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Geographic Information Science: Building a Doctoral Programme Integrating Interdisciplinary Concepts and Methods

Thomas Blaschke[a]*[,b], Josef Strobl[a,c], Karl Donert[d]

[a]*University of Salzburg, Centre for Geoinformatics, Hellbrunner Str. 34, 5020 Salzburg, Austria*
[b]*Research Studio iSPACE, Research Studio Austria FG, Leopoldskronstr. 30, 5020 Salzburg, Austria*
[c]*Austrian Academy of Sciences, GIScience Institute, , Schillerstr. 30, 5020 Salzburg, Austria*
[d]*President, EUROGEO, UK National Teaching Fellow, DigitalEarth.at Austrian Centre of Excellence,University of Salzburg, Schillerstr. 30,5020 Salzburg, Austria*

Abstract

Geographic Information Science (GIScience) is an interdisciplinary field that seeks to understand the nature of geographic phenomena and of geographic information. It provides theoretical foundations for Geographic Information Systems (GIS) and the rational for research and development of GIS in mainstream ICT. Building on Masters level education we argue that more coordinated and structured education and training is required at the doctoral level. We developed a formalized doctoral education and research training programme in GIScience at the University of Salzburg, by integrating students in three focused, interconnected, interdisciplinary research clusters. We illustrate how this programme seeks to acknowledge spatial principles, to explore scientific and educational uses of geographic information in order to elucidate the complex relationships that individuals and society have with GIS. It provides a framework for 'education through research' programme.

Keywords: GIScience; Geographic Information Science; GIS; doctoral programme; PhD curriculum; education through research;

1. Rationale

In 1998, the then U.S. Vice-President Al Gore articulated a vision of "Digital Earth" as a multi-resolution, three-dimensional representation of the planet that would make it possible to find, visualize, and make sense of vast amounts of georeferenced information on the physical and social environment. At that time, this vision of Digital Earth seemed almost impossible to achieve given the requirements it implied about access to computer processing cycles, broadband Internet, interoperability of systems, and above all data organization, storage, and retrieval. Since then, a considerable amount of research has been

* Corresponding author. Tel.: +43 662 8044-5225; fax: +43 662 8044-525.
E-mail address: thomas.blaschke@sbg.ac.at.

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undertaken, so that today, many of the elements of Digital Earth are not only available but they are also used daily by hundreds of millions of people worldwide.

For Geographic Information Science – GIScience in short – Blaschke and Strobl [1] analyse the literature and describe GIScience as an interdisciplinary field of research based upon the understanding that basic and applied research must be reflected within society [2, 3]. The European Union's concept of the 'Information Society' claims that the spatial aspect is pertinent to a majority of information aspects. Blaschke and Strobl [1, p. 10] argue that the spatial dimension is a key component of the 'context' of objects, and affects our daily lives and actions.

A doctoral degree – or Ph.D. (this paper consistently refers to 'Doctoral degree' to accommodate national variations) is a research degree, designed to prepare students to become scholars. At the conclusion of the degree programme, the student should have acquired the knowledge and skills expected of a scholar who has made an original contribution to the field and has attained the necessary expertise to continue to do so. Doctoral training has gained increased importance in the context of the Bologna Process since the Berlin Communiqué (2003), which included doctoral programmes as the 'third cycle'. Doctoral programmes also form the first phase of younger researchers' careers and are thus central in the drive to create new scientific knowledge, as more researchers need to be trained than ever before [4].

A majority of contemporary science doctoral education systems push students into specialized disciplinary research [5]. Academic departments typically act as local manifestations of a focused discipline and as the primary locus of control for doctoral education. Professional doctorates, applied research and workplace connections have become increasingly dominant forces in contrast to purely scientific research [6].

In the remainder of this article we position the concept of a new doctoral education programme, based on pure GIScience research, in which coordinated research aims for a better understanding of the complexity of interactions and inter-dependencies between environmental and social phenomena at different levels, i.e. from local to global.

2. Geographic Information Science

GIScience is a relatively new interdisciplinary field of research based upon the understanding that basic and applied research must be reflected within society [7]. GIScience-technology (not a contradiction as discussed later) has been well established in many different economic sectors, like natural resource management, real estate and insurance. New fields for GIScience 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 have played an important role at least in the technical realm.

A growing number of characteristics have made GIS a mainstream technology, where standard approaches have been adopted to replace earlier, more specialized ones and reflect economy of scale considerations. However there are many reasons for treating geographic information as special [8,9], and for educating specialists in GIS concepts, principles, and uses [10, 8, 11, 7, 12].

"If the ultimate goal of GIScience is to better understand how nature works and how we, as humans, can better organize our activities on the surface of the earth, then we must continue to push the development of GIScience along these two seemingly contradicting lines" [11, p. 532].

Scholten et al. [2] described 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 recently occurred in several other disciplines, but they have been built on ideas that are most 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 generally, in understanding economic activity. Space has recently found new theoretical significance in ecology [13].

In computer science, the Association for Computing Machinery founded a Special Interest Group on "issues related to the acquisition, management, and processing of spatially-related information".

The concept of GIScience has been adopted enthusiastically. Several journals have been (re)named, various books have been published [14, 15, 9], a major consortium of US universities has been established (the University Consortium for Geographic Information Science, www.ucgis.org). Specialist programmes have appeared in academic institutions and GIScience has been the subject of several studies of the National Research Council in the US and in European countries. The system versus science issue has been revisited [16, 17], and reports have been written calling for the establishment of major programmes of research funding [18]. Efforts have been made to define the grand challenges in the field, and to identify its fundamental principles [19].

3. Designing a doctoral programme in GIScience

3.1. Programme Vision

The University of Salzburg Austria is acknowledged as an important player in GIScience education. Doctoral developments, in the form of a doctoral college called DK GIScience have been proposed to stake out a leadership role in this rapidly expanding field by building excellence across existing areas of strength (Geoinformatics, Computer Science, Earth Science, etc.). The impetus for this has been the increasing realization that spatial organisation matters to researchers in the natural, social and behavioural sciences, engineering and the applied sciences, as well as the arts and humanities.

Geographical science research is becoming a task very relevant to society. A report of the US National Research Council from March 2010 (http://www.nap.edu/catalog.php?record_id=12860) identifies eleven questions that should shape the next decade of geographical science research. Reflecting a time when populations are moving and natural resources are being depleted, the questions aim to provide a more complete understanding of where and how landscapes are changing to help society manage and adapt to the transformation of the Earth's surface. The report identified research priorities and the approaches, skills, data, and infrastructure necessary to advance research. This educational programme covers and mirrors many aspects of these strategic directions. The GIScience doctoral programme addresses several spatial realms, and formulates a clear research agenda in the light of the recent adaptation of spatial concepts in conventional practices and for mass user applications. The overarching research perspective is how research in (geo)informatics can contribute to an evolving geo-aware society [20] in an organised way although recent empirical studies reveal problems with the linear assumption that more (spatial) ICT engagement may have direct measurable effects on social status [21]. DK GIScience focuses on the "science behind the systems" rather than the hype caused by virtual globes such as Google Earth or Microsoft Bing Maps and related fast technology-driven developments.

Based on this rationale the authors have developed a detailed concept for an interdisciplinary doctoral degree programme in GIScience (DK GIScience) that will be launched in the 2011-2012 academic year at the University of Salzburg, Austria. When amalgamating and synthesizing the common denominator of definitions on 'interdisciplinarity' we may argue that scholars identify disciplines as domains of inquiry that share objects of study, problems to investigate, values, terms, concepts and assumptions governed by a certain set of rules and categories guiding the pursuit of knowledge [22].

Our vision partially builds on the foresight, twenty years earlier, of the NCGIA [23], the progress since then, the explicit lessons learned, and recent technological developments in GIS and GIScience [1]. Although not directly comparable (the NCGIA initiative was a multi-million dollar US-wide long-term plan) one significant difference is that the NCGIA proposal was built on 'impediments' [23]: GIS technology was said to have enormous potential but that numerous roadblocks needed to be removed including user-friendly interfaces, institutional or standardization issues. Today, in many fields GIS is inevitably but intrinsically linked with mass user related workflows and to new scientific and societal

questions that need to be addressed. Rather than focusing on the impediments, the three building blocks of DK GIScience are centred around the opportunities for the extensive use of spatial thinking and quantitative analysis [24, 25, 2]. The significance of these impacts has been pervasively documented in a recent book edited by Scholten et al. on geospatial technologies and their proliferation throughout the sciences.

Consequently, the resulting DK GIScience concept for a doctoral programme aims at the development of relevant theory, methodologies and methods, and the cultivation of Geographic Information through an 'education through research' programme that will close the gap between the power and accessibility of tools on the one hand and the ability of scientists to make effective use of them on the other. This will be encouraged through an open-ended enquiry-driven research approach but within very specific and carefully planned avenues. In this way, an over-emphasis on instrumental activities should be avoided. Attention will be given to making explicit the rationales, aims and questions that underlie both the research project goals and educational goals.

3.2. The Salzburg Ten Basic Principles

The design of the DK GIScience doctoral programme has been motivated and influenced by "The Salzburg Ten Basic Principles". The Bologna Seminar on Doctoral Programmes for the European Knowledge Society held in Salzburg, Austria, February 2005 provided a major forum to discuss the Action Line in the Bologna Process entitled "European Higher Education Area and the European Research Area – Two Pillars of the Knowledge-based Society". Building upon the momentum of the 2004 Maastricht conference, members of the European University Association Doctoral Programmes Project were able to air their findings to a wider audience and contribute to the discussion on the future groundwork required for the successful development of the third cycle of the Bologna Process.

The Salzburg Seminar was a significant development in the sequence of Bologna Process events in that it established a working dialogue among higher education policy practitioners, university researchers and doctoral candidates on the key issue of how to promote closer links between the European Higher Education Area and the European Research Area in order to improve the quality and competitiveness of European higher education [26]. Subsequently, the EUA Glasgow Convention (2005) stressed that the core element of all doctoral programmes was training by research, but not necessarily only for research careers, but also for employment in other sectors.

3.3. Doctoral programmes represent a crucial part of university education and research

The motivation for the establishment of this interdisciplinary programme with a strong element of international outreach was to achieve an 'education through research' approach. The doctoral programme orchestrates ten research projects and sets precise standards for qualification requirements, the responsibilities and duties of the faculty members, supervisors and co-supervisors; the coordination of supervisors and their workloads; supervision models and an innovative mentorship model; the doctoral candidates' progress assessment; requirements for the doctoral thesis and its defence; and finally, the follow-up "tracking" of doctoral candidates' career outcomes and the visibility of the programme.

Traditionally and particularly in Austria, doctoral programmes used to be considered mainly as a gateway to future academic careers. In contrast to North America, the European model of doctoral education and training has been traditionally shaped by a traditional master–apprentice model [27]. With a significant increase in the number of doctoral candidates in recent years and major changes to the competitive nature of the global labour market, most universities, particularly in Austria, face a challenge to reform their doctoral programmes in order to adapt to new conditions. The University of Salzburg has reacted appropriately and has built a series of 'Bologna compliant' doctoral study programmes. The Bologna Process has thus had a significant impact for the development of doctoral degrees and has further

contributed to the debate on the need for change and for more focused, well-thought-out programmes. DK GIScience should be a role model in changing the approach to doctoral education to a more systematic and structured way, while at the same time working towards increased transparency in admission, selection and quality assessment.

3.4. The overarching research questions

Based on the explosive growth of geospatial technologies and their pervasive spread throughout the sciences [28, 2, 3], the state of knowledge in GIScience has been intensively reviewed. As a result, DK GIScience researchers hypothesize that a paradigm shift is currently taking place proceeding from the elemental recognition that all human action has a spatial footprint and that the spatial dimension of social interaction is of paramount importance for understanding all of the classic questions about the human condition, human-human and human-environment interactions. While this transformation has been taking place for several years [29] its impact has become increasingly dominant in many scientific fields such that it is acknowledged that the transformative impact of the spatial dimension has become relevant to many research questions [28, 30, 3]. It is not clear at this moment whether this spatiality is independent from recent technical developments, which have led to mass-market applications [7, 2] but it certainly requires new methodologies and methods of analysis [31, 32, 33]. This programme incorporates core spatial disciplines such as Geography, Earth Sciences, Computer Science, Social Sciences and Communication Media. In Social Sciences, the mode of analysis has been overwhelmingly qualitative and interpretive among humanities scholars and computational and GIS-based analyses have been very rare. We therefore recognised that a GIScience programme must be broad enough to afford students the opportunity to focus on theoretical foundations and interpretive, qualitative methods of analysis as well as on quantitative-spatial approaches. The overarching approach is to create new knowledge through integration, by establishing 'orchestrated interdisciplinary research' in an 'education through research' programme. At the core of this development are spatial data models, spatial data handling and spatial processes.

The wide range of in-depth investigations, ranging from Geology to Social Media, 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 [34] was acknowledged in medical imaging [35], cell biology [36] and nano-analysis [37]. The essential computational and analytic logic behind MRI and CT scans are basically the same as those used in geospatial methods. However, the development of relevant theory and concepts, and the cultivation of spatial literacy and 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. Therefore, a systematic literature review was conducted and an ambitious and coherent research agenda developed with a clear educational mission.

Based on a structured literature survey six major research fields were identified 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;

(b) developing faster 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 develops into a new research field i.e. "spatialization, media and society". Furthermore, this programme aims to introduce new ambitious research topics viz.

(e) geosensing technologies for pervasive computing applications

Cross-checking with the University Consortium for Geographic Information Science agenda (http://www.ucgis.org) confirmed that several research fields were reflected there and particularly

interoperability of GI;
extensions to GI representations *beyond 2D and single scale;*
cognition of GI [...] *to overcome the gap between human cognition and GIS;*
scale;
spatial analysis

4. Building a Thematic Framework

Geographic Information Science has an intimate relationship with the discipline of Geography, since they both address the same aspects of reality [38] from very similar perspectives. However, Geographic Information Science is (also) the "Science behind the system" [8] concerned with representation and computational issues, whereas Geography attempts to explain and predict geographic phenomena. A major issue is the intrinsic and increasingly widespread communicative 'nature' of geographic information [39, 40]. This is becoming more and more apparent in 'web 2.0' environments, along with 'Volunteered Geographic Information [41], Neogeography [42] and with real time sensing [43]. These are very recent developments [44] and research is beginning to systematically explore whether these issues may or may not significantly influence society.

In preparing for the development of this doctoral programme, a comprehensive survey of GIScience doctoral programmes worldwide was carried out in 2010. In all 27 programmes were identified which are 'at the core of GIScience' or have a 'spatial science' focus. This means they do not have a solely technical focus on GIS or Geoinformatics although many significantly overlap with Geoinformatics or Geomatique in the francophone countries. Eleven of these programmes are offered by US-Universities, three exist in Canada, seven in Europe, four in Asia and two in Australia. In essence, most existing programmes focus around long-standing expertise of university faculty and very few tackle GIScience in a fully interdisciplinary outlook.

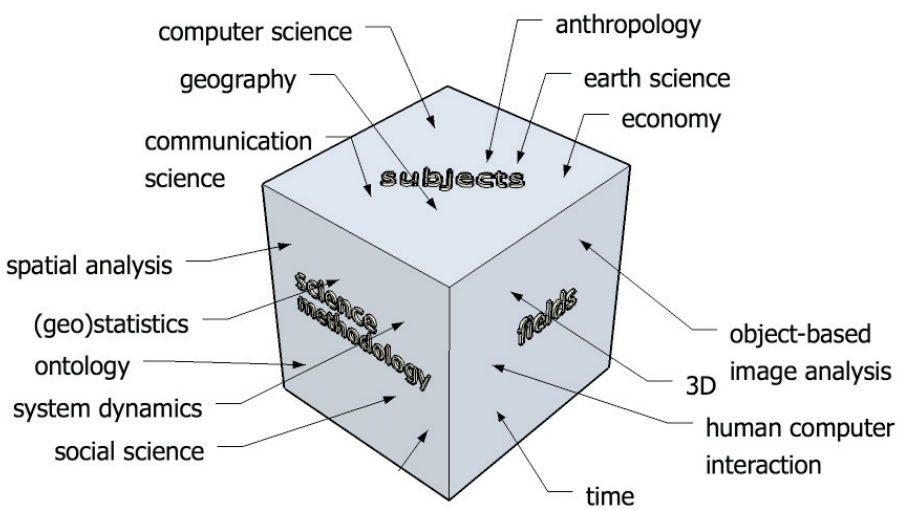

Fig. 1: The GIScience cube: research perspectives

The DK GIScience doctoral programme is designed to include diverse scientific areas (Fig. 1) though it is challenging to facilitate commonalities between e.g. four-dimensional geological processes and four-dimensional pattern analysis of movement of individuals in space. From the inter-relationships, three focussed research areas or 'clusters' have been identified as "time and space models", "data representation strategies" and 'spatialization, media and the society'. The latter explicitly incorporates research on the user's perspectives and builds strong connections to the interdisciplinarity afforded by Spatial Sciences / GIScience (i.e. applied geo-sciences) well beyond initiating fields such as Geography and Computer Science.

5. Conclusions

Based on 18 months preparation including a significant literature review, a successful funding proposal was made to the Austrian Science Fund. The DK GIScience programme was approved to cater for up to 24 doctoral students over a maximum period of twelve years. This will allow the education and training of up to three generations of doctoral students and the professional development of a significant number of GIScience researchers. The doctoral programme seeks to be a role model for the implementation of the third cycle of the Bologna process, by designing a high quality programme that is globally competitive. Through many accompanying measures, which could not comprehensively be described in this paper, it will seek to build a global network of other centres of excellence to advance knowledge.

The overarching thematic field of this doctoral programme is GIScience, including Geoinformatics and related disciplines within the ICT domain. The spatial dimension is a key component in the 'context' of objects that interplay in our daily lives and actions. It is the concept of 'location' that best provides wide-ranging means of connecting virtual and real worlds. This connection is in turn required to provide contemporary business models for the information economy.

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