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GEOGRAPHIC INFORMATION SCIENCE DEVELOPMENTS

Thomas Blaschke, Josef Strobl

Abstract: This paper summarizes and weights some trends and developments in Geographic Information Science – in short: GIScience – while excluding tendencies which are obvious to a *'GIS-literature'* audience already such as the *'Google Earth hype'*. The authors treat GIS and GIScience rather synergistically since the respective underlying constructs are essential for a spatially aware society, at least for a *"geo-literate"* society. The trends are liberally and not exhaustively organized in 10 themes which dramaturgically span from 1) spatial data abundance and 2) spatial thinking to 3) non-boolean searches and *'spatializing'* non-spatial data. 4) Spatial computing is expected to form the baseline for 5) ubiquitous computing. Major challenges rise for future information handling 6) beyond Cartesian metrics and 7) advanced spatial theory on the sphere. An additional topic is 8) user generated (volunteered) Geographic Information. All these - and other - trends may lead to 9) an *'un-GISing'* of GIS and GIScience, and may lend themselves as stepping stones towards 10) Geo-literacy and empowerment. Finally, the paper ends with an outlook on *"what's next"*.

Keywords: GIScience, spatial thinking, spatial computing, spatial theory, Geo-literacy, Geo-society

// GEOGRAPHIC INFORMATION SCIENCE: ENTWICKLUNGEN UND TRENDS

// Zusammenfassung: Der Artikel kategorisiert Trends und Entwicklungen in Geographic Information Science – kurz: GIScience – wobei weithin bekannte und offensichtliche Entwicklungen wie z.B. der *„Google Earth hype"* ausgeklammert werden. In der gebotenen Kürze werden die Trends ohne scharfe Trennung zwischen GIS und GIScience in 10 Themen organisiert: 1) vom Flaschenhals zum *„Datenüberfluss"*. 2) räumliches Denken. 3) Nicht bool'sche Suche und die *"Verräumlichung von* (ursprünglich nicht räumlichen) *Daten"*. 4) Räumliche Informationsverarbeitung als Grundlagen von 5) allgegenwärtiger (pervasiver) Informationsverarbeitung. Diese und weitere Entwicklungen stellen neue Herausforderungen an die Informationsverarbeitung, insbesondere hinsichtlich einer 6) *„nicht-Kartesischen Metrik"* und 7) einer sphärischen Informationsverarbeitung. Steigende Bedeutung hat die 8) Nutzer-generierte Information. Derzeit und wahrscheinlich in Zukunft zunehmend lässt sich ein Trend erkennen, der in der englischen Sprache neuerdings mit 9) *„unGISing"* bezeichnet wird. All dies – so glauben die Autoren – kann und muss mit zunehmend selbstverständlichen 10) *„Geo-Verarbeitungsfähigkeiten"* verbunden sein, u.a. auch hinsichtlich partizipativer Ansätze. Abschließend wird die Frage nach notwendigen Schritten in Wissenschaft und Forschung gestellt.

Schlüsselwörter: GIScience, räumliches Denken, räumliche Informationsverarbeitung, Raumkomzepte, Geo-Verarbeitungsfähigkeiten, Geo-Gesellschaft

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1. SCOPE

The term Geographic Information Science, or GIScience in short, was coined by M. Goodchild (1992) who started his article with the sentence: *"The geographical information system (GIS) community has come a long way in the past decade."* Based on a literature review we start this article with the hypothesis that Geographic Information Science has come a long way, too. While the relatively special nature of early GIS - relative to what was mainstream IT by then (Goodchild (1987); Anselin (1989); Coppock, Rhind (1991)) – has almost vanished when becoming part of mainstream IT the specificity of GIScience has yet to be defined. The NCGIA core Curriculum in Geographic Information Science (www.ncgia.uscg.edu/giscc/units/u002/u002.html) states that *"the science behind the technology considers fundamental questions raised by the use of systems and technologies is the science needed to keep technology at the cutting edge"* which refers to the older and simpler statement that GIScience is the *"science behind the systems"*. For a more philosophical and epistemological discussion we refer to Goodchild (1992, 2004), Sui (2004), Schuurmann (2004) and others. Especially Schuurman links the science and technology to the philosophical and theoretical grounding of GIS. What is left, then? Don't these fundamental papers comprehensively manifest GIScience? We believe they do, to a large extent. But when studying the major realm of literature we observe the following problems/issues:

- A vast majority of authors are from the English-speaking world, predominantly from North America. It is not clear if this body of literature really caters for the views of various cultures, generations and various levels of computer literacy and Geographical thinking.
- Glscience and GI-technology are sometimes separated from each other.
- Computer Science is more and more absorbing at least parts of what was the classic GIS community. As Reuter and Zipf (2008) lay out, interacting with other fast-moving disciplines such as Computer Science, 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.
- Especially in the German-speaking world and partially in Northern Europe, there is a significant body of literature which refers to *"Geoinformatics"* –as the francophone community may refer to *"Geomatics"* (Holmberg 1994; Blaschke 2003). We make the case that Geoinformatics is NOT a synonym to GIS or Glscience, it is closer related to informatics and has a strong background in surveying and photogrammetry.

2. GEOGRAPHIC INFORMATION SCIENCE

There is a significant body of literature about what exactly makes spatial special (Goodchild (1987), (1992), (2004); Anselin (1989); Longley et al. (2001); Sui (2001), (2004), just to name a few). Anselin (1989) identifies two characteristics that are almost universally true of geographic data: spatial dependence and spatial heterogeneity. Spatial dependence refers to the tendency for geographic data to exhibit spatial autocorrelation, the subject of Tobler's First Law of Geography (Longley et al. (2001)): *"all things are related but nearby things are more related than distant things."* Spatial dependence is the basis of all GIS data models, since it allows the kinds of simplifications that are essential to the description of what is in reality an infinitely complex world. The economic success story of GIS is well known and so is the one of the theory deficit which was the starting point of the NCGIA initiatives in the late 1980ies. While GIS has been technology-driven for the first 25 years or so, GIScience is very much about the society. It is the intellectual endeavour and the academic framework of solving problems within the area of GIS development and dissemination. While GIS is about the tools GIScience is about the development and evaluation of the tools and methods. It studies impacts on society and in doing so it may contribute to an improved understanding of methods and tools by experts and lay people. GIS is unique in its ability to threaten individual privacy, through the creation of massive, high-resolution databases and their linkage through street address and other geographic keys, and in its importance to surveillance. Thus, it created and still increases the need for studying its implications to the society.

GIScience may also be seen as an interdisciplinary field of research based upon the understanding that basic and applied research must be reflected within society (Goodchild (2004); Caron et al. (2008); Craglia et al. (2008)). The European Union's concept of the *'Information*

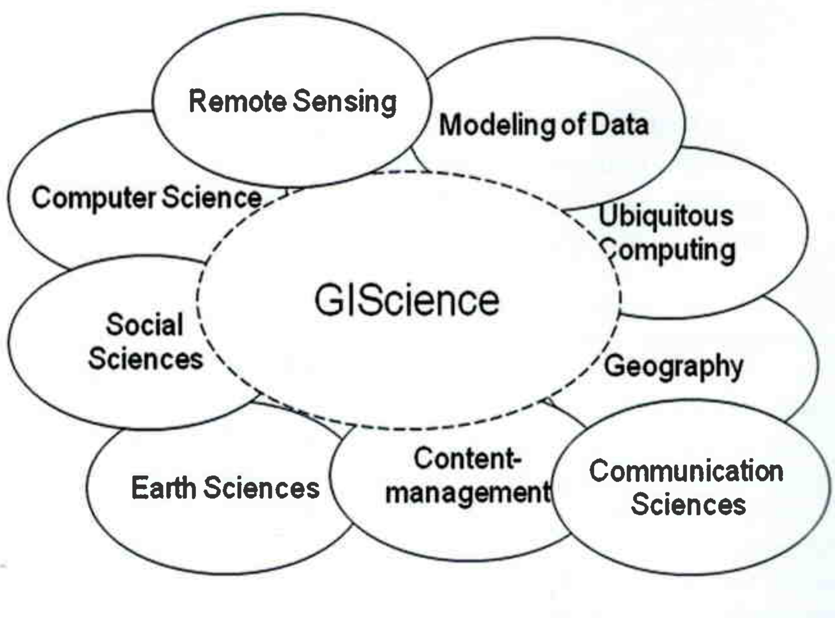

Figure 1: GIScience – a crosscutting discipline

Society' claims that the spatial aspect is pertinent to a majority of information aspects. The spatial dimension is a key component of the *'context'* of objects, and affects our daily lives and actions. It is the concept of *'location'* that provides the best general means of connecting virtual and real worlds. An unanswered question, though, is whether or not GIScience offers adequate methods and theories to support such an information society or even a *"Geo-society"*. It provides at least more and more the foundations of an object centred view beyond database concepts (Blaschke (2010)).

Up to now, GIScience-technology –starting from the narrower field of GIS has been established to a certain degree in different economic sectors, like natural resource management, real estate or insurance business. New fields for GIScience(-technology) arise e.g. in the health care sector, concerning epidemiology, hospital management and patient care logistics. Naturally, Geography was and is a logical conceptual framework for this arising field of science. But Geography has only partially played a leading role in conceptual developments over the last years. Rather, a truly interdisciplinary interplay of disciplines including Computer Science, Surveying, or Image Processing and application fields such as forestry, geology, spatial planning, hydrology, or utility management have played in important role at least in the technical realm.

Through time more and more aspects of GIS have become mainstream, and more and more standard approaches have been adopted to replace earlier specialized ones, reflecting the economies of scale inherent in the mainstream. However there are many reasons for treating geographic information as special (Goodchild (1992), (2005); Longley et al. (2001)), and for educating specialists in GIS concepts, principles, and use (Sui (2004); Goodchild (1992), (2004), (2006); Schuurman (1999); Craglia et al. (2008)). *"If the ultimate goal of GIScience is to better understand how nature works and how we 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"* (Sui (2004), p. 532).

3. MAIN TRENDS CHALLENGING GISCIENCE – 10 HYPOTHESES

In this section we identify ten major trends which affect GIScience and where GIScience has to find answers to (note: these are not necessarily recent trends already covered substantially within GIScience literature).

1) Spatial data abundance – instead of bottlenecks

While in earlier years of GIS data bottlenecks were repeatedly been identified as limitations for further development of custodial GIS or GIS for decision support (Malczewski 1999) data sharing and data standardisation lead to more data interchange. Even more significant in this respect was the development of data capturing devices and sensor technology. Driven by massive sensor deployment, we will even see a more massive stream of data in the future; some of these data are loosely integrated. This requires to accepting a *'living with inconsistencies'*. In an era of data abundance more contradictions between data exist. Some data will be more spatially accurate but not necessarily more appropriate for a specific application. A clear trend is that more current data exist, even real-time data. Similarly, more visual data are created but also *‚new'* kind of data. This includes non-conventional data (e.g. number of mouse clicks, time a user spent per web-view ...) but data are also increasingly acquired from non-conventional channels. A good example may be Google Flew as an early proxy for a real-world phenomenon.

Data redundancy is becoming commonplace in world of geospatial information and is fostering a new era of data standardisation, metadata and partially triggering the widely implemented spatial data infrastructures (SDIs). Data affluence triggers the quest for obtaining more precise results. Less obvious - and less imperative may be its utilization to overcome contradictions or (deliberate) falsifications. Future research is needed an explicit use of data redundancy to avoid some wrong interpretations. Innovative systems will support alternative solutions to a request, e.g. instead of clicking and getting one immediate value one may alternatively or additionally get the request checked for other options or provide e.g. average values. Alike the development of GIS over the past years into a service architecture was made possible by the standardisation of such services through nearly immediately accepted OpenGIS Web Services standards such as WMS, WFS, WCS, CSW, the plethora of data needs to be processed through a chain of standardised procedures. More recently, we witness the processing and analysis of geographic information through OGC Web Services such as Web Processing Service (WPS). Concerning data affluence, we need to establish cross-calculations and plausibility checks in a service-oriented environment.

2) Spatial thinking

After having worked for many years with and about GIS, geographic information and how to handle it we hypothesize that the majority of new technologies in handling Geographic information did not necessarily change generic concepts and spatial thinking. Conversely, in many cases, the opposite is true. Instead of revolutionizing scientific methodologies, we most often simply employ new technology to carry forward with old ways of thinking, and it can take a long time before the basic concepts are altered significantly. One challenge for GIScience is to embrace spatial concepts and concepts of other reasoning concepts such as temporal reasoning and to develop traditional HCI (Human Computer Interaction) concepts further. The spatial approach and GIScience may allow for a more diversified approach including languages, cultures and a user perspective. The user perspective will be imperative for the design of HCIs as we can already apprehend with today's virtual globes.

3) Non-boolean searches and spatializing non-spatial data

On the Internet, there are more and more examples which go beyond Boolean searches. Various software tools provide increased ease of use by making natural language queries possible, and deliver superior recalls. In a more qualitative spatial and temporal reasoning we are more dealing with abstractions which become closer to how people perceive the environment (street networks ...). This leads to the notion of semantic similarity which is

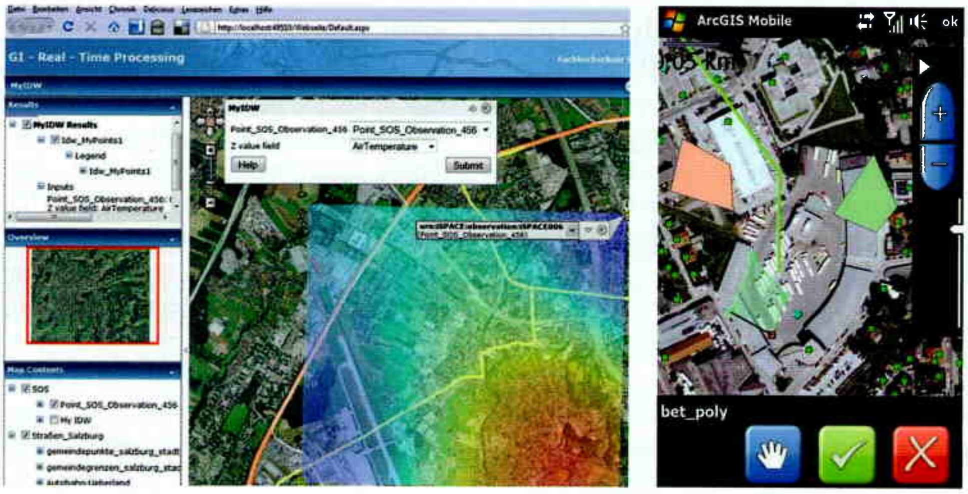

Figure 2: Real time temperature interpolation (Mittlböck and Resch, 2009); ArcGIS Mobile application (Vockner, unpublished).

making inferences about things which are not exactly the same. Even spatially, applications arise which are making predictions beyond exact matching. In a therefore somehow intertwined trend, we see more and more examples of *'spatializing non-Spatial Data'*. Existing attributes of non-spatial data may be used for spatial representation by converting the data to a form that has spatial attributes. For example distance metrics (dissimilarity, relevance, disutility, correlation) can be used to convert data to a spatial format using multidimensional scaling (MDS) techniques, factor analysis, Kohonen nets, clustering, geometric triangulation, or singular value decomposition. Another example are categorical data which may also be converted by assigning numeric indices and utilizing natural distributions in the data.

4) Spatial computing

The classic GIS approach may be associated with the phrase *"computing about space"*. Only more recently computing IN space becomes possible. The latter has been triggered by a mass usage of navigation systems starting off from car navigation. Today, sophisticated applications for bicycle navigation, pedestrian navigation and combined outdoor/indoor navigation are being developed. While car navigation is predominantly streamed information some highly interactive applications in pedestrian navigation are being developed.

In the late 1990ies technological advances made *'computing in space'* prototypically possible and a new field of mobile computing started to develop. This development was made possible by the increasing availability of wireless communication networks enabling fast data transfer, as well as the diffusion of mobile clients such as cell phones, PDAs and sensors that allowed for network communication. Mobile computing deals with questions related to building a distributed system based on mobile clients (Satyanarayanan (2001)). Moller-Jensen ((2005), p. 157) and Laube et al. ((2009), p. 163) present two approaches towards *"computing in space"*:

- Geo-sensornetworks: Data acquisition and (pre)processing with sensors that are distributed in space; recorded data are transferred to a server in real-time and stored there. This system is well-suited for the monitoring of environment properties (e.g. the surface temperature, see Fig. 2).
- Mobile GIS: Information extraction (data query and analysis) and presentation with mobile devices, in relation to the dependent position in space (GPS coordinates); access to numerous web services, especially location-based services (LBS) and mobile mapping (Fig. 2).

5) Spatial computing – ubiquitous computing

New research questions arise for mobile GIS applications, especially regarding human-computer interaction. Mobile usage may in many aspects be different from desktop applications and therefore other styles of interaction are required (Reichenbacher (2003)). First, interaction with geospatial applications is constraint by the small display size of mobile devices (Laube et al. (2009); Dix et al. (2000)) and research is needed allowing an effective use of the available space (Goodchild et al. (2004)). Second, the information provided by a mobile GIS needs to be adapted to the perceived environment, i.e. the context, of the user. This environment perception depends on the position, the travel speed and the purpose of the user (Moller-Jensen (2005), p. 157). Dix et al. ((2000), p. 147) elaborate on the importance of context in mobile systems. They present a design framework *"consisting of taxonomies of location, mobility, population, and device awareness"*. Through integrated GPS and compass the user of a mobile device is able to gather information about the current environment and relate real-world objects to the current position. LBS should account for this information by providing information in an egocentric way (e.g. maps that automatically adapt to the user's movements) rather than in the usual allocentric view, also known as *'birds-eye-view'* (Frank et al. (2004)). This development towards applications that offer personalized information to mobile devices is referred to as context- and location-aware computing (Dix et al. (2000)).

Technologically, we have probably only seen some initial developments and innovations are expected to be triggered by recent developments beyond traditional displays (folded displays, sunglasses ...), integrated electronic compass, semitransparent glasses leading e.g. to *'intelligent windshields'* in cars or adaptive optics reacting to sun conditions.

6) Beyond Cartesian metrics

Geographic representations such as analogue or digital maps typically rely on the metric space concept (e.g. Cartesian coordinates). They are typically presented at a specific scale and for a specific scale. Depending on the scale, maps are more or less generalized, but generalization is the same for the whole area that is mapped. Thus, every object and every feature shown in a static map is of same importance. This is known as the allocentric way of geographic representation (Frank et al. (2004)). However, in the mobile usage situation geospatial information may be presented in a different way as the human dimension comes in: Human-centred and context-aware representations should be provided. In contrast to the allocentric, the egocentric view of mobile applications should give more relevance to objects that are nearby and less to those that are outside the user's *"view of interest"*. Therefore other concepts are required in order to *"parallel the structure of geographic space that humans apprehend"* (Worboys (1996), p. 1). The human perception of the surrounding space is subjective. Depending on the context user X will perceive the distance from A to B different to user Y. In such a personalized space, distances are no longer objective and are often not symmetric (e.g. travel time) as they are in metric spaces. Mobile applications should account for these differences in human perception and be based on space concepts such as relative distance, proximity and neighbourhood (Worboys (1996)). Mobile representations should take topology into account since this concept supports the logics of human space perception. A person asking for the right way expects terms like *"to the right"*, *"close to"*, *"within"*, etc. rather than distances. In such a context, absolute measurements and metric space concepts are not satisfactorily. Based on relative distances, as context-dependent distances, nearness or proximity relationships between geospatial objects are more appropriate. The result is a topological space that relies on a nearness function (Worboys (1996)). Dix et al. ((2000), p. 306) explicitly mention the *"notion of nearness"* in the context of mobile systems and elaborate on this concept for both the metric and topological space. Another example is the usage of the terrain metaphor for *'theme scapes'* or *,spatializations'* of non-terrain topics and by *'navigating'* within these *,landscapes'*.

7) Advanced spatial theory on the sphere

Google Earth et al. have shown the masses that the Earth is not flat. Virtual globes have speed up the 3D visualisation. More recently, we observe analytical capacity being provided to mass users through digital globes but it seems that 3D analysis / *'analytics on the sphere'* is not mature as yet. Referring to Egenhofer (2005), (2009) we make the case for a coordinate-free spatial theory which may culminate in *,global spatial analytics'* (Egenhofer (2009)). We need opportunities to deal with 3D figures especially when integrating sensor information (is a cloud expanding or collapsing? Do new holes appear, or do existing holes join?) So far, we have difficulties to inter-subjectively describe and quantify such 3D developments through time (for further elaboration see Egenhofer (2005); Freksa et al. (2007)).

8) User generated (volunteered) Geographic Information

Producing geographic information has for centuries been a privilege of public organisations. Within very few years millions of lay persons started to communicate spatial information in a spatially explicit way through – generally speaking – web mapping. This new trend is closely coupled with

- ▶ the general web2.0 philosophy and
- ▶ the advent of virtual globes.

Traditional paper maps have for centuries allowed geographers, cartographers, surveyors and – more recently in the 1980ies and 90ies – qualified desktop mapping specialist to use to synthesize, analyse and explore them. It is obvious that the rise of GIS has stimulated these functions and has extended them (Kraak (2003)). Maps that used to be elaborate to produce can today be created in many alternatives views by the single click of the mouse. Additionally, many more maps are produced and used, a trend multiplied by the development of Internet and especially the WWW (Peterson (2003)). Parallel to the advent of Virtual Globes or triggered by them, respectively, the Web 2.0 hype fully encountered geospatial information and we talk about *"Volunteered Geographic Information"* (VGI, see e.g. Elwood (2008)). This necessarily prompts concerns with regard to its quality, reliability, information and source credibility and overall value. Flanagin and Metzger (2008) articulated strategies to discern the credibility of VGI and outlined specific research questions germane to VGI and credibility.

9) The *'un-GISing'* of GIS and GIScience

Today, GIScience 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 (Reuter, Zipf (2008)). While the 1990's were dominated by an object view of data features became a central subject of discussion in the Open Geospatial Consortium (OGC) and the ISO TC/211 during the last 10 years or so. Initially, features were more likely to be associated with the notion of bits of geometry. The - herein not satisfactorily - answered question is whether or not the notion of an object is any different from that of a feature. The notion of a feature can be part of cartography and visualization. It can also be part of the data modelling process. As we move away from a *'closed'* GIS-world the understanding of the terms *'feature'* and *'object'* may change. Are there features which specifically comprise the vocabulary for a particular application domain? Another *'old'* concept is the one of layers which dates back to the construction of ink plotters. The intellectual question today is: is the layer concept helpful in thinking about presenting and controlling the display of entities even if there is no real *'layering'* involved anymore in modern architecture? The more practical question, though, is whether or not this holds true within the context of the more recent development of SOA (Service oriented architecture).

10) Geo-literacy and empowerment

In tendency, GIS has always been expensive and throughout the 1970ies and 80ies, if not 90ies, it was difficult for e.g. developing countries and grassroots organisations to get access to the software and data, to acquire expertise in handling geographic data and to publish spatial data to a wider public. Today, financial investments can be minimized for *'mapping on the Web'*. Hardware costs are low and there are enough open source solutions available to produce Web Mapping Services (WMS), Web Coverage Services (WCS) or Web Feature Services (WCS) without costs for software licensing. Basically no organisation is excluded from the presentation of locations and geographic backdrops or more sophisticated interactive and customizable mapping solutions. Web Mapping is a mean to portray spatial information quickly and easily for most users, requiring only map reading skills. Web mapping services can be discovered through online directories that serve both spatial data (through metadata) and services information (see for example the OGC Catalogue Services draft specification).

But what about the producers' side? Technically, consensus among vendors in the OGC's Web Mapping Testbed has created ways for vendors to write software that enables users to immediately overlay and operate on views of digital thematic map data from different online sources offered though different vendor software. This set of interfaces is known as the OpenGIS® Web Map Server Interfaces Implementation Specification 3 and was developed by 20+ participating organisations.

The trend towards networked services means that local availability of computing and processing power becomes much less critical than the availability of band-width (Strobl (2005)). A fundamental step towards an empowerment of users with no formal education in spatial information handling and/or limited access is the provision of detailed educational and instructional online material of how to do it. For instance, a step-by-step cookbook explaining the implementation of WMS is available from the OGC: http://www.opengis.org/resources/?page=cookbooks.
There is no empirical evidence as yet whether or not such provision of directly utilizable skills leads to an empowerment of groups which have been excluded from the geospatial society so far.

4 GISCIENCE: WHERE NEXT?

After having worked with and about GIS, Geographic Information and how to handle it for many years the authors hypothesize that the vast majority of new technologies in handling Geographic information did not change generic concepts and spatial thinking. Conversely, in many cases, or perhaps in most cases, the opposite is true. Instead of revolutionizing scientific methodologies, we most often simply employ new technology to carry forward with old ways of thinking, and it can take a long time before the basic concepts are altered in any significant way.

We may use the above described trends in form of hypotheses for future challenges in GIScience. The issue becomes complicated when working on the sphere: when we look at 3D information and we provide viewpoints and perspectives other than just an orthogonal view. This is an example of a challenge to both GIS and to GIScience at the same time. In fact, both terms and the underlying constructs may be treated more synergistically: both are essential for a spatially aware society, at least for a *"geo-literate"* society. Concepts to handle these issues in an integrated way require to *"think outside icons and bottoms"* (Schuurman (2004)).

Using location again as the common denominator we will actively address this imperative of Schuurman at the GIScience research cluster Salzburg which is at the moment a virtual concatenation of the pure science oriented research at the Austrian Academy of Science GIScience department, the broad research interests of Z_GIS, the Centre for Geoinformatics at the University of Salzburg with 20+ years experience and the industry-oriented research at the research studio iSPACE. In this triangle of pure, pure/applied and applied research we follow the notion of *"thinking outside icons and bottoms"* aiming for scientific achievements through a *"creating instruments for ideation"* approach. ◀

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