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The Computer and Cartography

1.1 THE COMPUTER AT THE CENTER OF CARTOGRAPHY

Cartography is a discipline as old as humankind and as young as today's newspaper. Why is this? Cartography is old because as a means of expression the map probably predates many other forms of human communication, and maps survive that are several thousand years old. Cartography is young because it is a discipline that has been subjected to a series of revolutions in innovative technology. At first, these revolutions came separated by centuries, and in the case of the era following the decline of Greek and Roman cartography most of the cumulative knowledge of mapmaking was forgotten. Since the advent of the *digital computer*, however, we have become used to cartography as being in a state of almost constant technological revolution.

Why has this technological tool surpassed all others in the history of the discipline? How have cartographers adapted their discipline to this constant state of flux? And what will cartography look like in the years of innovation to come? In this book, we examine the computer revolution in cartography from the standpoint of how cartography has changed, and more important from the standpoint of how it has remained the same. As we shall see, the revolution has shaped a new cartography, in which the specifics of technology appear to be overwhelming.

Fortunately, the revolution has also sent cartography back to its historical and mathematical roots and therefore has made the basic principles of cartography as much in demand, if not more so, as at any previous time. When we think of the technology of mapmaking, the center of activity now lies within computer cartography. In the past, we thought of cartographers as scribes with quill pens scratching out maps of the world. This is simply no longer the way it is done. Mapmaking technologies have come and gone, and the simple origins are now very distant. Cartographers have changed the way they see the creation of maps and the role of mapmaking itself within cartography. This has been the case in both manual and computer cartography, for cartography is a set of skills and a body of theory, and the theory remains the same independent of what particular technology one happens to use to make any particular map.

This is why this book has the title *Analytical and Computer Cartography*, for there are two interlinked themes. The first theme, *analytical cartography* (Tobler, 1976), deals with the theoretical and mathematical background behind cartography and the rules cartographers employ in the mapping process. The other theme is hands-on *computer cartography,* the particular set of methods and techniques that the current technology uses to produce maps. If we use the term *computer cartography,* then in the past we have had quill-pen cartography, mapping-pen cartography, scribing cartography, and photogrammetric cartography, for these are some of the previous technologies we have used in the science of mapmaking. This book instructs the reader in mapmaking using the most current tool, the digital computer.

This does not necessarily affect the body of theory behind cartography, but rather emphasizes and reemphasizes the cartographic lessons of the past. For example, for most map projections, the underlying equations and transformational geometry were worked out, sometimes to perfection, in previous cartographic eras. Today the equations still work whether we produce the map by hand construction or by computer graphics. A typical laboratory for computer cartography may contain microcomputers with graphics cards, high-resolution color monitors, digitizers, color plotters, and printers rather than drafting tables and sinks. Although a student in a class on computer cartography may use such a laboratory now, we probably (in fact definitely) will have something different just a few years from now. This is the nature of scientific and technological revolutions. Most of the theory and principles presented and reviewed in this book will work just as well using the technology of next year or the next decade, however, just as most of the principles worked when they were derived centuries ago.

1.2 STAGES OF ADAPTATION OF THE COMPUTER

Morrison (1980) stated that there are three stages in the adaptation of a new technology. First of all, we have a reluctance to use the new technology; we close our eyes and pretend it isn't there. For example, in word processing technology, we may characterize this stage with statements such as, "I've been using an XYZ brand typewriter for 20 years, and it always works just fine. What are these word processors? I really don't need one, they are just too expensive." This is the *reluctance to use* stage. In the second stage, the *replication* stage, technology attempts to replicate the previous technology. If we return to the typewriter example, we might find IBM replacing its Selectric with a "memory" typewriter, with a single line display and some limited editing capabilities. This uses just a little of the new technology but does not "embrace" it, that is, fully take advantage of all of its features to do new things. We are still using the old technology, but are simply making it slightly better. We are copying the way typing was always done, that is, line by line.

In cartography, computer cartography was ignored for some time, as in the first stage, and then was faced by replication, producing pen plotters and table digitizers, which were simply updated electronic versions of the pens and drafting tables we had always used. The plotters were simply mechanical arms with pens fixed to them, and we still fed them pieces of paper and changed their ink. We took a digitizing tablet, much like a drafting table, and instead of using a mapping pen we used a cursor to draw lines. We replicated the previous technology, making maps exactly the way we used to, using only some aspects of the new technology.

The third stage is the full implementation of the new technology, in which we forget the previous technology, and the new technology becomes the current technology. Cartographers first had a reluctance to use computers altogether (“No computer can draw a map the way I can”), then they replicated the previous technology (“Well, maybe those computers can draw maps after all, but let me see them draw on Mylar and Leroy stencil the way I can”). Finally, in the full implementation of the technology we have to ask new questions altogether. This is a sign that a revolution has taken place, because new ideas are necessary to organize the new approach. We may ask, for example, if maps actually have to be on paper. New media are now available, such as microfilm, video, broadcast images, and holograms. Perhaps, more simply, we now have to ask ourselves just what a map actually is.

A characteristic of a developing technology is that we move through these stages. Also, however, we find that all stages usually exist at the same time. We still have both an ignorance of and a reluctance to use this technology. We have replication of the previous technology, but fortunately we also have some full implementations, and there are some good examples of people who have completely adopted computer technology and made a success of it.

More recently, Morrison (1993) has argued that the impact of the computer has gone even further and is eroding the boundaries of the organizations that conduct and control cartography. The flexibility of computer networks, the increasing collaboration between universities, government and industry, and the new highly portable technologies have made the formal cartographic organizations at least partially obsolete. Such institutional changes are likely to significantly impact the way cartographic data, expertise, and mapping problems are assembled to make maps with future mapping systems. The inevitable result will be a more spatially literate population making use of the tools and techniques of cartography in new and exciting ways. Chapter 6 provides an introduction to the critical issues of the impact of networks on cartography.

1.3 THE HISTORY OF COMPUTER CARTOGRAPHY

Computer cartography in the United States really dates back to a single article written by a graduate student at the University of Washington, Waldo Tobler. The paper “Automation and Cartography,” was published in the *Geographical Review* in 1959. At that time, plotting devices were simple cathode-ray tubes, and input and output were normally by punched cards. During the early years, the 1960s, the accent was on the creation of algorithms, that is, the creation of expressions of ways of doing things mechanically that had previously been done by hand. Because programming these algorithms was difficult, many remained unimplemented. So in the past, contour lines had been drawn by a cartographer, using knowledge about the lay of the land and perceptions about how the map should look. Later, the computer gained this ability, giving the cartographer the role of deciding how best to represent the lay of the land rather than how to draw contour lines.

The first problem that had to be solved was how to make a computer draw cartographic lines. The way to do that was to examine how the cartographer had made the decision, what methods were in use, and how they could be automated. In fact, many of those decisions are made on a very simple mathematical basis, and there is often a simple algorithm that will replace the method the cartographer has been using.

Cartographers devised a plethora of different algorithms, at first implemented as stand-alone computer programs and later consisting of program packages, peaking with the production in 1968 of the SYMAP package at Harvard University. The 1970s saw two major changes. First of all, the implementation of new algorithms brought innovations in producing new types of maps that had previously been impossible, certainly computationally, to produce. Within five years, most cartographic techniques were automated, even some complicated methods such as hill shading and cartograms. Computer programs were created that could produce almost all the various types of cartographic representation.

The second change, during the 1970s, was that people began to realize that applications of computer cartography had potential commercial value, just as a whole first generation of graduates from the universities that were specializing in computer cartography provided a small group of trained students for the job market. Many small companies started during this period, employing the new cartographers and using software engineering practices to produce some really effective and cost-competitive cartographic software. Most of this software was made available for those who wished to make new maps or those who wished to replace manual mapping systems. Federal, state, and local government frequently took the initiative in producing mapping software. This phase continues today and in fact is gaining momentum as the industry matures and as the microcomputer and workstation penetrate smaller and smaller drafting-office environments.

Some of the first programs were for the types of computers that were around in the 1970s: large mainframe computers, mostly IBM products that used existing languages such as FORTRAN and simple proprietary graphics plotting systems such as CALCOMP and Tektronics PLOT-10. In keeping with the times, most applications programs ran in batch mode and frequently used the line printer as the primary display device. A more detailed discussion of specific software packages and computer programs follows in Chapter 3.

1.4 NEW DISPLAY MEDIA

Computer cartography has dictated the development of new types of hardware. At the same time, computers have become much smaller and cheaper; in fact, we now use computers on our laps. Storage ability has improved greatly, bringing down the need to force things to fit into the smallest possible space. We have whole new storage technologies that did not exist in the early 1980s: optical discs, video, bubble, 8-mm tape and so forth. The CD-ROM in particular has become a major medium for the storage and distribution of map data. The four-disc set produced by the Defense Mapping Agency called the Digital Chart of the World, for example, contains 14 data layers including vegetation, coastlines, roads, hydrology, and place names for the entire world at a scale of 1 to 1 million.

We have new methods and new display media, which have broadened our minds about what a map is. We used to think of a map as something we could roll up in a tube. Now a map can be a set of electrical impulses on a video tube. Maps appear as searchable images on touch screen displays in conference centers, airports, grocery stores, and hotels, as displays on the dashboards of cars, and as components of computer software, such as games and atlases available from the local computer store. We can think of a map independently of the technology or device by which the actual image is to be prepared. Moellering has termed such maps “virtual maps” (Moellering, 1983).

Maps of immediate interest, such as satellite and weather maps, and those showing the locations of accidents and places in the news, travel patterns, and road blockages, can be interactively received, having been updated on an hourly basis. These maps never exist other than as sets of electrons falling on phosphors, and we have had to broaden our definition of what a map is to include these new media. Probably the most common map that the average person sees on a daily basis is the weather map on TV news programs. These maps are digitally produced, with the weather forecaster standing in front of a blank wall and the camera zooming onto a computer screen showing the weather map. In addition, the actual printing of maps back onto paper is now possible using entirely new methods and materials, such as ink-jet, laser-jet, and dye-sublimation technology, and direct plotting onto film and microfilm.

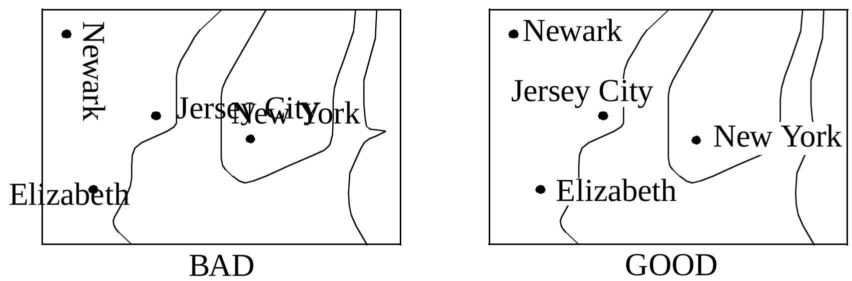
1.5 NEW CARTOGRAPHIC PROBLEMS

We are moving toward automating even the toughest cartographic problems, among them the automated placement of text, an often ignored but essential part of maps and we are also increasingly making maps directly from images, especially air photos and satellite images. Dealing with text has been a particularly difficult issue for computer cartography, especially because the production of text in traditional stick-up methods was undergoing its own technological revolution due to desktop publishing, phototypesetting, laser printing, and new drafting and reproduction materials.

A map is not just a collection of lines, colors, and polygons, it also has important textual information. The selection, placement, and production of text is a very important part of cartography. Previously, this aspect was virtually ignored by almost all computer mapping systems. At last we are dealing not only with some of the issues related to putting text on maps, but we are also working to make the computer automatically select and place text where appropriate.

To be able to have the computer decide where to put the text could automate the single most time-consuming task in manual cartography. Text positioning must be such that it does not overlap other labels or important information, and that the laws of text placement are obeyed. A pioneer system for automated text placement was the AUTONAP system (Ahn, 1984) (Figure 1.1).

Once the text has been selected and placed, symbolization is critical to the esthetics of the map. Choice for the text of font, color, spacing, path and slope are variables with which individual cartographers have been able to give a map a certain “style.” Much of the “artificial” look of computer-produced maps can be traced to text design. An effective mapping system would give the cartographer control over this intangible quality of maps.



1. A name must lie totally within the bounds of the map.
2. A name should not overlap with any other name or a feature.
3. If a name overlaps with a line feature, the line, not the name, should be interrupted.
4. If a name is to be horizontal, it should be parallel to the rectangular coordinates on a large scale map.

Figure 1.1 Sample text placement rules from the AUTONAP system.

Another problem is making maps directly from images. In the past we used to go out and survey areas using plane tables. Later this was replaced with photogrammetry, using air photos to compile and update maps. Increasingly, satellites are reaching higher and higher resolutions, making them suitable for mapping at larger and larger scales, certainly scales on the order of 1:50,000.

How to make maps directly from these images without the intervention of a human interpreter is the final part of this problem. Progress is being made in this area, especially in the fields of remote sensing and image processing. Features such as roads and rivers can now be identified from imagery and replaced directly with the appropriate cartographic symbols. Mapping some of these things requires the use of artificial intelligence methods.

At the extreme, one can imagine a fully automated mapping system, acquiring data by remote sensing, extracting, identifying, symbolizing the various features in the image by understanding their context and form, and labelling the features by searching data bases by location. Some of the more recent systems show promise of these sorts of capability, providing the conceptual problems can be solved in the future.

Developments in other parallel fields are also influencing current events in computer cartography. Surveying has undergone its own computer revolution, and many surveyors now use COGO (coordinate geometry) systems, automatic note takers, and pen plotters. Similarly, the computer-aided design (CAD) industry is producing highly sophisticated tools for automating the traditional drafting process, in much the same way that paint programs are automating the artistic painting process. These technologies are influencing and being influenced by developments in computer cartography.

1.6 THE COMPUTER'S INFLUENCE ON CARTOGRAPHY

What have been the implications of these technological changes, and what has happened to mapping? First of all, cartography is now fast, or at least faster. The compilation time for a 7.5-minute quadrangle, with field surveys and checking in the 1940s, when most of the series was made, was on the order of five years. To update the maps now, we use photogrammetric methods, and the survey and field work plus the cartography takes about two years. As we move to fully digital maps, we obviously decrease the time spent in making and remaking the map.

At the time extreme, consider instead the daily weather maps distributed by NOAA over the computer networks (see Chapter 6). Every hour, a new image of North America, admittedly at low resolution but showing up-to-date atmospheric conditions, is posted on the Internet. Weather stations, television weather forecasters, pilots, and even recreational boaters can download the image and have access to cartographic data within just minutes of the image having been recorded by the satellite. Mapping speed has been increased substantially by computer mapping systems.

The computer has also increased the potential map accuracy, although accuracy is more difficult to discuss, because most people confuse *accuracy* and *precision.* If someone were to ask me the time, and I replied that it was 4:12:15.783, I would be very precise. I might be completely wrong—the time could actually be 5:31—but I would be very precise. If I were to say about half past five, then I would be fairly accurate, although imprecise.

Has computer mapping made maps more accurate? It has certainly made them more precise. We are able to store and use many more numbers now and can compute lengths and areas with more significant digits than before. A surveyor can calculate the area of a new subdivision plot to the thousandth of a hectare. Are these numbers more accurate? It certainly seems that we have taken the old causes for inaccuracy, smudgy lines and shaky hands, and replaced them with other things, such as digitizer's neck and grid interpolation error. I would argue that perhaps, in the very long term, computers have made maps more accurate. More important, however, is that our accuracy levels are now measurable against the truth, or at least against other maps, and we have therefore made our maps more accountable. Much recent cartographic research has focused on the accuracy of digital maps, and some important findings have already found their way into cartographic theory.

A major innovation in surveying is the implementation of a system involving 21 geostationary satellites in orbit around Earth, whose locations are very precisely and accurately known, because the orbits are very predictable. The system is called the global positioning system (GPS). This means that if you have a receiver that receives and decodes the signals coming from these satellites, you can fix your location very precisely by three-dimensional triangulation from a set of three satellites. It is not unknown now for a system with some microcomputer postprocessing to give your latitude, longitude, and elevation to within about 10 millimeters. That is so accurate and precise that it is good enough to measure continental drift; in fact, this technology has contributed a great deal toward figuring out that the continents are moving around and by how much. The contributions of this satellite system to the mapping sciences of geodesy and surveying are already apparent, and measurement from GPS can now be sent directly to mapping software.

This new technology allows us to resurvey things with a new level of accuracy, and sometimes we have found that we have gotten things wrong, in some cases really wrong. A good example would be the Pacific islands, totally out of sight of every other piece of land in all directions, so that locations could only be fixed by astronomical measurements of latitude and longitude. With a GPS receiver we have found out that our maps show the islands in some cases tens of kilometers off their correct locations. In many senses, cartography has a long history of islands that appear and reappear, and move around with changes in mapping technology rather than having anything to do with Atlantis, the Bermuda Triangle, or plate tectonics. A whole new promontory was discovered in Antarctica, the Washington Monument was found to have been mislocated by several meters, and probably the most famous instance is that Mount Everest spent a short period between measurements as the second-highest rather than the highest mountain on Earth.

The digital computer allows us to gather cartographic data that is both precise and accurate. Unfortunately, the implication of quality that comes with accuracy and precision has not always been justified. When the source material for a digital map is a sheet map, the digital map can become a faithful exact reproduction of all the errors involved in putting the original map onto paper. It is important to retain a “fitness for use” criterion when considering the accuracy of digital cartographic data.

1.7 BENEFITS OF THE COMPUTER TO CARTOGRAPHY

What are some of the benefits of using computers in cartography, and has the computer made mapping more cost-effective? It is rather expensive to produce maps, and in the initial stages it was believed that computers would make it incredibly inexpensive to produce maps. In fact, in the long run, computer-produced maps seem to cost about the same, with a few exceptions, as hand made maps. On the other hand, it probably will not remain that way. If we think about the stages of adopting a new technology, much of the cost of computer cartography is due to replication of the previous technology. People still use figures such as the cost of digitizing a sheet map for a single mapping project, normally a one-time fixed cost. Far lower variable costs per map are possible by reusing the digital map base.

The level of output of maps has increased using computers. Most of the fixed costs of computer cartography are in preparing a new base map, and after this step it is both easier and less costly to produce maps from the base. For example, we may spend a great deal of money producing a new census tract base map after every decennial census, but in doing so we are ensuring that we can map on that base any of the variables from the census and that we can use the map base for numerous other derived maps and analyses. Only the data, the symbolization, and map types change.

This implies that we can increase output. What this means is that mapping projects that were previously not possible are now cost-effective, even inexpensive, perhaps affordable by overseas countries and local governments, which were previously excluded by cost from the mapping business. These completely new applications have the greatest potential for computer cartography, for these users have no previous technology to waste time replicating and they can reap the benefits of other peoples' experience.

The overall effects of the computer on the discipline of cartography are many. Cartography in the 1950s was much of a service discipline. A cartographer would be attached to a geography or geology program academically, or isolated in a map department commercially. A cartographer's function was as a technician, a producer of maps, rather than as a producer of systems for making maps. Wolter (1975) argued in *The Emerging Discipline of Cartography* that cartography has evolved, through its self-examination as a result of the computer age, all the requirements to become a distinct academic discipline in its own right. Today, the distinctiveness of the discipline and its new role are clear.

Certainly, if one examines the literature, this is evident. Much that is published in cartographic journals these days is clearly analytical cartography, although there are other approaches to the discipline (Moellering, 1991). One could argue that this is just a return to the preeminence of cartography, a return to the role that cartography held under the ancient Greeks or during the age of discovery. Many more people outside the discipline now encounter and eventually study cartography. As a result of this scrutiny from outside, we have been forced to define the cartographer's domain of interest very precisely. We have had to define in detail exactly what cartographers do, how they do it, exactly what the information they deal with is, and what its limitations are. And we have had to model the flow of this information through the mapping process.

The computer has relieved the cartographer from tedious production tasks. Anyone who has experience with manual cartography knows how much hard work goes into a manually produced map, even a poorly designed or inexpertly drafted one. The focus of cartography used to be on the production technology. If the computer is doing the minor production tasks for us, we can worry about other things, such as design—which is ultimately what a cartographer is trying to perfect. For one thing, the computer has allowed us to set up a design loop. The manual equivalent is to work on a series of separations one at a time, incorporating a single map design for each map project. We finally get to producing a map proof, and for the first time after perhaps 100 hours of work, get to see what the map looks like. What if we don't like what we see? More commonly, we might say, "If only this text were slightly smaller" or, "If only this red were green." It is too late to change the map; in other words, we have no design loop.

In a design loop, the finished product can be interactively modified to make all the changes we may wish to incorporate. In fact, we can use the design loop to produce experimental maps that will help us to learn better design: for example, to see why a map with 12 fonts and 30 shade classes really does look bad. This changes the emphasis from the technology to the design and further to the principles that make this a good design regardless of the technology. In this way, we can make maps look better — which is not a bad definition of what it is that cartographers now do.

The computer has produced a whole series of new capabilities. The ability to manipulate color is a good example of this. The computer has given us new types of maps and new media for their display. The field of scientific visualization has produced maps that can be walked around, manipulated and perceived as three-dimensional objects. Cartographers are now beginning to exploit the tools and methods of the new interactive media, multimedia, and animation to show spatial distributions over time and space (Andrews and Tilton, 1993). Similarly, we can use cartographic techniques to map new types of data beyond the traditional domain of cartography, such as statistical distributions, the ocean floor, Mars, or a molecule (Hall, 1992).

1.8 DISADVANTAGES OF THE COMPUTER FOR CARTOGRAPHY

The computer has had some negative effects on cartography. For one thing, the amount of technical training that a cartographer has to acquire has increased enormously. The cartographer of the 1990s must be a database expert, a user-interface designer, and a software engineer. He or she must also retain a sense of map esthetics, be familiar with diverse computing environments, and still produce maps. Cartographers ideally need training in image processing, remote sensing, photogrammetry, land information systems, geographic information systems, surveying and geodesy, and computer programming.

Another disadvantage of the computer for cartography as a discipline is that those not trained in cartography can now easily produce maps. Although in many cases this is a popularization of the mapping process, in the early days of computer cartography it led to a renewed need for good design and esthetics. For a time, in replicating the previous technology, mapmakers threw out the quality standards that the previous technology had contributed to cartography as a whole. For about 20 years computer cartography produced rather inferior products, which were accepted not because they were better but because they were new and different. Today, digitally produced maps are usually superior esthetically to those we can make by hand.

1.9 SOME GENERAL TRENDS

There have been many general trends within cartography as a result of the advent of the computer. One trend has been toward simpler maps. If we were stuck with a single product, we often believed that there were savings to be made by incorporating as much data as possible on a single map. Maps have become "single message," in much the same way as business graphics, with a good example being the weather map or the sales map. These are maps being used to communicate a message. A whole school of thought within cartography has concentrated on the effectiveness of maps in communicating a particular message to the map reader. This communication school has sought to improve map design to get the message across faster and more effectively.

The computer has given us defensible design. We can assign numbers to back up qualitative judgments. A good example is to use recognized error reduction techniques to choose class breaks for shaded maps or known methods to do line generalization and simplification. So an island may be eliminated on a map at a certain scale because it falls below a certain threshold area, rather than because it was easy to paint over the island with opaquing fluid on a negative.

The computer has promoted new types of cartographic symbolization and representation; that is, we have devised new types of maps as well as new ways of making the old types. An example is the depiction of terrain. Now we can generate realistic depictions of terrain to simulate the way the terrain will actually look to an observer. In particular, the computer has made thematic mapping available to those who are not cartographers but who work with statistical data with a geographic component. The computer, therefore, has opened up mapping to those without a formal training in the discipline. This may yet prove to be the most critical advance in the acceptance of computer mapping.

Finally, education has expanded cartography to include computer and analytical aspects. We have had an enormous increase in both the numbers of, and demand for, the type of college course at which this book is aimed. Almost every geography program in the country offers at least some form of computer (not necessarily analytical) cartography. Sometimes schools offer multisemester sequences, even entire specializations in computer cartography, usually coupled with sequences in geographic information systems and remote sensing. Increasingly, the graduates of these classes go on to find employment in the booming industry of computer cartography, well endowed, one hopes, with a sound base in the analytical aspects of the discipline, which will ensure those same students of employment in the future.

1.10 GEOGRAPHIC INFORMATION SYSTEMS

The influence of the computer on cartography has opened up cartographic methods and techniques to more general purpose uses of geographic information. Nowhere has this been more evident than in the field of geographic information systems (GIS). GISs are automated systems for the capture, storage, retrieval, analysis, and display of spatial data. Large numbers of these systems are now available to assist resource and spatial data managers with their planning and decision making, as well as their routine record keeping and inventory. Because these systems use geographic data extensively, most of the queries made of these systems provide cartographic solutions.

As a result, these systems are usually supplied with either an interface to a separate cartographic display system or contain their own such systems. The type, quality, and capabilities of these display systems vary remarkably from system to system, ranging from poor to the very best in quality. The major differences in how GISs generate maps are twofold. First, the map is either an intermediate or partial solution to a query and may therefore not contain any of the true cartographic elements other than a figure and a georeference system. This is not to say that the final maps that provide the problem solutions are not good cartography, but these maps instead reflect the emphasis on query and response rather than display.

Second, the user of a GIS is not always a cartographer and therefore does not place the same level of importance on the map as on the message the map conveys. GISs have become the primary way in which people are first introduced to computer cartography, and in some cases to analytical cartography. It is important to realize, however, that the goals of computer cartography and the goals of geographic information processing are not always identical, although they are always similar.

The skilled cartographer should develop an understanding of GISs and should see in them the challenge of a new set of demands on the theory and methods of cartography. It is not sufficient that the computer cartographer is interested solely in the graphic display of digital cartographic data, since the structuring, encoding, and the representation of the data are the very basis upon which analytical cartography is built. Cartographic transformations, the basis of analytical cartography, underlie all geographic data processing and therefore are of overlapping interest to cartographers and the builders and users of GISs alike.

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