NIILM University

Remote Sensing

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Chapter 1

Introduction to Active Remote Sensing and GIS

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object. In modern usage, the term generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of propagated signals (e.g. electromagnetic radiation). It may be split into active remote sensing, when a signal is first emitted from aircraft or satellites) or passive (e.g. sunlight) when information is merely recorded.

Electromagnetic radiation (EM radiation or EMR) is a form of radiant energy, propagating through space via photon wave particles. In a vacuum, it propagates at a characteristic speed, the speed of light, normally in straight lines. EMR is emitted and absorbed by charged particles. As an electromagnetic wave, it has both electric and magnetic field components, which oscillate in a fixed relationship to one another, perpendicular to each other and perpendicular to the direction of energy and wave propagation.

EMR is characterized by the frequency or wavelength of its wave. The electromagnetic spectrum, in order of increasing frequency and decreasing wavelength, consists of radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays. The eyes of various organisms sense a somewhat variable but relatively small range of frequencies of EMR called the visible spectrum or light. Higher frequencies correspond to proportionately more energy carried by each photon; for instance, a single gamma ray photon carries far more energy than a single photon of visible light.

Electromagnetic radiation is associated with EM fields that are free to propagate themselves without the continuing influence of the moving charges that produced them, because they have achieved sufficient distance from those charges. Thus, EMR is sometimes referred to as the far field. In this language, the near field refers to EM fields near the charges and current that directly produced them, as for example with simple magnets and static electricity phenomena. In EMR, the magnetic and electric fields are each induced by changes in the other type of field, thus propagating itself as a wave. This close relationship assures that both types of fields in EMR stand in phase and in a fixed ratio of intensity to each other, with maxima and nodes in each found at the same places in space.

EMR carries energy—sometimes called radiant energy—through space continuously away from the source (this is not true of the near-field part of the EM field). EMR also carries both momentum and angular momentum. These properties may all be imparted to matter with which it interacts. EMR is produced from other types of energy when created, and it is converted to other types of energy when it is destroyed. The photon is the quantum of the electromagnetic interaction, and is the basic "unit" or constituent of all forms of EMR. The quantum nature of light becomes more apparent at high frequencies (thus high photon energy). Such photons behave more like particles than lower-frequency photons do.

In classical physics, EMR is considered to be produced when charged particles are accelerated by forces acting on them. Electrons are responsible for emission of most EMR because they have low mass, and therefore are easily accelerated by a variety of mechanisms. Rapidly moving electrons are most sharply accelerated when they encounter a region of force, so they are responsible for producing much of the highest frequency electromagnetic radiation observed in nature. Quantum processes can also produce EMR, such as when atomic nuclei undergo gamma decay, and processes such as neutral pion decay.

The effects of EMR upon biological systems (and also to many other chemical systems, under standard conditions) depends both upon the radiation's power and frequency. For lower frequencies of EMR up to those of visible light (i.e., radio, microwave, infrared), the damage done to cells and also to many ordinary materials under such conditions is determined mainly by heating effects, and thus by the radiation power. By contrast, for higher frequency radiations at ultraviolet frequencies and above (i.e., X-rays and gamma rays) the damage to chemical materials and living cells by EMR is far larger than that done by simple heating, due to the ability of single photons in such high frequency EMR to damage individual molecules chemically.

Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding areas. Reflected sunlight is the most common source of radiation measured by passive sensors.

Examples of passive remote sensors include film photography, infrared, charge-coupled devices, and radiometers.

A radiometer is a device for measuring the radiant flux (power) of electromagnetic radiation. Generally, the term radiometer denotes an infrared radiation detector or Ultraviolet detector yet it also includes detectors operating on any electromagnetic wavelength.

A common example is the Crookes radiometer, an early-model device wherein a rotor (having vanes which are dark on one side, and light on the other) in a partial vacuum spins when exposed to light. A common myth (one originally held even by Crookes) is that the momentum of the absorbed light on the black faces makes the radiometer operate. If this were true however, the radiometer would spin away from the non-black faces, since the photons bouncing off those faces impart even more momentum than the photons absorbed on the black faces. Follow the link below for an in-depth explanation of the principles behind a Crookes radiometer.

The Nichols radiometer operates on a different principle and is more sensitive than the Crookes type.

A microwave radiometer operates in the microwave wavelengths. The radiometer contains argon gas to enable it to rotate.

The MEMS radiometer, invented by Patrick Jankowiak, can operate on the principles of Nichols or Crooke and can operate over a wide spectrum of wavelength and particle energy levels.Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR and LiDAR are examples of active remote sensing where the time delay between emission and return is measured, establishing the location, speed and direction of an object.

Remote sensing makes it possible to collect data on dangerous or inaccessible areas. Remote sensing applications include monitoring deforestation in areas such as the Amazon Basin, glacial features in Arctic and Antarctic regions, and depth sounding of coastal and ocean depths. Military collection during the Cold War made use of stand-off collection of data about dangerous border areas. Remote sensing also replaces costly and slow data collection on the ground, ensuring in the process that areas or objects are not disturbed.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such as El Niño and other natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, agricultural fields such as land usage and conservation, and national security and overhead, ground-based and stand-off collection on border areas.

The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation.The "electromagnetic spectrum" of an object has a different meaning, and is instead the characteristic distribution of electromagnetic radiation emitted or absorbed by that particular object.

The electromagnetic spectrum extends from below the low frequencies used for modern radio communication to gamma radiation at the short-wavelength (high-frequency) end, thereby covering wavelengths from thousands of kilometers down to a fraction of the size of an atom. The limit for long wavelengths is the size of the universe itself, while it is thought that the short wavelength limit is in the vicinity of the Planck length, although in principle the spectrum is infinite and continuous.

Most parts of the electromagnetic spectrum are used in science for spectroscopic and other probing interactions, as ways to study and characterize matter. In addition, radiation from various parts of the spectrum has found many other uses for communications and manufacturing.

For most of history, light was the only known part of the electromagnetic spectrum. The ancient Greeks recognized that light traveled in straight lines and studied some of its properties, including reflection and refraction. Over the years the study of light continued and during the 16th and 17th centuries there were conflicting theories which regarded light as either a wave or a particle

The first discovery of electromagnetic radiation other than light came in 1800, when William Hershel discovered infrared radiation.He was studying the temperature of different colors by moving a thermometer through light split by a prism. He noticed that the highest temperature was beyond red. He theorized that this temperature change was due to "calorific rays" which would be in effect a type of light ray that could not be seen. The next year, Johann Ritter worked at the other end of the spectrum and noticed what he called "chemical rays" (invisible light rays that induced certain chemical reactions) that behaved similar to visible violet light rays, but were beyond them in the spectrum. They were later renamed ultraviolet radiation.

Electromagnetic radiation had been first linked to electromagnetism in 1845, when Michael Faraday noticed that the polarization of light traveling through a transparent material responded to a magnetic field (see Faraday effect). During the 1860s James Maxwell developed four partial differential equations for the electromagnetic field. Two of these equations predicted the possibility of, and behavior of, waves in the field. Analyzing the speed of these theoretical waves, Maxwell realized that they must travel at a speed that was about the known speed of light. This startling coincidence in value led Maxwell to make the inference that light itself is a type of electromagnetic wave.

Maxwell's equations predicted an infinite number of frequencies of electromagnetic waves, all traveling at the speed of light. This was the first indication of the existence of the entire electromagnetic spectrum.

Maxwell's predicted waves included waves at very low frequencies compared to infrared, which in theory might be created by oscillating charges in an ordinary electrical circuit of a certain type. Attempting to prove Maxwell's equations and detect such low frequency electromagnetic radiation, in 1886 the physicist Heinrich Hertz built an apparatus to generate and detect what we now call radio waves. Hertz found the waves and was able to infer (by measuring their wavelength and multiplying it by their frequency) that they traveled at the speed of light. Hertz also demonstrated that the new radiation could be both reflected and refracted by various dielectric media, in the same manner as light. For example, Hertz was able to focus the waves using a lens made of tree resin. In a later experiment, Hertz similarly produced and measured the properties of microwaves. These new types of waves paved the way for inventions such as the wireless telegraph and the radio.

In 1895 Wilhelm Röntgen noticed a new type of radiation emitted during an experiment with an evacuated tube subjected to a high voltage. He called these radiations x-rays and found that they were able to travel through parts of the human body but were reflected or stopped by denser matter such as bones. Before long, many uses were found for them in the field of medicine.

The last portion of the electromagnetic spectrum was filled in with the discovery of gamma rays. In 1900 Paul Villard was studying the radioactive emissions of radium when he identified a new type of radiation that he first thought consisted of particles similar to known alpha and beta particles, but with the power of being far more penetrating than either. However, in 1910, British physicist William Henry Bragg demonstrated that gamma rays are electromagnetic radiation, not particles, and in 1914, Ernest Rutherford (who had named them gamma rays in 1903 when he realized that they were fundamentally different from charged alpha and beta rays) and Edward Andrade measured their wavelengths, and found that gamma rays were similar to X-rays, but with shorter wavelengths and higher frequencies.

Range of the spectrum

Electromagnetic waves are typically described by any of the following three physical properties: the frequency f, wavelength λ, or photon energy E. Frequencies observed in astronomy range from 2.4×1023 Hz (1 GeV gamma rays) down to the local plasma frequency of the ionized interstellar medium (~1 kHz). Wavelength is inversely proportional to the wave frequency, so gamma rays have very short wavelengths that are fractions of the size of atoms, whereas wavelengths on the opposite end of the spectrum can be as long as the universe. Photon energy is directly proportional to the wave frequency, so gamma ray photons have the highest energy (around a billion electron volts), while radio wave photons have very low energy (around a femtoelectronvolt). These relations are illustrated by the following equations:

$$f = \frac{c}{\lambda}, \quad\text{or}\quad f = \frac{E}{h}, \quad\text{or}\quad E=\frac{hc}{\lambda},$$

where:

c = 299792458 m/s is the speed of light in vacuum and

h = 6.62606896(33)×10−34 J s = 4.13566733(10)×10−15 eV s is Planck's constant.

Whenever electromagnetic waves exist in a medium with matter, their wavelength is decreased. Wavelengths of electromagnetic radiation, no matter what medium they are traveling through, are usually quoted in terms of the vacuum wavelength, although this is not always explicitly stated.

Generally, electromagnetic radiation is classified by wavelength into radio wave, microwave, terahertz (or sub-millimeter) radiation, infrared, the visible region we perceive as light, ultraviolet, X-rays and gamma rays. The behavior of EM radiation depends on its wavelength. When EM radiation interacts with single atoms and molecules, its behavior also depends on the amount of energy per quantum (photon) it carries.

Spectroscopy can detect a much wider region of the EM spectrum than the visible range of 400 nm to 700 nm. A common laboratory spectroscope can detect wavelengths from 2 nm to 2500 nm. Detailed information about the physical properties of objects, gases, or even stars can be obtained from this type of device. Spectroscopes are widely used in astrophysics. For example, many hydrogen atoms emit a radio wave photon that has a wavelength of 21.12 cm. Also, frequencies of 30 Hz and below can be produced by and are important in the study of certain stellar nebulae and frequencies as high as 2.9×1027 Hz have been detected from astrophysical sources.

Geographic information system (GIS)

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. The acronym GIS is sometimes used for geographical information science or geospatial information studies to refer to the academic discipline or career of working with geographic information systems and is a large domain within the broader academic discipline of Geoinformatics.

Geoinformatics is the science and the technology which develops and uses information science infrastructure to address the problems of geography, geosciences and related branches of engineering.

Geoinformatics has been described as "the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information" or "the art, science or technology dealing with the acquisition, storage, processing production, presentation and dissemination of geoinformation".

Geomatics is a similarly used term which encompasses geoinformatics, but geomatics focuses more so on surveying. Geoinformatics has at its core the technologies supporting the processes of acquiring, analyzing and visualizing spatial data. Both geomatics and geoinformatics include and rely heavily upon the theory and practical implications of geodesy.

Geography and earth science increasingly rely on digital spatial data acquired from remotely sensed images analyzed by geographical information systems (GIS) and visualized on paper or the computer screen.

Geoinformatics combines geospatial analysis and modeling, development of geospatial databases, information systems design, human-computer interaction and both wired and wireless networking technologies. Geoinformatics uses geocomputation and geovisualization for analyzing geoinformation.

Chapter 2

Satellite Navigation

A satellite navigation or sat nav system is a system of satellites that provide autonomous geo-spatial positioning with global coverage. It allows small electronic receivers to determine their location (longitude, latitude, and altitude) to high precision (within a few metres) using time signals transmitted along a line of sight by radio from satellites. The signals also allow the electronic receivers to calculate the current local time to high precision, which allows time synchronisation. A satellite navigation system with global coverage may be termed a global navigation satellite system or GNSS.

As of April 2013, only the United States NAVSTAR Global Positioning System (GPS) and the Russian GLONASS are global operational GNSSs. China is in the process of expanding its regional Beidou navigation system into the global Compass navigation system by 2020.The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be fully operational by 2020 at the earliest. France, India and Japan are in the process of developing regional navigation systems.

Global coverage for each system is generally achieved by a satellite constellation of 20–30 medium Earth orbit (MEO) satellites spread between several orbital planes. The actual systems vary, but use orbital inclinations of >50° and orbital periods of roughly twelve hours (at an altitude of about 20,000 kilometres (12,000 mi)).

Classification

Satellite navigation systems that provide enhanced accuracy and integrity monitoring usable for civil navigation are classified as follows:

- GNSS-1is the first generation system and is the combination of existing satellite navigation systems (GPS and GLONASS), with Satellite Based Augmentation Systems (SBAS) or Ground Based Augmentation Systems (GBAS). In the United States, the satellite based component is the Wide Area Augmentation System (WAAS), in Europe it is the European Geostationary Navigation Overlay Service (EGNOS), and in Japan it is the Multi-Functional Satellite Augmentation System (MSAS). Ground based augmentation is provided by systems like the Local Area Augmentation System (LAAS).

- GNSS-2 is the second generation of systems that independently provides a full civilian satellite navigation system, exemplified by the European Galileo positioning system. These systems will provide the accuracy and integrity monitoring necessary for civil navigation; including aircraft. This system consists of L1 and L2 frequencies for civil use and L5 for system integrity. Development is also in progress to provide GPS with civil use L2 and L5 frequencies, making it a GNSS-2 system.
- Core Satellite navigation systems, currently GPS (United States), GLONASS (Russian Federation), Galileo (European Union) and Compass (China).
- Global Satellite Based Augmentation Systems (SBAS) such as Omnistar and StarFire.
- Regional SBAS including WAAS (US), EGNOS (EU), MSAS (Japan) and GAGAN (India).
- Regional Satellite Navigation Systems such as China's Beidou, India's yet-to-be-operational IRNSS, and Japan's proposed QZSS.
- Continental scale Ground Based Augmentation Systems (GBAS) for example the Australian GRAS and the US Department of Transportation National Differential GPS (DGPS) service.
- Regional scale GBAS such as CORS networks.
- Local GBAS typified by a single GPS reference station operating Real Time Kinematic (RTK) corrections.

History and theory

Early predecessors were the ground based DECCA, LORAN, GEE and Omega radio navigation systems, which used terrestrial longwave radio transmitters instead of satellites. These positioning systems broadcast a radio pulse from a known "master" location, followed by repeated pulses from a number of "slave" stations. The delay between the reception and sending of the signal at the slaves was carefully controlled, allowing the receivers to compare the delay between reception and the delay between sending. From this the distance to each of the slaves could be determined, providing a fix.

The first satellite navigation system was Transit, a system deployed by the US military in the 1960s. Transit's operation was based on the Doppler effect: the satellites traveled on well-known paths and broadcast their signals on a well known frequency. The received frequency will differ slightly from the broadcast frequency because of the movement of the satellite with respect to the receiver. By monitoring this frequency shift over a short time interval, the receiver can determine its location to one side or the other of the satellite, and several such measurements combined with a precise knowledge of the satellite's orbit can fix a particular position.

Part of an orbiting satellite's broadcast included its precise orbital data. In order to ensure accuracy, the US Naval Observatory (USNO) continuously observed the precise orbits of these satellites. As a satellite's orbit deviated, the USNO would send the updated information to the satellite. Subsequent broadcasts from an updated satellite would contain the most recent accurate information about its orbit.

Modern systems are more direct. The satellite broadcasts a signal that contains orbital data (from which the position of the satellite can be calculated) and the precise time the signal was transmitted. The orbital data is transmitted in a data message that is superimposed on a code that serves as a timing reference. The satellite uses an atomic clock to maintain synchronization of all the satellites in the constellation. The receiver compares the time of broadcast encoded in the transmission with the time of reception measured by an internal clock, thereby measuring the time-of-flight to the satellite. Several such measurements can be made at the same time to different satellites, allowing a continual fix to be generated in real time using an adapted version of trilateration: see GNSS positioning calculation for details.

Each distance measurement, regardless of the system being used, places the receiver on a spherical shell at the measured distance from the broadcaster. By taking several such measurements and then looking for a point where they meet, a fix is generated. However, in the case of fast-moving receivers, the position of the signal moves as signals are received from several satellites. In addition, the radio signals slow slightly as they pass through the ionosphere, and this slowing varies with the receiver's angle to the satellite, because that changes the distance through the ionosphere. The basic computation thus attempts to find the shortest directed line tangent to four oblate spherical shells centered on four satellites. Satellite navigation receivers reduce errors by using combinations of signals from multiple satellites and multiple correlators, and then using techniques such as Kalman filtering to combine the noisy, partial, and constantly changing data into a single estimate for position, time, and velocity.

Civil and military uses

The original motivation for satellite navigation was for military applications. Satellite navigation allows for hitherto impossible precision in the delivery of weapons to targets, greatly increasing their lethality whilst reducing inadvertent casualties from mis-directed weapons. (See Guided bomb). Satellite navigation also allows forces to be directed and to locate themselves more easily, reducing the fog of war.

The ability to supply satellite navigation signals is also the ability to deny their availability. The operator of a satellite navigation system potentially has the ability to degrade or eliminate satellite navigation services over any territory it desires.

Global Navigation Satellite System (GNSS) receivers, using the GPS, GLONASS, Galileo or Beidou system, are used in many applications.

Navigation

- Automobiles can be equipped with GNSS receivers at the factory or as aftermarket equipment. Units often display moving maps and information about location, speed, direction, and nearby streets and points of interest.
- Aircraft navigation systems usually display a "moving map" and are often connected to the autopilot for en-route navigation. Cockpit-mounted GNSS receivers and glass cockpits are appearing in general aviation aircraft of all sizes, using technologies such as WAAS or LAAS to increase accuracy. Many of these systems may be certified for instrument flight rules navigation, and some can also be used for final approach and landing operations. Glider pilots use GNSS Flight Recorders to log GNSS data verifying their arrival at turn points in gliding competitions. Flight computers installed in many gliders also use GNSS to compute wind speed aloft, and glide paths to waypoints such as alternate airports or mountain passes, to aid en route decision making for cross-country soaring.

- Boats and ships can use GNSS to navigate all of the world's lakes, seas and oceans. Maritime GNSS units include functions useful on water, such as "man overboard" (MOB) functions that allow instantly marking the location where a person has fallen overboard, which simplifies rescue efforts. GNSS may be connected to the ships self-steering gear and Chartplotters using the NMEA 0183 interface. GNSS can also improve the security of shipping traffic by enabling AIS.
- Heavy Equipment can use GNSS in construction, mining and precision agriculture. The blades and buckets of construction equipment are controlled automatically in GNSS-based machine guidance systems. Agricultural equipment may use GNSS to steer automatically, or as a visual aid displayed on a screen for the driver. This is very useful for controlled traffic and row crop operations and when spraying. Harvesters with yield monitors can also use GNSS to create a yield map of the paddock being harvested.
- Cyclists often use GNSS in racing and touring. GNSS navigation allows cyclists to plot their course in advance and follow this course, which may include quieter, narrower streets, without having to stop frequently to refer to separate maps. GNSS receivers designed specifically for cycling often do not include sophisticated 'street-aware' mapping features, but are instead oriented towards recording the progress of the cyclist along their route. This data can be reviewed after the ride to inform the rider's training or competition planning, or uploaded to online services which allow riders to view and compare each other's rides.
- Hikers, climbers, and even ordinary pedestrians in urban or rural environments can use GNSS to determine their position, with or without reference to separate maps. In isolated areas, the ability of GNSS to provide a precise position can greatly enhance the chances of rescue when climbers or hikers are disabled or lost (if they have a means of communication with rescue workers).
- GNSS equipment for the visually impaired is available.
- Spacecraft are now beginning to use GNSS as a navigational tool. The addition of a GNSS receiver to a spacecraft allows precise orbit determination without ground tracking. This, in turn, enables autonomous spacecraft navigation, formation flying, and autonomous rendezvous. The use of GNSS in MEO, GEO, HEO, and highly elliptical orbits is feasible only if the receiver can acquire and track the much weaker (15 - 20 dB)

GNSS side-lobe signals. This design constraint, and the radiation environment found in space, prevents the use of COTS receivers. Low earth orbit satellite constellations such as the one operated by Orbcomm uses GPS receivers on all satellites

Global navigation systems

Operational

GPS

The United States' Global Positioning System (GPS) consists of up to 32 medium Earth orbit satellites in six different orbital planes, with the exact number of satellites varying as older satellites are retired and replaced. Operational since 1978 and globally available since 1994, GPS is currently the world's most utilized satellite navigation system.

In development

Compass

China has indicated they intend to expand their regional navigation system, called Beidou or Big Dipper, into a global navigation system by 2020 a program that has been called Compass in China's official news agency Xinhua. The Compass system is proposed to utilize 30 medium Earth orbit satellites and five geostationary satellites. A 10-satellite regional version (covering Asia and Pacific area) was completed by December 2011.

Galileo

The European Union and European Space Agency agreed in March 2002 to introduce their own alternative to GPS, called the Galileo positioning system. At an estimated cost of EUR 3.0 billion,the system of 30 MEO satellites was originally scheduled to be operational in 2010. The estimated year to become operational is 2014. The first experimental satellite was launched on 28 December 2005.

Galileo is expected to be compatible with the modernized GPS system. The receivers will be able to combine the signals from both Galileo and GPS satellites to greatly increase the accuracy.

Galileo is now not expected to be in full service until 2020 at the earliest and at a substantially higher cost.

Low Earth orbit satellite phone networks

The two current operational low Earth orbit satellite phone networks are able to track transceiver units with accuracy of a few kilometers using doppler shift calculations from the satellite. The coordinates are sent back to the transceiver unit where they can be read using AT commands or a graphical user interface. This can also be used by the gateway to enforce restrictions on geographically bound calling plans.

Chapter 3

Data Processing

Generally speaking, remote sensing works on the principle of the inverse problem. While the object or phenomenon of interest (the state) may not be directly measured, there exists some other variable that can be detected and measured (the observation), which may be related to the object of interest through the use of a data-derived computer model. The common analogy given to describe this is trying to determine the type of animal from its footprints. For example, while it is impossible to directly measure temperatures in the upper atmosphere, it is possible to measure the spectral emissions from a known chemical species (such as carbon dioxide) in that region. The frequency of the emission may then be related to the temperature in that region via various thermodynamic relations.

The quality of remote sensing data consists of its spatial, spectral, radiometric and temporal resolutions.

Spatial resolution

The size of a pixel that is recorded in a raster image – typically pixels may correspond to square areas ranging in side length from 1 to 1,000 metres (3.3 to 3,300 ft).

Spectral resolution

The wavelength width of the different frequency bands recorded – usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of seven bands, including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 μm. The Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 μm, with a spectral resolution of 0.10 to 0.11 μm per band.

Radiometric resolution

The number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of colour, in each band. It also depends on the instrument noise.

Temporal resolution

The frequency of flyovers by the satellite or plane, and is only relevant in time-series studies or those requiring an averaged or mosaic image as in deforesting monitoring. This was first used by the intelligence community where repeated coverage revealed changes in infrastructure, the deployment of units or the modification/introduction of equipment. Cloud cover over a given area or object makes it necessary to repeat the collection of said location.

In order to create sensor-based maps, most remote sensing systems expect to extrapolate sensor data in relation to a reference point including distances between known points on the ground. This depends on the type of sensor used. For example, in conventional photographs, distances are accurate in the center of the image, with the distortion of measurements increasing the farther you get from the center. Another factor is that of the platen against which the film is pressed can cause severe errors when photographs are used to measure ground distances. The step in which this problem is resolved is called georeferencing, and involves computer-aided matching up of points in the image (typically 30 or more points per image) which is extrapolated with the use of an established benchmark, "warping" the image to produce accurate spatial data. As of the early 1990s, most satellite images are sold fully georeferenced.

In addition, images may need to be radiometrically and atmospherically corrected.

Radiometric correction

Gives a scale to the pixel values, e. g. the monochromatic scale of 0 to 255 will be converted to actual radiance values.

Topographic correction (also called Terrain correction)

In the rugged mountains, as a result of terrain, each pixel which receives the effective illumination varies considerably different. In remote sensing image, the pixel on the shady slope receives weak illumination and has a low radiance value, in contrast, the pixel on the sunny slope receives strong illumination and has a high radiance value. For the same objects, the pixel radiance values on the shady slope must be very different from that on the sunny slope. Different objects may have the similar radiance values. This spectral information changes seriously affected remote sensing image information extraction accuracy in the mountainous area. It became the main obstacle to further application on remote sensing images. The purpose of topographic correction is to eliminate this effect, recovery true reflectivity or radiance of objects in horizontal conditions. It is the premise of quantitative remote sensing application.

Atmospheric correction

eliminates atmospheric haze by rescaling each frequency band so that its minimum value (usually realised in water bodies) corresponds to a pixel value of 0. The digitizing of data also make possible to manipulate the data by changing gray-scale values.

Interpretation is the critical process of making sense of the data. The first application was that of aerial photographic collection which used the following process; spatial measurement through the use of a light table in both conventional single or stereographic coverage, added skills such as the use of photogrammetry, the use of photomosaics, repeat coverage, Making use of objects' known dimensions in order to detect modifications. Image Analysis is the recently developed automated computer-aided application which is in increasing use.

Object-Based Image Analysis (OBIA) is a sub-discipline of GIScience devoted to partitioning remote sensing (RS) imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale.

Old data from remote sensing is often valuable because it may provide the only long-term data for a large extent of geography. At the same time, the data is often complex to interpret, and bulky to store. Modern systems tend to store the data digitally, often with lossless compression. The difficulty with this approach is that the data is fragile, the format may be archaic, and the data may be easy to falsify. One of the best systems for archiving data series is as computer-generated machine-readable ultrafiche, usually in typefonts such as OCR-B, or as digitized half-tone images. Ultrafiches survive well in standard libraries, with lifetimes of several centuries. They can be created, copied, filed and retrieved by automated systems. They are about as compact as archival magnetic media, and yet can be read by human beings with minimal, standardized equipment.

Inverse problem

An inverse problem is a general framework that is used to convert observed measurements into information about a physical object or system. For example, if we have measurements of the Earth's gravity field, then we might ask the question: "given the data that we have available, what can we say about the density distribution of the Earth in that area?" The solution to this problem (i.e. the density distribution that best matches the data) is useful because it generally tells us something about a physical parameter that we cannot directly observe. Thus, inverse problems are some of the most important and well-studied mathematical problems in science and mathematics. Inverse problems arise in many branches of science and mathematics, including computer vision, natural language processing, machine learning, statistics, statistical inference, geophysics, medical imaging (such as computed axial tomography and EEG/ERP), remote sensing, ocean acoustic tomography, nondestructive testing, astronomy, physics and many other fields.

History

The field of inverse problems was first discovered and introduced by Soviet-Armenian physicist, Viktor Ambartsumian.

While still a student, Ambartsumian thoroughly studied the theory of atomic structure, the formation of energy levels, and the Schrödinger equation and its properties, and when he mastered the theory of eigenvalues of differential equations, he pointed out the apparent analogy between discrete energy levels and the eigenvalues of differential equations. He then asked: given a family of eigenvalues, is it possible to find the form of the equations whose eigenvalues they are? Essentially Ambartsumian was examining the inverse Sturm–Liouville problem, which dealt with determining the equations of a vibrating string. This paper was published in 1929 in the German physics journal Zeitschrift für Physik and remained in obscurity for a rather long time. Describing this situation after many decades, Ambartsumian said, "If an astronomer publishes an article with a mathematical content in a physics journal, then the most likely thing that will happen to it is oblivion."

Nonetheless, toward the end of the Second World War, this article, written by the 20-year-old Ambartsumian, was found by Swedish mathematicians and formed the starting point for a whole area of research on inverse problems, becoming the foundation of an entire discipline.

Conceptual understanding

The inverse problem can be conceptually formulated as follows:

Data → Model parameters

The inverse problem is considered the "inverse" to the forward problem which relates the model parameters to the data that we observe:

Model parameters → Data

The transformation from data to model parameters (or vice versa) is a result of the interaction of a physical system with the object that we wish to infer properties about. In other words, the transformation is the physics that relates the physical quantity (i.e. the model parameters) to the observed data.

Chapter 4

History of Remote Sensing

The modern discipline of remote sensing arose with the development of flight. The balloonist G. Tournachon (alias Nadar) made photographs of Paris from his balloon in 1858. Messenger pigeons, kites, rockets and unmanned balloons were also used for early images. With the exception of balloons, these first, individual images were not particularly useful for map making or for scientific purposes

Systematic aerial photography was developed for military surveillance and reconnaissance purposes beginning in World War I and reaching a climax during the Cold War with the use of modified combat aircraft such as the P-51, P-38, RB-66 and the F-4C, or specifically designed collection platforms such as the U2/TR-1, SR-71, A-5 and the OV-1 series both in overhead and stand-off collection. A more recent development is that of increasingly smaller sensor pods such as those used by law enforcement and the military, in both manned and unmanned platforms. The advantage of this approach is that this requires minimal modification to a given airframe. Later imaging technologies would include Infra-red, conventional, doppler and synthetic aperture radar.

Aerial photography

Aerial photography is the taking of photographs of the ground from an elevated position. The term usually refers to images in which the camera is not supported by a ground-based structure. Platforms for aerial photography include fixed-wing aircraft, helicopters, multirotor Unmanned Aircraft Systems (UAS), balloons, blimps and dirigibles, rockets, kites, parachutes, stand-alone telescoping and vehicle mounted poles. Mounted cameras may be triggered remotely or automatically; hand-held photographs may be taken by a photographer.

Aerial photography should not be confused with Air-to-Air Photography, where one-or-more aircraft are used as Chase planes that "chase" and photograph other aircraft in flight.

Early History

Aerial photography was first practiced by the French photographer and balloonist Gaspard-Félix Tournachon, known as "Nadar", in 1858 over Paris, France. However, the photographs he produced no longer exist and therefore the earliest surviving aerial photograph is titled 'Boston, as the Eagle and the Wild Goose See It.' Taken by James Wallace Black and Samuel Archer King on October 13, 1860, it depicts Boston from a height of 630m.

Kite aerial photography was pioneered by British meteorologist E.D. Archibald in 1882. He used an explosive charge on a timer to take photographs from the air. Frenchman Arthur Batut began using kites for photography in 1888, and wrote a book on his methods in 1890. Samuel Franklin Cody developed his advanced 'Man-lifter War Kite' and succeeded in interesting the British War Office with its capabilities.

The first use of a motion picture camera mounted to a heavier-than-air aircraft took place on April 24, 1909 over Rome in the 3:28 silent film short, Wilbur Wright und seine Flugmaschine.

World War I

The use of aerial photography rapidly matured during the war, as reconnaissance aircraft were outfitted with cameras to record enemy movements and defences. At the start of the conflict, the usefulness of aerial photography was not fully appreciated, with reconnaissance being accomplished with map sketching from the air.

Germany adopted the first aerial camera, a Görz, in 1913. French Military Aviation began the war with several squadrons of Bleriot observation planes, equipped with cameras for reconnaissance. The French Army developed procedures for getting prints into the hands of field commanders in record time.

Frederick Charles Victor Laws initiated an aerial photography capability in 1912 for the 1st Airship Squadron and he began experimenting with aerial photographs from the British dirigible airship Beta. He discovered that vertical photos taken with 60% overlap could be used to create a stereoscopic effect when viewed in a stereoscope, thus creating a perception of depth that could aid in cartography and in intelligence derived from aerial images. The dirigibles were eventually allocated to the Royal Navy, so Laws formed the first aerial reconnaissance unit of fixed-wing aircraft; this became No. 3 Squadron RAF. The Royal Flying Corps recon pilots began to use cameras for recording their observations in 1914 and by the Battle of Neuve Chapelle in 1915, the entire system of German trenches was being photographed. In 1916 the Austro-Hungarian Monarchy made vertical camera axis aerial photos above Italy for map-making.

The first purpose-built and practical aerial camera was invented by Captain John Moore-Brabazon in 1915 with the help of the Thornton-Pickard company, greatly enhancing the efficiency of aerial photography. The camera was inserted into the floor of the aircraft and could be triggered by the pilot at intervals. Moore-Brabazon also pioneered the incorporation of stereoscopic techniques into aerial photography, allowing the height of objects on the landscape to be discerned by comparing photographs taken at different angles.

By the end of the war, aerial cameras had dramatically increased in size and focal power and were used increasingly frequently as they proved their pivotal military worth; by 1918 both sides were photographing the entire front twice a day and had taken over half a million photos since the beginning of the conflict. In January 1918, General Allenby used five Australian pilots from No. 1 Squadron AFC to photograph a 624 square miles (1,620 km2) area in Palestine as an aid to correcting and improving maps of the Turkish front. This was a pioneering use of aerial photography as an aid for cartography. Lieutenants Leonard Taplin, Allan Runciman Brown, H. L. Fraser, Edward Patrick Kenny, and L. W. Rogers photographed a block of land stretching from the Turkish front lines 32 miles (51 km) deep into their rear areas. Beginning 5 January, they flew with a fighter escort to ward off enemy fighters. Using Royal Aircraft Factory BE.12 and Martinsyde airplanes, they not only overcame enemy air attacks, but also bucked 65 mile per hour winds, antiaircraft fire, and malfunctioning equipment to complete their task circa 19 January 1918.

Commercial Aerial Photography

The first commercial aerial photography company in the UK was Aerofilms Ltd, founded by World War I veterans Francis Wills and Claude Graham White in 1919. The company soon expanded into a business with major contracts in Africa and Asia as well as in the UK. Operations began from the Stag Lane Aerodrome at Edgware, using the aircraft of the London

Flying School. Subsequently the Aircraft Manufacturing Company (later the De Havilland Aircraft Company), hired an Airco DH.9 along with pilot entrepreneur Alan Cobham.

From 1921, Aerofilms carried out vertical photography for survey and mapping purposes. During the 1930s, the company pioneered the science of photogrammetry (mapping from aerial photographs), with the Ordnance Survey amongst the company's clients.

Another successful pioneer of the commercial use of aerial photography was the American Sherman Fairchild who started his own aircraft firm Fairchild Aircraft to develop and build specialized aircraft for high altitude aerial survey missions. One Fairchild aerial survey aircraft in 1935 carried unit that combined two synchronized cameras, and each camera having five six inch lenses with a ten inch lenses and took photos from 23,000 feet. Each photo covered two hundred and twenty five square miles. One of its first government contracts was an aerial survey of New Mexico to study soil erosion. A year later, Fairchild introduced a better high altitude camera with nine-lens in one unit that could take a photo of 600 square miles with each exposure from 30,000 feet.

World War II

In 1939 Sidney Cotton and Flying Officer Maurice Longbottom of the RAF were among the first to suggest that airborne reconnaissance may be a task better suited to fast, small aircraft which would use their speed and high service ceiling to avoid detection and interception. Although this seems obvious now, with modern reconnaissance tasks performed by fast, high flying aircraft, at the time it was radical thinking.

They proposed the use of Spitfires with their armament and radios removed and replaced with extra fuel and cameras. This led to the development of the Spitfire PR variants. Spitfires proved to be extremely successful in their reconnaissance role and there were many variants built specifically for that purpose. They served initially with what later became No. 1 Photographic Reconnaissance Unit (PRU). In 1928, the RAF developed an electric heating system for the aerial camera. This allowed reconnaissance aircraft to take pictures from very high altitudes without the camera parts freezing. Based at RAF Medmenham, the collection and interpretation of such photographs became a considerable enterprise.

Cotton's aerial photographs were far ahead of their time. Together with other members of the 1 PRU, he pioneered the techniques of high-altitude, high-speed stereoscopic photography that were instrumental in revealing the locations of many crucial military and intelligence targets. According to R.V. Jones, photographs were used to establish the size and the characteristic launching mechanisms for both the V-1 flying bomb and the V-2 rocket. Cotton also worked on ideas such as a prototype specialist reconnaissance aircraft and further refinements of photographic equipment. At the peak, the British flew over 100 reconnaissance flights a day, yielding 50,000 images per day to interpret. Similar efforts were taken by other countries.

Uses

Aerial photography is used in cartograph (particularly in photogrammetric surveys, which are often the basis for topographic maps), land-use planning, archaeology,movie production, environmental studies, surveillance, commercial advertising, conveyancing, and artistic projects. In the United States, aerial photographs are used in many Phase I Environmental Site Assessments for property analysis.

Platforms

Radio-controlled model aircraft

Advances in radio controlled models have made it possible for model aircraft to conduct low-altitude aerial photography. This has benefited real-estate advertising, where commercial and residential properties are the photographic subject. Full-size, manned aircraft are prohibited from low flights above populated locations. Small scale model aircraft offer increased photographic access to these previously restricted areas. Miniature vehicles do not replace full size aircraft, as full size aircraft are capable of longer flight times, higher altitudes, and greater equipment payloads. They are, however, useful in any situation in which a full-scale aircraft would be dangerous to operate. Examples would include the inspection of transformers atop power transmission lines and slow, low-level flight over agricultural fields, both of which can be accomplished by a large-scale radio controlled helicopter. Professional-grade, gyroscopically stabilized camera platforms are available for use under such a model; a large model helicopter with a 26cc gasoline engine can hoist a payload of approximately seven kilograms (15 lbs).

Recent (2006) FAA regulations grounding all commercial RC model flights have been upgraded to require formal FAA certification before permission to fly at any altitude in USA.

In Australia Civil Aviation Safety Regulation 101 (CASR 101) allows for commercial use of radio control aircraft. Under these regulations radio controlled unmanned aircraft for commercial are referred to as Unmanned Aircraft Systems (UAS), where as radio controlled aircraft for recreational purposes are referred to as model aircraft. Under CASR 101, businesses/persons operating radio controlled aircraft commercially are required to hold an Operator Certificate, just like manned aircraft operators. Pilots of radio controlled aircraft operating commercially are also required to be licenced by the Civil Aviation Safety Authority (CASA). Whilst a small UAS and model aircraft may actually be identical, unlike model aircraft, a UAS may enter controlled airspace with approval, and operate within close proximity to an aerodrome.

Due to a number of illegal operators in Australia making false claims of being approved, CASA maintains and publishes a list of approved UAS operators

UAS (also known as drones) are hot topics for the media. Numerous stories have been published about approved operators such as COPTERCAM providing aerial photography services too low for manned aircraft, and too high for pole cameras. According to an article published by the Association for Unmanned Vehicle Systems International (AUVSI), approved operators like COPTERCAM have become leaders in the aerial photography industry in a relatively short period of time.

Because anything capable of being viewed from a public space is considered outside the realm of privacy in the United States, aerial photography may legally document features and occurrences on private property.

Multirotor helicopters

The COPTERCAM 8 aerial camera system

A number of multirotor UAS are purposely built for aerial photography.

ALMA antennas seen from above[

Octocopters (8 rotors)

Coptercam Aerial Camera System

Hexacopters (6 rotors)

Aibotix

Draganflyer

Quadcopters (4 rotors)

CyberQuad Maxi

Microdrone

Tricopters (3 rotors)

Multirotors have been the platform of choice for professional aerial photographers because they are mechanically simpler than helicopters, thus reducing the risk of mechanical failure. Correctly built and tuned they also offer less vibration and greater stability.

Multirotors generally have at least 2 rotors, however with the additional rotors, their payload lifting capacity and redundancy increases. If a 6 rotor aircraft loses power to one rotor it will lose yaw control. If an 8 rotor aircraft loses power to 1 rotor, there is negligible effect on control. This is an important design feature because unlike helicopters with a variable pitch rotor, multirotor aircraft do not have the ability to autorotate.

The flight control system consists of an attitude head reference system (AHRS which is generally also found in manned aircraft with autopilots). The gyros, accelerometers, magnetometers allows the flight control system to determine whether it is level, pitched, rolled and what direction it is pointing.

The navigation control system that consists of a GPS and barometer (pressure altimeter) tells the flight control system where it is, how high it is, and where it took off from. The navigation control system is also responsible for telling the flight control system how to hold a position, navigate to a position, and return to its launch location.

The flight control system controls the aircraft by determining which electronic motors need more power and which need less power unto 400 times every second. This is all achieved through software rather than mechanically adjusting control services like in on a plane. This reduces the risk of mechanical failure, however, the flight performance of a multirotor aircraft like the COPTERCAM relies on the quality of the software and the configuration of the system.

The radio control system allows the pilot to control the aircraft using a fly by wire system. The pilots radio control tells the flight control what the pilot wants to do, e.g. move forwards, climb, descend, move right, and the flight control board decides the speed of each motor required to perform the command. The range of the radio control system can vary between 2 km to 10 km depending environmental factors.

A second radio control is used to monitor aircraft performance on a moving map and also allows the co-pilot to put in navigation points and command the aircraft to fly autonomously. The range of the telemetry system can vary from about 5–20 km using standard radio modems, to hundreds of kilometres if the data is routed via the 3G mobile phone network.

Aerial camera systems like the COPTERCAM are also fitted with pan, tilt, roll and 10x zoom cameras which allows the aircraft to record and transmit to the ground and Internet live HD video via either a wireless digital video link of a 3G/4G wireless internet connection.

The development of artificial satellites in the latter half of the 20th century allowed remote sensing to progress to a global scale as of the end of the Cold War. Instrumentation aboard various Earth observing and weather satellites such as Landsat, the Nimbus and more recent missions such as RADARSAT and UARS provided global measurements of various data for civil, research, and military purposes. Space probes to other planets have also provided the opportunity to conduct remote sensing studies in extraterrestrial environments, synthetic aperture radar aboard the Magellan spacecraft provided detailed topographic maps of Venus, while instruments aboard SOHO allowed studies to be performed on the Sun and the solar wind, just to name a few examples.

Recent developments include, beginning in the 1960s and 1970s with the development of image processing of satellite imagery. Several research groups in Silicon Valley including NASA Ames

Research Center, GTE and ESL Inc. developed Fourier transform techniques leading to the first notable enhancement of imagery data.

Chapter 5

Training and Education

Remote Sensing has a growing relevance in the modern information society. It represents a key technology as part of the aerospace industry and bears increasing economic relevance – new sensors e.g. TerraSAR-X & RapidEye are developed constantly and the demand for skilled labour is increasing steadily. Furthermore, remote sensing exceedingly influences everyday life, ranging from weather forecasts to reports on climate change or natural disasters. As an example, 80% of the German students use the services of Google Earth; in 2006 alone the software was downloaded 100 million times. But studies has shown that only a fraction of them know more about the data they are working with.There exists a huge knowledge gap between the application and the understanding of satellite images. Remote sensing only plays a tangential role in schools, regardless of the political claims to strengthen the support for teaching on the subject. A lot of the computer software explicitly developed for school lessons has not yet been implemented due to its complexity. Thereby, the subject is either not at all integrated into the curriculum or does not pass the step of an interpretation of analogue images. In fact, the subject of remote sensing requires a consolidation of physics and mathematics as well as competences in the fields of media and methods apart from the mere visual interpretation of satellite images.

Many teachers have great interest in the subject "remote sensing", being motivated to integrate this topic into teaching, provided that the curriculum is considered. In many cases, this encouragement fails because of confusing information. In order to integrate remote sensing in a sustainable manner organizations like the EGU or digital earth encourages the development of learning modules and learning portals (e.g. FIS – Remote Sensing in School Lessons or Landmap – Spatial Discovery) promoting media and method qualifications as well as independent working.

TerraSAR-X, a radar Earth observation satellite, is a joint venture being carried out under a public-private-partnership between the German Aerospace Center (DLR) and EADS Astrium. The exclusive commercial exploitation rights are held by the geo-information service provider Astrium. TerraSAR-X was launched on June 15, 2007 and has been in operational service since

January 2008. With its twin satellite TanDEM-X, launched June 21, 2010, TerraSAR-X acquires the data basis for the WorldDEM, the worldwide and homogeneous DEM available from 2014.

Satellite and Mission

With its active phased array X-band SAR antenna (wavelength 31 mm, frequency 9.6 GHz), TerraSAR-X acquires new high-quality radar images of the entire planet whilst circling Earth in a polar orbit at 514 km altitude. The orbit is selected such that the satellite flies in a sun-synchronous dusk-dawn orbit, which means that it moves along the day-night boundary of the Earth and always presents the same face to the sun, ensuring an optimum energy supply via the solar cells. TerraSAR-X is designed to carry out its task for five years, independent of weather conditions and illumination, and reliably provides radar images with a resolution of up to 1m.

Features of TerraSAR-X:

- resolution of up to 1 m,
- excellent radiometric accuracy,
- geometric accuracy unrivalled by any other commercial spaceborne sensor,
- quick site access time of 2.5 days max. (2 days at 95% probability) to any point on Earth,
- unique agility (rapid switches between imaging modes and polarisations)

TerraSAR-X Imaging Modes

TerraSAR-X acquires radar data in the following three main imaging modes:

SpotLight: up to 1 m resolution, scene size 10 km (width) x 5 km (length)

StripMap: up to 3 m resolution, scene size 30 km (width) x 50 km (length*)

ScanSAR: up to 18 m resolution, scene size 100 km (width) x 150 km (length*)

(*StripMap & ScanSAR: acquisition length extendable to up to 1,650 km.)

In addition, the unique design of TerraSAR-X's SAR antenna allows a variety of polarimetric combinations: single or dual polarization and even full polarimetric data takes, are possible.

Depending on the desired application, one of four different product types (processing levels) can be selected

- Single Look Slant Range Complex (SSC)
- Multi Look Ground Range Detected (MGD)
- Geocoded Ellipsoid Corrected (GEC)
- Enhanced Ellipsoid Corrected (EEC)

RapidEye AG was a German geospatial information provider focused on assisting in management decision-making through services based on their own Earth observation imagery. The company operated a five satellite constellation producing 5 meter resolution imagery that was designed and implemented by MacDonald Dettwiler (MDA) of Richmond, Canada. Originally located in Munich, the company relocated 60 km southwest of Berlin to Brandenburg an der Havel in 2004. On December 18, 2012 the company announced that it has successfully relocated the company headquarters to Berlin, Germany. On November 6, 2013 RapidEye has officially changed its name to BlackBridge.

History

1996: The RapidEye business concept was designed by Kayser-Threde GmbH, based on a call for ideas from the DLR (German Aerospace Agency), on how to commercialize remote sensing in Germany.

1998: RapidEye was established as an independent company in Munich with seed financing from a few private investors and Vereinigte Hagelversicherung, a German agricultural insurance provider.

2004: Funding was secured for the RapidEye satellite constellation and ground segment with the help of the European Union, the State of Brandenburg (Germany), a banking consortium consisting of Commerzbank, EDC (Export Development Canada) and KfW Banking Group. Through a contract with the CCC (Canadian Commercial Corporation), MacDonald Dettwiler (MDA) was awarded the contract as the prime contractor to build RapidEye's satellite system. RapidEye relocated their business to Brandenburg an der Havel, Germany.

2008: RapidEye earned ISO 9001:2000 certification in April from TÜV Nord. On August 29, 2008, a DNEPR-1 rocket (a refurbished ICBM missile), was successfully launched from Baikonur in Kazakhstan carrying RapidEye's constellation of five Earth observation satellites designed and implemented by MacDonald Dettwiler (MDA) of Richmond, Canada.

2009: After the satellites completed their MPAR phase (consisting of testing and calibration) they became commercially operational in February 2009.

2011: RapidEye files for bancruptcy protection on 2011-05-30.

2011: RapidEye Blackbridge Ltd. of Lethbridge, Alberta, Canada acquired RapidEye AG on the 29th of August.

2012: RapidEye relocated headquarters to Berlin on December 17, 2012.

Applications

RapidEye provides geospatial information-based management solutions to the following industries:

- Agriculture – The RapidEye constellation is capable of field based, regional or global scale agricultural monitoring on a frequent revisit cycle. The information derived from the imagery can assist farmers in precision farming operations, agricultural insurers in damage assessment and risk management, or governments in food security and environmental compliance monitoring.
- Forestry – Satellite based information is increasingly being used by governments and commercial operators to assess forest status, measure the environmental and economical sustainability of forest operations and monitor illegal logging and deforestation.
- Security & Emergency - Fast turnaround of imagery showing current ground conditions following a natural or man-made disaster is essential for crisis management authorities in assessing the situation and helping to better coordinate rescue teams.
- Environment – Satellite imagery can provide valuable information to governmental agencies or industries, that monitor the environmental impact of human activities.

- Spatial Solutions – RapidEye satellite imagery is used as background imagery for a variety of purposes including mapping, navigation, flight simulation, gaming and as an integral component in geospecific 3D modeling.
- Energy & Infrastructure - The RapidEye constellation can monitor pipeline and transmission corridors and identify problems on the ground such as vegetation encroachment, nearby buildings, development of roads or leaks. It can provide land cover and land use classification data to telecommunication firms to assist in planning their antenna network.

Satellites

Five Identical Satellites: Built by Surrey Satellite Technology Ltd. (SSTL)[8] of Guildford, subcontracted by MacDonald Dettwiler (MDA), each satellite is based on an evolution of the flight-proven SSTL-100 bus. Each satellite measures less than one cubic meter and weighs 150 kg (bus + payload).

Each of RapidEye's five satellites contain identical sensors, are equally calibrated and travel on the same orbital plane (at an altitude of 630 km). Together, the 5 satellites are capable of collecting over 4 million km^2 of 5 m resolution, 5-band color imagery every day.

Sensors: The Jena-Optronik[9] multi-spectral imager, the Jena Spaceborne Scanner JSS 56, is a pushbroom sensor carried on each satellite. Each sensor is capable of collecting image data in five distinct bands of the electromagnetic spectrum: Blue (440-510 nm), Green (520-590 nm), Red (630-690 nm), Red-Edge (690-730 nm) and Near-Infrared (760-880 nm). The nominal resolution on the ground is 5 meters, corresponding to NIIRS 2.

RapidEye's satellites are the first commercial satellites to include the Red-Edge band, which is sensitive to changes in chlorophyll content. Studies show that this band can assist in monitoring vegetation health, improve species separation and help in measuring protein and nitrogen content in biomass.

Technical Specifications

Overview

Number of Satellites: 5

Spacecraft Lifetime: 7 years

Orbit Altitude: 630 km in Sun-synchronous orbit

Global Revisit Time: 1 Day

Inclination: 97.8 degrees (solar-synchron)

Equator Crossing Time: 11:00 am (approximately)

Ground sampling distance (nadir): 6,5 m

Pixel size (orthorectified): 5 m

Swath Width: 77 km

On board data storage: Up to 1500 km of image data per orbit

Image capture capacity: 4 million km2/day

Sensor Performance Specifications

440 – 510 nm (Blue)

520 – 590 nm (Green)

630 – 685 nm (Red)

690 – 730 nm (Red Edge)

760 – 850 nm (Near IR)

Remote sensing internships

One effective way to teach students the many applications of remote sensing is through an internship opportunity. NASA DEVELOP is one such opportunity, where students work in teams with science advisor(s) and/or partner(s) to meet some practical need in the community. Working through NASA, this program give students experience in real-world remote sensing applications, as well as providing valuable training.

DEVELOP is a training and development program sponsored by NASA's Earth Science Applied Sciences Program. Headquartered at NASA Langley Research Center, DEVELOP has teams at twelve locations around the country, one in Nepal and one in Mexico. Participants work with advisers and mentors to learn about the application of NASA Earth Science and remote sensing during three 10-week terms.

DEVELOP is based in the Earth Science Mission, which has the goal to "Develop a scientific understanding of Earth's system and its response to natural or human-induced changes, and to improve prediction of climate, weather, and natural hazards." With a unique focus on community concerns, DEVELOP offers participants the chance to work with remote sensing to research real-world problems.

History of DEVELOP

In 1998, two students participating in the Langley Aerospace Research Summer Scholars (LARSS) Program and one student participating in the Summer High School Apprenticeship Research Program (SHARP) at NASA Langley Research Center co-authored the white paper Practical Applications of Remote Sensing (Bauer et al., 1998). At that time, the Digital Earth Initiative, a federal inter-agency project dedicated to creating a virtual representation of the Earth to further human understanding of the world, was piloting an effort to increase public access to federal information about the Earth and the environment. A proposal combining NASA's Digital Earth Initiative and the students' paper advocated the formation of a student program, and in 1999 DEVELOP was formed.

Another such program is SERVIR. Supporting by the US Agency of International Development (USAID) and NASA, SERVIR provides students with valuable hands-on experience with remote sensing, while providing end-users with the resources to better respond to a whole host of issues. More information can be found on the SERVIR website.

Chapter 6

Advance Remote Sensing Software

Remote sensing data is processed and analyzed with computer software, known as a remote sensing application. A large number of proprietary and open source applications exist to process remote sensing data. Remote sensing software packages include:

Socet GXP from BAE Systems

TNTmips from MicroImages

TNTmips is a geospatial analysis system providing a fully featured GIS, RDBMS, and automated image processing system with CAD, TIN, surface modeling, map layout and innovative data publishing tools. TNTmips has a single integrated system with an identical interface, functionality, and geodata structure for use on Mac and Windows operating systems. The interface, database text content, messages, map production, and all other internal aspects of TNTmips have been localized for use in many languages, including, for example Arabic, Thai, and all romance languages. The professional version of TNTmips is in use in over 120 nations while the TNTmips Free version (restricted in project size) is used worldwide for educational, self learning, and small projects (e.g., archaeological sites, neighborhood planning, and precision farming).

General Information

TNTmips is a professional system for fully integrated GIS, image processing, CAD, TIN, desktop cartography, and geospatial database management.

License Levels

TNTmips Pro (professional license, TNTmips Basic (low cost license), TNTmips Free (freeware).

Special Academic License (SAL)

The TNT products include: TNTmips, TNTedit, TNTview, TNTatlas and TNTsdk. There is no distinction between TNTmips and TNT products with regards to license levels. All TNT products are available for Windows and Macintosh computers in a growing number of international languages.

PCI Geomatica made by PCI Geomatics, the leading remote sensing software package in Canada

PCI Geomatica is a remote sensing desktop software package for processing earth observation data, designed by PCI Geomatics Inc. The latest version of the software is Geomatica 2013. Geomatica is aimed primarily at raster data processing and allows users to load satellite and aerial imagery where advanced analysis can be performed. Geomatica has been used by many educational institutions and scientific programs throughout the world to analyse satellite imagery and trends, such as the GlobeSAR Program, a program which was carried out by the Canada Centre for Remote Sensing in the 1990s.

A very popular edition of Geomatica is known as Freeview, which permits users to load multiple types of satellite images as well as geospatial data that is stored in different formats. The software is available for download over the web, and has registered several thousands of downloads.

Image processing packages

Geomatica is one of several software packages available to the educational, commercial, and military users. Other similar packages include Erdas Imagine, Envi, and SocetSet (or Socet GXP). An independent review of the software and its functionality written by Directions Magazine is included here: http://www.directionsmag.com/articles/product-review-pci146s-geomatica-10/123136. Geomatica has also been compared to Envi and Erdas Imagine as it relates to orthorectification.

Open Geospatial Consortium

Geomatica includes a web coverage service interface that complies with the OGC Web Coverage Service (WCS) Interface Standard, which is a key area in which PCI Geomatics has contributed. Remote Sensing data providers distribute data in diverse formats, which makes sharing information across many different platforms challenging. WCS seeks to alleviate some of the data sharing challenges by publishing the geographic information and layers openly over the web.

IDRISI from Clark Labs

IDRISI is an integrated geographic information system (GIS) and remote sensing software developed by Clark Labs at Clark University for the analysis and display of digital geospatial information. IDRISI is a PC grid-based system that offers tools for researchers and scientists engaged in analyzing earth system dynamics for effective and responsible decision making for environmental management, sustainable resource development and equitable resource allocation.

Key features of IDRISI include:

- a complete GIS analysis package for basic and advanced spatial analysis, including tools for surface and statistical analysis, decision support, land change and prediction, and image time series analysis;

- a complete Image Processing system with extensive hard and soft classifers, including machine learning classifiers such as neural networks and classification tree analysis, as well as image segmentation for classification;

- integrated modeling environments including the Earth Trends Modeler for image time series of environmental trends and Land Change Modeler for land change analysis and prediction.

Image Analyst from Intergraph,

Intergraph Corporation is an American software development and services company.

It provides enterprise engineering and geospatially powered software to businesses, governments, and organizations around the world. Intergraph operates through two divisions: Process, Power & Marine (PP&M) and Security, Government & Infrastructure (SG&I). The company's headquarters is in Huntsville, Alabama, USA. In 2008, Intergraph was one of the hundred largest software companies in the world. In 2010, Intergraph was acquired by Hexagon AB.

Intergraph develops the geographic information system (GIS) application GeoMedia.

History

Intergraph was founded in 1969 as M&S Computing, Inc., by former IBM engineers who had been working with NASA and the U.S. Army in developing systems that would apply digital computing to real-time missile guidance. The company was later renamed to Intergraph Corporation in 1980.

In 2000, Intergraph exited the hardware business and became purely a software company. On July 21, 2000, it sold its Intense3D graphics accelerator division to 3Dlabs, and its workstation and server division to Silicon Graphics.

On November 29, 2006, Intergraph was acquired by an investor group led by Hellman & Friedman LLC, Texas Pacific Group and JMI Equity, making the company privately held. Most recently, on October 28, 2010, Intergraph was acquired by Hexagon AB.The transaction marks the return of Intergraph as part of a publicly traded company. As part of the Hexagon acquisition, Hexagon moved the management of ERDAS, Inc. from under Leica Geosystems to Intergraph.

and RemoteView made by Overwatch Textron Systems.

Dragon/ips is one of the oldest remote sensing packages still available, and is in some cases free.

Dragon refers to any of several remote sensing image processing software packages. This software provides capabilities for displaying, analyzing, and interpreting digital images from earth satellites and raster data files that represent spatially distributed data. All the Dragon packages derive from code created by Goldin-Rudahl Systems, Incorporated, and focus on geography education:

- OpenDragon is free to educational users. It was intended to be free worldwide, as well as open source (hence the name) but due to funding problems, is currently available only in Southeast Asia.
- Dragon Academic is functionally identical to OpenDragon.

- Dragon Professional is expanded to handle full-scene data sets from sensors such as Landsat TM, SPOT, and Aster.

Open source remote sensing software includes:

OSSIM,

OSSIM (Open Source Security Information Management) is an open source Security Information and Event Management system, integrating a selection of tools designed to aid network administrators in computer security, intrusion detection and prevention.

The project began in 2003 as a collaboration between Dominique Karg and Julio Casal. In 2008 it became the basis for their company AlienVault. Following the acquisition of the EUREKA project label and completion of R&D, AlienVault began selling a commercial derivative of OSSIM ('AlienVault Unified Security Management').

OSSIM has had four major-version releases since its creation and is presently on a 4.x.x version numbering.An Information visualization of the contributions to the source code for OSSIM is published at 8 years of OSSIM. The project currently contains approximately 7.4 million lines of code.

Version	Release Date
1.04	23 February 2008
2.1	10 July 2009
3.0	16 September 2011
4.0	July 17, 2012

Opticks (software),

Opticks is an open source, remote sensing application that supports imagery, video (motion imagery), Synthetic Aperture Radar (SAR), multi-spectral, hyper-spectral, and other types of remote sensing data. Opticks supports processing remote sensing video in the same manner as it supports imagery, which differentiates it from other remote sensing applications. Opticks was initially developed by Ball Aerospace & Technologies Corp. and other organizations for the United States Intelligence Community. Ball Aerospace open sourced Opticks hoping to increase the demand for remote sensing data and broaden the features available in existing remote sensing software. The Opticks software and its extensions are developed by over twenty different organizations, and over two hundred users are registered users at http://opticks.org. Future planned enhancements include adding the ability to ingest and visualize lidar data, as well as a three-dimensional (3-D) visualization capability.

Opticks can also be used as a remote sensing software development framework. Developers can extend Opticks functionality using its plug-in architecture and public application programming interface (API). Opticks is open source, licensed under GNU Lesser General Public License (LGPL) 2.1. Opticks was brought into the open source community in Dec 2007 and has a large developer community. For more information, see the history of Opticks.

Orfeo toolbox

Orfeo Toolbox (OTB) is a library for remote sensing image processing. The project had been initiated by the French space agency (CNES) in 2006 and is under heavy developments and the participation from the open source community is currently growing. The goal is to provide potential users of satellite images with all the tools necessary to use these images.The library is originally targeted at high resolution images acquired by the Orfeo constellation: Pleiades satellites and Cosmo-Skymed but also handles a wide variety of sensors.

OTB provides:

- Image access: read/write access for most remote sensing image formats (using GDAL), meta-data access, visualization
- Data access: vector data access (shapefile, kml), DEM model, lidar data
- Filtering: blurring, denoising, enhancement for optical or radar data
- Feature extraction: texture computations including Haralick, SFS, Pantex, Edge density, points of interest, alignments, lines, SIFT, SURF
- Image segmentation: region growing, watershed, level sets
- Classification: K-means, SVM, Markov random fields and access to all OpenCV machine learning algorithms
- Change detection
- Stereo reconstruction from images
- Orthorectification and map projections (using ossim)
- Radiometric indices (vegetation, water, soil)

- Object-based segmentation and filtering
- PCA computation
- Visualization: a flexible visualization system, customizable via plugins;
- and more.

The library is intensively tested on several platforms as Linux, Mac OSX and Windows OTB Dashboard. Most functions are also adapted to process huge images (>4GB) using streaming and to take advantages of multicore processor as often as possible.

The library have an extensive documentation for both API (OTB API) and illustrated capabilities in the Software Guide (html version).

Others mixing remote sensing and GIS capabilities are: GRASS GIS, ILWIS, QGIS, and TerraLook.

Chapter 7

Geographic information system (GIS)

A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. The acronym GIS is sometimes used for geographical information science or geospatial information studies to refer to the academic discipline or career of working with geographic information systems and is a large domain within the broader academic discipline of Geoinformatics.

Geoinformatics is the science and the technology which develops and uses information science infrastructure to address the problems of geography, geosciences and related branches of engineering.

Overview

Geoinformatics has been described as "the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information" or "the art, science or technology dealing with the acquisition, storage, processing production, presentation and dissemination of geoinformation".

Geomatics is a similarly used term which encompasses geoinformatics, but geomatics focuses more so on surveying. Geoinformatics has at its core the technologies supporting the processes of acquiring, analyzing and visualizing spatial data. Both geomatics and geoinformatics include and rely heavily upon the theory and practical implications of geodesy.

Geography and earth science increasingly rely on digital spatial data acquired from remotely sensed images analyzed by geographical information systems (GIS) and visualized on paper or the computer screen.

Geoinformatics combines geospatial analysis and modeling, development of geospatial databases, information systems design, human-computer interaction and both wired and wireless networking technologies. Geoinformatics uses geocomputation and geovisualization for analyzing geoinformation.

Applications

Many fields benefit from geoinformatics, including urban planning and land use management, in-car navigation systems, virtual globes, public health, local and national gazetteer management, environmental modeling and analysis, military, transport network planning and management, agriculture, meteorology and climate change, oceanography and coupled ocean and atmosphere modelling, business location planning, architecture and archeological reconstruction, telecommunications, criminology and crime simulation, aviation and maritime transport. The importance of the spatial dimension in assessing, monitoring and modelling various issues and problems related to sustainable management of natural resources is recognized all over the world. Geoinformatics becomes very important technology to decision-makers across a wide range of disciplines, industries, commercial sector, environmental agencies, local and national government, research, and academia, national survey and mapping organisations, International organisations, United Nations, emergency services, public health and epidemiology, crime mapping, transportation and infrastructure, information technology industries, GIS consulting firms, environmental management agencies), tourist industry, utility companies, market analysis and e-commerce, mineral exploration, etc. Many government and non government agencies started to use spatial data for managing their day to day activities.

A GIS can be thought of as a system that provides spatial data entry, management, retrieval, analysis, and visualization functions. The implementation of a GIS is often driven by jurisdictional (such as a city), purpose, or application requirements. Generally, a GIS implementation may be custom-designed for an organization. Hence, a GIS deployment developed for an application, jurisdiction, enterprise, or purpose may not be necessarily interoperable or compatible with a GIS that has been developed for some other application, jurisdiction, enterprise, or purpose. What goes beyond a GIS is a spatial data infrastructure, a concept that has no such restrictive boundaries.

In a general sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information for informing decision making. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations.

Geographic information science is the science underlying geographic concepts, applications, and systems.

Examples of GIS applications

Uses of GIS range from indigenous people, communities, research institutions, environmental scientists, health organisations, land use planners, businesses, and government agencies at all levels.

Some examples include:

Crime mapping

Historical geographic information system

GIS and Hydrology

Remote sensing application

Traditional knowledge gis

Public Participation GIS

Road Networking with GIS

Other GIS Applications

Other applications include the use of GIS techniques for Water, Wastewater and Stormwater systems, and in Solid Waste management.

Uses range from information storage; spatial pattern identification; visual presentation of spatial relationships; remote sensing - all sometimes made available through internet web interfaces, involving large numbers of users, data collectors, specialists and/or community participants.

The first known use of the term "Geographic Information System" was by Roger Tomlinson in the year 1968 in his paper "A Geographic Information System for Regional Planning". Tomlinson is also acknowledged as the "father of GIS".

Applications

GIS is a relatively broad term that can refer to a number of different technologies, processes, and methods. It is attached to many operations and has many applications related to engineering, planning, management, transport/logistics, insurance, telecommunications, and business. For that reason, GIS and location intelligence applications can be the foundation for many location-enabled services that rely on analysis, visualization and dissemination of results for collaborative decision making.

History of development

One of the first applications of spatial analysis in epidemiology is the 1832 "Rapport sur la marche et les effets du cholera dans Paris et le department de la Seine". The French geographer Charles Piquet represented the 48 districts of the city of Paris by halftone color gradient according to the percentage of deaths by cholera per 1,000 inhabitants.

In 1854 John Snow depicted a cholera outbreak in London using points to represent the locations of some individual cases, possibly the earliest use of a geographic methodology in epidemiology. His study of the distribution of cholera led to the source of the disease, a contaminated water pump (the Broad Street Pump, whose handle he disconnected, thus terminating the outbreak).

E. W. Gilbert's version (1958) of John Snow's 1855 map of the Shoo cholera outbreak showing the clusters of cholera cases in the London epidemic of 1854. While the basic elements of topography and theme existed previously in cartography, the John Snow map was unique, using cartographic methods not only to depict but also to analyze clusters of geographically dependent phenomena.

The early 20th century saw the development of photo zincography, which allowed maps to be split into layers, for example one layer for vegetation and another for water. This was particularly used for printing contours – drawing these was a labor intensive task but having them on a separate layer meant they could be worked on without the other layers to confuse the draughtsman. This work was originally drawn on glass plates but later plastic film was introduced, with the advantages of being lighter, using less storage space and being less brittle, among others. When all the layers were finished, they were combined into one image using a large process camera. Once color printing came in, the layers idea was also used for creating separate printing plates for each color. While the use of layers much later became one of the main typical features of a contemporary GIS, the photographic process just described is not considered to be a GIS in itself – as the maps were just images with no database to link them to.

Computer hardware development spurred by nuclear weapon research led to general-purpose computer "mapping" applications by the early 1960s. The year 1960 saw the development of the world's first true operational GIS in Ottawa, Ontario, Canada by the federal Department of Forestry and Rural Development. Developed by Dr. Roger Tomlinson, it was called the Canada Geographic Information System (CGIS) and was used to store, analyze, and manipulate data collected for the Canada Land Inventory – an effort to determine the land capability for rural Canada by mapping information about soils, agriculture, recreation, wildlife, waterfowl, forestry and land use at a scale of 1:50,000. A rating classification factor was also added to permit analysis.

CGIS was an improvement over "computer mapping" applications as it provided capabilities for overlay, measurement, and digitizing/scanning. It supported a national coordinate system that spanned the continent, coded lines as arcs having a true embedded topology and it stored the attribute and location information in separate files. As a result of this, Tomlinson has become known as the "father of GIS", particularly for his use of overlays in promoting the spatial analysis of convergent geographic data.

CGIS lasted into the 1990s and built a large digital land resource database in Canada. It was developed as a mainframe-based system in support of federal and provincial resource planning and management. Its strength was continent-wide analysis of complex datasets. The CGIS was never available commercially.

In 1964 Howard T. Fisher formed the Laboratory for Computer Graphics and Spatial Analysis at the Harvard Graduate School of Design (LCGSA 1965–1991), where a number of important theoretical concepts in spatial data handling were developed, and which by the 1970s had distributed seminal software code and systems, such as SYMAP, GRID, and ODYSSEY – that served as sources for subsequent commercial development—to universities, research centers and corporations worldwide.

By the early 1980s, M&S Computing (later Intergraph) along with Bentley Systems Incorporated for the CAD platform, Environmental Systems Research Institute (ESRI), CARIS (Computer Aided Resource Information System), MapInfo(MapInfo) and ERDAS (Earth Resource Data Analysis System) emerged as commercial vendors of GIS software, successfully incorporating many of the CGIS features, combining the first generation approach to separation of spatial and attribute information with a second generation approach to organizing attribute data into database structures. In parallel, the development of two public domain systems (MOSS and GRASS GIS) began in the late 1970s and early 1980s.

In 1986, Mapping Display and Analysis System (MIDAS), the first desktop GIS product emerged for the DOS operating system. This was renamed in 1990 to MapInfo for Windows when it was ported to the Microsoft Windows platform. This began the process of moving GIS from the research department into the business environment.

By the end of the 20th century, the rapid growth in various systems had been consolidated and standardized on relatively few platforms and users were beginning to explore viewing GIS data over the Internet, requiring data format and transfer standards. More recently, a growing number of free, open-source GIS packages run on a range of operating systems and can be customized to perform specific tasks. Increasingly geospatial data and mapping applications are being made available via the world wide web.

Chapter 8

GIS Techniques and Technology

Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a CAD program, and geo-referencing capabilities. With the wide availability of ortho-rectified imagery (both from satellite and aerial sources), heads-up digitizing is becoming the main avenue through which geographic data is extracted. Heads-up digitizing involves the tracing of geographic data directly on top of the aerial imagery instead of by the traditional method of tracing the geographic form on a separate digitizing tablet (heads-down digitizing).

Relating information from different sources

GIS uses spatio-temporal (space-time) location as the key index variable for all other information. Just as a relational database containing text or numbers can relate many different tables using common key index variables, GIS can relate unrelated information by using location as the key index variable. The key is the location and/or extent in space-time.

Any variable that can be located spatially, and increasingly also temporally, can be referenced using a GIS. Locations or extents in Earth space–time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. These GIS coordinates may represent other quantified systems of temporo-spatial reference (for example, film frame number, stream gage station, highway mile-marker, surveyor benchmark, building address, street intersection, entrance gate, water depth sounding, POS or CAD drawing origin/units). Units applied to recorded temporal-spatial data can vary widely (even when using exactly the same data, see map projections), but all Earth-based spatial–temporal location and extent references should, ideally, be relatable to one another and ultimately to a "real" physical location or extent in space–time.

Related by accurate spatial information, an incredible variety of real-world and projected past or future data can be analyzed, interpreted and represented to facilitate education and decision making. This key characteristic of GIS has begun to open new avenues of scientific inquiry into behaviors and patterns of previously considered unrelated real-world information.

GIS uncertainties

GIS accuracy depends upon source data, and how it is encoded to be data referenced. Land surveyors have been able to provide a high level of positional accuracy utilizing the GPS-derived positions. High-resolution digital terrain and aerial imagery, powerful computers and Web technology are changing the quality, utility, and expectations of GIS to serve society on a grand scale, but nevertheless there are other source data that have an impact on overall GIS accuracy like paper maps, though these may be of limited use in achieving the desired accuracy since the aging of maps affects their dimensional stability.

In developing a digital topographic data base for a GIS, topographical maps are the main source, and aerial photography and satellite images are extra sources for collecting data and identifying attributes which can be mapped in layers over a location facsimile of scale. The scale of a map and geographical rendering area representation type are very important aspects since the information content depends mainly on the scale set and resulting locatability of the map's representations. In order to digitize a map, the map has to be checked within theoretical dimensions, then scanned into a raster format, and resulting raster data has to be given a theoretical dimension by a rubber sheeting/warping technology process.

A quantitative analysis of maps brings accuracy issues into focus. The electronic and other equipment used to make measurements for GIS is far more precise than the machines of conventional map analysis. All geographical data are inherently inaccurate, and these inaccuracies will propagate through GIS operations in ways that are difficult to predict.

Data representation

GIS data represents real objects (such as roads, land use, elevation, trees, waterways, etc.) with digital data determining the mix. Real objects can be divided into two abstractions: discrete objects (e.g., a house) and continuous fields (such as rainfall amount, or elevations). Traditionally, there are two broad methods used to store data in a GIS for both kinds of abstractions mapping references: raster images and vector. Points, lines, and polygons are the stuff of mapped location attribute references. A new hybrid method of storing data is that of identifying point clouds, which combine three-dimensional points with RGB information at each point, returning a "3D color image". GIS thematic maps then are becoming more and more realistically visually descriptive of what they set out to show or determine.

Data capture

Example of hardware for mapping (GPS and laser rangefinder) and data collection (rugged computer). The current trend for geographical information system (GIS) is that accurate mapping and data analysis are completed while in the field. Depicted hardware (field-map technology) is used mainly for forest inventories, monitoring and mapping.

Data capture—entering information into the system—consumes much of the time of GIS practitioners. There are a variety of methods used to enter data into a GIS where it is stored in a digital format.

Existing data printed on paper or PET film maps can be digitized or scanned to produce digital data. A digitizer produces vector data as an operator traces points, lines, and polygon boundaries from a map. Scanning a map results in raster data that could be further processed to produce vector data.

Survey data can be directly entered into a GIS from digital data collection systems on survey instruments using a technique called coordinate geometry (COGO). Positions from a global navigation satellite system (GNSS) like Global Positioning System can also be collected and then imported into a GIS. A current trend in data collection gives users the ability to utilize field computers with the ability to edit live data using wireless connections or disconnected editing sessions. This has been enhanced by the availability of low-cost mapping-grade GPS units with decimeter accuracy in real time. This eliminates the need to post process, import, and update the data in the office after fieldwork has been collected. This includes the ability to incorporate positions collected using a laser rangefinder. New technologies also allow users to create maps as well as analysis directly in the field, making projects more efficient and mapping more accurate.

Remotely sensed data also plays an important role in data collection and consist of sensors attached to a platform. Sensors include cameras, digital scanners and LIDAR, while platforms usually consist of aircraft and satellites. Recently with the development of Miniature UAVs, aerial data collection is becoming possible at much lower costs, and on a more frequent basis. For example, the Aeryon Scout was used to map a 50-acre area with a Ground sample distance of 1 inch (2.54 cm) in only 12 minutes. The majority of digital data currently comes from photo interpretation of aerial photographs. Soft-copy workstations are used to digitize features directly from stereo pairs of digital photographs. These systems allow data to be captured in two and three dimensions, with elevations measured directly from a stereo pair using principles of photogrammetry. Analog aerial photos must be scanned before being entered into a soft-copy system, for high-quality digital cameras this step is skipped. Satellite remote sensing provides another important source of spatial data. Here satellites use different sensor packages to passively measure the reflectance from parts of the electromagnetic spectrum or radio waves that were sent out from an active sensor such as radar. Remote sensing collects raster data that can be further processed using different bands to identify objects and classes of interest, such as land cover.

When data is captured, the user should consider if the data should be captured with either a relative accuracy or absolute accuracy, since this could not only influence how information will be interpreted but also the cost of data capture. After entering data into a GIS, the data usually requires editing, to remove errors, or further processing. For vector data it must be made "topologically correct" before it can be used for some advanced analysis. For example, in a road network, lines must connect with nodes at an intersection. Errors such as undershoots and overshoots must also be removed. For scanned maps, blemishes on the source map may need to be removed from the resulting raster. For example, a fleck of dirt might connect two lines that should not be connected.

Raster-to-vector translation

Data restructuring can be performed by a GIS to convert data into different formats. For example, a GIS may be used to convert a satellite image map to a vector structure by generating lines around all cells with the same classification, while determining the cell spatial relationships, such as adjacency or inclusion. More advanced data processing can occur with image processing, a technique developed in the late 1960s by NASA and the private sector to provide contrast enhancement, false color rendering and a variety of other techniques including use of two dimensional Fourier transforms. Since digital data is collected and stored in various ways, the two data sources may not be entirely compatible. So a GIS must be able to convert geographic data from one structure to another.

Projections, coordinate systems, and registration

The earth can be represented by various models, each of which may provide a different set of coordinates (e.g., latitude, longitude, elevation) for any given point on the Earth's surface. The simplest model is to assume the earth is a perfect sphere. As more measurements of the earth have accumulated, the models of the earth have become more sophisticated and more accurate. In fact, there are models called datums that apply to different areas of the earth to provide increased accuracy, like NAD83 for U.S. measurements, and the World Geodetic System for worldwide measurements.

Spatial analysis with GIS

GIS spatial analysis is a rapidly changing field, and GIS packages are increasingly including analytical tools as standard built-in facilities, as optional toolsets, as add-ins or 'analysts'. In many instances these are provided by the original software suppliers (commercial vendors or collaborative non commercial development teams), whilst in other cases facilities have been developed and are provided by third parties. Furthermore, many products offer software development kits (SDKs), programming languages and language support, scripting facilities and/or special interfaces for developing one's own analytical tools or variants. The website "Geospatial Analysis" and associated book/ebook attempt to provide a reasonably comprehensive guide to the subject. The increased availability has created a new dimension to business intelligence termed "spatial intelligence" which, when openly delivered via intranet, democratizes access to geographic and social network data. Geospatial intelligence, based on GIS spatial analysis, has also become a key element for security. GIS as a whole can be described as conversion to a vectorial representation or to any other digitization process.

Slope and aspect

Slope can be defined as the steepness or gradient of a unit of terrain, usually measured as an angle in degrees or as a percentage. Aspect can be defined as the direction in which a unit of terrain faces. Aspect is usually expressed in degrees from north. Slope, aspect, and surface curvature in terrain analysis are all derived from neighborhood operations using elevation values of a cell's adjacent neighbors. Slope is a function of resolution, and the spatial resolution used to calculate slope and aspect should always be specified. Authors such as Skidmore, Jones and Zhou and Liu have compared techniques for calculating slope and aspect.

The following method can be used to derive slope and aspect:

The elevation at a point or unit of terrain will have perpendicular tangents (slope) passing through the point, in an east-west and north-south direction. These two tangents give two components, $\partial z/\partial x$ and $\partial z/\partial y$, which then be used to determine the overall direction of slope, and the aspect of the slope. The gradient is defined as a vector quantity with components equal to the partial derivatives of the surface in the x and y directions. The calculation of the overall 3x3 grid slope S and aspect A for methods that determine east-west and north-south component use the following formulas respectively:

$$\tan S = \sqrt{\left (\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2}$$

$$\tan A = \left ({\frac{\left ({\frac{-\partial z}{\partial y}}\right)}{\left ({\frac{\partial z}{\partial x}}\right)}}\right)$$

Zhou and Liu describe another algorithm for calculating aspect, as follows:

$$A = 270^\circ + \arctan \left ({\frac{\left ({\frac{\partial z}{\partial x}}\right)}{\left ({\frac{\partial z}{\partial y}}\right)}}\right) - 90^\circ \left ({\frac {\left ({\frac {\partial z}{\partial y}}\right)}{\left |{\frac {\partial z}{\partial y}}\right |}}\right)$$

Data analysis

It is difficult to relate wetlands maps to rainfall amounts recorded at different points such as airports, television stations, and schools. A GIS, however, can be used to depict two- and three-dimensional characteristics of the Earth's surface, subsurface, and atmosphere from information points. For example, a GIS can quickly generate a map with isopleths or contour lines that indicate differing amounts of rainfall. Such a map can be thought of as a rainfall contour map. Many sophisticated methods can estimate the characteristics of surfaces from a limited number of point measurements. A two-dimensional contour map created from the surface modeling of rainfall point measurements may be overlaid and analyzed with any other map in a GIS covering the same area. This GIS derived map can then provide additional information - such as the viability of water power potential as a renewable energy source. Similarly, GIS can be used compare other renewable energy resources to find the best geographic potential for a region.

Additionally, from a series of three-dimensional points, or digital elevation model, isopleths lines representing elevation contours can be generated, along with slope analysis, shaded relief, and other elevation products. Watersheds can be easily defined for any given reach, by computing all of the areas contiguous and uphill from any given point of interest. Similarly, an expected thawed of where surface water would want to travel in intermittent and permanent streams can be computed from elevation data in the GIS.

Topological modeling

A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modeling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

Geometric Networks

Geometric networks are linear networks of objects that can be used to represent interconnected features, and to perform special spatial analysis on them. A geometric network is composed of edges, which are connected at junction points, similar to graphs in mathematics and computer science. Just like graphs, networks can have weight and flow assigned to its edges, which can be used to represent various interconnected features more accurately. Geometric networks are often used to model road networks and public utility networks, such as electric, gas, and water networks. Network modeling is also commonly employed in transportation planning, hydrology modeling, and infrastructure modeling.

Hydrological modeling

GIS hydrological models can provide a spatial element that other hydrological models lack, with the analysis of variables such as slope, aspect and watershed or catchment area. Terrain analysis is fundamental to hydrology, since water always flows down a slope. As basic terrain analysis of a digital elevation model (DEM) involves calculation of slope and aspect, DEMs are very useful for hydrological analysis. Slope and aspect can then be used to determine direction of surface runoff, and hence flow accumulation for the formation of streams, rivers and lakes. Areas of divergent flow can also give a clear indication of the boundaries of a catchment. Once a flow direction and accumulation matrix has been created, queries can be performed that show contributing or dispersal areas at a certain point. More detail can be added to the model, such as terrain roughness, vegetation types and soil types, which can influence infiltration and evapotranspiration rates, and hence influencing surface flow. One of the main uses of hydrological modeling is in environmental contamination research.

Cartographic modeling

An example of use of layers in a GIS application. In this example, the forest cover layer (light green) is at the bottom, with the topographic layer over it. Next up is the stream layer, then the boundary layer, then the road layer. The order is very important in order to properly display the final result. Note that the pond layer was located just below the stream layer, so that a stream line can be seen overlying one of the ponds. The term "cartographic modeling" was probably coined by Dana Tomlin in his PhD dissertation and later in his book which has the term in the title. Cartographic modeling refers to a process where several thematic layers of the same area are produced, processed, and analyzed. Tomlin used raster layers, but the overlay method (see below) can be used more generally. Operations on map layers can be combined into algorithms, and eventually into simulation or optimization models.

Map overlay

The combination of several spatial datasets (points, lines, or polygons) creates a new output vector dataset, visually similar to stacking several maps of the same region. These overlays are similar to mathematical Venn diagram overlays. A union overlay combines the geographic features and attribute tables of both inputs into a single new output. An intersect overlay defines the area where both inputs overlap and retains a set of attribute fields for each. A symmetric difference overlay defines an output area that includes the total area of both inputs except for the overlapping area.

Data extraction is a GIS process similar to vector overlay, though it can be used in either vector or raster data analysis. Rather than combining the properties and features of both datasets, data extraction involves using a "clip" or "mask" to extract the features of one data set that fall within the spatial extent of another dataset.

In raster data analysis, the overlay of datasets is accomplished through a process known as "local operation on multiple rosters" or "map algebra," through a function that combines the values of each raster's matrix. This function may weigh some inputs more than others through use of an "index model" that reflects the influence of various factors upon a geographic phenomenon.

Geostatistics

Geostatistics is a branch of statistics that deals with field data, spatial data with a continuous index. It provides methods to model spatial correlation, and predict values at arbitrary locations (interpolation). When phenomena are measured, the observation methods dictate the accuracy of any subsequent analysis. Due to the nature of the data (e.g. traffic patterns in an urban environment; weather patterns over the Pacific Ocean), a constant or dynamic degree of precision is always lost in the measurement. This loss of precision is determined from the scale and distribution of the data collection. To determine the statistical relevance of the analysis, an average is determined so that points (gradients) outside of any immediate measurement can be included to determine their predicted behavior. This is due to the limitations of the applied statistic and data collection methods, and interpolation is required to predict the behavior of particles, points, and locations that are not directly measurable. Hillshade model derived from a Digital Elevation Model of the Valestra area in the northern Apennines (Italy).

Interpolation is the process by which a surface is created, usually a raster dataset, through the input of data collected at a number of sample points. There are several forms of interpolation, each which treats the data differently, depending on the properties of the data set. In comparing interpolation methods, the first consideration should be whether or not the source data will change (exact or approximate). Next is whether the method is subjective, a human interpretation, or objective. Then there is the nature of transitions between points: are they abrupt or gradual. Finally, there is whether a method is global (it uses the entire data set to form the model), or local where an algorithm is repeated for a small section of terrain.

Interpolation is a justified measurement because of a spatial autocorrelation principle that recognizes that data collected at any position will have a great similarity to, or influence of those locations within its immediate vicinity. Digital elevation models, triangulated irregular networks, edge-finding algorithms, Thiessen polygons, Fourier analysis, (weighted) moving averages, inverse distance weighting, kriging, spline, and trend surface analysis are all mathematical methods to produce interpolative data.

Address geocoding

Geocoding is interpolating spatial locations (X,Y coordinates) from street addresses or any other spatially referenced data such as ZIP Codes, parcel lots and address locations. A reference theme is required to geocode individual addresses, such as a road centerline file with address ranges. The individual address locations have historically been interpolated, or estimated, by examining address ranges along a road segment. These are usually provided in the form of a table or database. The software will then place a dot approximately where that address belongs along the segment of centerline. For example, an address point of 500 will be at the midpoint of a line segment that starts with address 1 and ends with address 1,000. Geocoding can also be applied against actual parcel data, typically from municipal tax maps. In this case, the result of the geocoding will be an actually positioned space as opposed to an interpolated point. This approach is being increasingly used to provide more precise location information.

Reverse geocoding

Reverse geocoding is the process of returning an estimated street address number as it relates to a given coordinate. For example, a user can click on a road centerline theme (thus providing a coordinate) and have information returned that reflects the estimated house number. This house number is interpolated from a range assigned to that road segment. If the user clicks at the midpoint of a segment that starts with address 1 and ends with 100, the returned value will be somewhere near 50. Note that reverse geocoding does not return actual addresses, only estimates of what should be there based on the predetermined range.

Multi-criteria decision analysis

Coupled with GIS, multi-criteria decision analysis methods support decision-makers in analysing a set of alternative spatial solutions, such as the most likely ecological habitat for restoration, against multiple criteria, such as vegetation cover or roads. MCDA uses decision rules to aggregate the criteria, which allows the alternative solutions to be ranked or prioritised. GIS MCDA may reduce costs and time involved in identifying potential restoration sites.

Data output and cartography

Cartography is the design and production of maps, or visual representations of spatial data. The vast majority of modern cartography is done with the help of computers, usually using GIS but production of quality cartography is also achieved by importing layers into a design program to refine it. Most GIS software gives the user substantial control over the appearance of the data.

Cartographic work serves two major functions:

First, it produces graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces (AJAX, Java, Flash, etc.).

Second, other database information can be generated for further analysis or use. An example would be a list of all addresses within one mile (1.6 km) of a toxic spill.

Graphic display techniques

Traditional maps are abstractions of the real world, a sampling of important elements portrayed on a sheet of paper with symbols to represent physical objects. People who use maps must interpret these symbols. Topographic maps show the shape of land surface with contour lines or with shaded relief.

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Spatial ETL

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GIS data mining

GIS or spatial data mining is the application of data mining methods to spatial data. Data mining, which is the partially automated search for hidden patterns in large databases, offers great potential benefits for applied GIS-based decision making. Typical applications including environmental monitoring. A characteristic of such applications is that spatial correlation between data measurements require the use of specialized algorithms for more efficient data analysis.

Chapter 9

Geostatistics and Geocoding

Geostatistics is a branch of statistics that deals with field data, spatial data with a continuous index. It provides methods to model spatial correlation, and predict values at arbitrary locations (interpolation). When phenomena are measured, the observation methods dictate the accuracy of any subsequent analysis. Due to the nature of the data (e.g. traffic patterns in an urban environment; weather patterns over the Pacific Ocean), a constant or dynamic degree of precision is always lost in the measurement. This loss of precision is determined from the scale and distribution of the data collection. To determine the statistical relevance of the analysis, an average is determined so that points (gradients) outside of any immediate measurement can be included to determine their predicted behavior. This is due to the limitations of the applied statistic and data collection methods, and interpolation is required to predict the behavior of particles, points, and locations that are not directly measurable. Hillshade model derived from a Digital Elevation Model of the Valestra area in the northern Apennines (Italy).

Interpolation is the process by which a surface is created, usually a raster dataset, through the input of data collected at a number of sample points. There are several forms of interpolation, each which treats the data differently, depending on the properties of the data set. In comparing interpolation methods, the first consideration should be whether or not the source data will change (exact or approximate). Next is whether the method is subjective, a human interpretation, or objective. Then there is the nature of transitions between points: are they abrupt or gradual. Finally, there is whether a method is global (it uses the entire data set to form the model), or local where an algorithm is repeated for a small section of terrain.

Interpolation is a justified measurement because of a spatial autocorrelation principle that recognizes that data collected at any position will have a great similarity to, or influence of those locations within its immediate vicinity. Digital elevation models, triangulated irregular networks, edge-finding algorithms, Thiessen polygons, Fourier analysis, (weighted) moving averages, inverse distance weighting, kriging, spline, and trend surface analysis are all mathematical methods to produce interpolative data.

Address geocoding

Geocoding is the process of finding associated geographic coordinates (often expressed as latitude and longitude) from other geographic data, such as street addresses, or ZIP codes (postal codes). With geographic coordinates the features can be mapped and entered into Geographic Information Systems, or the coordinates can be embedded into media such as digital photographs via geotagging.

Reverse geocoding is the opposite: finding an associated textual location such as a street address, from geographic coordinates.

A geocoder is a piece of software or a (web) service that helps in this process.

Address interpolation

A simple method of geocoding is address interpolation. This method makes use of data from a street geographic information system where the street network is already mapped within the geographic coordinate space. Each street segment is attributed with address ranges (e.g. house numbers from one segment to the next). Geocoding takes an address, matches it to a street and specific segment (such as a block, in towns that use the "block" convention). Geocoding then interpolates the position of the address, within the range along the segment.

Example

Take for example: 742 Evergreen Terrace

Let's say that this segment (for instance, a block) of Evergreen Terrace runs from 700 to 799. Even-numbered addresses fall on the east side of Evergreen Terrace, with odd-numbered addresses on the west side of the street. 742 Evergreen Terrace would (probably) be located slightly less than halfway up the block, on the east side of the street. A point would be mapped at that location along the street, perhaps offset a distance to the east of the street centerline.

Complicating factors

However, this process is not always as straightforward as in this example.

Difficulties arise when

distinguishing between ambiguous addresses such as 742 Evergreen Terrace and 742 W Evergreen Terrace.

attempting to geocode new addresses for a street that is not yet added to the geographic information system database.

While there might be 742 Evergreen Terrace in Springfield, there might also be a 742 Evergreen Terrace in Shelbyville. Asking for the city name (and state, province, country, etc. as needed) can solve this problem. Boston, Massachusetts has multiple "100 Washington Street" locations because several cities have been annexed without changing street names, thus requiring use of unique postal codes or district names for disambiguation.

Geocoding accuracy can be greatly improved by first utilizing good address verification practices. Address verification will confirm the existence of the address and will eliminate ambiguities. Once the valid address is determined, it is very easy to geocode and determine the latitude/longitude coordinates.

Finally, several caveats on using interpolation:

The typical attribution of a street segment assumes that all even numbered parcels are on one side of the segment, and all odd numbered parcels are on the other. This is often not true in real life.

Interpolation assumes that the given parcels are evenly distributed along the length of the segment. This is almost never true in real life; it is not uncommon for a geocoded address to be off by several thousand feet.

Interpolation also assumes that the street is straight. If a street is curved then the geocoded location will not necessarily fit the physical location of the address.

Segment Information (esp. from sources such as TIGER) includes a maximum upper bound for addresses and is interpolated as though the full address range is used. For example, a segment (block) might have a listed range of 100-199, but the last address at the end of the block is 110. In this case, address 110 would be geocoded to 10% of the distance down the segment rather than near the end.

Most interpolation implementations will produce a point as their resulting address location. In reality, the physical address is distributed along the length of the segment, i.e. consider geocoding the address of a shopping mall - the physical lot may run a distance along the street segment (or could be thought of as a two-dimensional space-filling polygon which may front on several different streets - or worse, for cities with multi-level streets, a three-dimensional shape that meets different streets at several different levels) but the interpolation treats it as a singularity.

A very common error is to believe the accuracy ratings of a given map's geocodable attributes. Such accuracy currently touted by most vendors has no bearing on an address being attributed to the correct segment, being attributed to the correct side of the segment, nor resulting in an accurate position along that correct segment. With the geocoding process used for U.S. Census TIGER datasets, 5-7.5% of the addresses may be allocated to a different census tract, while 50% of the geocoded points might be located to a different property parcel.

The accuracy of geocoded data can also have a bearing on the quality of research that can be done using this data. One study by a group of Iowa researcher's found that the common method of geocoding using TIGER datasets as described above, can cause a loss of as much as 40% of the power of a statistical analysis.An alternative is to use orthophoto or image coded data such as the Address Point data from Ordnance Survey in the UK, but such datasets are generally expensive.

Because of this, it is quite important to avoid using interpolated results except for non-critical applications, such as pizza delivery. Interpolated geocoding is usually not appropriate for making authoritative decisions, for example if life safety will be affected by that decision. Emergency services, for example, do not make an authoritative decision based on their interpolations; an ambulance or fire truck will always be dispatched regardless of what the map says.

Geocoding is interpolating spatial locations (X,Y coordinates) from street addresses or any other spatially referenced data such as ZIP Codes, parcel lots and address locations. A reference theme is required to geocode individual addresses, such as a road centerline file with address ranges. The individual address locations have historically been interpolated, or estimated, by examining address ranges along a road segment. These are usually provided in the form of a table or database. The software will then place a dot approximately where that address belongs along the segment of centerline. For example, an address point of 500 will be at the midpoint of a line segment that starts with address 1 and ends with address 1,000. Geocoding can also be applied against actual parcel data, typically from municipal tax maps. In this case, the result of the geocoding will be an actually positioned space as opposed to an interpolated point. This approach is being increasingly used to provide more precise location information.

Reverse geocoding

Reverse geocoding is the process of returning an estimated street address number as it relates to a given coordinate. For example, a user can click on a road centerline theme (thus providing a coordinate) and have information returned that reflects the estimated house number. This house number is interpolated from a range assigned to that road segment. If the user clicks at the midpoint of a segment that starts with address 1 and ends with 100, the returned value will be somewhere near 50. Note that reverse geocoding does not return actual addresses, only estimates of what should be there based on the predetermined range.

Multi-criteria decision analysis

Coupled with GIS, multi-criteria decision analysis methods support decision-makers in analysing a set of alternative spatial solutions, such as the most likely ecological habitat for restoration, against multiple criteria, such as vegetation cover or roads. MCDA uses decision rules to aggregate the criteria, which allows the alternative solutions to be ranked or prioritised. GIS MCDA may reduce costs and time involved in identifying potential restoration sites.

Data output and cartography

Cartography is the design and production of maps, or visual representations of spatial data. The vast majority of modern cartography is done with the help of computers, usually using GIS but production of quality cartography is also achieved by importing layers into a design program to refine it. Most GIS software gives the user substantial control over the appearance of the data.

Cartographic work serves two major functions:

First, it produces graphics on the screen or on paper that convey the results of analysis to the people who make decisions about resources. Wall maps and other graphics can be generated, allowing the viewer to visualize and thereby understand the results of analyses or simulations of potential events. Web Map Servers facilitate distribution of generated maps through web browsers using various implementations of web-based application programming interfaces (AJAX, Java, Flash, etc.).

Second, other database information can be generated for further analysis or use. An example would be a list of all addresses within one mile (1.6 km) of a toxic spill.

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Chapter 10

GIS Developments

Many disciplines can benefit from GIS technology. An active GIS market has resulted in lower costs and continual improvements in the hardware and software components of GIS. These developments will, in turn, result in a much wider use of the technology throughout science, government, business, and industry, with applications including real estate, public health, crime mapping, national defense, sustainable development, natural resources, landscape architecture, archaeology, regional and community planning, transportation and logistics. GIS is also diverging into location-based services, which allows GPS-enabled mobile devices to display their location in relation to fixed assets (nearest restaurant, gas station, fire hydrant), mobile assets (friends, children, police car) or to relay their position back to a central server for display or other processing. These services continue to develop with the increased integration of GPS functionality with increasingly powerful mobile electronics (cell phones, PDAs, laptops).

Open Geospatial Consortium standards

The Open Geospatial Consortium (OGC) is an international industry consortium of 384 companies, government agencies, universities, and individuals participating in a consensus process to develop publicly available geoprocessing specifications. Open interfaces and protocols defined by OpenGIS Specifications support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT, and empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications. Open Geospatial Consortium protocols include Web Map Service, and Web Feature Service.

GIS products are broken down by the OGC into two categories, based on how completely and accurately the software follows the OGC specifications.

OGC standards help GIS tools communicate

Compliant Products are software products that comply to OGC's OpenGIS Specifications. When a product has been tested and certified as compliant through the OGC Testing Program, the product is automatically registered as "compliant" on this site.

Implementing Products are software products that implement OpenGIS Specifications but have not yet passed a compliance test. Compliance tests are not available for all specifications. Developers can register their products as implementing draft or approved specifications, though OGC reserves the right to review and verify each entry.

Web mapping

In recent years there has been an explosion of mapping applications on the web such as Google Maps and Bing Maps. These websites give the public access to huge amounts of geographic data. Some of them, like Google Maps and OpenLayers, expose an API that enable users to create custom applications. These toolkits commonly offer street maps, aerial/satellite imagery, geocoding, searches, and routing functionality. Web mapping has also uncovered the potential of crowdsourcing geodata in projects like OpenStreetMap, which is a collaborative project to create a free editable map of the world.

Web mapping is the process of using maps delivered by geographical information systems (GIS). Since a web map on the World Wide Web is both served and consumed, web mapping is more than just web cartography, it is both a service activity and consumer activity. Web GIS emphasizes geodata processing aspects more involved with design aspects such as data acquisition and server software architecture such as as data storage and algorithms, than it does the end-user reports themselves. The terms web GIS and web mapping remain somewhat synonymous. Web GIS uses web maps, and end users who are web mapping are gaining analytical capabilities. The term location-based services refers to web mapping consumer goods and services. Web mapping usually involves a web browser or other user agent capable of client-server interactions.

While web mapping today is still being developed, challenges and innovations involving the feedback of the quality, the usability, the social benefits, and the legal constraints, drive its evolution.

Development and implementation

The advent of web mapping can be regarded as a major new trend in cartography. Until recently cartography was restricted to a few companies, institutes and mapping agencies, requiring relatively expensive and complex hardware and software as well as skilled cartographers and geomatics engineers.

With the rise of web mapping, a range of data and technology was born - from free data generated by OpenStreetMap to proprietary datasets owned by Navteq, Google, Waze, and others. A range of free software to generate maps has also been conceived and implemented alongside proprietary tools like ArcGIS. As a result, the barrier to entry for serving maps on the web has been lowered.

Types of web maps

A first classification of web maps has been made by Kraak in 2001. He distinguished static and dynamic web maps and further distinguished interactive and view only web maps. Today there an increased number of dynamic web maps types, and static web map sources.

Analytic web maps

Analytic web maps offer GIS analysis. The geodata can be a static provision, or need updates. The borderline between analytic web maps and web GIS is fuzzy. Parts of the analysis can be carried out by the GIS geodata server. As web clients gain capabilities processing is distributed.

Animated web maps

Animated Maps show changes in the map over time by animating one of the graphical or temporal variables. Technologies enabling client-side display of animated web maps in include scalable vector graphics (SVG), Adobe Flash, Java, QuickTime, and others. Examples of animated web maps include weather maps and traffic flow maps.

Collaborative web maps

Collaborative maps are a developing potential. In proprietary or open source collaborative software, users collaborate to create and improve the web mapping experience. Some collaborative web mapping projects are:

- HERE Map Creator
- Google Map Maker
- OpenStreetMap
- WikiMapia
- meta:Maps - a survey of Wikimedia web mapping proposals

Online atlases

The traditional atlas goes through a remarkably large transition when hosted on the web. Atlases can cease their printed editions or offer printing on demand. Some atlases also offer raw data downloads of the underlying geospatial data sources.

Realtime web maps

Realtime maps show the situation of a phenomenon in close to realtime (only a few seconds or minutes delay). Data is collected by sensors and the maps are generated or updated at regular intervals or immediately on demand. Examples are weather maps, traffic maps or vehicle monitoring systems.

Static web maps

Static web pages are view only with no animation and interactivity. They are only created once, often manually and infrequently updated. Typical graphics formats for static web maps are PNG, JPEG, GIF, or TIFF (e.g., drg) for raster files, SVG, PDF or SWF for vector files. These include scanned paper maps not designed as screen maps. Paper maps have a much higher resolution and information density than typical computer displays of the same physical size, and might be unreadable when displayed on screens at the wrong resolution.

Evolving paper cartography

Compared to traditional techniques, mapping software has many advantages. The disadvantages are also stated.

- Web maps can easily deliver up to date information. If maps are generated automatically from databases, they can display information in almost realtime. They don't need to be printed, mastered and distributed. Examples:
- A map displaying election results, as soon as the election results become available.
- A map displaying the traffic situation near realtime by using traffic data collected by sensor networks.
- A map showing the current locations of mass transit vehicles such as buses or trains, allowing patrons to minimize their waiting time at stops or stations, or be aware of delays in service.
- Weather maps, such as NEXRAD.
- Software and hardware infrastructure for web maps is cheap. Web server hardware is cheaply available and many open source tools exist for producing web maps. Geodata, on the other hand, is not; satellites and fleets of automobiles with high-tech, state-of-the-art equipment are used to collect the information on an ongoing basis. Perhaps owing to this, many people are still reluctant to publish geodata, especially in light of the fact that geodata are expensive in some parts of the world. They fear copyright infringements of other people using their data without proper requests for permission.
- Product updates can easily be distributed. Because web maps distribute both logic and data with each request or loading, product updates can happen every time the web user reloads the application. In traditional cartography, when dealing with printed maps or interactive maps distributed on offline media (CD, DVD, etc.), a map update caused serious efforts, triggering a reprint or remastering as well as a redistribution of the media. With web maps, data and product updates are easier, cheaper, and faster, and can occur more often. Perhaps owing to this, many web maps are of poor quality, both in symbolization, content and data accuracy.
- Web maps can combine distributed data sources. Using open standards and documented APIs one can integrate (mash up) different data sources, if the projection system, map

scale and data quality match. The use of centralized data sources removes the burden for individual organizations to maintain copies of the same data sets. The downside is that one has to rely on and trust the external data sources. In addition, with detailed information available and the combination of distributed data sources, it is possible to find out and combine a lot of private and personal information of individual persons. Properties and estates of individuals are now accessible through high resolution aerial and satellite images throughout the world to anyone.

- Web maps allow for personalization. By using user profiles, personal filters and personal styling and symbolization, users can configure and design their own maps, if the web mapping systems supports personalization. Accessibility issues can be treated in the same way. If users can store their favourite colors and patterns they can avoid color combinations they can't easily distinguish (e.g. due to color blindness). Despite this, as with paper, web maps have the problem of limited screen space, but more so. This is in particular a problem for mobile web maps; the equipment carried usually has a very small screen, making it less likely that there is room for personalisation.
- Web maps enable collaborative mapping. Similar to the Wikipedia project, web mapping technologies, such as DHTML/Ajax, SVG, Java, Adobe Flash, etc. enable distributed data acquisition and collaborative efforts. Examples for such projects are the OpenStreetMap project or the Google Earth community. As with other open projects, quality assurance is very important, however, and the reliability of the internet and web server infrastructure is not yet good enough. Especially if a web map relies on external, distributed data sources, the original author often cannot guarantee the availability of the information.
- Web maps support hyperlinking to other information on the web. Just like any other web page or a wiki, web maps can act like an index to other information on the web. Any sensitive area in a map, a label text, etc. can provide hyperlinks to additional information. As an example a map showing public transport options can directly link to the corresponding section in the online train time table. Having said that, development of web maps is complicated enough as it is: Despite the increasing availability of free and commercial tools to create web mapping and web GIS applications, it is still a more complex task to create interactive web maps than to typeset and print images. Many

technologies, modules, services and data sources have to be mastered and integrated The development and debugging environments of a conglomerate of different web technologies is still awkward and uncomfortable.

Global climate change, climate history program and prediction of its impact

Maps have traditionally been used to explore the Earth and to exploit its resources. GIS technology, as an expansion of cartographic science, has enhanced the efficiency and analytic power of traditional mapping. Now, as the scientific community recognizes the environmental consequences of anthropogenic activities influencing climate change, GIS technology is becoming an essential tool to understand the impacts of this change over time. GIS enables the combination of various sources of data with existing maps and up-to-date information from earth observation satellites along with the outputs of climate change models. This can help in understanding the effects of climate change on complex natural systems. One of the classic examples of this is the study of Arctic ice melting.

Adding the dimension of time

The condition of the Earth's surface, atmosphere, and subsurface can be examined by feeding satellite data into a GIS. GIS technology gives researchers the ability to examine the variations in Earth processes over days, months, and years. As an example, the changes in vegetation vigor through a growing season can be animated to determine when drought was most extensive in a particular region. The resulting graphic, known as a normalized vegetation index, represents a rough measure of plant health. Working with two variables over time would then allow researchers to detect regional differences in the lag between a decline in rainfall and its effect on vegetation. GIS technology and the availability of digital data on regional and global scales enable such analyses. The satellite sensor output used to generate a vegetation graphic is produced for example by the Advanced Very High Resolution Radiometer (AVHRR). This sensor system detects the amounts of energy reflected from the Earth's surface across various bands of the spectrum for surface areas of about 1 square kilometer. The satellite sensor produces images of a particular location on the Earth twice a day. AVHRR and more recently the Moderate-Resolution Imaging Spectroradiometer (MODIS) are only two of many sensor systems used for Earth surface analysis. More sensors will follow, generating ever greater amounts of data.

In addition to the integration of time in environmental studies, GIS is also being explored for its ability to track and model the progress of humans throughout their daily routines. A concrete example of progress in this area is the recent release of time-specific population data by the U.S. Census. In this data set, the populations of cities are shown for daytime and evening hours highlighting the pattern of concentration and dispersion generated by North American commuting patterns. The manipulation and generation of data required to produce this data would not have been possible without GIS.

Using models to project the data held by a GIS forward in time have enabled planners to test policy decisions using spatial decision support systems.

Chapter 11

GIS Applications

GIS in archaeology

GIS or Geographic Information Systems has over the last 10 years become an important tool in archaeology. Indeed, archaeologists were some of the early adopters, users, and developers of GIS and GISCience, Geographic Information Science. The combination of GIS and archaeology has been considered a perfect match, since archaeology often involves the study of the spatial dimension of human behavior over time, and all archaeology carries a spatial component.

Since archaeology looks at the unfolding of historical events through geography, time and culture, the results of archaeological studies are rich in spatial information. GIS is adept at processing these large volumes of data, especially that which is geographically referenced. It is a cost effective, accurate and fast tool. The tools made available through GIS help in data collection, its storage and retrieval, its manipulation for customized circumstances and, finally, the display of the data so that it is visually comprehensible by the user. The most important aspect of GIS in archaeology lies, however, not in its use as a pure map-making tool, but in its capability to merge and analyse different types of data in order to create new information. The use of GIS in archaeology has changed not only the way archaeologists acquire and visualise data, but also the way in which archaeologists think about space itself. GIS has therefore become more of a science than an objective tool.

GIS in survey

Survey and documentation are important to preservation and archaeology, and GIS makes this research and fieldwork efficient and precise. Research done using GIS capabilities is used as a decision making tool to prevent loss of relevant information that could impact archaeological sites and studies. It is a significant tool that contributes to regional planning and for cultural resource management to protect resources that are valuable through the acquisition and maintenance of data about historical sites.

In archaeology, GIS increases the ability to map and record data when it is used directly at the excavation site. This allows for immediate access to the data collected for analysis and visualization as an isolated study or it can be incorporated with other relevant data sources to help understand the site and its findings better.

The ability of GIS to model and predict likely archaeological sites is used by companies that are involved with utilizing vast tracts of land resources like the Department of Transportation. Section 106 of the National Preservation Act specifically requires historical sites as well as others to be assessed for impact through federally funded projects. Using GIS to assess archaeological sites that may exist or be of importance can be identified through predictive modeling. These studies and results are then used by the management to make relevant decisions and plan for future development. GIS makes this process less time consuming and more precise.

There are different processes and GIS functionalities that are used in archaeological research. Intrasite spatial analysis or distributional analysis of the information on the site helps in understanding the formation, process of change and in documentation of the site. This leads to research, analysis and conclusions. The old methods utilized for this provide limited exposure to the site and provide only a small picture of patterns over broad spaces. Predictive modeling is used through data acquisition like that of hydrography and hypsography to develop models along with archaeological data for better analysis. Point data in GIS is used to focus on point locations and to analyze trends in data sets or to interpolate scattered points. Density mapping is done for the analysis of location trends and interpolation is done to aid surface findings through the creation of surfaces through point data and is used to find occupied levels in a site. Aerial data is more commonly used. It focuses on the landscape and the region and helps interpret archaeological sites in their context and settings. Aerial data is analyzed through predictive modeling which is used to predict location of sites and material in a region. It is based on the available knowledge, method of prediction and on the actual results. This is used primarily in cultural resource management.

GIS in analysis

GIS are able to store, manipulate and combine multiple data sets, making complex analyses of the landscape possible. Catchment analysis is the analysis of catchment areas, the region surrounding the site accessible with a given expenditure of time or effort. Viewshed analysis is the study of what regions surrounding the site are visible from that site. This has been used to interpret the relationship of sites to their social landscape. Simulation is a simplified representation of reality, attempting to model phenomena by identifying key variables and their interactions. This is used to think through problem formulation, as a means of testing hypothetical predictions, and also as a means to generate data.

In recent years, it has become clear that archaeologists will only be able to harvest the full potential of GIS or any other spatial technology if they become aware of the specific pitfalls and potentials inherent in the archaeological data and research process. Archaeoinformation science attempts to uncover and explore spatial and temporal patterns and properties in archaeology. Research towards a uniquely archaeological approach to information processing produces quantitative methods and computer software specifically geared towards archaeological problem solving and understanding.

GIS and aquatic science

Geographic Information Systems (GIS) has become an integral part of aquatic science and limnology. Water by its very nature is dynamic. Features associated with water are thus ever-changing. To be able to keep up with these changes, technological advancements have given scientists methods to enhance all aspects of scientific investigation, from satellite tracking of wildlife to computer mapping of habitats. Agencies like the US Geological Survey, US Fish and Wildlife Service as well as other federal and state agencies are utilizing GIS to aid in their conservation efforts.

GIS is being used in multiple fields of aquatic science from limnology, hydrology, aquatic botany, stream ecology, oceanography and marine biology. Applications include using satellite imagery to identify, monitor and mitigate habitat loss. Imagery can also show the condition of inaccessible areas. Scientists can track movements and develop a strategy to locate locations of concern. GIS can be used to track invasive species, endangered species, and population changes.

One of the advantages of the system is the availability for the information to be shared and updated at any time through the use of web-based data collection.

GIS and fish

USGS sidescan radar image over base image from Army Corps of Engineers, indicating sturgeon location and river mile.

In the past, GIS was not a practical source of analysis due to the difficulty in obtaining spatial data on habitats or organisms in underwater environments. With the advancement of radio telemetry, hydroacoustic telemetry and side-scan sonar biologists have been able to track fish species and create databases that can be incorporated into a GIS program to create a geographical representation. Using radio and hydroacoustic telemetry, biologists are able to locate fish and acquire relatable data for those sites, this data may include substrate samples, temperature, and conductivity. Side-scan sonar allows biologists to map out a river bottom to gain a representation of possible habitats that are used. These two sets of data can be overlaid to delineate the distribution of fish and their habitats for fish. This method has been used in the study of the pallid sturgeon.

Over a period of time large amounts of data are collected and can be used to track patterns of migration, spawning locations and preferred habitat. Before, this data would be mapped and overlaid manually. Now this data can be entered into a GIS program and be layered, organized and analyzed in a way that was not possible to do in the past. Layering within a GIS program allows for the scientist to look at multiple species at once to find possible watersheds that are shared by these species, or to specifically choose one species for further examination. The US Geological Survey (USGS) in, cooperation with other agencies, were able to use GIS in helping map out habitat areas and movement patterns of pallid sturgeon. At the Columbia Environmental Research Center their effort relies on a customized ArcPad and ArcGIS, both ESRI (Environmental Systems Research Institute) applications, to record sturgeon movements to streamline data collection. A relational database was developed to manage tabular data for each individual sturgeon, including initial capture and reproductive physiology. Movement maps can be created for individual sturgeon. These maps help track the movements of each sturgeon through space and time. This allowed these researchers to prioritize and schedule field personnel efforts to track, map, and recapture sturgeon.

GIS and macrophytes

Surveyed (left) and predicted (right) distributions of submersed aquatic vegetation distribution Upper Mississippi River in 1989. The survey data were from the land cover/land use geographic information created by the U.S. Geological Survey Upper Midwest Environmental Sciences Center on the basis of interpretation of aerial photography of 1989.

Macrophytes are an important part of healthy ecosystems. They provide habitat, refuge, and food for fish, wildlife, and other organisms. Though natural occurring species are of great interest so are the invasive species that occur alongside these in our environment. GIS is being used by agencies and their respective resource managers as a tool to model these important macrophyte species. Through the use of GIS resource managers can assess the distributions of this important aspect of aquatic environments through a spatial and temporal scale. The ability to track vegetation change through time and space to make predictions about vegetation change are some of the many possibilities of GIS. Accurate maps of the aquatic plant distribution within an aquatic ecosystem are an essential part resource management.

It is possible to predict the possible occurrences of aquatic vegetation. For example, the USGS has created a model for the American wild celery (Vallisneria americana) by developing a statistical model that calculates the probability of submersed aquatic vegetation. They established a web link to an Environmental Systems Research Institute (ESRI) ArcGIS Server website *Submersed Aquatic Vegetation Model to make their model predictions available online. These predictions for distribution of submerged aquatic vegetation can potentially have an effect on foraging birds by creating avoidance zones by humans. If it is known where these areas are, birds can be left alone to feed undisturbed. When there are years where the aquatic vegetation is predicted to be limited in these important wildlife habitats, managers can be alerted.

Invasive species have become a great conservation concern for resource managers. GIS allows managers to map out plant locations and abundances. These maps can then be used to determine the threat of these invasive plants and help the managers decide on management strategies. Surveys of these species can be conducted and then downloaded into a GIS system. Coupled with this, native species can be included to determine how these communities respond with each other. By using known data of preexisting invasive species GIS models could predict future outbreaks by comparing biological factors. The Connecticut Agricultural Experiment Station Invasive Aquatic Species Program (CAES IAPP) is using GIS to evaluate risk factors. GIS allows managers to georeference plant locations and abundance. This allows for managers to display invasive communities alongside native species for study and management.

Geographic information systems in geospatial intelligence

Geographic information systems (GIS) play a constantly evolving role in geospatial intelligence (GEOINT) and United States national security. These technologies allow a user to efficiently manage, analyze, and produce geospatial data, to combine GEOINT with other forms of intelligence collection, and to perform highly developed analysis and visual production of geospatial data. Therefore, GIS produces up-to-date and more reliable GEOINT to reduce uncertainty for a decisionmaker. Since GIS programs are Web-enabled, a user can constantly work with a decision maker to solve their GEOINT and national security related problems from anywhere in the world. There are many types of GIS software used in GEOINT and national security, such as Google Earth, ERDAS IMAGINE, GeoNetwork opensource, and Esri ArcGIS.

Geospatial intelligence (GEOINT)

GEOINT, known previously as imagery intelligence (IMINT), is an intelligence collection discipline that applies to national security intelligence, law enforcement intelligence, and competitive intelligence. For example, an analyst can use GEOINT to identify the route of least resistance for a military force in a hostile country, to discover a pattern in the locations of reported burglaries in a neighborhood, or to generate a map and comparison of failing businesses that a company is likely to purchase. GEOINT is also the geospatial product of a process that is focused externally, designed to reduce the level of uncertainty for a decisionmaker, and that uses information derived from all sources.[The National Geospatial-Intelligence Agency (NGA), who has overall responsibility for GEOINT in the U.S. Intelligence Community (IC), defines GEOINT as "information about any object—natural or man-made—that can be observed or referenced to the Earth, and has national security implications."

Some of the sources of collected imagery information for GEOINT are imagery satellites, cameras on airplanes, Unmanned Aerial Vehicles (UAV) and drones, handheld cameras, maps, or GPS coordinates.Recently the NGA and IC have increased the use of commercial satellite imagery for intelligence support, such as the use of the IKONOS, Landsat, or SPOT satellites. These sources produce digital imagery via electro-optical systems, radar, infrared, visible light, multispectral, or hyperspectral imageries.

The advantages of GEOINT are that imagery is easily consumable and understood by a decisionmaker, has low human life risk, displays the capabilities of a target and its geographical relationship to other objects, and that analysts can use imagery world-wide in a short time. On the other hand, the disadvantages of GEOINT are that imagery is only a snapshot of a moment in time, can be too compelling and lead to ill-informed decisions that ignore other intelligence, is static and vulnerable to deception and decoys, does not depict the intentions of a target, and is expensive and subject to environmental problems.

Chapter 12

GIS file formats

GIS file format is a standard of encoding geographical information into a file. They are created mainly by government mapping agencies (such as the USGS or National Geospatial-Intelligence Agency) or by GIS software developers.

Metadata often includes:

- Elevation data, either in raster or vector (e.g., contour lines) form
- Shape layers, usually expressed as line drawings, for streets, postal zone boundaries, etc.
- Coordinate system descriptions.
- One or more datums describing the precise shape of the Earth assumed by the coordinates.

Raster

A raster data type is, in essence, any type of digital image represented by reducible and enlargeable grids. Anyone who is familiar with digital photography will recognize the Raster graphics pixel as the smallest individual grid unit building block of an image, usually not readily identified as an artifact shape until an image is produced on a very large scale. A combination of the pixels making up an image color formation scheme will compose details of an image, as is distinct from the commonly used points, lines, and polygon area location symbols of scalable vector graphics as the basis of the vector model of area attribute rendering. While a digital image is concerned with its output blending together its grid based details as an identifiable representation of reality, in a photograph or art image transferred into a computer, the raster data type will reflect a digitized abstraction of reality dealt with by grid populating tones or objects, quantities, cojoined or open boundaries, and map relief schemas. Aerial photos are one commonly used form of raster data, with one primary purpose in mind: to display a detailed image on a map area, or for the purposes of rendering its identifiable objects by digitization. Additional raster data sets used by a GIS will contain information regarding elevation, a digital elevation model, or reflectance of a particular wavelength of light, Landsat, or other electromagnetic spectrum indicators.

Raster data type consists of rows and columns of cells, with each cell storing a single value. Raster data can be images (raster images) with each pixel (or cell) containing a color value. Additional values recorded for each cell may be a discrete value, such as land use, a continuous value, such as temperature, or a null value if no data is available. While a raster cell stores a single value, it can be extended by using raster bands to represent RGB (red, green, blue) colors, colormaps (a mapping between a thematic code and RGB value), or an extended attribute table with one row for each unique cell value. The resolution of the raster data set is its cell width in ground units.

Raster data is stored in various formats; from a standard file-based structure of TIF, JPEG, etc. to binary large object (BLOB) data stored directly in a relational database management system (RDBMS) similar to other vector-based feature classes. Database storage, when properly indexed, typically allows for quicker retrieval of the raster data but can require storage of millions of significantly sized records.

Vector

In a GIS, geographical features are often expressed as vectors, by considering those features as geometrical shapes. Different geographical features are expressed by different types of geometry:

Points

A simple vector map, using each of the vector elements: points for wells, lines for rivers, and a polygon for the lake

Zero-dimensional points are used for geographical features that can best be expressed by a single point reference—in other words, by simple location. Examples include wells, peaks, features of interest, and trailheads. Points convey the least amount of information of these file types. Points can also be used to represent areas when displayed at a small scale. For example, cities on a map of the world might be represented by points rather than polygons. No measurements are possible with point features.

Lines or polylines

One-dimensional lines or polylines are used for linear features such as rivers, roads, railroads, trails, and topographic lines. Again, as with point features, linear features displayed at a small scale will be represented as linear features rather than as a polygon. Line features can measure distance.

Polygons

Two-dimensional polygons are used for geographical features that cover a particular area of the earth's surface. Such features may include lakes, park boundaries, buildings, city boundaries, or land uses. Polygons convey the most amount of information of the file types. Polygon features can measure perimeter and area.

Each of these geometries are linked to a row in a database that describes their attributes. For example, a database that describes lakes may contain a lake's depth, water quality, pollution level. This information can be used to make a map to describe a particular attribute of the dataset. For example, lakes could be coloured depending on level of pollution. Different geometries can also be compared. For example, the GIS could be used to identify all wells (point geometry) that are within one kilometre of a lake (polygon geometry) that has a high level of pollution.

Vector features can be made to respect spatial integrity through the application of topology rules such as 'polygons must not overlap'. Vector data can also be used to represent continuously varying phenomena. Contour lines and triangulated irregular networks (TIN) are used to represent elevation or other continuously changing values. TINs record values at point locations, which are connected by lines to form an irregular mesh of triangles. The face of the triangles represent the terrain surface.

Advantages and disadvantages

There are some important advantages and disadvantages to using a raster or vector data model to represent reality:

- Raster datasets record a value for all points in the area covered which may require more storage space than representing data in a vector format that can store data only where needed.
- Raster data is computationally less expensive to render than vector graphics
- There are transparency and aliasing problems when overlaying multiple stacked pieces of raster images
- Vector data allows for visually smooth and easy implementation of overlay operations, especially in terms of graphics and shape-driven information like maps, routes and custom fonts, which are more difficult with raster data.
- Vector data can be displayed as vector graphics used on traditional maps, whereas raster data will appear as an image that may have a blocky appearance for object boundaries. (depending on the resolution of the raster file)
- Vector data can be easier to register, scale, and re-project, which can simplify combining vector layers from different sources.
- Vector data is more compatible with relational database environments, where they can be part of a relational table as a normal column and processed using a multitude of operators.
- Vector file sizes are usually smaller than raster data, which can be tens, hundreds or more times larger than vector data (depending on resolution).
- Vector data is simpler to update and maintain, whereas a raster image will have to be completely reproduced. (Example: a new road is added).
- Vector data allows much more analysis capability, especially for "networks" such as roads, power, rail, telecommunications, etc. (Examples: Best route, largest port, airfields connected to two-lane highways). Raster data will not have all the characteristics of the features it displays.

Non-spatial data

Additional non-spatial data can also be stored along with the spatial data represented by the coordinates of a vector geometry or the position of a raster cell. In vector data, the additional data contains attributes of the feature. For example, a forest inventory polygon may also have an identifier value and information about tree species. In raster data the cell value can store attribute information, but it can also be used as an identifier that can relate to records in another table.

Software is currently being developed to support spatial and non-spatial decision-making, with the solutions to spatial problems being integrated with solutions to non-spatial problems. The end result with these flexible spatial decision-making support systems (FSDSSs) is expected to be that non-experts will be able to use GIS, along with spatial criteria, and simply integrate their non-spatial criteria to view solutions to multi-criteria problems. This system is intended to assist decision-making.

Popular GIS file formats

Raster formats

- ADRG - National Geospatial-Intelligence Agency (NGA)'s ARC Digitized Raster Graphics
- BIL - Band Interleaved by Line (image format linked with satellite derived imagery)
- CADRG - National Geospatial-Intelligence Agency (NGA)'s Compressed ARC Digitised Raster Graphics (nominal compression of 55:1 over ADRG)
- CIB - National Geospatial-Intelligence Agency (NGA)'s Controlled Image Base (type of Raster Product Format)
- Digital raster graphic (DRG) - digital scan of a paper USGS topographic map
- ECRG - National Geospatial-Intelligence Agency (NGA)'s Enhanced Compressed ARC Raster Graphics (Better resolution than CADRG and no color loss)
- ECW - Enhanced Compressed Wavelet (from ERDAS). A compressed wavelet format, often lossy.
- Esri grid - proprietary binary and metadataless ASCII raster formats used by Esri
- GeoTIFF - TIFF variant enriched with GIS relevant metadata

- IMG - ERDAS IMAGINE image file format
- JPEG2000 - Open-source raster format. A compressed format, allows both lossy and lossless compression.
- MrSID - Multi-Resolution Seamless Image Database (by Lizardtech). A compressed wavelet format, allows both lossy and lossless compression.
- netCDF-CF - netCDF file format with CF medata conventions for earth science data. Binary storage in open format with optional compression. Allows for direct web-access of subsets/aggregations of maps through OPeNDAP protocol.

Vector formats

- AutoCAD DXF - contour elevation plots in AutoCAD DXF format (by Autodesk)
- Cartesian coordinate system (XYZ) - simple point cloud
- Coverage - Esri's closed, hybrid vector data storage strategy. Legacy ArcGIS Workstation / ArcInfo format with reduced support in ArcGIS Desktop lineup
- Digital Line Graph (DLG) - a USGS format for vector data
- Enterprise Geodatabase - Esri's geodatabase format for use in an RDBMS
- File Geodatabase - Esri's file-based geodatabase format, stored as folders in a file system
- Geography Markup Language (GML) - XML based open standard (by OpenGIS) for GIS data exchange
- GeoJSON - a lightweight format based on JSON, used by many open source GIS packages
- GeoMedia - Intergraph's Microsoft Access based format for spatial vector storage
- ISFC - Intergraph's MicroStation based CAD solution attaching vector elements to a relational Microsoft Access database
- Keyhole Markup Language (KML) - XML based open standard (by OpenGIS) for GIS data exchange
- MapInfo TAB format - MapInfo's vector data format using TAB, DAT, ID and MAP files
- National Transfer Format (NTF) - National Transfer Format (mostly used by the UK Ordnance Survey)

- Personal Geodatabase - Esri's closed, integrated vector data storage strategy using Microsoft's Access MDB format
- Shapefile - Esri's open, hybrid vector data format using SHP (shape format), SHX (shape index format) and DBF (attribute format) files
- Simple Features - Open Geospatial Consortium specification for vector data
- SOSI - a spatial data format used for all public exchange of spatial data in Norway
- Spatial Data File - Autodesk's high-performance geodatabase format, native to MapGuide
- TIGER - Topologically Integrated Geographic Encoding and Referencing
- Vector Product Format (VPF) - National Geospatial-Intelligence Agency (NGA)'s format of vectored data for large geographic databases

Grid formats (for elevation)

USGS DEM - The USGS' Digital Elevation Model

DTED - National Geospatial-Intelligence Agency (NGA)'s Digital Terrain Elevation Data

GTOPO30 - Large complete Earth elevation model at 30 arc seconds

SDTS - The USGS' successor to DEM

Other formats

Binary Terrain (BT) - The Virtual Terrain Project's Binary Terrain format

Dual Independent Map Encoding (DIME) – A historic GIS file format, developed in the 1960s

Well-known text (WKT) – A text markup language for representing feature geometry, developed by Open Geospatial Consortium.

Well-known binary (WKB) - Binary version of Well-known text.

World file - Georeferencing a raster image file (e.g. JPEG, BMP)

To georeference something means to define its existence in physical space. Georeferencing may be applied to any kind of object or structure which can reasonably be related to a geographical location, such as Points of Interest, roads, places, bridges, or buildings. A geographical location represents a spatial reference within a geodetic reference system such as WGS-84. By relating an object to a location, it is possible to uniquely identify the object in physical space. Examples would include establishing the correct position of an aerial photograph within a map or finding the geographical coordinates of a place name or street address (Geocoding).

This procedure is thus imperative to data modeling in the field of geographic information systems (GIS) and other cartographic methods. When data from different sources need to be combined and then used in a GIS application, it becomes essential to have a common referencing system. This is brought about by using various georeferencing techniques. Most georeferencing tasks are undertaken either because the user wants to produce a new map or because they want to link two or more different datasets together by virtue of the fact that they relate to the same geographic locations.

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