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Interacting with GIS

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The user interface of a GIS determines to a large extent how usable and useful that system is for a given task for a user. The usability of GIS has significantly improved in recent years, through changes in our understanding of what system use should achieve, which communication channels it should exploit, and in what form the interaction should occur. This chapter analyses these characteristics of human interaction with GIS, looking back at what has been accomplished in practice, and forward to what can be expected from current research and development efforts. The emphasis lies on an overview of interaction paradigms, modalities, and styles in GIS, rather than on an exemplary discussion of particular systems. While other chapters discuss cognitive, social, institutional, and economic factors affecting GIS usability, the emphasis here is upon the technical aspects, as they are investigated in the field of human–computer interaction.

1 INTRODUCTION

Over the past decade, human interaction with GIS has received increasing attention among researchers, developers, and users. In the 1970s and early 1980s, GIS–user interfaces were dominated by command-style query languages accessible only to expert users. In the second half of the 1980s, graphical user interfaces (GUIs) used the same syntactic structures, but hid them behind icons and menus. This development has primarily improved the familiarity of systems by reducing the need to memorise commands and by providing visual feedback to users.

In the late 1990s, the state-of-the-art in commercial GIS–user interfaces is characterised by the use of windows, icons, menus, and pointing devices (WIMP-style interfaces). These group related operations into understandable chunks and represent them in menus or visually through icons with elementary direct-manipulation operations, like selection by pointing and clicking, or moving by dragging. Their prevailing paradigm of interaction is that of querying a geographical database and presenting the results in maps and tables (Egenhofer and Herring 1993). The map is used as a presentation medium for query results in their spatial context and as a referencing mechanism to indicate location by pointing (Frank 1993). This paradigm has recently been carried over from GIS to digital map libraries where users browse through datasets in a similar style, providing an abstraction from the physical location of geographical datasets when querying or searching them (Smith 1996). The World Wide Web (WWW) offers easy and wide access to these kinds of geographical data (Coleman, Chapter 22).

The functionality offered by current GIS–user interfaces primarily includes the selection of data layers; the identification of objects by location, name, and elementary spatial relations; and the modification of graphical output parameters such as colours and patterns. Most GIS designers have attempted to provide users with a wide range of functions, allowing them to ask as many as possible of the following generic spatial and temporal questions (adapted from Rhind and Openshaw 1988):

where is … ?
what is at location …?
what is the spatial relation between …?
what is in a particular spatial relation to …?

what is similar to …?
where has … occurred?
what has changed since …?
what will change if …?
what spatial pattern(s) exist(s) and where are anomalies?

While current interaction styles represent a significant improvement over the state-of-the-art a decade ago (Frank and Mark 1991), they generally fall short of achieving the usability necessary to solve spatial problems without being a GIS specialist. The user interface itself too often remains an impediment to effective system use in problem-solving or decision-making (Medyckyj-Scott and Hearnshaw 1993).

The proliferation of so-called GIS viewers with reduced functionality, tailored to the inspection of datasets, has reduced the complexity of system use at the inevitable expense of losing more powerful operations (see Elshaw Thrall and Thrall, Chapter 23). Recent developments toward more flexible and adaptable interfaces have eased customisation, but have not resolved this dilemma. In the absence of GIS-specific interface design guidelines, a growing variety of layouts and arrangements have appeared, limiting the possibility for knowledge transfer from one system to the other and improving usability at best marginally. At the same time, modern application programming tools for interface and system design have become widely available and are being used to implement and customise GIS applications. These range from simple macro languages to sophisticated programming languages including such mechanisms as inheritance and polymorphism (Maguire, Chapter 25).

Several ongoing developments are now pointing the way towards interfaces that offer substantial improvements in the usability of GIS. Among them are the focus on specific tasks and on the operations needed to accomplish them (Davies and Medyckyj-Scott 1995). Examples of such tasks include map digitising, where productivity is dramatically influenced by usability (Haunold and Kuhn 1994), and the interaction with car navigation systems where drivers have specific and very limited needs for spatial information, such as distance to and direction of the next turn (Waters, Chapter 59). Virtual reality systems have demonstrated that the concurrent use of multiple modes of interaction dramatically increases the engagement of the user by coming closer to natural ways of interacting with the world itself rather than with maps or other static models of it (Neves and Câmara, Chapter 39; Jacobson 1992). The primary interaction modes beyond keyboard input and visual presentation are sketching and gesturing in the visual channel; speech and other sound input and output; tactile input and feedback. Novel interaction devices come with displays in a wide variety of sizes and resolutions, enabling interaction that is tailored to special user needs like field portability or group work (Florence et al 1996). The current emphasis on multimedia technologies, in particular on video, CD-ROMs and the WWW, increases both the need and the possibilities for spatial representations and interaction. Scientific visualisation is creating and manipulating worlds of its own, in which motion, perspectives, and multiple representations convey information otherwise hidden in datasets (see Anselin, Chapter 17). The traditional textual query languages assume a new role as 'intergalactic data speak' (Stonebraker et al 1990), supporting interoperability by allowing heterogeneous systems to exchange data with each other (Sondheim et al, Chapter 24). Most of these developments are happening outside of the GIS field and come with their own theories of interaction and collaboration. They are, however, rapidly becoming the determining factors shaping human interaction with GIS.

This chapter reviews the state-of-the-art in GIS query and manipulation languages, measures it against the current understanding of usability requirements, and proceeds to an outlook of how current scientific and technological developments will shape future GIS–user interfaces. A survey of existing query languages or of tools for data capture, data manipulation, and application programming lies beyond its scope. The chapter compiles and integrates the various ways of comparing GIS–user interfaces from a user perspective, offering an introduction to the commonly-used terminology and criteria. It is structured in the following way for classifying interaction languages:

- the interaction paradigms (e.g. querying, browsing, interviewing, analysing, updating, experiencing);
- the interaction modalities (e.g. text, speech and sound, graphics, animation and video, sketching);
- the interaction styles (e.g. command-line, direct manipulation, filtering, delegation).

2 INTERACTION PARADIGMS

People want to do different things with a GIS: some use it as a substitute for a collection of paper maps; others consider it a repository of geographical data that they want to feed into a simulation model; and others think of a GIS as a model of reality in which they want to find interesting places, configurations, and relationships. These differences in the use of a GIS reflect different understandings or paradigms of use (Kuhn 1992). Some of these have traditionally been dominant (querying, browsing, analysing) and are, therefore, better supported by current commercial GIS software than others (interviewing, updating, experiencing).

2.1 Querying

Querying refers to the retrieval of information from a database using a language with well-defined syntax and semantics. The concept is adopted from database systems, where the query language provides a uniform way to access stored data. The idea of a database query is that the user specifies properties of the desired result. For example, if one wanted to know the population of all capitals in the European Union (EU), the query should ask for the names and populations of those cities in Europe that are capitals of a country that is an EU member.

Query languages allow users to retrieve data not only as they were stored, but also in combinations through which information can be obtained that is not directly stored. The combinations are based on logical operators such as conjunction, disjunction, and negation, plus some simple arithmetics. Though different types of query languages exist, the most prominent kind of languages is based on the Structured Query Language (SQL: Worboys, Chapter 26; Melton 1996). Written in SQL, the above example could read as follows:

SELECT name, pop FROM cities, countries
WHERE name = capital AND eumember = 'true'.

The advantage of using a query language rather than low-level programming is that a query language works independently of the contents of a database and, consequently, is useful for different database schemata. This data independence guarantees access without having to worry about storage locations and formats. Furthermore, logical and numerical computations need not be programmed. The result is a very powerful data retrieval mechanism based on a simple syntax and clean semantics (Frank 1982).

However, these benefits have their limitations. First of all, the above example shows that the user needs to know how the data are structured in the relational tables (what attributes exist in what table and what they are called). Second, most users find it difficult to phrase their requests in expressions involving logical connectors (e.g. AND, OR) whose semantics clash with those of their natural language counterparts (Mark, Chapter 7; Reisner 1981), and systems perform poorly in constructing and comparing different nested queries (Luk and Kloster 1986). Third, different data models may expose different properties that cannot be addressed by one and the same query language. For example, the use of a relational query language for a system based on an object-oriented data model would not support particular object-oriented characteristics, such as identity, encapsulation and inheritance (Atkinson et al 1989). In a similar vein, spatial characteristics have required extensions to query languages, primarily for the inclusion of spatial relations to allow users to make selections based on high-level spatial properties (Egenhofer 1994). Such spatially-extended query languages are based on an extension of the relational algebra to include spatial data types and operators (Güting 1988).

For human interaction with a GIS as a whole, database query languages are obviously biased toward the retrieval of data (Egenhofer and Kuhn 1991). Although the term 'query language' has taken on a broader meaning in the context of GIS (Egenhofer and Herring 1993), most GIS query languages treat geographical data as sets of attributes that can be logically combined in multiple ways. A query is usually considered a separate, standalone interaction and the next query does not build on the context established by the answers to previous queries (Egenhofer 1992). The narrow focus of a query language makes it difficult to support other tasks, such as asserting whether a certain set of facts is true or exploring whether an interesting configuration can be found in a dataset.

2.2 Browsing

With the proliferation of spatial datasets, finding those datasets that are of interest to a user has become an essential task. Consider digital libraries or the whole WWW acting as a huge but unstructured repository for spatial datasets. In such contexts, users commonly have little knowledge about the contents of the available datasets and cannot specify precisely what they want to retrieve. The paradigm of querying does not help here, as it would require exact knowledge of the configurations sought in order to specify appropriate constraints in a query. Rather, users want to be able to browse the data collections, enabling them to recognise rather than having to describe the desired data. The issue is not to find a needle in the haystack, but to look in a haystack for a straw of a shape and texture that the user is unable to specify prior to seeing it. Even if a user were to apply a query language to start a browsing activity, the result set of such a query would usually be very large and require a tedious case-by-case examination.

Browsing, like querying, is content-oriented, as users are looking for datasets that contain specific configurations; however, browsing generally requires additional information at a higher level of abstraction. Traditionally, browsing in GIS has been limited to searching by file names, providing very little and arbitrary information about contents. The current approach is to supply aggregate information and descriptions of dataset properties as metadata. It attempts to ease the user's task of selecting a dataset without having to examine all choices in detail. Emerging metadata standards, however, focus more on what the data producers have to say than on what the data users need to know (Timpf and Raubal 1996). Important descriptors are often unstructured text fields whose content is subject to chance and interpretation. While users can query and read such metadata prior to purchasing, downloading, or examining a dataset, they cannot yet browse them the same way as they would skim newspaper headlines and perceive relevant articles at a glance.

Browsable meta-information tailored to user needs will require search engines incorporating intelligent agents. These can learn about a user's task, mine through geographical datasets, and extract representative subsets, effectively bridging the gap between user needs and data sources.

2.3 Interviewing

The interaction with traditional information systems can be seen as based on the metaphor of an interview with a single person. The user asks questions and the information system responds. If the interviewed system contradicts itself, the user starts to lose trust in its statements. As long as users perceive each information system as the integrated coherent collection of a single person's knowledge, this paradigm is not challenged.

With a new generation of information systems, however, the understanding of what it means to use an information system may change. These information systems exploit multiple distributed datasets, using them to generate query answers or suggestions supporting the user's decisions. Much like the text-based search engines available today on the WWW, such distributed GIS will face a huge number of dispersed and often isolated data collections. The paradigm for using such information systems changes from the interview with a single person to the interview with multiple and diverse informants or agents, some of them digital, some of them human. These interviewees all hear the same question and they answer when they believe they have something to contribute; however, they are located at different sites such that they generally do not hear each others' answers. Some use this opportunity sparsely and provide input only when they believe that they have something significant to contribute. Others may answer each and every question asked. Some in the audience may be experts in certain areas, whereas others may have a less sophisticated background, but still voice their views. Some may have had recent insights that may affect the answer to a question, while others may contribute their outdated views. Since interviewers hear the views of a group of people, they are expected to make better-informed decisions.

2.4 Analysing

The mere retrieval of stored data is often insufficient since users want to relate and combine data to 'see' patterns and connections among different data elements. Such connections may be visible in reality, but different data collection methods may have hidden them. Or they may be truly discovered through the process of spatial analysis (see Getis, Chapter 16 and Openshaw and Alvanides, Chapter 18 for overviews of competing spatial analysis discovery paradigms). Traditional database query languages offer only modest support for combining data in the form of joining tables over common attribute values. Finding other relationships requires further mathematical analysis, often using statistical or computational methods.

The most common analysis tool for combining data in GIS is the overlay operation. It integrates two or more thematic layers through various analytical operations in order to generate a new layer. Map algebra (Tomlin 1990) has been the common framework for such operations, allowing users to specify (1) what layers to combine, (2) with what operations, and (3) what to do with the result. For example, in order to find the probability of pieces of land near a river being flooded, a layer representing flood risk zones can be overlain with a cadastral layer.

While the source domain of the map overlay metaphor in GIS – stacking transparent sheets on top of each other on a light table (Steinitz et al 1976) – implies an arithmetic multiplication of the layers, the digital environment enables a much larger set of operations. Tomlin's semi-formal model is strictly raster-oriented, but corresponding overlay operations have also been implemented for vector data. Map algebra remains a core functionality in GIS–user interfaces, served by a variety of user interface styles from command line to iconic, direct-manipulation languages (Bruns and Egenhofer 1997; Kirby and Pazner 1990).

More advanced analysis operations rely on sophisticated spatial analysis techniques such as those explored in the spatial analysis chapters of the Principles part of this volume and by Eastman (Chapter 35). Their integration into spatial query languages (Svensson and Zhexue 1991) occurs in highly dispersed ways that have so far shown no common thread toward generic GIS analysis (Yuan and Albrecht 1995). The state-of-the-art solution is to adopt a 'toolbox' metaphor, allowing for an open collection of analysis tools, though often at the expense of limited usability.

2.5 Updating

Few geographical datasets are static and keep their currency and validity over extended periods of time. Updates, corrections, and the generation of 'what if?' scenarios are important operations through which users want to change geographical data. The changes include adding new data and modifying or removing existing data. Adding new data to a dataset means to embed the new data within the setting of existing data (see Peuquet, Chapter 8, for the case of temporal updating; and Goodchild and Longley, Chapter 40, for a discussion of the 'life of a dataset').

Most query languages offer some constructs for elementary updates, though not always in ways that readily support user tasks or are easy to learn and use. Special languages for data manipulation, on the other hand, are much less developed and standardised than query languages. The reason for this is their tight coupling to specific application requirements. For example, a language to design and modify the geometry of a cadastral database requires entirely different operations from one designed to maintain the accuracy of a statistical database (Kuhn 1990).

Operations to update geographical data can be classified according to their scope. At the elementary level, all manipulation involves changing a particular value or adding (deleting) an object. Both of these kinds of operations can apply to data themselves or to the schema of a database, although the latter is not always supported at the end-user interface of a GIS. At a higher level, these elementary operations can be aggregated to changes of value or object collections. Various constraints on these collective changes propagate down from the user's task (e.g. to split a parcel) to the elementary value and object level. In order to maintain the consistency of a database, the commitment of these changes has to be coordinated by transactions (Bédard, Chapter 29). Their granularity can vary from single value changes to modifications sweeping through entire databases. A key problem with current query and manipulation languages is that they operate primarily at lower levels, leaving the management of transactions to the discretion of organisational, rather than purely technical, considerations.

2.6 Experiencing

An entirely different paradigm of interaction with GIS is that of operating within the modelled world itself rather than asking questions about it or writing instructions for changes. Virtual reality, as an immersive variant of direct manipulation, offers this possibility (Neves and Câmara, Chapter 39). In the context of GIS, the idea of 'living' in the model rather than just looking at it has an immediate appeal. Since the phenomena modelled by GIS exist at human or larger scales, it appears natural to provide digital equivalents for human ways of interacting with the world, such as turning one's head, walking, driving, flying, gesturing, and manipulating objects. Systems providing these have been in use for years in applications like flight simulation or games. Their greatest potential for GIS lies in the possibility of overlaying sensory input from the real world with that from one or more models. These ideas have, however, not yet significantly influenced the traditional, map-oriented architectures of GIS interfaces (Kuhn 1991). For some years to come, the interface between our bodies and GIS models is likely to remain the tiny area of our fingertips (on a keyboard or mouse) and overlays will be limited to digital map layers.

3 INTERACTION MODALITIES

Communication between people exploits multiple modalities (spoken, written, gestured, graphical) which map onto different communication channels (visual, auditory, tactile). Each of the modalities has its own strengths and the unavailability of one or the other may seriously impede how people are able to interact with each other and with their environment. A key to successful communication is the appropriate combination and redundant use of different modalities: people gesture while talking, or annotate drawings with spoken or written text. Similar to communication among people, the choice of modalities plays a key role in the success or failure of the interaction between one or more users and a GIS. GIS have often been referred to as early examples of multimedia systems, integrating alphanumerical with map-like and other graphical representations. Ample opportunities for the use of modalities beyond static text and graphics exist and GIS query languages are increasingly making use of them. Almost no theory exists, however, on how to combine multiple modalities appropriately (Egenhofer 1996a).

3.1 Text

Text has been the principal mode for providing instructions to a GIS – be they typed or selected from menus or forms. Unlike in conventional information systems, however, the presentation of query results to a user in textual form has always been secondary to graphical presentations. This is partially so because most GIS replaced map use or production systems in instances where there was little need to convey text to users. Only with the advent of the requirement for data exchange among GIS did the emphasis on textual information strengthen, and ASCII text files have become a standard way to move data from one system to another. Text is then used to transmit attribute data as well as encoded geometry, but it is another system, not an interactive user, that requests the data.

Text input or output can come in more-or-less-structured form, ranging from free-form natural language texts, to structured tables, to expressions coded in a formal language. Independently of the form, however, textual descriptions of spatial situations are frequently ambiguous and may lead to misinterpretations (cf. the difficulties when using textual directions in way-finding). The use of traditional textual spatial query languages has serious limitations, because geographical concepts are often vague, imprecise, little understood, or not standardised (Fisher, Chapter 13). The dilemma is most apparent in the semantics of spatial terms (Mark, Chapter 7). What does it take to refer to something as a 'mountain' and when would it be more appropriate to call it a 'hill'? Likewise, what paths would qualify to 'cross' the Rocky Mountains and when is a restaurant really 'in town'? These difficulties make most current textual spatial query languages error-prone and difficult to use. They leave the interpretation of terms up to the designers, while users have to comply with their (often hidden) judgements.

On the other hand, the ambiguity inherent in textual descriptions of spatial situations can be exploited to express just that: situations that are not fully determined. Linguists and designers of visual languages have found that icons or sketches (see section 3.5) often over-specify spatial relations (Haarslev and Wessel 1997). For example, one can ask verbally for an object located 'outside' a region, while a corresponding icon always implies a certain distance and especially a direction from the region. In such cases, text is actually more appropriate than graphics or sketches to represent spatial configurations.

3.2 Speech and sound

Some situations of GIS use make it impractical to enter text by typing or selecting; for instance, when working with a mobile GIS in the field. Similarly, it can be preferable to receive output in spoken or other auditory rather than visual form, for instance when driving, assisted by a vehicle navigation system (Waters, Chapter 59). Speech recognition and synthesis techniques are today sufficiently advanced to allow effective communication in situations with a limited vocabulary and few users. An even more limited interaction language allows for a broader range of users (e.g. call-in information systems for public transportation schedules), and vice versa (e.g. text entry systems on a PC).

There are, so far, few examples of using sound in human interaction with GIS (see Shiffer, Chapter 52; Shiffer 1995; Weber 1997). Apart from the intrusiveness of sound in professional as well as private environments, lack of understanding of the role sound plays in cognition (e.g. to identify and locate objects) seems to hinder a broader use of this medium. Considering that sound plays a crucial, though often unconscious, role in our interaction with the world, it can be expected to become more important in GIS–user interfaces. An important reason for further development of auditory interfaces is that they represent the only practical modality supporting visually handicapped users in highly interactive settings.

3.3 Graphics

The strong traditional link between geographical information and graphical communication has led to a higher emphasis on graphics in GIS–user interfaces than in those of most other information systems. These graphics are predominantly maps, which have evolved to become the most sophisticated means of communication about geography during the past 3500 years. Most GIS offer at least some map output to present query results or support data entry. These screen maps are slowly becoming more versatile than simple digital versions of their paper ancestors, offering ways of interacting to refine a query or ask further queries. Users can often point to features on maps to obtain or enter information about them, select map features as input for operations, outline a zoom window to get a map with different contents at a larger scale, or select different layers of information.

In addition to maps, business graphics supply a graphic modality to represent attribute data by graphs and diagrams (e.g. see Elshaw Thrall and Thrall, Chapter 23). Where they occur in isolation, there is nothing that distinguishes them in a GIS from other software that visualises tabular data. Where they are combined with base maps, however, they achieve one of the most refined modes of representing information visually: thematic maps. The key interaction issue posed by them is how users can choose among symbolisation options and how system designers can provide reasonable default symbolisation (see Kraak, Chapter 11).

3.4 Animation and video

Moving pictures have yet to find their role in communicating geographical information in a GIS (but see Raper, Chapter 5). Attempts at using them have so far concentrated on video clips, offering more intuitive perspectives on buildings and landscapes than maps or textual descriptions can provide (Shiffer 1995; but see Batty, Chapter 21). While such animated views can be very useful (for instance, in a system assisting home buyers), they also consume considerable system and user resources and are difficult to integrate with other parts of a GIS–user interface. Nevertheless, video sequences represent highly valuable information sources within a GIS, and the real issue is to develop appropriate indexing and retrieval systems that can support users in monitoring changes. Time has been noted as a domain of considerable research and development efforts regarding GIS languages. These efforts focus on modelling aspects, but query languages will look very different depending on what kinds of models they support.

3.5 Sketching

Sketching has been used primarily for design tasks as they occur in computer-aided design (CAD) systems. SketchPad (Sutherland 1963) and ThingLab (Borning 1986) were initial approaches to formulate spatial constraints graphically, a principle that was later introduced to GIS interfaces (Egenhofer 1996b; Kuhn 1990). Sketching has also been explored to describe consistency constraints in spatial databases through the construction of situations that would establish unacceptable database states (Pizano et al 1989) or the definition of spatial relations by examples (Petersen and Kuhn 1991). These approaches have confirmed that sketches, like all graphic representations, are good at describing single configurations, but fail in scenarios that require multiple geometric specifications ('this or that', 'this without that') or topological information only ('across', 'outside'). Despite these shortcomings, sketching offers great potential for interaction with GIS when it is given its appropriate role (describing unique, but not exactly determined situations) and combined with other modalities (primarily speech; Egenhofer 1996a, 1996b). It also shows the way to a much more prominent role for gestures in interaction. The very limited understanding of how people assign meaning between speech, gestures, and other means of communication, however, still hinders the development of broadly usable interaction techniques along these lines.

4 INTERACTION STYLES

Independently of the chosen interaction paradigms and modalities, query and manipulation languages can be classified according to their interaction styles. The style of an interaction captures how users express queries or updates and how they receive results: by written commands, direct manipulation, dynamic queries, or delegation.

4.1 Command-line input

Command-line systems represented the state-of-the-art before GUIs became available in the early 1980s. Their syntax can be formally defined, making command interpreters and compilers relatively easy to create. For all their learnability and other usability problems, command-line systems have some definite advantages, particularly for experienced users. Macro commands are easy to write by grouping commands in a text file. Adding programming constructs, such as variables, functions, branching, and looping, can make the power and flexibility of a complete programming language available to the user. However, command-line interfaces have poor cognitive characteristics. The users are interacting through text only and a screen full of text has too high a density of information. Textual objects are more difficult to identify and locate on a screen than graphical objects. Also, typing is physically tiring and error-prone.

The major problems with command-line interfaces are: (1) determining the appropriate command for a task; (2) remembering its name and the names of variables; and (3) entering commands in the correct syntax. The last two problems are significantly reduced in form-based interfaces, which often come as parts of direct manipulation interfaces, but do not constitute a dominating GIS interaction style by themselves.

4.2 GUIs, WIMPs, and direct manipulation

Contemporary GUIs are essentially extensions of window-based operating systems. Such window environments depend on high-quality bit-mapped raster displays and some kind of pointing device (mouse, track ball, joystick etc.). This dependency explains why the terms WIMP (windows, icons, menus, and pointing devices) and GUI are often used interchangeably. GUIs have a much stronger visual component than command-line interfaces and have therefore also been called visual interfaces. The windows, icons, and menus determine the visual characteristics of the user interface.

Icons are symbolised pictorial representations for objects or operations in a user interface. The small space allocated to their pictorial part necessitates careful design and testing. Many icons found in current GIS–user interfaces are more important as place holders for commands (exploiting the user's spatial memory) than as symbols whose meaning can be understood on first sight. Icons can be enhanced through the use of animation or sound.

While most menus are textual, menus with graphics or icons, for instance in the form of tool bars, have become more popular. Dynamic or contextual menus constrain a user to allowable actions at any given time, significantly reducing the chance for errors. Windows allow users to switch rapidly and coherently between multiple tasks or multiple parts of a single task. Various strategies exist for managing the organisation of several screen windows.

Pointing and typing characterise the physical aspects of GUIs. Pointing is used to select objects and operations, typically within a window. For example, a map algebra or SQL expression may be created in a form by pointing to various icons and objects on a map. The users are still composing a command line, but instead of typing, they recognise and select tokens and the system does the typing.

The interaction style supported by GUIs or WIMPs has been introduced in practice by the Xerox Star development (Smith at al 1982) and in theory by Ben Shneiderman (Shneiderman 1983). Although the principles of direct manipulation are by now commonplace, they are far from always being satisfied in GIS interfaces and warrant careful consideration in every design process of the need for:

- visual presentation of objects and operations;
- visual presentation of results;
- rapid, incremental, and reversible operations;

- selection by pointing rather than typing;
- immediate and continuous feedback.

All variations of direct manipulation share a few key qualities: the appearance of and interaction with a system are based on metaphors and multiple metaphors need to be combined (Kuhn 1995; Mark 1992). When moving text in a wordprocessor or dragging a document icon to a folder, users are engaged in a multi-modal activity. What they see and what they do are closely coupled, both physically and conceptually.

Direct manipulation is an appropriate interaction style for the primarily visual operations in a GIS, like zooming, panning or map overlays. Historically, the process of map overlay has been a visual and tactile operation, presenting a rich source domain for direct manipulation metaphors. By enforcing a visual representation of data and operations, direct manipulation also fosters exploratory data analysis (Anselin, Chapter 17). Exploration requires a dynamic, absorbing, and engaging task environment. Users need to become less aware of the existence of the user interface and more immersed in their analytical tasks. Such genuinely empowering environments are still rare. The use of metaphors and direct manipulation alone does not automatically lead to them. The metaphors must draw on the visual and physical characteristics inherent in the user's understanding of a task.

4.3 Filtering

The consequent application of direct manipulation principles to querying led to a variety of interaction techniques that can best be characterised as interactive filters for spatial data. While traditional GIS query languages apply direct manipulation to the composition of queries which are then sent as commands to the database, interactive filters are directly evaluated while the user sets some parameters, with update rates in the order of 100 milliseconds. The effect is that users have a much greater sense of control over the database and an opportunity to 'play' with the data. This supports to a large extent the paradigm of exploration, and supports browsing as well as exploratory data analysis. Examples for such filtering techniques are dynamic queries, dynamic filters, and magic lenses.

Dynamic queries give users interactive control over the setting of query parameters, usually in the form of sliders or buttons (Shneiderman 1994). They were invented with GIS as one of the key applications in mind. An example is a dynamic 'home finder' with sliders for distances to two places, number of bedrooms, and cost, plus buttons for home type and home features. While the user manipulates these, a map displays the location of homes satisfying the criteria. Clicking at these points reveals detailed descriptions of homes.

Dynamic filters continuously control the density of information shown on screen and provide panning and zooming techniques to focus on portions of the displayed contents (Ahlberg and Shneiderman 1994). Magic lenses (Stone et al 1994) are yet another filtering tool that allows users to change the presentation of objects over which the lens is laid. For example, a portion of a topographic map can change into a weather map or a population map when a special lens is applied to it.

The exploratory nature of the filtering interaction style allows for discovering patterns in the data, forming and testing hypotheses about correlations, and identifying outliers. As such, filtering is a practical approach to interactive data mining (Fayyad et al 1996). Technical problems are posed by the bottleneck of accessing databases and displaying the data rapidly. A more fundamental issue is the application-specific nature of each interface: a home finder looks quite different from, say, a cancer rate visualisation tool. This shows again the persistent trade-off between generality and usability of interaction languages.

4.4 Delegation

Delegation is a style of interaction founded on a special, terse form of communication, where the system takes on the role of an agent or assistant to the user. It has the advantage of establishing a restricted, fairly simple, and familiar communication protocol. Delegation is often seen as an antithesis to direct manipulation (Negroponte 1989) and gets naturally associated with speech-based interaction. It has the potential to compensate for the negligence of the auditory channel in visual interfaces. By its terseness, delegation suits current speech recognition technology quite well. On the other hand, the difficulties of knowing what to ask for and of being able to express it, as well as the decoupling of input and output in the interaction process, have so far prevented successful delegation interfaces in GIS. A more fundamental obstacle is the lack of formal theories for talking about space (Mark and Gould 1991).

5 LOOKING AHEAD

The overview of various kinds of GIS interaction languages in this chapter has been written from a human–computer interaction perspective. It focused on paradigms, modalities, and styles of interaction, as developed in theory and practice over the past two decades. Today, user interface design and interaction research are increasingly driven by broader cognitive, social and economic concerns (Mark and Frank 1991; Nyerges et al 1995). Cognitive sciences investigate how people think and communicate about their applications or about space and how this affects the usability of technology (Mark, Chapter 7). Social studies focus on the role of technology in society, which is strongly influenced by system usability. Economic approaches such as business re-engineering study the core processes of organisations and how they can better be supported by interactive systems and shared databases (Campbell, Chapter 44). The impact of these developments goes beyond traditional GIS applications to areas where geographical information plays a role in decision-making, but GIS cannot yet be applied due to their complexity.

A conclusion emerging from our analysis of interaction issues is that GIS will probably never offer a common query language, let alone common ways of manipulating data. Such generic approaches attempt too much for too many different settings. Indeed, today's market shows a departure altogether from the idea of a GIS platform common to the large and rapidly expanding spectrum of applications. A wider perspective on geoprocessing is emerging, considering it an integral part of enterprise computing. This idea has forged the Open GIS Consortium (OGC, see *http://www.opengis.org*), a cooperative effort between researchers, developers, and users to standardise object-oriented software interfaces for open, interoperable GIS (Sondheim et al, Chapter 24). It is based on the consensus that standardising software interfaces (in the sense of an 'intergalactic data speak', i.e. relatively low-level data retrieval languages along the lines of extended SQL) while diversifying user interfaces will significantly improve overall usability.

In this scenario, integration will occur with other tools at the user sites (databases, spreadsheets, groupware, workflow management, etc.) rather than with GIS in other application domains. Application programming interfaces will support specific classes of GIS tasks and users much better than today. This change in thinking about GIS architectures is almost certain to affect GIS user interfaces at least as much as the introduction of visual interfaces.

With the integration of geoprocessing into mainstream computing comes also a chance to turn things around and use spatial forms of interaction in non-spatial applications (Kuhn 1996). Using spatial metaphors to structure interaction with non-spatial information is at least as old as the desktop metaphor (Smith et al 1982). More recent examples include the use of a landscape metaphor to visualise, explore, and query non-spatial data (Wise and Thomas 1995). With novel interaction paradigms like that of experiencing, and modalities like speech and gestures further developing, entirely new interaction styles along the lines of filtering will develop within and outside the GIS field. Space and spatial interaction, as fundamental categories of human cognition, will be one of their key characteristics.

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