Mapping Kinds in GIS and Cartography

For Catherine Kendig (editor), *Natural Kinds and Classification in Scientific Practice.*

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COMMENTS WELCOME.

> "GIS provides a context, an information resource, and an environment for geographical thinking and research… [that] is open rather than closed [and] can accommodate pluralistic research styles" (Stan Oppenshaw 1991 627).
>
> "All theory… is gray. In mapmaking, good results are more important than theoretical knowledge. A useful map can only be produced by a meticulously careful process of design and the most precise reproduction." (Eduard Imhof 2013 [1965] 86)
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> "our most recent examples show that paradigms provide scientists not only with a map but also with some of the directions essential for map-making" (Thomas Kuhn 1970 109).

0. Introduction

Geographic Information Science (GIS) is a scientific inter-discipline that aims to discover patterns and trends in, and produce visual displays of, spatial data. Businesses use GIS to determine where to open new stores, and GIS helps conservation biologists identify field study locations with relatively little anthropogenic influence (Mitchell 1999; Chrisman 2002). GIS products include topographic and thematic maps of the Earth's surface, climate maps, and spatially-referenced demographic graphs and charts. The annual global GIS market (approx. $10 billion[1]) is of the same order of magnitude as CERN's total budget to date (approx. $13 billion[2]).

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[1] While non-trivial to determine, one report by Global Industry Analysts, Inc. predicts that the global GIS market will reach $10.6 billion by 2015 (http://www.harrisburgu.edu/news/article.php?id=913), with another report by TechNavio calculating and forecasting a compound annual growth rate (CAGR) of roughly 10% (http://www.businesswire.com/news/home/20110318005466/en/Research-Markets-Global-Geographic-

Furthermore, it is only an order of magnitude less than the biotechnology global market, and with roughly the same growth rate ($281.7 billion; 10% CAGR[3]). In addition to its social, political, and economic importance, GIS is worthwhile to explore in its own right because of its methodologically richness, and because it is an instructive analogue to other sciences. The lack of attention to the sciences of GIS and cartography by history and philosophy of science (HPS), science and technology studies (STS), and related fields—though not geography or sociology—clearly merits remedy. Indeed, the overarching purpose of this chapter is to provide some first steps towards a philosophy of GIS and cartography, which we can call PGISC.

This anthology investigates natural kinds and classification in scientific practice. PGISC is fertile territory for rethinking natural kinds in light of scientific practices. I focus on the use of natural kinds in data modeling and map generalisation practices of GIS and cartography. We shall see how practices of making and using kinds are contextual, fallible, plural, and purposive. Collecting and collating geographical data, building geographical databases, and engaging in spatial analysis, visualization, and map-making all require organizing, typologizing, and classifying geographic space, objects, relations, and processes. The rich family of kinds involved in these activities are here baptized *mapping kinds*.

Mapping kinds remain only one aspect of PGISC. Philosophical concerns of realism, representation, explanation, reduction, theory structure can also be expanded and reconstructed by turning to GIS and cartography in themselves and as analogues to other sciences. For instance, attention to GIS practices helps enrich and clarify ongoing philosophical debates about, e.g., (i) metrology and the nature of data, (ii) modeling, abstraction, and idealization in science, and (iii) the role of visualization in science. Moreover, products of these fields of inquiry, such as maps, are analogues to other scientific products, such as theories (i.e., the map analogy, viz. "a scientific theory is a map of the world"). In short, PGISC can inform philosophy of science as well as GIS and cartography.

Information-Systems-Market#.UuVIJGTTk18). It remains unclear how and whether these reports incorporate lost revenue via illegal pirating, or unreported revenue via clandestine purchases (e.g., by the CIA, NSA), of GIS software and hardware.

[2] See Knapp "How Much Does it Cost to Find a Higgs Boson?".

[3] See http://www.researchandmarkets.com/reports/41522/biotechnology_global_industry_guide and http://www.ibisworld.com/industry/global/global-biotechnology.html.

The epigraphs capture this chapter's argumentative spread. The first makes explicit the functionality and promise of GIS as a science. Oppenshaw's hope can be generalized to philosophical analysis, for which GIS can become an analytical exemplar. Imhof defends a practice-based and pragmatic view—rather than a theory-centric semantic or syntactic one—on cartography and science. Indeed, try substituting "model" for "map." Results rather than knowledge are considered crucial; design and reproduction balance. Finally, the map analogy is used in perhaps the most influential philosophy of science book of the 20th century, Kuhn's *The Structure of Scientific Revolutions*.

The chapter is organized as follows. The first section reviews GIS, while the second turns to practices of data modeling and map generalisation, and to the plurality of mapping kinds. Other important practices and kinds involved in GIS and cartography are set aside. That is, surveying and census practices, visualization and spatial analysis, and so forth, must await future exploration from a PGISC perspective. Consonant with the themes of this anthology, the third section explores philosophical antecedents of natural kinds, consistent with mapping kinds: "plural" kinds (e.g., John Dupré, Nelson Goodman, and Muhammad Khalidi), "inferential" kinds (e.g., W.V.O. Quine, Ingo Brigandt, and Alan Love), and "reconstructing" kinds (e.g., John Dewey and Ian Hacking).

1.0. Why GIS?

In order to explain the content and methodology of GIS, analysis of the central issues, a highly abbreviated history, a plurality of definitions, and the epistemic-technological structure of GIS are reviewed in what follows. GIS might be to HPS and STS fields what fruit flies were to the Morgan laboratory at Columbia University in the early 20th century.

1.1. Central Issues of GIS

According to Ronald Abler's report of the National Science Foundation (NSF) National Center for Geographic Information and Analysis (NCGIA) funded in 1988, five central "priority issues" of GIS are:

1. new modes and methods of spatial analysis,
2. a general theory of spatial relationships,
3. artificial intelligence and expert systems in GIS,
4. visualization and

5. social, economic and institutional issues. (Abler 1988 304)

A few years later, and working at the newly-established NCGIA at UC Santa Barbara, the influential GIS researcher Michael F. Goodchild presented another list of "key issues" for GIS:

1. Data collection and measurement;
2. Data capture;
3. Spatial statistics;
4. Data modeling and theories of spatial data;
5. Data structures, algorithms, and processes;
6. Display;
7. Analytical tools; and
8. Institutional, managerial, and ethical issues. (Goodchild 1992 34-40)

These lists present snapshots of the empirical, computational, visual, cognitive, social, and ethical concerns of GIS researchers. Although Abler used the designation "Systems," in Goodchild's 1992 piece "GIS" had become "Geographic Information *Science*." Indeed, Goodchild (2010) traces the source of the term "GIScience" to Goodchild's 1990 Zurich keynote address on "Spatial Information science" (see also Schuurman 2004 6-8). At other times, the last letter is also taken to mean "Studies" or "Services." In summary, GIS engages a broad range of interdisciplinary issues as part of its aim at collecting, analyzing, and rendering spatial information. The territory for PGISC is rich.

1.2. An Abbreviated History

Historically, as Nicholas Chrisman notes, GIS is an outcome of WWII operations research that "helped bring the computer into nearly every part of modern life." Chrisman takes the "systems concept" as a natural source for conceiving GIS "as a series of procedures… lead[ing] from input to output." GIS was thus typically presented as a scientific process moving "from data sources through processing to displays" (1999 178). As an inter-discipline or *trading zone* (Galison 1997; Winther 2014a), GIS combines computer science with geography, cartography, cognitive science, statistics, and sociology. Thus, other historical influences must be incorporated. For instance, the analysis in Chrisman (1999) can be complemented with the concept of "information," pertinent to computer science and Shannon's information theory, and cartography (e.g., Koláčný 1969; Chrisman 2002); by recalling the *quantitative revolution* in geography during the 1960s and 1970s (e.g., Tobler 1966/1989; Harvey 1969); and by not ignoring the cartographic *communication paradigm*, dominant particularly in the 1970s and 1980s (e.g., Ratajski 1972; see MacEachren 1995 8-

9). Undoubtedly the quantitative revolution of geography and the communication paradigm of cartography, while today critiqued, respectively, by Critical GIS (e.g., Crampton 2010) and semiotic and cognitive analyses of map symbolization and design (e.g., MacEachren 1995), remain vital sources of GIS.

A crucial year was 1991, which marked the appearance of "the first solid support for the claim that GIS is entering into a new phase and approaching the possibility of creating a separate discipline" (Pickles 1995a 12) with the publication of Maguire, Goodchild, and Rhind (eds, 1991). Openshaw (1991) defends GIS (see epigraph). In contrast, Pickles (1991) strongly critiqued GIS's role in the "surveillant society." The *GIS wars* were afoot, with "empiricist," "positivist," and "technicist" GIS defenders on one side, and "critical theory," "post-structuralist," and "relativist" critics of GIS on the other (see Pickles 1995b; Schuurman 1999, 2004; Crampton 2010). By the turn of the millennium, a reconstructed "critical GIS" aware of the benefits and wary of the risks of GIS had emerged. Even so, tensions between technoscience perspectives and critical social theory intuitions remain alive today (Kwan 2002; Pvlovskaya 2006; Crampton 2010).

The histories found in the work of Crampton, Chrisman, Goodchild, Pickles, Schuurman, and D.R. Fraser Taylor have tended to be linear and with simplified and somewhat uncritical historiographies.[4] Alternative narratives and pieces contributing to a fuller history of GIS may still be found. This is a promising universe for younger historians of science interested in being among the first to tell a detailed story of a socially, ethically, and economically relevant science, increasingly crucial in today's world. Given that many major players remain alive, an interview-based history is still possible.

1.3. Definitions

Definitions involve background assumptions and a point of view. Chrisman (1999) identifies three approaches in which definitions of GIS are embedded: (i) the *systems flow* approach of operations research and of information theory (e.g., senders and encoders, receivers and decoders), (ii) a *content* approach emphasizing maps, and (iii) a *toolkit* approach focusing on the specific technologies available (e.g., GIS versus CAD versus DBMS, Cowen 1988; see also Maguire

[4] Roger Tomlinson's and Lee Pratt's roles in forming the Canada Geographic Information System will be part of such a history, as will Howard Fisher's Harvard Laboratory for Computer Graphics and Spatial Analysis (e.g., Chrisman 2006). Coppock and Rhind (1991) provide an instructive diagram of the "companies, government agencies, universities, etc."—that is, places—where "ideas or concept, often embodied in a software package or database" were developed; lines in their diagram indicate "direct or indirect migration or influence" (24).

1991). One definition from each approach shall suffice. A paradigmatic systems flow definition mirrors the linearity of the information communication process:

> GIS [is] a system for capturing, storing, checking, manipulating, analysing and displaying data which are spatially referenced to the Earth (Department of the Environment 1987, p 132). (Cited in Chrisman 1999 178).

The data of GIS are intrinsically spatially referenced (Haining 2003; Tomlin 2013). Without locational information, other measured features of cases (e.g., height, population density) are meaningless for GIS purposes. This definition emphasizes the flow of information. Second, a content approach "defines the GIS by what it contains, either as a special case of more general information systems or as an amalgamation of more specific uses." (Chrisman 1999 179). Chrisman locates the following definition in a forestry journal:

> A form of MIS [Management Information System] that allows map display of the general information (Devine and Field 1986, p 18). (Cited in Chrisman 1999 179).

Of course, many proponents of GIS in the early 1990s would have critiqued such map-centrism (Couclelis 1992; Goodchild 1992; Tobler 2002). A *death of the map* was afoot (Schuurman 2004; Winther in prep and under review; submitted). For instance, Waldo Tobler identifies the "flat earth syndrome" (2002, 493) and calls for a "global spatial analysis." He urges listeners and readers to "forget about working on maps" (496), admitting that "map projections, my specialty, are now obsolete" (497). Finally, a contemporary characterization of GIS exemplifies the toolkit approach:

> A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.[5]

Combined especially with the earlier (1997) definition of GIS presented in Chrisman (1999 180-1), it becomes evident that ESRI's (Environmental Systems Research Institute) focus is on the various software packages and hardware devices constitutive of GIS activities. It is unsurprising that a firm developing and selling these products would characterize GIS in this way. While initially resisting definitions of GIS, Chrisman eventually produced his own reduced definition:

> Geographic Information System (GIS) – Organized activity by which people measure and represent geographic phenomena then transform these representations into other forms while interacting with social structures." (1999 183-5)

[5] From the ESRI website, http://www.esri.com/what-is-gis/overview#overview_panel (accessed January 26, 2014). ESRI (Environmental Systems Research Institute) was founded in 1969 by Jack Dangermond, a current billionaire. This is the same year that he earned his masters degree from Harvard's Graduate School of Design, where Dangermond had worked in Howard Fisher's lab. ESRI is the single biggest seller of GIS products on the market today.

This definition was developed in the context of a "nested ring" structure of GIS, where "each ring encapsulates the more technical decisions inside, mobilizing them in a more complex structure." (Chrisman 1999 184) Accordingly, "measurement and representation" were prior to, and embedded in, "transformations and operations" of various sorts (e.g., spatial analysis, visualizations), which, in turn, were prior to, and embedded in, "social, cultural, and institutional context[s]." These definitions point to the complex marketplace of disciplines and research questions involved in GIS. Given the rich intellectual differences among these definitions, and the breadth of concerns covered, the need for a PGISC strongly emerges.

1.4. The Epistemic-Technological Structure of GIS

Data collection and collation, database management, map generalisation, visualization, and spatial analysis are central inferential (and automated) processes of GIS. Questions regarding the relative roles of human and computer persist (Taylor 1991; Longley et al. 2011). In contrasting "artificial" and "amplified" intelligence, Weibel (1991) walks a middle path between analog and digital cartography[6]. He identifies advantages to amplified intelligence, including that "knowledge is contributed by human experts in a direct way," and "it leaves creativity with the user to devote attention to interesting aspects of map production." (185) Two decades later we are still far from fully automated map production systems. AI continues, in many ways, to be a dream (Ekbia 2008). But the symbiotic relation between humans and computers is clearly strong as indicated by the related fields of AI, machine learning, and Human-Computer Interaction (HCI), and any PGISC must address these.

GIS's relation to cartography is complex (e.g., Visvalingam 1989; Winther in prep and under review; submitted). Nadine Schuurman plausibly detects a "switch" from "a map to model-oriented approach to generalization" (1999, 83). In North America, the "culture of cartography" had been dominant, while "Europeans had developed a *landscape model* [the database] that is based on derived data" (ibid). The key shift was from earlier work "with mental models of maps" to committing to "the database" as generative of "information and map objects" (2004, 48-49; Figure 1). Schuurman highlights Brassel and Weibel (1988) as instrumental to this shift. Brassel and Weibel characterized generalisation "as an intellectual process, [which] structures experienced reality into a number of individual entities, then selects important entities and represents them in a new form" (1988 230-1). They distinguish two kinds of "objectives for spatial modeling"

[6] Distinction in Robinson et al. 1995.

corresponding to two kinds of generalisation: (i) "spatial modeling for purposes of data compaction, spatial analysis and the like [i.e.,] *statistical generalization*" and (ii) "*cartographic generalization*," which, "in contrast, aims to modify local structure and is non-statistical" (232; see Figure 2 233). By identifying a broader set of generalisation types beyond mere visual display and map-making, Brassel and Weibel prompted the emerging GIS community to move past the map and cartography. Modeling, broadly construed, rather than map-making and map-use, became central to GIS.

Figure 1 captures the epistemic-technological structure of GIS. Information flows from the Earth to the database via complex data collection and collation practices such as surveying and census, and, through structured data models (e.g., Suppes 1962), to technology-supported, purpose-driven theoretical modeling (e.g., EDA Haining 2003; MCE Carver 1991) and cartographic generalization, to theoretical and visual knowledge products. Circles represent epistemic and technological processes. Boxes indicate products. Statistical generalisation, which "is mainly a filtering process… [in which] concepts of reliability, tolerance or error may be applied" (Brassel and Weibel 1988 232), can be deployed for database complexity management. Inferences such as explaining or predicting demographic trends, making land-use decisions, or guessing the most likely border crossings of illicit drug trafficking, can be achieved by theoretical modeling alone, or by modeling in conjunction with visual cartographic generalisation. Moreover, sometimes the user simply desires to produce maps as the end-product of the knowledge-production process. Detailed technology and institutional organization remain unmarked in my figure. Due to visualization and generalisation constraints, certain arrows are missing. For instance, maps can interact with theoretical modeling, and inferences can sometimes be read directly off the map. Theoretical modeling can lead directly to inferences, without cartographic generalization assistance. Even so, maps are worth highlighting as particular end-products.

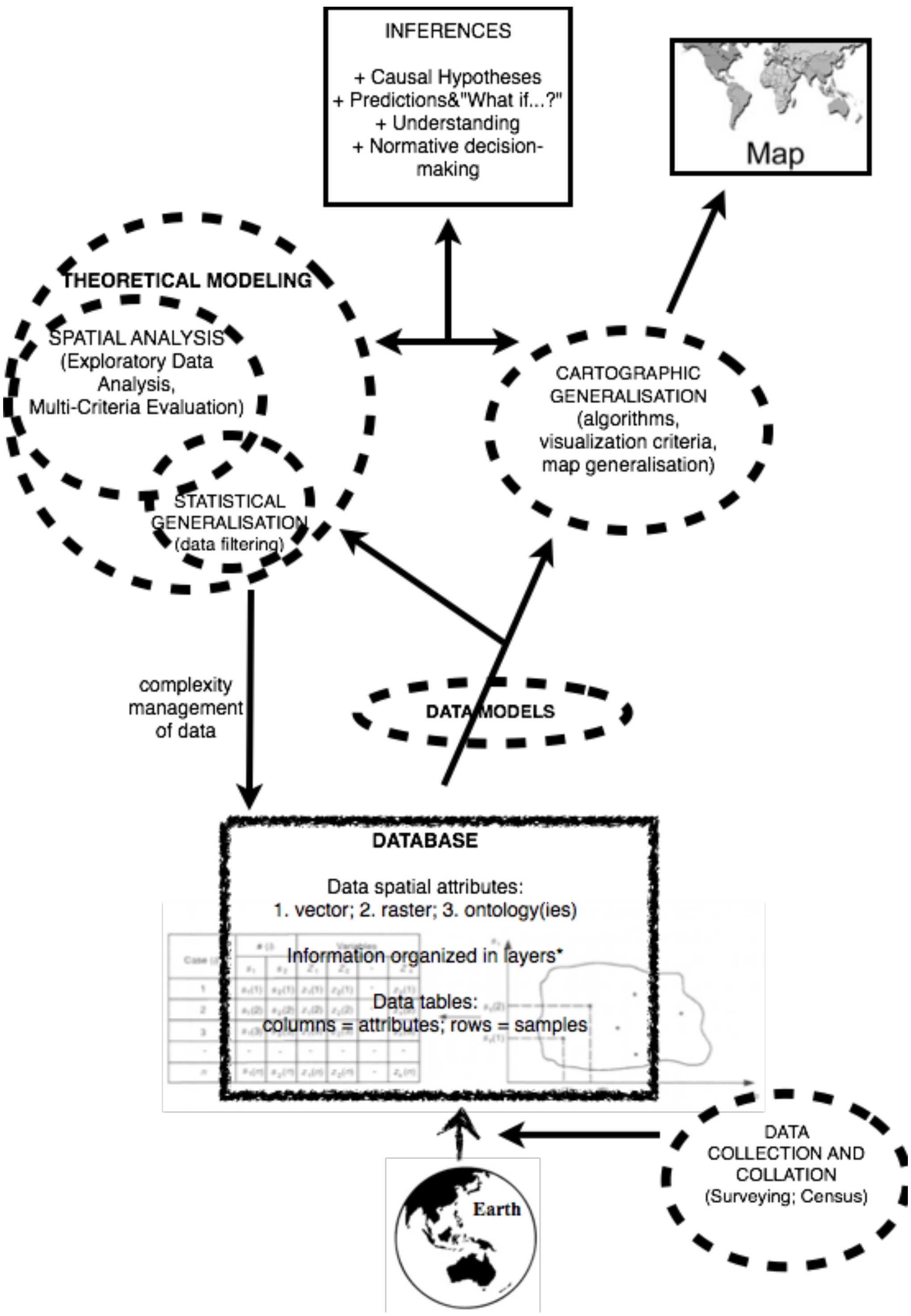

Figure 1. *The Epistemic-Technological Structure of GIS*.

GIS's interdisciplinarity and rich epistemic-technological structure make it a promising land for philosophers interested in exploring scientific modeling and visualization, cognition and HIC, and the social and ethical impact of science. As a specific case study of the philosophical quality of GIS, the next section turns to kind-making.

2.0. Mapping Kinds: Data Modeling and Map Generalisation

Rich geographic features and processes that have been collected and collated through various technologies (e.g., theodolite, GPS) must be structured into databases for further analysis and map-making. That is, a *physical ontology* is discovered and constructed in practices of data modeling (e.g., Galton 2000; Peuquet 2002; Goodchild 2004). Moreover, map-making itself involves (automated or conscious) inferential processes of abstraction and generalisation. In order to understand how kinds are simultaneously recognized and made, data modeling and map generalisation processes of cartography and GIS are reviewed. Data modeling is described in terms of *calibrating kinds*, *feature kinds*, and *object kinds*. Subsequently, purposive and partial kind-making processes of manual and digital map generalisation are addressed. Map generalisation involves processual kinds such as *AMPLIFY*, *JOIN, SEPARATE,* and *ELIMINATE*. Function and process, rather than static pre-existence, are foregrounded. Most generally and following the map analogy, a study of GIS suggests that kinds and kind-making in other scientific theories and models should be interpreted functionally and processually.

2.1. Data Modeling

GIS models and maps rely on geographic information organized into kinds, captured in databases. Goodchild (1995) follows computer science in defining data models thus: "the set of rules used to create a representation of information, in the form of discrete entities and the relationships between them." (36; see Suppes 1962) Up until the mid-1990s, two "models of the world" (Mitchell 1999 14; see Schuurman 2004)—i.e., two physical ontologies—dominated GIS data modeling: raster and vector. Whereas the first organizes the world into a Cartesian grid, the second carves up the world into mutually exclusive and collectively exhaustive irregular polygons, such as census or cadastral units. Each has advantages and disadvantages concerning ease of data collection, error proclivity (e.g. locational, ecological fallacy, and "modifiable areal unit problem"), computational efficiency, and appropriateness (Goodchild 1989; Haining 2003; Schuurman 2004;

Longley et al. 2011). Indeed Tomlin (2013) quips: "Yes, raster is faster, but raster is vaster, and vector just seems more correcter." (26) Because of their fundamentality in space-carving, Cartesian pixels or vector polygons can be baptized *calibrating kinds*.

These two inter-translatable geometry-based models of the world serve as the unifying matrix on which a complex array of geographic features is captured. That is, data of various sorts are linked to point locations (raster view) or to polygons (vector view)[7]. Geographic data can be stored in tables with location or polygons as rows and features as columns (Brassel and Weibel 1998; Haining 2003). Cartographically, the data can also be represented in distinct "map layers," each of which is framed via pixels (or polygons). Each map layer captures a small number of predicates (e.g., population density, income – sometimes indicated at different time slices).[8] The topographic ("general image of the Earth's surface" Kraak and Omeling 2011 44) or thematic (population density, crime rate, etc.) features represented on each data table column or map layer, or both, can be termed *feature kinds*. The map analogy comes to the fore here because every scientific paradigm, theory or model must take *some* stance towards the calibration—i.e., form—of its data, and the features—i.e., content—the paradigm, theory or model wishes to capture in data models. A physical ontology has to be articulated. Calibrating and feature kinds combined—i.e, calibrating/feature kinds—were the form and content of early GIS data models.

The concepts and language of GIS evolved in concert with technological innovations stemming from computer science. The calibrating kinds of the vector view—i.e., polygons—were sometimes referred to as "objects" (Goodchild 1989; Couclelis 1992; Haining 2003). This manner of kind-ing space was associated with a discontinuous and individual-based perspective on the world, as opposed to the "field" view of continuous and homogenous rasters. But eventually it was recognized that both pixel and polygon calibrating kinds are "geometry-centric" (Longley et al. 2011 221) and today *both* are often referred to as "fields" (Schuurman 2004; Longley et al 2011). In contrast, *object kinds* constitute a fundamentally different manner of representing geographic information, and space. These are not spatial vectors such as census units or states or countries – the "objects" of yesteryear. Rather, they are individual kinds of things such as "oil wells, soil

[7] More precisely, the term "vector" stems from the fact that geographic polygons consist of a series of lines each of which has magnitude and direction. Vector geometrization in general involves categorizing two-dimensional space in irregular ways, classifying points, lines or areas (Goodchild 1989 107; Monmonier and McMaster 1994 Figure 1 94; Longley et al. 2011 214 and 221).

[8] The map layer perspective on storing cartographic information leads to "club sandwich" (Couclelis 1992 65) or "layer-cake" (Schuurman 2004 36) caricatures of GIS.

bodies, stream catchments, and aircraft flight paths" (ibid 222). Object kinds in GIS originated in object-oriented programming (Goodchild 1995 38-39; Chrisman 2002 83-5; Schuurman 2004 36). In contrast to geometry-centric data modeling modes that permit neither empty space nor pixel nor polygon overlap, GIS data models based on object kinds insist on emptiness and overlap. Via encapsulation, inheritance, and polymorphism,[9] object-oriented programming permits significant flexibility and structural capacity in working with object kind data models (Longley et al. 2011 222).[10] Today, objects are distinguished from fields, and object kinds emerging from programming systems in the 1990s assist in making new data model types.

Further questions regarding path-dependency and the biases, heuristics, and judgments associated with practices of data encoding (e.g., which kind of data model—field or object—is chosen for a particular purpose?) and data management (e.g., inter-operability and translatability among data models, Tomlin 2013, and multiple representation databases, Sarjakoski 2007), and practices of data collection and collation (Figure 1) remain promising areas for future PGISC exploration.

2.2. Map Generalisation, in General

Map generalisation in the broadest terms involves *transforming* and *selecting* kinds.[11] For example, smoothing lines and aggregating buildings (represented either as calibrating/feature kinds or object kinds) are examples of transforming single kinds. Eliminating entire classes of kinds or dissolving out an area are examples of selecting different kinds. Töpfer and Pillewizer succinctly describe "cartographic generalisation" as "the reduction of the amount of information which can be shown on a map in relation to reduction of scale" (1966 10). Perhaps the first to have framed map generalisation was Max Eckert in the early 20th century (Eckert 1908; Regnauld and McMaster 2007 37). Wright (1942 531-3) identified "simplification and amplification" as the key generalisation moves. While holding that "no rules can be given for generalization," Raisz (1962 38) posited three aspects of generalisation called "combine," "omit," and "simplify." Robinson and Sale (1969) influentially recognized four "elements of cartographic generalization," viz.

[9] Telegraphically: "Encapsulation describes the fact that each object packages together a description of its state and behavior." "Inheritance is the ability to reuse some or all of the characteristics of one object in another object." "Polymorphism describes the process where each object has its own specific implementations for operations like draw, create, and delete." (Longley et al. 2011 222)

[10] Object kinds are considered ontologies" by some (e.g., Agarwal 2005) who turn to work by Barry Smith and his collaborators (e.g., Smith and Mark 2001). However, the object kinds of object-oriented programming and those of "ontologies" have distinct historical trajectories and different individuation criteria.

[11] On the biological distinction between transformation of individuals (qua single kinds) and selection of individuals (qua distinct kinds) within populations, see Levins and Lewontin 1985 85-86.

simplification, *symbolization*, *classification* and *induction*. These elements are subject to "controls" such as *the objective*, *the scale*, and *the quality of data* (Robinson and Sale 1969 52). Especially in the last 20 years, as we shall see further below, cartographic generalisation has become automated. Today, "elements" roughly correspond to "operators" of "spatial and attribute transformations" (Shea and McMaster 1989, McMaster and Shea 1992) and "algorithms" (e.g., Harrie and Weibel 2007), while "controls" map onto "geometric conditions" and "transformation controls" (McMaster and Shea 1992), and "constraints" (Harrie and Weibel 2007). A more branching narrative of the development of map generalisation may be required (McMaster and Shea 1992 17-19; Schuurman 2004 43-49; see Crampton 2010 for a pluralist history).

2.3. Manual Map Generalisation

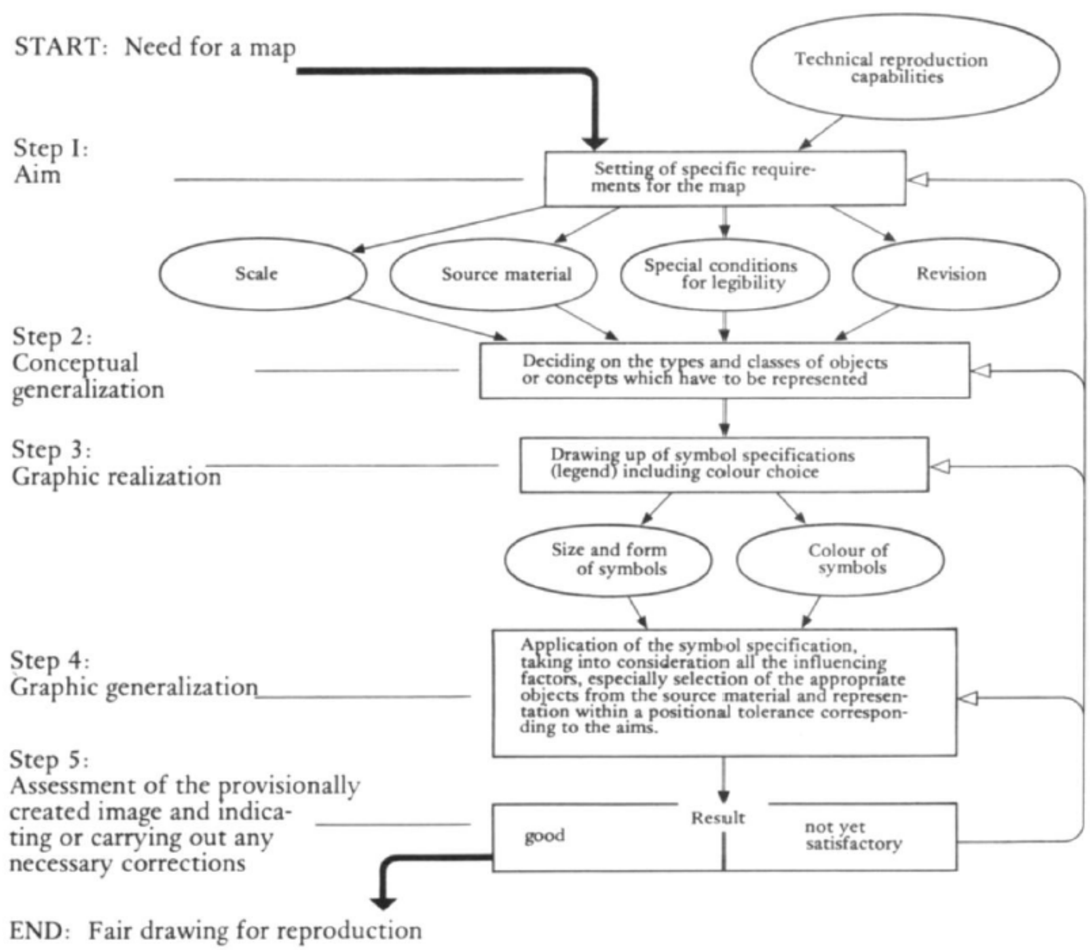

Figure 2. *Functional Flow Chart of Map Generalisation*. Swiss Society of Cartography 1977 16.

Analogously to any scientific abstraction, map generalisation must take functional context seriously. Indeed, the Swiss Society of Cartography's classic analysis of cartographic generalization *starts* with the "need for a map." The "aim" of the map grows out of this need. Once scale, source, legibility conditions, and revision have been specified from the need and aim can the conceptual and graphical aspects of the map be determined and implemented. A functionalist top-down approach to map generalisation is here suggested. The figure remains non-committal about which kinds of geographic information should be represented, focusing instead on cognitive understanding and communicative effectiveness of the map. Indeed, map-making is made a function of map use, which itself involves descriptive and prescriptive purposes, with the latter including decision-support and management (Crain and MacDonald 1984; Berry 1987). The Swiss Society of Cartography writes:

> Cartographic generalization requires prior knowledge of the essence and the function of the map. Consequently we first of all have to ask ourselves about the purpose of the map, the extent of its information contents and also about the requirements of the map user regarding the power of expression of a map type desired for a specific purpose. (1977 5)

Purpose and use play center stage here.[12] Their verbatim citation from Imhof's *Kartographische Geländedarstellung* furthers the functionalist—rather than semantic or syntactic—vision:

> "The objective of generalization is the highest accuracy possible in accordance with the map scale, good geometric informative power, good characterisation of the elements and forms, the greatest possible similarity to nature in the forms and colours, clarity [of meaning] and good legibility, simplicity and explicitness of the graphical expression and coordination of the different elements." (Imhof cited in Swiss Society of Cartography 1977 12[13])

The map must fit the purpose. Map generalisation must start from map need (compare epigraph). On the same page of the original, Imhof writes:

> The modes of cartographic representation depend on the character of the landscape, the scales, the quality of topographic surveys and other basemaps, the purpose of the maps, the representational intentions of the maker, teaching methods, traditions, habits, the knowledge and abilities of compilers, draftsmen and reproduction technicians, the processes of reproduction and also the expenditure of time and money on production. (Imhof 2013 86)

Following the map analogy, Imhof's pragmatic view of cartographic representation could certainly be generalised to other forms of scientific representation, outside of cartography and GIS.[14]

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[12] See also Muehrcke (1972) and Muehrcke & Muehrcke (1998) for a functionalist approach to what Phillip Muehrcke has consistently called "map abstraction."

[13] Imhof 1965 100. Brackets are added from the English translation, 2013 86. The Swiss Society of Cartography cut out the last phrase: "and finally, summarizing all these qualities, a beauty peculiar to the map itself." (2013 86)

[14] On the pragmatics of modeling see, e.g., Winther 2012a.

2.4. Digital Map Generalisation Pluralism in GIS

A significant interpretative problem presented by the history and pre-history of GIS is that it remains unclear whether *digital cartography* (Robinson et al. 1995) and *digital generalization* (McMaster and Shea 1992) are continuous with earlier *analog cartography* and *manual generalization*.[15] After all, earlier, pre-GIS cartography required significant human aesthetic and judgment components (Wright 1942) and was "labor-intensive," "subjective," and "holistic" in contrast to automated, "consistent," and "much like the finite logic of a serial computer" (McMaster and Shea 1992 2). Thus, whether concepts such as "simplification" or "classification" share meanings, and imply the same consequences today and yesterday remains unclear.

Nevertheless, I explore *digital* map generalisation procedures, setting aside deeper matters regarding continuity of terms, periodization of history, and paradigm identification. Of interest is the sheer plurality of digital map generalisation procedures as well as map (and modeling) aims and audiences. There are multiple modes of *selecting* calibrating-feature kinds or object kinds, and *transforming* the ones that remain, given map purpose (Figure 3). A useful place to start is Shea and McMaster's (1989) classification of twelve digital generalisation operators: simplification, smoothing, aggregation, amalgamation, merge, collapse, refinement, typification, exaggeration, enhancement, displacement, and classification (see also author references suppressed). In their 1992 book, McMaster and Shea remove typification as a spatial transformation and add symbolization, classifying it with classification as attribute transformations.

Consider, in particular, simplification and smoothing. Simplification is the retention of the fewest number of data points or features necessary to accurately represent a single kind of object. As an example, the Douglas-Peucker algorithm keeps only those coordinate points of a line exceeding a pre-defined tolerance, and thereby produces a piecewise "zig-zag" from a meandering line (e.g., representing a river or road). This zig-zag retains the essential properties of the original line. Smoothing involves diminishing deviations and perturbations from general trends, given a particular number of data points or features. As an example consider transforming an irregular quadrilateral to a square. While McMaster and Shea's classification is fairly comprehensive, there are important missing generalisation procedures, including dissolution, segmentation, and selection (e.g., Monmonier 1996 29). In fact, there is no single agreed-upon classification, or map generalisation model (e.g., Ratajski 1972; Brassel and Weibel 1988; McMaster and Shea 1992;

[15] Returning to Brassel and Weibel 1988, this discussion concerns *cartographic* generalisation rather than *statistical* or *modeling* generalisation.

Kilpeläinen 2000). Algorithmic implementation, conceptual model of map generalisation adhered to, and background knowledge and objectives influence each creator's classification and model.

As one tentative way of classifying the procedures of map generalisation (abstraction, idealization), consider organizing these procedures into inferential processes that either transform or select among the kinds given by the data models (Figure 3). Intuitively complementary processes of *REDUCE* and *AMPLIFY*, *JOIN* and *SEPARATE* are part of an overarching framework of seven basic procession kinds within which the rich variety of easily 20 map generalisation procedures gleaned from multiple sources could be placed. Under my analysis, the kinds of map generalisation individuate inferential or automated *processes*, rather than objects or individuals. Even if the three-layer classification embodied in Figure 3 turns out to be neither collectively exhaustive nor mutually exclusive, the fundamental distinction between transforming single kinds and selecting among kinds, and the basic seven *processual kinds*[16] of generalisation procedures, provide partial insight into the logic and goals behind generalisation.[17] Each processual kind can be implemented computationally in various ways (e.g., Cantwell Smith 1996). Moreover, the individuation criteria of the lowest-level processual kinds (e.g., smoothing and simplification) have to do with similarity of *computational result* rather than with static feature similarity. Finally, holistic cognitive, communicative, and aesthetic considerations of information visualization must also be addressed philosophically in trying to understand how and why these processual kinds can and should interact in producing visual maps (Bertin 1983 [1967]; Swiss Society of Cartography 1987; Ware 2013). PGISC can be articulated to explore these concerns of the pragmatics of modeling and visualization.

[16] Processual kinds are investigated in the biological sciences in Winther 2006a, 2011.

[17] Analogously to other sciences, the plurality of generalisation procedures results in difficulties and tensions requiring negotiation (e.g., Muehrcke 1972; Swiss Society of Cartography 1987; McMaster and Shea 1992; Weibel, Keller, and Reichenbacher 1995; Monmonier 1996). First, trade-offs are inevitable (Levins 1966; Winther 2006b, 2012a; Weisberg 2013). For instance, displacing objects could problematize their smoothing. Second, generalisation procedure application is not commutative. Different map products result from different series of operator applications (Mackaness 1991; Monmonier and McMaster 1990). Abstraction comes at a price.

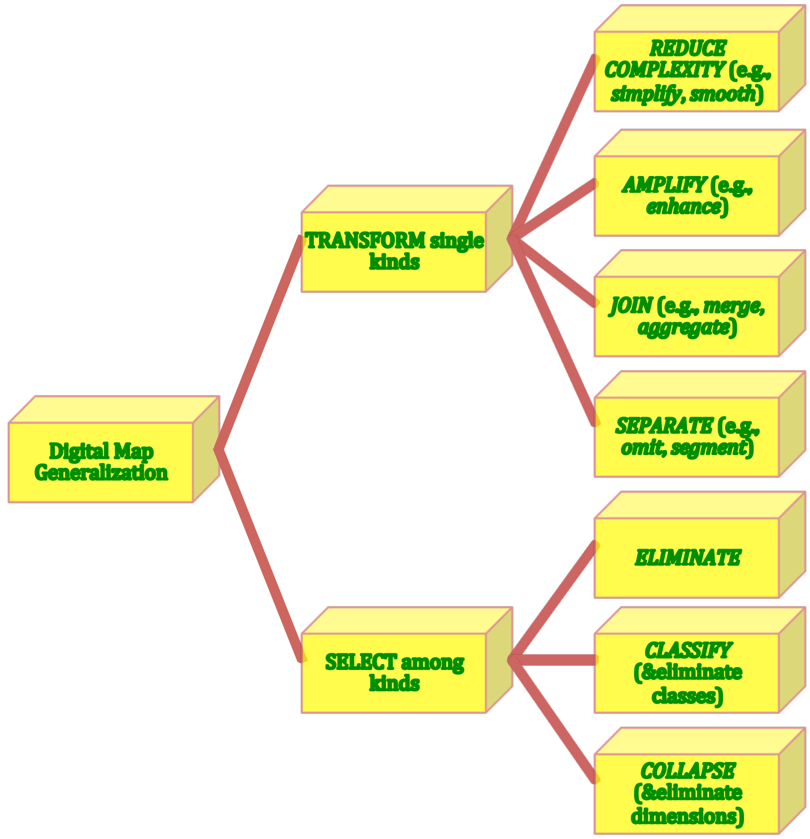

Figure 3. *Map generalisation PROCESSUAL KINDS.*

In summary, in digital map generalisation, the calibrating-feature kinds or object kinds present in data models are transformed or selected, or both, to produce a simplified and idealized map representing certain aspects of complex geographic reality, in light of map purposes. Philosophical considerations regarding *kinds-in-practice* (e.g., calibrating kinds and feature kinds) and *kinds-of-practice* (e.g., processual kinds) can be of benefit to GIS and philosophy alike. GIS is an exemplar (Kuhn 1970) whose pragmatic orientation can be extended, via the map analogy, to many other sciences.

3.0. Towards a Philosophy of Mapping Kinds

Recall that the overarching aim of this chapter is to motivate a PGISC, particularly an analytic PGISC (aPGISC). In this final section, a précis is provided of why GIS is a particularly instructive locus for exploring, and perhaps reconstructing, philosophy. Three overarching philosophical perspectives on kinds help place mapping kinds in perspective.

First, a number of philosophers of science analyze kind and classification *pluralism*. Under this view, there is no single, ideal, and eternal hierarchical classification of kinds of objects. For instance, Nelson Goodman prefers to speak of "relevant" rather than "natural" kinds in part because the latter "suggests some absolute categorical or psychological priority, while the kinds in question are rather habitual or traditional or devised for a new purpose." (1978 10). Moreover, Dupré's "promiscuous realism" argues for the interest-relativity of abstracting and generalising kinds. Dupré observes:

> Is the kind of pluralism I have been advocating consistent with a realistic attitude to the various kinds, and even individuals, that I have discussed? There are a number of pluralistic possibilities that I have defended, but none, as far as I can see, forces one to abandon realism. … Provided realism is separated from certain essentialist theses, I see little more reason why the possibility of distinct and perhaps overlapping kinds should threaten the reality of those kinds. (1993 57)

Similarly, Khalidi notes:

> The idea that there are crosscutting taxonomies is closely related to the view that scientific classification is *interest relative*. If classification is always relative to certain interests, we would expect some taxonomies to reorganize some of the same entities in different ways without displacing existing ones. (1998 42)

As examples of this "plural kinds" argument, recall field vs. object views on geographic space. Depending on a variety of goals and technical realities, either of these two inter-translatable kind-ings of space can be adopted. Of course, the plurality of inferential processes of map generalisation—which may or may not be practiced together—can also be conceived within a plural kinds framework.

Another, not unrelated, strategy for understanding kinds philosophically is an approach that focuses on the role of kinds in *scientific inference*. While he worries about similarity relations and thought that mature science could and would do without natural kind terms, WVO Quine also believes that "some such notion [of kind], some similarity sense, was seen to be crucial to all learning, and central in particular to the processes of inductive generalization and prediction which are the very life of science." (133) Indeed, kinds are "functionally relevant groupings in nature" whose recognition permits our inductions to "tend to come out right." (126) That is, kinds help ground fallible inductive inferences and predictions, so essential to scientific projects including those of GIS and cartography. Brigandt (2009) and Love (2009) take this epistemic understanding of kind terms further. Brigandt wishes to bracket the search for "a unique *metaphysical* account of 'natural' kind" calling instead for "the *epistemological* study of how and for what purposes various natural kind concepts are employed in scientific reasoning." (78) Love interprets typology and natural kinds as involved in "representational reasoning" and "explanatory reasoning." (52 ff.) The move from a metaphysical to an epistemic analysis of kinds—already instituted by Quine (and Goodman)—is welcome in a philosophical field otherwise emphasizing essences, rigid designators, and other elements of the abstract, theory-centric "book of the world," such as counterfactually-supported universal non-*ceteris paribus* laws, and their relation to kinds (but see Campbell, O'Rourke, and Slater 2011). Certainly PGISC requires understanding how a variety of mapping kinds are involved in scientific inference.

Finally, a rather different approach is to leave the concept behind altogether, either via utter *rejection* or systematic *reconstruction*. Upon providing an erudite discussion of the natural kind tradition, Hacking (2007) concludes with this paragraph:

> Although one may judge that some classifications are more natural than others, there is neither a precise nor a vague class of classifications that may usefully be called the class of natural kinds. A stipulative definition, that picks out some precise or fuzzy class and defines it as the class of natural kinds, serves no purpose, given that there are so many competing visions of what the natural kinds are. In short, despite the honourable tradition of kinds and natural kinds that reaches back to 1840, *there is no such thing as a natural kind*. (238-9)

Wishing less to banish kinds from science and more to reconstruct them, John Dewey elucidates the standard view of species thus:

> Just as we naturally arrange plants and animals into series, ranks and grades, from the lowest to the highest, so with all things in the universe. The distinct classes to which things belong by their very nature form a hierarchical order. There are castes in nature. The universe is constituted on an aristocratic, one can truly say a feudal, plan. (*Reconstruction in Philosophy* 113)

Dewey resisted the standard view of natural kinds, inherited from the Greeks, and itself inflected by Greek socio-political context. Instead, Dewey presents an analysis of kinds (and classes and universals) as fallible and context-specific hypotheses permitting us to operative effectively in addressing problematic situations. For instance, consider this passage from *Quest for Certainty*:

> *The* object is an abstraction, but unless it is hypostasized it is not a vicious abstraction. It designates selected relations of things which, with respect to their mode of operation, are constant within the limits practically important. … It marks an ordering and organizing of responses in a single focused way in virtue of which the original blur is definitized and rendered significant (190)

Depending on the project at hand, a particular object will be classed and individuated as a kind. Dewey is applying his "reconstruction of philosophy" program of (i) understanding concepts and kinds as tools, (ii) insisting that the function of philosophy is criticism, and (iii) viewing abstraction and analysis as embedded in larger wholes of social, communicative, and material needs (e.g., Winther 2014b). GIS and cartography provide excellent scenarios of reconstructed kinds straddling theory and practice, and realism and constructivism.

Mapping kinds can be understood from various philosophical perspectives, including "pluralism kinds," "scientific inference kinds," and "reconstructive kinds." None of these are mutually exclusive. Moreover, the analysis of mapping kinds presented in this chapter encourages their adoption, and the concomitant bracketing (or rejection?) of more standard essentialist perspectives on natural kinds.

4.0. Conclusion

GIS and cartography suggest that kinds are simultaneously discovered and constructed. Geographic features, processes, and objects are of course real. Yet, we must structure them in our data models and, subsequently, select and transform them in our maps. Realism and (social) constructivism are hence not exclusive in this field (e.g., Sismondo 1998; Schuurman 1999; Sismondo and Chrisman 2001). Moreover, kind-ing inferential processes—mediated by technology, cognition, and communication—force the questioning of a strong theory vs. practice distinction. That is, kinds are no longer purely theoretical, living as abstract concepts referring to ontological essences and serving as small mirrors of nature. Instead, kinds are shaped by design principles, communicative context, and local aims and norms. Furthermore, kinds are as much about process as about objects. That is, they emerge from, and sometimes are, processes in the world and in our minds (and in our technologies and society), and not just individuals with static essences. After all, recall the rich and sometimes conflicting processual kinds of map generalisation. In short, PGISC suggest at least the strong possibility that realism vs. constructivism and theory vs. practice should not be absolutely contrasted as eternal binaries. Surely, further development of PGISC will permit reflection on natural kinds, and other standard philosophical concerns, from a practice-turn perspective. Most generally, analytic PGISC suggests that a practice-turn view is detail-based; relevance-oriented; and deflationary or reconstructive about metaphysics.

GIS, and its related sister or mother disciplines of geography and cartography can become an ideal model system for philosophy of science as well as HPS, STS, history of science, and sociology of science. It is a young field, perhaps only 25 years old, and relatively small in size.[18] It is clearly interdisciplinary, involving a broad range of expertise, technologies, practices, aims and norms, and, finally, styles, paradigms, and models of analysis and thought (Winther 2012b). Finally, many GIS and cartography scholars are highly reflective about conceptual, methodological, and theoretical matters, as should be clear from the sections above. Indeed, it would be a pity, if not socially and intellectually and socially irresponsible, *not* to further develop PGISC, in both its analytic and "continental" critical varieties.

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[18] For instance, one of the most important conferences GIScience (Michael Goodchild pers. comm. January 20, 2014) "regularly brings together more than 200 international participants from academia, industry, and government organizations." http://www.giscience.org/ accessed February 10, 2014.

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