Building Location–Based Mass Collaboration Systems: Challenges and Opportunities

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Abstract with the rise of Web 2.0 and social computing, we have been witnessing a revolution in the way spatial information is being accessed and utilized. However, the paradigm that governs the generation of spatial information products such as in GIS applications has not changed much. The rise of web–based mass collaboration, offers an opportunity to develop a new paradigm for creating and sharing spatial information products. To illustrate this, we have developed wikiGIS, a location–based mass collaboration system that is designed to generate spatial knowledge products through self–organization, decentralization, and peer–to–peer mass collaboration. Open–source software tools provide a natural fit for implementing such location–based mass collaboration systems. In this paper we review the design and development of wikiGIS, analyze the suitability of existing open source tools, and identify key challenges for tools that support location–based mass collaboration systems.

1 Introduction

In recent years we have been witnessing a revolution in the way people access and utilize spatial data, information, and knowledge. The availability of the Global Positioning System (GPS), the development of broadband (wired and wireless) communication networks, the emergence of affordable location–aware mobile devices, the growing popularity of geo–browser (e.g., Google Earth and Microsoft Virtual Earth), and the ability to easily chain geographic web services [8] have brought personalized spatial information products to the fingertips of everyday users. Within a

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few years spatial information has become an on–demand, cheap and easy–to–use consumer product.

However, the paradigm that governs the generation of spatial information products has not changed much. Today, the creation of spatial knowledge still relies heavily on a handful of domain experts who are responsible for collecting, analyzing and disseminating such knowledge in highly controlled and centralized organizational frameworks. This approach is rooted in the perception of Geographic Information Systems (GISs) as an *expert* system. Spatial knowledge is often statically stored in central knowledge bases and cannot be easily modified. Invaluable local spatial knowledge that citizens have plays little, if any, role in the process of creating spatial information products, and the ability of citizens to initiate, influence and contribute to this process is virtually nonexistent. This trend is likely to intensify as it is estimated that by 2011 individuals will be responsible for producing about 70% of the worldwide digital data volume [12].

The rise of web–based mass collaboration, in particular in the context of Web 2.0 and peer knowledge production [23], offers a tremendous opportunity to transform the way spatial information products are created. Within the Web 2.0 framework, citizens can go beyond the passive role of spatial information consumers and become spatial data creators [29], participate in organizing spatial data into information, and contribute to distilling spatial data into a salient body of coherent knowledge. By leveraging online communities and online mass collaboration technologies, we have, for the first time, the ability empower and engage citizens in data gathering, sense–making, and knowledge sharing. Thus, spatial knowledge creation and dissemination can become a dynamic distributed collaborative process.

Given these recent trends and opportunities, we have been developing the concept of *location–based mass collaboration systems*: a web–based platform for enabling the collection, creation, and organization of spatial knowledge, through the power of large–scale citizen collaboration [13]. Our goal is to build a spatially–enabled mass collaboration platform that is open and decentralized, yet provides the necessary aggregation mechanisms for creating high–quality information goods. Such a platform could serve numerous applications, which range from participatory journalism and disaster recovery to urban planning, environmental monitoring, and active mobility.

Open Source Software (OSS) can make significant contributions to the development of such systems. Strong evidence to this can be found in a recent white–paper that surveyed the state of major open source GIS software development initiatives [24], which identified 33 different utilities that range from development libraries to desktop and web applications. As will be discussed in this paper, while this rapidly increasing pool of software tools can already support to some extent the development of location–based mass collaboration systems, further development is needed in order to unleash the full potential of location–based mass collaboration systems. The overarching motivation for this paper is therefore the current gap between the need and availability of well–established theories, models, and tools for developing web–based systems, which support the creation of *spatial knowledge* through peer production and mass collaboration processes.

2 From public participation to mass collaboration

Due to the centralized nature of GIS, Public Participation Geographic Information Systems (PPGISs) have been introduced in the 1990s as a tool for increasing public engagement [26]. However, in a PPGIS authorities still control the input, its form, and the outcomes. In contrast, an alternative approach has emerged in recent years – Naïve Geography – that recognizes the importance of *common–sense user–level local* geographic knowledge [16]. This idea is linked to Neo–Geography, in which the roles of data consumers, communicators, and producers is blurred [18][19]. The combination of Naïve and Neo–Geography paradigms offer several significant advantages over the existing GIS and PPGIS paradigms. **First**, Naïve and Neo–Geography allow tapping into the inherent spatial intelligence citizens have about their immediate surrounding [19]. **Second**, they enable individuals to contribute up–to–date data and knowledge, thus making the generated knowledge more current. **Third**, if done on a large scale, they enable to harness the wisdom of the crowds in the process of creating spatial knowledge, thus *potentially* enhancing its quality.

The combination of user–generated data (e.g. so–called ‘Volunteered Geographic Information’ [18]) and collaborative sense–making has been made possible through the introduction of mass collaboration systems, e.g. wikis, that allow large distributed self–organized online groups to co–create information and knowledge resources. Simply put, a wiki is an enabling tool – a web-based software that allows all viewers of a page to change the content by editing the page online in a browser [15]. Mass collaboration systems, and in particular wikis, have already made a significant impact. Perhaps the most prominent example to this impact is Wikipedia [33][10]. Since its creation in 2001, Wikipedia quickly became a worthy rival to traditional encyclopedias that are created by domain experts [17]. Wikipedia now includes over 10 million entries and attracts over 680 million visitors per year [7]. Similar examples can be found in Open Source Software [33][14].

Research on the design, development and utilization of mass collaboration systems for spatial knowledge generation is only in its infancy. Rinner [25] proposed the concept of an Argumentation map where individuals could contribute information to an on–line discussion forum regarding pre–determined geo–spatial data. Sui [29] suggested that contributions of data need not be limited to location, and can include any georeferenced data. Similarly, [20] and [11] suggest that bottom–up GIS created on the same principles of Wikipedia will support the development of better spatial content.

Currently, there is a rapidly growing number of on–line applications that demonstrate some of the principles described above. For example, in MITs ‘WikiCity-Rome’ Project [5], citizens serve as voluntary sensors [18] and fuse on–line collaboration with mobile devices to allow citizens to broadcast their location in real time. In other initiatives, such as Wikimapia [6] and OpneStreetMap [2] citizens participate in a collaborative mapping effort in which each mapped location is associated with a wiki page that summarizes the available location–related information. In these applications emphasis is put on collaborative spatial data collection while little attention is given to the process of *aggregating* low–level data into high–level knowledge through mass–collaboration processes.

3 Building location–based mass collaboration systems

3.1 Design

Location–based mass collaboration systems aim to provide open decentralized web platform through which aggregation mechanisms for creating high–quality spatial information products are made available. This is accomplished through the fusion of four key elements (further discussion of these elements can be found in [13]):

- **Spatial** – the ability to represent, store, retrieve and query spatial entities (e.g., points, lines, and polygons) and their attributes.
- **Temporal** – the ability to associate data entities with a time stamp. Time is essential not only for understanding when things happen, but also for evaluating data relevancy and reviewing revision history. For example, by determining how *relevant* user contributed data is through a time decay function.
- **Social** – the ability to harness mass collaboration depends on a constructive active user community. Prior mass–authoring projects (e.g. Slashdot, Wikipedia) show that leveraging on the collective wisdom of the masses [30], and providing mechanisms for handling conflict and vandalism are essential.
- **Information aggregation** – the ability to collect data, organize it into information and synthesize it into salient knowledge. This is accomplished in two stages: (a) Data gathering: allowing a multitude of opinions and views, and encouraging conflict and contradiction. The underlying assumption is that diversity of opinions will result in higher–quality information; (b) Synthesis and sense–making: providing mechanisms that allow users to filter–out low quality information, synthesize multiple evidences into coherent information, and resolve conflicts.

Based on these four basic elements, location–based mass collaboration systems provide a framework for gathering, combining and synthesizing data from various sources into spatial knowledge (Fig. 1). In this framework data from in–situ geosensors [32] and existing spatial databases can be combined with human observations that are gathered and contributed by participating citizens. Unlike other existing frameworks, location–based mass collaboration systems aim not only to gather data but also to synthesize it into salient knowledge through community–driven processes. Location–based mass collaboration systems therefore enable users to go beyond data collection and play a pivotal role in spatial knowledge creation.

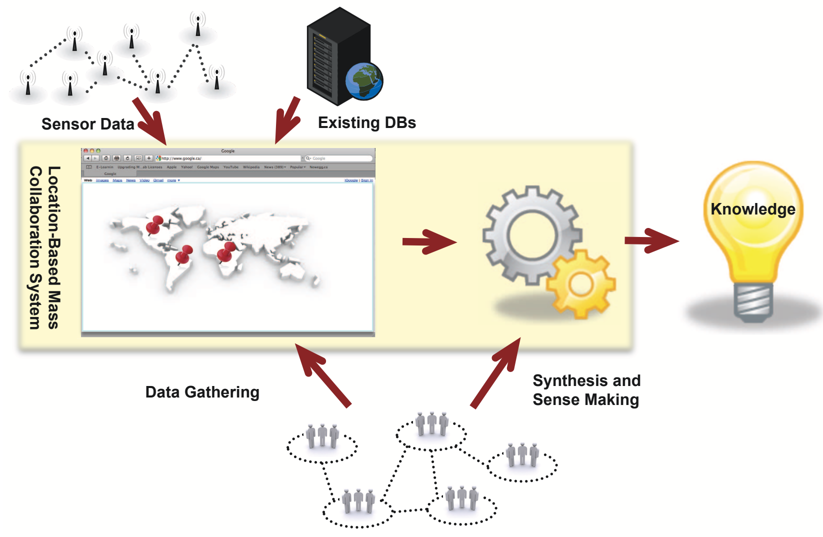

Fig. 1 The location–based mass collaboration framework

3.2 The building blocks

Location–based mass collaboration systems are driven by a bottom–up process of data gathering that is later synthesized to knowledge. Based on this, we distinguish between two constructs, namely *events* and *cases*. An event represents a spatially and temporally tagged observation that is reported by a single contributor. It reflects the experience, opinion, or the data that was collected. From a spatial perspective, an event can be represented by a single georeferenced spatial entity (e.g., a point, polyline or ploygon). From a temporal perspective, an event is associated with a relevancy that decays over time. A case on the other hand, is formed by the aggregation of corroborating events that share a common theme. Cases therefore represent a higher level of aggregation and synthesis of events into a salient knowledge entity. When a case is created, a polygon delineating the extents of the aggregated events is created. here a polygon represents a schematic outline of the geographic region of the phenomenon described in the case.

To accommodate these different elements location–based mass collaboration systems should wrap together three primary building blocks [12]. **First**, in order to support the collection of events an environment in which data can be uploaded and presented to the community should be provided. The technology most appropriate for gathering multiple views is discussion forum, where each event is represented by a thread. This allows to discuss the event among community members. By incorporating a rating mechanism, where users rate others postings, we can get an aggregated relevancy score for each event. Rating mechanism can provide the first level of sense–making and could help detect hot–spots. **Second**, in order to support the synthesis of multiple events we create a higher–level information object, a case. This calls for using a technology that supports deliberation. We utilize wiki technology for aggregating citizens evidence into higher–level synopsis (i.e. a case), and associate a wiki page with each case. Cases inherit and aggregate the relevancy of the events associated with them. Wikis are particularly appropriate there since they allow developing mechanisms for deliberation (e.g. discussion pages), conflict resolution and consensus building (e.g. mediation committees, voting), quality control (e.g. watch–lists), and role assignment (e.g. moderators and meta–moderators). Similarly to the existing mechanisms for text revision control and comparison in wiki systems, a case wiki should support spatial revision control, i.e. the ability to go back through the revision history of spatial features and the ability to compare two versions. **Third**, in order to provide spatial data management, handling, and display a web GIS server should be integrated. The primary role of the GIS server is to manage spatial data storage and retrieval, map rendering, layer management and provide basic viewing capabilities (e.g., pan, zoom or select). Integrating these building blocks into a location–based mass collaboration system can be done through a wrapper. The key role of the wrapper is to coordinate the activity and data flows between the different components, control user authentication, and provide general user interface functionality.

3.3 The wikiGIS platform

Over the last two years our group has been developing wikiGIS [9] as prototype location–based mass collaboration system that was used to explore the ideas described above. WikiGIS, which is based entirely on open source software tools, is a web application that wraps together three primary components: a web GIS server (GeoServer [1]), a discussion board (phpBB [3]) and a wiki (Twiki [4]). The web GIS server provides the spatial frame of reference and basic GIS functionality, such as support for multiple thematic map layers, map display controls (zoom, pan), symbology, and map annotation. In addition, the GIS server is responsible for hosting and maintaining the spatial database. In order to maintain database compatibility, all wikiGIS components are based on the PostgreSQL database engine. The wikiGIS wrapper integrates all three components together into a single web application. The wikiGIS user interface (Fig. 2) supports three display modes: an event view, in which only the map and the discussion board are visible; a case view, in which only the map and the wiki are visible; and hybrid view, in which the map as well as the discussion forum and the wiki are visible.

One of the key elements of the wikiGIS wrapper is its ability to seamlessly navigate between the different components. For instance, by selecting a case polygon on the map it is possible to review the corresponding case wiki page, and through that the discussion board events that contributed to the creation of the case. Similarly, by selecting a case in the wiki component it is possible to review both the case on the GIS map and the corresponding events. A unique feature of wikiGIS is that geographic information is fully integrated with both the wiki and the discussion board. Similarly to text editing in a wiki, the spatial representation (i.e. the delineating polygon of a case) can also be edited when a wiki page is revised through a modified wiki revision tracking mechanism.

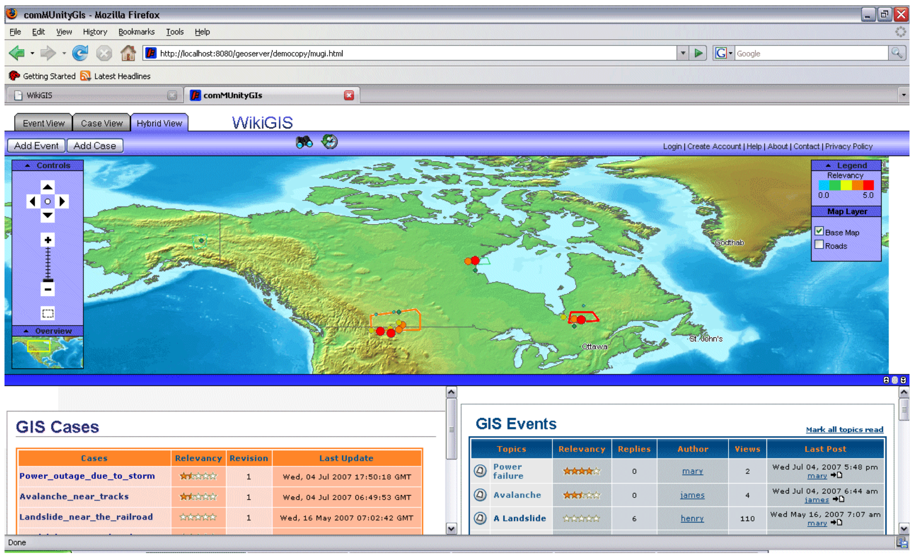

Fig. 2 The wikiGIS user interface

3.4 Database integration in wikiGIS

A primary challenge in the design of wikiGIS has been the seamless integration of the different components at the database level. This integration is essential for creating and maintaining a seamless linkage between spatial data, events, and cases, both in space and time. A schematic Entity–Relationship Diagram of wikiGIS is given in Fig. 3. WikiGIS is comprised of four different databases that are integrated by the wrapper: the geodatabase database, the wiki database, the discussion board database and the wrapper database. The wikiGIS wrapper database is responsible for managing all the data related to events, cases, and their relevancy rating. The management of events, cases and their association is done in the three relations `events`, `cases`, and `event_to_cases` respectively. Since each event and case is associated with a relevancy measure, the wikiGIS wrapper is also responsible for maintaining event and case relevancy records over time. The wrapper also maintains all user–related information, so that when a user logs into the wikiGIS application she is also automatically logged into the discussion board and the wiki.

The geodatabase (maintained by GeoServer) is responsible to storing all spatial data. When cases and events are created in the wrapper the corresponding spatial entities (i.e. points and polygons) are created in the geodatabase in the `event_features` and `case_features` tables. All spatial data is kept in the ESRI shapefile format. Since wikiGIS is not locked to a specific application domain and is designed to facilitate many different types of spatial events, each event is also associated with a layer that represents a thematic category of spatial features (e.g., oil spills, landslides, etc.). Note that since wikiGIS maintains a full record of the history of spatial features, every revision of a case would create a new spatial feature in the `case_features` table.

Once an event is created in wikiGIS, a new discussion board topic is created in the `bbtopics` table and the association between the event and the post is stored in the `event_posts` relation. Each post in the discussion board, whether it is an event or a response to an existing event, can be accompanied by additional multimedia files (e.g., images, video clips, voice recordings, etc.) that is stored in `bbposts_attach`. The discussion board entries are kept in the `bbposts` relation and `bbposts_tree`.

The wiki database is similar to the discussion board database. Upon the creation of a case in the wikiGIS wrapper it is linked to a wiki page in the `case_wiki_revision` relation. Users can also add multimedia files (e.g., images, video clips, voice recordings, etc.) to a wiki page. As the case evolves and is revised the revision history is kept in the `wiki_revision` table along with the corresponding time stamp. Note that in the wikiGIS wrapper spatial data is regarded as an integral part of the wiki page data, hence it is possible to edit the case polygon directly from the wiki page.

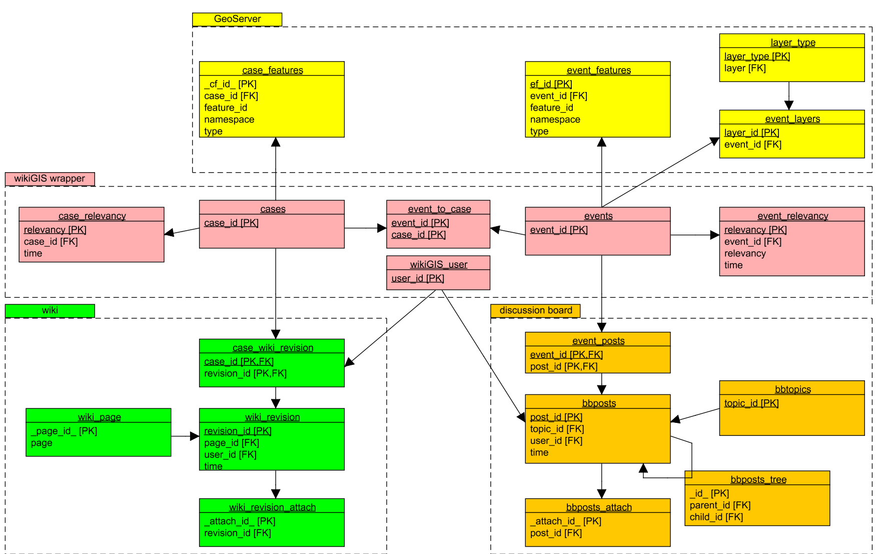

Fig. 3 The wikiGIS Entity–Relationship Diagram (`[PK]` - Primary Key, `[FK]` - Foreign Key)

4 Emerging challenges

Our experience in designing and developing the wikiGIS platform using open source tools as described in the previous section has highlighted several key challenges that relate to both the theoretical foundations and the technological tools that are currently available for building location–based mass collaboration systems. In this section we discuss these challenges and outline possible future development avenues. It should be noted that the discussion presented here is from the *system perspective*, i.e. it is focused on developing open source design methodologies and implementation tools. We leave the discussion of the social, behavioral and organizational dimensions for discussion in future work.

- **Design patterns**: while there are many grassroots initiatives that aim to leverage web GIS and web 2.0 technologies (e.g., using the Google Maps API or Microsoft Virtual Earth Map Controls SDK), the are often based on an ad–hoc design and there is currently no clear design methodologies for building such applications. Moreover, current mass–collaboration tools (i.e. wiki and discussion board platforms) are often not well integrated with the spatial dimension. There is therefore a need to develop a theoretical foundation for designing and building location–based mass collaboration systems. A first step towards that can be the critical study, systematic mapping and classification of existing initiatives as many of them share some common structure and functionality elements that can be leveraged towards the creation of more general *design patterns* for location–based mass collaboration systems. A first attempt to conceptualize this idea can be found in [22], which reviews some emerging techniques and constructs that would allow practitioners and technology implementers to design successful wiki–based systems. However, this review is not focused on the spatial dimension.
- **Collaborative data layers**: in traditional desktop and web GIS systems the organization of spatial data is thematically driven (e.g., roads layer, buildings layer, etc.) and it is typically received from a single source. In the location–based mass collaboration framework data layers are still thematic, but the layer creation process is entirely different: users *weave* layers together in a distributed bottom–up process by contributing data ‘patches’. The social and collaborative dimensions of the data collection process become important since they play a vital role in the self–organization of the user community, wiki revision control, and have a key role in evaluating data quality. Consequently, a new data model that supports these dimensions should be developed.
- **Fusing quantitative and qualitative**: the creation of high–level spatial knowledge through large–scale citizen collaboration is based on the synthesis of data from citizens and from existing spatial databases. Some data may be *quantitative* (e.g., human observations) while other data are *quantitative* (e.g., an existing map layer or data from in–situ geosensor network [32]). The first step in generating knowledge from such data is the fusion of the different data sources. One particularly attractive technique for achieving this is the Dempster–Shafer theory [28]

due to its ability to incorporate the notion of evidence, and therefore provide a well–structured mathematical framework for incorporated citizen–generate data and existing map data.

- **Quality mechanisms**: the difficulty of dealing with spatial data quality in location–based mass collaboration systems originates not only from the multidimensionality of the data. The introduction of large–scale user–generated data collection, much of which will be in the form of qualitative observations, creates some significant new challenges for the existing data quality estimation methods and practices [19]. Unlike spatial data collection processes that is carried out by experts who implement strict standards, data contributed by citizens has little or no quality control, and as a result it is difficult to evaluate whether it is trustworthy. Recent work has suggested utilizing *trust* as a key construct for data quality [11]. In light if this, two mechanisms are of particular interest here:

  – **Spatio–temporal rating systems**: in typical rating system individual items can be ranked according to how users judge their quality [27]. This approach can be further developed to handle spatial data by associating data segments (e.g., segments of a polyline or a region of a polygon) with a quality rating. The temporal domain can also be incorporated by introducing relevance, i.e. applying a decay function to the rating that decreases the elements score as time passes. Relevance was already successfully implemented in a simplistic form in the wikiGIS prototype, and we hope to further develop it in the future.
  – **Spatial recommender systems**: the guiding principle behind collaborative recommender (or filtering) systems is the ability to match users (i.e. estimate a similarity score) based on their profile similarity [27]. Collaborative filtering can be adopted as an implicit spatial (and spatio–temporal) quality estimation mechanism by expanding the similarity scores currently used to the spatio–temporal domain, e.g. incorporating space and time in the user profile. For instance, given a user interest in a specific area at a specific time interval, the system may recommend to the user data sources data that were contributed by other users based on the areas in which these users reside or actively contribute data to.

- **Text and multimedia georeferencing**: much of the information in the proposed framework is provided in the form of text (i.e. discussion board entries and wiki pages). Although all text in wikiGIS has some relation to a spatial location (e.g., the location of the event), the text may also contain references to many other spatial locations that have a contextual relation to the event or case reported. In order to better exploit the potential of the discussion board and the wiki pages it is necessary to develop tools that would be able to detect such spatial references and their context. This is particularly important in search operations. A possible solution for the development of such georeferencing capabilities is through the creation of *geo–folksonomies* [11], i.e. user–generated gazetteers that would allow users to create and use context–driven georeferencing information.

5 conclusion and outlook

The ability to organize information and create knowledge products through self–organization, decentralization, and peer–to–peer mass collaboration is already making an impact on our culture, society, and economy [33][10]. The spatial domain is no exception, and therefore creating a solid theoretical and technological framework for location–based mass collaboration systems is likely to have a significant impact in many application domains that rely on spatial knowledge. Such systems should be seen in the broader context of emerging spatial knowledge networks [21][31] that would make localized and personalized spatial knowledge available to anyone, anywhere, at any time. Such networks are not centrally controlled – they are in a constant flux through social networks imbedded in spatial domains, and are governed by continuously evolving virtual communities.

This paper reviewed the design and development of wikiGIS, a location–based mass collaboration system prototype. Our work demonstrated how currently existing open source tools (GIS and others) enable to create some of the basic functionality of location–based mass collaboration systems, through a customized wrapper that seamlessly integrates the different system building block. However, we argue that in order to exploit the full potential of location–based mass collaboration systems it is necessary to push the envelope of existing open source tools. In particular, further development of design patterns and support for collaboration–aware data integration and management tools and quality mechanisms are required.

An underlying assumption in this paper has been that the principles of self–organization, decentralization, and peer–to–peer mass collaboration will 'naturally' lead to high–quality spatial information products. While there is significant evidence supporting this (e.g., Wikipedia and OSS), research on OSS projects indicates that there is currently only a partial understanding of the nature of these *collaboration processes* and the settings necessary for their success [14]. Moreover, recent work on Wikipedia emphasizes the critical role of *governance* (i.e. rules and guidelines) in the production of high–quality information products [34]. A key challenge in building location–based mass collaboration systems will therefore be the development of a better understanding of location–driven collaboration processes and of adequate spatially–aware governance mechanisms.

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