Building an Interactive Multimedia Information System: The GeoMed Case Study

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Abstract. Implementation of information systems has witnessed a movement towards data types of increasing complexity. This is widely facilitated by recent advances in computing and communication. At the same time, the user community does not only need access to existing information in various systems, but efficient ways to contribute its own. This paper discusses issues on the development of an Interactive Multimedia Information System on the World-Wide Web. Reporting work on GeoMed, a new EU-funded project aiming at building a Geographical Mediation System, we indicate means of indexing, organization and management of information. Multimedia information is represented in GeoMed within electronic documents and messages, not only as passive data but as graphical user interfaces to external Information Systems. Concepts discussed include Multimedia Information Management Systems, semantics, annotation tools, knowledge representation structures and reasoning mechanisms.

1 INTRODUCTION

During the last five years, implementation of information systems has witnessed a movement towards data types of increasing complexity. The simple information expressed in numbers and character strings, while still important, has been joined by large numbers of multimedia "documents" and complex data forms [31]. This is widely facilitated by recent advances in computing (low-cost, high-speed hardware components) and communication (proliferation of World-Wide Web and Internet services). The related user community is also undergoing similar changes. It is expected that Internet access will reach very high numbers (according to some estimates, the 10% barrier of the US population has already been broken).

Simultaneously, the "information highway" becomes a two-way street; users should not only have improved access to existing information, but also the appropriate means to contribute their own. The distinction whether a user will be an expert or not becomes more and more unclear. For instance, in a city planning procedure where a variety of organizations and individual users is involved, each participant (including ordinary citizens) is eventually expert in his respective field or in expressing his own interests. As a result of the above, the core task of an Information System nowadays should become to simultaneously support many users with the integration and representation of shared multimedia information.

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This paper reports our work on the EU-funded GeoMed (Geographical Mediation) project, addressing issues on the development of an Interactive Multimedia Information System (IMIS) on the Web. Section 2 introduces the project and sketches the services that will be provided. Section 3 describes in more detail features of the system. A framework for a Multimedia Information Management System is given, and the concepts of semantics, annotation tools, knowledge representation structures and reasoning mechanisms are presented. Section 4 discusses the importance of the users' participation and interaction in such a system and highlights related work.

2 THE GeoMed PROJECT

World-Wide Web provides an interesting platform for the implementation of certain types of MISs. Such an approach will certainly become quite popular in various applications, ranging from scientific collaboration to politicial negotiation and from medical diagnosis to home shopping. However, special attention must be paid to indexing, organization and management of information in the unstructured world of the Web.

GeoMed aims at improving both the accessibility of geographical information in heterogeneous, distributed Geographical Information Systems (GISs), and the users' participation in related decision making processes, such as city, regional or environmental planning. Multimedia information is represented within electronic documents and messages, not only as passive data but as graphical user interfaces to external Information Systems. The GeoMed server is being written in Java, which will eventually allow it to be used with a variety of operating systems. GeoMed provides three types of services, namely information, documentation and mediation services:

- *Information services* provide efficient access to multimedia information in distributed databases over wide-area networks. This would include services for finding relevant multimedia data, converting proprietary data to standard formats for data interchange (by "wrapping" their appropriate objects), as well as ways of viewing and browsing multimedia information from within general purpose hypermedia systems such as the Web.
- *Documentation services* provide a "shared workspace" for storing and retrieving multimedia documents. For this purpose, GeoMed uses the BSCW (Basic Support for Cooperative Work) system [2], originating at GMD and being further developed in the CoopWWW EEC project. The above workspace is actually a multimedia information repository

which stores and manages both data and metadata (the information about the structure of data).

- *Mediation services* provide a new kind of issue-based conferencing and group decision support system. Users can propose and discuss alternative solutions to some problem or issue by sending electronic messages to a GeoMed server. While receiving these messages, the system builds up an issue-based information system on the Web by classifying the inputs according to their context. Users are able to use hyperlinks to access a structured protocol of the discussion, which is based on argumentation elements such as issues, positions, constraints and arguments (pro and contra). Hyperlinks between these kinds of elements and the original messages allow quick and easy access to the original full contents of the cited messages.

In order to use GeoMed one requires only a Web browser and Internet access. Users' messages may include any HTML hypermedia elements, such as links to other resources on the Web, images, movies and sound files. Many of these links may depend on the content. Thus, clicking on an object should lead to information related to that. Messages sent to the system are structured and indexed according to an argumentation model. The above structure provides a view on the messages which substantially facilitates the browsing and retrieval of the required past contributions to the discussion. As illustrated in Figure 1, this schema is more precise than the typical "thread" mechanism of newsgroups. The index is stored in a relational database, allowing messages and the argumentation elements within messages to be selected, filtered and sorted using standard SQL as a database query language.

The system aggregates the users' preferences and, making use of reason maintenance and constraint satisfaction techniques, prioritizes the alternative positions that have been proposed (for more see [14]). A Web-based user interface provides a simple way for users to make common queries, eliminating the need of familiarity with SQL. The use of established database technology also provides transaction control and improved security, with optional user accounts and password protection.

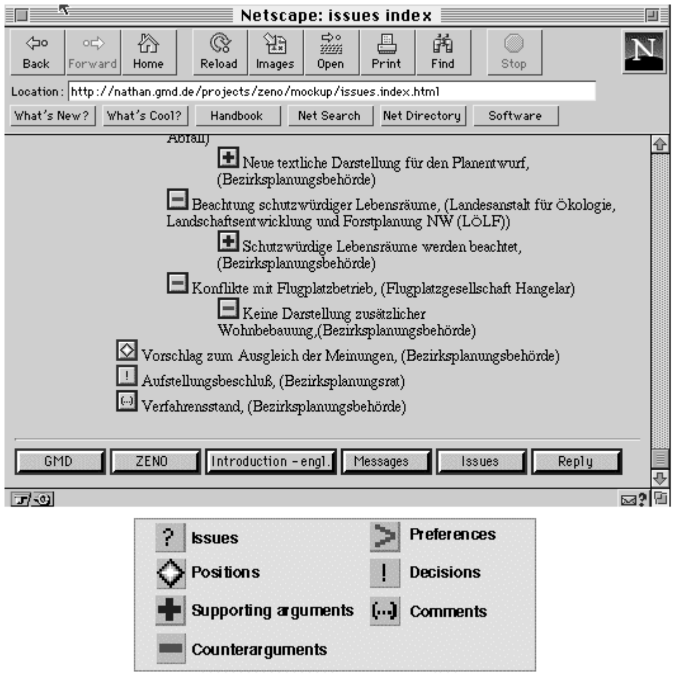

Figure 1. Structure of the discussion in GeoMed.

3 SYSTEM'S FEATURES

Data management in a multimedia information system (MIS) should be based on both Database and Knowledge Representation (KR) systems. The former are oriented towards the efficient management of large amounts of data, while the latter aim at providing a more structured representation of the universe of discourse. KR has been regarded as fundamental in the implementation of Intelligent Information Systems for more than ten years. However, only recently research to establish connections between the theoretical foundations of it with database systems is taking place. KR-based applications will be largely enhanced by the implementation of the appropriate database interfaces. Furthermore, existing KR approaches are not the most appropriate for multimedia data, and enhanced representations are needed. As a result, a number of representations has been proposed to handle several types of information. For example, consider the 2D Strings for Iconic Indexing in Image Databases [4], [5].

Most of the current applications of MISs consist of both procedural and declarative (factual) knowledge. Depending on the content of the multimedia information, knowledge representation has to be based on some traditional (e.g., rule-based, predicate-logic or object-oriented schemata) or information-specific (e.g., 2D Strings) representation. The resulting KR formalisms should enable these systems to fulfil the requirements of various user groups. More specifically, MISs should be robust enough to process advanced, content-based queries, and deal with information that exists in distributed multimedia repositories.

3.1 Multimedia Information Management Systems

Each form of multimedia data type requires its own collection of first-class concepts (operations and functions), along with the implementation of the appropriate data structure and access methods. It would be impossible to cope with the explosion of multimedia information, unless it is organized such that we can retrieve it fast when needed. Past experiences with alphanumerical data advocate the design and implementation of the appropriate multimedia information management systems (MIMSs). These systems should not merely be multimedia information repositories; instead, they should provide efficient retrieval methods, based on the content of the multimedia information itself. Navigation and browsing in a MIMS are also important.

According to related research [18], it is not enough to extend the existing database technology in order to deal with multimedia information. What is needed is to consider the issues of multimedia information management from the very beginning; multimedia information is not an appendix to a main, textual database. In the case of Spatial DBMSs, for instance, a number of alternative data structures has been proposed for the manipulation of spatial data. In addition to being data-oriented, data structures may also be query-specific. Different structures may be used for different types of queries on the same data sets.

In the sequel, we discuss features of MIMSs which will be eventually provided in the GeoMed system. These features aim to address the user requirements and industrial needs which have been brought up through an earlier feasibility study.

3.2 Annotation tools, semantics and information retrieval

MIMSs should be able to answer advanced queries. Usually, multimedia information can be described in many different ways. Thus, specification of the appropriate semantics (such as keywords, and other meta-data) is of high importance. Domain experts may be the best *annotation tool* available for the specification of semantics. Instead of trying to develop automatic annotation tools, we should rely on human expertise and intelligence, whenever we can. Annotation can also be obtained from the usage of data. By observing how a particular image satisfies users, annotations may be modified and new ones assigned. Finally, annotations should be live rather than assigned just at the input time.

These semantics should be used in *content-based retrieval* of multimedia information. Meta-data have an important role in content-based retrieval: they provide very important information for browsing data and can be used to reduce the search space. Techniques to introduce and manage semantics play a primary role here. User queries require assignment of semantics to data. However, the fact that semantics are domain-dependent as well as subjective has to be taken into account. MIMSs should provide an environment in which data interpretation from different perspectives is facilitated.

The manipulation of multimedia information involves both *machine-based* activities, where a database or other information resource is used, and *human-based* activities, where a person or a group is required to intervene, interacting with the information system. Most modern information retrieval systems are interactive. The user evaluates items, e.g. with regard to relevance, as he proceeds through the search, and may change the search strategy at any point in this process [34]. An efficient MIMS should be able to exploit the above interaction. User acts, such as navigation, selection, and refinement of the search, help greatly in reducing the burden of the related algorithms. Furthermore, integration of multiple search modalities, like SQL, keywords or content-based retrieval, both at the level of algorithms and user interface will be increasingly essential in these systems.

Besides, multimedia data often require special interfaces that must be supported by the appropriate MIMS. For example, spatial data are often best queried through a display of the space, upon which the user can outline regions that may be hard or impossible to describe as an SQL query.

Multimedia information repositories should maintain an evolving set of representations of the same or similar information (both for data and metadata). Relationships among these representations must be also maintained. In this way, changes to one representation of an object can be propagated to related representations. The concepts of *versions* and *configurations* are introduced at this point. The former refers to snapshots of an element evolving over time, while the latter to specific collections of versions. Repositories should support the evolution of the structure of information and its metadata properly.

Data conversion and integration is another basic requirement for the system. It is related to the interconnection of information resources having a wide variety of formats and models. In general, some integrating notation and model must stand in the middle among all these sources. Each source is "wrapped" by a component that translates between the viewpoint of the source and the shared, global viewpoint. Higher-level products may then be built from these wrapped sources.

Wiederhold uses the concept of *mediators* as a means to combine disparate information sources [36]. He considers mediators to be tools able to perform customized integration of the information, perhaps with additional filtering or processing. According to him, we have to model information processing in future information systems as an interaction between data and knowledge. The term *data* describes specific instances and events, while *knowledge* describes abstract classes and each class typically covers many instances [37]. Data may be gathered automatically or clerically, while experts are needed to gather and formalize knowledge.

The above kind of partitioning is then mapped into information processing modules which are assigned to the nodes of distributed information systems. Of great importance are modules that *mediate* between the users' workstations and data resources [36]. Their role is similar to that envisioned for *agents* in the AI community. In fact, they are views of many information sources, integrated to form a coherent whole. They have the knowledge (e.g., administrative and technical expertise) to create the appropriate information for the decision making procedures.

In the next two subsections we describe the knowledge representation structures and the inference and reasoning mechanisms involved in GeoMed's information management system. Due to the fact that the project is mostly associated with spatial information, the concepts used are GIS-oriented. However, generalizations towards a multimedia information system are quite straightforward (see also [22]).

3.3 Knowledge Representation Structures

GeoMed is mostly based on qualitative representation structures. Qualitative knowledge representation does not require an intermediate domain in which scale is defined, but comparisons are performed directly in the represented domain; in the domain of spatial knowledge, object locations are compared through *spatial relations*. Spatial relations have been classified in several types, including *direction relations* that describe order in space (e.g., *north, north-east*), *topological relations* that describe neighbourhood and incidence (e.g., *inside, overlap*), and *distance relations* (e.g., *near, far*) [25]. The qualitative representation of spatial knowledge has certain advantages:

- users often communicate their requests using linguistic terms that correspond to spatial relations;
- the precision of quantitative representations is not always desirable;

- qualitative knowledge is usually cheaper to acquire, store and process.

Most of the work in Artificial Intelligence concerned with qualitative spatial reasoning has focused on *logic-based representations*. Such representational systems permit the description of real-world knowledge into predicates and rules of inference. Randell et al. [29] developed a theory for topological reasoning in 2D space expressed in a many-sorted logic. Sistla et al. [32] proposed a set of rules for inference of direction and topological relations in 3D images and proved soundness and completeness. A variety of approaches has been based on Allen's temporal reasoning approach [1]; extensions of Allen's interval algebra to higher-dimension spaces can be found in [24].

Related research has been carried out in the area of *spatial constraint networks*. A spatial constraint network is a graph-based description of a scene, where the nodes represent objects and the arcs correspond to disjunctions of possible spatial relations between them. Inserting a new relation between two objects in the network affects not only the two objects, but the insertion might yield additional constraints between other objects (*constraint propagation*). Studies of constraint propagation and consistency checking in networks of topological relations can be found in [33] and [9]. Hernandez [16] studied constraint networks of direction and topological relations.

Egenhofer and Herring [8] have developed a system which deals with the binary topological relations *disjoint, meet, equal, overlap, contains* (and the converse relation *inside*) and *covers* (and the converse *covered-by*). In their notation, each object P is represented in 2D space as a point set which has an interior (P^0) and a boundary (∂P). The topological relation between any two objects (point sets) P and Q is described by the four intersections of P's boundary and interior with the boundary and the interior of Q (based on the concepts of point-set topology). Egenhofer [7] extended the system by introducing the 9-intersection matrices which also include objects' exteriors.

Chang et al. [5] developed the two-dimensional string (*2D string*) representation for encoding *symbolic images*, images where distinct objects are denoted by different symbols. A 2D string is a pair of one dimensional strings (u, v) that preserve direction relations on each axis. Although topological relations are not explicitly represented, topological information can sometimes be extracted from 2D strings. Several variations, such as the *2D-H strings* and the *2D-G strings* have been introduced to extend the expressive power of the original 2D strings [4].

A hierarchical variation of symbolic images, called *symbolic arrays*, was used as the spatial working memory representation in the knowledge representation scheme for Computational Imagery [26]. Each array represents spatial relations (symbolic arrays have been used primarily for direction relations) among the distinct parts of a complex spatial entity. A part may be decomposed in an array of simpler parts at the immediately lower level (aggregation hierarchies). Direction relations between parts that exist in different regions are not explicitly represented but they can sometimes be retrieved using appropriate inference mechanisms. Several functions which operate on symbolic arrays have been developed. These functions can be used to create symbolic arrays from other representations that store spatial knowledge (such as a frame database of complex objects), to modify symbolic arrays (e.g., rotate an array or move an object within an array) or to extract information found in the array [11].

Qualitative representation structures offer an appropriate framework for the application of spatial inference mechanisms. Such mechanisms are very important for MISs such as GeoMed for two reasons: First for detecting inconsistencies that may occur by combining spatial knowledge from different sources. For example, consider a database of maps. If city A is northeast of city B in the map of region X, and B is north of C in the map of region Y, then the existence of A south of C in region Z would yield an inconsistency. Such inconsistencies may occur when data about the same or overlapping areas are collected from different sources such as images, topographic surveys, verbal descriptions etc. (for an extended discussion see [10]. GeoMed will involve multiple systems that store huge amounts of spatial data in various formats and of variable quality. Users will query the systems requiring fast and accurate results (and not answers of the form "A is north and south of C"). Spatial inference mechanisms will play an important role for the detection of inconsistencies in the data and the integration of the different systems. Second, the spatial inference mechanisms are essential for facilitating collaborative spatial planning in GeoMed. During the process of planning a number of decision makers assert spatial constraints which may yield inconsistencies. The inference mechanism is responsible for detecting such inconsistencies and communicating them to the debate mediator (for an overall discussion on the issues involved in collaborative spatial decision making procedures with the use of qualitative constraints see [21]).

3.4 Inference and Reasoning mechanisms

For the following discussion we assume that the database can be represented as a set of binary spatial constraints (relations) between distinct objects (even if the objects are represented by absolute co-ordinates the corresponding qualitative representation can be easily derived). Since, as we mentioned above, data may come from different sources of variable quality, the database may contain inconsistencies. Spatial inference mechanisms should remove inconsistencies and provide a set of constraints that corresponds to the actual configurations of objects in space. They may have multiple goals: find one solution that satisfies all constraints, find all possible solutions, a number of possible solutions etc. It is difficult to develop a model that can express all types of spatial constraints and is capable of performing efficient inconsistency detection. Work on spatial constraint satisfaction problems has concentrated mostly on *homogeneous constraints*, that is constraints of the same form (only topological or only direction relations). Even for such cases, a large class of problems is intractable [15].

The first step of an inference mechanism is path consistency checking using some composition table. *Composition* infers the relation between two objects A and C when their relation with a third object B is known. If, for example, A is *inside* B, and B is *north* of C, we can conclude that A is *north* of C. The path consistency algorithm explicates all constraints between every pair of objects and removes relations that yield inconsistencies. Work in the area of spatial reasoning has produced composition tables for homogeneous spatial constraints (e.g., topological in [7], direction in [27]) and for combinations of several types of constraints (e.g., topological and direction in [16], direction and distance in [10]).

Path consistency algorithms have a polynomial complexity [33], [9] but in general do not suffice for achieving satisfiability. They reveal only local inconsistencies, and search-based constraint satisfaction algorithms (such as backtracking) have to be applied to locally consistent networks in order to ensure global satisfiability. Although such algorithms have a worst case complexity exponential in the number of objects, efficient heuristics provide good results in most cases.

Satisfiability does not necessarily imply realizability in space. In graph theory it is known that we cannot draw a complete graph of more than four vertices in a way that no two edges intersect each other. This is called the *planarity problem* and a similar case exists for objects in 2D space; a set of spatial constraints may be satisfiable, but still there may not exist a planar model of arbitrary objects that satisfies the given constraints. Although checking planarity belongs to NP-Hard, Grigni et al. [15] suggest that heuristics have very good chances of recognising planarity problems. Figure 2 illustrates the parts of the spatial inference mechanism; the parts are in non-decreasing order of computational complexity.

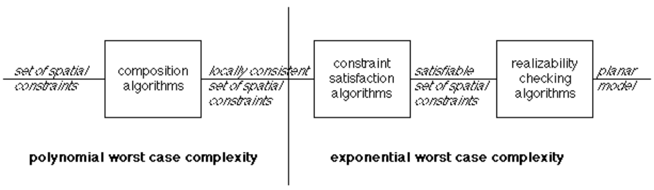

Figure 2. Spatial inference mechanism.

Although a large part of the spatial inference mechanism involves problems that are in general exponential, the specific structure of the Spatial Domain facilitates the development of efficient heuristics, and leads to polynomial algorithms for certain sub-cases.

4 DISCUSSION

As further discussed in [35], it is rather impossible to completely automate the processes described in the previous section. Users involved usually have diverse and conflicting interests, authorities and positions. Nevertheless, the use of information technology may assist them in various ways. One important goal is to provide easy access to the current knowledge, at any time. Referring to GeoMed, this goal would be greatly facilitated if all relevant data and documents, including cartographic and thematic maps, decisions, minutes, evaluations, etc., would be made available and maintained in electronic form, in a well-structured and organized way. Another possibility, and this is our primary goal, would be to provide direct computer support for the argumentation, negotiation and mediation process. A computer network can be used as a medium for such a process, in which documents are structured and indexed according to their role and function, using a model of argumentation.

Many years ago, Petri developed his theory of regulated and reasoned communication, mediated by information technology [28]. Related ideas about an "Issue-Based Information System" (IBIS) were developed in the early seventies [23], [30]. IBIS was used in some pilot applications [38], [6], but was not widely adopted due to limitations of the state of technology at the time. One reason was the restricted availability of computers and computer networks and their prohibitive cost. In addition, the lack of computing standards inhibited electronic communication in heterogeneous organizations and computing environments. Finally, the user interfaces available at the time were too difficult for most people to use. For the development of an efficient system, the above observations implied three major practical requirements, which are almost ideally met by exploiting the Internet and, particularly, the World-Wide Web:

- the system must be available on all prominent operating systems and hardware platforms;
- it must provide relatively inexpensive access to a broad public, and
- it must have a very intuitive and easy user interface.

The quality and acceptability of geographical planning decisions depends not only on the availability and distribution of accurate information, but also on the fairness and openness of the planning procedure. When planning the path of a high-speed train through communities and natural spaces, or the location of a site for storing hazardous wastes, for example, the interests and perspectives of the affected communities and citizens, the responsible regional or federal governments, environmental protection groups and industry representatives are likely to be in conflict. Involving representatives of these diverse interests in the planning process, at the earliest possible stage, can facilitate not only the extraction of a better, higher quality plan, but also of a plan more likely to be accepted by the affected communities, helping to avoid long, expensive delays or even legal battles.

As mentioned above, the messages sent to the GeoMed system are structured and indexed. Building on decision theory and a formal model of argumentation [3], [12], [13], [19], [20], [14], the system offers intelligent assistance to human mediators, facilitators, arbitrators or any kind of "trusted third parties" by providing an *issue-based discussion forum* or conferencing system. Typically, a human mediator will be responsible for indexing the documents according to this model, with some assistance from the system. In this way, such a system can be also used to open and democratize public decision-making and planning procedures, helping to improve the quality and acceptability of decisions.

In line with the above, is the MIT's "Open Meeting" system [17] for asynchronous conferencing and collaboration. Recent experiments with it demonstrated that the World-Wide Web can support productive, wide-area collaboration for policy planning and problem solving. The system's architecture is built on a theory that identified the interactions needed for the above kinds of debates, and provided ways to reduce the impediments to such interactions that arise with a dispersed, large group of participants. The system supported a large on-line meeting (more than 4000 participants) for the States' vice-president Al Gore on the National Performance Review and fully achieved its design goals.

5 CONCLUSIONS

Reporting work on GeoMed, this paper discusses issues on the development of an Interactive Multimedia Information System on the World-Wide Web. The system focuses on improving both the accessibility of multimedia information in heterogeneous, distributed Information Systems, and the users' participation in related decision making processes, such as city, regional or environmental planning. Multimedia information is represented in GeoMed within electronic documents and messages, not only as passive data but as graphical user interfaces to external Information Systems. Among the concepts discussed above are these of a Multimedia Information Management System, semantics and annotation tools, knowledge representation structures, and inference and reasoning mechanisms.

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