GEOGRAPHIC INFORMATION SCIENCE - WHERE NEXT?

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Introduction

The title question "Where next?" is based on a number of assumptions in (at least) three dimensions, the analysis of which will actually help in answering the question itself.

In order for the "where" to be meaningful, there needs to be a frame of reference, within which to determine the current position as well the target location – and the route taking us from here to there. The "next" part of the question implies a temporal dimension, together with a unit speed of the clock ticks. And finally, we have to make assumptions about the momentum of the object under consideration, i.e. GI Science: Does the "where next?" mean we picture GIS resting at some position, leisurely pondering which path to choose now, or do we assume a system in motion for which we try to extrapolate the trajectory?

Clearly, without making all those assumptions explicit, the chapter can't possibly make much sense. On the other hand, all the choices that need to be made are subjective to a certain degree, biased by the background of the authors, and so it should not be too surprising if some readers disagree with the frame of reference chosen, others with the temporal units, and yet others with the calculation of the trajectory. But this is not a problem at all; because in order to disagree, one needs to consciously make one's own choices, define a frame of reference etc., thereby coming up with a different prognosis – which is just as good as the authors'. And think about it: The real value of any of those technological predictions, extrapolations, forecasts or whatever does not lie in what they say, but in the reactions they provoke in the readers' minds.

A simple approach towards answering the question would be focusing on inner consistency of the present volume and maintain that – of course – GI Science should strive to meet the Grand Challenges outlined in the previous chapter. That would keep this chapter very short indeed, but it would answer the wrong question. A Grand Challenge is typically defined as "a ca.15-year project with clearly defined criteria of success or failure, resulting in fundamental and radical advances in basic science or engineering." The title question, however, asks where NEXT, and we certainly don't want to suggest that the clock of progress in GI Sciences ticks in units of 15 years.

So our question boils down to the problem of which path to take in order to get there. Clearly, GI Science is not an isolated field; to the contrary: It is closely interacting with other fast-moving disciplines such as Computer Science, and one can expect most progress in those areas where it is possible to leverage new results in other fields, provided they are in line with one's own agenda. Incidentally, a group of Computer Scientists around Tony Hoare has been discussing Grand Challenges for CS for some time, and it is interesting to note that at least two of the topics named are immediately relevant for our discussion. Quoting from a recent version of the list (http://www.nesc.ac.uk/esi/events/Grand_Challenges/index.html), we find (together with brief references to projects addressing those challenges):

Science for Global Ubiquitous Computing: Within 20 years computers will be ubiquitous and globally connected, and academics and scientists believe they will be regarded collectively as a single Global Universal Computer (GUC). Professor Robin Milner of the University of Cambridge says the challenge is to work out who will program the GUC, who will benefit, how will they benefit, and how do we trust it.

Memories for Life: In 10 to 20 years digital data and images that are unique to us will have grown substantially. This data will include digital pictures, emails, phone numbers and audio recordings. The project will seek to establish a way in which all this data can be securely stored and searched. Professor Aaron Sloman of the University of Birmingham says research will attempt to establish how someone can search all records and data stored on their system - whatever form that may take - in a secure environment, from wherever is convenient.

The first topic should be immediately obvious: Global ubiquitous computing will require deeply integrated facilities for locating devices, for navigation, and for many other types of spatial referencing.

The second topic might be less obvious, but is potentially even more interesting. Most of the data / information pertaining to a person's life has explicit (and more often implicit) spatial dependencies, which may not be important at the time of recording, but will be relevant for retrieval in various contextual settings.

So let us now define the "here" and "there" in terms of the themes appearing in the list of Grand Challenges, keeping in mind that "next" should refer to a foreseeable future rather than some 15+ years down the road. We are convinced that the "next" important developments in GI Science will happen along the following three dimensions: concepts and methods, applications, and platforms. Of course, one can name additional dimensions, which might be interesting to consider, but for the current purposes, we will flatten them out and just take into account the ones mentioned. The rest of the chapter will illustrate the anticipated developments in some detail, but let us briefly summarize what we are going to discuss:

? ***Concepts and Methods*****:** GI Science will incorporate formal models for describing deep semantics of a large variety of spatial phenomena. This will enable new levels of quality in spatial reasoning, thereby enabling common-sense modelling, which necessarily requires profound understanding of space.

? ***Applications*****:** GI Science will enable and support new applications. As an example consider the Virtual Telescope, which already has proved to be a research vehicle proper (Ref. to CNN report).

? ***Platforms*****:** The results of GI Science will be delivered on and influence the development of new platforms, such as the Grid. The NGG2-report (NGG2) contains a number of scenarios illustrating the need for sophisticated spatial referencing. For instance, the idea of a mobile assistant with a large repertoire of user support functions not only requires locating the device in some coordinate system. Supporting trip planning and scheduling also requires the automatic analysis of the device's (i.e. user's) trajectory – just to mention one example.

In the following discussion, we assume that all the developments under consideration will follow a trend that can be observed in many areas of IT and its supporting disciplines: Integration.

Many of the current efforts are directed at integrating information and services from different domains and contexts, such that they can be used and exploited in a uniform way. The success of XML and all its derivates is due to the strong momentum behind the idea of integration. Web services carry the idea from data to applications, and, again, integration is the name of the game. Semantic modelling in its many different guises aims at integration of information from heterogeneous sources – if at anything. And even a well-established field such as databases undergoes a transition, which some observers call a "revolution" (Gray 2004), because of the integration of data of arbitrary types into one consolidated overall architecture.

So our main hypothesis is that GI Science will, in the foreseeable future participate in and contribute to the ongoing effort of large-scale information integration. GIS is well-positioned for that task, because it has a tradition of working towards the integration of heterogeneous data sets like raster and vector data with alphanumeric information.

Wrapping everything together in one sentence, we can say that GIS will be instrumental in integrating data and services from heterogeneous sources into a uniform architecture, using new concepts and methods, delivering these new services via the Grid, thus enabling a whole range of new applications.

Let us now consider the trends in each of the three dimensions in turn.

Dimension 1: Concepts and Methods

Semantic Geoinformation

In the field of concepts and methods, we expect the most interesting developments in approaches to modelling semantic aspects of space and spatial objects. So far, modelling was largely restricted to mathematical formalisms and – to a certain degree – image processing techniques. However, for integrating geo objects with information from other domains and for reasoning about spatial phenomena, a deeper semantic representation of spatial relationships is needed. This is in line with observations from other fields, where the traditional specialized models are also found to be too narrow for integrating data with information from different domains. The most notable expression of this diagnosis is the development of what is summarily called the Semantic Web (Berners-Lee et al. 2001). Whereas in the current WWW one can search for data by specifying reference strings, the goal of the Semantic Web is to provide means for searching at a semantic level, i.e. for concepts rather than words, for relationships between those concepts, be they causal, temporal, or spatial.

Currently, a number of languages suited for that type of semantic modelling and querying are being developed. The latest achievement is the Web Ontology Language OWL which builds on the Resource Description Framework (RDF) (Smith et al 2003). OWL allows to define and instantiate *ontologies*, which are explicit formal descriptions of concepts or classes in a domain of discourse, which express a shared specification of a conceptualization. OWL thus provides the possibility of expressing information associated with people, events, devices, places, time, and space etc. Moreover, it provides means for sharing such context knowledge, thereby minimizing the cost of sensing.

A number of current GIS issues are related to a lack of formal expression of semantics of the domain of discourse. The challenge, therefore, is to define reasonably general ontologies dealing with spatial phenomena expressed in OWL. These then need to be integrated into the current major standardisation effort for GI services and data - the OGC open web services (OWS), as the technical fundaments for Spatial Data Infrastructures (SDI). In particular ontologies seem to be relevant in the area of Global Ubiquitous Computing (see the Applications section). This is because they are needed to model the diverse aspects of the context of a situation. Apart from that they are of course relevant for semantic interoperability due to the semantic heterogeneity of geographic information. This has already triggered intense research efforts (e.g. Frank 1994, Winter 2000, Fonseca et al. 2002). A spatial ontology primarily deals with physical space and spatial relations, but also with abstract spaces that can be mapped onto the physical primitives. Next to the work within GIScience related proposals for ontologies were developed, like DAML-Space, OpenCyc, SUMO or the Region Connection Calculus (RCC). Right now, one can also find examples of draft ontologies identifying relevant domains for integrated ubiquitous applications (e.g. Chen 2004). These usually include the following domains (among others):

- Spatial objects and their relationships
- Temporal relations
- Person profiles/user models
- Events
- Device profiles
- Digital document models
- Security and privacy policies

The spatial and temporal domains have been the primary focus of GIScience. A temporal ontology generally describes time and temporal relations using "time instants" and "time intervals". Similarily Zipf and Krüger (2002) presented a conceptual model and its application to GML.

But, of course, semantic modelling might not be the miracle cure solving all the open problems in integrating data from heterogeneous sources. Ontologies are necessary to model and represent semantic knowledge. But the question of which are the stable basic concepts from which to build the whole domain such that reasoning about those concepts will be powerful enough to support future applications is still under debate. The early attempts made some 15 – 20 years ago under names like "expert systems" were only moderately successful and typically limited to a very narrow domain. This time, the real challenge is to model spatial semantics (and all the others) such that their integration will yield a useful formal model of what is sometimes referred to as "common knowledge", something projects like Cyc strive for already for years (Lenat et al. 1990).

Dimension 2: Applications

UbiGIS - Ubiquitous GI Services

Ubiquitous Computing (UbiComp, UC) is regarded as one of the coming long-term trends in information technology. The term designates the pervasive use of compute services. - the possibility of the use of computer-aided services as a ubiquity. The underlying system will contain billions of tiny, wireless, connected computing devices (mostly not computers as we know them), which are integrated into a multitude of objects of everyday life (Weiser 1991). Among others, the following items characterize Ubiquitous Computing:

- spontaneous networks, service description, service discovery
- wireless and mobile communication
- new man-machine interfaces and interaction paradigms
- adaptation to context and situation , in particular localization

We want to focus on the last item in the list, which has a more fundamental relationship to GIScience. In the light of UbiComp, the relationship between spatial data infrastructures (SDI) and LBS becomes obvious: Both concepts support the access to GI services at any time at any place using different clients based on an infrastructure providing open interfaces. The need for transparent access to computerized services independently of further restrictions is also one of the main objectives of UbiComp. As a broader topic behind all of this we suppose the following question: "How can GIScience support the ubiquitous access to and use of the wide variety of geographic information and applications in an optimal way?" So the term "ubiquitous" extends the anywhere, anytime, to anyone approach of Location Based Services (LBS) to the paradigm: the right thing at the right time the right way to the right person(s).

Implied by the idea of an interoperable spatial data infrastructure (SDI) as well as a consequence of new developments in mobile computing and Human Computer Interaction (HCI), one can expect GI services to be available ubiquitously to all users. For this the term Ubiquitous Geographic Information Services = Ubiquitous GIS = UbiGIS has been suggested (Zipf 2004). This term can be defined as: *Pervasive services based on UbiComp technology and devices, supporting context-dependent (i.e. adaptive) interaction, realized by information and functions of geographic information services based on interoperable SDI.*

Often LBS are parameterized by coordinates in some spatial frame of reference. In the UbiComp-approach, however, a more general approach is needed, taking the *contex*t of the overall situation into account. Dey and Abowd (2000) characterize context as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant for the interaction between a user and an application, including the user and the application themselves." Therefore any information that is available at the time of an interaction can be considered as context information.

As a simple example, consider a system that allows a user to ask questions such as: "What are the interesting objects in my vicinity?" Depending on where the user is, what he wants to achieve and what the general current situation (which might be modelled through a variety of application specific parameters) is, his definitions of both "vicinity" and "interesting object" may vary considerably from fashion shops in driving distance to pre-historic artefacts in a museum. The information about the situation and environment (the context) can be (and has been) categorized in many ways, but an agreed on formalization is still missing. While first context-aware systems have presented progress, there are still improvements necessary for supporting knowledge sharing and context reasoning.

The adaptivity of GI services to context can be seen as one of the next steps for GIScience research in order to achieve more intuitively usable GI systems. In this overview we only can present hints as to which adaptive services might be suitable within the context of GI services. This is derived from first results regarding adaptive mobile GI services in our projects. The following categories of adaptation have been identified:

- adaptation of the visual presentation of the contents offered – both of the text and the graphic information (pictures, maps, video, VR models);
- adaptation of route planning (by individual weighting and restrictions);
- adaptation of queries (combined location- and interest-based tips;
- adaptation of the offered contents (e.g. concerning detailedness, topic).

In GIScience first work on context-awareness has been started recently (Zipf 1998). Focus has been on the area of mobile maps (Meng et al. 2004, Zipf 2002), navigation support (Kray 2002) or wayfinding with landmarks (Winter et al. 2004), as well as space-time accessibility (e.g. Raubal et al. 2004). Further examples for adaptive GI applications include e.g. the computation of routes based on context-related criteria (Jöst & Stille 2003) or user-aware spatial push of information (Zipf and Aras 2002).

But apart from the possibility of using context as parameter for adapting GI services, there is one even more important aspect to context that makes it important for the GIScience community to work on this issue in more detail: Context parameters are related to space. This is in fact sort of a corollary to Toblers First Law of Geography (Tobler 1970). In more detail the following principles apply to context (Schmidt 2002):

- Context has an origin location.
- The relevance of the context reaches its maximum at this origin.
- The relevance of the context decreases with distance from that origin.
- Exceeding a certain distance the context is no longer relevant.
- If there are multiple identical sensors (for sensing context information) available, the one which is spatially most close has the highest relevance.

This relationship can for example be modelled by fuzzy functions. Generally this is not stationary, but can move (e.g. with the user) and may be distorted in a direction, e.g. where the user walks to. Furthermore there are usually a large range of context factors present which overlap in space. All of these principles apply not only to space, but also to time, resulting in an interesting spatio-temporal modelling task.

Dimension 3: Platforms – From Spatial Data Infrastructures (SDI) to Geospatial GRID Computing (GeoGRID)

Spatial Data Infrastructures (SDI)

The current main effort regarding the integration of GI services and data is the development of spatial data infrastructures (SDI). From a simplified technical point of view, SDI can be regarded as the provision of distributed GI services and geodata by means of web services using open standards. On the other hand mobile GIS offer GI functionality on handheld computers (e.g. for mapping, data acquisition or infrastructure maintenance etc.) dependent from their location. This requires an infrastructure of GI services and wireless access to geodata, which is based on open interfaces – in other words a wireless SDI. We cannot dig deeper into those technical issues, but one can see that National Spatial Data Infrastructures (NSDI) are currently evolving in all parts of the world. This should lead to a new quality of improved access to spatial data in the mid range future.

Integrating ubiquitous Positioning Facilities and Location Models

Positioning is a basic functionality for LBS and ubiquitous services, with in-door positioning being as important as global positioning. Considerable work has been done in mobile computing, leading to location models that are not based on earth-bound coordinate systems we are accustomed to in GIS. So GIScience needs to provide mappings between emerging ego-centric or object-centric location models or such based for example on network topology (e.g. Beigl et al. 2001) as depicted in fig 1 and conventional geographic or geodetic spatial reference systems. Applying these for example to intelligent positioning and navigation support include the combination of several approaches, which mutually improve or replace themselves in case of partial failure (Kray 2002).

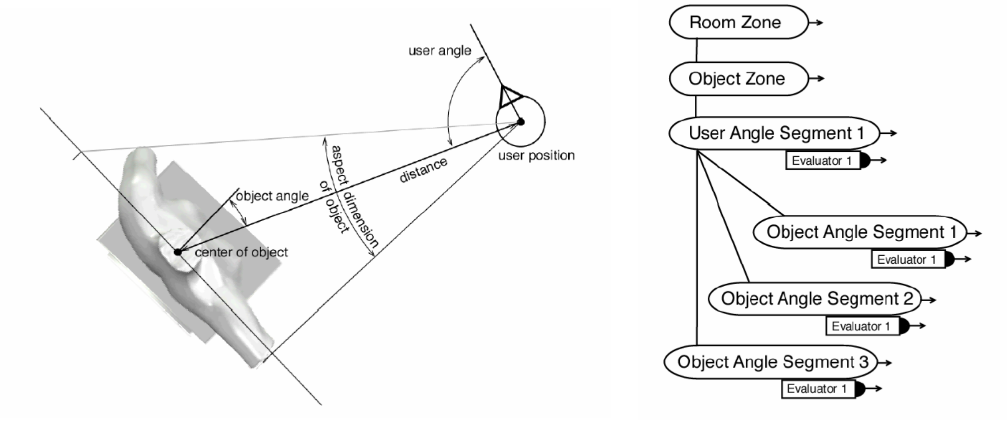

Fig 1: Object-centric location models (Goßmann & Specht 2002)

Networks of Location Aware Sensors

Classically sensors in the context of GI comprise those built for measuring environmental data (remote sensing being the most prominent example), but recently networks of stationary or mobile sensors for heterogeneous parameters are coming into focus. Therefore researchers and are investigating the interoperable integration of sensors through the OGC Sensor Web Enablement initiative. Apart from this classical view, location-aware sensors for whatever parameters constitute important elements for both context awareness and personalization within UbiComp. Through the availability of such new sensors the development of adaptive applications becomes possible. Such a location-aware interoperable sensor infrastructure even is important for non-GI applications, because of the relation between space and context as outlined above. Such sensors are being equipped with basic processing and communication capabilities, e.g. in projects like "Smart Dust" (Kahn et al. 1999) or "smart-its" (http://www.smart-its.org), leading to a georeferenced distributed global computing platform. When we envisage such large future networks of sensors delivering masses of data all the time (again remote sensing as a primary example) we are faced with the problem of mining these huge amounts of distributed data sources for interesting patterns. This requires for new middleware concepts, which leads us to that the idea of Grid computing.

The GeoGRID - towards Geospatial GRID Computing

GRID Computing (GC) is a new concept for distributed high-performance computing through a coordinated use of geographically distributed large virtual collections computation resources realized through use of computer clusters, but which should no be confused with the term "Grid" in the sense of data structure for raster data, as used in GIScience so far. GC applications utilize high-speed networks and a new generation of middleware linking network, computing resources and traditional geospatial applications. Tasks of this middleware include for example security and resource management. As the concept of CG also supports the aim to make high-performance computer-processing power available ubiquitously, just as other infrastructure, there is a clear relationship to Ubiquitous Computing, which is also highlighted in the NGG2–report (NGG2 2004). Through the distribution of data, software and computing resources we find three aspects of GC related to space. In order to realize a Grid the use of standards and open protocols and interfaces is necessary which builds a bridge to the already mentioned activities of both the OGC and the development of SDI. Again we find our topic of integration, as these worlds need to come together to realize the vision of the Global Ubiquitous Computer that could be used in a range of tasks. A scenario where all of this can easily be integrated would be the case of support for disaster management, that really brings together the vision of Ubiquitous Computing and Grid computing (NGG2 2004, Zipf 2004) with several clear relationships to GIScience and therefore realizes an ideal scenario for UbiGIS. First actual examples of GI application using GC technology as the Globus Toolkit middleware for spatial interpolation or wathershed modeling on raster data have already being presented (Wang et al. 2002).

In order for the Grid to achieve its integrative goal, more is needed than just a set of middleware standards. As is pointed out in (Gray 2003), seamless integration will also require the nucleus of a "global information schema", which is to unify the following categories: units, accuracy, precision, definition of quantities, representation, semantics. Those unifying means have to be cross-domain, and they have to support automatic schema generation and translation. And again, since many data have a spatial connotation, GIS will have to contribute to building this global information schema.

Summary

The above discussion has focused on various projects and ideas related to the three dimensions of progress we had identified in the beginning. But one could ask: "Assuming that integration is indeed the prevailing direction of innovation, what could be the result of integrating GI services into other platforms?"

That's a hard question; but let us try to come up with an answer anyway. Consider today's mobile phones. They provide you with an infrastructure for communicating from (almost) any location; the contents can be voice, images, and data. It would be extremely useful to augment this technology with location and navigation services in all conceivable contexts and frames of reference. Of course, each of those contexts refers to a different type of application, but there needs to be an enabling platform that supports them all and allows for seamlessly switching from one to next. Providing the principles and specifications for such a platform and integrating it into the existing framework of mobile computing is definitely an attractive and attainable goal.

Besides technical questions a range of social issues need to be examined in which we could not dig into, e.g. concerning acceptance, social consequences, data security and privacy (see e.g. Dobson and Fisher 2003). For example it is often claimed, that the acquisition of personal and context information needs to be open to the end user, which is in fact seldom realized. This means that the user always should have full knowledge and control over the data that is being collected and that only authorised persons and systems can access these.

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