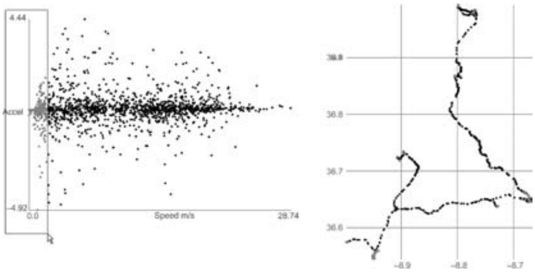
Section B
Creating Instruments for Ideation
Software Approaches to Geovisualization Perspectives



5. Creating Instruments for Ideation: Software Approaches to Geovisualization
Andrienko et al. 103
6. Statistical Data Exploration and Geographical Information Visualization
Martin Theus 127
7. Graph Drawing Techniques for Geographic Visualization
Peter Rodgers 143
8. Exploratory Visualization with Multiple Linked Views
Jonathan C. Roberts 159
9. Visualizing, Querying and Summarizing Individual Spatio-Temporal Behaviour
David Mountain 181
10. Impact of Data and Task Characteristics on Design of Spatio-Temporal Data Visualization Tools
Natalia Andrienko, Gennady Andrienko & Peter Gatalsky 201
11. Using Multi-agent Systems for GKD Process Tracking and Steering: The Land Use Change Explorer
Monica Wachowicz, Xu Ying & Arend Ligtenberg 223
12. Signature Exploration, a Means to Improve Comprehension and Choice within Complex Visualization Processes: Issues and Opportunities
Penny Noy 243
13. Facilitating Interaction for Geovisualization
Jason Dykes 265

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

Exploring Geovisualization
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Chapter 5

Creating Instruments for Ideation: Software Approaches to Geovisualization

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Abstract

New visualization techniques are frequently demonstrated and much academic effort goes into the production of software tools to support visualization. Here, the authors of subsequent chapters in this section identify reasons why they continue to enhance and develop the instruments that they design to support the process of geovisualization, justifying their ongoing work and in doing so offering some perspectives on and solutions to the issues that they address. A number of inter-related themes arise including: advances in technology that create opportunities and generate demands for new geovisualization solutions; increasingly rich data sets and sources that drive design due to the associated potential for revealing new structures and relationships; various and novel tasks to which geovisualization is being applied associated with debate and continuing research concerning the kinds of instrument that are required to best undertake particular tasks in particular conditions; an increasingly diverse set of users who require a variety of tools, environments and systems to support ideation in its numerous forms, including those who participate in simulations of visualization when learning; changes in the available expertise that prompt the development of ideas and instruments that borrow from advances and methods in cognate disciplines such

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as Cognitive science, Statistics, Information Visualization, Knowledge Discovery and Datamining (KDD), Human–Computer Interaction and Scientific Visualization.

Key issues in developing tools that address these requirements are those of interoperability and re-use. The potential advantages for geovisualizers and tool designers of common software approaches and the sharing of ideas are attractive. They allow us to proceed at speed, designing and adjusting our tools and interacting with revealing views of our data to address our objectives of creating superior instruments and enhancing our knowledge of spatio-temporal phenomena. Developing our geovisualization in this way will enable us to participate effectively in the processes of visualization and ideation and advance our science.

5.1 Introduction

During the last decade, numerous geovisualization tools have been developed by various individuals and organizations to support a variety of purposes, for example, (see Gahegan, this volume (Chapter 4)). Many of these have highly interactive and manipulable interfaces and yet we continue to build new tools using a range of technologies and techniques. Why do we invent new instruments? Or why do we *need* to invent new instruments? There are many possible motivations:

1. New *technology* continues to appear and it often enables us to do things that were not possible before.
2. We may be able to acquire *data* of a new form or quality that cannot be analyzed with existing tools as the data sets may be so large, dense or contain so many dimensions that no current tool supports interactive investigation effectively.
3. As geovisualization becomes more popular and exploited more widely, we encounter new *tasks* that cannot be performed using existing tools. Effectively geovisualization may be used to address new societal requirements.
4. The particular needs of specific *users* (from this growing user base) are likely to vary and tools may serve a new or changing user base.
5. Accessing *expertise* from cognate disciplines may contribute to what already exists and enhance it further.
6. Collaboration between researchers may improve our ability to visualize geographic information and to develop the various instruments that support this process. The notion of *interoperability* underlies our efforts to develop ideas and generate knowledge from our data using instruments for ideation.

Ideation relates to the formation of ideas and concepts, the end goal of much geovisualization. Today there are many tools and techniques for creating instruments for ideation – sophisticated hardware, advanced programming languages, graphics libraries, visual programming systems and complex GUIs. In each, the developer or visualizer wishes to generate effective interactive graphic realizations of their data that are useful to them and/or their users. Indeed, these geovisualizers will come across many challenges. We suggest six factors that help explain why new tools and techniques may be developed.

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

In this chapter, we expand upon these ideas and consider how each of these issues influence and shape the way we use and develop software instruments that support the exploratory process. Some examples of our software approaches are documented in the chapters that follow in this section.

5.2 Technology Issues

Current technology has an important enabling and limiting impact upon the available range of instruments for ideation, which changes significantly over time (Cartwright et al., 2001; Fairbairn et al., 2001). In 1854, Dr. John Snow and colleagues manually plotted the locations of deaths from cholera on a paper map in order to show the outspread of the disease (Tufte, 1997; Brodlie et al., 2000). Today, Snow would most likely load these data into a GIS and look at a map display on a computer screen. In 1967, Bertin (Bertin, 1983) described advanced equipment for manipulation of data represented on paper strips or cards. Current computers obviously offer far more sophisticated opportunities for manipulating data representations and interacting with them. It is natural that builders of tools for ideation, either for their own use or for use by others, aim to utilize the most applicable capabilities of the current technologies.

A major benefit of contemporary computer technology is the possibility to rapidly generate various graphical displays from data. This gives us an opportunity to try alternative transient realizations of data, discard those deemed ineffectual but when necessary reproduce them again, and look at several displays simultaneously to provide multiple views of data (McCormick et al., 1987; Becker et al., 1987; Stuetzle, 1988; Roberts, 2000). Such techniques are paramount to the process of geovisualization and enable us to address the data, task and user issues that also drive our pursuit of innovative and effective instruments. They have stimulated much of the work reported in this section.

We also use advances in technology to store large amounts of data and access them on demand with minimum effort. Moreover, it is increasingly easy and common to obtain additional data when necessary in an analysis, from a range of sources including the Web or from the wireless “information everywhere” devices. The speed of computation that technology now allows enables us to combine visualization with computationally intensive methods of data analysis such as exploratory statistics or datamining: one can rapidly obtain the results of computation and compare them with what is observed or interpret them through depiction on a map or a graph.

Of course, interaction and display manipulation play crucial roles in data exploration (MacEachren, 1994a–c). The speed of data access and display generation also allows the development of dynamic representations capable of changing in real time. Thus, dynamic and animated maps are now widespread and offer exciting opportunities for representing geographic data. 3D graphical representations can be realized with relative ease, and are frequently used, for example, (see Wood et al., this volume (Chapter 14)), yet we are only beginning to determine ways to utilize their potency most effectively for data analysis and ideation by developing and testing tools, for example, (see Kirschenbauer, this volume (Chapter 18) and Coors et al., this volume (Chapter 27)).

It is not only the increase of computer power that offers us new opportunities to create more sophisticated instruments, but also the progress in software environments, such as the development of programming tools that are high level and/or cross platform and the availability of libraries and reusable software components. Examples include the MacroMedia products, Java, Tcl/Tk, the OpenGL libraries and the OpenSource paradigm. These environments and related methods of development have capabilities for visualization and enable us to produce flexible applications that are quickly extensible and may run on a variety of platforms. As a result, more sophisticated and dynamic graphics can be created and widely used.

Besides increasing the opportunities, technical progress raises demands and poses challenges that drive our research and the development and testing of our instruments. New types and volumes of data made possible by technological advances may need handling in innovative ways and so require the development of geovisualization techniques (see §5.3). The Web not only enables us to obtain more data when needed but also raises issues relating to data merging, data representation, and the analysis of complex, heterogeneous data sets. Moreover, the Internet and other communications technologies such as mobile devices are changing the way people are working.

Indeed, mobile devices do not only enable people to compute anywhere and to access data from everywhere but also create a demand for new instruments that are designed specifically for such devices and which can be conveniently and effectively used. In the design of these instruments, one must creatively manage limitations that once appeared to be issues of the past: small screens with low resolution, memory restrictions, limited computational power and reduced possibilities for interaction. The lucrative games industry is beginning to discover the need and market for device specific applications, and work is in progress to take advantage of opportunities for mobile geovisualization, for example, (see Coors et al., this volume (Chapter 27)).

Technical progress enables people situated at different physical locations to work cooperatively, hence, there is a demand for geovisualization tools that support this mode of remote collaboration, for example, (see Brodlie et al., this volume (Chapter 21)), which in itself leads to new geovisualization tasks (see §5.4). The availability of computers, data, and the Internet encourages more people to do their own exploration and take part in knowledge construction. This calls for the creation of widely accessible instruments (including those available over the Web) that can be operated by users with different levels of sophistication and computer competence. The availability of such tools confronts designers with further challenges. How are such accessible prompts to geovisualization made understandable to a wide and usually unknown audience? Such issues are further explored in §5.5.

Whilst being convenient for tool developers, modern software consumes far more computer resources than before. In some cases (for example, using Java), it can be argued that the costs of high-level flexible tools are significantly slower software applications than older alternatives written in Fortran, C or C^{++}. Whilst this issue can be addressed by improvements in processor speeds it is exacerbated when coupled with the "mobile device considerations" introduced above. Code reuse and exchange of components also poses numerous difficulties, some of which are discussed in §5.7, below.

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Hence, we see that technological progress has tremendous influence on the development of instruments for ideation and explains much of the rationale for our work. This influence is two-sided. On the one hand, progress creates new opportunities that may be explored and utilized. On the other hand, it creates new demands that need to be satisfied. The new demands often come together with particular restrictions and considerations that have to be appreciated. In keeping up with new technologies, geovisualizers should not disregard earlier ideas, approaches, and methods. After all, as we have seen, even the idea of manipulating data displays first appeared in the pre-computer era. In the current absence of formal theory to guide or prescribe our use of the new opportunities that technology offers to us, existing knowledge and the methods of the present and past provide important resources on which to build our knowledge and techniques (see also §5.6).

5.3 Data

Motivation to develop novel graphic representations and interaction techniques can come from the data itself and our abilities to access and use it (Gahegan et al., 2001). Besides increasing the opportunities, technical progress raises demands and poses challenges that drive our research and the development and testing of our instruments. Continuing technological advances have had a profound effect upon the nature and volumes of data available to the geovisualization community. The current ease with which data are recorded and acquired results in huge data volumes that cannot be effectively explored using standard methods of representation and interaction.

New data sets are being generated by such diverse applications as mobile communications technology, digital commercial transactions, Web-logging software, traffic monitoring systems, closed circuit television, various flavours of GPS "tagging" and countless others. These data sets often contain spatial and temporal referencing, whether stored explicitly or implicitly, and may benefit from either the development of new visualization techniques or the adoption of techniques from one domain by another. Consequently, a wide range of new media (such as imagery, animations and audio) is increasingly being used, offering the investigator a variety of data models. Encouraging the user to interact with different media can add a qualitative perspective, for instance by representing a phenomenon in context, that quantitative approaches alone may not be able to offer (Shiffer, 1995 a,b).

The data structure used to represent the phenomena of interest has implications for which visualization techniques are available and appropriate, for example, (see Keim et al., this volume (Chapter 2)). Many structures are static, representing the situation at a single moment or with no reference to time at all. Relationships can be uncovered between different parameters through techniques such as interactive statistical data exploration, but these cannot reveal dynamic processes. Data structures that incorporate time lend themselves to techniques that can represent these dynamic processes. Animation is one approach to showing time elapsing and works well for presenting information about entities evolving under the influence of long-term trends. The progression of urban form is an example (Acevedo and Masuoka, 1997). A current challenge lies in enhancing animation tools that simply present patterns to interactive techniques where user-controlled animation allows variable selection and control over a dynamic display to compare the behaviour of different entities over the same time period (Andrienko and Andrienko, 1999a–e; Rana and Dykes, 2003; see Andrienko et al., this volume (Chapter 10)).

Time can also be represented without the need for animation. In particular, spatial plots can be combined with temporal plots to allow simultaneous interaction with both space and time. Such approaches have a long history, and include another much cited graphic that pre-dates computer supported visualization, Minard's depiction of Napoleon's Russian campaign (Tufte, 1983), but have now evolved into interactive approaches allowing selection for comparison and focus (Peuquet and Kraak, 2002; Andrienko et al., 2003).

Whether a discrete or continuous data structure has been used also has implications for the visualization techniques that are applicable. Discrete approaches are more appropriate for modelling and analysis of entities, such as the movement of individuals or groups. Continuous structures, such as elevation models and point density surfaces, are more appropriate for representing the wider trends over an area: representation of and interaction with these models is quite distinct to discrete approaches. This continuous sampling strategy can generate very large datasets, often only a small subset of which is relevant to the task being undertaken by a particular user. Abstracting the relevant information from the continuous model at the appropriate scale can reduce data volume and prevent the "information overload" associated with very large datasets (Rana and Dykes, 2001). Moreover, there is a need to store these large structured volumes of data in appropriate databases such that the information is readily available and integrated with appropriate mining and visualization tools (Gahegan et al., 2001).

As indicated above, the automated collection of data has become increasingly commonplace leading to a massive increase in the volumes of data that are generated. Such datasets may contain much richer information that can be revealed through most current visualization techniques, requiring the development of new methods and instruments that draw upon them. Various methods have been applied to address this particular problem. Classification by aggregating a collection of samples into a single entity, or by using pruning methods for hierarchical data, can allow large data volumes to be represented more clearly (Kumar et al., 1997). However, these aggregate entities may have different characteristics to the individual entities they represent and a dual approach may have to be adopted if the same interaction technique is to be implemented for source and aggregated data. Under these circumstances, the experience that geo-scientists have in dealing with issues of scale and scale-dependent phenomena, and their visualization could be beneficial to a wider community (for example, see Wood, this volume (Chapter 15)). Classification can also facilitate or even permit interaction with large data volumes. When interacting with a very large number of graphic elements in a display, processing time can otherwise prevent a technique from supporting the real-time interaction required for visualization (see Theus, this volume (Chapter 6)). Here, we see a clear association between the data and technology considerations that influence the instruments that we develop and the techniques that we use.

As is the case on paper, on-screen realizations of large data sets can cause particular problems for the viewer in detecting and discerning the symbols used, assembling them into patterned regularities and estimating the magnitudes that they represent (Cleveland, 1993). Interesting trends may be lost through over plotting and the magnitude and distribution of outliers. Various graphic and software techniques can be implemented (Theus, this volume (Chapter 6)). One approach is to summarize key trends: for example GPS track logs representing individual movement can be used to generate point-density surfaces giving a representation of where an individual spends their time and their familiarity with specific locations from which information can be extracted (Dykes and Mountain, 2003; Mountain, this volume (Chapter 9)).

arunselvaminThe phenomena that geovisualizers usually study exist in a space–time framework. Static 2D maps that offer an impression of a complex 3D space at a particular time rely upon dimension reduction. Much cartographic effort has always gone into minimizing the impact of reduction upon the anticipated tasks to which the map is put. However, geovisualization techniques can be applied to data that have no spatial or temporal dimensions. A 2D surface can be generated by principle components analysis and geovisualization interaction techniques applied to it. Similarly, clusters in self-organizing maps are described in terms of distance, however none of the original dimensions that led to the map need relate to spatial metrics (for example, see Koua and Kraak, this volume (Chapter 33)). The results of techniques that use this spatialization (Fabrikant, 2000a,b) aim to utilize human abilities to interpret landform and interacting with non-spatial data in this way may offer new insight (for example, see Fabrikant and Skupin, this volume (Chapter 35)). Thus, a clear opportunity exists to explore the utility of such techniques and develop new instruments of ideation specifically for spatialization.

Each graphic depiction of a data model that we develop is one of an infinite number of alternative views. Individuals developing geovisualization techniques are often attempting to display a single specific relationship at the expense of other trends and background noise. Successive transitory screen realizations designed for private "idea chasing" are not intended to communicate a single message about the data to a wide audience as has been the case with many traditional maps. The increasingly rich and potentially revealing data sets becoming available are leading to an increasing number of abstract, novel and interactive graphic realizations of data sets being developed by those creating instruments for ideation.

5.4 Tasks

Whilst technological advances and the availability of new data drive a need for new views, Casner (1991) convincingly demonstrates that the same data need to be represented in different ways using different views in order to effectively serve different information needs. The information needs that require these views are defined by different tasks. Casner considers examples of tasks such as planning a journey from city A to city B with a stopover in city C (where one has an appointment for a particular time) and finding the cheapest flight or most direct travel route. For each task, he proposes a graphical display that allows it to be effectively fulfilled. There is no "ideal" graphic realization of the data suited for all purposes. Indeed, the tasks that Casner considers have little to do with exploration, namely there is no attempt to grasp inherent characteristics of unfamiliar data and gain knowledge about the underlying phenomena. However, there may well be generic tasks in data exploration that define geovisualization. Has a data explorer any particular goal in mind while looking at some unfamiliar dataset from different perspectives in a hope to gain serendipitous insights into the information? And if so, is knowledge about possible tasks an important factor when designing instruments for ideation? If Casner's supposition is applicable to exploratory map use it would account for the variety of approaches employed in geovisualization, and as tasks change new instruments need to be developed to support them.

Designers and developers of geovisualization tools, including those who have contributed to this chapter and the discussions surrounding its development, may have different approaches to considering tasks. Some believe that having a defined task is not (or not always) necessary in Information Visualization. Others are convinced that tasks always exist, explicitly or implicitly, even when an explorer seems "just to look" at data.

Advocates of task-driven tool design argue that usually an explorer does not only *look at* data but also *looks for* something "interesting", such as a configuration that may contribute to a better understanding of the data or underlying phenomena. This may be, for instance, a salient pattern of spatial distribution, a local anomaly, some indication of unusual behaviour or an indication of a possible dependency between phenomena or processes. In order to find these "interesting" things, an explorer actually performs a range of exploratory tasks (possibly, without even realizing this): observing a spatial distribution, attempting to detect patterns and anomalies, looking for possible relationships, and so on. These tasks are, of course, very different from those contemplated by Casner. Apart from being less precise and more general, exploratory tasks are often fulfilled in parallel or combination (Gahegan et al., 2001). In the case of Casner's examples, a single (often more straightforward and well specified) task is considered in isolation.

While an explorer may not be aware of their tasks or know the specific outcomes, those designing tools that support ideation must consider them explicitly and deliberately design any instrument so that it can assist in the observation of distributions and behaviours, expose patterns and facilitate detection of relationships. Taking into account the concurrency of exploratory tasks it may be inappropriate to follow the approach of building separate graphical realizations for each task. Instead, one should try to design to support a range of tasks, possibly through various methods of interaction. When a single graphical depiction appears to be insufficient, several interlinked complementary realizations of the data may be appropriate. Whichever combination of graphics and exploratory environment is used to support ideation, applying Casner's model to the realm of geovisualization explains the proliferation and development of instruments and suggests that a tool designer needs to know which exploratory tasks exist and to find methods of supporting them in order to promote ideation. Gahegan, this volume (Chapter 4) identifies outcomes of ideation when considering the nature of the research process and suggests a framework for determining the utility of tools and techniques according to a low-level analysis of tasks.

Various approaches to defining possible tasks have been developed and numerous alternative task taxonomies suggested (Knapp, 1995; Qian et al., 1997; Shrager and Langley, 1990; Shneiderman, 1998) and Plaisant, this volume (Chapter 3) provides a simple taxonomy of seven "basic tasks". Despite their differences, these taxonomies exhibit some commonality. They are typically built from generic tasks like "identify", "locate", "compare", or "associate". Such broad task categories cannot help a tool designer much in isolation unless they are explicitly related to data and refined in terms of the nature of the data to which they relate. Thus, it is hardly possible to create a tool supporting the abstract task "compare". Instead, one needs to determine which specific comparison tasks exist for a particular dataset or for a range of datasets with similar structures. This demonstrates another interaction between our identified motivating factors, a clear relationship between data and task.

Let us assume, for example, that we need to explore data about objects that move in both time and space. We can instantiate the generic "compare" or "relate" into several more specific tasks:

- compare positions of two or more objects at a particular moment in time;
- compare positions of an object at different moments in time;
- compare trajectories of different objects;
- compare trajectories made by the same object during different time intervals;
- compare the speed of movement of different objects during the same time interval;
- compare the speed of movement of the same object during different time intervals;
- compare distances travelled;
- … and so on.

These tasks are obviously different and need to be supported in different ways. Hence, specialization of generic tasks in terms of data components is essential for the successful design and use of tools for ideation. An ideal task taxonomy for a tool designer would be the one that allows apparent and straightforward specialization. Object orientation may be an appropriate methodology for developing tools that utilize such a taxonomy (Boukhelifa et al., 2003).

Once we have understood which tasks (potentially) exist, we need to find ways of supporting them. Unfortunately, no appropriate theory or guidelines currently exist, upon which we can rely. Certain empirically derived pieces of knowledge are useful however. For example, choropleth maps may be appropriate for detecting spatial patterns in certain circumstances but are inappropriate for comparing objects (Jung, 1995). Although we primarily deal with geographic information in this chapter, we should not restrict ourselves only to cartographic representations but adapt tools and approaches from different disciplines to our purposes (see §5.6). For instance, a scatter plot is good for detecting correlations between phenomena characterized by numeric attributes, and a time-series plot can be effectively used for exploring spatio-temporal data. We should also remember that we have the possibility to enhance our displays by facilities to interact with them and manipulate them, and this may radically change their properties so that choropleth maps, as in the example above, can be made more suitable for comparative tasks (Andrienko and Andrienko, 1999d, e). Moreover, interaction can also help us to link together multiple displays serving different tasks.

Although we reuse the experience accumulated in the geovisualization area as well as in Information Visualization and statistics, in many cases it is not obvious what kind of instrument is needed for a specific task. In such cases, we may try different tools, either from the existing set or by devising new realizations *ad hoc* to suit, until we find one that satisfies the particular task in hand. For example, when using geovisualization to explore data about earthquake occurrences using an interactive animated map display, one may find that it does not facilitate the detection of spatio-temporal clusters. In trying to explain this failure, it is possible to hypothesize that the task of cluster detection requires the spatial and temporal dimensions of the data to be viewed simultaneously and in a uniform way. This consideration may lead to the idea of using the "space–time cube" where time is represented by an additional spatial dimension (Mountain, this volume (Chapter 9)). As a result, knowledge about both the process and the nature of the use of graphics is improved. This example demonstrates once again that data and tasks are interlinked factors that shape the design and use of our geovisualization instruments. And the low-level tasks to which geovisualization may be applied are changing as a result of other factors discussed in this chapter such as advances in technology, changes in the amounts and types of data that are available and changes in the type of user who make use of geovisualization.

5.5 Users

Whilst data and tasks shape the nature of geovisualization techniques and tools, the degree to which they are appropriate will ultimately depend upon those who use them. Users have a host of expectations, individual experiences, skills, domain specific knowledge and various capabilities and limitations. Importantly, they are the people who expect to gain knowledge and understanding through their interactions! Creating effective instruments for geovisualization requires us to design tools with which the target user(s) can efficiently and effectively interact (Fuhrmann et al., this volume (Chapter 28)).

Thus, it is important to consider who is doing the visualization: not only does the user come with a package of skills, but they also have varying degrees of domain knowledge. For instance, a geologist may have refined skills in interpreting 3D representations, due to their experience with solid models and volumetric concepts (Gahegan, 1998). However, users without these skills may wish to access and interpret the data using alternative realizations.

The background and skills of particular users have a considerable influence on the way in which instruments are used and their effectiveness. For example, an individual who foresees that they are going to use a system many times may invest a substantial amount of time and effort in learning it. However, an occasional user may wish to get some results quickly. Moreover, the need to extend our domain knowledge and that of geovisualization may require a geovisualizer to simply create unique graphics rapidly or demonstrate a particular aspect of their work. To minimize development time and expedite the generation of ideas resulting from successive interactive graphics they would usually prefer to build their hand crafted exploratory instruments from pieces of existing functionality that offer flexibility and efficiency. Thus interoperability issues become important (see §5.7).

Users with specific domain knowledge may drive system development. It is often the case that these domain experts end up developing appropriate tools themselves. Thus, toolkits need to be built that enable the user to quickly build a prototype system from a series of available techniques. This may draw upon many methods of interoperability, from a quick and easy graphical style using a dataflow model of interconnectivity, to a very flexible but complex set of package interactions, relying on knowledge of code and data formats, which is more sophisticated and powerful than a simple model of interconnectivity, but may be harder to use. Some of the various possible approaches towards interoperability are discussed further in §5.7.

Other users may have different expectations of a particular tool, perhaps depending on their level of expertise, experience, or time available to learn and use the software. One expert user may be more patient with a slow system, waiting for a particular realization to be rendered just to get that high quality and accurate display, while another may wish to generate quick representations that are not necessarily exact. When following Shneiderman's mantra "Overview First Then Details on Demand" (Shneiderman, 1996), the user often wishes to simply provide an overview followed by a process of finding out more about the representation. In §5.4, we identified that different tasks in this process require different solutions. But equally defining what an effective overview may consist of is another issue and the answer is likely to be user dependent. Is it, for example, a simple scatter plot showing the statistical relationship between two attributes for all cases in one display (with the resulting problems of interactivity and possible overplotting), or is it a higher level abstraction with symbols depicting the centres of gravity of the major clusters that appear on the plot (and so the problem becomes one of finding an algorithm to effectively abstract the groupings)? Or is it a map, or a set of maps, showing the spatial distribution of one or more of the attributes? Different users may have different answers and each will certainly want to subsequently zoom, pan, filter, and request details on demand in different ways.

Personal abilities are one of the characteristics that affect a user's preferences in exploring information. They include physical constraints (e.g., sensory and cognitive limitations) as well as a variety of academic abilities (e.g., levels of reading, writing, arithmetic and interpretive skills). These all may have an effect – to a greater or lesser degree – on the level of interaction required by the user and to the appropriateness of any particular combination of realization and interactivity. The area of unseen disabilities, especially in the case of arithmetic skills, can be considered as one of "difference" (Slocum et al., 2001) and includes diverse styles such as in task-action choices and in general spatial awareness skills. In the field of human computer interaction (HCI), the issue of task-action consistency suggests that it is advisable to have multiple task-action methods as different people will regard different tasks as being variously similar or dissimilar (Grudin, 1989). Even though we follow best design practices, individual users are still different and have varying abilities. Indeed, it is these differences that make it difficult to fully understand how users are going to use a system, and often user trials reveal different methods of interaction from those that were expected. As is the case with different tasks, where multiple views may be required, different users are likely to require multiple visualization methods to engender understanding most successfully.

Users and tasks go hand in hand. Complex tasks usually require non-trivial interfaces. Confining ourselves to limited modes of interaction and/or representations might restrict developers and investigators. For example, complex multi-variate views such as parallel coordinates and mosaic plots may involve some training to be used effectively by a mass audience. Indeed education is an important issue as we hope that insight is extended as yesterday's new view becomes tomorrow's bread and butter graphic device. Developers should not shy away from producing complex systems that may require users to invest time and effort into learning how to use them effectively – if they are effective. After all in the 1700s, Playfair's scatter plots were unlikely to have been greeted by mass approval and widespread comprehension. Moreover, cooperative work by multiple users on data exploration and analysis requires specific support. A strong impact on tool design is whether the intention is for use by an individual or a group (for example, see Brodlie et al., this volume (Chapter 21)). Developing instruments that provide effective solutions to the latter of these scenarios under particular circumstances is a key objective.

Thus, different kinds of users will require and work most effectively with different instruments to support their geovisualization, and exploring the possibilities is a key motivating factor for those involved in tool specification and development. For example, applications software that is to be used widely should be stable, reliable and have a consistent look-and-feel (see Plaisant, this volume (Chapter 3)). Other systems offering additional flexibility (such as those that make use of many linked views and complex graphical representations) may be more appropriate for exploratory work undertaken by experienced and skilled users, rather than tools used in a limited context such as education.

To summarize our arguments, we can say that users are diverse and so a variety of tools, environments and systems are appropriate to support ideation in various contexts. When faced with developing software for wide use, the application of multiple linked views allows a variety of user skills and abilities and background systems to be supported. In addition, a non-trivial solution with sophisticated interaction methods that is geared expert use and may offer considerable flexibility has an important role, as do a more limited and less polished or robust tools that are developed in order to demonstrate or test particular techniques. Indeed some tools may offer a variety of levels of complexity of functionality and interface through "multi-layered designs" (see Plaisant, this volume (Chapter 3)) or by developing smooth links between modes of interaction (for example, see Dykes, this volume (Chapter 13)).

5.6 Expertise from Different Fields

Finding an appropriate representation technique using suitable methods of interaction is a common challenge in any discipline that makes use of graphics. Geovisualizers can thus draw beneficially from other communities, and many of the techniques and much of the work cited thus far in this chapter does so. This may in turn lead to the need for a wide range of skills. The complexity and specialist nature of the tools and techniques available in other disciplines may prohibit their use in certain circumstances. Collaboration and the delegation of roles may allow more work to be achieved more effectively. Indeed, the 1987 special issue of the Journal of Computer Graphics concerning Visualization in Scientific Computing (McCormick et al., 1987) was enthusiastic about the benefits of having interdisciplinary teams when producing effective visualization tools. There is a good argument for teams composed of a diverse group of investigators with a variety of expertise. The McCormick report describes a group combined of:

1. specialists with knowledge and skills relating to the target domain;
2. visualization scientists with software, hardware, networking, languages, operating systems and database skills;
3. support personnel with skills to “configure and maintain visualization facilities”;
4. artists with specialist knowledge in composition, lighting and color;
5. cognitive scientists.

Thus, bringing people together often benefits the research (a philosophy of two – or more – heads being better than one). More recently, the US National Research Council on “Geospatial Information and Information Technology” embraces this interdisciplinary perspective (Computer Science and Telecommunications Board, 2003). Many tool development projects do include scientists with geographic and computing expertise, but it is rare that a geovisualization project includes investigators with a more diverse range of skills. Conversely, more diversity may not in fact be better for the project as managerial problems surface: for example, as any software engineer knows – getting more programmers on a project, that is already running late, in fact slows down the project as a whole (Brooks, 1995). This is a difficult equilibrium to resolve and maintain, but one that must be addressed. Experiences of managing large collaborative projects in the open source community may offer some solutions and the opportunity to extend the threshold beyond which the benefits of collaboration between individuals from different domains are offset by the costs of coordination. Technological advances that permit and support collaborative work should prove to be valuable (Brodlie et al., this volume (Chapter 21)).

Another challenge with such a diverse group of experts is that the primary focus for each individual might be quite different. Geovisualizers often have a particular graphical representation of a geographic scenario as a primary focus, while Information Visualization focuses on attempts to graphically depict structures that are abstract and have no physical location or space equivalence. Conversely, statisticians may tend to depict relationships within sampled data, which can give new insight to the generating process, whereas Information Visualization faces the most general challenge in not being restricted to any specific domain. Despite these differences, increasing overlap exists (as indicated in many of the chapters of this book) and evidently geovisualization can gain much from the diverse knowledge available in cognate disciplines. This may prompt the development of new tools and techniques.

Geovisualization and various other related fields are complementary in a number of ways. In the case of geovisualization and statistics, the two disciplines can be considered as relating to different stages of the process of seeking understanding of a dataset. Geovisualization has tended to focus on and support data exploration occurring in the earliest stage of GI scientific endeavour, with an objective of generating plausible hypotheses concerning inherent data characteristics and relationships. Traditionally, statistics becomes particularly appropriate when the hypotheses need to be validated and models built. Gahegan (see Chapter 4) argues strongly that geovisualization is a broader process that supports the entire practice of GIScience and (graphical) exploratory statistics has provided much impetus for geovisualization.

Statistical data, here considered to be the characteristics of data that do not describe geographical location or properties, is usually multi-variate. Thus, the structures to be identified are interactions between numerous variables. These configurations are often far too complex to be captured by simple coefficients, and call for graphical exploration or complex statistical models. Linked highlighting and plots for high-dimensional data are the building blocks of interactive statistical graphics, and all (human–computer interactions) must be built to support these tasks and plots. “Statistical thinking”, that is knowledge about distributions and relationships between them, is very important in geovisualization when participating in exploratory data analysis (EDA).

A different relationship exists between geovisualization and knowledge discovery in databases. Like geovisualization, KDD techniques are also meant for revealing significant characteristics and relationships in unfamiliar datasets. KDD is defined as a non-trivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data (Fayyad et al., 1996a,b). This is usually applied to very large datasets. Whilst geovisualization focuses on knowledge extraction undertaken by a *human analyst* and the interactive visual tools designed to support them, KDD offers techniques for the *automatic* extraction of knowledge from data. Combination of these two approaches may exploit the strength of each of them and compensate for limitations (Andrienko and Andrienko, 1999b, c; Andrienko et al., 2001; Keim and Kriegel, 1996; MacEachren et al., 1999). Thus, the “human eye” can perceive and process some spatial relationships from a visual representation such as a map while a computer draws upon the relationships encoded in digital spatial information. Yet only limited characteristics of the various aspects of spatio-temporal arrangement that may be potentially relevant can currently be represented in a format suitable for datamining. Examples include, distances between centroids or neighborhood relationships. Results of datamining, in turn, require a human analyst to evaluate and interpret them and, hence, need to be appropriately visualized. On the other hand, computers are superior to humans in processing large volumes of data, and this advantage is exploited in exploratory tools

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

that combine geovisualization with KDD techniques and there is an opportunity for further developments in this area (see Wachowicz et al., this volume (Chapter 11)).

Indeed, examples also exist whereby artificial intelligence techniques are incorporated in geovisualization tools (Andrienko and Andrienko, 1999c–e). Such agents may be used to identify items of interest or to help users to select and generate appropriate graphical realizations. Sometimes new representation and interaction forms are brought to geovisualization from other disciplines, for example, direct manipulation from HCI or graph drawing techniques (Rodgers, this volume (Chapter 7)).

Scientific visualization is another field that can benefit geovisualization. It is best at representing an object or a single phenomenon or process. Understanding the physical structure of the problem and finding the optimal way to render it are the main tasks. Thus, scientific visualization instruments are often unique to a particular problem. A usual interaction is to navigate through different (virtual) views of the object or phenomenon of interest. Since geographic inquiry tends to involve real world phenomena that have changing locations in 3D space and time, geovisualization can borrow from scientific visualization realization/rendering expertise (Wood et al., this volume (Chapter 14)). This includes the development and testing of hardware-based advances (see Döllner, this volume (Chapter 16); Kirschenbauer, this volume (Chapter 18)) and those that develop software solutions to support interaction, often across multiple linked views (for example, Lopes and Brodlie, this volume (Chapter 14); Roberts, this volume (Chapter 8)).

The common theme of all disciplines concerned with visualization is the exploration of a scenario (problem, phenomenon, data or object). By interacting closely with graphical representations, the user may better understand the data, gain information from it and so acquire knowledge of the phenomenon under study. Although there may be differences in focus, skills, ideals or terminology, interdisciplinary projects should be encouraged and the creation of instruments that borrow from advances and methods in a variety of related domains offers a clear rationale for the range of approaches to creating instruments for geovisualization and continued development.

5.7 Interoperability

The increasing requirement to integrate expertise with specialist knowledge and skills, and the call for user, data and task-specific solutions, indicate a need for systems to be interoperable. Indeed, Geography itself can be viewed as the integration of perspectives, which is reflected in our constant requirement to reach beyond ourselves to find new instruments to address emerging problems. Consequently, some consider the whole issue of open systems for geovisualization to be a long-term major concern: that analyses should not be limited to tools developed by individuals (see Gahegan, this volume (Chapter 4)). One way to achieve this goal is to reduce or remove the need for any prior agreement concerning the way in which major parts of a system (sometimes termed "components") interact.

Additionally, no single individual has the resources needed to develop the ultimate geovisualization system that can accommodate the various tasks, users, data and other factors that we have considered here. But effective systems could be built

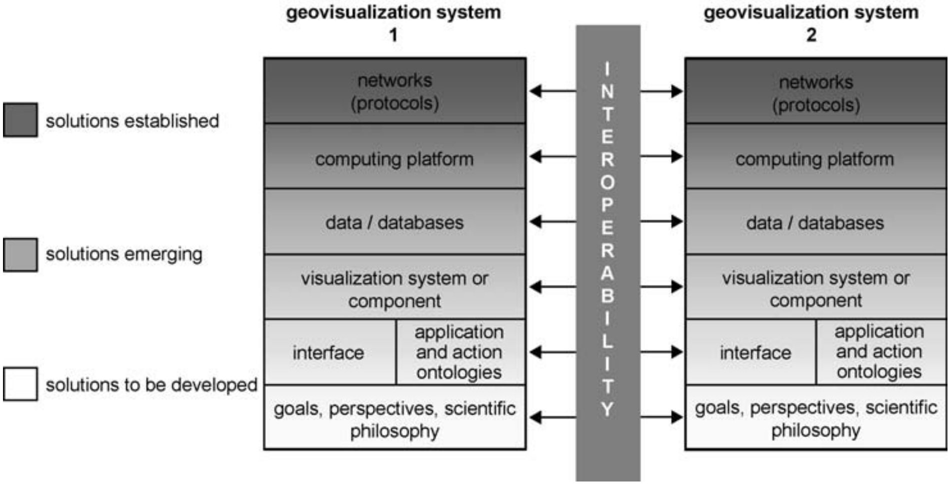

Figure 5.1. Levels of inter-operability, with the current position in terms of the status of solutions to each of the aspects of interoperability schematically represented.

efficiently, if ways could be found to integrate the wide range of tools available, both within the geovisualization speciality groups and in the wider community of visualization researchers, while maintaining flexibility and extensibility. That is not to say that great things cannot be achieved using existing approaches, but rather this is a call to look forward to the next major challenge – one that must be faced collectively for progress to be made.

There are many dimensions to the problem of interoperating visualization tools, and some of these are depicted graphically here. Figure 5.1 illustrates the various levels of abstraction that comprise all facets of the term "interoperability", from the basic connections of machines on a shared network, through the sharing of data, to the fusion of perspectives. At this time, perhaps our most pressing problem is that of consistency of the "world view". This is a concept that covers all assumptions made in relation to semantics, semiotics, user interactions and so on. It is shown as the combination of "interface" and "application and action ontologies" in Figure 5.1. Different user communities and tool developers have different ontological commitments (such as different world views) and different ideas about how one component might interact with another. These can be thought of as types of implied application ontologies (the data models embodied by the tools) and action ontologies (which particular actions are supported, such as linking and brushing). More precisely, the application ontology is the specific way that an application task is conceptualized (in this case by a component or a system). Ideally, an application ontology is shared between components that are collaborating. The action ontology comprises the various actions that are defined by different systems or tools that need to be mapped to other systems and tools, such as linking, brushing, sampling or grouping.

While these ontological differences may be small, say within a distinct laboratory (though they need not be) they may be considerable when considering wider communities of researchers discussed in §5.6. This will be especially so if their work is motivated by completely different problems or perspectives. This begs the question – to what extent are we able to borrow tools? For example, does the inclusion of spatial data dictate that distinct tools are needed? These questions relate to those that concern some visualization researchers: to what extent can generic techniques and tools meet a variety of general goals?

At the moment, we tend to build systems that contain our own ontologies explicitly, hard-coded. We need to either find a way of decoupling graphical functionality from our ontology, and coding it separately, or of re-purposing or wrapping existing ontologies so that we can manipulate them to our own purpose. These issues are studied by a community of researchers under the heading of “problem solving environments”, and are well understood, though good solutions are largely elusive (Schuchardt et al., 2001).

The sharing of ontologies only solves the conceptual models used and the way in which components interact with various events, by themselves these problems do not guarantee that the combined systems appear to be logically integrated or to have any kind of consistency as far as the user is concerned. Parallel efforts are also required to solve user–interface issues, so that the components assembled appear to be logically consistent in use. For example, it would be desirable for components to use the same look and feel, the same layout guidelines and the same data interfaces. Again this involves decoupling of logical design from user–interface design, and coordination of layout issues among components, preferably at runtime, for the maximum flexibility. Here, interoperability issues overlap with those of usability.

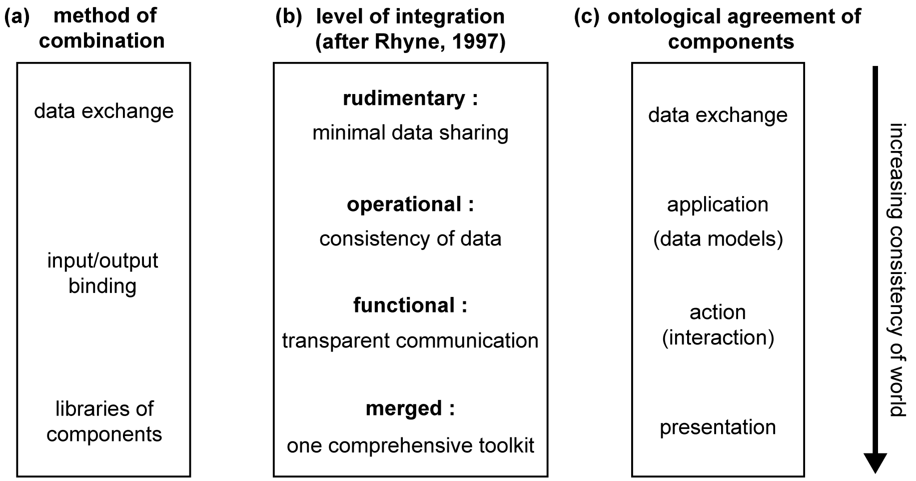

Figure 5.2. Methods of interaction between components for visualization: (a) method of combination; (b) levels of integration (Rhyne, 1997); (c) level of ontological agreement of components. Note that Rhyne’s model was designed specifically for geographic information and scientific visualization systems.

J. Dykes, A.M. MacEachren, M-J. Kraak (2005), Exploring Geovisualization, Pergamon, 732pp. 0-08-044531-4

Rhyne (1997) suggests a plan of interaction that provides a systematic framework to describe this problem – four levels of interaction: rudimentary, operational, functional and merged. These levels are shown in the centre portion of Figure 5.2, alongside representations of the two other integration themes just discussed – means of combining tools and level of world view consistency. Rhyne's levels relate specifically to the integration of geographic information and scientific visualization systems, but the concepts are relevant to our more general focus:

1. The rudimentary interaction level uses the minimum amount of data sharing and exchange. A significant obstacle is the situation where data are the same, but formats different. This requires expansion and adoption of standards for data exchange. Simply encouraging data exchange can however result in advances. A number of the current authors have shared data and applied their own different instruments to address various geovisualization issues and develop unique solutions.
2. The operational level attempts to provide consistency of operation, consistency of data, removal of redundancies and inconsistencies between technologies.
3. The functional level provides transparent communication between the components. Transparent communication implies that they can understand each other, without the use of a third party.
4. The merged level describes toolkits built from the ground up.

Note that the merged level is not necessarily the desired point to be achieved by all systems. It may be inappropriate or infeasible because, for example, the interaction and presentation aspects may be too tightly coupled to be consistent between different systems that it is desired to integrate. So, we might have current systems where we can interoperate across networks, platforms, even share and exchange components, but we cannot make either their ontologies (application and action) or their interfaces agree. Above that we have absolutely no idea about their underlying philosophies since they are not represented explicitly anywhere in the systems. This position is illustrated schematically in Figure 5.1.

Whilst various levels of integration of ideas and software components are possible, lessons from attempts to produce common components and standards in Computer Science indicate patchy success. In particular, difficulties arise because of the time taken to decide standards and the increased effort required by developers to meet the requirements. In the worst case, the effectiveness of the component produced can be severely compromised, because the standard does not implement required operations or forces inappropriate behaviour. As technology and perceived requirements change, so may the standards, invalidating legacy components. The evolving open source community offers a developing methodology and considerable experience in managing collaboration from which we can learn. The influence of powerful commercial organizations is also an important issue here. Such organizations can be very reluctant to contribute to coordinated efforts, either maintaining a proprietary system, or driving standards efforts towards their agendas. Yet, good examples exist whereby commercial organizations are successful partners in such projects. The possibility of extending such successes to geovisualization is a motivating challenge and demonstrates that tool developers should not preclude those with commercial interests from engaging in collaboration.

The potential rewards of common software approaches are indisputably appealing: the reuse of code avoiding re-inventing the wheel; the effective communication of ideas via the distribution of components; the rapid and efficient development of new tools based on a firm and dependable environment that contains a comprehensive collection of modules representing the current state of the art. And above all interoperability allows us to proceed at speed, to interact with computers rapidly and so quickly design, modify and interact with revealing views of our data to address our need to develop instruments for the reasons cited in this chapter and thus aid the process of ideation.

5.8 Summary

In introducing the variety of approaches and objectives reported in the chapters that follow in this section of *Exploring Geovisualization* we asked why we invent new instruments and whether we need to do so. The arguments that we have presented identify motivations relating to inter-related changes and variations in the technology and data available, the tasks identified, the skills and experience of users and the availability of associated expertise to fuel our research. These factors demonstrate the wide range of issues that should be considered by those supporting and performing geovisualization and account for the equally varied set of research issues and solutions demonstrated in our work. Our thoughts on interoperability demonstrate an opportunity and identify “re-use” as a key theme that transcends much of our work. At a high level, the re-use of concepts generated by the “ideas chasers” is important, as the advances that they make are adopted, adapted or rejected. Collaboration between people with different skills should be encouraged to foster new ideas. We should not underestimate the importance of ideas re-use as our knowledge of geovisualization improves along with our subject-area expertise. At a more technical level, increasing the various levels of interoperability offers us the opportunity to develop more efficient and flexible instruments to support ideation (see Dykes, this volume (Chapter 13)). And whilst each of the various levels of interoperability that we have identified may be appropriate under certain circumstances each also comes with a set of technical, social, operational and even geovisualization issues that must be resolved.

In addition, we believe that tool development has an important pedagogic aspect. When newly exposed to an existing body of tools researchers can sometimes bring novel ideas to the table. Whilst some “wheel re-invention” may take place when developing packages that largely duplicate existing tools, this can be minimized by taking advantage of existing resources and can equip researchers with the capabilities to develop new tools that expand upon and enhance current technology and techniques and address some of the issues raised here.

In this introduction, we have asked more questions than we have answered. However, further reading will show the "richness" of approaches represented by the chapter authors as each strives to create and use instruments for ideation relevant to the data, questions, tasks, and expertise that they and their users are interested in as technology advances. These solutions will undoubtedly be different, and will change as technologies, expectations and knowledge develop.

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