Cartographic Interaction: Introduction and Overview

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Synopsis

This entry provides an introduction and overview of cartographic interaction, defined as the modification of a digital cartographic representation in response to user input. The entry begins with a look at the changing nature of the map as a result of the Digital Revolution. I then provide a brief history of geovisualization as a way to emphasize the importance and potential of cartographic interaction. I close outlining the multiple ways that cartographic interaction can be conceptualized, using this as a way to organize the remaining entries on cartographic interaction.

Folks who have inspired much of my thinking on this: Gennady Andrienko, Natalia Andrienko, Remco Chang, Jeremy Crampton, David DiBiase, Jason Dykes, Rob Edsall, Alan MacEachren, Mark Monmonier, Ben Shneiderman, John Stasko

Keywords

cartographic interaction, dynamic cartography, interactive maps, geographic visualization, swoopy, Cartography^3, exploration, discovery, goals, objectives, operators, user inputs, operands

Introduction

What image first comes to mind when asked to think of a map? Do you think of the reference map of the world hanging in your 4th grade social studies classroom? Perhaps you think of the printed road atlas you keep in your car or the tourism brochure you grabbed while on your last vacation. Maybe you enjoy hiking and are familiar with topographic maps or recently purchased a home and had to become all too familiar with parcel maps. If you take the subway into work, then perhaps a linear cartogram comes to mind first. If you are really a map geek like us, you might remember a thematic map portraying statistical data that you saw printed in a textbook or newspaper article.

While you might mention these traditional, static map examples if pressed, it is likely that you also would name examples from a new class of maps born from the availability of cheap personal computing technology and a pervasive digitally-native transfer mechanism (i.e., the Internet). These two developments – popularly referred to as the *Digital Revolution* **[glossary link]** – have turned Cartography on its head, both as a professional practice and as an academic discipline. The trickle down influence of the Digital Revolution over the past 20-25 years acted as the primary impetus for a generation of ground-breaking research and development on animated **[update link]**, multi-scale, on-demand, and real-time maps, all of which were either impossible or prohibitively difficult to create previously. In short, it is the Digital Revolution that is at the heart of Cartography 2.0 **[update link]**.

It can be argued that no single development of the Digital Revolution has had a more transformative impact on the conceptualization, design, and use of maps than the possibility of cartographic interaction. Think again about the map examples that immediately came to mind in the above exercise; it is likely that many of these examples provide digital interaction with the map. Are you an iPhone user? If so, you may have listed the Google Maps web mapping service. Even if you aren't an Apple Zombie, you still may have listed Google Maps or one of the many other web mapping services (e.g., Microsoft Bing Maps, MapQuest, Yahoo! Maps). Own an in-car navigation system? If yes, then you likely listed a GPS-based mapping system from suppliers like Garmin, Magellan, or TomTom. Spend a lot of your time on a university campus? If so, you might have listed your university's interactive campus map. You may have even listed several map-based systems (e.g., ArcMap) that facilitate the creation of maps but are not technically maps themselves.

These interactive examples are a indication of what I think is a shifting conceptualization of the map. In his classic text *How Maps Work*, Alan MacEachren (1995) defined the map using radial categorization (Figure 1a). The complete map space was organized along two axes, termed motivating characteristics: (1) degree of abstraction (image versus diagram) and (2) map scale (atom versus universe). All existing maps can be placed somewhere in this space, with those falling closest to the center of the radial categorization acting as the prototypical example that most quickly comes to mind when thinking of a map. As MacEachren's radial categorization was offered very early in the Digital Revolution, his focus was primarily on categorizing static maps; his selection of degree of abstraction and map space as the primary motivating characteristics are a reflection of this focus.

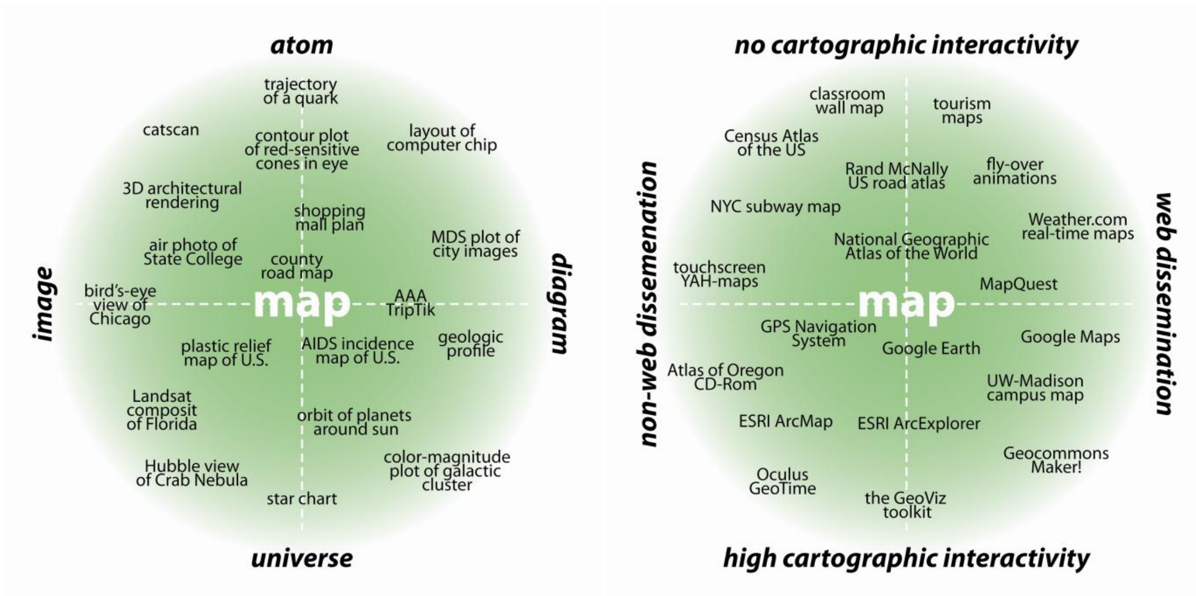

Figure 1: The shifting conceptualization of the map. (a) Defining the map using radial categorization, redrawn from MacEachren (1995: 161), using the motivating characteristics of degree of abstraction and map scale. (b) A radial categorization of 21st century maps, using the motivating characteristics of web dissemination and cartographic interaction. Today's prototypical map is one that provides at least a medium amount of cartographic interaction.

I offer an alternative radial categorization of the map using two different motivating characteristics to better account for the important developments stemming from the Digital Revolution (Figure 1b). The first axis – *web dissemination* – describes the degree to which the map (including all of its contents) is delivered using the Internet. This continuum ranges from maps that are available only in print or on CD-ROM, through maps that must first be obtained offline but stream in data and system updates from the web, through maps that can be downloaded directly from the web but must be used locally, through maps that use the Internet as a platform, allowing for use within a web browser. Method of dissemination is important for radial categorization because it dictates map exposure to the general public, which directly influences the conceptualization of the map. The second axis – *cartographic interaction* – describes the number and complexity of available cartographic interactions. This continuum ranges from static maps with no digital cartographic interaction, through natively static maps that are made available digitally, through natively digital maps with only limited interactivity, to maps and mapping environments that offer a robust suite of cartographic interactions.

Although many conclusions can be inferred from the Figure 1 comparison, nothing is more evident than the growing centrality of at least a medium degree of cartographic interaction in the conceptualization of the map – it can be expected that this will become only truer as the central prototype continues to shift. Thus, a greater emphasis within Cartography in needed moving forward in order to better understanding the nature of cartographic interactions and how these interactions can be best implemented by interfaces.

A Brief History Lesson

Research on cartographic interaction is one that is very closely tied to *geographic visualization* **[glossary link]** (or geovisualization), a research effort focused upon the design and use of maps for exploration and discovery. It is therefore convenient to explain the importance of cartographic interaction through a brief history of geovisualization. From its inception, geovisualization drew primarily from three fields: (1) Cartography, (2) Exploratory Data Analysis **[glossary link]** (EDA), and (3) Visualization in Scientific Computing **[glossary link]** (ViSC). The range of influence today is no doubt much broader.

The primary discipline of influence on geovisualization is Cartography, and more broadly the range of abstraction and representation techniques that fall under the mapping sciences umbrella. Early scholars viewed geovisualization as a new perspective on Cartography to balance the then dominant, but limited, *communication model* **[glossary link]** (i.e., the map as a pipeline through which a message can be delivered perfectly from mapmaker to map reader - more on this below). Therefore, geovisualization should be seen as a sub-thrust of research within Cartography rather than a wholly separate area of study; the inherent interdisciplinary nature of geovisualization and its lack of a focus on 'traditional' cartographic topics has made this connect less obvious today.

The second influence on geovisualization was the rise of Exploratory Data Analysis **[glossary link]** (EDA) within statistics. Traditional statistical approaches viewed the application of statistics as a confirmatory step in the scientific process. This means that statistics were applied only as the final step in analysis in order to confirm or reject a previously worked out hypothesis. Statistics were applied only to arrive at a final answer to a research question. Statistician John Tukey realized, however, that the it is often much more difficult to identify a question that needs answering than actually finding the answer. To this end, Tukey developed a set of statistical and graphical techniques in the 1970s and 1980s to assist in the exploration of a dataset in order to reveal facts and patterns that were previously unknown, leading to viable research questions. This exploratory approach became known as *exploratory data analysis* **[glossary link]**; the geographic equivalent is commonly referred to as exploratory spatial data analysis (ESDA).

The third early influence on geovisualization was the call in the mid-1980s for research on the visualization of scientific computing **[glossary link]** (ViSC). In the highly influential National Science Foundation report (McCormick et al. 1987: 63), visualization was promoted as a tool for assisting scientific research, providing researchers with "a method for seeing the unseen" to the end of developing insight. ViSC was more about simply representing data graphically (something that cartographers had been doing for decades). It also called for leveraging the new opportunities made available by the then nascent Digital Revolution, with the ability for scientists to interact with their data seamlessly among the priorities. Thus, ViSC – and the fields of Information Visualization and Visual Analytics that grew in part out of ViSC – always recognized a duality between representation and interaction.

One of the earliest frameworks integrating Cartography, EDA, and ViSC into what would now be called geovisualization was offered by David DiBiase (1990). In his *swoopy* diagram (Figure 2), DiBiase identified four stages of scientific research:

(1) *Exploration* **[glossary link]** - Examining the data from multiple perspectives to identify research questions and to generate research hypotheses

(2) *Confirmation* **[glossary link]** - Formally testing hypotheses to answer research questions

(3) *Synthesis* **[glossary link]** - Summarizing and integrating insights generated from multiple iterations of the exploratory and confirmation stages to develop a final solution to the research questions

(4) *Presentation* **[glossary link]** - Communicating the uncovered solution to a wider audience

The genius of the swoopy diagram was that DiBiase was able to integrate existing science workflows into a clear overall picture - and one that included cartographers throughout the process. Prior to this time, Cartography and other graphic design fields were focused upon *visual communication* (synthesis + presentation) of a known fact to a wider audience. DiBiase coupled this traditional focus with the ViSC call for the use of representations to facilitate *visual thinking* **[glossary link]**, or the use of visuals for exploration and reasoning to the end of uncovering facts that were previously unknown. Further, within this realm of private visual thinking, DiBiase located both traditional statistical methods used for hypothesis confirmation and the new suite of techniques developed for exploratory hypothesis generation. As the scientist moves from exploration to presentation, the amount of different possible map representations decreases (or 'swoops') from infinity to one.

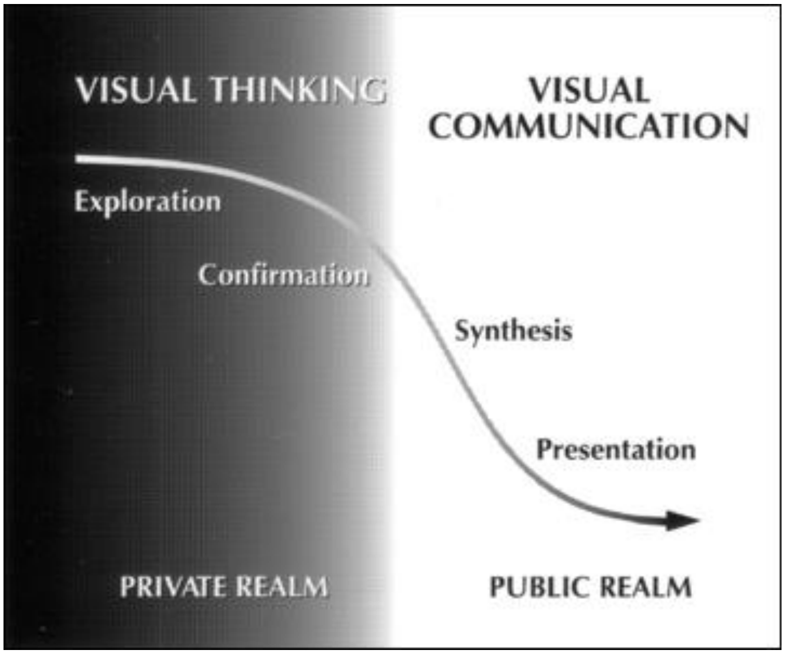

Figure 2: The swoopy diagram. DiBiase (1990) integrated Cartography, EDA, and ViSC into a single scientific workflow, including four stages: exploration, confirmation, synthesis, and presentation. As the scientist moves from exploration to presentation, the amount of different possible map representations decreases (or 'swoops') from infinity to one. Source: http://www.geovista.psu.edu/publications/others/dibiase90/swoopy.html.

The swoopy diagram was used as the input for perhaps the most important and overarching cartographic frameworks currently in place: Alan MacEachren's (1994) *Cartography*[3] **[glossary link]**. Cartography[3] (Figure 3) summarizes all possible map uses according to three axes: (1) revealing unknowns versus presenting knowns, (2) private map use versus public map use, and (3) high versus low human-map interaction. Through the center of the cube is DiBiase's swoopy, illustrating the change from visualization (i.e., infinite possible views) to communication (i.e., one optimal view). As mentioned previously, the focus in Cartography was upon communication rather than visualization prior to Cartography[3], meaning that cartographers had a firm grasp on the best ways to present geographic information. What Cartography[3] did do was suggest the best way to support visualization: through high levels of human-map interaction. In order to learn something new through maps (the primary goal of science), rather than just communication something that is already known, **cartographic interaction is key**. Such exploration of numerous, user-defined, and ephemeral map representations reveals characteristics and patterns in the dataset that were previously unknown, leading to the generation of hypotheses and new ideas. Thus, the basic premise of exploratory geovisualization is that “insight is formed through interaction” (Roberts, 2008: 26).

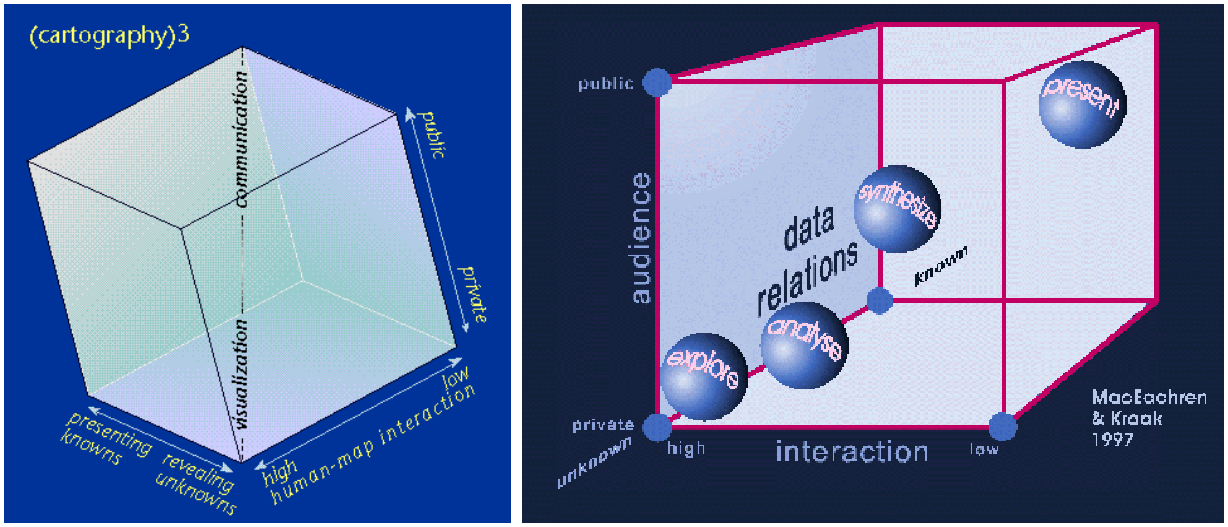

Figure 3: Two versions of Cartography^3. (a) The original offering showing the continuum between visualization (i.e., infinite possible views) and communication (i.e., one optimal view) (MacEachren 1994). (b) A version directly plotting the swoopy diagram inside of the Cartography3 (note: confirmation is renamed as analyze) (MacEachren & Kraak 1997). Source: http://www.geovista.psu.edu/sites/icavis/icavis/poland1.html

Conceptualizing Interaction

In a very real sense, all maps support at least some cartographic interaction Consider a paper road map. Map use typically begins by completely unfolding the road map (i.e., gaining an overview **[update link]**) to identify the present location or desired destination. The map user then may fold and unfold the map, hiding and revealing different subsections (i.e., pan **[update link]**) or may hold the map closer or nearer to his or her face (i.e., zoom **[update link]**). The map user may reference a symbol placed on the map in the legend or may use the reference index to find the landmark's position on the map (i.e., link/relate **[update link]**). Further, map users may draw or write notes on the map (i.e., annotate **[update link]**) to keep track of important routes or directions. If multiple people are using the map (i.e., a collaborative environment **[update link]**), one user may point at a location for another to view (i.e., select/highlight **[update link]**) or identify a subset of important topics to identify on the map (i.e., filter **[update link]**). Finally – and speaking directly from experience – the user may forget the directions and try to recreate the wayfinding process (i.e., re-do/re-visualize **[update link]**). It is clear that many digital interaction techniques are modeled upon their real-world analogs, and that both of these are in fact interactions.

Undoubtedly, however, the Digital Revolution has increased (or at least the potential to increase) the usability and utility of cartographic interaction. MacEachren and Monmonier (1992: 197) identified very early in the development of geovisualization that the digital environment "allows visual thinking/map interaction to proceed in real time with cartographic displays presented as quickly as an analyst can think of the need for them." Cartographic interaction in a digital environment empowers users to affect immediate changes to the map display as they are thinking through a problem or question. These changes are much more complex than those evoked by analog interactions, going as far as changing the representation technique or dataset completely. Because of the digital environment, an interaction with one view can be coordinated with other views (sparking a cascade of changes to the multi-view display) and a log of interactions is much more easily recorded. Digital interactions can also evoke higher-level computational algorithms and spatial analyses that perform automated tasks that would otherwise be prohibitively difficult or impossible to complete on a printed map. Because of these reasons, I find it appropriate to narrow the definition of *cartographic interaction* **[glossary link]** only to include the modification of a digital cartographic representation in response to user input.

While the above definition is a workable, catch-all view of interaction, there are multiple granularities at which interaction can be conceptualized; Figure 4 summarizes these levels.

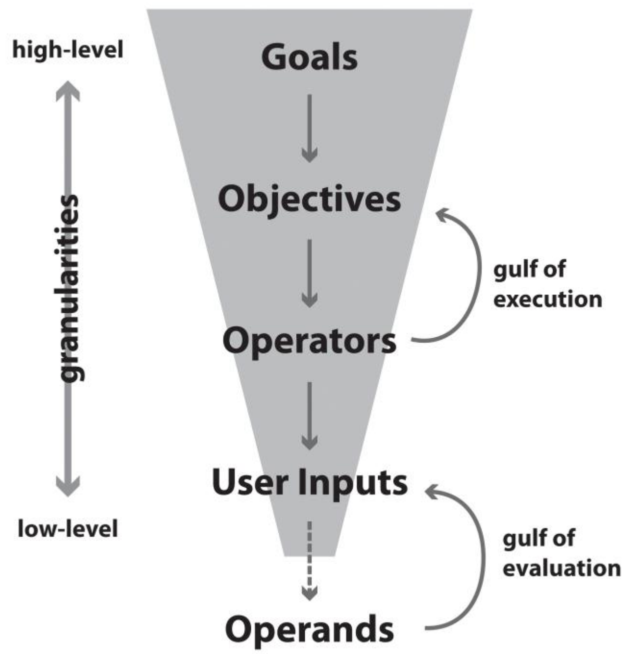

Figure 4: Levels of Cartographic Interaction. Cartographic Interaction can be conceptualized in at least five ways: (1) goals, (2) objectives, (3) operators, (4) user inputs, and (5) operands.

At the highest level are user goals. The user's *goals* determine the use of geospatial information and interactive maps in the first place. In the context of exploratory geovisualization, initial user goals are often open-ended or poorly defined, and may emerge as the user is interacting with the map. Closely related to user goals, but not completely synonymous, are user objectives. *Objectives* **[glossary link]** are the clearly defined tasks that a user must complete in order to achieve a goal. Objectives can be thought of as the user's intention for using a single cartographic interaction (i.e., what they want to accomplish when using a specific interface widget). Objectives therefore form the cognitive input for cartographic interaction. The development of objective ontologies (i.e., a complete set of user tasks that an interactive system must support) is an important research topic that cross-cuts the disciplines of Cartography, GIScience, Information Visualization, Visual Analytics, and Human-Computer Interaction.

At one level beneath objectives, interaction can be conceptualized in terms of interface operators. *Operators* **[glossary link]** are digital tools through which cartographic interactions are made possible. Operators generally rely upon one of five interface styles: (1) direct manipulation, (2) menu selection, (3) form fill-in, (4) command language, and (5) natural language (Shneiderman and Plaisant 2010). However, it is important to note that operators are different than interface styles, as the same operator can be implemented using multiple (or all) interface styles. A key role of the user interface designer is to ensure that the provided set of operators completely supports the user's objectives; the mismatch between user objectives and interface operators is referred to as the *gulf of execution* **[glossary link]**. The Cartography 2.0 interaction entries primarily reports at the operator level, closely following the operator taxonomy offered by MacEachren and colleagues (1999). This taxonomy includes six operators: (1) *assignment* **[glossary link]** (changing the mapping of variables to graphic components), (2) *brushing* **[glossary link]** (highlighting a set of entities in one view and observing effects in linked views), (3) *focusing* **[glossary link]** (limiting the inclusion of data in the linked views to a specified value range), (4) *colormap manipulation* **[glossary link]** (assigning specific colors to individual observations or a subset of observations falling within a specified range of values), (5) *viewpoint manipulation* **[glossary link]** (changing the size, position, and orientation of the information graphic onscreen), and (6) *sequencing* **[glossary link]** (animating the views over time).

The lowest level of conceptualization cartographic interaction is in terms of the input device. Input devices generally fall into two categories: text-entry (i.e., the keyboard) and pointing (e.g., mouse, multi-touch screen, directional pad, graphics tablet, joystick, touchpad, touch point, touch screen, and track ball). The focus at this level is on the physical human input required to manipulate the provided interface operators. Most development environments provide the necessary logic to convert basic user inputs (i.e., raw input) into meaning information that can be ingested by the application for manipulation of the display (i.e., semantic input); as a result, user interface designers typically only think of this level of interaction at the evaluation stage of design.

The final way to conceptualize cartographic interaction is in terms of operands. *Operands* **[glossary link]** are the recipient of the cartographic interaction (i.e., what the user is interacting with). This makes an operand conceptualization less a different level of interaction granularity and more an important part of overall cartographic interaction experience. In terms of interactive cartography, the operand is always information. However, the type of information (multivariate, spatio-temporal, etc.) and the step in the data visualization pipeline (i.e., interacting with the information behind the representation, changing both information and display, or interacting with the representation only, without changing the information) can both vary. Developing with the operand in mind is important, as it is necessary to provide feedback to the user about how the operand has changed based on the cartographic interaction; the mismatch between the change to the operand affected by the interface operator and the change to the operand that the user sees in the representation is referred to as the *gulf of evaluation* **[glossary link]**. Minimization of the gulf of execution and gulf of evaluation are of equal importance for ensuring successful cartographic interaction.

Glossary of Terms

assignment **-** changing the mapping of variables to graphic components

brushing **-** highlighting a set of entities in one view and observing effects in linked views

Cartography[3] - a summary of all possible map uses according to three axes: (1) revealing unknowns versus presenting knowns, (2) private map use versus public map use, and (3) high versus low human-map interaction

cartographic interaction - the modification of a digital cartographic representation in response to user input

communication model - a perspective on Cartography viewing the map as a pipeline through which a message can be delivered perfectly from mapmaker to map reader

Digital Revolution - the late 20th century development of cheaply available of cheap personal computing technology and a pervasive digitally-native transfer mechanism (i.e., the Internet)

colormap manipulation **-** assigning specific colors to individual observations or a subset of observations falling within a specified range of values

confirmation - formally testing hypotheses discovered during exploration to answer research questions

exploration - examining the data from multiple perspectives to identify research questions and to generate research hypotheses

exploratory spatial analysis - a set of statistical and graphical techniques to assist in the exploration of a dataset in order to reveal facts and patterns that were previously unknown, leading to viable research questions

focusing **-** limiting the inclusion of data in the linked views to a specified value range

geographic visualization - a research effort within Cartography focused upon the design and use of maps for exploration and discovery

gulf of evaluation - the mismatch between the change to the operand affected by the interface operator and the change to the operand that the user sees in the representation

gulf of execution - the mismatch between user objectives and interface operators *objectives* - the clearly defined tasks that a user must complete in order to achieve a goal

operands - the recipient of the cartographic interaction

operators - are digital tools through which cartographic interactions are made possible

presentation - communicating the uncovered answers to research questions to a wider audience

sequencing - animating the views over time

synthesis - summarizing and integrating insights generated from multiple iterations of the exploratory and confirmation stages to develop a final solution to the research questions

viewpoint manipulation - changing the size, position, and orientation of the information graphic onscreen

visual *thinking* **-** the use of visuals for exploration and reasoning to the end of uncovering facts that were previously unknown.

visualization in scientific computing - visualization as a tool for assisting scientific research, providing researchers with a method for seeing the unseen to the end of developing scientific insight