Geographic Information Science as a common cause for interdisciplinary research

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Abstract

Geographic Information Science (GIScience) seeks to understand the nature of geographic phenomena and geospatial information. It provides theoretical foundations for Geographic Information Systems (GIS) and the rationale for research and development in GIS and their applications. In this article, we analyse the role of GIScience as a common denominator among and between various disciplines, acting as a facilitator for interdisciplinary research. Starting from the development of a coordinated and structured doctoral programme, ten senior university faculty members from different disciplines examine the commonalities of spatial[1] concepts in their respective fields in three interdisciplinary research clusters. Since the educational rationale was published recently, we focus on the role of GIScience in building an interdisciplinary and inter-departmental research alliance

[1] Because of limited space we focus in this paper on the spatial domain and will only briefly reflect the spatio-temporal complexity

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and conclude that the university-wide visibility has increased and opens new changes for another ‘spatial turn’.
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1 Introduction

Geographic Information Science – GIScience in short - is a relatively new interdisciplinary field of research based upon the understanding that basic and applied research must be reflected within society (Goodchild, 1992; 2004a; Craglia et al, 2008; Singleton and Longley, 2009). New fields for GIScience and GIScience-related technology research have arisen e.g. in the health care sector concerning epidemiology, hospital management, and patient care logistics. Interdisciplinary domains including computer science, surveying, or image processing and applied fields such as forestry, geology, spatial planning, hydrology, or utility management - all playing an important role at least in the technical realm.

A growing number of characteristics have made GIS a mainstream technology, where more and more standard approaches have been adopted to replace earlier, more specialized ones, reflecting economy of scale considerations. However, there are many reasons for treating geographic information as a ‘special’, and certainly fruitful perspective (Goodchild, 1992; 2005; Longley et al, 2010; Torrens, 2010), and for educating specialists in GIS concepts, principles, and uses (Bednarz, 2000; Goodchild, 1992, 2004a; Sui, 2004a; Schuurman, 2006; Craglia et al, 2008; Donert, 2008).

Scholten et al. (2009) describe the explosive growth of geospatial technologies and their pervasive spread throughout the sciences. However, Geography and Geographic Information Science only tell part of the story, because a spatial turn has occurred in several other disciplines, built on ideas strongly associated with Geography. Paul Krugman’s 2008 Nobel Prize in Economics was based on his reintroduction of the importance of location and geographical factors, in understanding economic activity. Space has found new theoretical significance in ‘spatial ecology’ (Zimmerer, 2007) as well as in applied disciplines like geomarketing.

We developed a GIScience doctoral programme addressing several of these spatial realms, and formulating a research agenda in the light of the recent adaptation of spatial concepts in conventional practices and for mass user applications. At the core of this article, we will report on the attempt to articulate transversal research questions in GIScience defined by Geographers, Geologists, Computer Scientists, an Economist, and several

GIS/Geoinformatics experts. The resulting research perspective is manifested in three entities: Research cluster A focuses on the conceptual modelling and representation of space, spatial features and phenomena, and in providing a spatial view onto various kinds of physical and abstract information objects in order to leverage the potential power of a 'spatial perspective'. Cluster B focuses on time and processes. Time has, conceptually, long been considered a symmetrical counterpart of spatial dimensions (Janelle 2001), although in practice multiple dimensions frequently were relegated to secondary ‘attribute’ status, with temporal characteristics (as well as z as a third dimension) handled as attributes of planar features. We discuss that only recently a full integration into spatial / spatiotemporal data models has been pursued. Cluster C focuses on how research in GIScience can contribute to an evolving geo-aware society (Goodchild, 2005; Strobl, 2005) which reveals spatial literacy (Bednarz, 2011). Research focuses on the “science behind the systems”. Such a view requires to define research avenues – metaphorically aligned to the “windows of perception” in Figure 1. Still, GIScience research also technologically addresses the unprecedented increase in the availability of tracking data related to the movement of human beings, groups of people, vehicles or moving objects in general, typically captured through location-aware mobile devices featuring GNSS receivers.

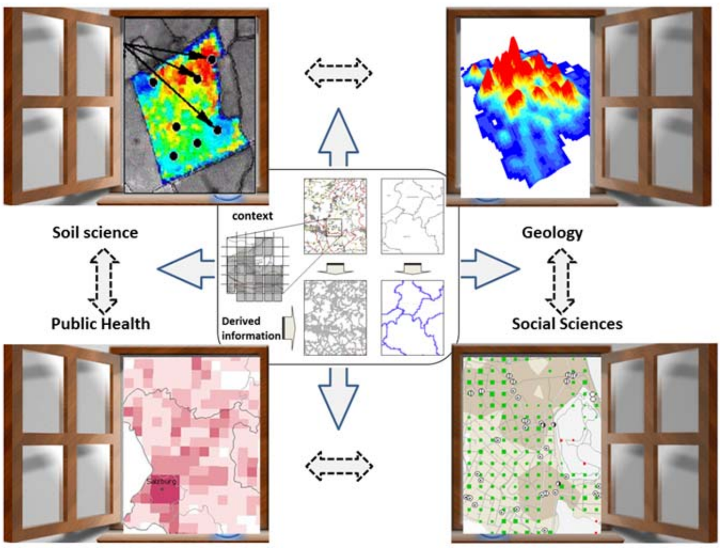

Fig.1. The ‘spatial turn’ and disciplines: Facilitating interdisciplinarity through cross-cutting methodologies?

2 GIScience and interdisciplinarity

2.1 Academic disciplines - interdisciplinarity

An (academic) discipline may be regarded as "a particular branch of learning or body of knowledge whose defining elements, phenomena, assumptions, epistemology, concepts, theories, and methods—distinguish it from other knowledge formations" (Repko 2008: 4). Baerwald (2010) argues that many disciplines are defined primarily by the things they study. If a scholar is a botanist, everybody knows he or she studies plants, a zoologist focuses on animals, a political scientist concentrates on governments and political systems etc. As we witness an enormous increase in scientific literature, which is said to double about every 18 to 20 months, it is getting more difficult to have a complete overview of a discipline in a classic sense and we observe specialization in sub-disciplines. For example, molecular biology today seems to have little in common with organismic biology. Simultaneously, new fields of study arise such as nanotechnology or neuroscience - which do not fit into the classic schemata.

The term *interdisciplinarity* was originally used for education and training pedagogies, which incorporated studies that use methods and insights of several established disciplines or traditional fields of study. Interdisciplinarity, therefore, involves researchers or scholars who are connecting and integrating several academic disciplines, schools, or technologies in the pursuit of a common task. Jantsch (1972) already identified three forms of collaborative activity among scholars from different fields: a) *multidisciplinary* research as the coming together of scholars from different fields in ways that maintain the autonomy of different disciplines and that would not lead to changes in existing disciplinary and theoretical structures; b) *interdisciplinary* research characterizes the collaboration of scholars working on a uniform, disciplinary-transcending terminology or common methodology, cooperating within a common framework; c) *transdisciplinary* which characterizes research engaged in a "mutual interpenetration of disciplinary epistemologies" (Jantsch, 1972: 104).

2.2. New research fields

The 'discipline-based model' is still dominantly used when organizing academic education and institutions. It somehow controls the resources that go into teaching, research, and outreach activities. This model capitalizes on the benefits of specialization - allowing specialists within a discipline to refine theories, methods and technologies, and push the bounds of knowledge outward within that field. For the following sections of this article, it is important to note that a combinatory use of concepts or methodologies of multiple disciplines does not automatically constitute interdisciplinarity. Instead, we may simply - avoiding the discipline discussion – refer to new 'research fields'. Examples include the already mentioned nanotechnology or Business Informatics. Business informatics is a discipline combining Information Technology, Informatics, or Computer Science – depending on the tradition, school and continent - and management concepts. The term is widely used in the German language as "Wirtschaftsinformatik". In the information systems research community, there has been a discourse about the European vs. the American tradition of doing research. The argumentation is driven by the fact that the European (mainly German and Scandinavian) tradition of information systems research argue that IT-systems need to provide a benefit for the users. The American argument – mostly driven by American business schools – is geared more towards the scientifically based description of how IT-systems work and what properties they have (following a behavioristic approach). One might say that this is targeted towards existing (historic) systems and not towards new, innovative solutions. Österle et al. define the following phases/activities in Information Systems Research:

- *Analysis: Problem description, state of the art, research plan, selection of those factors that are relevant for the problem. Polls, surveys, case studies, interviews, etc. are the methods to be used.*
- *Conceptual design: Construction of the artefacts following established methods, etc.*
- *Building prototypes, demonstrators, etc.*
- *Evaluation: Checking whether the artefacts meet the objectives, experiments, simulation, field experiments, etc.*
- *Diffusion: Dissemination of results, papers, course books, lectures, demos, spin-offs, etc.*

Österle et al. argue that this particular combination of activities constitutes a research field.

2.3 Conclusions for designing a GIScience research program

In the following section, we develop a particular instance of a research framework for GIScience. It is not a general framework but one which can serve as a guiding principle at a single, medium-size university. In essence, we consider Geographic Information Science to incorporate core spatial disciplines such as Geography and Earth Sciences, Computer Science and Social Sciences and Communication Media, just to name some of the core disciplines. In Social Sciences, the mode of analysis has been predominantly qualitative – but not exclusively since disciplines such as Economics, Psychology, and Geography have always included quantitative methods – and interpretive among humanities scholars[2] and computational. In the past GIS-based analyses were very rare e.g. in Communication Media. We, therefore, identify the need for quantitative and GIS-based approaches, so that a GIScience program must be broad enough to afford students the opportunity to focus on theoretical foundations and interpretive, qualitative-spatial methods of analysis as well as on quantitative-spatial approaches.

3 Joining our own GIScience research agendas

Developing a research framework, which shall serve as a structural framework and agenda for long term research needs to take into account salient disciplinary features. More than being a sum of the parts – bits and pieces from individual disciplines and ultimately personal research histories of the participating faculty members - such a research framework potentially allows for providing a coarser, more focused perspective on required GIscience concepts and underlying GIS-related actions. It also allows for communicating essential structuring aspects based on universal spatial awareness. The selection of which disciplinary features and structuring aspects to choose from was grounded on a literature survey and on drawing from existing research agendas. Based on a structured literature survey six major research fields were identified (mainly based on Armstrong, 2000; Batty et al., 2010; Blaschke and Strobl, 2010; Bodenhamer et al, 2010; Brown et al, 2004; Burrough and Frank, 1996; Couclelis, 1999; Craglia et al., 2008; Crampton, 2009; de Smith et al., 2009; diBiase et al., 2006; Dobson and Fisher, 2003; Duckham et al., 2003; Egenhofer and Mark, 1995; Fabrikant and Buttenfield, 2001; Goodchild, 1992; 2004a; 2004b; 2005; 2006; 2007; 2009a; Goodchild and Janelle, 2010; Grossner et al., 2008; Jones, 2007; Kemp, 2010; Kraak, 2003; 2008; Kwan, 2009; Kwan and Schwanen, 2009; Kuhn, 2003; Longley et al., 2010; Mark, 2000; 2003; Nellis, 2005; Sui, 2004a; 2004b; Sui and Goodchild, 2003; Taylor and Johnston, 1995; Zhang and Goodchild, 2002), as:

(a) the search for general GIScience principles, such as the enumeration of possible (topological) relationships between events or features and the construction of objects;

[2] We need to avoid a detailed discussion here because of space limitation but we should mention that social sciences and humanities are sometimes separated.

(b) developing effective algorithms, information architectures, and more efficient indexing schemes;

(c) spatial organization and spatial contextualisation of data;

(d) developing new ways of visualizing and communicating geographic information, which grows into a new research field i.e. "spatialization, media, and society". Furthermore, this programme aims to introduce two new, ambitious research topics viz.

(e) geosensing technologies for applications leveraging pervasive computing, and

(f) participatory geoinformation-society.

Based on these more generically formulated research fields we developed our common research agenda which reflects the existing body of knowledge and the specifics of the University. When cross-checking with the University Consortium for Geographic Information Science who outlines a research agenda while addressing 10 foremost research challenges (http://www.ucgis.org) we identified several of the research fields of our GIScience program to be reflected in the UCGIS research agenda, particularly:

1. interoperability of GI;
2. extensions to geospatial representations beyond 2D and single scale;
3. cognition of GI [...] to overcome the gap between human cognition and GIS;
4. scale;
5. spatial analysis
6. GIS and society

This overlap seems to be substantial: no single group will fully cover this 'umbrella' research agenda- As laid out in the next section we formulate three research clusters which are logically linked along a 'knowledge chain'. This provides structure and direction for the selected research themes, and defines an operational structure for interdisciplinary working groups – beyond the classic view of one professor plus postdocs and PhD-students - for collaboration across PhD topics. Research clusters share common research questions, and will address multiple objectives co-operatively. Concepts of spatial thinking and spatial theory are the linchpins of this innovative cross-cutting field of research. Discipline-wise, Geography, Geology, and Computer Science play significant roles but – as reflected by the faculty composition within – it may be seen as a fertile ground for "transgressing the traditional boundaries of science, social theory, technology, and the humanities, and capacious imaginations will be required to realize the potential of GIS to better understand scientific problems" (Sui 2004b: 67). These clusters are critically important building blocks for workflows and information processing chains based on geospatially referenced information.

The overarching approach of this research-oriented GIScience doctoral program is to create new knowledge through integration, by establishing 'orchestrated interdisciplinary research' in an 'education through research' program. At the core of the program are spatial (data) models, information extraction from spatial data, and spatial processes. Still, a group of ten senior scholars cannot exhaustively cover the entire field of GIScience, resulting in a specific and focused research agenda.

4 Research cluster A: representation and methods

The wide range of in-depth investigations, ranging from Geology to Social Geography, reflects the fact that Geographic Information Systems and software for image processing, pattern recognition, and scientific visualization are in widespread use throughout academia, from the physical sciences to the humanities and technical/computer sciences supporting geospatial methods. Functions for the manipulation, analysis, and modelling of spatial data are also available today in standard statistical and mathematical packages. Recently, for instance, the use of object based image analysis methods developed in the geo-domain (Blaschke, 2010) was acknowledged in medical imaging (Marschallinger et al., 2009), cell biology (Hofmann et al., 2009) and nano-analysis (Tiede et al., 2009). We may argue that the essential computational and analytic logic behind MRI and CT sensors are basically the same as in geospatial methods. However, the development of relevant theory and concepts, and the cultivation of spatial literacy (Bednarz, 2011) and generic spatial intelligence through education, has lagged behind. A gap, therefore, exists between the power and accessibility of tools on the one hand and the ability of researchers, students, and the general public to make effective use of them on the other hand.

5 Research cluster B: time and process models

Time has, conceptually, long been considered a symmetrical counterpart of spatial dimensions (Janelle, 2001), although in practice multiple dimensions frequently were relegated to secondary 'attribute' status, with temporal characteristics (as well as z as a third dimension) handled as attributes of planar features. Only recently has a full integration into spatial / spatiotemporal data models been pursued (Raper, 2000). Monitoring and modelling of spatial change today (be it at the landscape or global scales) is a core theme demonstrating the power of and need for interdisciplinary approaches.

This integration, or the potential integration, respectively, is considered a key requirement for dynamic modelling of geospatial processes, with terms like ‘movement’, ‘change’, ‘transfer’ etc. inherently being tied to integrated consideration of time and space dimensions. Early conceptual explorations like the ‘Detroit movie’ (Tobler, 1970), followed much later by ‘Flowmapper’ (based on Tobler, 1987), already demonstrated a focus on visualisation and dynamic cartography (Kraak, 2008), leading to a visualisation-oriented development and a lack of sound foundations in data management and process modelling – a clear case of the (visualisation) user interface running ahead of the actual substance of spatiotemporal modelling. In other words, impressive dynamic visualisation was glossing over the fact that underlying structures were only dedicated to and optimised for visualisation, but not analysis and modelling.

Of course, visualisation is a key instrument for generating hypotheses, and can very well lead to conceptual innovation. An important starting point was presenting the three (meta-) dimensions of space, time, and attribute as equally relevant connected domains, with 2D sections through this cube defining types of geographical analyses as defined by Brian Berry’s ‘data matrices’ (Berry and Marble, 1968) in the early stages of the ‘quantitative revolution’.

Within the framework of these dimensions, a somewhat different view on similar geometric metaphors of the space-time cube and space-time prism was used by Torsten Hägerstrand when first introducing the conceptual and empirical foundations for movements through space (Hägerstrand, 1973; 1995) as traces and paths in time and space, leading to the concept of time geography.

This approach essentially being an early example of individual-based representation in social environments, physical processes in space were approached from a general systems theory perspective leading to simulation (Chorley and Kennedy, 1971). Their mathematically and physically founded view on process modelling was implemented only to a limited degree, with work on ‘PCRaster’ by Peter Burrough’ s group in Utrecht being rather the exception than the rule. While Langran (1992) summarizes conceptual views on space-time, adequate implementations in current software tools are still rare due to limitations in data models.

Dynamic models of the environment heavily depend on calibration and parameterisation through empirical measurements, which are expensive to conduct over longer periods of time at multiple locations throughout a study area. This limiting factor has only recently been mitigated with the advent of inexpensive and integrated sensor systems, accompanied by efficient sensor interoperability facilitated by the sensor web developments.

This, in turn, has led to a bottleneck in data processing, with traditional databases not able to keep up with the enormous streams of spatiotemporal data. As a result, the implementation of dedicated data types has been suggested (Güting et al., 2000; Güting and Schneider, 2005). The concept of 'moving objects databases' has become particularly relevant in the domains of society and transportation, where increasingly humans and vehicles are serving as sensors, generating enormous quantities of spatiotemporal data and providing a foundation for modelling the flows and dynamics of people, information, goods, and assets through space.

Current developments are characterised by two complementary approaches: 'bottom up' ('individual based', e.g. 'agents') simulation of elementary entities and their behaviour being aggregated towards groups, regions, and 'societies', and the 'top down' perspective as made popular through the Club of Rome's world models (Meadows, 1972). This system dynamics (Forrester, 1969; Randers, 1980) approach of stocks, flows, and feedback structures is designed to help with the understanding of complex systems over time, and has only received limited attention (and integration) from a spatial sciences perspective.

While time and space, and the modelling of spatiotemporal dynamics have been consistently recognized as an important element of the GIScience research agenda (Egenhofer and Golledge, 1998; McMaster and Usery, 2005), progress in bridging the gap between conceptual understanding and practical implementations and applications was limited, mainly to visualisation-centric solutions.

6 Research cluster C: spatialization, media, and society

We consider communication and media as the user interface (in a wide sense) as well as hypotheses generator for geospatial research and ultimately practical applications. Cognitive processes lead to mental maps[3] or

[3] The terms „mental maps“ is used here to refer to the cognitive and emotive activities of individuals to create mental representations of spaces and entire environments which are intuitively used to inform, guide, and determine thoughts and actions (Heiser and Tversky, 2006)

‘mindscapes’ which are highly relevant for action. They, in turn, modify physical and societal spaces. This cycle of

communication/media → mental maps → human action → altered physical/social space

is thus an inseparable part of GIScience, specifically informing and controlling the course of human (inter)action.

As geographic principles and cartographic techniques are increasingly deployed in the visualization and processing of non-geographic information (Skupin and Fabrikant, 2003), Geographic Information Science needs to provide a methodological bridge matching spatial entities and related cognitive categories that underlie our understanding and representation of space (Couclelis, 1999; Fabrikant and Buttenfield, 2001). This is the area of investigation, research, and doctoral learning of this research cluster addressing the unprecedented increase in the availability of tracking data related to the movement of human beings, groups of people, vehicles or moving objects in general, typically captured through location-aware portable devices such as GPS receivers. This is the link to Research cluster B: Capture of trajectory data at fine temporal and spatial granularities also require new concepts of representation of detailed geospatial trajectories or ‘lifelines’ (see Laube et al., 2007) in order to allow for scalable processing opening new options for analysis.

Introducing the spatial perspective into schools of thought that are not yet or not in any significant manner ‘spatially aware’ is not just a technical question. Rather, as it can be shown for instance in the inquiry domain of learning processes, it opens up new ground for basic research, which goes even beyond the analytical into the heuristic.

Recent work (Dodge et al., 2008; Resch et al., 2009; Torrens, 2008, 2010) on analysis adds, in contrast to summary trajectory statistics on speed, properties such as motion, azimuth, or sinuosity and refers to the variability of motion properties throughout space and time. This way this research cluster links to cluster B and goes further into communication science, navigation experience, Geoweb-engineering concepts, geospatial visual analytics (Andrienko et al., 2009), and geo-spatial privacy (Armstrong et al. 1999).

Geospatial visual analytics enhances purely visual and interactive methods with new possibilities provided by computational techniques related to data mining, statistics, and optimization. Potential enhancements come also from developing methods to support analytical reasoning, argumentation, knowledge building, and knowledge communication (Andrienko et al., 2009). Geo-privacy involves human, natural, and technical sciences alike and is associated with the placement of confidential, personal, secret, or proprietary data on a map. Developing appropriate methods to protect such data from being “uncovered” is one important research challenge.

Other research should evaluate the effects that such methods have on visual displays (Leitner and Curtis, 2006) or on the results of spatial analysis (Armstrong et al., 1999). For stronger coverage of the user perspective in GI, novel approaches to interaction need to be explored and studied in detail.

7 Conclusions

We started from the vision that Geographic Information Science is developing into an interdisciplinary research field or even a discipline of its own, at least not simply being part of Geography, Computer Science or the intersection of both. GIS has in essence always been a set of tools designed for processing, analysis, modelling, and storage of spatial data emerging in the 1960s (see Foresman, 1998). It now constitutes a large and growing industrial sector. More recently, it has become apparent that geospatial technologies are based on, and in turn raise issues of fundamental significance, and that these issues form a domain of science whose discoveries provide the basis for the technologies (Goodchild, 2009). This science is known as Geographic Information Science (Goodchild, 1992) or GIScience in short but also referred to as geospatial science, geoinformatics, geomatics, and spatial science. This may partly be owed to the fact that the interdisciplinarity inextricably linked to GIScience spans from (hard) sciences to engineering to social sciences. Goodchild (2010), for instance, considers parts of the discipline (also he does not decide whether it is a discipline are an interdisciplinary field) and its disciplinary leanings as varying considerably, e.g. Geodesy as true science, Cartography as somewhere between science and art, and photogrammetry as more akin to a branch of engineering. Whether or not being acknowledged as a science provides a scientific perspective and a theoretical framework with a core of theory, data handling methodologies and methods, sometimes directly connected to software engineering work and increasing engagement with related disciplines.

This article has – in a condensed form – provided a rationale for a focused GIScience research framework. This provides a structure and an agenda for a 12-year doctoral program and several dozen PhD topics. The division into the three research clusters has consequences for the educational program. This is currently described in a separate article under review and – in a very condensed form – in Blaschke et al. (2011). It may just be mentioned here that the clusters have different associated faculty in respect to disciplinary background, and different specific classes and workshops offered - although all in all these specific classes only account for 10 ECTS (European Credit Transfer System) within the 180 ECTS Doctoral Program. Our long-term goal is to contribute to the advancement of GIScience through an ‘education through research program’ and its well-defined research avenues made operational in three clusters. Subsequently, we are aiming to further developing interdisciplinary research teams – not groups of individuals.

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