

Geo-collaboration and P2P Geographic Information Systems: Current Developments and Research Challenges

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Abstract

Geo-collaboration appears when individuals or groups of individuals work together to solve spatial decision-making problems facilitated by geospatial information technologies. In this paper we focus on current developments in geo-collaboration where we take an example of public participatory geoinformation systems (PP GIS). This research field focuses on the issues related to the participation of the general public in democratic processes. PP GIS applications usually adhere to classical client/server architectures. In this paper we call for additional research in P2P computing related to its possible use in applications which support spatial decision-making processes. We conclude the paper with a summary of relevant research issues and our further research work.

1. Introduction

Estimates in [1] show that 80% of all decisions are somehow related to space. In emergency management scenarios, for example, origins and destinations of phone calls, e-mail messages, assessment of place at risk, location of an accident, allocation of the rescue teams etc. involve geographic information. Geographic information represents the basis for the decision-making process in many application areas. In this paper we focus on collaboration enabled by geoinformation which is often referred to as geo-collaboration.

As an example of geo-collaborative systems we present public participatory geographic information systems. PP GIS is a field of research that focuses on the use of GIS by the general public and aims at involving the citizen in a decision-making processes. These systems are designed as distributed GIS services and include functionality that can be executed remotely by the users regardless of the implemented platforms. These services are geared towards interoperable platforms that resulted from recent developments of W3C standards in the area of middleware, networking and interchange formats (e.g. HTTP, SOAP, XML etc.)

and OGC standards in the area of geoinformation interoperability (GML) and OpenGIS Service Architecture.

These recent trends make new collaborative applications and P2P based architectures possible. The integration of peer-to-peer (P2P) technology and the proliferation of location-based mobile devices may enable new forms of collaboration. The need for collaborative work with geospatial data has escalated in recent times due to events such as terrorist activities and natural disasters like the December 2004 tsunami. Additional research is needed to understand the basis for collaborative interactions with geoinformation and the possibilities for a deployment of such software architectures. A higher level of geo-collaboration, beyond simply sharing geographic data, is required to support the new demands.

In this paper we outline research areas related to geo-collaboration with a special focus on the P2P geographic information systems (GIS). We provide definitions for geo-collaboration and geo-coordination and introduce the concept of public participatory GIS. We show the P2P GIS architecture and two prototype P2P GIS applications. We summarise the main research issues with respect to geo-collaboration and P2P GIS and conclude the paper with directions for further research.

2. Geo-collaboration and Geo-coordination

Current research in geoinformation science includes collaborative methods for working with geospatial data. For example, in emergency management situations such as fire in the city, or a bomb attack at an event, teams of specialists from multiple, disparate organizations often need to share geoinformation, maps, GPS locations, and other related data. They also have a need to cooperate in making decisions based on the analysis and visualization of geospatial data, and coordinate their activities. A new term some researchers [2, 3] use to describe this approach is "geo-collaboration". They view collaboration as a

committed effort of two or more people to devise a new understanding or solution for a spatial-based decision making task. They see geo-collaboration as a group of individuals working together to solve geographic problems facilitated by geospatial information technologies. Some others consider geo-collaboration as a form of collaboration that involves geoinformation. Depending on the time of the interaction we can distinguish between the following two forms of geo-collaboration;

- *asynchronous* where different individuals or groups use shared information at different times, or
- *synchronous* where information is shared among the parties at the same time.

In general, collaboration can be differentiated from cooperative or coordinated efforts such that in cooperative efforts, participants agree to work on different tasks and share results; and in coordinated efforts, participants agree to sequence the results of their cooperative effort [4]. [5] define coordination as “managing dependencies between activities”. They constituted the interdisciplinary study of “coordination theory” and argue that coordination describes a rather abstract concept which can only occur where the involved entities (e.g. people, groups, task forces, etc.) perform activities with interdependent tasks.

3. Collaborative Public Participatory GIS

Public participatory GIS make use of GIS technology and involve sharing of spatial data and spatial decision-making applications by various organisations and individuals. They enable geo-collaboration within the process of public participation in democratic processes such as for example voting.

3.1. Basic Concepts and Definitions

The term geographic information systems (GIS) is frequently applied to geographically oriented computer technology, and is difficult to define due to many different ways of representing and classifying objects and subjects. Some of the well known definitions have been listed in [6]. Here, we take a broad definition which defines GIS as “a system of hardware, software, data, people, organisations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth” [7].

The GIS field is further characterised by a great diversity of applications. A GIS used to support public participation is often referred to as public participatory GIS (PP GIS). The term public participation GIS was coined at the I-19 Initiative workshop of the National

Center for Geographic Information and Analysis in the United States. At that time, PP GIS was defined as “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” [8]. [9] identify PP GIS as a broad tent with multiple meanings and a set of emerging forms of community interaction with GIS that are linked to the social and geographic context of PP GIS production and implementation. [10] consider PP GIS as a research field that focuses on the use of GIS by the general public with the aim to involve citizens in spatial planning processes.

3.2. Comparison between the US and Europe

In recent years, research in the area of PP GIS resulted in scientific discussions published in numerous research papers. Prototype applications supporting PP GIS range from Internet-based spatial multimedia systems to conventional field-based participatory development methods with modest GIS components. Geo-collaborative capabilities and functionalities include access and exchange of geoinformation that can be enabled anytime. In our previous work [11, 12] we analysed twelve selected, online available PP GIS applications in respect to the possible differences between US and Europe. The analysis criteria were the complexity of GIS functionalities, usability, interactivity and visualisation. First results of ongoing research exhibit that a vast majority of applications only deliver information to the citizen in a one-way communication process. This implies that they do not enable geo-collaboration, but rather serve as an information delivery platform. The analyzed applications vary strongly concerning the included GIS functionalities and their complexity. This research has been part of an ongoing research initiative of the new Sun Centre of Excellence for Map-Based Online Public Participation MAP¹.

3.3. PP GIS Applications

In this sub-section we present two PP GIS application examples; the first one developed in Europe and the second one in the US. The most often cited European project Virtual Slaithwaite² has been developed by the School of Geography, University of Leeds (see Figure 1). The emphasis of this application is on decision support systems that increase public access to spatial data. Application users can view the

¹ <http://map3.salzburgresearch.at>

² <http://www.geog.leeds.ac.uk>

map showing the village Slaithwaite, they can apply basic GIS functionalities such as zoom, pan, overly, and suggest for changes in the plan of the future village development [13, 14].

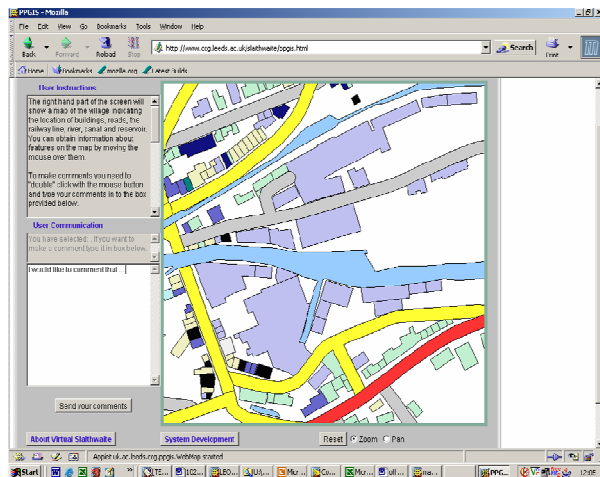


Figure 1. Virtual Slaithwaite

For the American example we take the case of the Orange County Interactive Mapping, which was developed by the City of Orlando. It is an online mapping solution, where the users have the possibility to extract different information from the map, post their comments on the map and send a selected part of the map to the Board of County Commissioners [12].

3.4. PP GIS Architecture

Currently, GIS applications in general and PP GIS applications in particular are based on the classic client/server (C/S) paradigm. Basically, it can be distinguished between (i) *fat server – thin client* and (ii) *thin server – fat client* approaches. In the first approach, all the necessary calculations and processes are executed on a server. The client's task is only to display the information delivered by the server. In the second approach, the calculation efforts are shifted to the client machine. This configuration requires an installation of a client-side application and certain hardware performance that facilitates these efforts on the client-side and allows for local storage of spatial data. The advantages of this approach are *scalability* because the server is relieved with respect of a decreased number of simultaneous connections; *improved performance* due to the majority of tasks executed on the client side which reduces waiting time for the results coming from the server; and *less network traffic* due to the reduced network load.

For traditional stationary GIS applications these architecture approaches may suffice. New, location-based mobile and geo-collaborative applications urgently need new solutions. The currently known approaches are static and do not provide the flexibility necessary to adequately serve the users who should have the opportunities to actively take part in the system via their contributions. In such flexible solutions, the users get the opportunity to become active and publish their opinions related to certain issues.

Due to the great diversity of entities involved in geo-collaborative processes, such as various content providers, repositories, maintainers and consumers, the deployment of PP GIS services cause difficulties especially in integration and availability issues of distributed information. Internet-based spatial data decision-making applications, which focus on the exchange of geoinformation require sophisticated server-side functionality. This prevents many individual data providers from participating and collaborating, and hampers the exchange of geoinformation. Small and portable devices such as smartphones, personal digital assistants (PDA), tablet PCs and special-target devices increasingly play an important role in geoinformation [15]. Due to these new developments we argue for novel approaches with respect to the design and implementation of geo-collaborative applications. We propose the incorporation of peer-to-peer (P2P) concepts into GIS based computing.

4. Peer-to-Peer GIS Computing

Peer-to-Peer (P2P) systems represent a novel approach in the architecture and system design of geo-collaborative applications. Such architectures are characterized by the direct sharing of computer resources such as CPU cycles or storage, or information rather than requiring the intermediation of a centralized server, which makes the overall system behavior more flexible [16]. In a system like this, basically all involved entities -i.e. peers- have equal rights and duties. However, peers may play specific "roles" e.g. consumer, producer, mediator etc. for a certain period of time.

GIS applications are complex systems and can be modelled as layered architectures in order to make them more transparent. The following four layers can be identified: hardware layer, architecture layer, application layer, and social layer. The concept of geo-collaboration inherently represents a P2P constellation on the social layer, with human beings representing the peers. Hence, it is not trivial to define P2P GIS

computing, which additionally, must always be conducted at each considered layer separately. For our work we determined the following definition:

Peer-to-Peer networks represent distributed systems with interconnected, heterogeneous and equal entities i.e. peers which are able to dynamically adapt the topology of the overlay network according to the available nodes, for the purpose of beneficially sharing resources respectively distributing geographic content independent from a central authority. Each node is able to transiently take on a certain role.

Due to the complexity of geoinformation sources, some systems may inhere P2P aspects on certain layers but not necessarily on all [17]. Especially with respect to public participatory GIS, P2P concepts could beneficially contribute to the design and implementation of such layered concepts. In our work, we distinguish between stationary and mobile P2P-based geographic information systems and hybrid types combining these two with the client/server paradigm.

4.1. Stationary P2P GIS

Stationary P2P GIS include stationary units acting as peers and being able to exchange geoinformation in a P2P based network. Examples of traditional P2P systems such as the famous file sharing applications like Napster or Gnutella are referred to as stationary P2P systems because these are deployable on stationary hardware devices such as desktop computers or server machines. With respect to GIS, stationary P2P concepts should be exploited for sharing computational resources for expensive geographic calculations and for the storage and maintenance of extensive geographic data.

4.2. Mobile P2P GIS

Mobile P2P systems are a rather novel approach for combining P2P concepts with mobile computing technologies such as WirelessLAN, Bluetooth, and telecommunication networks such as for example GMS, GPRS, EDGE, and UMTS [18]. They gain on their importance due to the increasing desire of human beings to use information systems while they are on their way [15]. Support of mobility is becoming a more and more important research issue in the design of mobile P2P systems. As a consequence, the flexibility and independence of the users may be increased also in a physical way, such that they are able to interact with the mobile P2P-based GIS whenever they want and wherever they are.

4.3. Hybrid P2P GIS

Hybrid P2P GIS architectures combine stationary and mobile units e.g. peers. Future geo-collaborative applications will most likely be supported by hybrid architectures. These architectures adopt concepts of stationary and mobile P2P as well as of C/S approaches always according to the specific requirements of a certain application area. Additional research of their usability, design and advantages is required.

4.4. P2P GIS Example Applications

Due to the lack of research in P2P GIS, there are also almost no research papers available in this field. This results also in a lack of P2P GIS prototype applications. We could identify only the following two applications that can be classified as P2P GIS: Toucan Navigate and OPUS.

Toucan Navigate³ (TN) includes geospatial tools add capabilities, which enable collaborative decision-making within the Groove environment. The Groove environment enables collaboration using P2P computing. Every computer that is part of the workgroup can act as a server with the ability to traverse organizational firewalls. The collaborative capabilities include just in time access to vital information and data that can be shared between all members of the workgroup. All members of the workgroup using TN can view the same maps and locations, add or update their own locations and the spatial data included in the current view, and can communicate with each other.

OPUS, which stands for **OPen Use Server⁴**, is considered to be the first implementation that uses file sharing architecture called Rapid Online Mapping Network (RoMap.net). It consists of a set of protocols allowing compliant GIS applications to work together in a heterogeneous network enabled by a peer-to-peer architecture. OPUS is developed by the use of combined Java, Apache, PHP, and MapServer technologies.

³

<http://www.infopatterns.net/Products/ToucanNavigate.html>

⁴

http://www.atsincorp.com/Project_Web_solutions/ROMap.pdf

5. P2P GIS: Research Challenges

Research in P2P GIS is a rather novel area which is now possible due to the recent developments in the area of distributed GIS, XML, and GML (Geographic Markup Language). Many research issues are still subject to ongoing efforts. This chapter summarises research issues with respect to geo-collaboration and P2P GIS. The list of these issues cannot be considered as completed and is a matter of further extension.

5.1. Infrastructures for Geoinformation Exchange

Geo-referenced data enable the implementation of spatial decision-making applications. [19] distinguishes between directly and indirectly geo-referenced data and considers referenced documents and images included in digital libraries as indirectly geo-referenced data. Geo-referenced data are often stored at different locations and in different formats which makes an exchange of geoinformation and spatial data difficult. Due to the lack of appropriate infrastructures, spatial metadata and their descriptions, most state-of-the-art P2P systems cannot handle the exchange of geo-referenced data. New concepts of expressive, highly interoperable spatial metadata based on qualitative spatial reference models and adaptable structures for geographic names are needed [20]. A particularly interesting research area is the development and deployment of P2P networks for the exchange of geo-referenced data and geoinformation. This work has to be integrated with the ongoing efforts for semantic integration of spatial data [20] and information retrieval.

5.2. Barriers for P2P Geo-collaboration

The barriers imposed to the collaborating entities involved in P2P geo-collaboration is another research issue. It has to be examined whether P2P networks lower the barrier for participation and thus, allowing individuals and/or groups of individuals to contribute geo-referenced data and geoinformation and its exchange, or rather represent a barrier for such participation. Additional investigation is needed in the possibilities of lowering the barriers for participation enabled by P2P GIS architectures.

5.3. P2P GIS Architectures

One of the major challenges in research on P2P GIS architectures represents the division of roles for the peers within each layer and its corresponding

consequences when the roles change within the layers. An example of such situation would be hybrid P2P GIS application, which supports rescue teams in an emergency situation. In such situation the leader of the team as defined on a social layer might not be the same person as the leader on an architectural, or hardware layer. The research challenge is in investigation of these layers, how to support the processes of geoinformation exchange, retrieval and storage by developing appropriate, adjusted, underlying (technical) layers.

5.4. Distribution of Tasks within P2P Nodes

Distribution of tasks within P2P nodes and also distribution of data space among the nodes is a crucial question. What would be the optimal distribution, how should the tasks be distributed, what is the optimal architecture for the distributed data spaces. In particular, concepts for the distribution of tasks between “regular” P2P nodes and specialised service nodes as well as concepts for the integration of spatial and terminological reasoning capabilities into P2P software have to be investigated.

5.5. Interaction with Geoinformation

Small, location-aware handheld devices make it possible for everyone to have access to geoinformation anywhere and anytime. Much of the work until now has focused on the issues of the interaction of human beings with the new technology. The new challenge is to support human interaction with the geoinformation with respect to adequate user interfaces and interaction mechanisms within the geographic content. The possible use of landmarks and their usability in P2P GIS applications should be investigated. A landmark in this context can be defined as a physical space that has key characteristics which make them recognizable and memorable in the environment [21].

6. Conclusions and Further Work

In this paper we addressed the issues of geo-collaboration with a special focus on the possible integration of P2P concepts within spatial decision-making systems. Some recent developments in geoinformation have contributed to the possibilities of the adoption of P2P computing in GIS. These architectures aim at sharing geoinformation such as for instance maps or satellite images by interfacing between different systems using P2P networking.

In this paper we call for additional research in this area especially due to the lack of P2P architectures

within the GIScience community. The major research topics outlined in this paper with respect to geo-collaboration and P2P GIS can be summarised as follows: 1) Investigations of the applicability of stationary and mobile P2P architectures with respect to GIS; 2) Definitions of novel P2P GIS concepts and architectures; 3) Enrichment of P2P GIS systems by an incorporation of spatial metadata and infrastructures for data exchange.

The new ongoing IST project, WORKPAD, aims at addressing some of the above listed research issues. Within this project we aim at focusing on the integration of resource-restricted portable devices enabling geo-collaboration, on appropriate adaptation of the user interface, and on the incorporation of P2P concepts into spatial decision-making systems. We will study these issues on the selected emergency management scenarios.

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