13 Mapping kinds in GIS and cartography

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> GIS provides a context, an information resource, and an environment for geographical thinking and research . . . [GIS] is open rather than closed [and] can accommodate pluralistic research styles.[1]

> 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.[2]

> [O]ur most recent examples show that paradigms provide scientists not only with a map but also with some of the directions essential for map-making.[3]

0. Introduction

Geographic Information Science (GIS) is a scientific inter-discipline aiming to discover patterns 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.[4] 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 (approximately $10 billion[5]) is of the same order of magnitude as CERN's total budget to date (approximately $13 billion[6]), which it is only an order of magnitude less than the annual biotechnology global market. In addition to its social, political, and economic importance, GIS is worthwhile to explore in its own right due to its methodological richness, and because it is an instructive analogue to other sciences. The lack of attention to the sciences of GIS and cartography by the history and philosophy of science (HPS), science and technology studies (STS), and related fields – though not geography or sociology – clearly merits remedy. This chapter works towards a philosophy of GIS and cartography, or PGISC.

PGISC fits well in this volume on rethinking natural kinds in light of scientific practices. 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. I focus on the use of natural kinds in data modeling and map generalization practices, showing how practices of making and using kinds are contextual, fallible, plural, and purposive. The rich family of kinds involved in these activities are here baptized *mapping kinds*.

Mapping kinds are only one aspect of PGISC. Philosophical concerns of realism, representation, explanation, reduction, and theory structure can also be expanded and reconstructed through an analysis of GIS. For instance, attention to GIS practices helps enrich and clarify ongoing philosophical debates about, for example, (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 (e.g., "a scientific theory is a map of the world"). In short, PGISC can inform philosophy of science as well as GIS and cartography.

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, substituting "model" for "map" shows that 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 twentieth century, Kuhn's *The Structure of Scientific Revolutions*. This serves as one example of the map analogy's ubiquity in philosophical analyses of science.[7]

The chapter is organized as follows. The first section reviews GIS, while the second turns to practices of data modeling and map generalization 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. Central issues of GIS

In order to explain the content and methodology of GIS, an analysis of the central issues, a highly abbreviated history, a plurality of definitions, and the epistemic-technological structure of GIS are reviewed. GIS might be to HPS and STS what fruit flies were to the Morgan laboratory at Columbia University in the early twentieth century. According to Ronald Abler's report of the National Science Foundation's National Center for Geographic Information and Analysis (NCGIA), the five "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.
5 Social, economic, and institutional issues.[8]

A few years later, 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.
8 Institutional, managerial, and ethical issues.[9]

These lists present snapshots of the empirical, computational, visual, cognitive, social, and ethical concerns of GIS researchers. The territory for PGISC is a rugged landscape, with a broad range of interdisciplinary issues.

1.1. An abbreviated history

As Nicholas Chrisman observes, 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 typically presented as a scientific process moving "from data sources through processing to displays".[10] As an inter-discipline or *trading zone*,[11] GIS combines computer science with geography, cartography, cognitive science, statistics, and sociology. Thus, other historical influences must be tracked. For instance, Chrisman's analysis can be complemented in several ways: by the concept of "information", pertinent to computer science and Shannon's information theory, as well as to cartography;[12] by recalling the *quantitative revolution* in geography during the 1960s and 1970s;[13] and by not ignoring the cartographic *communication paradigm*, dominant particularly in the 1970s and 1980s.[14] Undoubtedly, the quantitative revolution in geography and the communication paradigm of cartography – while today critiqued by Critical GIS[15] and by semiotic and cognitive analyses of map symbolization and design[16] – remain vital sources of GIS.

The 1991 publication of Maguire, Goodchild, and Rhind[17] 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".[18] Whereas Openshaw[19] defends GIS (see epigraph), Pickles[20] critiques 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.[21] By the turn of the millennium, a reconstructed "critical GIS" emerged, aware of the benefits and wary of the risks of GIS. Even so, tensions between technoscientific and critical social theory perspectives remain alive.[22]

The histories found in the work of Crampton, Chrisman, Goodchild, Pickles, Schuurman, and D. R. Fraser Taylor have tended to be linear historiographies.[23]

Alternative narratives and pieces contributing to a fuller history of GIS may still be found. This is a promising avenue for younger historians interested in being among the first to detail the story of a socially, ethically, and economically relevant science. Given that many major players remain alive, an interview-based history is still possible.

1.2. Definitions

Definitions involve background assumptions and a point of view. Chrisman[24] 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)[25]. First, 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.[26]

This definition emphasizes the flow of information. The data of GIS are intrinsically spatially referenced,[27] which is required for other measured features (e.g., height, population density) to be meaningful. 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".[28] Chrisman locates the following definition in a forestry journal:

> A form of MIS [Management Information System] that allows map display of the general information.[29]

Of course, many proponents of GIS in the early 1990s would have critiqued such map-centrism.[30] A *death of the map* was afoot.[31] For instance, Waldo Tobler identifies the "flat earth syndrome"[32] and calls for a "global spatial analysis". He urges listeners and readers to "forget about working on maps",[33] admitting that "map projections, my specialty, are now obsolete".[34] 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.[35]

Combined especially with the earlier (1997) definition of GIS presented in Chrisman,[36] it becomes evident that the focus of the Environmental Systems Research Institute (ESRI) 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.[37]

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".[38] 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 trading zone of disciplines and research questions involved in GIS. Given the differences of perspective among these definitions, the need for a PGISC seems evident.

1.3. The epistemic-technological structure of GIS

Data collection and collation, database management, map generalization, visualization, and spatial analysis are central inferential and automated processes of GIS. Questions regarding the relative roles of human and computer persist.[39] For instance, in contrasting "artificial" and "amplified" intelligence, Weibel walks a middle path between analog and digital cartography.[40] Weibel identifies advantages to amplified intelligence, including that "[k]nowledge is contributed by human experts in a direct way", and "[i]t leaves creativity with the user to devote attention to interesting aspects of map production".[41] Two decades later, we are still far from fully automated map production systems. AI continues, in many ways, to be a dream.[42] 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.[43] Nadine Schuurman plausibly detects a "switching from a map to model-oriented approach to generalization".[44] 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".[45] The key shift was from earlier work "with mental models of maps" to committing to "the database" as generative of "information and map objects".[46] Schuurman highlights Brassel and Weibel[47] as instrumental to this shift. Brassel and Weibel characterize generalization "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".[48] They distinguish two kinds of "*objectives* for spatial modeling" corresponding to two kinds of generalization: (i) "spatial modeling for the 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".[49] By identifying a broader set of generalization 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.

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

2.0. Mapping kinds: data modeling and map generalization

Rich geographic features and processes 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.[50] Moreover, map-making itself involves (automated or conscious) inferential processes of abstraction and generalization. It is to these purposive processes that I now turn.

2.1. Data modeling

GIS models and maps rely on geographic information organized into kinds, captured in databases. Goodchild 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".[51] Up until the mid-1990s, two "models of the world"[52] – that is, 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 the "modifiable areal unit problem, MAUP)", computational efficiency, and appropriateness.[53] As Tomlin quips, "Yes, raster is faster, but raster is vaster, and vector just seems more correcter".[54] 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).[55] Geographic data can be stored in tables with location or polygons as rows and features as columns.[56] 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.[57] The topographic ("general image of the Earth's surface"[58]) or thematic (e.g., population density, crime rate, income, 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 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".[59] 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",[60] and today *both* are often referred to as "fields".[61] In contrast, *object kinds* constitute a fundamentally different manner of representing geographic information. These are not spatial vectors such as census units or states or countries – the "objects" of yesteryear. They are individual kinds of things such as "oil wells, soil bodies, stream catchments, and aircraft flight paths".[62] Object kinds in GIS originated in object-oriented programming.[63] In contrast to geometry-centric data modeling modes permitting 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,[64] object-oriented programming permits significant flexibility and structural capacity in working with object kind data models.[65] 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[66] and multiple representation databases[67]) remain promising areas for future PGISC exploration.

2.2. Map generalization, in general

Map generalization in the broadest terms involves *transforming* and *selecting* kinds.[68] 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".[69] Perhaps the first to have analyzed map generalization was Max Eckert in the early twentieth century.[70] Wright identified "simplification and amplification" as the key generalization moves.[71] While holding that "no rules can be given for generalization," Raisz posited three aspects of generalization called "combine", "omit", and "simplify".[72] Robinson and Sale influentially recognized four "elements of cartographic generalization", namely, *simplification, symbolization, classification*, and *induction*. These elements are subject to "controls" such as *the objective, the scale*, and *the quality of data*.[73] Especially in the last 20 years, cartographic generalization has become automated. Today, "elements" roughly correspond to "operators" of "spatial and attribute transformations"[74] and "algorithms",[75] while "controls" map onto "geometric conditions" and "transformation controls"[76] and "constraints".[77] A more branching narrative of the development of map generalization may be required.[78]

2.3. Manual map generalization

Similarly to any scientific abstraction, map generalization must take functional context seriously. Indeed, the Swiss Society of Cartography's classic analysis of cartographic generalization *starts* with the "need for a map"[79]. The "aim" of the map grows out of this need. Only once scale, source, legibility conditions, and revision have been specified, given the need and aim, can the conceptual and graphical aspects of the map be determined and implemented. A functionalist top-down approach to map generalization is here suggested. Map-making is a function of map use, which itself involves descriptive and prescriptive purposes.[80] 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.[81]

Purpose and use play center stage here.[82] Their verbatim citation from Imhof's *Kartographische Geländedarstellung* bolsters the functionalist – rather than syntactic or formalist – 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.[83]

The map must fit the purpose. Map generalization must start from map need (compare epigraph). Following the map analogy, Imhof's pragmatic view of cartographic representation could certainly be generalized to other forms of scientific representation, outside of cartography and GIS.[84]

2.4. Digital map generalization pluralism in GIS

A significant interpretative problem in the history and prehistory of GIS is that it remains unclear whether *digital*[85] and *digital generalization*[86] are continuous with earlier *analog cartography* and *manual generalization*.[87] After all, pre-GIS cartography required significant human aesthetic and judgment components[88] and was "labor-intensive", "subjective", and "holistic" in contrast to automated, "consistent", and "much like the finite logic of a serial computer".[89] Thus, whether concepts such as "simplification" or "classification" share meanings and imply the same visualization consequences today and yesterday remains unclear.

Nevertheless, I explore *digital* map generalization procedures, setting aside deeper matters regarding continuity of terms, periodization of history, and paradigm identification. Of interest is the sheer plurality of digital map generalization procedures as well as map (and modeling) aims and audiences. There are multiple modes of *selecting* calibrating-feature kinds or object kinds, and of *transforming* the ones that remain, given map purpose (Figure 13.1). Shea and McMaster's classify 12 digital generalization operators: simplification, smoothing, aggregation, amalgamation, merge, collapse, refinement, typification, exaggeration, enhancement, displacement, and classification.[90] In their 1992 book, McMaster

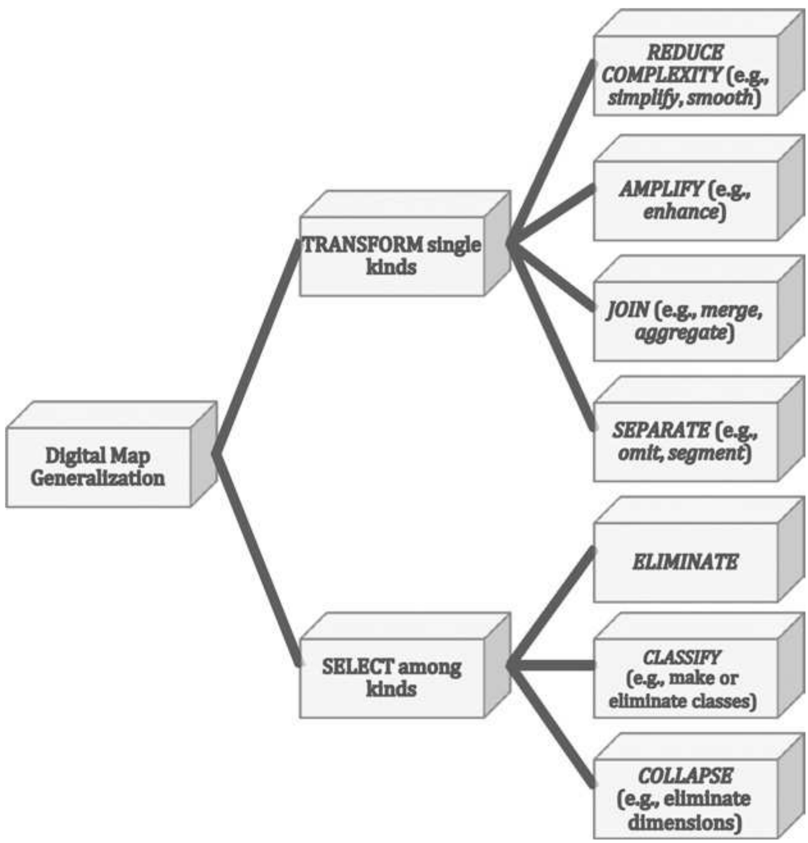

Figure 13.1 The processual kinds of map generalization.

and Shea remove typification as a spatial transformation and add symbolization, classifying it with classification as attribute transformations.

Consider 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 that exceed a predefined 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. For instance, consider transforming an irregular quadrilateral to a square. While McMaster and Shea's classification is fairly comprehensive, important generalization procedures are missing, including dissolution, segmentation, and selection.[91] In fact, there is no single agreed-upon classification or model of or map generalization.[92] Algorithmic implementation, conceptual model of map generalization adhered to, and background knowledge and objectives influence each creator's classification and model.

As one way of classifying map generalization (alternatively: abstraction, idealization) procedures, we can organize them into inferential processes that either transform or select among the kinds given by the data models (Figure 13.1). Intuitively complementary processes of *REDUCE* and *AMPLIFY*, *JOIN* and *SEPARATE* are part of an overarching framework of seven basic processual kinds within which the rich variety of approximately 20 map generalization procedures gleaned from multiple sources could be placed. Under my analysis, map generalization kinds individuate inferential or automated *processes*, rather than objects or individuals. Even if the three-layer classification embodied in Figure 13.1 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*[93] of generalization procedures, provide partial insight into the logic and goals behind map generalization.[94] Each processual kind can be implemented computationally in various ways.[95] 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.[96] PGISC explores the pragmatics of modeling and visualization.

In summary, in digital map generalization, the calibrating-feature kinds or object kinds present in data models are transformed or selected, or both, to produce a simplified, abstracted, 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[97] 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. In this final section, a précis is provided of why GIS is a particularly instructive locus for exploring, and perhaps helping reconstruct philosophy. Three overarching philosophical perspectives on kinds help place mapping kinds in perspective.

First, a number of philosophers of science analyze pluralisms of kinds and classifications. 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".[98] Moreover, Dupré's "promiscuous realism" argues for the interest-relativity of abstracting 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.[99]

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.[100]

As examples of this *plural kinds* argument, recall field versus 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 generalization – which may or may not be practiced together – can also be conceived within a plural kinds framework.

A related strategy for understanding kinds philosophically is an approach that focuses on the role of kinds in *scientific inference*. While he thinks that mature science can and will do without natural kind terms, W.V.O. 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".[101] Indeed, Quine holds that kinds are "functionally relevant groupings in nature" whose recognition permits our inductions to "tend to come out right".[102] That is, kinds ground fallible inductive inferences and predictions, so essential to scientific projects including those of GIS and cartography. Brigandt and Love 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 different natural kind *concepts* are employed in scientific reasoning".[103] Love interprets typology and natural kinds as involved in "representational reasoning" and "explanatory reasoning".[104] The move from a metaphysical to an epistemic analysis of kinds – already instituted by Quine (and Goodman) – is welcome in a philosophical field emphasizing essences, rigid designators, counterfactually supported universal non–ceteris paribus laws, and other elements of the abstract, theory-centric "book of the world".[105] 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 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*.[106]

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

> . . . [J]ust 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.[107]

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

> *The* object is an abstraction, but unless it is hypostatized 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.[108]

Depending on the project or inquiry, a certain object will be classed and individuated as a certain 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 and practices.[109] GIS and cartography provide excellent scenarios of reconstructed kinds negotiating 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". These are not mutually exclusive. Moreover, my investigation the analysis of mapping kinds presented encourages their adoption, and the concomitant deemphasis 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.[110] Moreover, kind-ing inferential processes – mediated by technology, cognition, and communication – force the questioning of a strong theory versus practice dichotomy. Kinds are no longer purely theoretical concepts serving as little little mirrors of nature. Instead, they are shaped by design principles, communicative context, and local aims and norms. Kinds can be both about objects and processes. Not just static essences, kinds emerge from processes in the world, in our minds, and in our technologies and societies. PGISC suggests the possibility that realism versus constructivism and theory versus practice should not be deemed two absolute binaries. Further development of PGISC will permit reflection on natural kinds, as well as other standard philosophical concerns, from a Pragmatic View perspective.[111] Such a practice-turn view is detail based and relevance oriented, with a deflationary and reconstructive approach to metaphysics.

GIS and its related disciplines of geography and cartography provides a model system for philosophy of science as well as for HPS, STS, history of science, and sociology of science. GIS is a young field, approximately 25 years old, and relatively small in size.[112] It is clearly interdisciplinary, involving a range of expertises, technologies, practices, and aims and values, as well as a variety of styles, paradigms, and models.[113] Interestingly, many GIS and cartography scholars are already philosophically reflective about conceptual, methodological, and theoretical matters. It would be a pity, if not socially and intellectually irresponsible, *not* to further develop PGISC, in both its analytic and "continental" varieties.

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Notes

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5 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.strategyr.com/Geographic_Information_Systems_GIS_Industry_Market_Report.asp) [accessed 11 November 2014], 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-Information-Systems-Market#.UuVIJGTTk18) [accessed 11 November 2014]. 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.

6 See: Knapp, A. (2012) 'How Much Does It Cost to Find a Higgs Boson?' *Forbes*, July 5, 2012, at: http://www.forbes.com/sites/alexknapp/2012/07/05/how-much-does-it-cost-to-find-a-higgs-boson/ [accessed 11 November 2014].

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9 Goodchild, M.F. (1992) 'Geographical Information Science', *International Journal of Geographical Information Sciences*, 6:1, pp. 31–45, pp. 34–40.

10 Chrisman, N. (1999) 'What Does 'GIS' Mean?' *Transactions in GIS*, 3, pp. 175–186, p. 178.

11 Galison, P. (1997) *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press; and, Winther, R.G. (2014a) 'Evo-Devo as a Trading Zone', In: Love, A. (ed.), *Conceptual Change in Biology: Scientific and Philosophical Perspectives on Evolution and Development*. Berlin: Springer, pp. 459–482.

12 See: Koláčný, A. (1969) 'Cartographic Information – a Fundamental Concept and Term in Modern Cartography', *The Cartographic Journal*, 6, pp. 47–49; and, Chrisman, N., *Exploring Geographic Information Systems*.

13 See: Tobler, W. (1989) 'Numerical Map Generalization', *Cartographica*, 26:1, Monograph 40, pp. 9–25. Originally informally published in 1966 as a discussion paper of the Michigan Inter-University Community of Mathematical Geographers. Also: Harvey, D. (1969) *Explanation in Geography*. New York: St. Martin's Press.

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17 Maguire, D.J., Goodchild, M.F. and Rhind, D.W. (eds.) (1991) *Geographical Information Systems: Principles and Applications, Vols. 1 and 2*. Harlow, UK: Longman Scientific & Technical.
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21 See: Pickles, J. (ed.) (1995a) *Ground Truth: The Social Implications of Geographic Information Systems*. New York: Guilford Press; Schuurman, N. (1999) 'Reconciling Social Constructivism and Realism in GIS', *ACME: An International E-Journal for Critical Geographies*, 1:1, pp. 73–90; Schuurman, N. (2004) *GIS: A Short Introduction*. Malden, MA: Blackwell Publishing; Crampton, J.M., *Mapping: A Critical Introduction to Cartography and GIS*.
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23 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 – see: Chrisman, N. (2006) *Charting the Unknown: How Computer Mapping at Harvard Became GIS*. Redlands, CA: ESRI Press. Coppock and Rhind 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"; Coppock, J.T. and Rhind, D.W. (1991) 'The History of GIS', In: Maguire, D.J., Goodchild, M.F. and Rhind, D.W. (eds.) *Geographical Information Systems: Principles and Applications – Vol. 1: Principles*. Harlow, UK: Longman Scientific & Technical, pp. 21–43, p. 24.
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27 Haining, R. (2003) *Spatial Data Analysis: Theory and Practice*. Cambridge UK: Cambridge University Press; Tomlin, C.D. (2013) *GIS and Cartographic Modeling*. (2nd edition) Redlands, CA: ESRI Press, p. 26.
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31 Schuurman, N., *GIS: A Short Introduction*; Winther, *When Maps Become the World*.
32 Tobler, W., 'Global Spatial Analysis', p. 493.
33 Tobler, W., 'Global Spatial Analysis', p. 496.
34 Tobler, W., 'Global Spatial Analysis', p. 497.
35 From the ESRI website, http://www.esri.com/what-is-gis/overview#overview_panel [accessed 26 January 2014]. Also found here, with attribution to ESRI: http://www.bouldercounty.org/dept/adminservices/pages/bouldercountygis.aspx [accessed 25 October 2015]. ESRI (Environmental Systems Research Institute) was founded in 1969 by Jack Dangermond, a current billionaire. This is the same year that he earned his master's 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.
36 Chrisman, N., 'What Does 'GIS' Mean?, pp. 180–181.
37 Chrisman, N., 'What Does 'GIS' Mean?' pp. 183–185.
38 Chrisman, N., 'What Does 'GIS' Mean?' p. 184.
39 Taylor, D. R. F. (1991) 'Geographic Information Systems: The Microcomputer and Modern Cartography', In: Taylor, D. R. F. (ed.) *Geographic Information Systems: The Microcomputer and Modern Cartography*. Oxford, UK: Pergamon Press, pp. 1–20; Longley, P. A., Goodchild, M. F., Maguire, D. J. and Rhind, D. W. (2011) *Geographic Information Systems & Science*. (3rd edition) Hoboken, NJ: John Wiley & Sons Inc.
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45 Ibid, p. 83.
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48 Brassel, K. E., and Weibel, R., 'A Review and Conceptual Framework of Automated Map Generalization', pp. 230–231.
49 Brassel, K. E., and Weibel, R., 'A Review and Conceptual Framework of Automated Map Generalization', p. 232; also see their Figure 2, p. 233.
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53 Goodchild, M.F. (1989) 'Modeling Error in Objects and Fields', In: Goodchild, M.F. and S. Gopal, *The Accuracy of Spatial Databases*. London: Taylor and Francis, pp. 107–113; Haining, R., *Spatial Data Analysis: Theory and Practice*; Schuurman, N., *GIS: A Short Introduction*; Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., *Geographic Information Systems & Science*.

54 Tomlin, C.D., *GIS and Cartographic Modeling*, p. 26.

55 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, M.F. (1989), 'Modeling Error in Objects and Fields', p. 107; Monmonier, M. and McMaster, R. B. (1992) 'The Sequential Effects of Geometric Operators in Cartographic Line Generalization', *International Yearbook of Cartography*, 30, pp. 93–108, Figure 1 p. 94; Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W. (2011), *Geographic Information Systems & Science*, p. 214 and p. 221).

56 Brassel, K.E. and Weibel, R., 'A Review and Conceptual Framework of Automated Map Generalization'; Haining, R., *Spatial Data Analysis: Theory and Practice*.

57 The map layer perspective on storing cartographic information leads to "club sandwich" (Couclelis, H., 'People Manipulate Objects (but Cultivate Fields)', p. 65) or "layer-cake" (Schuurman, N., *GIS: A Short Introduction*, p. 36) caricatures of GIS.

58 Kraak, M.J. and Ormeling, F. (2011) *Cartography: Visualization of Spatial Data*. (3rd edition) New York: Guilford Press, p. 42.

59 Goodchild, M.F., 'Modeling Error in Objects and Fields'; Couclelis, H., 'People Manipulate Objects (but Cultivate Fields)'; Haining, R., *Spatial Data Analysis: Theory and Practice*.

60 Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., *Geographic Information Systems & Science*, p. 221.

61 Schuurman, N., *GIS: A Short Introduction,* pp. 31–40; Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., *Geographic Information Systems & Science*.

62 Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., *Geographic Information Systems & Science*, p. 222.

63 Goodchild, M.F., 'Geographical Information Systems and Geographic Research', pp. 38–39; Chrisman, N., *Exploring Geographic Information Systems*, pp. 83–5; Schuurman, N., *GIS: A Short Introduction*, p. 36.

64 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 whereby each object has its own specific implementation for operations like draw, create, and delete." Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., *Geographic Information Systems & Science*, p. 222.

65 Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., *Geographic Information Systems & Science*, p. 222. Object kinds are considered "ontologies" by some (for example, Agarwal, P. (2005) 'Ontological Considerations in GISscience', *International Journal of Geographical Information Systems*, 19:5, pp. 501–536) who turn to work by Barry Smith and his collaborators (for example, Smith, B. and Mark, D.M. (2001) 'Geographical Categories: An Ontological Investigation', *International Journal of Geographical Information Systems*, 15:7, pp. 591–612). However, the object kinds of object-oriented programming and those of "ontologies" have distinct historical trajectories and distinct individuation criteria.

66 Tomlin, C.D., *GIS and Cartographic Modeling*.

67 Sarjakoski, L.T. (2007) 'Conceptual Models of Generalisation and Multiple Representation', In: Mackaness, W.A. Ruas, A. and Sarjakoski, L.T. (eds.) *Generalisation of Geographic Information: Cartographic Modelling and Applications*. Oxford: Elsevier, pp. 11–35.

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74 McMaster, R.B. and Shea, K.S. (1989) 'Cartographic Generalization in a Digital Environment: When and How to Generalize', In: *AUTO-CARTO 9, Ninth International Symposium on Computer-Assisted Cartography*. Baltimore, MD: AUTO-CARTO 9, pp. 56–67; McMaster, R.B. and Shea, K.S., (1992) *Generalization in Digital Cartography*. Washington, DC: Association of American Geographers.

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76 McMaster, R.B., and Shea, K.S., *Generalization in Digital Cartography*.

77 Harrie, L. and Weibel, L., 'Modelling the Overall Process of Generalisation'.

78 McMaster, R.B., and Shea, K.S., *Generalization in Digital Cartography*, pp. 17–19; Schuurman, N. *GIS: A Short Introduction*, pp. 43–49. See: Crampton, J.W., *Mapping: A Critical Introduction to Cartography and GIS* for a pluralist history.

79 See flow diagram on p. 16 of Swiss Society of Cartography, Cartographic Generalisation: Topographic Maps (Zürich: SGK-Publikationen, 1977, 2nd edition).

80 Crain, I.K. and MacDonald, C.L. (1984) 'From Land Inventory to Land Management', *Cartographica*, 21, pp. 40–46; Berry, J.K. (1987) 'A Mathematical Structure for Analyzing Maps', *Environmental Management*, 11:3, pp. 317–325.

81 Swiss Society of Cartography (1977) *Cartographic Generalisation: Topographic Maps*. (2nd edition) Zürich: SGK-Publikationen, p. 5.

82 See also: Muehrcke, P. C (1972) *Thematic Cartography*. Washington, DC: Association of American Geographers, Resource paper no. 19, Commission on College Geography; and Muehrcke, P. C. and Muehrcke, J. O. (1998) *Map Use: Reading, Analysis and Interpretation*. (4th edition) Redlands, CA: ESRI Press for a functionalist approach to what Phillip Muehrcke has consistently called "map abstraction."

83 Imhof cited in Swiss Society of Cartography, *Cartogdraphic Generalisation: Topographic Maps*, p. 12. Imhof, E., *Kartographische Geländedarstellung*, p. 100. Brackets are added from the English translation: Imhof, E., *Cartographic Relief Presentation*, p. 86. The Swiss Society of Cartography omit the last phrase: "and finally, summarizing all these qualities, a beauty peculiar to the map itself." Imhof, E., *Cartographic Relief Presentation*, p. 86.

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Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/fall2015/entries/structure-scientific-theories/>.

85 Robinson, A.H., Morrison, J.L., Muehrcke, P.C., Kimerling, A.J., and Guptill, S.C., *Elements of Cartography*.

86 McMaster, R.B., and Shea, K.S., *Generalization in Digital Cartography*.

87 Returning to Brassel, K.E., and Weibel, R., 'A Review and Conceptual Framework of Automated Map Generalization', this discussion concerns *cartographic* generalisation rather than *statistical* or *modeling* generalisation.

88 Wright, J.K., 'Map Makers are Human'; and Steward, H.J. (1974) *Cartographic Generalisation: Some Concepts and Explanation*. Monograph 10 in the *Cartographica* series. Toronto: University of Toronto Press.

89 McMaster and Shea, *Generalization in Digital Cartography*, p. 2.

90 McMaster, R.B., and Shea, K.S., 'Cartographic Generalization in a Digital Environment: When and How to Generalize'. See also: Winther, R.G., *When Maps Become the World*.

91 See: Monmonier, M. (1996) *How to Lie with Maps*. (2nd edition) Chicago: University of Chicago Press, p. 29.

92 See: Ratajski, L., 'Cartology'; Brassel, K.E., and Weibel, R., 'A Review and Conceptual Framework of Automated Map Generalization'; McMaster, R.B., and Shea, K.S., *Generalization in Digital Cartography*; Kilpeläinen, T. (2000) 'Maintenance of Multiple Representation Databases for Topographic Data', *The Cartographic Journal*, 37, pp. 101–107.

93 Processual kinds are investigated in the biological sciences in Winther, R.G. (2006a) 'Parts and Theories in Compositional Biology', *Biology and Philosophy*, 21, pp. 471–499; and, Winther, R.G. (2011) 'Part-Whole Science', *Synthese*, 178, pp. 397–427.

94 Like other sciences, the plurality of generalization procedures results in tensions requiring negotiation (see, for example, Muehrcke, P.C., *Thematic Cartography*; Swiss Society of Cartography, *Cartographic Generalisation: Topographic Maps*; McMaster, R.B., and Shea, K.S., *Generalization in Digital Cartography*; Weibel, R., Keller, S. and Reichenbacher, T. (1995) 'Overcoming the Knowledge Acquisition Bottleneck in Map Generalization: The Role of Interactive Systems and Computational Intelligence', *Lecture Notes in Computer Science (COSIT '95, Vol. 988)*. Berlin: Springer-Verlag, pp. 139–156; Monmonier, M., *How to Lie with Maps*). First, trade-offs are inevitable: Levins, R. (1966) 'The Strategy of Model Building in Population Biology', *American Scientist*, 54, pp. 421–431; Winther, R.G. (2006b) 'On the Dangers of Making Scientific Models Ontologically Independent: Taking Richard Levins' Warnings Seriously', *Biology and Philosophy*, 21, pp. 703–724; Winther, R.G., 'Mathematical Modeling in Biology: Philosophy and Pragmatics'; Weisberg, M. (2013) *Simulation and Similarity: Using Models to Understand the World*. New York: Oxford University Press). For instance, displacing objects could problematize their smoothing. Second, generalization procedure application is not commutative. Different map products result from different series of operator applications (Monmonier, M. and McMaster, R.B., 'The Sequential Effects of Geometric Operators in Cartographic Line Generalization'). Abstraction comes at a price.

95 See: Cantwell Smith, B. (1996) *On the Origin of Objects*. Cambridge, MA: MIT Press.

96 Bertin, J. (1967/1983) *Semiology of Graphics: Diagrams, Networks, Maps*. Translated by W.J. Berg. Madison: University of Wisconsin Press; Swiss Society of Cartography, *Cartographic Generalisation: Topographic Maps*; Ware, C. (2013) *Information Visualization: Perception for Design*. Waltham: Morgan Kaufmann.

97 Kuhn, T., *The Structure of Scientific Revolutions*.

98 Goodman, N. (1978) *Ways of Worldmaking*. Hassocks: The Harvester Press, p. 10.

99 Dupré, J. (1993) *The Disorder of Things: Metaphysical Foundations of the Disunity of Science*. Cambridge, MA: Harvard University Press, p. 57.

100 Khalidi, M.A. (1998) 'Natural Kinds and Crosscutting Categories', *Journal of Philosophy*, 95, pp. 33–50, p. 42.

101 Quine, W.V.O. (1969) 'Natural Kinds', *Ontological Relativity and Other Essays*. New York: Columbia University Press, pp. 114–138, p. 133.

102 Ibid, p. 126.

103 Brigandt, I. (2009) 'Natural Kinds in Evolution and Systematics: Metaphysical and Epistemological Considerations', *Acta Biotheoretica*, 57:1, pp. 77–97, p. 78.

104 Love, A. (2009) 'Typology Reconfigured: From the Metaphysics of Essentialism to the Epistemology of Representation', *Acta Biotheoretica*, 57:1, pp. 51–75, p. 52 ff.

105 But see: Campbell, J.K., O'Rourke, M. and Slater, M.H. (2011) *Carving Nature at Its Joints: Natural Kinds in Metaphysics and Science*. Cambridge, MA: MIT Press.

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108 Dewey, J. (1984/1929) *The Quest for Certainty, Vol. 4*. In: Boydston, J.A. (ed.) *The Later Works of John Dewey, 1925–1953*. Carbondale: Southern Illinois University Press, p. 190.

109 See: Winther, R.G. (2014b) 'James and Dewey on Abstraction', *Pluralist*, 9:2, pp. 1–28.

110 See Sismondo, S. (1998) 'The Mapping Metaphor in Philosophy of Science', *Cogito*, 12:1, pp. 41–50; Schuurman, N., 'Reconciling Social Constructivism and Realism in GIS'; Sismondo, S. and Chrisman, N. (2001) 'Deflationary Metaphysics and the Natures of Maps', *Philosophy of Science*, 68, pp. S38–S49; and, Dodge, M., Kitchin, R., and Perkins, C. (eds.) (2009) *Rethinking Maps: New Frontiers in Cartographic Theory*. London: Routledge.

111 Winther, R.G., 'The Structure of Scientific Theories'.

112 One of the most important conferences, GIScience, (Michael Goodchild in personal communication, 20 January 2014) "regularly brings together more than 200 international participants from academia, industry, and government organizations." At: http://www.giscience.org/ [accessed 10 February 2014].

113 Winther, R.G. (2012b) 'Interweaving Categories: Styles, Paradigms, and Models', *Studies in History and Philosophy of Science – Part A*, 43, pp. 628–639; and, Winther, R.G., *When Maps Become the World*.