ARTICLE

Interactivity and Cartography: A Contemporary Perspective on User Interface and User Experience Design from Geospatial Professionals

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ABSTRACT

This article reports on a semi-structured interview study with 21 geospatial professionals to provide a contemporary snapshot of expert opinion on the design and use of interactive maps and map-based systems (treated together as "cartographic interfaces"). Interview questions were based on key themes regarding interaction discussed within cartography and across the related fields of human-computer interaction, information visualization, usability engineering, and visual analytics, enabling a comparison of the current states of science and practice regarding user interface (UI) and user experience (UX) design in cartography. The results are organized according to five broad topics germane to UI/UX design in cartography: (1) the meaning of cartographic interaction in both research and practice (*what?*), (2) the purpose of cartographic interaction and the value it provides (*why?*), (3) the times when interaction positively supports work/play and therefore should be provided (*when?*), (4) the way in which user differences impact the success of the cartographic interaction (*who?*), and (5) the opportunities for or limitations on cartographic interaction imposed by the computing device supporting the interaction (*where?*). The interview study is significant for two reasons: first, it charts current trends in interactive mapping from the perspective of expert professionals, a population often missed in quantitative cartographic scholarship, and, second, it enables a reflection on future trends in UI/UX design in cartography, both those resulting from existing gaps between science and practice and those arising from emerging conceptual and technological developments.

Keywords: interactive maps, cartographic interaction, user interface (UI) design, user experience (UX) design, human-computer interaction, geovisualization, geovisual analytics

RÉSUMÉ

L'article rend compte d'une étude par entrevues semi-structurées menée auprès de 21 spécialistes de la science géospatiale dans le but de donner un aperçu actuel de l'opinion d'experts sur la conception et l'utilisation de cartes et systèmes cartographiques interactifs (traités ensemble comme étant des « *interfaces cartographiques* »). Les questions d'entrevue portaient sur des thèmes importants liés à l'interaction dans le domaine de la cartographie et les domaines connexes de l'interaction homme-machine, de la visualisation de l'information, du génie de la convivialité et de l'analyse visuelle, ce qui a permis de comparer les états actuels de la science et de la pratique au sujet de la conception de l'interface utilisateur (IU) et de l'expérience utilisateur (EU) en cartographie. Les résultats sont organisés en fonction de cinq grands sujets pertinents pour la conception de l'IU et de l'EU en cartographie : (1) la signification de l'interaction cartographique dans la recherche et la pratique (*quoi?*); (2) le but et la valeur de l'interaction cartographique (*pourquoi?*); (3) les moments où l'interaction soutient de façon positive le travail ou le jeu et devient donc essentielle (*quand?*); (4) la manière dont les différences relatives aux utilisateurs produisent un effet sur le succès de l'interaction cartographique (*qui?*); et (5) les possibilités ou les limites de l'interaction cartographique imposées par l'appareil informatique offrant cette interaction (*où?*). L'étude par entrevues est importante parce qu'elle dégage les tendances actuelles en cartographie interactive à l'aide du point de vue de professionnels, un groupe souvent ignoré dans le cadre de l'apprentissage cartographique quantitatif, et qu'elle favorise une réflexion sur les futures tendances de la conception de l'IU et de l'EU en cartographie, que celles-ci résultent de lacunes existantes entre la science et la pratique ou de nouveaux progrès conceptuels et technologiques.

Mots clés : cartes interactives, interaction cartographique, conception d'interface utilisateur (IU), conception d'expérience utilisateur (EU), interaction homme-machine, géovisualisation, analyse géovisuelle

Introduction: Interaction Design in Cartography

Maps have gone viral (Elmer 2013; Muehlenhaus 2014). Public fascination with maps is crescendoing, with a new blog post or news report on a particular set of maps circulating on our social media pages daily. But maps also are used to address many of our planet's most pressing problems: they organize activities during emergency and crisis events; they inform how best to cope with changing climates and demographics; they are used to discover and react to patterns in disease; they assist in managing local and global trade. Maps support scientific exploration, public policy and government planning, and the making of decisions from the mundane to the critical. Maps have never been so important, and, importantly, the forms in which we encounter them are evolving at the same time as their popularity is rising (Harrower 2008). These maps are increasingly digital and increasingly delivered online or through mobile applications. Further, these maps are increasingly interactive, allowing users to manipulate the map display according to their particular needs and preferences. As a result, cartographers increasingly must be familiar with topics of *representation design* as well as *interaction design*; they must understand how to properly *encode* geographic information based on principles of perception, cognition, and semiotics as well as how to properly *code* a useful and usable interface for manipulating the resulting maps.

The topic of interaction design is treated across the fields of human-computer interaction, information visualization, usability engineering, and visual analytics, with multiple scholars from these fields calling for the creation of a science of interaction to pair with our existing understanding of representation (Thomas and others 2005; Yi and others 2007; Pike and others 2009). The call for empirical research on interaction has been paralleled within cartography, with the importance of cartographic interaction often stressed in the context of geographic visualization (e.g., MacEachren and Kraak 1997, 2001; Cartwright and others 2001; Dykes 2005; Andrienko and others 2007; MacEachren 2013). Professionally, such work increasingly is being described as user interface (UI) or user experience (UX) design, or their merger as UI/UX design (Hassenzahl and Tractinsky 2006). In past work, I reviewed the existing theoretical frameworks and empirical insights about interaction reported in the literature, rethinking principles derived from related fields for the cartographic context (Roth 2013b). Through the literature review, six fundamental research questions emerged that are facing UI/UX design in cartography: (1) *What* is cartographic interaction? (2) *Why* provide cartographic interaction? (3) *When* should cartographic interaction be provided? (4) *Who* should be provided with cartographic interaction? (5) *Where* should cartographic interaction be provided? (6) *How* should cartographic interaction be provided? The first five questions approach the context of cartographic interaction, and associated recommendations for designing interfaces, while the sixth question deals with the mechanics of UI/UX design in cartography; Table 1 organizes common research topics on interaction according to these fundamental questions, as adapted from Roth (2013b).

Table 1. Six fundamental research questions facing UI/UX design in cartography

Question	Definition	Selected research topics
What?	The meaning of cartographic interaction in both research and practice	Analogue vs. digital interaction, interaction vs. interface, response time, stages of interaction, interactive maps vs. map-based applications
Why?	The purpose of interaction and the value it provides	Visual thinking, geographical insight, exploration vs. confirmation vs. synthesis vs. presentation, decision-making support
When?	The times when interaction positively supports work/play and therefore should be provided	Static vs. interactive maps, interface complexity, work productivity, flexibility vs. constraint, work vs. enabling interactions
Who?	The way in which user differences impact the success of the cartographic interaction	User-centred design, ability vs. expertise vs. motivation, adaptive cartography, geo-collaboration
Where?	The opportunities for or limitations on cartographic interaction imposed by the computing device supporting the interaction	Input capabilities, bandwidth, processing power, display capabilities, mobile mapping, location-based services
How?	The fundamental interaction primitives and the design of interfaces implementing them	Interaction primitives, interaction primitive taxonomies, syntactics, interface styles, interface design

In this article, I report on a semi-structured interview study designed to gather empirical evidence about current practices and future directions in cartographic UI/UX design. Twenty-one interviews were conducted with expert geospatial professionals to gather their attitudes, beliefs, and values regarding the design and use of interactive maps and map-based applications (together described as *cartographic interfaces*). I purposefully sampled cartographic interface "power users," as this professional population often is missed in quantitative cartographic scholarship, although I acknowledge that this highly expert sample does not represent all users of cartographic interfaces. Further, I recruited geospatial professionals from seven different application domains to gather feedback across the entire UI/UX solution space. The interview study therefore serves as a contemporary snapshot of expert opinion across mapping contexts, providing a benchmark for assessing where we have been and where we are going regarding cartographic UI/UX design. Key and probe questions were based on the fundamental research questions identified in the aforementioned literature review, affording a direct comparison between the current states of science (from the literature review) and practice (from the interviews) regarding cartographic interaction. The emphasis of this article is on the context of cartographic interaction, and thus it reports on insights generated about the first five fundamental research questions facing UI/UX design in cartography; because of the different nature of the sixth question (*how?*), it is treated elsewhere using different method and analysis techniques (see Roth 2013a).

The article proceeds in four sections. In the next section, a review of relevant literature on interaction is provided; the purpose of this section is not to reproduce the Roth (2013b) literature review but instead to introduce the important concepts related to each of the five research questions addressed in the interviews. The method design is described in the third section, including discussion of the interview protocol and the coding scheme used to analyse the interview transcripts. Results are presented in the fourth section, with discussion organized according to the five research questions. The final, concluding section provides an outlook on future opportunities regarding cartographic interaction, as illuminated by the interview study.

Background: The Context of Cartographic Interaction

WHAT IS CARTOGRAPHIC INTERACTION?

The *what?* question approaches the meaning of cartographic interaction and the scope that it covers. It is the existential question of a science of cartographic interaction: what counts as a cartographic interaction, and what does not?

There are at least four contested or unresolved issues in the literature regarding the definition and scope of interaction. A first, important issue is whether an interaction should be conceptualized as a *one-way* manipulation of a map by a user (e.g., Buja, Cook, and Swayne 1996; Yi and others 2007) or as a *two-way* conversation between user and map (e.g., Norman 1988). I have argued for the latter in past work, defining *cartographic interaction* as the two-way dialogue between a user and a map mediated by a computing device (Roth 2012). Such a definition explicitly distinguishes an *interaction*, or the series of requests and responses between user and map, from an *interface*, or the digital tool developed to support such interactions (Beaudouin-Lafon 2004). Such a definition also falls more closely in line with the emerging field of *UX design*, which emphasizes the achievement of user goals to ensure a satisfying and valuable experience with the digital interface, in contrast to *UI design*, which primarily emphasizes the graphics, sounds, and haptics of the digital interface (Hassenzahl and Tractinsky 2006).

A second issue is the distinction between analogue and digital cartographic interactions. While nearly all research in human–computer interaction, information visualization, usability engineering, and visual analytics assumes a digital environment, multiple scholars within cartography have reminded us that analogue or paper maps are also interactive and thus potentially fall within the scope of a science of cartographic interaction (e.g., MacEachren and Ganter 1990; Wood 1993; Peterson 1998; Cartwright and others 2001). Further, such analogue interactions with paper maps may serve as natural metaphors for informing the design of digital interactions (Cartwright 1999).

A third, related issue is the immediacy of the interaction. While an analogue interaction responds immediately (e.g., a line appears on a paper map as soon as we annotate the map with a pen), there is often a lag in a digital interaction because of limitations in computing power (Gahegan 1999); at what point is the lag so great that the user experience is no longer considered "interactive"? Recommendations from human–computer interaction indicate that the system should respond within 1 or 2 seconds of the user input (Wardlaw 2010), although GIScientists note that such immediacy is uncommon in cartographic interaction given the volume of the underlying geographic information (Haklay and Li 2010).

The fourth and final issue returns the focus to the interface rather than the interaction, as defined above. This issue centres on the difference between a broader map-based system (e.g., Esri's ArcMap application in its entirety) and the unique map views created within the system (e.g., the layout view in ArcMap). An important component of the debate is the directness of the implemented interface style. Shneiderman and Plaisant (2010) identify five interface styles: *direct manipulation*, which relies on pointing devices to probe, drag, and adjust the

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map itself, and four *indirect styles* (menu selection, form fill-in, command language, and natural language) which "redirect" the interface away from the map. I have argued for a broad definition of cartographic interfaces that includes both one-off interactive maps (e.g., those embedded in online articles by the *New York Times*) and robust map-based applications (e.g., ArcMap), as both support two-way cartographic interaction (Roth 2013b).

WHY PROVIDE CARTOGRAPHIC INTERACTION?

The *why?* question approaches the purpose of cartographic interaction and the value it provides. In other words, what are the broader goals that initiate the two-way cartographic interaction conversation, motivating use of cartographic interfaces?

DiBiase's (1990) *swoopy* schematic provides a useful theoretical framework regarding the purpose of maps, both interactive and static. The swoopy schematic successfully ameliorates the traditional research emphasis in cartography on *visual communication* (e.g., A.H. Robinson 1952; Board 1967; Koláčný 1969) with research on *visual thinking* derived from exploratory data analysis (Tukey 1980) and visualization in scientific computing (McCormick, Defaranti, and Brown 1987). Four stages of science are identified in order within the swoopy framework:

1. *Exploration*: the examination of information from multiple perspectives to generate new research hypotheses and to reveal unknown insights about the phenomenon under investigation (i.e., the least structured form of visual thinking)
2. *Analysis*: the testing of newly generated hypotheses and the search for relationships in newly revealed insights, answering questions rather than generating them; this stage was renamed by MacEachren and Kraak (1997) from DiBiase's original use of *confirmation*, better reflecting terminology in GIS science
3. *Synthesis*: the integration of insights generated from multiple iterations of exploration and analysis to develop a final, comprehensive solution for presentation
4. *Presentation*: the map-based dissemination of findings or results to a wider audience (i.e., the purpose of visual communication)

The "swoop" then indicates the number of unique maps required to support each stage, with the number of maps decreasing from exploration (approaching the infinite) to presentation (one optimal map). High levels of cartographic interaction are considered essential for seamless map exploration to occur, as such interaction allows the user to generate a new map once a need for it is recognized (MacEachren and Monmonier 1992). In the Cartography^3 framework, MacEachren (1994) identifies the amount of cartographic interaction (described as "human-map" interaction) as one of three axes that contextualize or explain all possible map uses, including the transition from exploration (high human-map interaction) to presentation (low human-map interaction). The second axis in this framework describes the user task, marking a transition from revealing unknown insights during exploration to communicating known insights during presentation; this axis was later renamed by MacEachren and colleagues (2004) as "knowledge construction" (exploration and analysis) versus "information sharing" (primarily presentation). The third and final axis describes the map user, varying from private use during exploration to public use during presentation; the term "private" was later changed to "specialist" by MacEachren and colleagues (2004) to emphasize the importance of user expertise during map use generally, and in employing cartographic interaction specifically.

It is important to note that other theoretical frameworks regarding the purpose of interaction (i.e., *why?*) exist across human–computer interaction, information visualization, usability engineering, and visual analytics, most notably Pirolli and Card's (2005) sensemaking process. Alternative frameworks were not assessed during the interview sessions given the centrality of swoopy and Cartography^3 frameworks in cartography and given the time limitations of the interview sessions.

WHEN SHOULD CARTOGRAPHIC INTERACTION BE PROVIDED?

The *when?* question addresses the appropriate contexts for interactive versus static maps and, when cartographic interaction is appropriate, the amount of interaction that is necessary. If a cartographic interaction is defined as the dialogue between a user and a map, mediated through a computing device, the *when?* question represents a focus on the interactive map component, or an interface-centred perspective on cartographic interaction.

The human-map interaction axis in the Cartography^3 framework is a continuum from low to high in both the number of supported interactions (*interface scope*) and the precision in performing each interaction (*interface freedom*); these concepts are described together as *interface complexity* (Harrower and Sheesley 2005). The topic of interface complexity commonly is approached from the perspective of productivity, or the ability to effectively and efficiently complete work. An increase in interface complexity supports a broader array of user tasks and improves the flexibility with which users ultimately can complete these tasks (Cooper and Reimann 2003; Roth and Harrower 2008). Despite the promise of complex digital interfaces, only minimal gains in work productivity were observed during the early portion of the digital revolution, a phenomenon referred to as the *productivity paradox* (Landauer 1995; Haklay and Nivala 2010). As a

result, a design philosophy emerged at this time celebrating simple interfaces that support a small set of user tasks, constraining interface complexity (Kelly 1982; Albrecht and Davies 2010). In the field of usability engineering, this balance is recognized as the trade-off between the utility (i.e., usefulness) and the usability (i.e., ease of use) of an interface (Grinstein and others 2003; Fuhrmann and others 2005).

There are proponents for both interface flexibility and interface constraint within cartography and across related fields. The push toward increased interface flexibility has led to the development of numerous interactive mapping tool kits, with some enabling users to add their own custom components (Takatsuka and Gahegan 2002; Weaver 2004; Chen 2006; Hardisty and Robinson 2011). However, there is an accumulating body of evidence specific to cartography suggesting that interface constraint actually improves productivity (Davies 1998; Keim 2002; Keehner and others 2008; Dou and others 2010). Finally, a growing number of scholars avoid generalities, instead advocating for application of a user-centred design process to identify the appropriate interface complexity for a given mapping context (Gabbard, Hix, and Swan 1999; Slocum and others 2003; Fuhrmann and Pike 2005; A.C. Robinson and others 2005; Roth and others 2015); additional details about a user-centred perspective are treated in the next subsection.

WHO SHOULD BE PROVIDED WITH CARTOGRAPHIC INTERACTION?

The *who?* question approaches the impact of the user on cartographic interaction, rather than the cartographic interface and its level of complexity. Accordingly, the *who?* question represents a user-centred perspective on cartographic interaction.

There are three user characteristics identified in the literature that impact interface design and interaction success. The first is the user's innate perceptual and cognitive *abilities*. For over half a century, cartographers have investigated the perceptual and cognitive limits of map readers to the end of designing the cartographic representation to accommodate these limits (Montello 2002). In addition to perception and cognition, research on human motor skills, such as pointing, keying, and swiping, is relevant to a science of cartographic interaction (White 2009). Also, there is an important body of knowledge emerging on *spatial ability*, or the capacity for organizing and leveraging knowledge about one's environment to navigate or manipulate it (Golledge 1992). Interestingly, there is conflicting scientific evidence concerning the impact of spatial ability on cartographic interaction, with some studies observing a difference across spatial ability (e.g., Montello and others 1999) while others show no difference (e.g., Keehner and others 2008).

A second user characteristic relevant to cartographic interaction is user *expertise*. As mentioned above, user expertise is one of the three axes in the Cartography[3] framework contextualizing or explaining all map uses, with MacEachren (1994) recommending a decrease in assumed expertise when moving from exploration to presentation and an increase in assumed expertise when increasing interface complexity. Expertise, however, is a multifaceted concept that includes the user's education, experience, and familiarity (Roth 2009a). Expertise therefore describes the way in which the user's abilities are enhanced through the provision of educational materials or training about the cartographic interface, through trial-and-error experimentation with the cartographic interface, or through familiarity with digital interfaces in general.

The third and final user characteristic impacting cartographic interaction is user *motivation*, or the degree to which the user wishes to make use of the cartographic interface out of either interest or need (Greif 1991; Roth and Harrower 2008). While research on motivation within cartography is minimal, discussion in human-computer interaction and usability engineering suggests that low levels of motivation (i.e., when a person does not enjoy using an interface) can lead to unsuccessful interactions even when that user has the ability and expertise to use the interface successfully (Norman 2004).

WHERE SHOULD CARTOGRAPHIC INTERACTION BE PROVIDED?

The *where?* question addresses the impact of the digital environment itself on the cartographic interaction. If the *when?* and *who?* questions represent an interface-centred and user-centred perspective respectively, then the *where?* question represents a technology-centred perspective on cartographic interaction, focusing on the computing device mediating the two-way conversation.

Discussion in the human–computer interaction literature generally emphasizes one of three components of the computing device. The first technological component is the input device, or the way in which the user initiates the two-way interaction. Input devices primarily support pointing (i.e., selecting an item onscreen) or keying (i.e., entering text). While most discussion to date is on interaction through indirect pointing devices (e.g., joysticks, mice, trackpads), interface design across indirect and direct pointing devices (e.g., touchscreens and multitouchscreens) is becoming increasingly important given the pervasiveness of mobile devices (Muehlenhaus 2013). Keying primarily is supported through the use of keyboard devices, although there have been recent breakthroughs in voice recognition that support multimodal keying input; multimodal pointing input can be completed through gesture-based interaction and eye-tracking (MacEachren and others 2005).

The second technological component relates to the issue of interaction speed introduced above, which is impacted by both the network bandwidth and the hardware processing power (Gahegan 1999). The ability to instantaneously query a voluminous spatial database and return a result set over a network is of cardinal concern in the current Big Data era (Yang and others 2011). While bandwidth and processing power both have exhibited exponential growth in recent years, data volume is increasing at a similar or faster rate, resulting in a possible catch-22 in which our computing technology may never catch up to our information-processing needs (Shneiderman and Plaisant 2010).

The third and final technological component is the display device, or the way in which the map responds in the two-way interaction. Drawing from and extending Harrower, Keller, and Hocking (1997), I identified at least nine characteristics of display devices that impact the success of a cartographic interaction: (1) screen resolution, (2) screen size, (3) colour depth, (4) luminance capability, (5) refresh rate, (6) expected viewing distance, (7) display continuity, (8) lighting conditions, and (9) portability (Roth 2013b). As with issues surrounding input devices, new challenges in cartographic interaction design related to display devices are arising from the increased pervasiveness of mobile devices, which have a considerably reduced screen size and are used in very different viewing conditions compared to personal computers.

Method Description: Semi-structured Interviews

PARTICIPANTS

Twenty-one geospatial professionals were sampled purposively to participate in a series of one-on-one semi-structured interviews. The sample size ($n = 21$) is consistent with other qualitative studies in cartography and GIScience (e.g., Monmonier and Gluck 1994; Harrower, MacEachren, and Griffin 2000; Slocum and others 2004; Bhowmick and others 2008; A.C. Robinson, Roth, and MacEachren 2011) and was the point at which saturation was reached in the interview study. *Purposive sampling* describes the selection of participants based on their fitness to a small set of pre-defined criteria associated with the research topic (Patton 1990). Criteria for participation included regular use of cartographic interfaces as part of their work responsibilities, expertise in one of the targeted application domains, and 18 years of age or older; additional experience designing and developing cartographic interfaces was considered a plus given the expected added depth of knowledge regarding UI/UX design in cartography. Geospatial professionals were recruited from one of seven application domains: (1) emergency response and crisis management, (2) environmental science and human-environment geography, (3) epidemiology and public health, (4) history and historical geography, (5) intelligence analysis, (6) news and new media, and (7) resource management. Between two and four geospatial professionals were recruited from each of the seven application domains (Table 2). These domains were targeted to capture feedback on UI/UX design across a breadth of mapping contexts, including the use of discrete versus continuous data, the use of homogeneous versus heterogeneous data sources, the mapping of individual incidents versus spatial aggregates, reliance on primarily 2D versus 3D interactive mapping environments, and the use of primarily reference versus thematic interactive maps; Table 3 summarizes the participant balance across these five cartographic interaction contexts.

Table 2. Cartographic interaction interview participants by application domain

Application domain	Number of participants
Emergency response and crisis management	4
Environmental science and human-environment geography	2
Epidemiology and public health	4
History and historical geography	2
Intelligence analysis	3
News and new media	3
Resource management	3
Total	21

A background survey was administered at the start of each interview session to establish several characteristics of the interview participants. All participants (21 of 21) had earned at least one bachelor's degree, and the majority (17 of 21) of participants had earned a graduate degree; five participants had earned an MD or PhD. Given recruitment across multiple domains, the degree programs themselves varied greatly. The majority (16 of 21) of participants reported using geographic information every day, with no participant directly using geographic information less than monthly (Table 4). The regularity of using static maps and interactive maps varied more across participants, an indication that cartographic products typically support only a subset of work activities. The majority (18 of 21) of participants reported using both static maps and interactive maps at least monthly, with 16 participants using interactive maps at least weekly. The three participants who rarely used cartographic interfaces indicated that they did use them more regularly in past positions, but now manage individuals who use cartographic interfaces rather than using such tools themselves; these individuals therefore were qualified to participate in the interview study.

Table 3. Participant balance across cartographic interaction contexts

Interactive mapping quality	Former only	Latter only	Both
Discrete versus continuous data	10	3	8
Homogeneous versus heterogeneous data sources	9	7	5
Individual incidents versus spatial aggregates	10	3	8
2D versus 3D interactive mapping environments	12	3	6
Reference versus thematic interactive maps	10	5	6

Note: The "former only" column lists the number of participants indicating that they used only the first type of interactive mapping in the "versus" binary, while the "latter only" column gives the number of participants indicating that they used only the second type in the binary; the "both" column lists the number of participants who stated that their work makes use of both types of interactive mapping qualities.

Table 4. Regularity of use of geographic information, static maps, and interactive maps

Regularity of use	Geographic information	Static maps	Interactive maps
Daily	16	9	7
Weekly	3	3	9
Monthly	2	6	2
Yearly	0	0	0
Rarely	0	3	3
Total	21	21	21

MATERIALS AND PROCEDURE

The *semi-structured interview* method is a variant of one-on-one interviewing that uses a baseline set of *key* questions (i.e., structured questions) across all interview sessions, while allowing the interviewer to ask follow-up or *probe* questions (i.e., unstructured questions) and to change the order of questioning if appropriate (A.C. Robinson 2009). The semi-structured variant was selected for consistency across participants, while affording the flexibility to probe participants about topics on which they were particularly knowledgeable or had particularly strong opinions. Interview questions were informed by the above background review to allow for comparison of the current states of cartographic interaction science and practice. The set of interview questions and probes is available in Table 5.

Following completion of the structured background survey, questioning proceeded in three sections. In the first section of the interview, participants were asked to discuss their daily work responsibilities that involve geographic information. No reference was made at this point to UI/UX design to allow users to discuss work that currently may not be supported by cartographic interfaces, but possibly could be; once participants were prompted to think about cartographic interaction, their ideas generally were constrained by the current or past cartographic interfaces they had encountered.

Questioning narrowed in the second section of the interview to address the cartographic interfaces used in support of the participants' work. Before the interview session, participants were asked to forward a list of cartographic interfaces that met one of three conditions: (1) one-off interactive maps or map-based systems currently integrated into their workflows, (2) one-off interactive maps or map-based systems they would like to use, but currently do not, and (3) one-off interactive maps or map-based systems they have used in the past, but have abandoned. Such collection of participant map examples before the interviews proved useful for advancing and supplementing discussion in a past ethnographic study examining primarily static mapping practices (A.C. Robinson and others 2011). Table 6 lists all of the tools identified by multiple participants; tools listed only once are not included in the table to avoid potential identification of the participant. Esri's ArcMap and the two Google mapping products were the only cartographic interfaces identified by a majority or large minority of participants. Many of the other tools identified were one-off interactive maps generated for a single project or custom map-based systems that support a single work task. During the second section of the interviews, participants were asked to demonstrate each of the cartographic interfaces; to describe how each cartographic interface does support, could support, or did support their work; and to recall any *critical incidents* with the cartographic interfaces that influenced their task performance and overall user satisfaction (Gabbard and others 1999).

In the final interview section, participants were asked directly about the five fundamental questions facing UI/UX design in cartography. This debriefing period afforded participants the opportunity to provide any additional thoughts or final remarks regarding cartographic interaction that had yet to be discussed. The interview was designed to last approximately 60 minutes; most interviews took approximately 75 minutes, and no interview lasted longer than 90 minutes.

Table 5. Interview protocol

Type	Question
Part 1: Work tasks and geographic information	
key	Please describe the geospatial data sets that you use in your daily work.
probe	Are the geographic phenomena conceptually discrete or continuous in space?
probe	Do the geographic phenomena change smoothly or abruptly across space?
probe	Is the data set composed of individual incidents or aggregates?
probe	Is the data set primarily homogeneous numerical data or a mixture or numerical and non-numerical data?
key	What work tasks do you carry out that require you to use these geospatial data sets?
probe	What is the purpose of performing this task?
probe	What is the result or output of performing this task?
probe	Which of the tasks listed above require you to use static maps?
probe	Which of the tasks listed above require you to use interactive maps?
key	Do you complete these tasks in a typical order or workflow?
probe	Is it possible to compartmentalize each task into a prototypical workflow of discrete steps?
probe	Is the work process iterative in any way?
probe	Were you taught this workflow, or is it something that you figured out on your own?
probe	Are there other possible ways of achieving the goals of the workflow?
key	Are there any tasks that you complete using a series of static maps that would be improved if you had an interactive version of the map?
probe	What would the interactive version let you do that you cannot do now?
Part 2: User demonstration	
key	Spend a minute or two to demonstrate the basic functionality of the interactive map, as you understand it. Please verbalize what you are doing and why as you interact with the tool.
key	Which of your current work tasks does this tool support? Quickly demonstrate how the tool supports each of these tasks, explaining why you are using the tool the way you are.
probe	How do or might you use these tools to transform or manipulate your data sets?
probe	How do or might you use these tools to represent or symbolize your data sets?
probe	How do or might you use these tools to support problem solving or decision making?
key	Which tasks does the interactive map support that are not part of your current work responsibilities but are of potential use to your own work and to your field/domain? Why?
key	Which tasks doesn't the interactive map support? How could this tool be improved to support these tasks?
key	Can you recall any times that these tools were especially or surprisingly useful for accomplishing a given task? Similarly, can you recall any times that these tools failed to support your work?
key	What are your favourite two or three aspects/features of this tool? What are your least favourites? Why?
Part 3: Debriefing	
key	What makes a map "interactive"?
probe	Are systems that take a long time to respond to user input interactive maps?
probe	Are map-based systems like ArcMap interactive maps?
probe	Are mashups interactive maps?
probe	Are animations interactive maps?
probe	Are paper maps interactive maps?
key	Is adding interactivity to the map always good or always bad? In what situations is it good, and in what situations is it bad? Why?
key	How widespread is the current use of digital maps and map-based systems by professionals in your field? Why do you think this is the case?
probe	How common are desktop interactive maps?
probe	How common are web-based interactive maps?
probe	How common are web map mashups?
key	Do you think the training on both *making* and *using* interactive maps is sufficient in your field? How would you go about training individuals to use interactive maps in your domain?
key	Is there anything else you would like to share about interactive maps that we have not already discussed?

Table 6. Interactive maps or map-based systems demonstrated during the interviews

Interactive map or map-based system	Number of participants
Esri ArcMap	15
Google Maps	13
Google Earth	9
GeoCommons	2
Remote Access (Group 1 Solutions)	2
SAS (Statistical Analysis System)	2
The National Map (USGS)	2

Note: 45 other tools were listed once.

QUALITATIVE DATA ANALYSIS

All interviews were completed at the participant's work location in a private room and audio-recorded for subsequent qualitative data analysis. *Qualitative data analysis* (QDA) describes the systematic interpretation of qualitative information, such as text (e.g., interview transcripts), photos, maps, and field observations (Dey 1993; Miles and Huberman 1994). In the most robust form of QDA, the documents in the set are decomposed to their smallest unit of analysis and a series of codes are applied to the units by several independent coders, with the coding then compared across coders to ensure reliability in interpretation of the document set and applied coding scheme (Haug, MacEachren, and Hardisty 2001).

Transcription of the interview recordings was completed using the Transana QDA software and then unitized at the statement level in Microsoft Excel for completion of *margin coding*, or the marking of any units that are representative of one or several established codes (Bertrand, Brown, and Ward 1992). The above background review was used to develop a 14-part coding scheme with five higher-level categories relating to each of the five fundamental questions facing a science of cartographic interaction; Table 7 provides definitions of each of the 14 codes and the six higher-level categories. Margin coding was completed by the principal investigator on all 21 transcripts using the 14-part coding scheme; Table 8 lists the frequency of codes across the 21 transcripts. A total of 1413 codes were applied to the 21 transcripts, an average of 67.3 codes per transcript.

Table 7. Coding scheme applied for qualitative data analysis of the cartographic interaction interviews

ID	Name	Definition
What: statements indicating the meaning of cartographic interaction and the scope it covers		
what1	Cartographic interaction	A characteristic or example of cartographic interaction and interactive maps
what2	Not cartographic interaction	A characteristic or example of a non-interactive map, defining cartographic interaction by what it is not
Why: statements indicating the purpose of cartographic interaction and the value it provides		
why1	Exploration	The use of cartographic interaction to support exploration
why2	Analysis	The use of cartographic interaction to support analysis
why3	Synthesis	The use of cartographic interaction to support synthesis
why4	Presentation	The use of cartographic interaction to support presentation
When: statements indicating the appropriate level of cartographic interaction		
when1	Interaction flexibility	The need to increase the amount or freedom of the cartographic interaction provided
when2	Interaction constraint	The need to constrain the amount or freedom of the cartographic interaction provided
Who: statements indicating the impact of the user on cartographic interaction		
who1	Ability	The impact of user ability (i.e., perception, cognition, and motor skills) on cartographic interaction
who2	Expertise	The impact of user expertise (i.e., education, experience, and familiarity) on cartographic interaction
who3	Motivation	The impact of user motivation (i.e., interest and need) on cartographic interaction
Where: statements indicating the impact of technology on the cartographic interaction		
where1	Input devices	The impact of the available input devices on cartographic interaction
where2	Bandwidth and processing	The impact of bandwidth and processing power on cartographic interaction
where3	Display devices	The impact of the display capabilities on cartographic interaction

Table 8. Frequency of codes (sum and average per participant) applied for qualitative data analysis of the cartographic interaction interviews

ID	EMG (4)		ENV (2)		EPI (4)		HIS (2)		INT (3)		NEW (3)		RES (3)		ALL	
	Sum	Avg.	Sum	Avg.	Sum	Avg.	Sum	Avg.	Sum	Avg.	Sum	Avg.	Sum	Avg.	Sum	Avg.
What?	*32*	*8.0*	*25*	*12.5*	*77*	*19.3*	*25*	*12.5*	*64*	*21.3*	*69*	*23.0*	*21*	*7.0*	*313*	*14.9*
what1	20	5.0	21	10.5	54	13.5	19	9.5	47	15.7	40	13.3	15	5.0	216	10.3
what2	12	3.0	4	2.0	23	5.8	6	3.0	17	5.7	29	9.7	6	2.0	97	4.6
Why?	*72*	*18.0*	*39*	*19.5*	*106*	*26.5*	*36*	*18.0*	*69*	*23.0*	*99*	*33.0*	*102*	*34.0*	*523*	*24.9*
why1	5	1.3	5	2.5	17	4.3	12	6.0	7	2.3	28	9.3	13	4.3	87	4.1
why2	26	6.5	13	6.5	60	15.0	15	7.5	30	10.0	12	4.0	33	11.0	189	9.0
why3	6	1.5	1	0.5	6	1.5	4	2.0	9	3.0	5	1.7	8	2.7	39	1.9
why4	35	8.8	20	10.0	23	5.8	5	2.5	23	7.7	54	18.0	48	16.0	208	9.9
When?	*29*	*7.3*	*31*	*15.5*	*41*	*10.3*	*14*	*7.0*	*37*	*12.3*	*59*	*19.7*	*51*	*17.0*	*262*	*12.5*
when1	19	4.8	19	9.5	29	7.3	13	6.5	25	8.3	33	11.0	33	11.0	171	8.1
when2	10	2.5	12	6.0	12	3.0	1	0.5	12	4.0	26	8.7	18	6.0	91	4.3
Who?	*17*	*4.3*	*12*	*6.0*	*21*	*5.3*	*9*	*4.5*	*28*	*9.3*	*79*	*26.3*	*41*	*13.7*	*207*	*9.9*
who1	1	0.3	0	0.0	0	0.0	1	0.5	1	0.3	9	3.0	0	0.0	12	0.6
who2	15	3.8	11	5.5	20	5.0	8	4.0	27	9.0	40	13.3	34	11.3	155	7.4
who3	1	0.3	1	0.5	1	0.3	0	0.0	0	0.0	30	10.0	7	2.3	40	1.9
Where?	*29*	*7.3*	*1*	*0.5*	*7*	*1.8*	*5*	*2.5*	*19*	*6.3*	*14*	*4.7*	*13*	*4.3*	*88*	*4.2*
where1	7	1.8	1	0.5	0	0.0	1	0.5	1	0.3	6	2.0	0	0.0	16	0.8
where2	13	3.3	0	0.0	7	1.8	3	1.5	14	4.7	6	2.0	11	3.7	54	2.6
where3	9	2.3	0	0.0	0	0.0	1	0.5	4	1.3	2	0.7	2	0.7	18	0.9
Total	*179*	*44.8*	*108*	*54.0*	*252*	*63.0*	*89*	*44.5*	*217*	*72.3*	*320*	*106.7*	*228*	*76.0*	*1413*	*67.3*

EMG = emergency response and crisis management; ENV = environmental science and human-environment geography; EPI = epidemiology and public health; HIS = history and historical geography; INT = intelligence analysis; NEW = news and new media; RES = resource management.

Two coders with training in interactive cartography and geovisualization were hired to independently apply the same 14-part coding scheme used in the initial coding, with code reliability assessed using the inter-rater reliability score described by A.C. Robinson (2008). A preliminary draft of the Roth (2013b) literature review on cartographic interaction was given to the independent coders as training notes on each of the codes; review of these notes was followed by a 60-minute training session before coding. The two coders achieved inter-coder reliability scores of 90.7% and 90.2%, indicating a high degree of reliability in the interpretation and application of the coding scheme, particularly considering the large total number of codes applied across the 21 transcripts. Upon completion of coding, statements were sorted into a set of spreadsheets by code and summarized using the synoptic-style reporting described by Monmonier and Gluck (1994) and Roth (2009b), which uses anecdotes and quotes offered by individual participants to express and enrich key patterns found when analysing the codes in aggregate form. The following section provides a summary of the interview results, organized by each of the five assessed questions facing a science of cartographic interaction.

Results and Discussion: Current Trends

WHAT IS CARTOGRAPHIC INTERACTION?

Two codes were included under the *what?* category, the first indicating a characteristic or example of cartographic interaction (*what1*) and the second indicating a characteristic or example that is not cartographic interaction (*what2*). Overall, participants described what cartographic interaction is (average of 10.3 statements per participant) more often than what it is not (average of 4.6).

When asked to provide a general definition of cartographic interaction, many participants emphasized the ability to "manipulate" a cartographic representation. One participant stated that "cartographic interaction is the ability to change [the map]," while another participant defined cartographic interaction as the ability "to manipulate the map [...] not permanently, but temporarily to meet your needs." No participant explicitly described cartographic interaction as a conversation or a dialogue between a user and an interface, as presented by Norman (1988), indicating that the distinction between interactions and interfaces is not apparent to, or not relevant to, the user. Several participants acknowledged the importance of the

user's goals and objectives in the cartographic interaction, with one participant stating that cartographic interaction allows users "to ask a relevant question for themselves" and a second participant defining cartographic interaction as a way to "answer questions before you ask them"; both definitions align more closely with UX design than UI design. Interestingly, all participants defined cartographic interaction within the context of a digital environment, even when prompted to consider whether interactions with paper maps should be included within the scope of cartographic interaction.

A subset of participants indicated that the immediacy of system response matters, stating that interaction requires "instant modification" or that interaction should result in "immediate changes on the fly." One participant bounded the time for completing the cartographic interaction, stating that "a good interactive map would only take seconds" to update the display. Although there was general agreement that "the more time it takes between map updates, the less interactive it becomes," most participants did not believe that there is a hard constraint on system response time for a map to be considered "interactive." One participant identified the USGS National Map as an example of an interactive web map that rarely responds within the two-second time frame because of the large data volume included in the system, stating that "sometimes you ask it to do something and it takes a minute or two, but that's still an interactive map to me." A second participant stated that it is still a cartographic interaction even if the system takes a month or year to respond, but that it is just "a less satisfying interaction," potentially indicating that response time is a key component of a positive user experience. It is important to note that interaction time was discussed not just in terms of the immediacy of the system response but also in terms of the speed with which users can achieve their goals and objectives. One participant stated that the benefit of cartographic interaction "is coming to a decision point faster" and went on to say that "you can do [a task] faster if you *aren't* doing it with your eyes, visually inspecting the map." Thus, the utility of cartographic interaction may be a reduced reliance on the map itself.

Participants were split with regard to the inclusion of map-based systems as cartographic interfaces. This was most evident in discussion of the three commonly identified map-based systems listed in Table 5: Esri's ArcMap, Google Maps, and Google Earth. ArcMap supported the work of 15 of the 21 participants interviewed. While all participants agreed that ArcMap enables cartographic interaction, many participants also categorized ArcMap (i.e., one example of a map-based system) as a cartographic interface when explicitly questioned. However, several participants made a clear distinction between ArcMap itself and the cartographic products created using the system. One participant stated, "It is certainly interactive [...] but not in the spirit of interactive maps," while another participant stated, "The product you produce [with ArcMap] is an interactive map" but indicated that ArcMap is not a cartographic interface itself.

There was similar disagreement over the two products from Google. Google Maps supported the work of 13 of the 21 participants, while Google Earth supported the work of 9 of the 21 participants. Proponents of Google Maps and Google Earth as cartographic interfaces noted that "you can always enter something [into Google Maps and Google Earth] and it will modify the map immediately" and that "you are able to view the data in different ways." However, several participants also enforced the aforementioned distinction between the overall system and products of the system. One participant stated, "Google Maps by itself is not an interactive map," and a second participant stated that "if you had a .kml [...] and you load it into Google Earth, that's an interactive map; Google Earth is not an interactive map." Such an interpretation possibly suggests that a "slippy" web map service is not necessarily a cartographic interface until mashed up with additional information by the user. Interestingly, the strongest arguments against considering web map services as cartographic interfaces came from the three participants in the domain of news and new media, the subset of participants who most commonly worked with web maps. It remained unclear, despite probing, whether the distinction among one-off interactive maps, map-based systems, and web map services impacts interaction in any way.

Interestingly, several participants considered cartographic interaction as specific to the direct manipulation interface style. For instance, one participant divided ArcMap into components that provide cartographic interaction and those that do not, stating that "only the map view is interactive." A second participant stated that it matters if "you are going through the map interface or the controls outside it," arguing that it is interaction with the map itself that makes the interaction "cartographic." The majority of participants did not agree that the direct manipulation interface style was required for cartographic interaction. One participant stated that "the map itself does not have to be interactive as long as there is a system around it that allows you to manipulate it." A second participant stated, "You also can use dialog boxes and buttons and menus to [interact] with the map," identifying direct manipulation of non-map widgets as well as menu selection and form fill-in as potential examples of cartographic interaction. The most poignant example of cartographic interaction provided through an interface style other than direct manipulation came from the pair of participants in the domain of epidemiology and public health, who rely primarily on the Statistical Analysis System (SAS) to com-

plete their work (Table 5). SAS uses a powerful command language interface style to provide sophisticated spatial analysis and modelling. Although the output maps generated by SAS are static images, the act of generating the maps was considered "an interactive process." One SAS user stated that it is an interactive map "because I tell SAS what I need and it gives me the maps I need," while the second stated that "I am writing the code on the fly [...] the code is an interface." Such a perspective appropriately includes the command language interface style as one solution for supporting cartographic interaction.

The interviews exposed a fifth, previously undiscussed issue regarding the *what?* question that relates to the association of cartographic interaction and real-time data feeds, such as GeoRSS. The importance of live data on cartographic interaction was emphasized by a large subset of participants. One participant stated that "having live data is a key characteristic of interactive maps," while another stated that having live data behind the map is the "main property I think of when I think of an interactive map"; this second participant went on to qualify that the data do not have to be live for the map to be interactive, but "it makes it more interactive." The strongest stance was taken by a third participant, who emphasized that "the data has to be live [...] the link between the web map and the database cannot be broken." Such a position confuses dynamism related to system changes, such as data updates, with dynamism related to user input, defined as cartographic interaction here.

One issue related to the *what?* question of cartographic interaction on which participants generally agreed is that cartographic interaction should not be conceptualized as a binary between "interactive" and "non-interactive" but rather as a continuum from low interactivity to high interactivity. Conceptualizing cartographic interaction as a continuum matches MacEachren's (1994) inclusion of human-map interaction as an axis in the Cartography^3 framework. Participants described such a continuum as "a range of interactivity," "different levels of interaction," or "shades of gray." Primary considerations for this continuum are the number of interactions implemented in a cartographic interface and the freedom in performing each provided interaction, following the definition of interface complexity provided above; as one participant stated, "the higher level of interaction goes along with the ability to choose and select more things." As described above, additional qualities that influence the perceived level of cartographic interaction include the immediacy of the map response to the cartographic interaction, the direct manipulation interface style, and live underlying geographic information. The cartographic interaction continuum is explored further when summarizing statements regarding the *when?* category.

WHY PROVIDE CARTOGRAPHIC INTERACTION?

Four codes were included under the *why?* category to identify statements related to each of DiBiase's (1990) four stages of science: (1) exploration (*why1*), (2) analysis (*why2*), (3) synthesis (*why3*), and (4) presentation (*why4*). Participants engaged more with the *why?* question than any other question, producing a total of 523 unique statements (average = 24.9 statements per participant). Participants most commonly discussed the stages of presentation (average = 9.9) and analysis (average = 9). The goal of exploration (average = 4) was discussed less than half as often as analysis or presentation, a somewhat surprising finding given the emphasis on supplying high levels of cartographic interaction in exploratory geovisualization. The synthesis stage (average = 1.9) was the least frequently discussed of DiBiase's four stages of science.

The value of cartographic interaction for exploration was acknowledged only by several participants. One participant stated that cartographic interaction helps to "see patterns [that] lead us to new questions"; a second offered that "for me, maps aren't the final answer, [they are] a starting point"; and a third suggested that interactive maps are useful because "you can use them as a sand table to play out scenarios." Aside from several isolated statements, questioning on exploration did not yield the expected depth of discussion, with most participants stating that exploration was not a primary goal of their daily work. Many participant responses included the general terms "get a feel for" or "familiarize yourself," indicating that exploration may be an informal preparation stage of their work that is completed quickly before continuing on to other core tasks. Only participants from the domain of epidemiology and public health evoked the term "hypothesis."

One possible explanation for this gap between the expected application of cartographic interaction for exploration, as drawn from scholarly arguments on exploratory geovisualization, and the actual real-world practice is that all interview participants were experts in their domain, meaning they were very familiar with the phenomenon under investigation and efficient at their work tasks. In support of this explanation, one participant asserted that cartographic interfaces mostly are used "for things I already have a clear idea about," while a second suggested that the use of cartographic interaction for exploration "is better when whoever is using it doesn't know what they want right away." Such an interpretation brings into question the contemporary appropriateness of the "user" as an axis in the Cartography^3 framework, as successful applications of cartographic interaction for the exploration stage may require less user expertise than applications for the analysis stage (as well as synthesis and presentation).

A second possible explanation for the relatively infrequent application of cartographic interaction for exploration may relate to the difference between expertise with interactive maps and expertise in the application domain; I have found this distinction to be important in past research using static maps (Roth 2009a). Expertise with cartographic interfaces may be more important for the exploration stage because of the expected increased flexibility in manipulating the map, while expertise in the application domain may be more important for the analysis stage because of the improved understanding of the mapped phenomenon that is needed for interactive application and interpretation of sophisticated spatial models and statistics.

A third, equally plausible explanation for the discrepancy between science and practice may be that the exploration stage is harder to formalize than others given its open-ended, highly iterative nature and therefore is simply more difficult to articulate in an interview format. It should be noted that a difference was not observed between scientists and non-scientists in the depth of discussion concerning exploration, an important consideration given that DiBiase's (1990) swoopy framework is specific to the mission of science. The average number of statements regarding exploration was slightly smaller for the five participants who had earned an MD or PhD (average = 3.4) – and thus those participants who had worked within the mission of science in the past, if not still doing so currently – than for the remaining 16 participants, who had not earned an MD or PhD (average = 4.4).

Participants engaged more heavily with questions regarding the analysis stage. Many participants indicated that it was more important in their work to answer questions than to generate them. One participant stated, "I think the question is why you are using the interactive map; I think we definitely have some research questions that we want to answer, where we have something that we want to find from the map." Similarly, another participant stated that submitting spatial queries through cartographic interaction "gets most questions answered immediately" and went on to say that "live interactive mapping quickens the analytical process." Much of the discussion on the analysis stage was generated when geo-processing or spatial analysis algorithms were applied using Esri's ArcMap or similar GIS tools during the demonstration portion of the interview; here, the cartographic interactions supported by ArcMap and other map GUIs (graphical user interfaces) were used both to inform the parameters of the applied computational procedures and to interpret the output of these procedures. Participants from the domains of emergency response and crisis management and of epidemiology and public health also discussed examples of using cartographic interaction to configure, monitor, and interpret spatial models, an interesting finding given the focus on interactive steering of models and simulations in the original report by McCormick and others (1987) on visualization in scientific computing. Yet multiple participants revealed that the links between cartographic interfaces and geo-processing, spatial modelling, or spatial statistics did not yet sufficiently meet their needs. One participant suggested, "In my opinion, I think if we can combine or incorporate additional statistical analysis methods into our interactive maps, that would be very helpful," while another stated that "it would be nice to have an interface between a map and our model." Tight integration between visual and computation methods is a primary goal of visual analytics (Thomas and others 2005); the general emphasis on analysis over exploration across the interviews provides support for the transition from isolated research on geovisualization to integrated research on geovisual analysis.

Discussion concerning the synthesis stage was minimal. The discussion on synthesis that did occur primarily was related to Web 2.0 technologies, particularly the gathering and integration of multiple data feeds and web services. Several participants indicated the potential of using mashups to combine disparate information, with one participant stating that it was useful to "take two disparate web services and combine them in a new way" and a second stating that "we'll get all these data feeds together [...] to load disparate information." Among the interactive maps and map-based systems demonstrated, one was a web geoportal that primarily supported synthesis. The user of this geoportal described it as being extremely well received, stating that "people come to this tool to get the big picture because it incorporated all of these data feeds; it was a Web 2.0 capability and no one had anything like that."

Interestingly, participants most frequently discussed the value of cartographic interaction in support of presentation, which does not follow the Cartography^3 framework but perhaps is not surprising given the ubiquity of online interactive mapping services primarily leveraged to disseminate geographic information. A key theme discussed across all domains was the potential of using online interactive mapping services to "share mission-critical information" with decision makers, a finding that supports MacEachren and others' (2004) renaming of the user–task axis of Cartography^3 as "knowledge construction" (exploration and analysis) versus "information sharing" (presentation). As one participant explained, "With mashup technology, the bar is being lowered so that more people can develop their own mapping application [...] to promote data-driven decision making." Participants identified cartographic interaction as particularly valuable for presentation of geographic information that is highly dynamic; one participant stated that "you can use [cartographic interaction] for decision making [...]

particularly for dynamic incidents." The presentation of real-time information for situational awareness and decision making perhaps explains why many participants emphasized live data as an important attribute of cartographic interaction when discussing the *what?* question. In several cases, cartographic interaction was applied for geo-collaborative decision making; as one participant stated, "folks call in [to an Internet meeting] from different parts of the country and use the interactive tool to view the incident [...] and collaboratively make decisions." Aside from decision making, participants identified several other advantages of cartographic interaction for the presentation stage, including "sharing [of] important information," "report generation and documentation," "visual storytelling," and "quality control." The latter comment suggests the potential for leveraging cartographic interaction to cope with the uncertainties inherent in all geographic information (MacEachren and others 2012). As one participant explained, "The number one advantage [of cartographic interaction] is getting good data [...] we are having a paradigm shift where people are saying put [the map-based system] out there because that will shame people essentially to correct their data, because the whole organization has visibility to it."

WHEN SHOULD CARTOGRAPHIC INTERACTION BE PROVIDED?

Two codes were included under the *when?* category to identify characteristics or examples of when the interface complexity should be increased (*when1*) and characteristics or examples of when the interface complexity should be constrained (*when2*), including when a static map should be used in place of an interactive one. Participants were approximately twice as likely to describe situations requiring additional flexibility in the supplied cartographic interaction (average = 8.1 statements per participant) than situations requiring additional constraint in the supplied cartographic interaction (average = 4.3).

Overall, participants advocated for an increased level of interface complexity, both in the number of unique interactions and in the freedom in performing each interaction. One participant asserted, "Generally, the more functionality, the better," while another stated, "From what I've seen of the R&D world, we are going to keep pushing that high interactivity [...] it is a goal to keep trying to do more and better." Further, most participants agreed that increased levels of interface complexity act to increase their individual productivity and decrease their perceived workload. One participant stated, "I'm starting to view interaction as production [...] because it saves time and money," while a second stated, "An interactive map saves a lot of space and time, it can reduce my workload and people can learn some information quickly." This finding is interesting given the above review of the productivity paradox and evidence that interface constraint may improve productivity. This general agreement on the positive impact on productivity that results from increased levels of cartographic interaction is explained in part by the participants' expertise with interactive mapping and familiarity with their work tasks. However, this agreement provides initial evidence that the productivity paradox may no longer be observed regarding cartographic interaction, perhaps because of the pervasiveness of computing technology and digital mapping in contemporary society.

When asked to explain why provision of increased interface complexity is seen as a wholesale benefit, several interesting responses were elicited from participants in the domain of news and new media. This subset of participants expressed that to do their work well, it was essential to understand the degree to which emerging technologies, such as interactive mapping, can be transitioned from specialist application to popular consumption. Thus, these participants were deeply interested in the *when?* question, particularly in identifying the level of interface complexity that promotes the most interest in the mapped topic. Arguing for increased levels of cartographic interaction, one participant stated, "I see people's reactions when they use interactive maps; they immediately engage with it, there's something that we love about the feedback, about clicking on a map, about getting that sense of ownership over the map itself or the process." This participant went on to say that "they get this sense of being involved with the process of [making] the map itself." This sense of ownership over the map, and the empowerment and engagement it engenders, provides further evidence that productivity should not be the only consideration when designing a cartographic interface. Another participant stated that it is not enough just to provide high levels of interface complexity to users but that cartographic interfaces need to go beyond the "out-of-the-box" or "cookie-cutter" designs common to web map mashups. This participant asserted, "There's a certain look and feel in interaction that's being established by non-cartographers; there's something being lost with the emotional impact, the affective nature, of maps when every map out there starts to look and feel the same." This participant went on to say that "we're losing the nuance of the artistic side of cartography" and encouraged exploration of alternative cartographic interactions and cartographic interface styles. This discussion relates to the importance of avoiding the *lorem ipsum map*, or the inappropriate use of a generic interface shell that improperly relates to the mapped phenomenon (Roth and Harrower 2008), and connects to broader research on aesthetics in cartography (e.g., Kent 2005).

Participants did provide several reasons for constraining cartographic interaction despite broadly arguing for increased flexibility. Institutional limitations were identified as the primary reason why higher levels of interface complexity are not encouraged. A first institutional concern is the lack of available resources for modernizing mapping

practices by either acquiring licenses for commercial map-based systems or developing custom in-house products. One participant stated that "it's just a time investment we often don't have," while a second stated that use of "the more sophisticated [interactive maps] tend to be at places that have money." Several participants identified institutional perception as a secondary concern to the institutional limits on time and money. One participant stated that "I think there's probably a kind of stigma with [cartographic interfaces], it's perceived as complicated to do, maybe difficult to use products like that" and went on to suggest that "it's just kind of a resistance to change; we've been using static maps for a long time, they're used to looking at maps in that format, and it's hard to change perception." This particularly is a concern given the quickly evolving nature of computing technology; as one participant stated, "We have fixed-price projects, and if something wasn't included in the original scope, we can't include it." Therefore, a new cartographic interface design and development project may be dated before it is completed, a truism that acts to decrease institutional-level interest in chasing emerging mapping technologies. Effective solutions for overcoming institutional limitations were not offered when probed. Aside from institutional limitations, several participants discussed the practical trade-off between usability and utility that occurs when designing and developing cartographic interfaces. Several participants were able to offer examples when cartographic interaction was limited to make the interface transparently usable for a target user group, although the discussion of these examples was unexpectedly abbreviated; the lack of depth to the discussion on the usability-utility trade-off likely is a result of recruiting cartographic interaction users rather than cartographic interaction designers and developers.

WHO SHOULD BE PROVIDED WITH CARTOGRAPHIC INTERACTION?

Three codes were included under the *who?* category relating to each of the three user characteristics summarized above. The first code indicates the impact of user ability, such as perception, cognition, and motor skills (*who1*), on cartographic interaction; the second code indicates the impact of user expertise, such as education, experience, and familiarity (*who2*); and the final code indicates the impact of user motivation, such as interest and need (*who3*). The majority of participant discussion related to user expertise (average = 7.4 statements per participant). There was minimal discussion across participants on the impact of user motivation (average = 1.9) and user ability (average = 0.6).

The *who1* code was the least frequently applied code of the 14-part scheme. Overall, only 12 statements regarding user ability were offered, the majority (9 of 12) coming from participants in the domain of news and new media. One participant indicated that the user's "spatial awareness" is important for successful cartographic interaction, a user characteristic related to Golledge's (1992) spatial ability. Several participants indicated that age plays an important role in design of cartographic interfaces, but did not clarify which user abilities are most impacted across age and did not suggest how the interface complexity should be revised given variation in age.

Participants instead focused their attention on the topic of user expertise. All participants agreed that increased user expertise requires increased interface complexity, as suggested by the Cartography[3] framework. However, there was disagreement on which of the possible measures of expertise mattered more when determining the appropriate interface complexity: user education or user experience. To some participants, user education was essential to successful cartographic interaction. As one participant stated, "it is a struggle we have now, maintaining the skills of our user base," lamenting that often "there's a resistance to learn new things, because it's not what people are used to." Therefore, there may be an individual, user-based resistance to increased interface complexity that parallels the broader institutional resistance discussed above. Advocates of the importance of education were comprehensive in their listing of educational materials and activities; examples included educational artefacts like "code documentation," "guidebooks," "map brewers and wizards," "training exercises," "user examples," and "web resources," as well as educational communications like "conferences," "discussion forums," "expert GIS users on staff," "formal coursework," and a "training workshop."

However, other participants noted that it was experience, and not education, through which they had gained their expertise, stating that they were "self-taught" or that they had received "on-the-job training." This subset of participants suggested that the education they did receive did not prepare them to use cartographic interfaces appropriately. One participant stated that "the person who goes through [the training] has the leg up on everyone else, probably, but for me the more important training is that of being out there and doing it," while another stated, "I think most of the things I've learned have been as a result of working alongside people [...] formal coursework, all it does is build a vocabulary around things that you probably already understand fairly well." The lack of agreement across participants and domains reveals that background on both education and experience should be collected when administering scientific experiments on cartographic interaction.

Finally, some participants noted that user familiarity with cartographic interfaces has increased to a point where extensive education or experience is not needed in some contexts. This again is perhaps a result of the pervasiveness of computing technology and digital mapping in contemporary society. As one participant noted, "we're at the point where [our group] can use geospatial tools

without much help; it's not a specialty field anymore." This sentiment potentially challenges the positive relationship between expertise and interface complexity assumed in the Cartography[3] framework, and instead falls in line with calls to put powerful interactive mapping tools into the hands of the general public (e.g., Rød, Ormeling, and van Elzakker 2001; Wood 2003; Turner 2006).

Despite the overall small amount of discussion, several important insights were revealed about the impact of user motivation on cartographic interaction. Three-quarters (30 of 40) of the statements regarding user motivation came from the domain of news and new media, the only domain exhibiting wide variation in user motivation because of the application of cartographic interaction for entertainment-related tasks as well as work-related tasks. One participant from this domain reported that "there are two types of people [that use interactive news graphics], there's someone that wants their hand held, and someone that wants to dive right in," and went on to describe these two types of users as "Bart Simpson people" (unmotivated) and "Lisa Simpson people" (motivated), informal terminology used in data journalism. Bart Simpson people are "more organic" and desire interactive maps "that have a clear entry point into the graphic" and that let them "quickly come away with some [message]." In contrast, Lisa Simpson people are "more quantitative" and will want to "dive right into the map" and "get into the weeds." The challenge, at least in news and new media, is to design an interactive map that supports both motivation levels, a goal that relates to scholarly arguments for multi-layer cartographic interfaces (Kang, Plaisant, and Shneiderman 2003) that exhibit a cascading information-to-interface ratio (Roth and Harrower 2008). It is important to note that several participants outside of news and new media described the use of incentives to improve user motivation and promote buy-in; one participant recommended the release of "little teasers" to generate interest before the complete release of a cartographic interface, while a second participant commended the administration of "contests" that "offer a cash prize" for the best application of the cartographic interface.

Finally, discussion about the *who?* question included several responses about the infrequent application of a user-centred approach for design and development of cartographic interfaces. Across domains, participants indicated that what may be described as a user-centred approach was not common; as one participant bluntly stated, "it is not super popular." A second participant stated that "there's a big gap, in that the people who are designing this stuff are not talking [to] or getting a feeling for the people who use it," later stating that "you have to design products to meet [our] needs, but no one has done a good needs assessment." A third participant went as far as saying that the lack of continual user input throughout design and development is "the biggest problem" in the use of cartographic interaction; this participant went on to say that "it's hard to design something if you don't know your audience." When probed, all participants stated that they wanted greater input into the design and development of the cartographic interfaces that they use to support their work.

WHERE SHOULD CARTOGRAPHIC INTERACTION BE PROVIDED?

Three codes were included under the *where?* category, relating to each of the three technological components described above: the first code indicates the impact of the available input devices on cartographic interaction (*where1*); the second code indicates the impact of bandwidth and processing power, together restricting interaction speed (*where2*); and the third code indicates the impact of the display capabilities (*where3*). The *where?* question was the least frequently discussed of the five research questions facing a science of cartographic interaction (average = only 4.2 statements per participant). This in part is explained by emphasizing the comparison between science and practice in the interview protocol, rather than that between technology and practice. Participants engaged with issues related to bandwidth and processing power most frequently (average = 2.6), followed by issues related to the display capabilities (average = 0.9) and input devices (average = 0.8).

The small amount of discussion on user input focused on pointing devices. All cartographic interface demonstrations were completed primarily with a mouse or touchpad, excepting the demonstration of the aforementioned SAS, which relied heavily on keyboard input. There was punctuated discussion of technologies beyond the standard pointing and keying devices, particularly the potential of touchscreens. A pair of participants from the domain of emergency response and crisis management reported that their agency was switching to tablet laptops for in-vehicle use by first responders. In both cases, the participants' in-house systems were modified for the touchscreen input device to account for the reduced precision in pointing, particularly moving toward "bigger buttons" so that users can "hit them easily." The pair of participants indicated that the touchscreen was well received by users; one participant stated that "it is convincing a lot of these guys that GIS is a good thing." Several participants discussed the potential of speech input, or a "voice control map," but no participant was currently using such an input device. There also were several references to the use of large-size scanners, an indication that many firms are still in the process of digitizing their collections of geographic information.

Participants identified interaction speed as the most important technology issue facing a science of cartographic interaction. As one participant stated, "speed is [of] the utmost importance." Interestingly, participants were more

concerned with bandwidth than processing power. While participants offered isolated examples of poor processing performance, most participants perceived modern processing capabilities to be sufficient. One participant stated, "You can run [the cartographic interface] in real time or faster," while another said that "it was computationally intensive in the earlier days [...] but now it moves forty times faster." This finding may be an indication that the supposed catch-22 of offsetting increases in processing and data volume is not occurring, or is not perceived to be occurring, and that processing power has improved enough to handle the largest spatial data sets used in practice. Alternatively, it could be that users are simply not employing cartographic interfaces for the largest of spatial data sets because they have learned that their computing devices cannot handle them; thus, users are getting better at working around known limitations in processing.

Participants instead expressed concern with Internet bandwidth, an indication of the growing influence of web-based mapping applications. One participant stated that "a network may not support geospatial work yet [because] it's a load on the bandwidth," while a second stated that the bandwidth is "often so poor [...] that the utility of using a [web-based] application in the field isn't really there yet." Further, many participants were hesitant to move their work online because of general problems with network connectivity, despite the promise of combining cartographic interaction and cloud computing. One participant stated, "I wouldn't want to take the computing I do locally and move it entirely to the web because then I'm dependent on an Internet connection," while a second participant asserted, "We don't work off the server [...] because normally we lose connectivity during emergencies."

Interestingly, only participants from the domains of emergency response and crisis management (with regard to the touchscreen implementation described above) and news and new media were concerned with cartographic interaction on mobile devices. Such a finding suggests that we are still at the dawn of the mobile revolution and that a great amount of work remains to be done to realize the potential of mobile cartography. Multiple participants voiced concerns over network security, providing justification for why their expert-use cartographic interfaces have not been moved online or onto mobile devices.

Of the nine characteristics of display devices described earlier in this article, participants focused on screen size. Participants from the domains of emergency response and crisis management and intelligence analysis described wall-size digital displays available to support group discussion and decision making. Cartographic interaction with these displays was performed by a single user at a central terminal (i.e., no touchscreen or speech/gesture recognition). These participants indicated that these wall-size displays were useful for geo-collaborative purposes but that most emergency operations centres "don't really have the luxury of a huge video wall." No statements were offered about the other eight characteristics of displays.

Outlook: Future Opportunities

In this article I report on a semi-structured interview study designed to illuminate current trends in UI/UX design for cartography, as identified by expert geospatial professionals working in the field. Interview questions were informed by a prior literature review on interaction design spanning the fields of cartography, human-computer interaction, information visualization, usability engineering, and visual analytics (Roth 2013b), allowing for comparison of the current states of science and practice on cartographic interaction. The interview study therefore provides a snapshot of UI/UX design for cartography as approached today. Looking to the future, there are several emerging developments that are likely to force us to repurpose or reimagine cartographic interaction design:

1. *UX Design as Cartography*: Arguably, cartographers always have been UX designers, given the traditional goal of communicating a message to a targeted audience. As "map readers" become "map users" through cartographic interaction, understanding and improving the user experience has become paramount to cartography (Muehlenhaus 2013). Further, cartographers are particularly well positioned to serve as UX designers on larger GIS projects, bringing insights about both representation design and interaction design to improve GIS software and analytical products. However, it was clear from the interviews that users want to be more involved in the design and development process, suggesting that we may be privileging UI design over UX design across the cartographic community. Moving forward, effort is needed to integrate theoretical principles and practical guidelines from the field of UX design into the cartographic canon. Importantly, cartographers also are likely to be able to contribute to UX design, refocusing UX principles and guidelines for the cartographic context.
2. *Mobile Mapping and Responsive Cartographic Design*: The pervasiveness of mobile devices has presented both opportunities and constraints for cartographic interaction. Given the minimal discussion on mobile mapping elicited from interview participants, however, it is possible that mobile mapping is less relevant for experts compared to novice users, or, more likely, that the full potential of mobile mapping has yet to be realized. To support seamless user experiences across desktop and mobile devices, web designers have moved to the model of *responsive design*, or the development of

multiple layout and style rules that adjust the web page according to the constraints imposed by the display device (Marcotte 2011). The importance of responsive design on mobile devices already has resulted in a rapid technological transition in web mapping away from proprietary plugins unsupported by mobile devices (e.g., Flash Player) and toward open web standards (e.g., HTML, CSS, and JavaScript) (Roth and others 2014). Such technological innovation must be paired with scientific innovation to produce generalizable, software-unspecific guidelines for responsive design in cartography; this includes design recommendations for both cartographic representation and cartographic interaction. Responsive cartographic design – adjusting the cartographic interface according to the user, computing device, and map context – is the true promise of adaptive cartography (Reichenbacher 2003).

3. *Interactive Visual Storytelling in Cartography*: The interview study revealed that cartographic interaction is no longer limited to the goal of exploration and therefore should not be provided only for expert or specialist use as prescribed by the Cartography[3] framework. For explanation, participants cited the general public's increased familiarity with digital interfaces as well as the motivating feeling of empowerment people experience when given control over the map. Interesting research and development on the provision of interactive graphics for the purpose of presentation has been completed under the heading of *visual storytelling* in the fields of data journalism (Cairo 2013) and information visualization (Gershon and Page 2001). While research on rhetoric and storytelling is emerging in cartography, research on interactive mapping for the purpose of presentation is minimal (for an example, see Muehlenhaus 2014). Future work is needed to port design recommendations on interactive visual storytelling from the domains of data journalism and information visualization to the cartographic context, as well as to determine how interactive maps enable a unique form of visual storytelling.
4. *Participatory Mapping and Contributed Geographic Information*: While interactive visual storytelling primarily describes the consumption of content that is carefully designed by the cartographer, cartographic interfaces also can support the authoring of new content by the user. Further, cartographic interaction enables citizens to participate in the mapping process, effectively crowdsourcing maps used for public planning and decision making. Scholars have described such content authored by non-expert citizens, when made publicly available, as *volunteered geographic information* (Goodchild 2007; Elwood 2008) or, more recently, *contributed geographic information* (Harvey 2013; Sack 2013). The interviews revealed concerns about the security and sensitivity of contributed geographic information, ethical concerns that are mirrored in the literature (Wilson 2012). A core issue is the balance of freedom versus constraint when users are authoring content interactively; it remains unclear whether and when users should be prevented from contributing potentially sensitive information. Future research is needed to understand the differential impact of authoring versus consumption on cartographic interaction design, specifically considering the context of crowdsourcing, contributed geographic information, and participatory mapping.
5. *Aesthetics of Cartographic Interface Design*: This article approaches the topic of cartographic interaction design from a primarily discursive or reason-based epistemology, following larger calls to establish a science of interaction across human-computer interaction, information visualization, usability engineering, and visual analytics. That said, cartography is and always will be both art and science. The artistic component of cartography is enjoying a revival within academic cartography, with scholarship emphasizing the importance of aesthetics, emotion, and style to the effectiveness of a map (e.g., Kent 2005; Field and Demaj 2012; Jenny and Buckley 2013). The interview study suggested that the concepts of aesthetics, emotion, and style are as important to cartographic interaction as they are to cartographic representation. Specifically, multiple participants bemoaned the establishment of cartographic interface design conventions that are based on a small subset of recognizable web mapping technologies. Moving forward, additional research is needed to generate and evaluate alternative cartographic interface design styles, as well as to understand the cross-linkages among cartographic interface design aesthetics, user motivation, and cartographic interaction success.

Interaction is too fundamental to modern cartographic design to ignore, both theoretically and practically. An interdisciplinary approach is needed to leverage insights on UI/UX design already established in the fields of human-computer interaction, information visualization, usability engineering, and visual analytics. That said, a targeted research agenda is needed within cartography to understand the uniqueness of the cartographic context, to learn how interactions with *spatial* representations are *special*. The current climate of cartography is overwhelmingly positive, and the future of cartography exceedingly bright given parallel innovations in UX design, responsive

web design, visual storytelling, crowdsourcing, and aesthetics. The topics of interaction and representation should be approached as equals when pursuing cartography's next horizon.

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