The core of GIScience

a process-based approach

ITC Educational textbook series

UNIVERSITY OF TWENTE

FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

ITC

Chapter 10

Visualization and dissemination

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10.1 Visualization

10.1.1 GISs and maps

There is a strong relationship between maps and GISs. Maps play a role at any moment one uses a GIS. They can be used as input, to verify data, to prepare a spatial analysis and of course to present results. As soon as a "where?" crops up in a question, a map can often be the most suitable tool for solving the question and providing the answer. "Where do I find Enschede?" and "Where do ITC's students come from?" are both examples. Of course, the answers could be in non-map form, such as "in the Netherlands" or "from all over the world". These answers could be satisfying enough. However, it is clear that these answers do not give a full picture. A map would put these answers in a spatial context. It could show where in the Netherlands Enschede is to be found and where it is located with respect to Schiphol–Amsterdam airport, where most students arrive when they come to the Netherlands. A world map would refine the answer "from all over the world," since it reveals that most students come from Africa and Asia, and only a few come from the Americas, Australia and Europe, as can be seen in Figure 10.1.

As soon as the location of geographic objects is involved ("where?"), a map becomes useful. However, maps can do more than just provide information on location. They can also inform about the thematic attributes of the geographic objects to be found in them. An example would be "What is the predominant land use in southeast Twente?" The answer could, again, be just verbal and state "Urban." However, such an answer does not reveal patterns of land use. In Figure 10.2, a dominant northwest–southeast urban buffer can be clearly distinguished. Maps can answer the "What?" question only in relation to location (the map as a reference frame). A third type of question that can be answered from maps is related to "When?" For instance, "When did the Netherlands have its longest coastline?" The answer might be "1600," and this would probably be satisfactory for most people. However, it might be interesting to see how this has changed over the years. A set of maps as demonstrated in Figure 10.3 could provide the answer.

To summarize, maps can deal with questions/answers related to the basic components of spatial or geographic data: location (geometry), characteristics (thematic attributes) and time, and combinations thereof. As such, maps are the most efficient and effective means of transferring spatial information. The map user can locate geographic objects, while the shape and colour of signs and symbols representing the objects inform about their characteristics. They reveal spatial relations and patterns and offer the user insight into and overview of the distribution of particular phenomena. An additional characteristic of on-screen maps is that these are often interactive and have a link to a database; this allows for more complex queries.

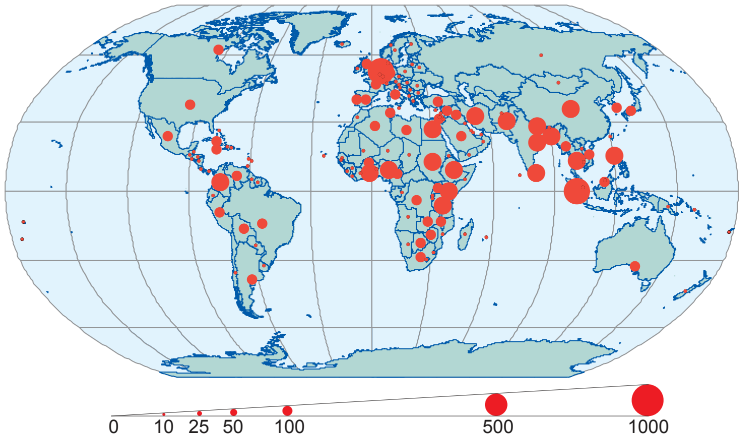

Figure 10.1
Maps and location: "Where do ITC cartography students come from?" Map scale is 1:200,000,000.

map as a model

Looking at these three sets of maps demonstrates an important quality of maps: the ability to offer an abstraction of reality. A map simplifies by leaving out certain details, but at the same time, when well designed, it puts the remaining information in a clear perspective. The map in Figure 10.1 only needs the boundaries of countries and a symbol to represent the number of students per country. In this particular case, there is no need to show cities, mountains, rivers or other phenomena.

This characteristic is well illustrated when one puts a map next to an aerial photograph or satellite image of the same area. Products such as the latter give all information observed by the capturing devices used. Figure 10.4 shows an aerial photograph of the ITC building and a map of the same area. The photograph shows all visible objects, including parked cars and small temporary buildings. From the photograph, it becomes clear that the weather, as well as the time of day, has had an influence on its contents: the shadow to the north of the buildings obscures other information. The map on the other hand, only gives the outlines of buildings and the surrounding streets. It is easier to interpret because of the selection/omission and classification of features. The symbolization chosen highlights the ITC building. Additional information, not available in the photograph, has been added, such as the name of the main street: Hengelosestraat. Other non-visible data, such as cadastral boundaries or even the sewerage system, could have been added in the same way. However, this also demonstrates that selection means interpretation, and there are subjective aspects to that. In certain circumstances, a combination of photographs and map elements can be useful.

There is a relationship between the effectiveness of a map for a given purpose and the

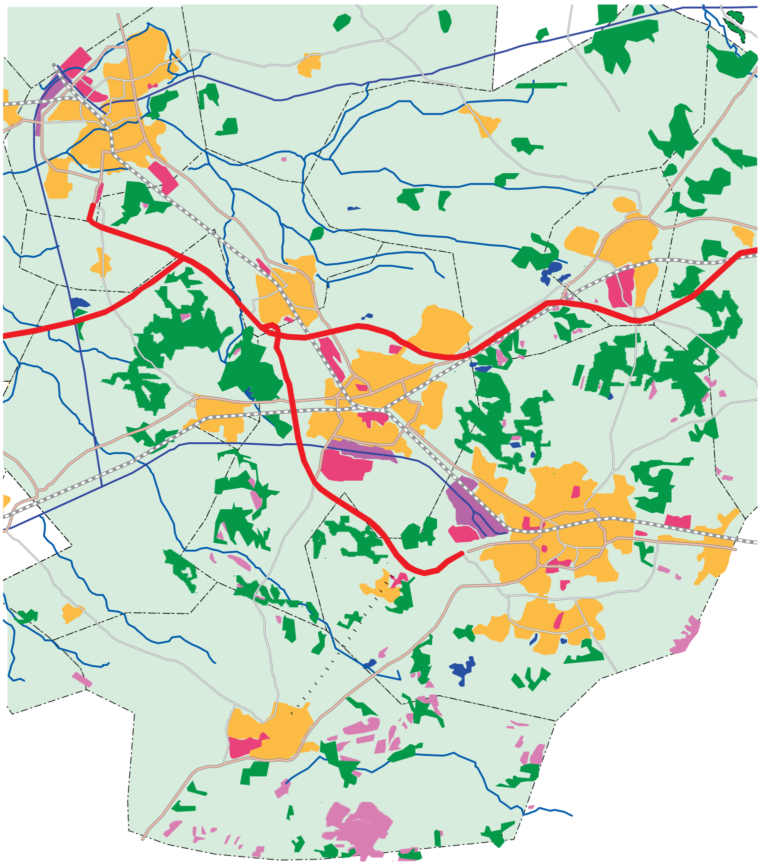

Figure 10.2
Maps and characteristics: "What is the predominant land use in southeast Twente?"

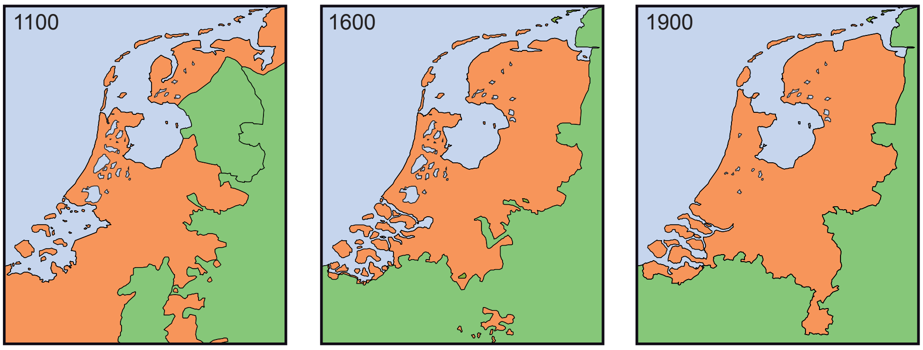

Figure 10.3
Maps and time: "When did the Netherlands have its longest coastline?"

map's scale. The Public Works department of a city council cannot use a 1:250,000 map for replacing broken sewer pipes, and the map of Figure 10.1 cannot be reproduced at scale 1:10,000. The map scale is the ratio between a distance on the map and the corresponding distance in reality. Maps that show much detail of a small area are called large-scale maps. The map in Figure 10.4 displaying the surroundings of the ITC building is an example of such a map. The world map in Figure 10.1 is a small-scale map. Scale indications on maps can be given verbally, such as "one-inch-to-the-mile", or as a representative fraction like 1:200,000,000 (1 cm on the map equals 200,000,000 cm (or 2000 km) in reality), or by a graphic representation such as the scale bar on the map in Figure 10.4b. The advantage of using scale bars in digital environments is that its length also changes when the map is zoomed in, or enlarged, before printing. Sometimes it is necessary to convert maps from one scale to another, which may lead to problems of cartographic generalization.

map definition

Having discussed several characteristics of maps, we are now able to define a map. Board [10] defines a map as "a representation or abstraction of geographic reality. A tool for presenting geographic information in a way that is visual, digital or tactile." The first sentence in this definition contains three key words. The "geographic reality" represents the object of study: i.e. our world. "Representation" and "abstraction" refer to models of these geographic phenomena. The second sentence reflects the appearance of the map. Can we see or touch it? Or is it stored in a database? In other words, a map is a reduced and simplified representation of the Earth's surface, or parts of it, on a plane.

Figure 10.4
Comparing an aerial photograph (a) and a map (b) of the same area.

Traditionally, maps have been divided into two sorts: topographic maps and thematic maps. A topographic map visualizes, limited by its scale, the Earth's surface as accurately as possible. This may include infrastructure (e.g. railways and roads), land use (e.g. vegetation and built-up areas), relief, hydrology, geographic names and a reference grid. Figure 10.5 shows a small-scale topographic map (with text omitted) of Overijssel, the Dutch province in which Enschede is located.

Thematic maps represent the distribution of particular themes. One can distinguish between socio-economic themes and physical themes. The map in Figure 10.6a, showing population density in Overijssel, is an example of the first and the map in Figure 10.6b, displaying the province's drainage areas, is an example of the second. As can be observed, both thematic maps also contain some information found in the topographic map (Figure 10.5), so as to provide a geographic reference to the theme represented.

The amount of topographic information required depends on the map theme. In general, a physical map will need more topographic data than most socio-economic maps, which normally only need administrative boundaries. The map of drainage areas should have had rivers and canals added, while the inclusion of relief would also have made sense. Today's digital environment has diminished the distinction between topographic and thematic maps. Often, both topographic and thematic maps are stored in a database as separate data layers. Each layer contains data on a particular topic and the user is able to switch layers on or off at will.

The design of topographic maps is mostly based on conventions, some of which date back several centuries. Take, for example the following colour conventions: water in blue, forests in green, major roads in red, and urban areas in black. The design of

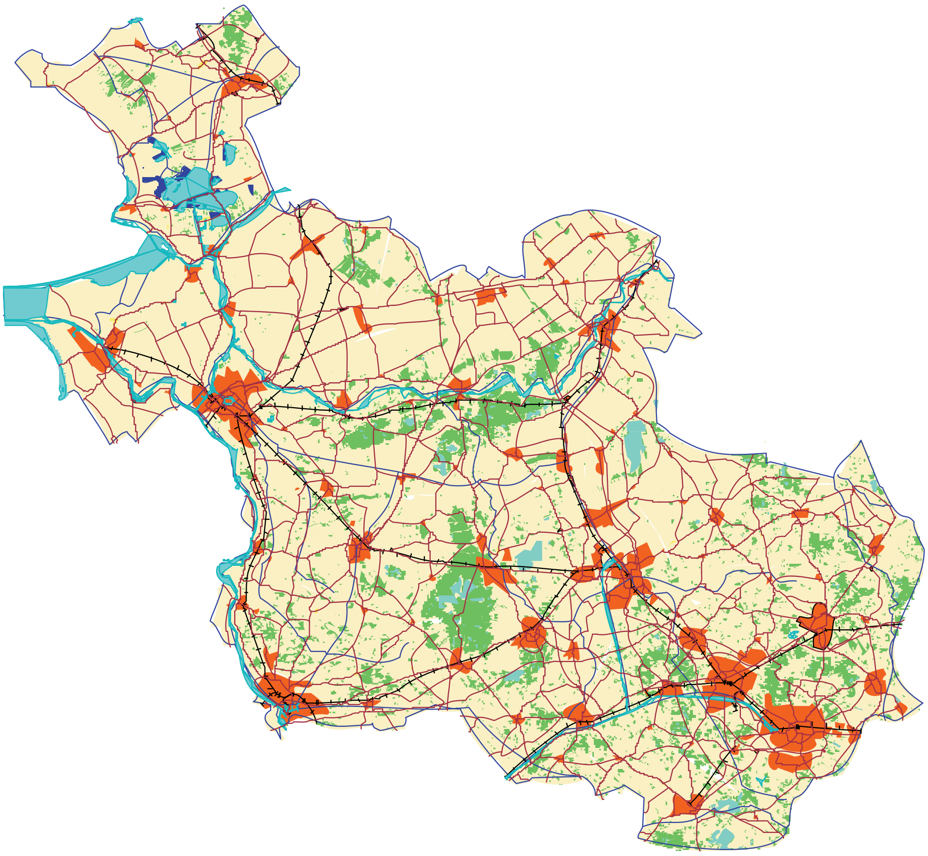

Figure 10.5
A topographic map of the province of Overijssel. Geographic names and a reference grid have been omitted for reasons of clarity.

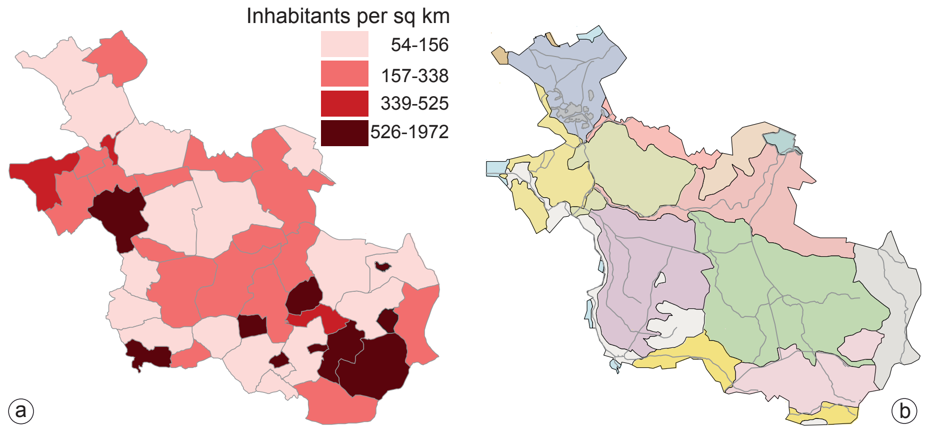

Figure 10.6
Thematic maps: (a) socio-economic thematic map, showing population density of the province of Overijssel (higher densities in darker tints); (b) physical thematic map, showing watershed areas of Overijssel.

thematic maps, however, should be based on a set of cartographic rules, also called *cartographic grammar*, which will be explained in Subsections 10.1.4 and 10.1.5 (but see also [60]).

cartographic grammar

Suppose that one wants to quantify land use changes in a certain area between 1990 and the current year. Two data sets (from 1990 and, say, 2008) can be combined with an overlay operation (see Section 9.4). The result of such a spatial analysis could be a spatial data layer from which a map can be produced to show the differences. The parameters used during the operation are based on models developed by the application at hand. It is easy to imagine that maps can play a role during this process of working with a GIS, by showing intermediate and final results of the GIS operations. Clearly, maps are no longer the only final product, which they used to be.

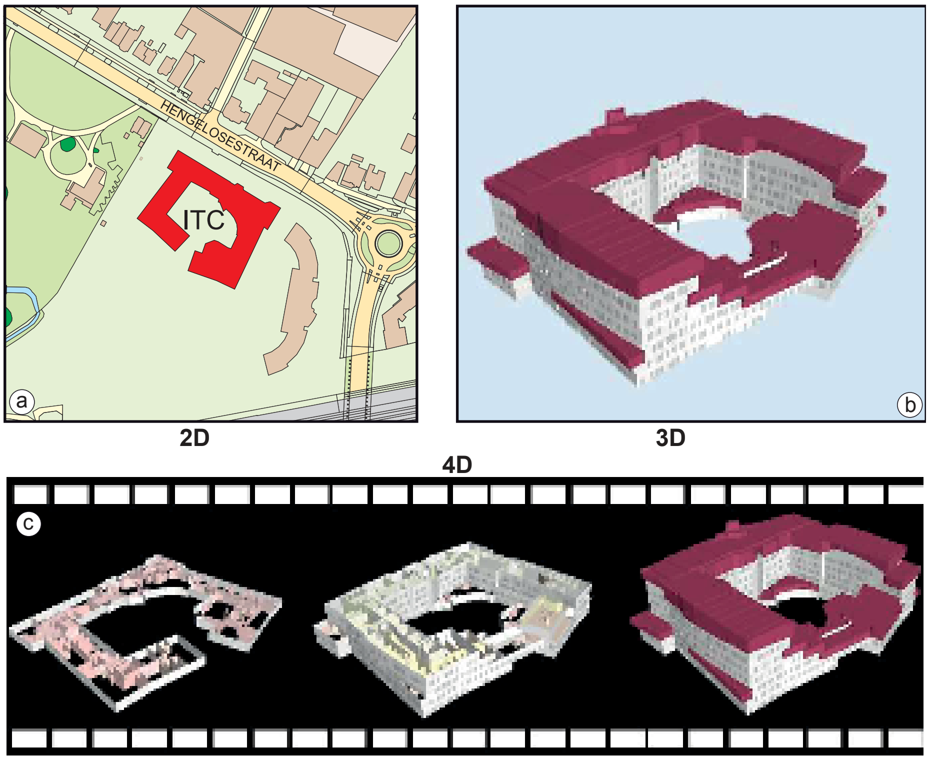

Figure 10.7
The dimensions of spatial data: (a) 2D, (b) 3D, (c) 3D with time.

Maps can further be distinguished according to the dimensions of spatial data that are graphically represented (Figure 10.7). GIS users also try to solve problems that deal with three-dimensional reality or with change processes. This results in a demand for other than just two-dimensional maps to represent geographic reality. Three-dimensional and even four-dimensional (namely, including time) maps are then required. New visualization techniques for these demands have been developed. Figure 10.7 shows the dimensionality of geographic objects and their graphic representation. Part (a) shows a map of the ITC building and its surroundings, while part (b) provides a three-dimensional view of the building. Figure 10.7c shows the effect of change, at three moments in time during the construction of the building.

10.1.2 The visualization process

The characteristic of maps and their function in relation to the spatial data handling process has been explained in the previous section. In this context, the cartographic visualization process is considered to be the translation or conversion of spatial data from a database into graphics, which are predominantly map-like products. During the visualization process, cartographic methods and techniques are applied. These can be considered to form a kind of grammar that allows for the optimal design and production of the maps, depending on the application (see Figure 10.8).

The producer of these visual products may be a professional cartographer, but they may also be an expert in a particular discipline, for instance someone mapping vegetation stands using remote sensing images or mapping health statistics in the slums of a city. To enable the translation from spatial data into graphics, we assume that the data are available and that the spatial database is well structured.

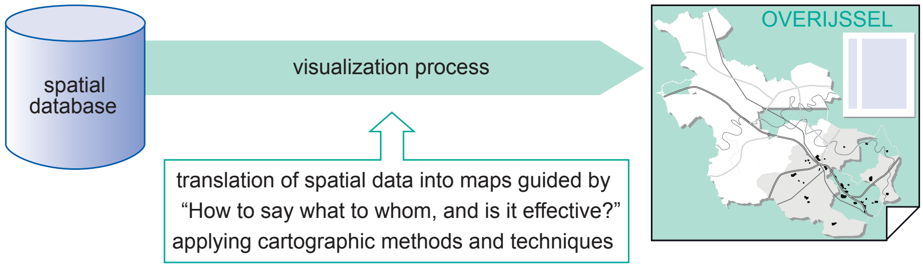

Figure 10.8
The cartographic visualization process.

The visualization process can vary greatly depending on where in the spatial-data handling process it takes place and the purpose for which it is needed. Visualizations can be, and are, created during any phase of the spatial-data handling process as indicated before. They can be simple or complex, while the production time can be short or long.

Some examples are the creation of a full, traditional topographic map sheet, a newspaper map, a sketch map, a map from an electronic atlas, an animation showing the growth of a city, a three-dimensional view of a building or a mountain, or even a real-time map display of traffic conditions. Other examples include "quick and dirty" views of part of the database, the map used during the updating process or during a spatial analysis. However, visualization can also be used for checking the consistency of the acquisition process or even the database structure. These visualization examples from different phases in the process of spatial data handling demonstrate the need for an integrated approach to geoinformatics. The environment in which the visualization process is executed can vary considerably. It can be done on a stand-alone, personal computer, a network computer linked to an intranet, or on the World Wide Web (WWW/Internet).

In any of the examples just given, as well as for the maps in this book, the visualization process is guided by the question "How do I say what to whom?" "How" refers to cartographic methods and techniques; "I" represents the cartographer or map-maker; "say" deals with communicating in graphics the semantics of the spatial data; "What" refers to the spatial data and its characteristics, (for instance, whether they are of a qualitative or quantitative nature); "Whom" refers to the map audience and the purpose of the map—a map for scientists requires a different approach than a map on the same topic aimed at children. All these issues will be elaborated upon in following subsections.

In the past, cartographers were often solely responsible for the whole map compilation process. During this process, incomplete and uncertain data often still resulted in an authoritative map. The maps created by a cartographer had to be accepted by the user: cartography, for a long time, was very much driven by supply rather than demand. In some respects, this is still the case. However, nowadays one accepts that just making maps is not the only purpose of cartography. The visualization process should also be tested for its effectiveness. To the proposition "How do I say what to whom" we have to add "and is it effective?" Based on feedback from map users, or knowledge about the effectiveness of cartographic solutions, we can decide whether improvements are needed, and derive recommendations for future application of those solutions. In particular, with all the visualization options available today, for example animated maps, multimedia and virtual reality, it is essential to test the effectiveness of cartographic methods and tools.

The visualization process is always influenced by several factors, i.e. the answers to questions:

- What will be the scale of the map: large, small, other? This introduces the problem of generalization. Generalization addresses the meaningful reduction of the map content during scale reduction.
- Are we dealing with topographic or thematic data? These two categories have traditionally resulted in different design approaches, as was explained in the previous subsection.
- More important for the design is the question of whether the data to be represented are of a quantitative or qualitative nature.

Some of these questions can be answered by just looking at the content of the spatial database.

We should understand that the impact of these factors/answers may increase, since the compilation of maps by spatial data handling is often the result of combining different data sets of different quality and from different data sources, collected at different scales and stored in different map projections. Cartographers have all kind of tools available to visualize the data. These tools consist of functions, rules and habits. Algorithms used to classify the data or to smooth a polyline are examples of functions. Rules tell us, for instance, to use proportional symbols to display absolute quantities or to position an artificial light source in the northwest to create a shaded relief map. Habits or conventions—or traditions as some would call them—tell us to colour the sea blue, lowlands green and mountains brown. The efficiency of these tools depends partly on the above-mentioned factors and partly on what map users are used to.

10.1.3 Visualization strategies: present or explore?

Traditionally, the cartographer's main task was the creation of good cartographic products. This is still true today. The main function of maps is to communicate geographic information, i.e. to inform the map user about location and the nature of geographic phenomena and spatial patterns. This has been the map's function throughout history. Well-trained cartographers are designing and producing maps, supported by a whole set of cartographic tools and theory as described in cartographic textbooks [105], [60].

Over the past few decades, many others have become involved in making maps. The widespread use of GISs has increased the number of maps made tremendously [69]. Even spreadsheet software commonly used in offices today has mapping capabilities, although most users are not aware of this. Many of these maps are not produced as final products, but rather as intermediaries to support the user in her/his work with spatial data. Hence, the map has started to play a completely new role: it is not only a communication tool, but also has become an aid in the user's (visual) thinking processes.

This thinking process is accelerated by continuing developments in hardware and software. New media such as CD-ROMs and the World Wide Web enable dynamic presentation and also user interaction. These have been accompanied by changing scientific and societal needs for georeferenced data and, as such, for maps. Users now expect immediate and real-time access to the data, data that have become abundant in many sectors of the geoinformation world. This abundance of data, seen as a "paradise" by some sectors, is a major problem in others. We lack the tools for user-friendly queries and retrieval when analysing the massive amount of (spatial) data produced by sensors, which is now available via the Word Wide Web. A new branch of science is currently evolving to deal with this problem of abundance. In the geo-disciplines, it is called visual data mining.

All these developments have enhanced the meaning of the term visualization. According to dictionaries, it means "to make visible" or "to represent in graphical form". It can be argued that, in the case of spatial data, this has always been the business of cartographers. However, progress in other disciplines has linked the word to more specific ways in which modern computer technology can facilitate the process of "making visible" in real time. Specific software toolboxes have been developed, and their functionality is based on two key words: *interaction* and *dynamics*. A separate discipline called scientific visualization has developed around those keywords [72] and it has also had an important impact on cartography. New discipline offers the user the possibility of instantaneously changing the appearance of a map. Interaction with the map will stimulate the user's thinking and will add a new functions to the map: it not only communicates, but also prompts thinking and decision-making.

interaction and dynamics

Developments in scientific visualization stimulated DiBiase [29] to define a model for map-based scientific visualization, also known as geovisualization, that covers both the presentation and exploration functions of the map (see Figure 10.9). Presentation is described as "public visual communication" since it concerns maps aimed at wide audiences. Exploration is defined as "private visual thinking" because it is often done by an individual playing with the spatial data to determine its significance. It is obvious that presentation fits into the traditional realm of cartography, where the cartographer works on known spatial data and creates communicative maps. Such maps are often created for multiple uses.

Exploration, however, often involves an expert in a particular discipline who creates maps while dealing with unknown data. These maps are generally for a single purpose, expedient in the expert's attempt to solve a problem. While dealing with the data, the expert should be able to rely on cartographic expertise provided by the software or some other means. Essentially, here the problem of translation of spatial data into cartographic symbols also needs to be solved. The above trends all have to do with what has been called by Morrison [77] the "democratization of cartography". As he explains it: "using electronic technology, no longer does the map user depend on what the cartographer decides to put on a map. Today the user is the cartographer . . . users are now able to produce analyses and visualizations at will to any accuracy standard that satisfies them."

Exploration means to search for spatial, temporal or spatio-temporal patterns, and relationships between patterns or trends. In the case of a search for patterns, a domain expert may be interested in aspects such as the distribution of a phenomenon, the occurrence of anomalies, or the sequence of appearances and disappearances. A search for relationships between patterns could include, for example, changes in vegetation indices and climatic parameters or locations of deprived urban areas and their distance to educational facilities. A search for trends could, for example, focus on developments in the distribution and frequency of landslides. Maps not only enable these types of searches; findings may also trigger new questions and lead to new visual exploration (or analysis).

What is unknown for one is not necessarily unknown to others. For instance, browsing in an atlas of the World on a DVD is an exploration for most of us, because of the wealth of information at our finger tips. With products like these, such exploration takes place within boundaries set by the producers. Browsing Google Earth is probably an adventure for everyone since everyone can add their own data! Cartographic knowledge is incorporated in the program, resulting in pre-designed maps. Some

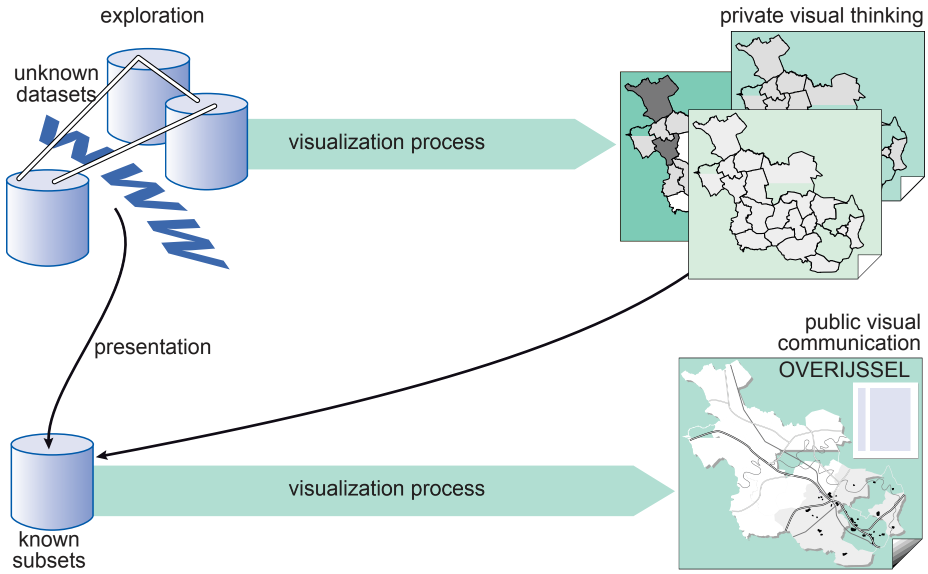

Figure 10.9
Private visual thinking and public visual communication.

users may feel this to be a constraint, but the same users will probably no longer feel constrained as soon as they follow the web links attached to this electronic atlas. This shows that the data, the users, and the user environment influence one's view of what exploration entails.

To create a map, one selects relevant geographic data and converts these into meaningful symbols for the map. In the past, printed maps had a dual function. They acted as a database of the objects selected from reality, and they communicated information about those geographic objects. The introduction of computer technology and databases, in particular, has created a split between these two functions of the map. The database function is no longer required for the map, although each map can still function like a database. The communication function of maps has not changed.

The sentence "How do I say what to whom, and is it effective?" guides the cartographic visualization process and summarizes the cartographic communication principle. Especially when dealing with maps in the realm of presentation cartography (Figure 10.9), it is important to adhere to cartographic design rules. This is to guarantee that the resulting maps are easily understood by their users.

How does this communication process work? Well, see Figure 10.10. The process starts with information to be mapped (the "What" from the sentence). Before anything can be done, the cartographer should get a feel for the nature of the information, since this determines the graphical options; cartographic information analysis provides that feel. From this knowledge, the cartographer can choose the correct symbols to represent the information in the map. Cartographers have a whole toolbox of visual variables available to match symbols with the nature of the data. For the rules, see Subsection 10.1.4.

In 1967, the French cartographer Bertin published the basic concepts of the theory of map design in his book Sï£¡miologie Graphique [7]. He provided guidelines for making good maps. Nevertheless, if 10 professional cartographers were given the same mapping task and each were to apply Bertin's rules (see Subsection 10.1.4, this would still result in 10 different maps. For instance, if the guidelines dictate the use of colour, it is not stated which colours should be used. Still, all 10 maps could be of good quality.

Returning to the scheme, the map (the medium that does the "say" in our sentence above) is read by the map users (the "whom" from the sentence). They extract some information from the map, represented by the box entitled "Info retrieved". From the figure it becomes clear that the boxes with "Information" and "Info retrieved" do not overlap. This means the information derived by the map user is not the same as the information that the cartographic communication process started with.

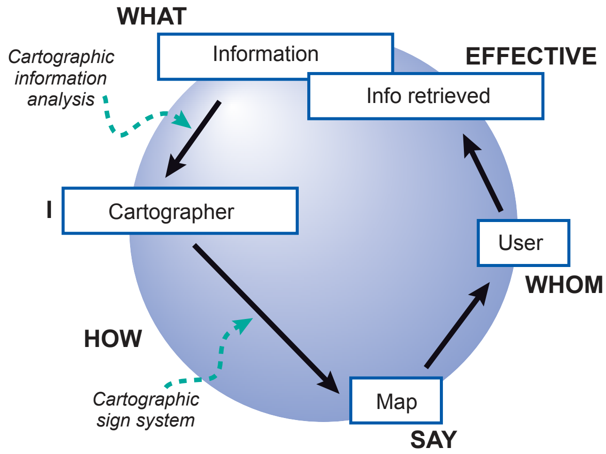

Figure 10.10
The cartographic communication process, based on "How do I say what to whom, and is it effective?"

There may be several causes for this. Perhaps all the original information was not used or perhaps additional information was added during the process. Perhaps the cartographer deliberately omitted information with the aim of emphasizing the remaining information. Another possibility is that the map user does not understand the map fully. Information gained during the communication process could be the result of the cartographer adding extra information to strengthen the information already available. It is also possible that the map user has some prior knowledge on the topic or area, which would allow him or her to combine this prior knowledge with knowledge retrieved from the map.

10.1.4 The cartographic toolbox

What kind of data do I have?

To find the proper symbology for a map one has to analyse the cartographic data. The core of this process of analysis is to access the characteristics of the data to find out how they can be visualized, so that the map user will interpret them properly. The first step in the analysis process is to find a common denominator for all the data. This common denominator will then be used as the title of the map. For instance, if all data are related to land use collected in 2005, the title could be "Land use of . . . 2005". Second, the individual component(s), such as land use, and probably relief, should be analysed and their nature described. Later, these components should be visible in the map legend.

We have already discussed different kinds of data values in Section 8.1 in relation to the types of computations we can do on them. Now it is time to look at the different types of data in relation to how they might be mapped or displayed.

data types

Data will be of a qualitative or quantitative nature. Qualitative data is also called nominal data, which exists as discrete, named values without a natural order amongst the values. Examples are different languages (e.g. English, Swahili, Dutch), different soil types (e.g. sand, clay, peat) or different land use categories (e.g. arable land, pasture). In the map, qualitative data are classified according to disciplinary insights, such as a soil classification system represented as basic geographic units: homogeneous areas associated with a single soil type, recognizable by the soil classification.

Quantitative data can be measured, either along an interval or ratio scale. For data measured on an interval scale, the exact distance between values is known, but there is no absolute zero on the scale. Temperature is an example: 40 °C is not twice as hot as 20 °C, and 0 °C is not an absolute zero.

Quantitative data with a ratio scale do have a known absolute zero. An example is income: someone earning $100 earns twice as much as someone with an income of $50. In order to generate maps, quantitative data are often classified into categories according to some mathematical method.

In between qualitative and quantitative data, one can distinguish ordinal data. These data are measured along a relative scale and are as such based on hierarchy. For instance, one knows that a particular value is "more" than another value, such as "warm" versus "cool". Another example is a hierarchy of road types: "highway", "main road", "secondary road" and "track". The different types of data are summarized in Table 10.1.

Table 10.1
Differences in the nature of data and their measurement scales.

Measurement scale	Nature of data
Nominal, categorical	Data of different nature / identity of things (qualitative)
Ordinal	Data with a clear element of order, though not quantitatively determined (ordered)
Interval	Quantitative information with arbitrary zero
Ratio	Quantitative data with absolute zero

How can I map my data?

Basic elements of a map, irrespective of the medium on which it is displayed, are point symbols, line symbols, area symbols, and text. The appearance of point, line, and area symbols can vary depending on their nature. Most maps in this book show symbols in different size, shape and colour. Points can vary in form or colour to represent the location of shops or they can vary in size to represent aggregated values (e.g. number of inhabitants) for an administrative area. Lines can vary in colour to distinguish between administrative boundaries and rivers, or vary in shape to show the difference between railroads and roads. Areas follow the same principles: differences in colour distinguishes between different vegetation.

map symbology

Although variations in the appearance of symbols are only limited by the imagination, there are a few categories into which they can be grouped. Bertin [7] distinguished six categories, which he called the visual variables, which may be applied to point, line and area symbols. As illustrated in Figure 10.11, the symbols are:

- size;
- value (lightness);
- texture;
- colour;

- orientation; and
- shape.

These visual variables can be used to make one symbol different from another. In doing this, map-makers have, in principle, freedom of choice, provided they do not violate the rules of cartographic grammar. They do not have any such choice when deciding where to locate the symbol in the map: the symbol should be located where the feature belongs. Visual variables influence the map user's perception in different ways. What is perceived depends on the human capacity to see:

- what is of equal importance (e.g. all red symbols represent danger), saturation differences;
- order (e.g. the population density varies from low to high—represented by light and dark colour tints, respectively);
- quantities (e.g. symbols changing in size with small symbols for small amounts); and
- instant overview of the mapped theme.

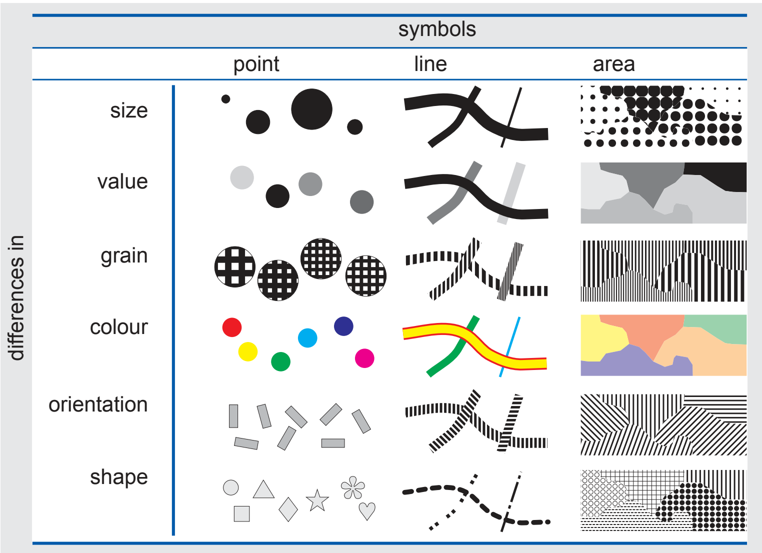

Figure 10.11
Bertin's six visual variables illustrated.

There is an obvious relationship between the nature of the data to be mapped and the "perception properties" of visual variables. In Table 10.2, the measurement scales as defined in Table 10.1 are linked to the visual variables displayed in Figure 10.11. "Dimensions of the plane" is added to the list of visual variables; it is the basis, used for the proper location of symbols on the plane (map). The perception properties of the remaining visual variables have been added. In the next subsection we discuss some typical mapping problems and demonstrate the use of the principles that have been outlined.

Table 10.2
Measurement scales linked to visual variables based on perception properties.

Perception properties	Visual variables	Measurement scales Nominal	Ordinal	Interval	Ratio
	Dimensions of the plane	x	x	x	x
Order & quantities	Size		x	x	x
Order	(Grey) value		x	x	
	Grain/texture		x	x	
Equal importance	Colour hue	x			
	Orientation	x			
	Shape	x			

10.1.5 How to map . . . ?

This subsection deals with characteristic mapping problems. We first describe a problem and then briefly discuss a solution based on cartographic rules and guidelines. The need to follow these rules and guidelines is illustrated by some maps that have been poorly designed—but are nevertheless commonly found.

How to map qualitative data

If, after a long period of fieldwork, someone has finally delineated the boundaries of a province's watersheds, probably they will be interested in making a map showing these areas. The geographic units in the map will have to represent the individual watersheds. In such a map, each of the watersheds should get equal attention; none should stand out above the others.

The application of colour would be the best solution since is has characteristics that allow one to quickly differentiate between different geographic units. However, since none of the watersheds is more important than the others, the colours used have to be of equal visual weight or brightness. Figure 10.12 gives an example of a map in which colour has been used correctly. The readability is influenced by the number of displayed geographic units. In this example, there are about 15. When this number is much higher, the map, at the scale displayed here, will become too cluttered. The map can also be made by depicting the watershed areas with different forms (small circles, squares, triangles, etc.) in one colour (e.g. black for a monochrome map)—as an application of the visual variable "shape". The amount of geographic units that can be displayed is then even more critical.

Figure 10.13 shows two examples of how not to create such a map. In (a), several tints of black are used—as an application of the visual variable "value". Looking at the map may cause perceptual confusion since the map image suggests differences in importance that are not there in reality. In Figure 10.13b, colours are used instead. However, where most watersheds are represented in pastel tints, one of them stands out because of its bright colour. This gives the map an unbalanced look. The viewer's eye will be distracted by the bright colours, resulting in unjustified weaker attention for other areas.

How to map quantitative data

If, after executing a census, one would like to create a map of the number of people living in each municipality, one would be dealing with absolute quantitative data. The geographic units will logically be the municipalities. The final map should allow the user to determine the amount per municipality and also offer an overview of the geo-

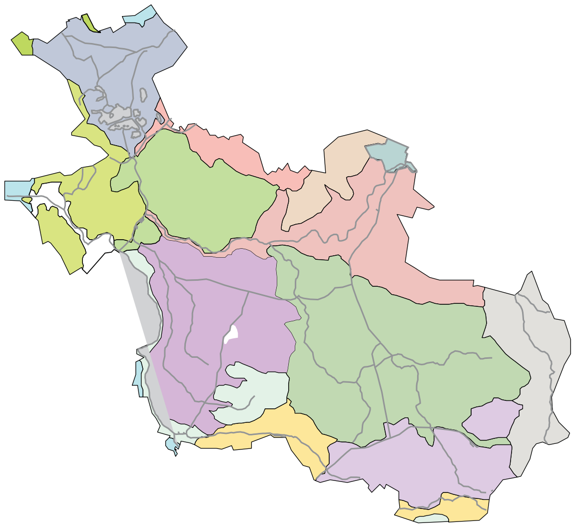

Figure 10.12
A good example of a well designed map.

graphic distribution of the phenomenon. To achieve this objective, the symbols used should possess properties that facilitate quantitative perception. Symbols varying in size would fulfill this demand. Figure 10.14 shows the final map of inhabitants in the province of Overijssel.

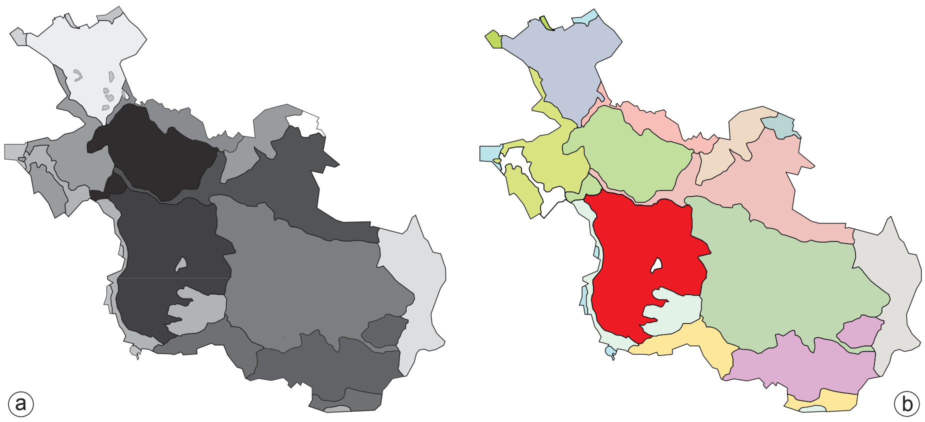

Figure 10.13
Two examples of poorly designed qualitative maps: (a) misuse of tints of black; (b) misuse of bright colours.

The fact that it is easy to make errors can be seen in Figure 10.15. In Figure 10.15a, different tints of green (the visual variable "value") have been used to represent absolute population numbers. The reader might get a reasonable impression of the individual amounts but not of the actual geographic distribution of the population, as the size of the geographic units will influence the perceptional properties too much. Imagine a small and a large unit having the same number of inhabitants. The large unit would visually attract more attention, giving the impression there are more people than in the small unit. Another issue is that the population is not necessarily homogeneously distributed within the geographic units.

Colour has also been misused in Figure 10.15b. The four-colour scheme applied makes it is impossible to infer whether red represents more-populated areas than blue. It is impossible to instantaneously answer a question like "Where do most people in Overijssel live?"

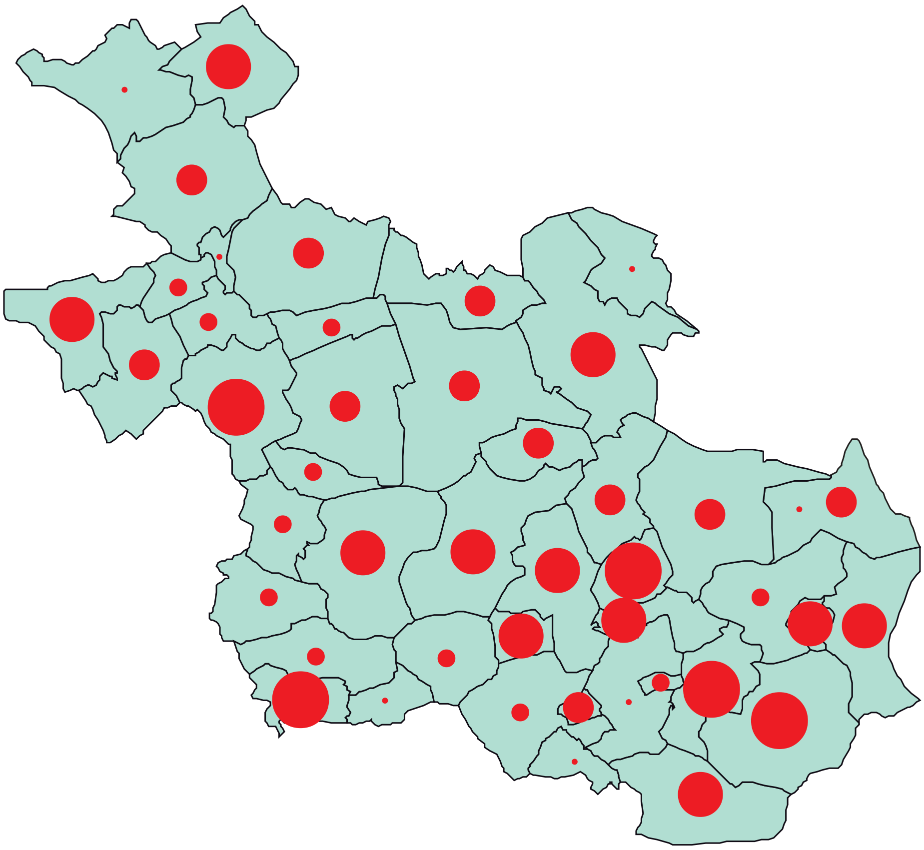

Figure 10.14
Mapping absolute quantitative data.

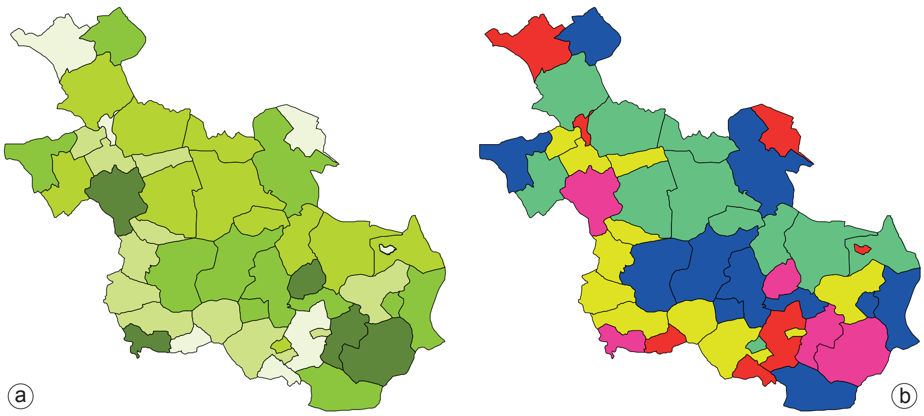

Figure 10.15
Poorly designed maps displaying absolute quantitative data: (a) incorrect use of green tints for absolute population figures; (b) incorrect use of colour.

On the basis of absolute population numbers per municipality and their geographic size, we can also generate a map that shows population density per municipality. We are then dealing with relative quantitative data. The numbers now have a clear relation with the area they represent. The geographic unit will again be "municipality". The aim of the map is to give an overview of the distribution of the population density. In the map of Figure 10.16, value has been used to display the density from low (light tints) to high (dark tints). The map reader will automatically, at a glance, associate the dark colours with high density and the light colours with low density.

Figure 10.17a shows the effect of incorrect application of the visual variable “value”. In this map, the value tints are out of sequence. The user has to go to quite some trouble to find out where in the province the high-density areas can be found. Why should the lighter, mahogany-red represent areas with a higher population density than darker, burgundy-red. In Figure 10.17b colour has been used in combination with value. The first impression of the map reader would be to think that the brown areas represent those areas with the highest density. A closer look at a legend would tell you that this is not the case and that those areas are represented by another colour that does not “speak for itself”.

If one studies the poorly designed maps carefully, the information can be derived in one way or another, but it takes quite some effort to do so. Proper application of cartographic guidelines guarantee that this will go much more smoothly (e.g. faster and with less chance of misunderstanding).

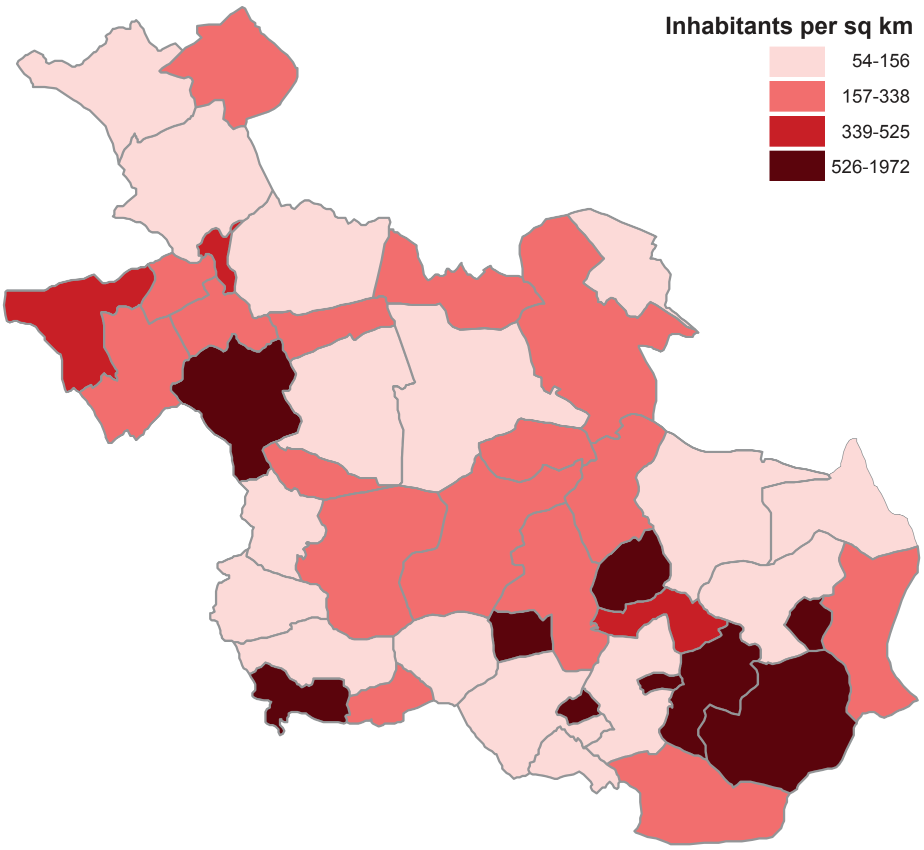

Figure 10.16
Mapping relative quantitative data.

How to map terrain elevation

Terrain elevation can be mapped using various methods. Often, one will have collected an elevation data set for individual points such as peaks, or other characteristic points in the terrain. Obviously, one can map the individual points and add the height information as text. However, a contour map, in which the contour lines connect points of equal elevation, is generally used. To visually improve the information content of such a map, the space between the contour lines can be filled with colour

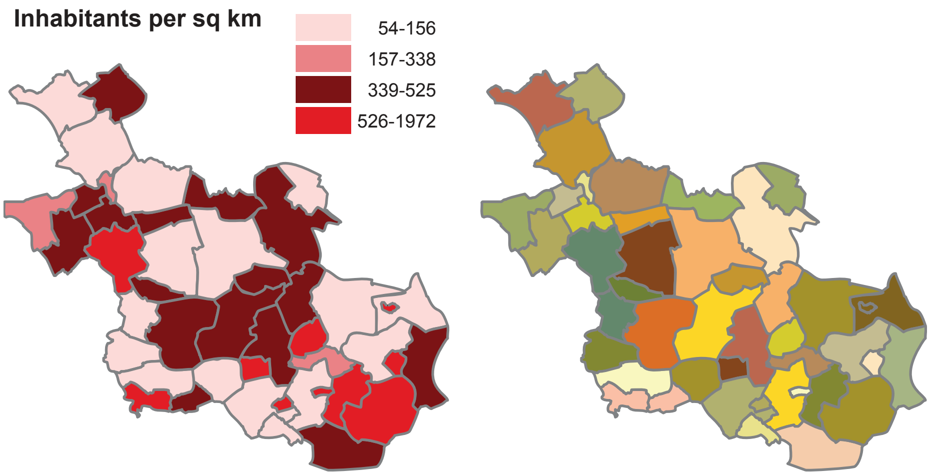

Figure 10.17
Poorly designed maps representing relative quantitative data: (a) lightness values used out of sequence; (b) colour should not be used.

and value information following a convention, e.g. green for low elevation and brown for areas of high elevation. This technique is known as hypsometric or layer tinting.

Even more advanced is the addition of shaded relief. This will improve the impression of three-dimensional relief (see Figure 10.18). The shaded-relief map uses all three-dimensional information available to create shading effects. This map, represented on a two-dimensional surface, can also be floated in three-dimensional space to give it the real three-dimensional appearance of a "virtual world", as shown in Figure 10.18d. Looking at such a representation, one can immediately imagine that it will not always be effective. Certain (low) objects in the map will easily disappear behind other (higher) objects. Interactive functions are required to manipulate the map in three-dimensional space in order to look behind some objects. These manipulations include panning, zooming, rotating and scaling.

Scaling is needed particularly along the z-axis since some maps require small-scale elevation resolution, while other require large-scale resolution, i.e. vertical exaggeration. One can even imagine that other geographic, three-dimensional objects (for instance, the built-up area of a city and individual houses) have been placed on top of the terrain model, as is done in Google Earth. Of course, one can also visualize objects below the surface in a similar way, but this is more difficult because the data to describe underground objects are sparse.

Socio-economic data can also be viewed in three dimensions. This may result in dramatic images that will be long remembered by the map user. Figure 10.19 shows the absolute population figures of Overijssel in three dimensions. Instead of using proportionally sized circles to depict the number of people living in a municipality (as we did in Figure 10.14), the proportional height of a municipality now indicates total population. The image clearly shows that the municipality of Enschede (the largest column to the lower right) has by far the highest population.

How to map time series

The third dimension of GIS routines is no longer reserved solely for advanced handling of spatial data. Nowadays, the handling of time-dependent data is also a feature of these routines, a consequence of the increasing availability of data captured at different periods in time. In addition to this abundance of data, the GIS community wants to analyse changes caused by real-world processes. To that end, single time-slices of data are no longer sufficient and the visualization of these processes cannot

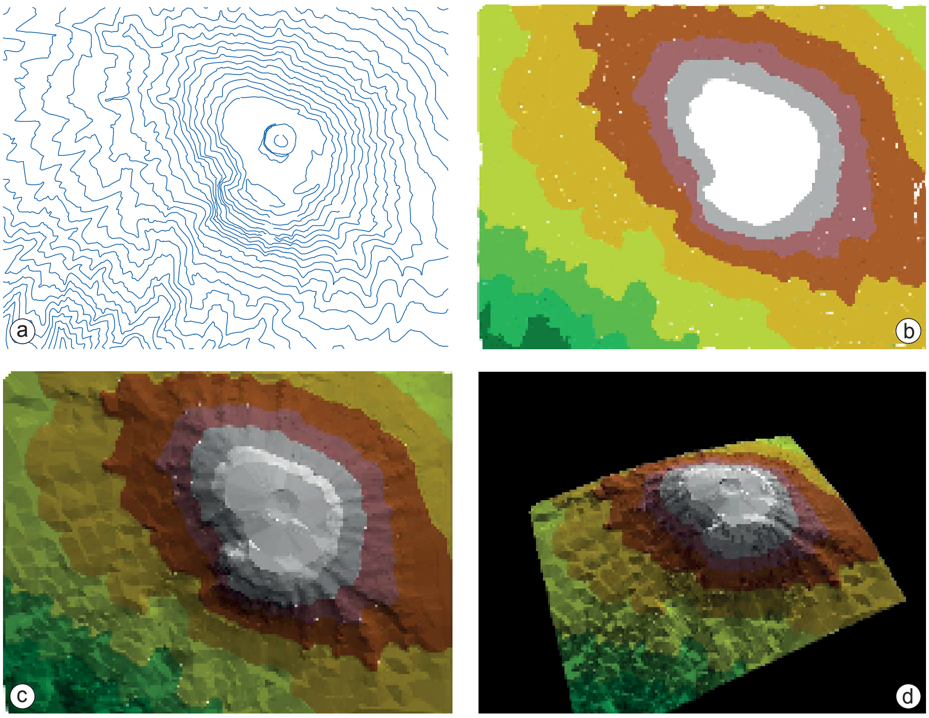

Figure 10.18
Visualization of terrain elevation: (a) a contour map; (b) a map with layer tints; (c) a shaded-relief map; (d) 3D view of the terrain.

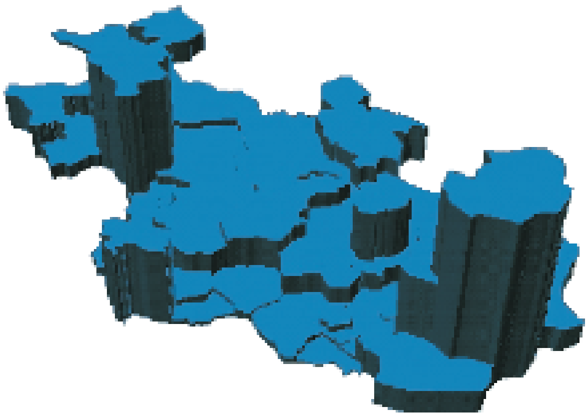

Figure 10.19
Quantitative data visualized in three dimensions.

be supported by only static, printed maps.

Mapping time means mapping change. This may be change in a feature's geometry, in its attributes, or both. Examples of changing geometry are the evolving coastline of the Netherlands (as displayed in Figure 10.3), the location of Europe's national boundaries, or the position of weather fronts. Changes in the ownership of a land parcel, in land use or in road traffic intensity are other examples of changing attributes. Urban growth is a combination of both: urban boundaries expand with growth and simultaneously land use shifts from rural to urban. If maps are to represent events like these, they should be suggestive of such change.

Suggestion of change implies the use of symbols that are perceived as representing change. Examples of such symbols are arrows that have an origin and a destination. These are used to show movement and their size can be an indication of the magnitude of change. Size changes can also be applied to other point and line symbols to show increase and decrease over time. Specific point symbols such as “crossed swords” (battle) or “lightning” (riots) can be found to represent dynamics in historic maps. Another alternative is the use of the visual variable value (expressed as tints). In a map showing the development of a town, dark tints represent old built-up areas, while new built-up areas are represented by light tints (see Figure 10.20a).

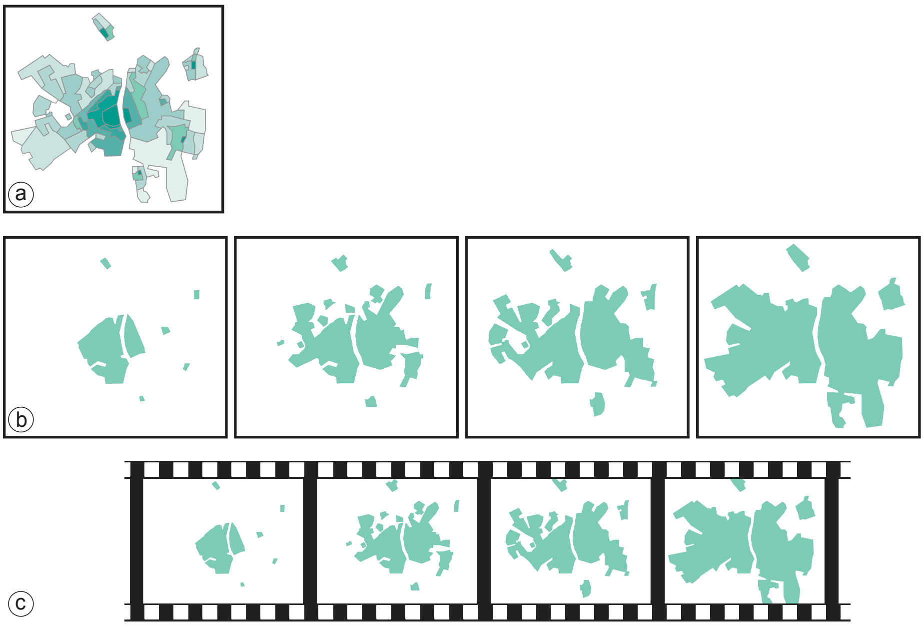

Figure 10.20
Mapping change; example of the urban growth of the city of Maastricht, The Netherlands: (a) single map, in which tints represent age of the built-up area; (b) series of maps; (c) (simulation of an) animation.

Three temporal cartographic techniques can be distinguished (see Figure 10.20):

- *Single static map* Specific graphic variables and symbols are used to indicate change or represent an event. Figure 10.20a applies the visual variable “value” to represent the age of built-up areas;
- *Series of static maps* A single map in the series represents a “snapshot” in time. Together, the maps depict a process of change. Change is perceived by the succession of individual maps depicting the situation in successive snapshots. It could be said that the temporal sequence is represented by a spatial sequence that the user has to follow to perceive the temporal variation. The number of images should be limited since it is difficult for the human eye to follow long series of maps (Figure 10.20b);
- *Animated map* Change is perceived to evolve in a single image by displaying several snapshots one after the other, just like a video clip of successive frames. The difference from the series of maps is that the variation can be deduced from real “change” seen taking place in the image itself, not from a spatial sequence (Figure 10.20c). For the user of a cartographic animation, it is important to have tools available that allow for interaction while viewing the animation. Seeing an animation play will often leave users with many questions about what they have seen. And just replaying the animation is not sufficient to answer questions like “What was the position of the northern coastline during the 15th century?” Most of the general software packages for viewing animations already offer facilities

such as “pause” (to look at a particular frame) and ‘(fast-)forward’ and ‘(fast-)backward’, or step-by-step display. More options have to be added, such as the possibility to go directly to a certain frame based on a task command like: “Go to 1850”.

10.1.6 Map cosmetics

Most maps in this chapter are correct from a cartographic grammar perspective. However, many of them lack the additional information needed to be fully understood that is usually placed in the margin of printed maps. Each map should have, next to the map image, a title to inform the user of the topic visualized. A legend is necessary to understand how the topic is depicted. Additional marginal information to be found on a map is a scale indicator, a North arrow for orientation, the map datum and map projection used, and some lineage information, (such as data sources, dates of data collection and methods used). Furthermore, information can be added that indicates when the map was issued and by whom (author/publisher).

All this information allows the user to obtain an impression of the quality of the map and is comparable with meta-data describing the contents of a database or data layer. Figure 10.21 illustrates these map elements. On printed maps, these elements (if all are relevant) have to appear next to the map face itself. Maps presented on screen often do without marginal information, partly because of space constraints. However, on-screen maps are often interactive and clicking on a map element may reveal additional information from the database. Legends and titles are often also available on demand.

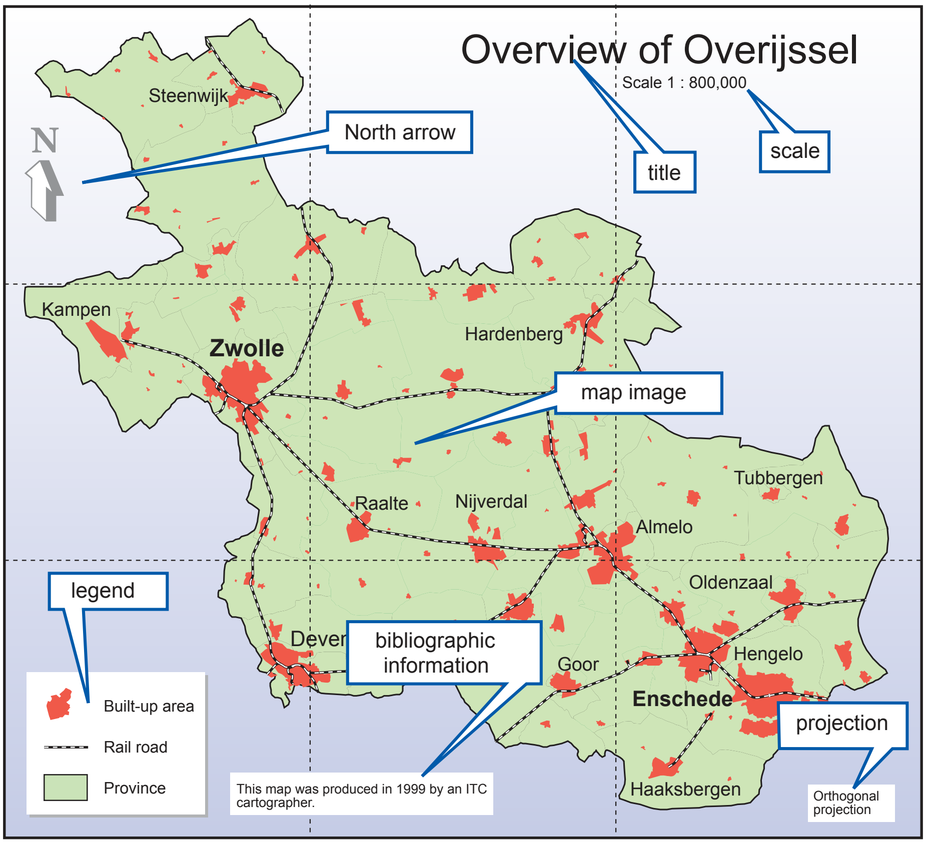

Figure 10.21
A printed map and its marginal information.

The map in Figure 10.21 is one of the first in this section that has text included. Figure 10.22 is another example. Text is used to transfer information in addition to that through the symbols used. This can be done by the applying visual elements to the text as well, as in Figure 10.22: italics—is a case of the visual variable orientation—have been used for building names to distinguish them from road names. Another common example is the use of colour to differentiate (at a nominal level) between hydrographic names (in blue) and other names (in black). The text should also be placed in a proper position with respect to the object to which it refers.

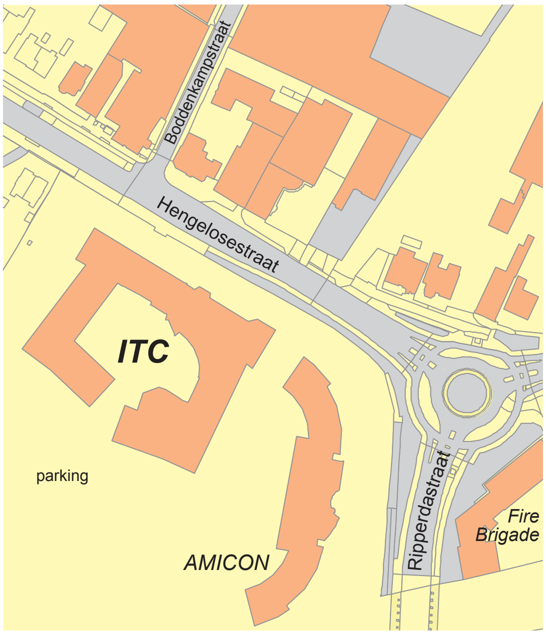

Figure 10.22
Text in a map.

Figure 10.23
Visual hierarchy and the location of the ITC building: (a) hierarchy not applied; (b) hierarchy applied.

Maps constructed according to basic cartographic guidelines are not necessarily visually appealing maps. Although well-constructed, they might still look sterile. The design aspect of creating appealing maps also has to be included in the visualization process. “Appealing” does not only mean having nice colours. One of the keywords here is contrast. Contrast will increase the communication role of the map since it creates a hierarchy in the map contents, assuming that not all information is of equal importance. This design trick is known as visual hierarchy or the figure–ground concept. The need for visual hierarchy in a map is best understood by looking at the map in Figure 10.23a, which just shows lines. The map of the ITC building and surroundings in part (b) is an example of a map that has visual hierarchy applied. The first object to be noted will be the ITC building (the darkest patch in the map) followed by other buildings, with the road on a lower level and the urban land parcels at the lowest level.

10.1.7 Map dissemination

Map design will not only be influenced by the nature of the data to be mapped or the intended audience (the “what” and “whom” from “How do I say what to whom, and is it effective?”). The output medium also plays a role. Traditionally, maps were produced on paper, and many still are. Currently, though, many maps are presented on-screen, for a quick look, for a presentation or for display on the Internet. Compared to maps on paper, on-screen maps have to be smaller, so their contents should be carefully selected. This might seem a disadvantage, but presenting maps on-screen offers very interesting alternatives. In the previous subsection, we mentioned that the legend only needs to be a mouse click away. A mouse click could also open a link to a database, revealing much more information than a printed map could ever offer. Links to other than tabular or map data could also be made available.

Maps and multimedia (photography, sound, video, animation) can be integrated. Some of today’s web atlases are good examples of how multimedia elements can be integrated with a map. For example, pointing to a country on a world map may start the national anthem of the country or shows its flag. It can be used to explore a country’s language; moving the mouse would start a short sentence in the region’s dialects.

The World Wide Web is nowadays a medium commonly used to present and disseminate spatial data. Maps can, however, still play their traditional role, for instance to show the location of objects or provide insight into spatial patterns, but because of the nature of the Internet, a map can also function as an interface to additional information. Geographic locations on the map can be linked to photographs, text, sound or other maps, perhaps even functions such as on-line booking services.

Maps can also be used as previews of spatial-data products to be acquired through a spatial-data clearinghouse that is part of a Spatial Data Infrastructure. For that purpose, we can make use of geo-webservices, which can provide interactive map views as an intermediate step between data and web browser (please refer to Subsection 8.5.4).

How can maps be used on the Internet? We can distinguish several methods that differ in terms of technical skills needed from both the user’s and provider’s perspective. An important distinction is the one between static and dynamic maps.

Many static maps on the Web are view-only. Organizations, such as map libraries or tourist information providers, often make their maps available in this way. This form of presentation can be very useful, for instance, to make historical maps more widely accessible. Most static maps, however, offer more than view-only functionality: they may present an interactive view to the user by offering zooming, panning or hyperlinking to other information. The much-used “clickable map” is an example of the latter and is useful as an interface to spatial data. Clicking on geographic objects may lead the user to quantitative data, photographs, sound or video clips or other information sources on the Web.

The user may also interactively determine the contents of the map by choosing the data layers and even the visualization parameters, and by choosing symbols and colours. Dynamic maps are about change; change in one or more of the spatial data components. On the Web, several options to play animations are available. The Web also allows for the fully interactive presentation of 3D models. Virtual Reality Markup Language (VRML), for instance, can be used for this purpose. It stores a true 3D model of objects, not just a series of 3D views.

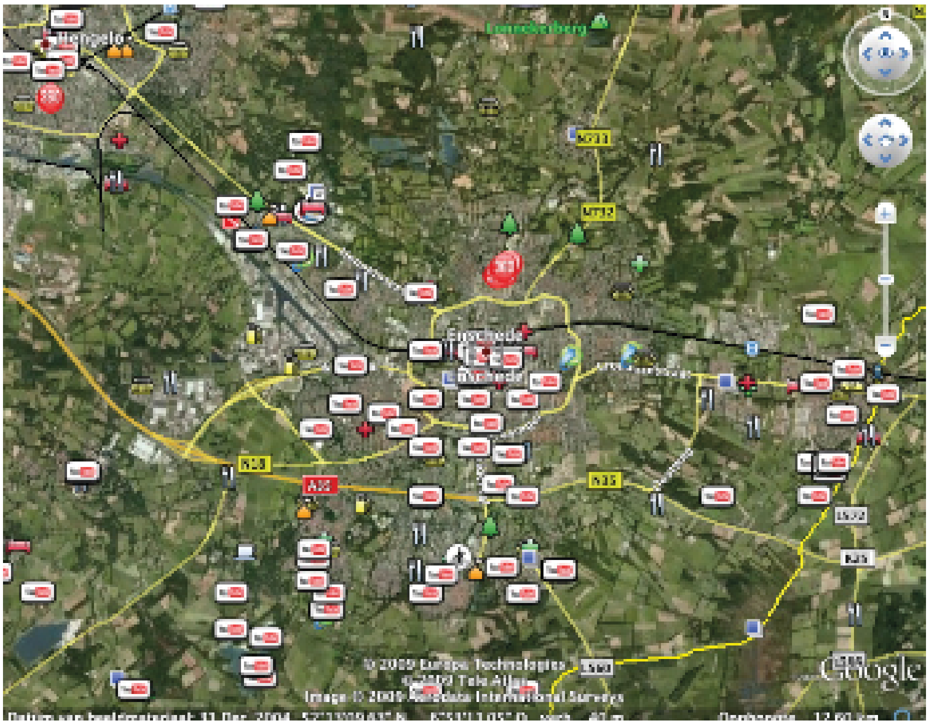

Figure 10.24
Enschede in Google Earth.
Source: [40].

Current mapping options on the Web also allow everyone to contribute their own data. These maps do not always adhere to the guidelines given earlier in this section but they do, nevertheless, have a role to play. Figure 10.24 shows the Enschede area in Google Earth with all available layers switched on. Users can add their own data if they like. Examples of additions would be GPS track and/or waypoints or even 3D buildings. Figure 10.25 is another example of what is known as neo-geography: a detailed view from the Open Street Map of the world (`www.openstreetmap.org`). All content in this map has been contributed by volunteers. The map shows the area around the ITC building. Note that some work still has to be done on this map, as a road recently built "behind" the building (in fact south of the building, but north of the railway tracks) is still missing.

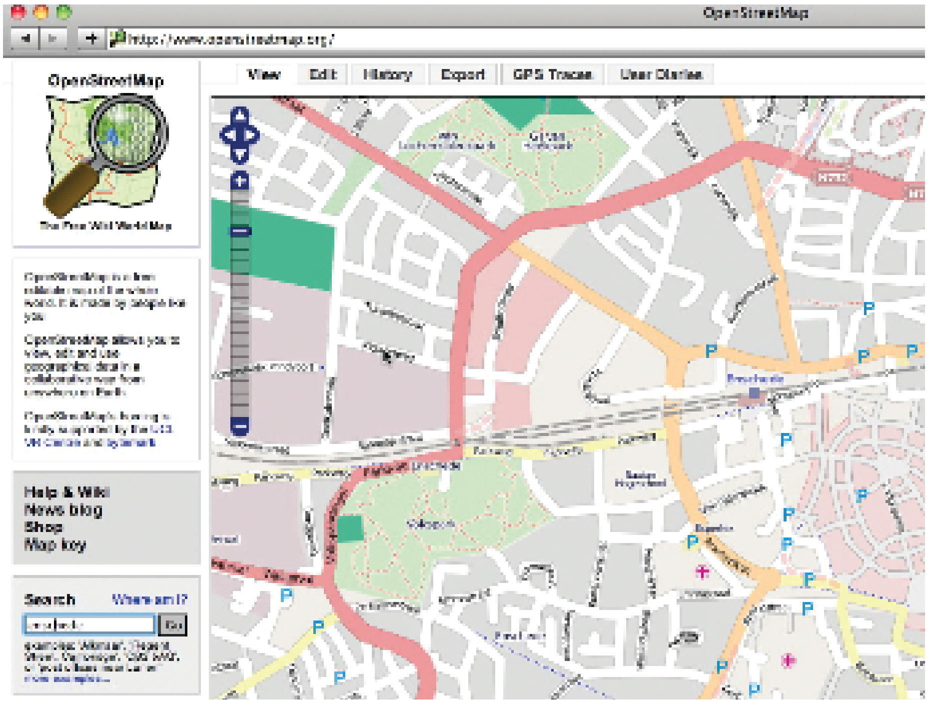

Figure 10.25
Part of the city of Enschede around the ITC building, as shown by OpenStreetMap [87].