Ethical Implications of Technical Limitations in Geographic Information Systems[1]

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Abstract. A geographic information system (GIS) allows a user to combine digitized data sets from multiple sources to produce a customized map. Like traditional paper maps, GIS maps should be accurate. Unlike traditional maps, however, technical limitations raise new ethical issues for geographic information systems. These technical limitations include unavoidable inaccuracies introduced by the digitization of continuous data, the projection of three-dimensional data onto a two-dimensional plane, and incompatibilities of data sets stored in different formats. Consistency checks and technical standards may mitigate the harmful consequences of these technical limitations.

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Ethical Implications of Technical Limitations in Geographic Information Systems

1. Introduction

On January 8, 2005, the *USS San Francisco* submarine collided with an underwater mountain. One crewmember was killed, and 97 others were injured. According to the official report of the *San Francisco* accident investigation (2005), the submarine's navigation map did not show the mountain, although other maps on board, not used for navigation, did show the mountain. The inaccurate navigation map, therefore, contributed to the fatal accident.

Modern maps have evolved into computer-based geographic information systems, which integrate traditional maps with additional data. These systems are used extensively by companies for marketing products, by the military for navigation, and by government agencies for urban and regional planning. Figure 1 shows an example of a map created in a geographic information system (GIS). The map displays four data layers that can be downloaded free of charge via the Internet. The first (top) layer shows important places in Dover, Delaware such as hospitals and religious institutions. The second layer shows roads in Dover; it designates each type of road (primary, secondary, etc.) by a different kind of line. The third layer shows bodies of water. The fourth layer shows the Dover city limits, Dover suburbs, and limits of other cities.

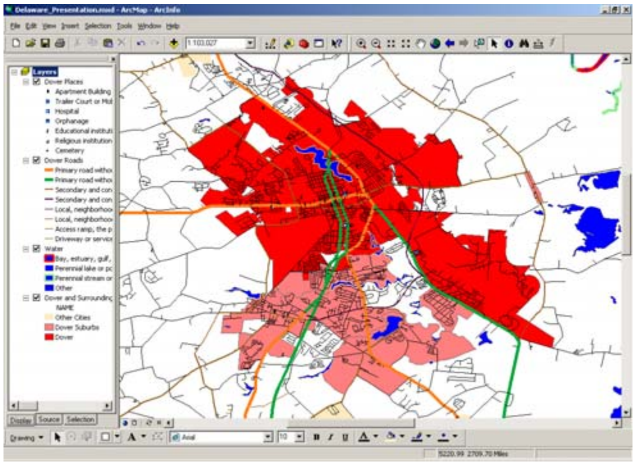
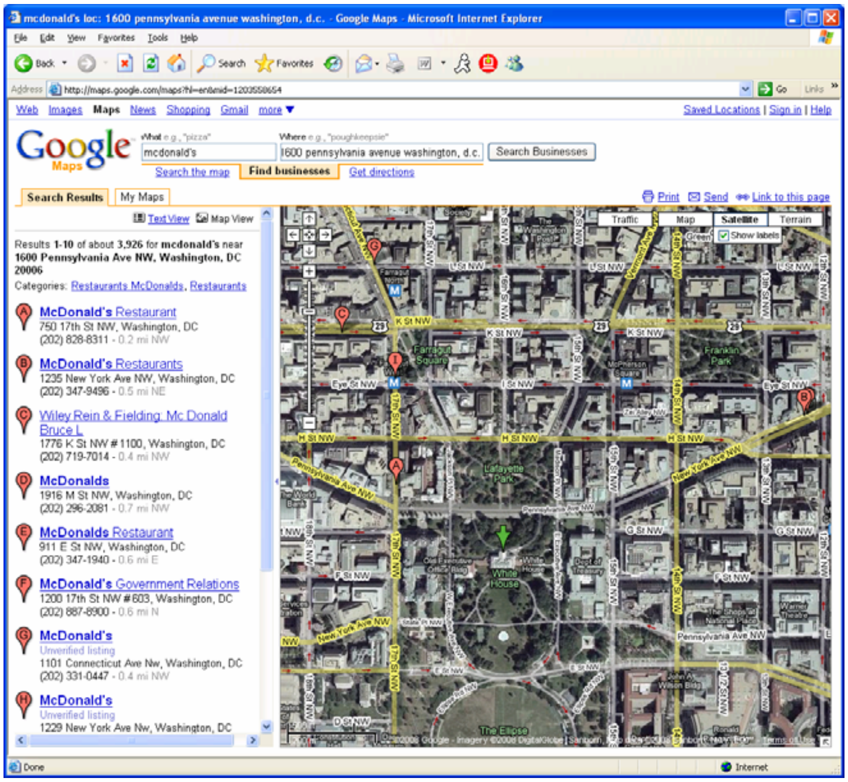


Figure 1. GIS screenshot using ArcMap software

Geographic information systems are available not only to institutions but also to individuals. When people travel to other cities, they use the Internet to visit Google Maps (maps.google.com), Yahoo Maps (maps.yahoo.com), or Mapquest (www.mapquest.com), where they create personalized maps with driving directions and locations of restaurants. For example, Figure 2 shows a Google Maps search for McDonald's restaurants near 1600 Pennsylvania Avenue.



http://maps.google.com/maps?hl=en&eid=1203558654

What e.g., "pizza": mcdonald's

Where e.g., "poughkeepsie": 1600 pennsylvania avenue washington, d.c.

Results **1-10** of about **3,926** for **mcdonald's** near **1600 Pennsylvania Ave NW, Washington, DC 20006**

Categories: Restaurants McDonalds, Restaurants

A **McDonald's** Restaurant
750 17th St NW, Washington, DC
(202) 828-8311 - 0.2 mi NW

B **McDonald's** Restaurants
1235 New York Ave NW, Washington, DC
(202) 347-9496 - 0.5 mi NE

C Wiley Rein & Fielding: Mc Donald Bruce L
1776 K St NW # 1100, Washington, DC
(202) 719-7014 - 0.4 mi NW

D **McDonalds**
1916 M St NW, Washington, DC
(202) 296-2081 - 0.7 mi NW

E **McDonalds** Restaurant
911 E St NW, Washington, DC
(202) 347-1940 - 0.6 mi E

F **McDonald's** Government Relations
1200 17th St NW # 603, Washington, DC
(202) 887-8900 - 0.6 mi N

G **McDonald's**
Unverified listing
1101 Connecticut Ave Nw, Washington, DC
(202) 331-0447 - 0.4 mi NW

H **McDonald's**
Unverified listing
1229 New York Ave Nw, Washington, DC

Figure 2. McDonald's Query near the White House

Users can enter a starting location to receive personalized driving directions to a selected McDonald's. Google also allows users to upload maps that they created to share with others. Figure 3 shows a home-made map with embedded photos.

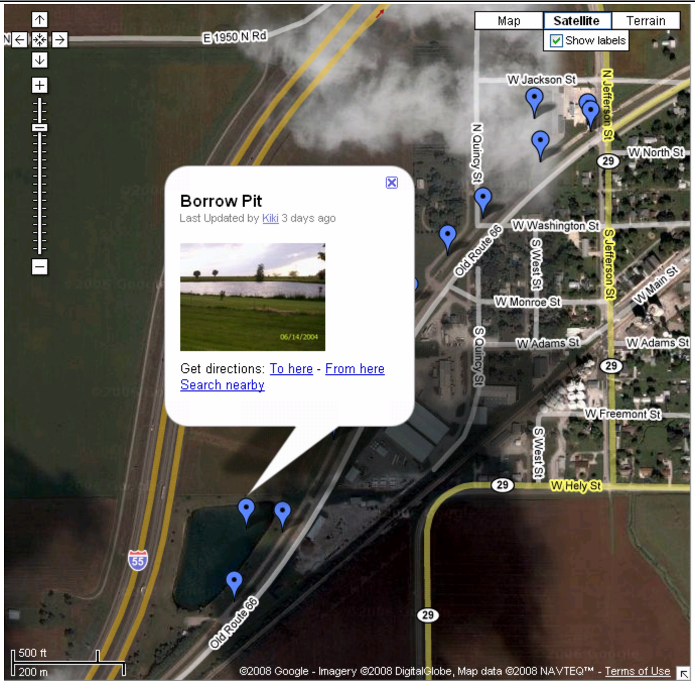


Figure 3. Homemade Route 66 map with embedded photos

Geographic information systems differ from traditional maps in three significant ways. First, all data in a GIS exist in digital form. That is, original data derived from measurements of locations of roads, rivers, forests, and buildings are converted to numbers represented in fixed precision, with a limited number of bits. The process of converting continuous measurements to a binary representation with a fixed number of bits is called **quantization**. Images from photographs are digitized by imposing a grid, a process called **sampling**, which defines the locations of individual pixels. The color or light intensity in each pixel is then quantized. Second, a GIS allows the user to design a map by combining data from multiple sources; the combination process is called **layering**. Third, whereas a printed map is fixed, a GIS user can easily change the appearance of a map. For example, the user can change the color used to denote a lake and the symbol used to denote a school.

As illustrated by the story of the *USS San Francisco*, inaccuracies in maps and in geographic information systems can have morally significant consequences. The inaccuracies in a GIS arise not only from mistakes in the original data but also from errors inherent in quantization and sampling, and from inconsistencies in the layering of data from multiple sources. In this paper, we explore the ethical implications of the inaccuracies caused by technical limitations of geographic information systems, implications that go beyond the ethics of traditional maps. We focus on the ethical obligations of technical professionals who use these systems to create maps that support social decisions, rather than the actions of individuals who create maps for their personal use. That is, we consider a professional who creates a contour map for digging a tunnel as part of a highway construction project, rather than an individual who creates a map for a family vacation. We conclude that GIS technical practices have ethical implications because they can produce important social consequences.

2. Literature Review

2.1. Ethics in Cartography

Geographic information systems share the ethical concerns of traditional maps that have previously been identified by other scholars.

Obviously, a map should be accurate. Inaccuracies can arise from misrepresentations, from alterations of data, and from outright blunders. According to Monmonier (1996), a map published by the American Automobile Association in the 1960s accidentally omitted Seattle, Washington.

Although map errors can arise from unintentional omissions, a map must necessarily omit many details. According to Harley (1989, 1990, 2001), decisions about what to include in a map are inherently ethical. For example, among “points of interest,” should a map show toxic waste dumps? Should a map include a historical but derogatory name such as “Nigger Creek”? Even the choice of symbols could cause offense. For example, on some maps, a cross denotes both a church and a synagogue.

Some errors are caused by GIS users out of ignorance. Jenkins and McCauley (2006) explain how a user’s knowledge of the “sinks” and “fill” algorithms in a GIS can affect the accuracy of GIS maps. Sinks are small depressions in the Earth’s surface that are filled when water movement is modeled in a GIS. When sinks are eliminated, planners may make decisions that endanger wetland species or increase flooding in some areas. Therefore, the ignorant use of the “sinks” and “fill” algorithms can cause errors in GIS maps. Haque (2003) argues that because a lack of GIS knowledge causes unethical mapmaking, peer review and continuing education are required to promote ethical GIS use. As Onsrud (1995, 1997) notes, although some groups can enforce legal GIS practices, no group monitors the ethical decisions made in using a GIS.

Even when the data in a map are accurate, data about individuals can threaten their privacy (Crampton, 1995) and their dignity (Curry, 1995). Curry (1995) asserts that when an individual is an object of study, he loses human qualities and becomes a mere data point. Usually the ethical treatment of data differs from the ethical treatment of persons. For instance, data can be compiled and analyzed without consideration of personal privacy or rights. Curry claims that GIS users have difficulty applying ethics to a GIS because they are torn between deontological and consequentialist values—between respecting the rights of individuals and striving for good consequences in handling data accurately. The conflict between deontological and consequentialist values is not unique to geographic information systems, however; this conflict occurs frequently in everyday life. For example, when a policy allows border patrol officers to search a vehicle for illegal drugs, the policy subordinates the privacy of individuals (a deontological value) to the potential reduction in drug-trafficking (a consequentialist value).

Crampton (1995) and Harley (2001) complain that most discussions of ethics in cartography have focused on internal issues such as copyright and professional practices, rather than on external issues such as the social implications of maps and the perpetuation of power relations: maps tend to serve the interests of people with socioeconomic power by highlighting institutions such as government and commercial buildings. Crampton and Harley disparage internal ethical issues and call for greater attention to external ethical issues. In contrast, we will show how internal issues of technical practices affect external issues of social consequences.

2.2. Ethics of Information Systems

All modern information systems enable users to create documents easily and to disseminate those documents widely. These properties of rapid, inexpensive creation and dissemination usually have good consequences. During the recovery from Hurricane Katrina in 2005, emergency personnel used geographic information systems to tailor maps and spatial analyses to specific requests. Geographic information systems dramatically decreased the time necessary to create ad hoc maps, and they enabled real-time changes to maps that would not have been possible on paper maps. GIS maps were able to show real-time data such as the number of displaced people in a specific area. First-responders accessed these maps online from wherever they could find an Internet connection. Because many users in many locations could access the maps, they could respond to needs quickly, and they could target efforts to specific areas (ESRI, 2005).

While a GIS can promote the good by providing accurate data quickly, a GIS can also cause harm through misrepresentations and biases. Curry (1995) defines a “good map” as a map without misrepresentations or biases. By contrast, Friedman and Nissenbaum (1996) show that biases seem inherent in every information system. Friedman and Nissenbaum classify information system biases into three types: preexisting, technical, and emergent. A **preexisting bias** is a personal or societal bias that occurs before data are added to a computer system. A preexisting bias could be intentional or unintentional. For example, a computer algorithm may help a bank officer decide whether to grant a loan based on several criteria, which might be biased. According to the decision criteria, an applicant who lives in an “undesirable” location such as a low income neighborhood could be less likely to receive a loan (Friedman & Nissenbaum, 1996). A **technical bias** results from limitations on hardware, software, or algorithms. For instance, a small computer screen restricts what data the user can see. When presented with a long list of options that do not fit on one screen, the user would be more likely to choose only from options offered on the screen rather than from the full range of options. If the full list of options is ordered alphabetically, then one end of the alphabet would be favored. An **emergent bias** arises after an information system is in use. An emergent bias usually results from changes outside the system. For example, suppose a passenger who wishes to travel overseas has reserved seats on two connecting flights: the first domestic, the second international. If the airline adds international flights to its existing domestic schedule, then the passenger’s original itinerary might not be the most convenient. The itinerary is biased toward previously scheduled flights.

Like other information systems, a GIS has preexisting, technical, and emergent biases. Unlike traditional information systems, however, a GIS handles data that have been digitized, and a GIS allows users to layer data from multiple sources. Whereas the data in a personnel database consist of text and integers, which can be represented exactly, the data in a GIS include digitized images and measurements of physical quantities, which can be represented only approximately. Whereas a personnel database usually has a fixed structure and appearance, a

GIS permits the combination of a variety of data to create ad hoc maps. We will show how these two special properties affect the ethical implications of a GIS.

3. GIS Terminology

We define some standard GIS terms that are used in the examples in subsequent sections of this paper. For more detailed definitions of these terms see Burrough & McDonnell (1998) and the Web site http://www.gis.com/whatisgis/index.html.

A **polygon** is a closed shape such as a square or circle. A **polyline** is a sequence of short, connected, straight line segments that approximates a curve. In Figure 1, roads are represented by polylines, and bodies of water are represented by polygons.

Vector data are composed of points, polylines, and polygons. **Raster** data are organized on a grid composed of cells of equal size. In raster data, each grid cell contains an integer value to describe the cell.

Data are **symbolized** when a color or shape is assigned to a point, polyline, or polygon. For example, in Figure 1, bodies of water are symbolized as blue polygons.

A **layer** is a data set from a single source. A GIS might combine a road layer, a building layer, and a topography layer from three different sources.

When used in a GIS, data such as aerial and satellite photographs need to be altered through a process called **projection**. A projection allows images of a three-dimensional (3D) object with curvature like the earth's surface to be displayed on a two-dimensional (2D) computer screen. Figure 4 shows three different projections of the earth: the Gall-Peters projection, the Mercator projection, and the Robinson projection. Notice how the shape and size of each continent vary between projections.

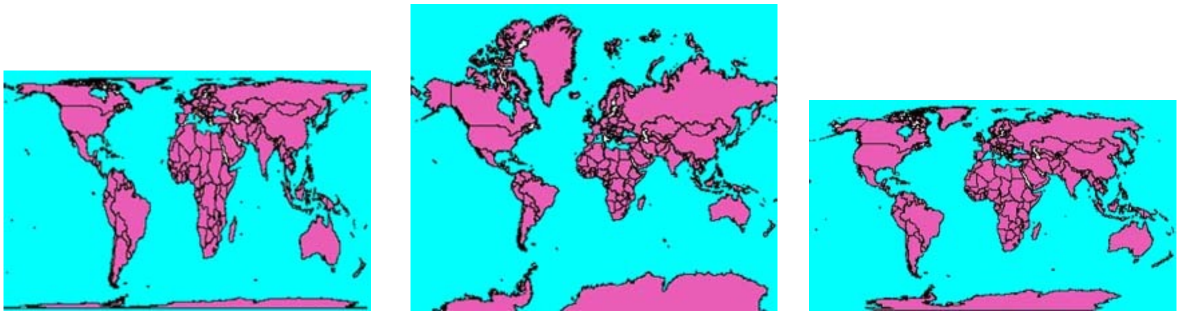


Figure 4. Left to right: Gall-Peters projection, Mercator projection, and Robinson projection

Maps in a GIS need not only a projection, but a **datum** as well. A datum specifies a reference ellipsoid, which models the shape of the earth, and a base point as the origin for a coordinate system of latitudes and longitudes. The latitude and longitude of every map feature are defined in relation to the base point. Two standard datums are the State Plane Coordinate System and the World Geodetic System (WGS) 84.

4. Errors

Although human mistakes can cause errors in map data, we will show how technical limitations can also produce errors.

First, raw map data are collected with survey equipment—surveyor's transits, aerial reconnaissance cameras, remote sensing satellites, and handheld GPS (global positioning system) devices. Because all equipment can measure elevations and distances to only a certain degree of precision, no measurement is completely accurate.

After data are collected, for use in a GIS, the data must be digitized. In the digitization process, the sampling of images and the quantization of measurements always introduce inaccuracies. A black-and-white print photograph is digitized by defining a pixel size and a number of quantization bits. In a low resolution photo, each pixel might correspond to a three by three meter area; in a high resolution photo taken from the same vantage point, each pixel might correspond to a six by six inch area. For each pixel, the overall light intensity is quantized by converting the intensity level to a number between zero and $2^n–1$, where n is the number of bits. Although a low resolution photo might be adequate for mapping large features such as the boundary of a lake, a low resolution photo introduces inaccuracies by obscuring small features such as fire hydrants. To find small features would require a high resolution photo, but a high resolution photo occupies more disk space and requires more processing time. When photographs are taken digitally, the resolution can be coarsened and the number of quantization levels can be reduced in order to minimize the space required to store the digital photo, but these steps also introduce further inaccuracies.

Although sampling and quantization cause errors, those errors might not be perceived by people. For example, humans can hear sounds whose frequencies are below about 20 kHz (20 thousand cycles per second). When an audio signal is sampled at 40 kHz (or a higher frequency), all of the sounds that humans can hear can be reconstructed from the digital samples. For recording on a compact disc, music is sampled at 44.1 kHz, and each sample is quantized to 65,536 levels with 16 bits. (Cyganski et al. (2001) and Kuc (1999) explain the theory of sampling and quantization for general audiences.)

By using limits of human visual perception, we can determine sampling rates and quantization levels that would produce map displays for which digitization errors would not be detected by individuals. For instance, a curving road is digitized as a polyline that approximates the original curve. Figure 5a shows two polylines: one has ten line segments, and the other has twenty line segments at 1:36000 scale. The polyline that comprises twenty line segments represents the original curve better than the polyline of ten segments; when viewed at 1:36000 scale, it is nearly indistinguishable from the original curve. But the polyline of twenty segments requires more storage space and more computation time to process. The viewing scale can also affect the user's perception of a map feature. Figure 5b shows the same road and segments shown in Figure 5a, but at 1:12000 scale. At this scale, a user can clearly distinguish the original road from both the ten and twenty segment polylines.

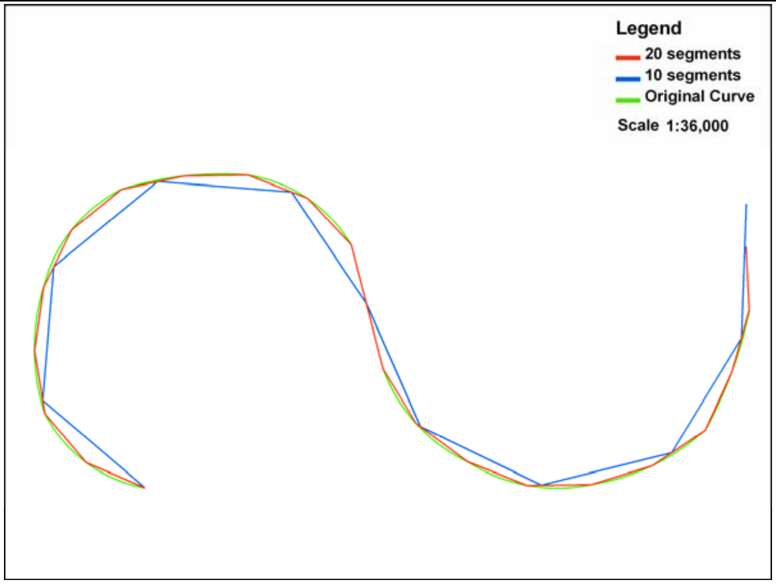


Figure 5(a). Polylines of different number of segments at 1:36000 scale

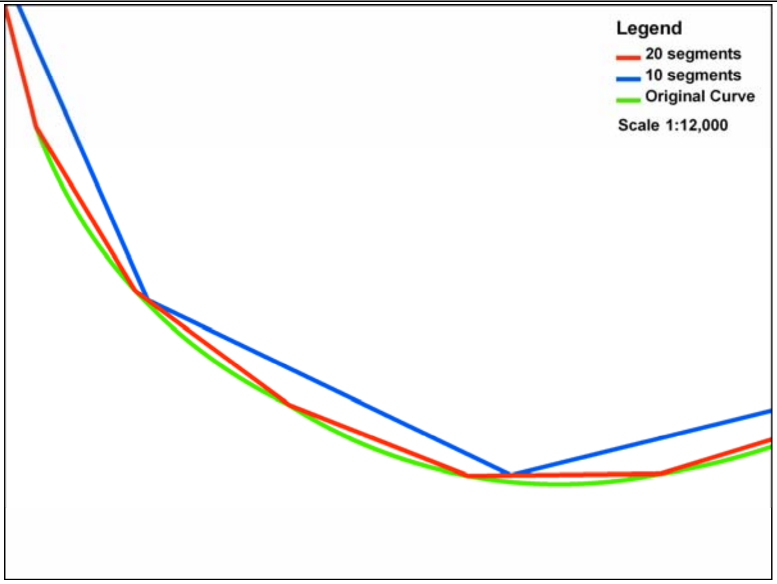


Figure 5(b). Polylines of different number of segments at 1:12000 scale

When GIS maps are used not for displays but for computational purposes, however, digitization errors could produce inaccurate results. Many utility companies use GIS calculations to determine charges. Suppose a municipal water company needs to calculate the areas of impervious surfaces within tax parcels. The impervious surface area is used to charge the parcel owner a fee for water runoff. A small error by a digitizer could significantly increase the calculated area of the impervious surface, and consequently, the parcel owner would be charged a significantly higher fee. In Figure 6(a), the impervious surface in a tax parcel is drawn accurately, and in Figure 6(b), one boundary of the impervious surface is drawn one foot wide of the actual boundary. The change from Figure 6(a) to Figure 6(b) results in an increase of ten square feet, an increase sufficient to raise the parcel owner's fee.

Figure 6(a). Impervious area of 100 square feet (green)

Figure 6(b). Impervious area of 110 square feet (red)

Even when the digitization of measurement data is sufficiently accurate for intended uses, the combination of data taken at different points of time can produce errors in GIS maps. For example, the Topologically Integrated Geographic Encoding and Reference (TIGER) system roadmap is a popular data set because it is free, but the last comprehensive update of the TIGER roadmap occurred in 1990. Although some roads have been added to the TIGER roadmap since 1990, many roads are omitted. In particular, the TIGER roadmap has an incomplete record for Las Vegas, whose population grew by 80% from 1990 to 2000. The layering of a TIGER roadmap with recent (post-2000) data from Las Vegas would produce many errors.

5. Inconsistencies

On September 11, 2001, terrorists flew passenger planes into the twin towers of the World Trade Center in New York City. First-responders were hindered in performing GIS analyses because different agencies had created different, inconsistent data sets. No one could be sure that one agency's data would be as accurate or up-to-date as another agency's. When GIS workers from the Federal Emergency Management Agency arrived in New York, they had difficulty finding a digital set of floor plans for the buildings. They created basic maps by digitizing tourist maps, and then they obtained floor plan data sets from three different sources. The resulting maps showed inconsistencies. For example, utility plans did not match the building footprint (Langhelm, 2004). More specifically, first responders had difficulty finding the water valves to shut off the water around ground zero. The paper water maps were stored in Rego Park, Queens. A city employee had to sort through those paper maps while communicating with responders at ground zero with a radio (Belson, 2008).

Sometimes GIS maps contain inconsistencies that are much less dramatic or not noticeable by a user at all. For example, a Web consultant created maps for a travel Web site by layering data from many different sources. The datums of the layers were overlooked during map production because all important locations on the maps appeared to be correct. The data layers actually were assigned to four different datums. The differences between datums used by NAD (North American Datum) 1927 and NAD 1983 result in discrepancies of 12 to 18 cm in locations (NADCON, n.d.). The differences between NAD and World Geodetic System (WGS) produce discrepancies of typically around one meter (Schwarz, 1989). These discrepancies would not be noticeable to a user who merely viewed the maps, but they could cause errors if a user tried to measure the distance between points assigned to two different datums.

Inconsistencies can arise when combining data from photos of different resolutions, and when combining data from data sets that have different formats, in particular, when grid data are combined with vector data. In the example in Figure 7, the points, polygons, and polylines of the vector data set generally do not match up with the boundaries of raster grid cells. Because the presence of multiple data formats complicates data analyses, users typically convert data to a common format by rasterizing the vector data. The rasterization process assigns only one value to each grid cell, based on the data present in the cell (Longley et al., 2001). When only one value is assigned to each grid cell, however, data are easily lost or misrepresented. For example, suppose each polygon in Figure 7 represents a particular crop grown on a farm. The normal rasterization process assigns to each grid cell the value of the polygon that occupies the greatest area of the cell. In Figure 7, the rasterized data set does not have a cell with value 2 for the crop represented by the small pink triangular polygon. If the rasterized map is used to determine farm subsidies, then crop 2 will not be subsidized.

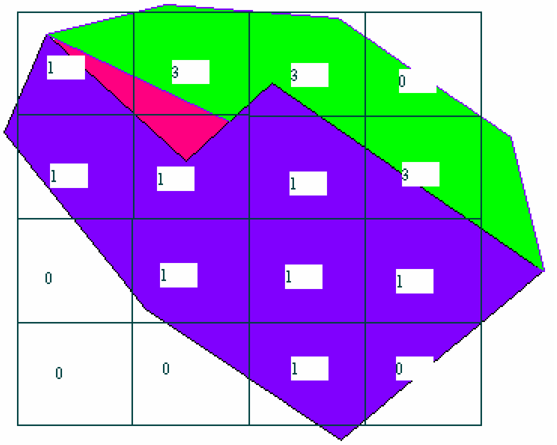


Figure 7. Rasterization of grid cell values

Using a finer grid with smaller raster grid cells would allow crop 2 to be represented, but would increase the required computer memory and disk space to store the GIS. The storage requirement is proportional to the number of grid cells: if the linear dimension of a grid cell is halved, then the storage requirement quadruples. Thus a finer grid requires more memory and consequently more processing time for analysis.

A different process for rasterizing vector data might attempt to ensure that for each crop whose proportion of field area exceeds a threshold, the crop is represented by at least one grid cell; further, the overall proportion of grid cells for each crop should approximate the proportion of its total area. In this second process, crop 2 might be represented by one cell in which it appears.

Inaccuracies arise when a data set with a datum for small areas such as State Plane Coordinates is combined with another data set that uses a datum for large areas such as WGS 84. For example, suppose town A is in a data set assigned a State Plane Coordinates datum, town B is in a data set assigned a WGS 84 datum. When the two data sets are combined in a GIS map, the GIS automatically relocates points according to the datum first used in constructing the current map; thus, if town A and its data set are added to the map first, then town B will be relocated according to the State Plane datum. After the coordinates of town B are converted from WGS 84 to the State Plane system, the measured distance in the GIS map between town A and town B might differ from the actual distance between the towns by as much as a kilometer in each of three dimensions (Dana, 2003).

Layering data sets with different projections creates inconsistencies in a GIS map. Figure 4 shows how the boundaries of the same region do not align when different projections are layered. A user studying Greenland will have difficulty combining a data set in the Gall-Peters projection with a data set in the Mercator projection.

6. Malleability

In typical maps, blue polygons represent water, and green polygons represent trees. The rules that define map representations are called **symbology**. When creating a map using GIS software, the user can choose the default symbology, or the user can define a personal, idiosyncratic symbology. A user who chooses blue polygons for trees and green polygons for water could mislead map viewers, however.

In Figure 8(a), a set of population density data for Manhattan (New York City) is classified using the default symbology method called **Jenks natural breaks**. The Jenks natural breaks method determines the ten ranges of density values by minimizing the sum of the squared differences between an actual value and the mean of its assigned range. Alternatively, in Figure 8(b), the user defines a symbology that represents the same set of density data with an equal interval classification: each range has the same size. While the two symbologies are applied to the same set of data, the figures convey drastically different messages about the population density of Manhattan.

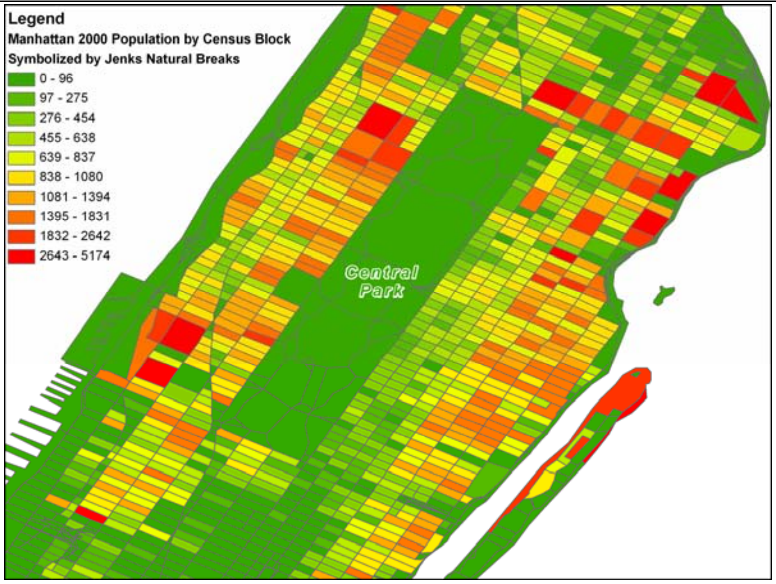


Figure 8(a). Jenks natural breaks classifications

Figure 8(b). Equal interval classification

7. Professional Responsibility

According to Baase (2003, pp. 171–182), the users of any computer model should ask critical questions about the accuracy and completeness of the data and about the validity of the assumptions in the model. Similarly, users of a GIS should understand the sources of inaccuracies, such as the sources that we described in previous sections of this paper. In this section, we identify three ways by which a GIS user or developer can responsibly mitigate problems caused by these inaccuracies.

First, when creating maps, a GIS user can compensate for some inconsistencies by using consistency checks. Some inconsistencies can be avoided by matching the datum, projection, and data format of each new data set added to the existing data in a GIS document. Information about the datum, projection, and data format should be included in the **metadata** that accompany each data set. Metadata are the data that describe and document the geographic data set. The GIS user should compare the metadata of two data sets to verify their consistency and compatibility. A standard format for metadata has been developed so that the GIS itself could compare the metadata to check for inconsistencies automatically. As data sets are combined, the GIS can at least warn the user about inconsistencies in a map. This warning helps the user identify the problems caused by inconsistent data, and the warning makes the user accountable for these problems. A GIS user who is held accountable for the inconsistencies is more likely to take responsible action to minimize or eliminate the consequences of the inconsistencies. For example, if the projections used by the data sets differ, then the user could require the GIS to convert data from one projection to the other; with the advent of on-the-fly projection, a GIS might convert the projection automatically without informing the user. It is difficult to eliminate all data inconsistencies, however, because a GIS can combine massive amounts of data from multiple sources into one document.

Second, a GIS user can reduce errors in a GIS map by following technical standards. Although Harley (2001) criticized technical standards for reducing the diversity of representations, standards are widely used in other technologies to facilitate interoperability. For instance, an audio jack standard ensures that headphones manufactured by Shure fit in an MP3 player manufactured by Apple. The GIS developer community should formulate technical standards for users. For example, a standard color scheme could specify darker colors for larger numerical values.

Third, a GIS user makes deliberate choices that involve tradeoffs between cost, storage space, and computation time to minimize the effects of errors on subsequent analyses. For instance, if an analysis requires the GIS user to choose an expensive, high resolution photo that requires a large amount of storage space, then the user will need to tolerate large computation times. Similarly, the GIS user should understand the tradeoffs in choosing between vector data and rasterized data, and should know when each format is appropriate. The decisions of a GIS user resemble the decisions of engineers to minimize production time, minimize production cost, and maximize product quality: all three objectives cannot be achieved simultaneously. Typically, an engineer or GIS user is given a budget and a schedule, and he must maximize the quality within cost and time constraints. In addition, the GIS user must also ensure that these decisions do not violate the consistency checks and minimum technical standards.

Geographic information systems are so new that they lack common standards of practice. In much of engineering, technical standards such as building codes have simplified the ethics of technical decisions (Florman, 1987, page 87). Though an engineer should not adhere slavishly to an obsolete standard, in typical cases, complying with standards fulfills the engineer’s professional responsibility. In the absence of standards, however, engineers and GIS users must rely on ethical reasoning to make wise decisions.

As a step toward defining standards of professional practice, the GIS Certification Institute (GISCI, www.gisci.org) has developed a Code of Ethics (2003) and a statement of Rules of Conduct for Certified GIS Professionals (2006). The GISCI code and rules resemble the codes of ethics for other technical professionals such as engineers, but the GISCI rules include GIS-specific principles, such as requiring adequate metadata documentation. A GIS user who combines data layers without checking the metadata for compatibility would be considered incompetent.

For all professions, standards of practice are needed to define technical competence, which is an ethical obligation of professionals. For example, the IEEE Code of Ethics (2006) states that members are obligated "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations." The Code of Ethics of the National Society of Professional Engineers (2007) requires that engineers "perform services only in their areas of competence." Once the GIS community defines professional standards of practice, GIS users will know how to fulfill their ethical obligation as professionals to be technically competent.

8. Conclusions

Although other scholars have characterized the ethical issues in geographic information systems primarily as achieving accuracy, in this paper, we have explained how technical limitations in digitization and layering produce unavoidable inaccuracies in a GIS. These limitations include the resolution of image samples, the quantization of continuous values, and the combination of data in incompatible formats from multiple sources. In other words, all data in a GIS are wrong. Thus, designers and users should adopt professionally responsible practices and technical standards that minimize the effects of erroneous data.

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