is the set of similarities between two metadata entries, with the similarity $W_S : S \rightarrow [0, 1]$. W_S is an unreliable value and should be regarded only as an indicator for the similarity. Two entries might be similar because the described data covers the same geographic space, for example the area of a city. Else, the data have nothing in common: one provides a street network, the other precipitation values. When used for assessing relevant search results, similarity is an ad-hoc value depending on the requested information. The suggested solution used for the catalog is the permanent storage of queries in the catalog. The graph G_M does not only include the metadata records M_d , but also the query records M_r. A query record has the same structure as M_d, but is describing desired GI, not one actually existing in the repository. Having both, metadata and query records, in the graph allows for similarities between predefined search queries and existing database records. Searching the catalog is now different: the user can either select on of the existing query records, e.g. describing street data, adapt it or create a new one. Adding query records to the repository results in an evolving catalog which (a) is able to adapt to the user requirements and (b) allows for context-aware inquiries. This is a novel feature which helps to improve the acceptance of catalogs for the discovery of GI.

Due to the fact that user contributions can affect the popularity of the registered GI, the user and user relations have to be modeled in a network as well. Similar to the metadata and its similarities, the social network can be modeled as a graph $G_U = \{U, A, W_A\}$. Here, the nodes are the users and the edges are the degree of affiliation between the users. A user's rating of the quality of another user's GI does have an impact on the overall quality rating of the map. And maps with higher quality are considered more valuable, and gain a better position in searching results. Having the acquaintance modeled in the system can prevent that users knowing each other can take advantage of the collaborative approach. A user's rating will have less impact on the overall quality of a map, if he has a relation to the user who created the map. Taking the degree of affiliation between the catalog users into account to assess the reputation and the effects of an operations will help to avoid fraud. This novel approach is therefore important to ensure the trust between the users and the credibility of the underlying application, the catalog.

5 Conclusion

Defining the effects of implicit and explicit actions on the powerful (soft) semantics, namely the similarities of metadata records, can help to capture some of the emergent semantics. The impact on the formal semantics on the other hand have been barely discussed. Formal semantics on the domain level require consistent and sound ontologies, which can usually only be ensured by skilled catalogers. Semantic annotations are part of the formal semantics, and a mistake here can render the described map unusable. To avoid the risk of unusable domain ontologies, future work will include an investigation how we can assess the experience of the catalog users. Every user is able to search the catalog and influence the implicit semantics, but only few experienced should be able to change the formal semantics. We propose reputation, which is built upon the history of past interactions and can be used as indicator for the experience of the user. A reputation value of a particular user can increase or decrease during the time depending on the interaction with the catalog. We will assemble different kinds of user contributions and classify them in terms of impact on the findability and their dependency on reputation accordingly. The modeling approach for the metadata and query records, the domain ontologies, and the reputation of catalog users has been barely discussed in this paper. Further research is required here as well to address open issues like the formalization, scalability and robustness of the model.

This paper was focusing on a catalog for GI. But the approach for a collaborative creation of metadata is neither restricted to GI nor to catalogs. Relying on a catalog can have serious drawbacks like single point of failure, lack of scalability, and also issues of trust. With the advent of distributed user identity systems like OpenID (see http://www.openid.net), we also need to implement methods to decouple a user's reputation from the actual catalog and make it available to other platforms, for example catalogs organized in a Peer-to-Peer network.

We have proposed a collaborative approach for creating and modifying metadata for GI. The metadata model is extensible and allows for semantic-based discovery. Relying on cataloger alone for the creation of metadata makes the descriptions not flexible, comprehensive and reliable enough. A collaborative approach helps to avoid these problems, but can only play a complementary role to ensure consistency. Incorporating the user can help to close the gap between the implicit, informal and dynamic semantics hidden within the system on the one side and the explicit, formal and stable domain knowledge on the other. A novel contribution of the discussed approach is the use of reputation for this, and in particular how this reputation is built depending on the affiliation to other users. In the context of catalogs for GI used for PPGIS, the idea of incorporating the user to increase the usability is novel as well. But we believe that all web-based applications which are used for the publication and discovery of all kinds of information will be able to improve the findability and therefore also the usefulness of the managed information, if they incorporate the proposed approach.

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