An Empirically-Derived Taxonomy of Cartographic Interaction Primitives

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1. Introduction: A Scientific Foundation for Interactive Maps

One of the largest breakthroughs for Twentieth Century Cartography was the identification and articulation of the *visual variables* (Bertin 1967|1983, Morrison 1974, Caivano 1990, MacEachren 1992). The visual variables, and associated syntactics that inform their application, provide a theoretical framework that enables the science of *cartographic representation* (MacEachren 1995). However, many advances in Twenty-first Century Cartography fall outside the topic of representation; the now ubiquitous digital environment affords the creation of maps that are animated, context-dependent, multiscale, real-time, and web-based. Although all of these topics are promising research areas for Twenty-First Century Cartography, Dykes (2005) argues that no single product of the Digital Revolution has had a more transformative impact on the conceptualization, design, and use of maps than the possibility of digital *cartographic interaction* (i.e., interactive maps).

Unlike the representation counterpart, there has yet to be an accepted taxonomy of basic interaction units—or *interaction primitives*—to enable the emerging science of cartographic interaction. Most extant taxonomies focus upon one of three stages in the overall interaction process: (1) the *objective*, or the user's intention in using the interface, (2) the *operator*, or the functions provided by the cartographic interface to support the user's objective, and (3) the *operand*, or the recipient of the interaction operator (Roth 2011); a review of the stages of cartographic interaction, and the relationship of extant taxonomies to these stages, is provided in Roth (submitted). One limitation of extant taxonomies contributing to their lack of general adoption is that the vast majority of these taxonomies are not empirically derived, but instead rely on secondary sources or personal experience.

The research reported here directly contributes to this gap, taking an empirical approach to establishing a scientific foundation for cartographic interaction. Specifically, the card sorting method was employed to identify and articulate the basic primitives of cartographic interaction. *Card sorting* requires participants to organize a set of instances (i.e., *cards*) into internally-homogenous groupings (i.e., *categories*) based on similarity along an identified sorting principle (i.e., the *sorting criterion*) (Roth et al. 2010, Roth et al. 2011).A pair of guided card sorting studies were administered to categorize two sets of interaction primitives, the first including objective primitives and the second including operator primitives; the objective card sorting study unexpectedly generated insight into a potential taxonomy of interaction *goals* (i.e., meta-objectives) as well as interaction operands, resulting in a four-dimensional taxonomy of cartographic interaction primitives (**Table 1**). Parameters and results of the two card sorting studies are discussed in the following subsections.

2. Methods: Card Sorting of Interaction Primitives

2.1 Participants

Fifteen participants were sampled from the domains of Interactive Cartography and Geovisualization to complete the pair of card sorting studies, a sample size recommended by Nielsen (2004). Participation was limited to cartographic interface designers/developers to elicit cognitive structures that were ecologically valid. Each participant completed both sorts.

2.2 Materials

Each card contained a single text statement, with the statements drawn from two sources. First, a set of semi-structured interviews (n=21) were conducted with expert users of cartographic interfaces to elicit examples of objective or operator primitives (see Roth 2012). These example statements were identified from interview transcripts by two independent coders (reliability scores of 90.7% and 90.2%). These statements were complemented by definitions of objective and operator primitives included in the literature. In total, 178 and 206 cards were included in the objective and operator sorts (see Roth 2011 for the set of statements).

2.3 Procedure

Both card sorting studies followed the *guided sorting* procedure, a variation appropriate when investigators wish to enforce a pre-determined sorting criterion, but are not yet aware of the categories (Roth et al. 2011). Participants explicitly were instructed to sort on the concepts of objectives and operators for the first and second card sorting study, respectively. The pair of card sorting studies were administered online using the WebSort.net sorting tool. Before submitting their final sorting structures, participants were required to provide a name for each created category and an explanation about their categorization using the 'Leave a comment' tab.

2.4 Statistical and Visual Analysis

Results of the pair of card sorting studies were interpreted using descriptive statistics and exploratory statistical graphics (Hannah 2005). The primary metric used to interpret guided card sorting studies is *pairwise agreement* (i.e., card-versus-card similarity), or the percentage of participants that rated a given pair of cards as members of the same category (Rugg and McGeorge 2005). The pairwise agreement scores were analyzed using average link clustering analysis, with the clustering results used to generate dendogram and agreement matrix statistical graphics. A similarity score was generated for both card sorting studies to assess variation in categories across participants (Klippel and Li 2009), producing an overall similarity score of 63.0% for the objective sort and 83.3% for the operator sort.

3. Results

3.1 Participant Agreement on Objectives

Structures elicited from participants in the objective card sorting study exhibited a large amount of variation (**Figure 1**). Participant comments provided through the 'Leave a comment' tab revealed that at least three competing criteria were leveraged during sorting, two of these criteria were related to the interaction operand while the third revealed a set of meta-objectives, described as user goals.

The first confounding operand-based sorting criteria confirmed Peuquet's (1994) TRIAD framework (i.e., information components), leading to three operand-based primitives based on search target (**Table 1e**). The second confounding operand-based sorting criteria confirmed Bertin's (1967|1983) levels of map reading (i.e., the percentage of all map features under consideration), resulting in two operand-based primitives based on search level (**Table 1f**).

Most of the included objective cards provide examples of basic information retrieval from the map. However, roughly two dozen of the cards required what participants described as a "broader assessment" or "advanced decision making." **Figure 1** indicates that participants generally separated these cards from the rest of the set as two individual categories; the first category includes situations requiring the user to determine what may occur based on current conditions and domain knowledge, while the second category includes situations requiring the user to determine what should occur next, again based on current conditions and domain knowledge. The objective card sorting therefore identified three broad user goals (**Table 1a**).

The objective card sorting study revealed five objective primitives once controlling for the three competing sorting criteria described above (**Table 1b**). Most participants accepted a continuum of increasing *sophistication* (i.e., cognitive difficulty; see Crampton 2002) in their discrimination of objective categories, ranging from the most basic *identify* primitive to the most complex *delineate* primitive.

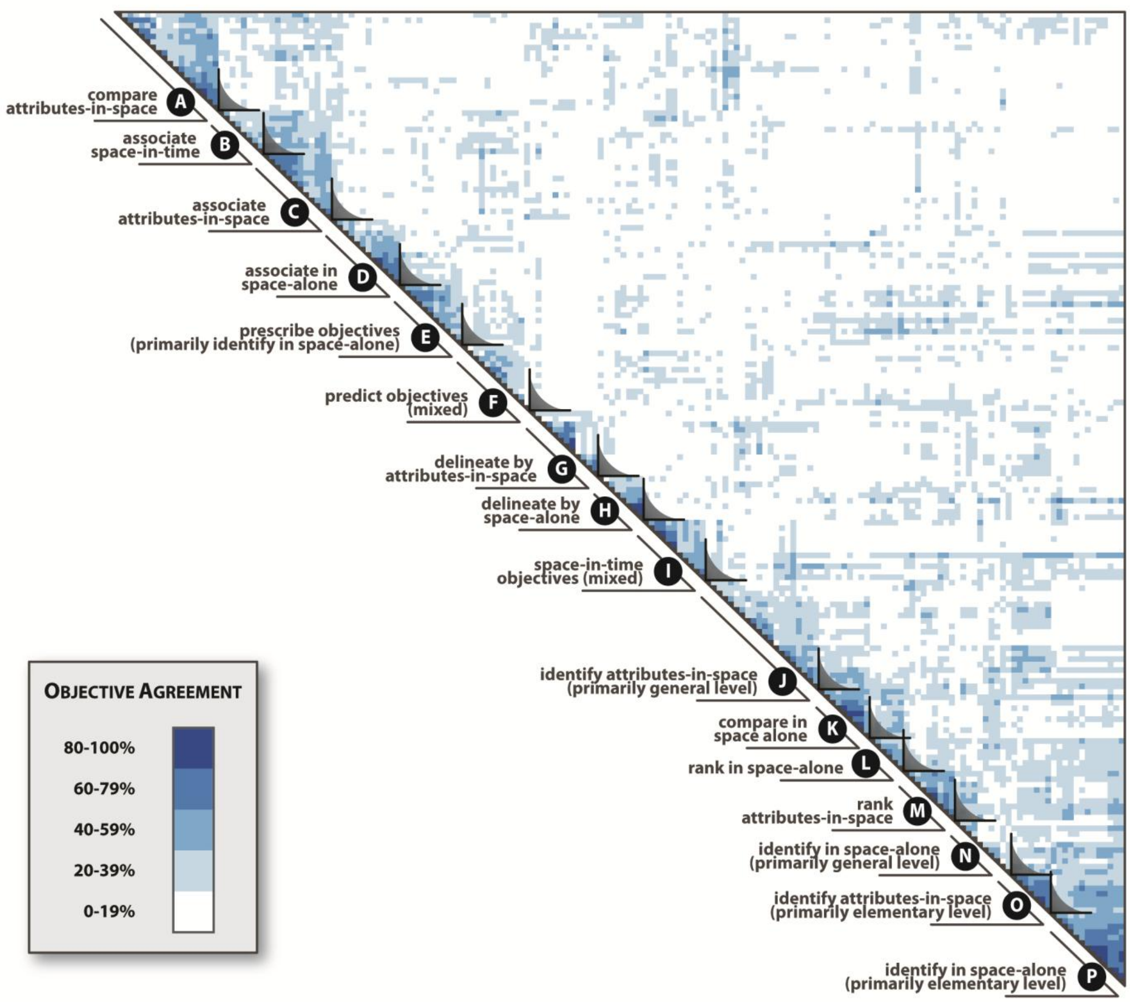

Figure 1. The Card-by-Card Agreement Matrix for the Objective Card Sorting Study

3.2 Participant Agreement on Operators

Unlike the objective card sorting study, the cognitive structures elicited during the operator card sorting study exhibited a high degree of similarity across participants (**Figure 2**). Interestingly, participants isolated primitives that support *work interactions*, or cartographic interactions that directly accomplish the objective, from those that support *enabling interactions*, or cartographic interactions that are required to prepare for, or clean up from, work interactions (Davies 1998).

The operator card sorting study revealed a set of 12 fundamental operator primitives (**Table 1c**). Interestingly, neither "brushing" nor "linking"—two of the three most common operator primitives found in extant taxonomies—were identified as unique operator primitives across the participant sorts. Participants generally considered brushing as a two-step process in which the direct manipulation interface style is used to assign an operator to one or more map features of interest (i.e., *brushing*+operator) and linking was considered an extension of brushing in which associated information items in linked views receive the same operator (i.e., *brushing*+operator+*linking*).

In total, the operator card sorting study revealed five enabling cartographic operators (**Table 1d**). Approximately 50 of the 206 operator cards (~25%) represent enabling interactions, illustrating the importance of considering such operator primitives during the conceptual design and development of a cartographic interface.

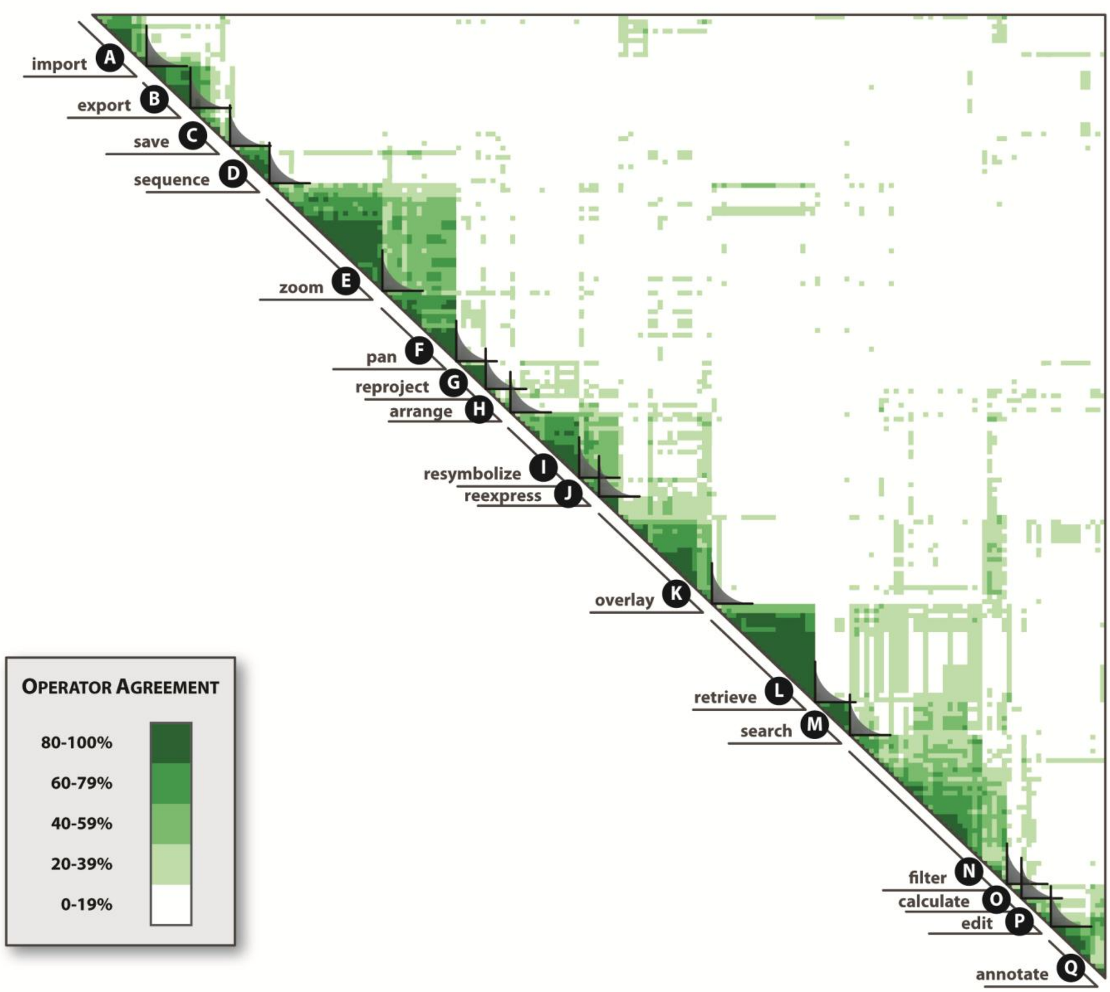

Figure 2. The Card-by-Card Agreement Matrix for the Operator Card Sorting Study

Table 1. An Empirically Derived Taxonomy of Cartographic Interaction Primitives

PRIMITIVE	*DEFINITION*
Goals (a)	
procure	retrieve information about the represented geographic phenomena
predict	forecast what may occur in the future based on current conditions of the represented geographic phenomena
prescribe	decide what should occur in the future based on current conditions of the represented geographic phenomena
Objectives (b)	
identify	examine and understand a single map feature
compare	determine the similarities and differences between two or more map features
rank	determine the order or relative position of two or more map features
associate	determine the relationship between two or more map features
delineate	organize map features into a logical structure
Operators	
Work (c)	
reexpress	set or change the cartographic representation form
arrange	manipulate the layout of a cartographic representation when multiple are provided
sequence	generate an ordered set of related cartographic representations
resymbolize	set or change the design parameters of a cartographic representation without changing the represented map features or the cartographic representation form
overlay	adjust the feature types included in the cartographic representation
reproject	set or change the cartographic projection used for the cartographic representation
pan	change the geographic center of the cartographic representation
zoom	change the scale and/or resolution of the cartographic representation
filter	alter the cartographic representation to indicate map features that meet one or a set of user-defined conditions
search	alter the cartographic representation to indicate a particular location or map feature of interest
retrieve	request specific details about a map feature or map features of interest
calculate	derive new information about a map feature or map features of interest
Enabling (d)	
import	load an existing dataset or previously generated cartographic representation
export	extract the generated cartographic representation, the geographic information underlying the representation, or the status of the system for future use outside of the cartographic interface
save	store the generated cartographic representation, the geographic information underlying the representation, or the status of the system for future use within the cartographic interface
edit	manipulate the geographic information underlying the representation to alter all subsequent cartographic representations of that information
annotate	add graphic markings and textual notes to the cartographic representation to externalize insight generated from work interactions
Operands	
Search Target (e)	
space-alone	interact with the geographic component of the cartographic representation only
space-in-time	interact with the temporal component of the cartographic representation to understand how a dynamic geographic phenomenon acts over time
attribute-in-space	interact with the attribute component of the cartographic representation to understand how one or several characteristics of a geographic phenomenon varies across space
Search Level (f)	
elementary	interact with a single map feature
general	interact with several-to-all map features

4. Conclusion and Outlook

The pair of card sorting studies reported in this chapter resulted in an interaction primitive taxonomy with four dimensions: goals, objectives, operators, and operands (**Table 1**). The taxonomy of cartographic interaction primitives described above affords a greater degree of ecological validity than other, extant taxonomies based on secondary sources or personal experience. Despite this increased validity, it is important to note that any taxonomy of cartographic interaction primitives—like existing taxonomies of visual variables—requires additional empirical examination to tweak the included primitives and also must remain malleable to changes in cartographic interaction use and technological capabilities. Future work includes a series of closed card sorting studies using the established primitive categories, allowing for further refinement of the taxonomy, as well as cartographic interaction studies to understand the syntactics of cartographic interaction primitives, ultimately allowing for the prescription of cartographic interaction operators according to the objective and operand context.

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