VS-361 Introduction to Geographical Information System (GIS)
(Adapted from Inside AutoDesk World, Vance; Smith; Appell)

Geographic Information System

A GIS is any computer-based method of managing and analyzing geographic (or mapping) data. Geographic data include graphical data (also referred to as spatial data), such as lines and polygons, as well as attribute data, such as numeric and textual data typically found in a database. Its ability to establish a link between graphical and attribute data is what makes a GIS so powerful, and what sets it apart from CAD systems. For example, if a line in a GIS represents a road, the GIS can tell you not only its length, but also its name, number of lanes, when it was last paved, speed limit, and any other data that might be associated with the road.

A GIS also allows you to analyze and display data in highly sophisticated ways. For example, if there is a point on a map that represents a hospital, you could ask the GIS to show the nearest major road. You could also ask the computer to display the roads in varying thickness based on the number of lanes per road, and to create a thematic map that clearly shows which roads are most heavily traveled. This power to analyze information and then display it in a variety of ways that allow for quick and easy discernment of patterns in data is what makes a GIS such a useful tool in many different fields.

History of GIS

Computerized GIS as a field has been around for about 30 years, but GIS software was little known among people outside the field until recently.

The need to link graphical and attribute data has been around for nearly as long as maps. Even the earliest cartographers might have wanted to provide supplementary information about their maps, such as which ocean routes had the highest instances of sea monster sightings, or where plentiful fresh water could be found in desolate regions. Some historians of GIS might date its beginnings to the nineteenth century, when the concept of map overlays first came into being.

Overlaying refers to the practice of displaying the same map in various "layers," where each layer represents a different set of information about the geographical area in question. For instance, a map of a forest might have a layer showing the location of various wildlife species, and another layer might show the exact same area in terms of vegetation types. By superimposing one layer on top of the other, you might discover that some types of animals prefer to make their habitats in proximity to specific types of vegetation. Exploring such relationships is one aspect of implementing geographic analysis, and is an important component of a GIS.

It might not seem like you would need a computer to perform the simple task of placing one map on top of another and then examining patterns. As an example at the other extreme, consider the task set before the Canadian Department of Forestry and Rural Development in the 1960s. The government decided it wanted to chart all of Canada in such a way that the resulting maps would facilitate the development of land and resource management. This would be an enormous undertaking, requiring that the maps created classify the entire country according to a wide assortment of statistical *requirements encompassing not only wildlife habitat and vegetation, but soil and mineral types, land usage, and census partitions, just to name a few.*

Clearly such an enormous undertaking could not be accomplished with traditional mapping practices. Therefore, the Canada Geographic Information System (CGIS), headed by the "grandfather of GIS," Roger Tomlinson, was created to develop a new technology with the use of computers that would simplify the process. Both because it is generally accepted as the earliest example of a modern GIS, and because it pioneered so many technological innovations, CGIS is often considered the birthplace of the field of GIS.

Most users of GIS today do not need to carry out spatial analysis of an entire country, but they generally do have large data sets and complex analysis requirements. Computers can save an astonishing amount of time and effort in the solution of spatial queries, which is why GIS as a field is generally seen as a scion of the computer age, even though it shares some of its ancestry with the ancient art of cartography.

The rise of GIS since the watershed of CGIS has been greatly assisted by several factors. The increasingly sophisticated informational requirements of our age have created a demand for tools that will help manage unwieldy amounts of data. The exigency of global concerns such as environmental and population stress have rendered GIS an especially vital and pertinent analytical method. However, the most important factor is without a doubt the parallel growth of related technologies, such as CAD, and improvements in computer technology and overall availability.

Over the two decades (20 years) following the implementation of CGIS, the notion of using computers for collecting and analyzing geographical data, slowly but surely gained currency as the possibilities for GIS applications increased. The Harvard Laboratory for Computer Graphics and Spatial Analysis, headed by Howard Fisher, made huge strides in advancing GIS technology during this period. In the late 1960s, pioneer GIS companies such as Environmental Systems Research Institute (ESRI) and Intergraph (initially called M&S Computing, Inc.) were formed.

Computer technology was still in its infancy at this time, and was cumbersome, expensive, and unfamiliar to most people. For the most part government agencies were the primary users of GIS in its early phases, and many uses were found for it.

At the local level,
  - *GIS was used for emergency vehicle and garbage truck routing, and utilities and tax zone analysis;*

At the provincial or state level
  - *GIS proved invaluable for land and resource management; and*

At the federal level
  - *GIS was implemented by such diverse agencies as,*
    the National Aeronautics and Space Administration (NASA);
    the Environmental Protection Agency (EPA);
    and the Census Bureau.

By the early 1980s, professional organizations and publications dedicated to GIS had sprung up; several companies had caught on to the technology and introduced GIS software to the marketplace. However, these GIS packages were still hindered by:

- *non-intuitive user interfaces;*
- *limited functionality;*
- *the lack of available GIS data;*
- *and the expense of computer hardware.*

These factors made GIS out of reach to most people and small businesses.

With the tremendous growth in processing power and reduction in the price of personal computers in the 1980s and 1990s, however, the typical computer user gained the means to accomplish feats that previously could be handled only by mainframe computers. Moreover, computer software kept pace with the increasing capabilities of the hardware, so that advanced GIS technology soon came within reach of the average user.

Even with affordable and accessible computer technology, however, a GIS is only as good as the data that go into it. The fundamental virtue of GIS lies in its ability to integrate and analyze a variety of data pertaining to geographic entities.

Where do such data sets come from?

The U.S. Census Bureau has played a vital role in accelerating the progress of the GIS field by supplying an enormous amount of geographically referenced data. The Census of 1970 witnessed the use of the Dual Independent Map Encoding (DIME) format, which was the first time census information had been geocoded for use with computers. The DIME files were merely a precursor (albeit an important one) to the real boon to GIS, the 1990 Census data.

This information includes two data formats: Topologically Integrated Geographically Encoded and Referenced (TIGER) files, and Summary Tape Files (STF). In a nutshell, the TIGER files provide geographic information (such as addresses and features) about a country, whereas the STF files contain attribute information (such as age, gender, and income) of the population.

The TIGER and STF files represent a vast quantity of comprehensive information about the United States, all of which is in the public domain. These files have become the basis for many new data products, and ensure that there are data available for the expanding GIS market. In addition, the U.S. Defence Mapping Agency compiled a map of the world, called Digital Chart of the World, and published in 1992.
The Digital Chart of the World, which contains both geographic and attribute data, is also in the public domain. New GIS users from other countries that do not have much digitized geographic information of their own frequently get their projects started here.

GIS is now a multi-billion dollar industry, with an annual growth rate projected at upwards of 20 percent. GIS software has matured greatly since the inception of the field. It has become easier to use, the functionality has evolved tremendously, and data availability has grown so that the answer to virtually any map-related question can be found with the click of a mouse. The number of desktop mapping and GIS *software packages for the PC has grown phenomenally in recent years. Companies such as Microsoft, Lotus, and Corel have introduced desktop-mapping components to their business suite packages, in Microsoft Excel, Lotus 1-2-3, and Corel Draw, respectively.*

The technology has become so affordable and user friendly that even the smallest enterprise can use GIS. This availability in turn has served to open up new vistas in GIS applicability as more and more businesses discover that they can solve problems and improve efficiency through the informational empowerment of GIS. Essentially, any business that can use a map of whatever type-be it a travel agency, a taxi service, or a marketing company making use of demographics-can benefit from GIS.

Providing a complete history of GIS is beyond the outline, but with the explosive growth of the GIS field has come many excellent references and Web sites that can provide you with much more detail about the remarkable emergence and maturation of this fascinating field. What should be clear here is that the GIS field exists at the nexus (connection) of several exciting disciplines, each of which appears to both feed off, and help generate the success of, the others.

New strides in software development generate consumer awareness of the manifold advantages GIS technology can bring to the workplace. This awareness, coupled with an increasingly global outlook in virtually every area of modern life, becomes in turn a demand forever more ambitious and creative technology. GIS is an exciting field that has really blossomed in recent years.

Computer Aided Design

CAD software is used to help design graphics or pictures, especially technical drawings such as those used by architects and engineers. What sets a CAD program apart from other drawing programs is its ability to incorporate relative proportion. For example, an artist using a typical drawing program has no need to know that a line on the screen might represent ten feet; whereas an architect or an engineer must know the exact distance any line on the screen represents. If the line represents a wall, an architect needs to know its exact dimensions to ensure that other walls will fit with it precisely. This sensitivity to proportion in conjunction with unsurpassed accuracy prompts many people to use CAD systems for creating maps.

CAD systems tend to have extensive drawing tools and functions. Whether the data are derived from paper drawings (or from pre-existing paper maps) or drawn on screen, CAD can create high quality maps as output. Many people who are now being assigned to create geographic data are the very same engineers who have been using CAD systems for years to complete their more traditional work.

Engineers and others will often create geographic data using CAD systems, and only later discover CAD's primary limitation with respect to examining the data they have created: it lacks data analysis tools. While a CAD program may have superior drafting capabilities, it can neither ask nor answer questions that involve information external to what it has drawn-that is the purpose of a GIS. Nevertheless, the large amount of existing map data in CAD format can be very useful to the GIS professional.

Major Differences Between CAD and GIS:

Some of the differences between CAD and GIS may appear to be minor at first glance, but they can greatly influence the way a program is designed..

***Attributes**. The key feature of a GIS is its ability to link graphical data with data stored in an alphanumeric database (the alphanumeric data linked to a graphical entity are known as the entity's attributes). This feature allows data (e.g., county populations) to be used in connection with the graphics (e.g., select all counties with a population greater than 50,000, but with an area of less than 50 square miles). The ability to treat graphics as just one more aspect of a larger database is the most important difference between GIS and CAD. In fact, many GIS programs emphasize the database part of the program over the graphical part.*

***Topology.** Topology is the ability of GIS software to recognize the spatial relationship among graphical objects. For example, does one object touch another (is county A next to county B), or is one object contained by another (in which county is this lake)? This ability allows you to ask questions such as "Which parcels might require government aid if the river overflows?" or "What is the quickest route from point A to point B?"*

***Size of data.** GIS is typically concerned with problems that involve large amounts of data, both graphical and attribute. For example, a GIS could help you locate an appropriate site in a particular city for a new hotel. The data for that city might include (and the question or query would use) street data for all streets, both minor and major; all parcel data, including land values in an associated database; tax zones; neighbourhoods and crime rates; and competitor's locations – possibly hundreds of megabytes of data or more. Because the average CAD package processes data in RAM, it would require huge amounts of this type of memory to store all data used in the query, if it could handle the questions that require alphanumeric data at all.*

GIS data traditionally use a disk-based model, meaning that the data are stored and accessed on disk. This characteristic has many ramifications for the functionality of GIS, but perhaps the most critical is that a GIS system can use large amounts of data without the need for large amounts of RAM.

***Location:** In most CAD applications, it is not important where the graphical objects are located in the physical world, but in many GIS applications, the ability to specify location is an important feature. This is very closely tied to the size of the data as well, because one of the requirements for being able to open data from many different sources is knowing how to overlay it correctly (when data derive from disparate sources that might be stored with different coordinate systems).*

***Graphical tools.** Because CAD is primarily a drafting tool, it is free of many of the responsibilities of GIS (such as support for attribute data and large data sets), and traditionally has better, more flexible tools for tasks related to the graphical part of the data. For example, CAD usually has more types of graphical entities, and better editing tools for working with them.*

What do these differences mean for the average GIS or CAD package, and even more importantly, for the average GIS or CAD user? Because of its superior graphical capabilities, CAD is often considered a better choice for creating map output.

However, because of its data handling capabilities, GIS is traditionally better at handling analysis and small-scale (large data) maps.

This would seem to imply that CAD could be used for creating and editing the graphical data, as well as creating quality output to paper, while a GIS could use the CAD data, along with attribute data, for analysis. In practice, however, it has often turned out that each type of software has had trouble using the other one's data.

GIS Concepts:

Earlier, GIS was defined as "any computer based method of managing and analyzing geographic (or mapping) data." This is a very high level definition that tells you almost nothing about the specifics. Although implementation details and decisions can be answered in a variety of ways (and there are notable exceptions to some of the topics described here) you will see how most GIS packages work, and how respective data sets are structured.

Spatial Data

Geographic data are usually categorized as:
***spatial (**graphical) **data**;*
*and **attribute data** (tabular data from some form of database).*

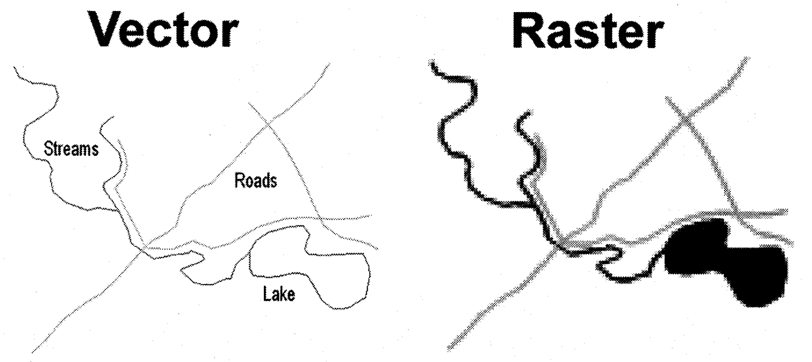
***Spatial data** describe **where** map features are, whereas*
***attribute data** describe **what** they are.*

An obvious corollary to this, but one that many people miss, is that the geographic features in a GIS "know" where they are. What this really means is that the GIS knows how to interpret the data in a way that relates it to a location on Earth. This concept is actually more involved than it may initially appear. For more information on how a GIS knows, see the supplementary notes.

Spatial Data Representation

Spatial data have ***two*** *primary modes of representation:* ***raster and vector****. Vector. data are described by points and lines (vectors), and contain information only. where those points and lines exist. Raster data are plotted on a grid, where every point in the grid contains information. Even if there is nothing there, raster data will communicate that nothing. The following illustration shows examples of raster and vector data for the same geographic feature.*

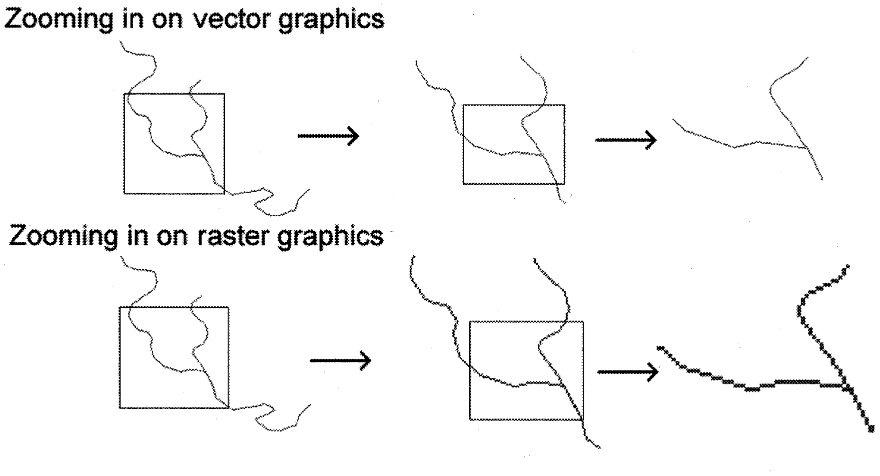
Examples of Raster and Vector data.



Raster data are often called "bitmap" data, which you might recognize graphic data format but as a graphics format. Each grid point describes one *<u>pixel</u>* *of a picture for printer output or screen display. Raster format is often used to store photographs and pictures; it is perfect for storing certain types of geographic data, such as aerial photographs and satellite imagery. Some GIS software products such as 'World' supports the play of raster data formats, but the bulk of World's functionality is focused on vector data formats.*

Vector data are the traditional format for GIS software. Vector data are described not by a grid of pixels, but by the points that constitute the ends of lines. For example, in the previous illustration, a line in the vector data could be described by saying that it starts at the point (5, 10) and ends at the point (10, 15), and that it is blue. This is a much more efficient way of storing a line than storing all of the points that make up the line, as is done with raster, and it means that the line remains a line as you zoom in. Consider the sample of zooming into vector and raster data in the next illustration.

Zooming into Vector v/s Raster data.



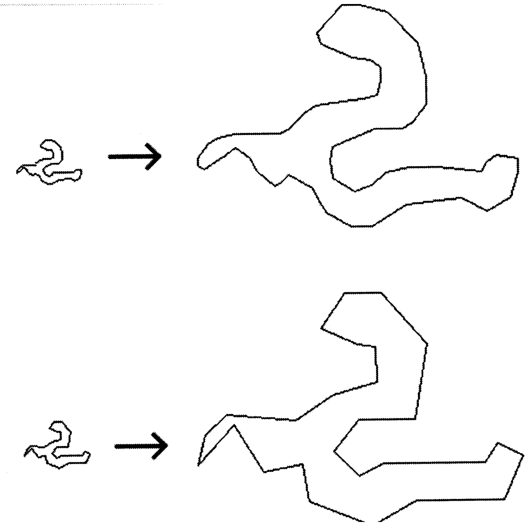
A Word about Scale.

Scale is one of the most important concepts in mapping, and it is also the most frequently confused. Map scale, such as 1:200, consists of two numbers describing the ratio between map units (the first number and the real-word units (the second number). If the units are in inches, the map scale 1:200 means that one-inch on the map is equal to 200 inches in reality. Scale is thus a critical art of defining a map because it allows you to determine exact measurements for the real-world objects the map objects represent.

One confusing aspect of map scale lies in its terminology: large scale and small scale. Because a map scale is a ratio, or faction, a large-scale map is one that has a SMALL second number (such as 1:10) and shows a relatively small area; the larger the scale, the closer it comes to representing reality in actual measurements. Thus, a map with a scale of 1:10 displays objects closer to their real size (larger) than a smaller-scale map of 1:20,000. The easiest way to remember the difference is to think of scale in terms of the map objects; the larger the objects appear, the larger the scale. The smaller the objects appear (and thus the larger the area of the world you display), the smaller the scale. An example of large-scale map might be 1:200 (such as a map of a house property), while an example of a small scale might be 1:2,000,000 (such as a map of the world).

In GIS, scale refers to two separate processes: the scale at which you view or print a map, and the scale at which the data were digitized. Digitizing is the process of creating digital maps from printed (paper) maps. If the scale of the original printed map was 1:2,000,000, you will not be able t use the data in a large-scale map (say, 1:20,000), because it will not be accurate enough. (In this case, every error in digitizing will be magnified 100 times). The following illustration shows why this can be a problem if not taken into account. Note that the two objects on the left appear to be about the same, and they are when viewed at such a small scale. However, as you zoom in on them (the objects on the right), you can tell that the top one was digitized at a higher scale (and thus, with more detail) than the bottom one.

If this illustration were a lake to be viewed on large-scale maps, the detailed top object would be more useful than the less detailed lower object. However, the lower object would be better for small-scale maps, where the detail is not necessary and simply uses more storage space. Choosing the correct data (or digitizing at the correct scale, if you are creating your own data) is more than just knowing what data to acquire; it also includes knowing about how the data were created.



Digitizing scale contrast: object at the top digitized at higher scale than lower object.

Common GIS Outputs:

GIS software is designed to extract information from data. The information can be in many forms, but three are 4 common formats that most GIS products support.

Printed Maps:
This is the obvious result you might expect from a GIS, but in practice it is probably the least frequently used of the four output methods. Printed maps are extremely useful for sending to other people, especially people who do not have the GIS software themselves. However, creating paper maps is a slow process at times, and is therefore often reserved for the final product of a project, rather than for interim output.

Tabular Data:
Basically this means that GIS is used to analyze data, and create or alter columns in the attributed database itself. This attribute database could then be output to a database program. For example, GIS software could be used to add a column to a bank database of housing loans. This new column might contain the tax zone each property's address falls into. The pre-existing database program could then calculate the number of loans in each tax zone the bank provides on an annual basis. Although most GIS products would contain a database capable of handling this sort of problem entirely within the GIS software, this is an example of a GIS program fitting into an existing application.

Reports:
These ate the printed output of tabular data. Reports are a way of displaying tabular data. Reports are a way of displaying tabular data in a way the average reader will easily understand. Pie charts or colour-coded ranges are examples. Reports often summarized the data in a tabular database in a way that simplifies analysis.

Screen Output:
This is the most overlooked output of GIS, yet probably the most frequently used. The person using the GIS is often the decision-maker, or works very closely with the decision-maker who bases decisions on the output of the GIS. In most cases, analysis and decisions are made based on an on-screen map created on the fly. One of the most attractive characteristics of GIS lies in allowing you to examine a map on the computer screen and then say, "Yes, but what if this part were X instead of Y?" GIS allows questions of this nature to be answered almost instantly on the screen. Waiting for a printed map to get every hypothetical question answered, on the other hand, would greatly reduce both your efficiency and flexibility.