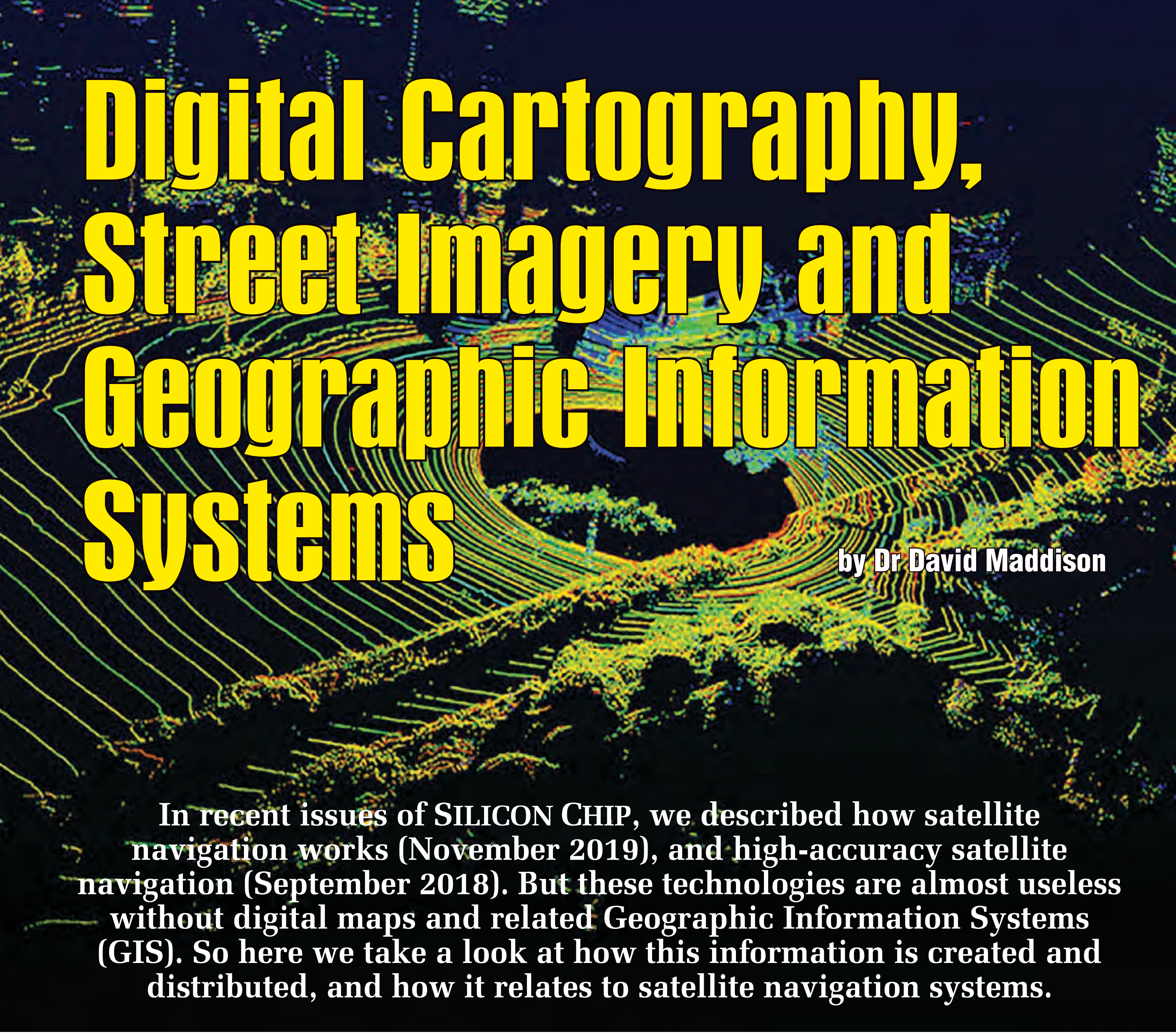


Digital Cartography, Street Imagery and Geographic Information Systems

by Dr David Maddison

In recent issues of Silicon Chip, we described how satellite navigation works (November 2019), and high-accuracy satellite navigation (September 2018). But these technologies are almost useless without digital maps and related Geographic Information Systems (GIS). So here we take a look at how this information is created and distributed, and how it relates to satellite navigation systems.

Digital cartography, also known as digital mapping, is the process by which information is collected, compiled and formatted to produce maps in an electronic form. These can be used in a variety of applications, but most commonly they are used for everyday navigation tasks via smartphones or in-car navigation systems.

Digital maps can also be used to represent a variety of other information such as income levels, voting patterns, sales figures, disease outbreaks, pollution levels, agricultural productivity, soil types, rainfall or any of thousands of other metrics.

Technologies used to analyse, manipulate and acquire such data are referred to as Geographic Information Systems or GIS.

The history of modern mapping

In the past, such information was represented on paper maps, but those took a long time to produce, and could not be easily updated. It was also more difficult to overlay other data on paper maps compared to electronic systems.

One of the earliest attempts at using maps for spatial analysis was by physician John Snow in 1854, with his famous cholera map of the Broad Street area of London (Figs.1 & 2). This lead to the determination that one cholera outbreak was due to a contaminated public hand water pump. Removing the handle of the pump, rendering it inoperative, stopped the outbreak.

This followed on from French geographer Charles Picquet, who published a map in 1832 showing cholera death rates.

The data from the John Snow cholera map is sometimes used today in digital mapping training exercises.

Modern digital cartography has its origins in the late 1960s to 1970s (with certain applications as early as the 1950s), when computers were starting to become available with the large amount of memory and processing speed needed to produce digital maps.

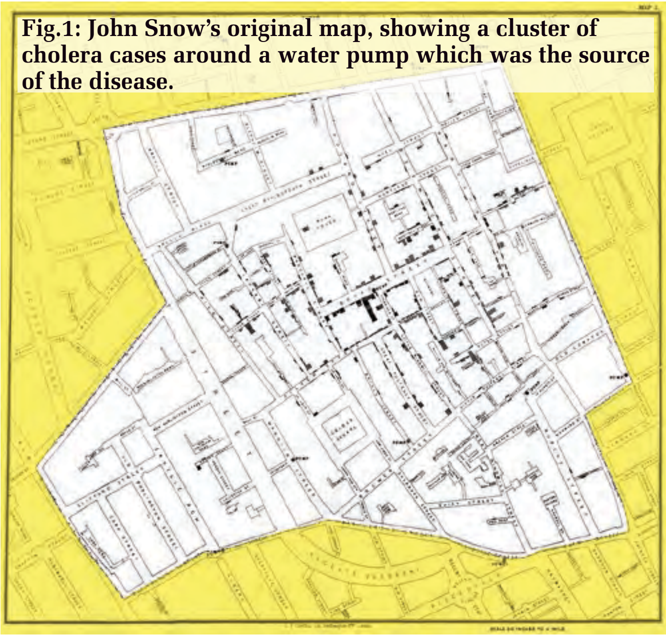


Fig.1: John Snow's original map, showing a cluster of cholera cases around a water pump which was the source of the disease.

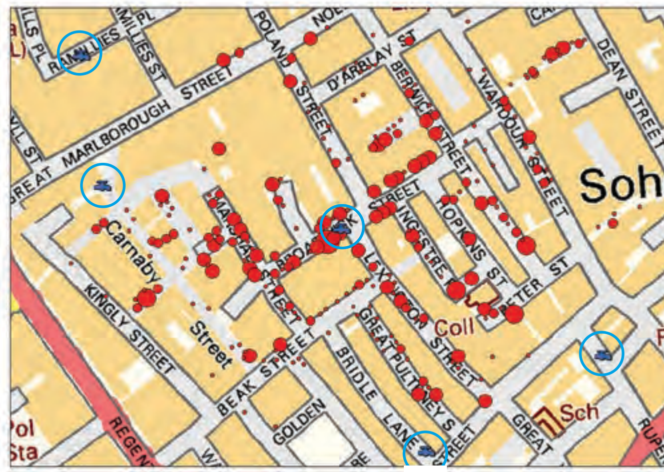


Fig.2: a portion of John Snow's data replotted on modern digital maps of the area by Dr Robin Wilson, clearly showing the position of the pumps (blue icons). The size of the red dots represents the number of cholera cases at a particular location. There are five pumps visible, but the disease outbreak is clustered around one.

Digital cartography was initially known as computer-assisted cartography. It preceded the speciality of Geographic Information Systems (GIS) involving the storage, retrieval, analysis and display of spatial data on a cartographic background, such as the modern version of John Snow's map shown in Fig.2.

Different types of map projections require the evaluation of complex mathematical formulae on a repeated basis, and this was an early advantage for the use of computers in cartography.

As early as the late 1950s, alphanumeric character line printers were used to make crude maps, with an approximate resolution of ten columns per inch across the page and six or eight rows per inch down the page.

Output quality continued to improve with the development of more advanced plotters through the 1960s and 1970s. Eventually, regular printers could produce high-resolution images and plotters became unnecessary. It also helped that monitors became capable of displaying high-resolution images.

Early digitisation of maps and aerial photos

Before the availability of GPS, digital cameras and computers were used to copy features from aerial photographs into digital maps. With the advent of computers, it became possible to digitise such maps or to directly digitise features from a photograph. Aerial and satellite photography is still used today in the production of maps.

An early example of such a digitising unit is the Kern ER34 (Fig.3), combined with the Kern PG2 photogrammetric stereo plotter (Figs.4 & 5). The stereo plotter was used to perform an analog transfer of data from stereo aerial photos to other materials, such as paper or to a computer, when fitted with an appropriate interface.

Thus it could produce mapping data by either analog or digital methods. The machine corrects for distortion in the photograph and plots the data onto a map, or sends digital data to a computer. Because of the stereo nature of the photos, elevation contours could be produced. This elevation data was also used to create a Digital Elevation Model (DEM) of the terrain in the digital age.

Fig.3: the Kern ER34 digitising unit from 1979 which used a Zilog Z80 microprocessor. It displayed coordinates on numerical LED displays and data was acquired from a digitising device like a Kern PG2 stereo plotter, connected via a TTL interface. Data could also be recorded to an external computer via RS-232.

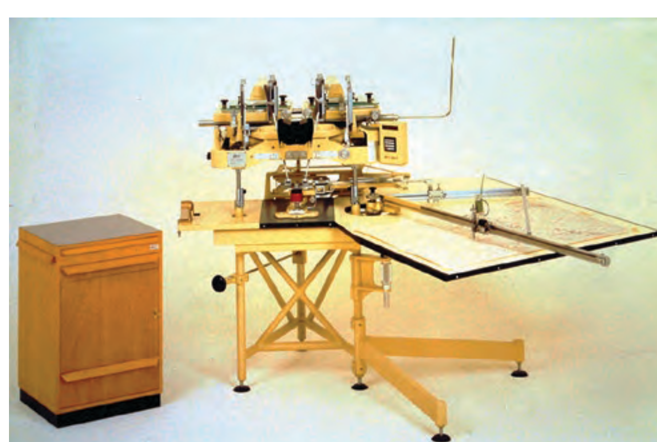


Fig.4: a Kern PG2 stereo plotting instrument. When fitted with rotary encoders, it could send data to the Kern ER34 digitising unit. Otherwise, it acted as a conventional stereo plotting device, thus straddling the old and new ways of mapping.

Fig.5: a photo from the "The Ontario Land Surveyor" of Winter 1979, showing the Kern PG2 stereo plotter connected to a Kern DC2-B Digitiser-Graphics Computer and an "automatic drafting table". Aspects of feature extraction from stereo photos were automated or semi-automated.

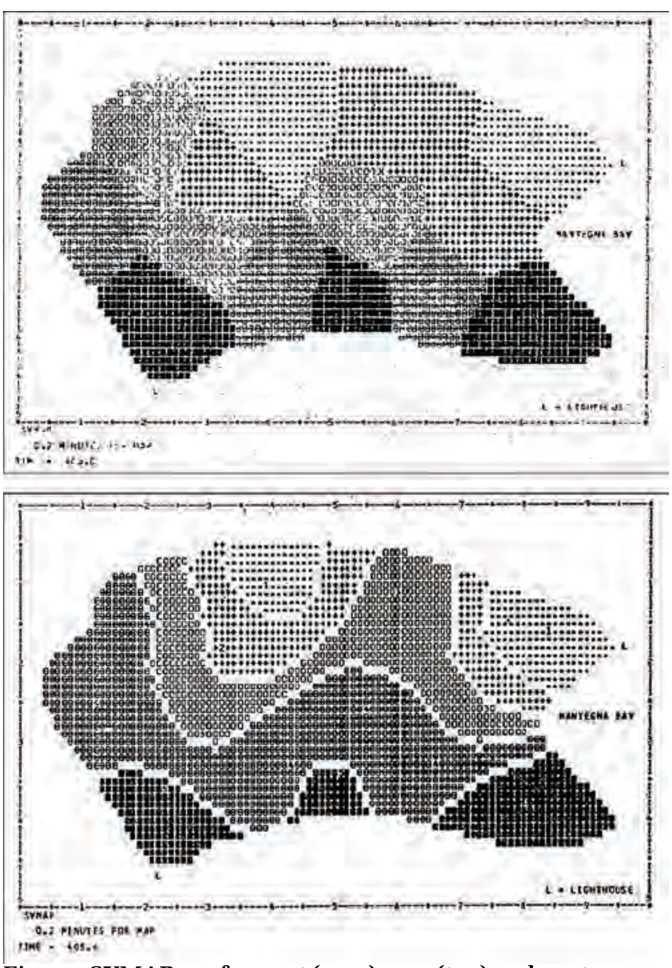


Fig.7: a SYMAP conformant (area) map (top) and contour map (bottom) from 1963. There are no true graphics involved; this map is made of characters printed on a line printer, some of which are overprinted to produce greyscales.

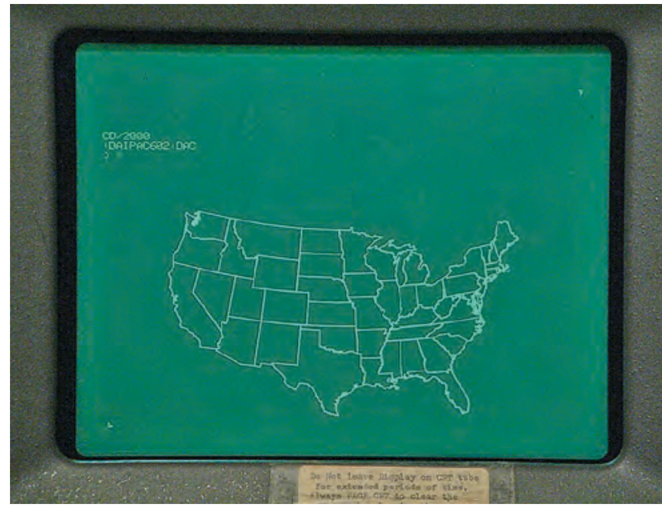


Fig.6: vector map data displayed on a Tektronics 4014 storage tube graphics terminal, released in 1972. Memory was expensive in early computers, so only the endpoints of the straight lines representing the vector elements are stored in computer memory. The lines drawn between them exist only as persistent images in the phosphor of the display. Source: David Gesswein of PDP8Online.

Before Google Maps, most of the world was mapped using stereo plotter machines such as these.

Digital map data could also be plotted or displayed on a video display unit such as a Tektronics graphics terminal (Fig.6), instead of plotting it on paper.

Map-making today

Today, maps are usually made straight from digital images such as aerial or satellite photos, or from remote sensing images, or other digital data such as GPS plots or LIDAR/radar data. These allow elevation to be fed directly into a

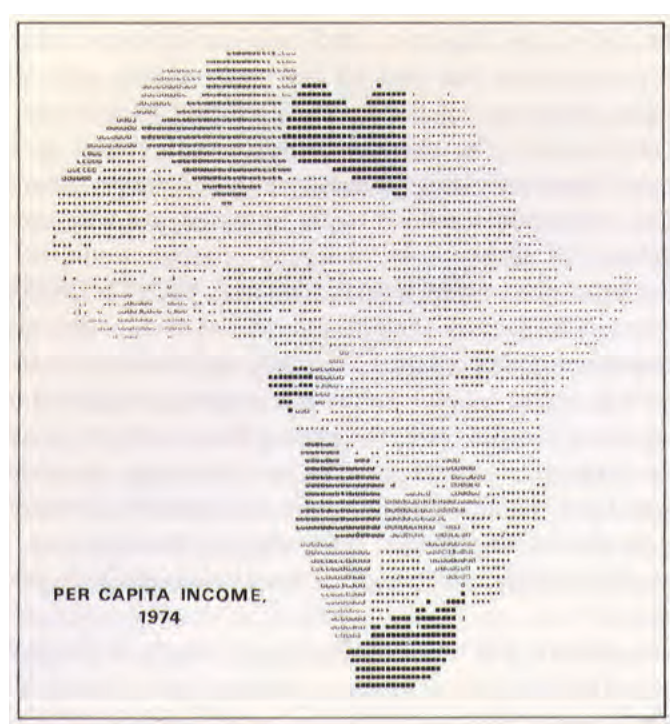


Fig.8: a map from 1974 showing income levels printed using alphanumeric characters on a line printer.

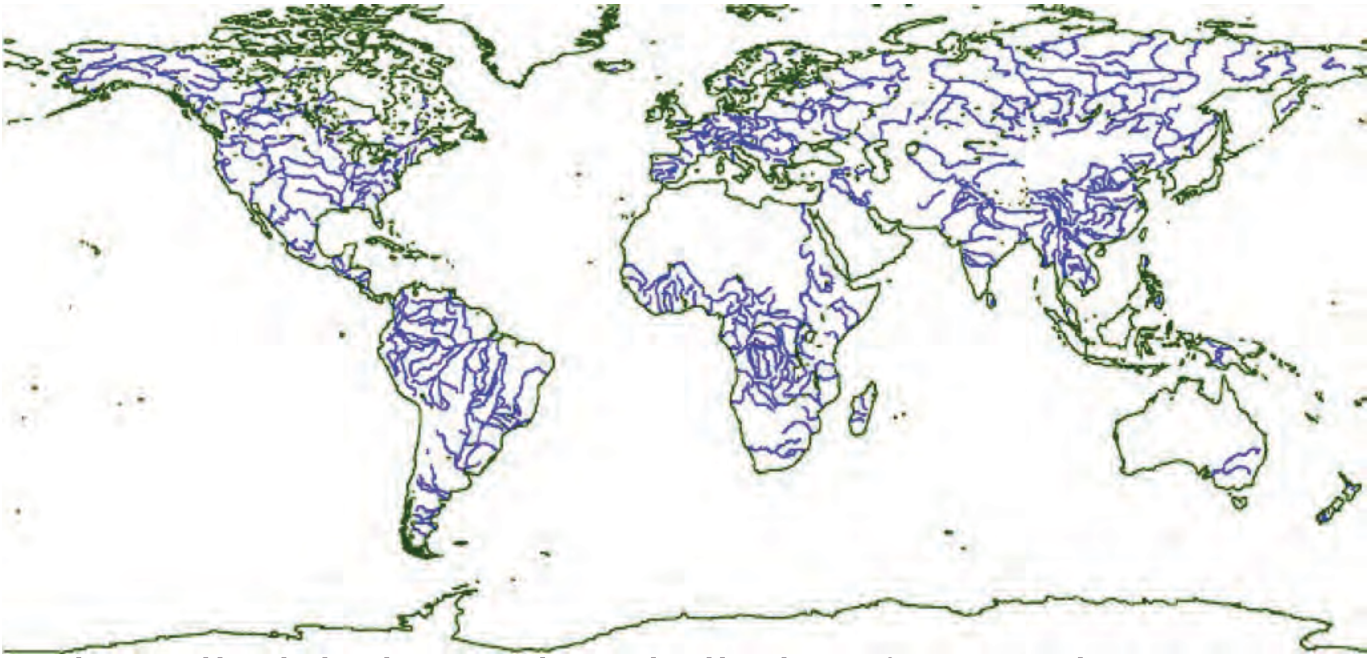


Fig.9: the CIA World Databank II, showing rivers but not political boundaries. Reference Gorny and Carter, 1987.

computer, avoiding numerous intermediate steps like manually "walking the land", as used to be done before aerial photography.

These days, the focus is very much on adding layers of information as in Geographic Information Systems (GIS), ie, building GIS databases.

SYMAP software

Howard Fisher invented the SYMAP (Synergistic Mapping) system in 1963. It was the first computer mapping system that could be used to analyse and produce maps of spatially distributed data (Figs.7 & 8). With the aid of grants and other individuals, he established the Harvard Laboratory for Computer Graphics and Spatial Analysis and developed SYMAP for release in 1966, along with other mapping systems.

The laboratory existed at Harvard University (in Cambridge, USA) from 1965 to 1991, and it pioneered early digital cartographic and geographical information systems (GIS). SYMAP became popular in the late 1960s because it

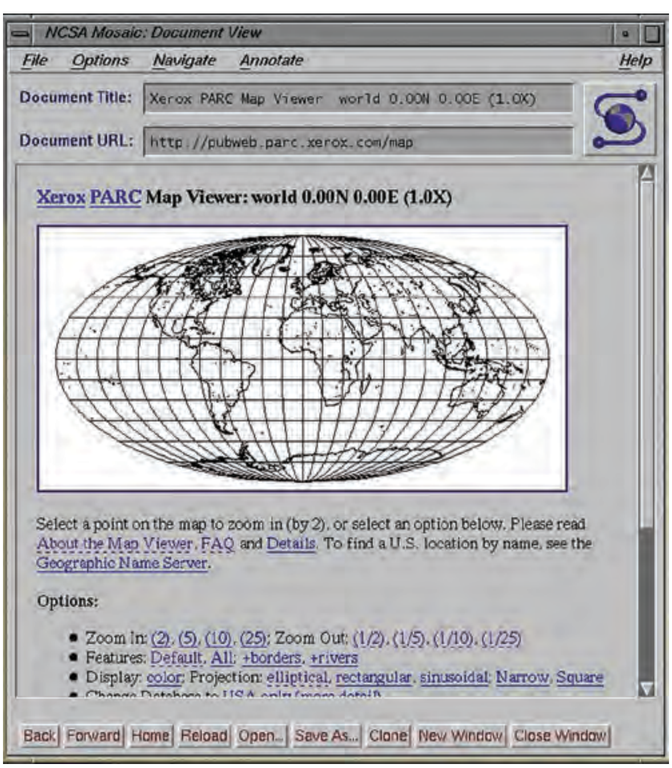


Fig.10: a Xerox PARC map view, as shown in the 1993 Mosiac browser.

The "godfather" of digital mapping

One of the little-known but important figures of digital mapping is Jack Dangermond. He founded the Environmental Systems Research Institute (Esri; www.esri.com/en-us/home) in California in 1969, which in 2014 had a 43% worldwide market share of Geographic Information System products, with ArcGIS Desktop being the main one.

The company has seen the transition from minicomputers to workstations, PCs, the internet, cloud computing and mobile devices. The company remains privately held by the Dangermond family.

It has survived despite popular mapping applications like Google because Google Maps is mostly consumer-oriented and Esri focuses on government, business and professional organisations and the highly specialised geospatial information they require. One of the recent major developments of Esri was the establishment of the Los Angeles GeoHub, as described in this article.

Their popular programs include ArcScan as an extension to ArcGIS Desktop, for raster to vector data conversion; ArcView, ArcEditor and ArcInfo are often mention in literature and have been renamed as Basic, Standard, and Advanced versions of ArcGIS Desktop.

Fig.11 (above): an early version of MapQuest from 1996, as displayed in the Netscape browser. Source: Computer History Museum.


Fig.12: a Google Street View car in Australia. Note the cameras on top of the mast and the two LIDAR devices beneath the blue camera housing.

could produce inexpensive maps with the standard technology of the time, which were useful although of relatively low quality.

The output was produced on a line printer which drew character-based "graphics" by techniques such as overprinting multiple characters to produce dark areas, or with less overprinting to produce light areas, thus creating a crude type of greyscale.

CIA World Databanks I and II

The CIA World Databank I was first discussed in 1966. You can view the original memo online at siliconchip.com.au/link/aay6

The original proposal was for a map of the world which would require 50,000 data points.

The CIA World Databank II was released in 1985, and was a vector map of land outlines, rivers and political boundaries of the world (see Fig.9). The maps comprise five million data points and are simple black and white images. They have been typically used as a basis for composing other maps. This map data can be downloaded from siliconchip.com.au/link/aay7

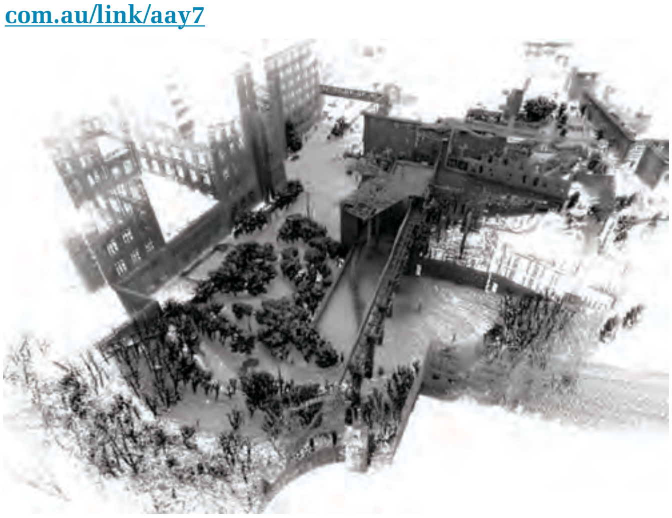


Fig.13: a typical image as produced by the company "Real Earth" using a Velodyne LIDAR "Puck LITE", the same type said to be used on Google Street View cars. This 3D imagery can be used for guidance by autonomous vehicles such as cars and drones. Google also produces photographic imagery and other data.

If you want to see some beautiful examples of CIA Cartography, visit the following links: siliconchip.com.au/link/aay8 and siliconchip.com.au/link/aay9

The Xerox PARC map viewer

The Xerox PARC (Palo Alto Research Center) Map Viewer was the first online map released via the then-young World Wide Web in 1993. It was the first map database to be shared online (see Fig.10).

This was mainly an experiment in interactive information retrieval, rather than a product that could be used for serious navigation. The maps were static images and could not be zoomed or panned, as we are now used to with products like Google Maps.

MapQuest

MapQuest followed on from the Xerox PARC Map Viewer and was established as an online commercial web service in 1996 (Fig.11). Unlike the Xerox Map Viewer, the maps could be zoomed and panned. The company and its predecessors had been in business since the 1960s, and these early web maps were based on digital maps and codes they produced in the 1980s.

Google Earth

Google Earth provides a continuous view of the whole Earth based on satellite and aerial imagery. It has its origins in the 1990s with a computer gaming company called Intrinsic Graphics. It was used as a demonstration platform

Fig.14: a Velodyne VLP-16 LIDAR device, as used on Google cars.

Fig.15: an Apple Maps vehicle near Philadephia, USA. There are thought to be 12 cameras plus LIDAR sensors in the pod on the roof. Source: David Levy.

Fig.16: the Mapillary coverage of Australia.

for 3D gaming software libraries, but the company board wanted to focus on games and not mapping, so created a new company called Keyhole Inc.

They used the technology to stream map databases over the internet. The company was highly successful, and in 2004, Google found that one-quarter of its searches were geospatial in nature, so they acquired that company.

Google now acquires the imagery from several sources, and the maps are available at various resolutions, depending on the area of the Earth covered, at pixel resolutions from 15cm to 15m. Depending on the location, Google Earth can also provide 3D views of certain buildings and also historical imagery.

Google Street View (see below) is now integrated into Google Earth. It also now incorporates 3D imagery of the ocean floor.

Google Maps

Google Maps is the digital mapping service with which most people are likely to be familiar. It is installed on most smartphones and also accessible via the web on desktop and notebook PCs. It shows street maps, aerial/satellite imagery or a hybrid view which combines both.

High-resolution imagery, where available, is taken from low-flying aircraft at an altitude of 240-640m (800-2100 feet). Other imagery is from satellites at slightly lower resolutions. The map data is mostly purchased or leased from aerial imagery producers or copyright holders.

What most people probably do not know is that Google Maps has its origins in a Sydney-based company, Where 2 Technologies. Their software program called Expedition was developed by Danish brothers Lars and Jens Rasmussen and Australians Noel Gordon and Stephen Ma. Google purchased the rights to this software in 2004.

There is an interesting video about Google Maps by an Australian student, Ruby Cogan, titled *"Google Maps - The Australian Co-Inventor, Noel Gordon"* at **https://youtu.be/Es19FvYYI_0**

Google Street View

Google Street View cars have been imaging and mapping Australian streets since 2008. The latest version of Google cars have seven cameras (previous versions had fifteen) – see Fig.12. The current cameras have a resolution of 20MP, and the images taken are mathematically stitched together to produce spherical images.

You can therefore click just about anywhere in Google Maps and see what the street looks like, at that location, from just about any angle.

In addition to those cameras used for general street imagery, the cars also have two high-definition cameras facing left and right, which read street numbers, business names and other written information to produce map metadata.

Apart from cameras, the cars are also said to have two Velodyne VLP-16 "Puck LITE" LIDAR sensors (Figs.13 & 14). LIDAR is akin to radar using lasers. These are presumably used to build a 3D model of the streetscape, perhaps for use by self driving-cars as well as mapping purposes. Naturally, the cars also carry GPS receivers so that they know where each set of images was taken.

For more information on those LIDAR units, see the video titled *"Velodyne Alpha Puck Sensor"* at **https://youtu.be/KxWrWPpSE8I**

Apple Maps and Look Around

Apple has a mapping product like Google Maps, and has also introduced a product similar to Google Steet View called Apple Look Around. They started imaging Australian cities

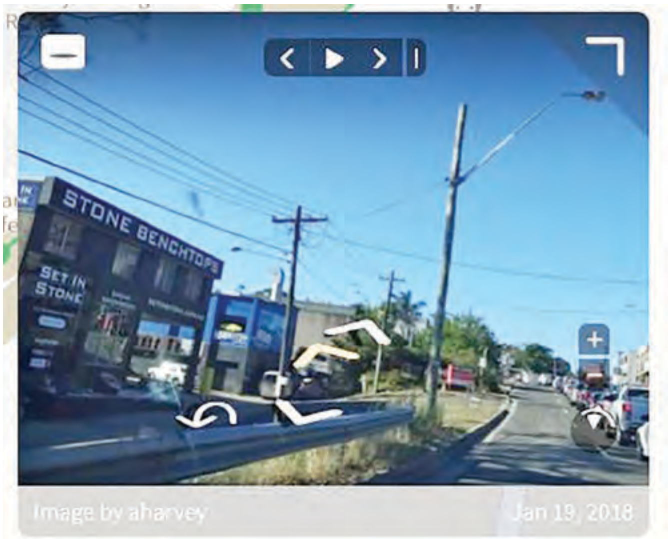


Fig.17: an example of imagery available from Mapillary.

Fig.18: an OpenStreetMap view of lower Manhattan, USA, showing the detail available. These maps are made by ordinary people walking or driving around.

in November 2019 (Fig.15) and are expected to be finished by the end of 2020. A list and schedule for Australian image collection can be seen at **siliconchip.com.au/link/aaya**

OpenStreetMap

OpenStreetMap is a volunteer collaborative project to provide free maps of the whole world. You can participate in digital mapping yourself by contributing to the OpenStreetMap project at **siliconchip.com.au/link/aayb**

There are many ways of contributing, including walking or driving routes, geocoding information such as street numbers, and examining and entering data from out-of-copyright maps.

OpenStreetCam and Mapillary imagery

It is also possible to contribute street imagery through unrelated projects such as Mapillary (**www.mapillary.com/** – see Figs.16 & 17) or OpenStreetCam (**https://openstreetcam.org** – see Fig.18). There are iOS and Android apps for both of these services.

Digitising old maps

There is a great deal of valuable information in old maps, such as the location of buildings, roads or property boundaries which might no longer exist. So there are efforts underway all over the world to digitise them.

At the most basic level, historical maps can be scanned just like a photograph. The resulting images can then be made available online for computers and smartphones.

Georeferencing is the process of associating a map image with a precise physical location, so that it can be used with a GPS enabled program (Figs.19 - 22). When georeferencing an old map, it is typically necessary to use four points and to know which projection system was used to draw the map. Of course, the original map also must be checked to ensure it is accurate.

Another way old maps can be used is to compare them with modern maps or satellite imagery once they have been georeferenced.

Suppose you had an old treasure map or a historical map of some town, or wartime battle. Assuming it was accurately drawn, it could be used as a raster map (more on raster maps later) in a GPS-enabled program or App once certain geographic features in the map were used to georeference it.

The British Library has a crowd-sourcing project that you can participate in to help georeference historical maps in its collection; see **www.bl.uk/georeferencer/**

An example of where an old map has been digitised and georeferenced for historical interest, and where that map can be compared with a new OpenStreetMap version interactively, can be seen at **siliconchip.com.au/link/aayc**

That site also includes a description by Koko Alberti of how the digitised map was produced, and a comparison with the modern map (see Fig.20). You can also view maps of numerous cities worldwide in this manner at the following website: **siliconchip.com.au/link/aayd**

Also see the related video titled *"HyperCities NewYork-Collection"* at **https://youtu.be/-3J8uSRHwX8**

The free smartphone App for Android and iPhone called "GPS on ski map" by Maprika can be used to georeference and view old scanned maps on your device. It is not just for ski maps as the name implies. See the video on how to do this titled *"Secrets of how we use GPS with old maps on your phone!"* at **https://youtu.be/qvI71ihRV-o**

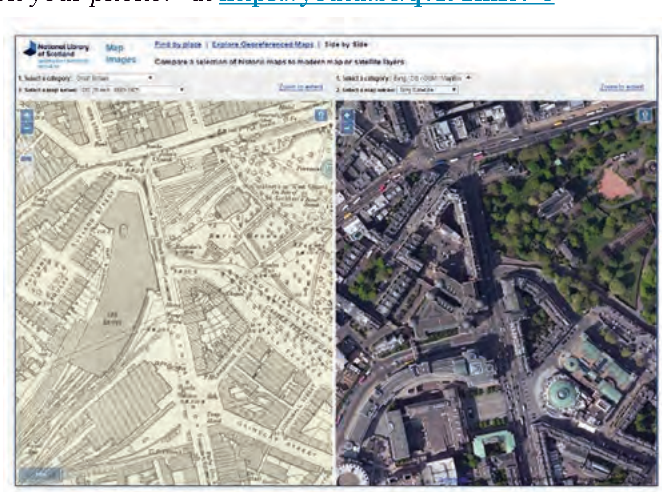


Fig.19: a comparison of a georeferenced historical map and modern satellite imagery, from the collection of the National Library of Scotland.

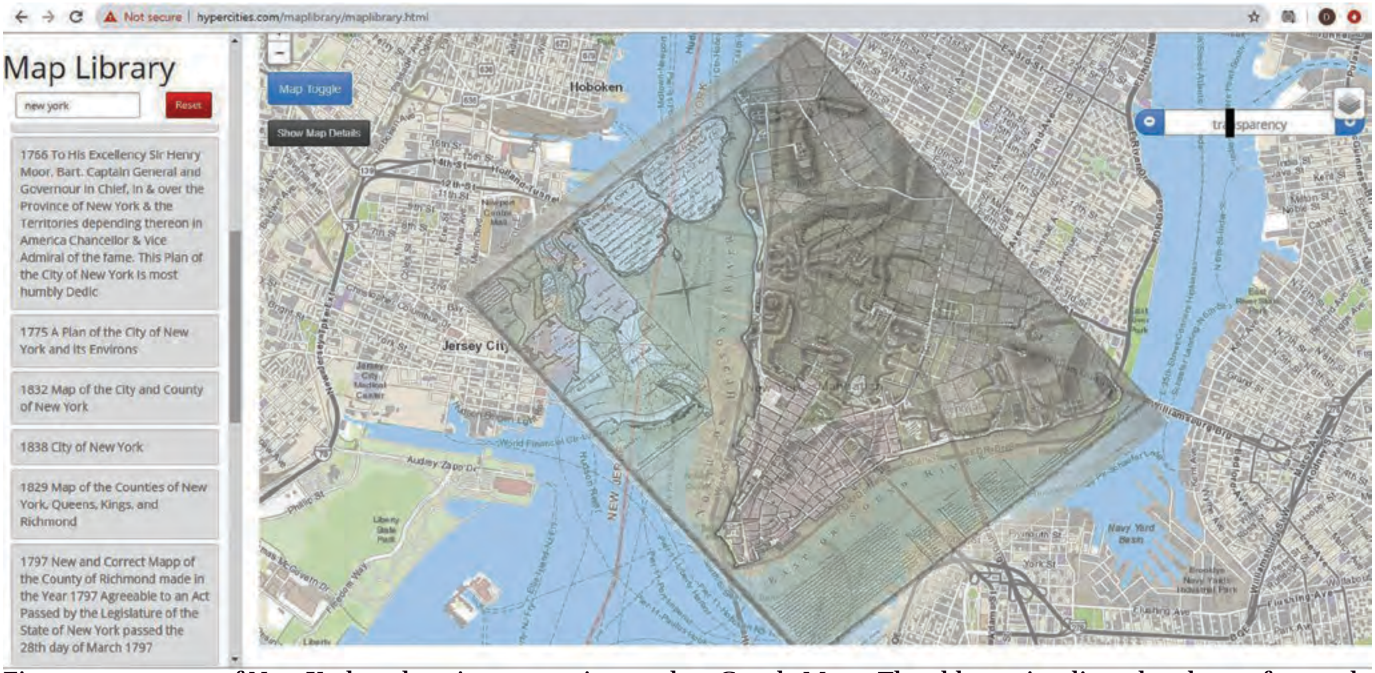


Fig.20: a 1775 map of New York and environs superimposed on Google Maps. The old map is adjusted and georeferenced, so it fits accurately on the modern map. The level of transparency of the old map can be adjusted.

Several maps are available for that App, including for Australia, or you can scan or acquire your own.

Another free App for viewing old maps is Old Maps Online (www.oldmapsonline.org/), available on the web or for iOS or Android. It indexes over 400,000 old maps including many old Australian maps. On the web interface, old maps can be overlaid with modern maps with varying transparency to best see the differences (Fig.21 & 22).

Apart from historical interest, it is also important to digitise old maps which contain property boundaries for government administration or the location of underground utilities (see our article on mapping utilities in the February 2019 issue – siliconchip.com.au/Article/12334).

This information can still be relevant even if it is one hundred or more years old. Such maps may be georeferenced and vectorised (see below) to bring them into conformity with modern map databases.

Raster vs vector map data

Map data may be represented as either raster data or vector data. Raster (or bitmap) graphics are like a photograph or other image, where the data is represented by a grid of individual pixels or picture elements.

In contrast, vector maps (which are the more typical representation for road maps) are shape-based, which means that the image elements are made up of points, lines and polygons (representing areas). Instead of pixels, the elements of vector data are known as vertices (coordinates) and paths (lines joining vertices). In other words, it's like "joining the dots" (see Fig.23).

With vector maps, it is only necessary to record data points where a change occurs. For example, a straight road between two points can be described with just two data points regardless of its length. The software fills in the straight line between the points, whereas a raster map would require hundreds of points.

Thus vector maps are much more memory-efficient than raster maps due to fewer data points, although raster maps require less computational power to render as they are displayed "as is" in their final form. With vector maps, the

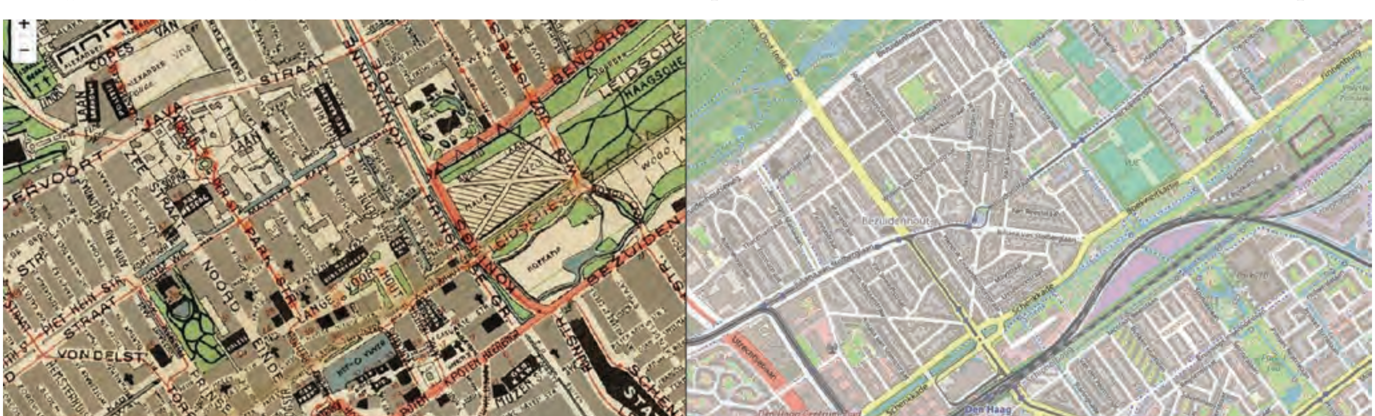


Fig.21: an old wartime map of The Hague (left) compared with the modern OpenStreetMap form (right). In the interactive version of the map, the split between the two can be moved so changes between old and new maps can be readily seen. The old map is a digitised raster image while the OpenStreetMap version consists of vectors.

Fig.22: an old map of the Lane Cove area of Sydney overlaid onto a modern map, generated by www.oldmapsonline.org/

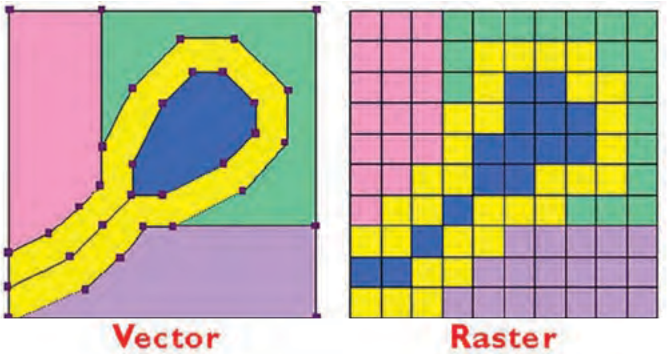


Fig.23: a comparison of vector and raster representation of map data. At higher zoom levels, raster graphics appear chunky, but vector graphics mostly maintain their appearance. Text is a common everyday type of vector graphics. In a modern word processor, the text remains smooth regardless of the font size selected, even though the data comes from the same font file.

map has to be regenerated from data points every time it is displayed.

To avoid a "pixelated" appearance, raster data must be of a sufficiently high resolution. In contrast, vector maps appear smooth at any resolution, assuming there is be a sufficient number of data points to represent whatever is being portrayed accurately.

Both raster and vector map data have specific advantages and disadvantages. Apart from the computational resources mentioned above, it is not practical to represent certain forms of data in vector form.

For example, satellite or other imagery is best represented in raster form.

For other forms of maps, especially when they involve lines, curves and shapes such as roads, borders, boundaries of various kinds, it is very efficient to represent them in vector form.

In some cases, raster and vector images might be combined, such as when a vector street map is overlaid on a satellite photo.

Once a map is vectorised, additional layers of information can be easily added. For example, where buildings are represented, the age or function of a building could be stored in the database and then it would be possible to only display on a map buildings only of a certain age or function.

Download free Australian government maps

Some government agencies offer free digital topographic maps. Australian topographic maps at 1:50 000, 1:100 000, 1:250 000 and 1:1 million scales can be downloaded for free from Geoscience Australia; see: siliconchip.com.au/link/aayg

Free digital maps are also available for NSW at resolutions as high as 1:25,000, see: siliconchip.com.au/link/aayh

Queensland maps can be obtained for free at: siliconchip.com.au/link/aayi

ACT maps can be procured at: siliconchip.com.au/link/aayj

Other states and territories appear not to offer free digital maps, but there are free maps for Victoria (soon to be expanded to other states) at: www.getlost.com.au/

Free topographic digital maps for New Zealand are available at: siliconchip.com.au/link/aayk

This is the basis of Geographic Information Systems (see below).

Geographic Information Systems (GIS)

A Geographical Information management System is intended to capture, analyse and present location-dependent information on a map (see Fig.25). This allows better decisions to be made, based on geography. Examples of where this can be useful are for retailers to figure out where to put a new store or for police forces can discover patterns in criminal activity.

When the data is presented on a map, it is much easier to understand and interpret than when presented as a list. Information is typically shown in the form of "layers" of map data (see Fig.27).

Examples of layers might include parcels of land, zoning, topography, demographics, location of houses, office

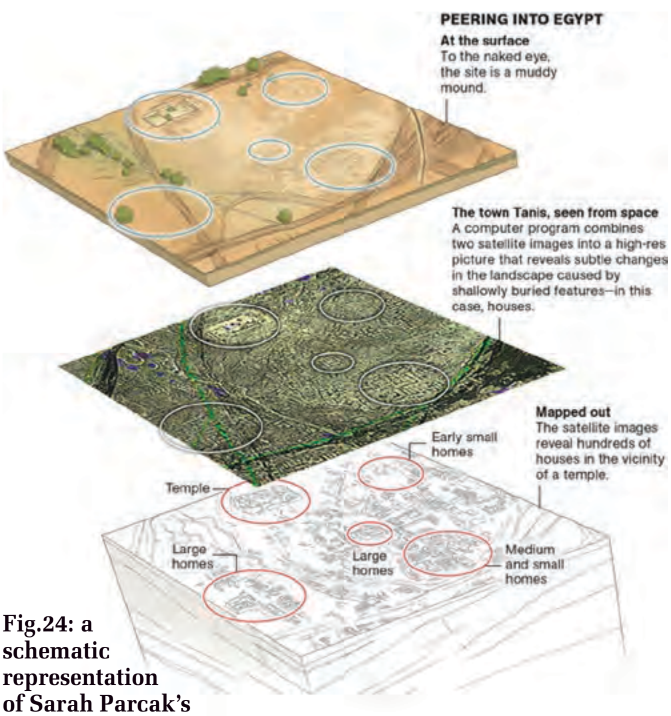


Fig.24: a schematic representation of Sarah Parcak's discovery of Tanis in Egypt, showing how faint surface features visible only from satellite revealed an ancient township.

Fig.25: a Google Maps view of the northern beaches area of Sydney, where the Silicon Chip office is located. This combines two different 'layers': a satellite view as a raster image, and a street map with names as a vector image. In geographic information systems, many different layers can be added.

buildings and shops etc.

Alone, individual items of information might be meaningless, but when combined, relationships can be seen to emerge.

Google Earth and satellite-based archaeology

A new area of archaeology has begun, with high-resolution Google Earth imagery being used to discover new archeological sites. This imagery is used by both amateurs and professionals, although sadly it is also being used by criminals to loot such sites.

One of the pioneers of using satellite imagery for archaeological purposes is Dr Sarah Parcak. (See Fig.24). She discusses her work in the following videos:

- *"The Future of Archaeology: Space-based Approaches"* (2001) at https://youtu.be/n_KZLsO3XYY
- On the looting of archeological sites, *"Culture Heroes: Sarah Parcak | Nat Geo Live"* at https://youtu.be/RP9nuUg0Hw0
- *"The Greatest Living Space Archaeologist - Sarah Parcak"* at https://youtu.be/p89DCFK6nH0

She has made numerous discoveries. More of her work and videos can be seen at: www.sarahparcak.com/

Moving to the archaeology of more recent structures, there is a video about using old scanned maps with Google Earth overlays to find the locations of old homes. It is titled *"Finding old homes using Google Earth overlays"* and can be viewed at https://youtu.be/6sjIbIpyPmM

This video is from the USA, but the techniques demonstrated are just as relevant for Australia.

Ocean floor composition

Digital maps are not just limited to land. They can also

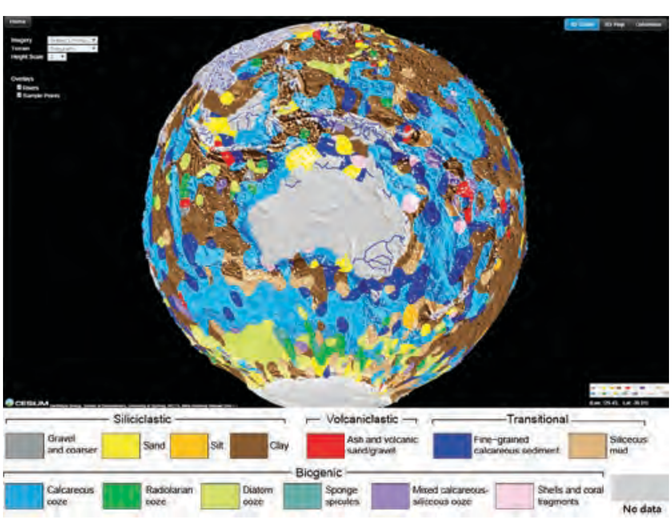


Fig.26: the first digital seafloor map, produced in 2015 by Dr Adriana Dutkiewicz and colleagues, showing the distribution of sediments based on 14,500 samples. Source: EarthByte Group, School of Geosciences, University of Sydney and National ICT Australia (NICTA), Australian Technology Park, NSW.

Free open-source mapping software

Apart from commercial offerings, you can use some free Geographic Information Systems as follows:

- QGIS: www.qgis.org/en/site/
- GDAL: https://gdal.org/
- gvSIG: www.gvsig.com/en
- Whitebox GAT: siliconchip.com.au/link/aayl
- SAGA: www.saga-gis.org/en/
- GRASS: https://grass.osgeo.org/
- MapWindow: www.mapwindow.org/
- ILWIS: siliconchip.com.au/link/aaym
- GeoDa: siliconchip.com.au/link/aayn
- uDig: http://udig.refractions.net/
- OpenJUMP: www.openjump.org/
- DIVA-GIS: www.diva-gis.org/
- OrbisGIS: http://orbisgis.org/

There is an online georeferencing tool called Georeferencer at: www.georeferencer.com/

Instructions on how to georeference in QGIS are at: siliconchip.com.au/link/aayo and also see siliconchip.com.au/link/aayp indicate seafloor composition. The first digital map showing seafloor composition was produced in Australia (see Fig.26). This revealed sediment distribution to be significantly different and more complex than indicated in earlier hand-drawn maps. You can view an interactive 3D version of this map at siliconchip.com.au/link/aaye

Digital maps of off-earth locations

Google has added digital maps and imagery for the Earth's moon and other planets and moons, as well as views of the interior of the International Space Station (ISS). The feature is hard to find so go to www.google.com.au/maps and select "Satellite View", then zoom out as far as possible using the "-" zoom control.

On the left, you will then see a panel enabling you to view digital maps and imagery of Mercury, Venus, Earth, the ISS, the Moon, Mars, Ceres (a dwarf planet), Io, Europa, Ganymede, Callisto (moons of Jupiter), Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Iapetus (moons of Saturn), Pluto and Charon (moon of Pluto).

You can also see images of the universe at Google Sky (www.google.com/sky/).

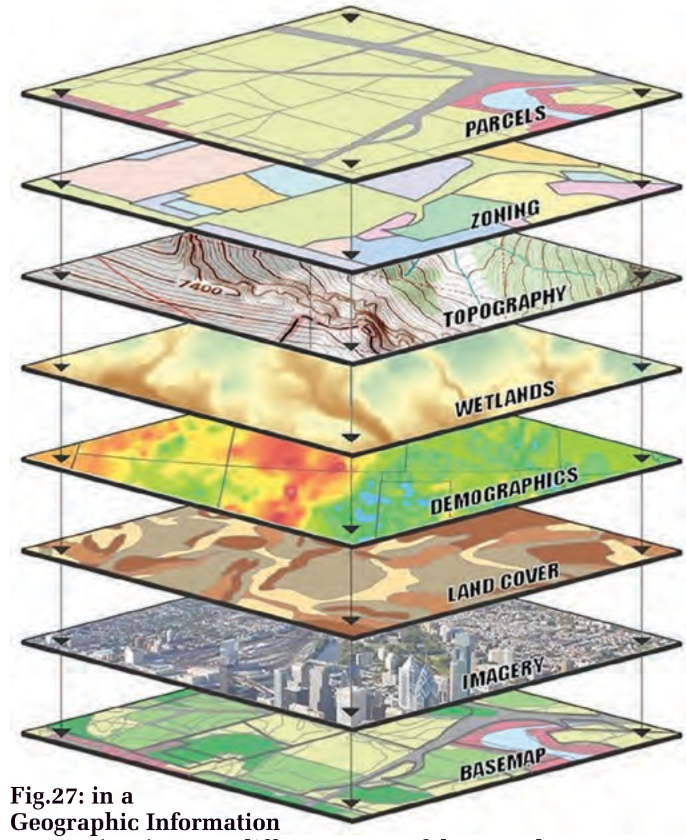


Fig.27: in a Geographic Information System (GIS), many different types of data can be combined to reveal spatial trends and to show how different types of features relate to each other.

SLAM (Simultaneous Localisation and Mapping)

SLAM is a method by which autonomous vehicles or other electronic mapping devices can map caves, mines or other planets. The vehicles which can use this technique include robot vacuum cleaners and lawnmowers, unmanned aerial vehicles (UAVs), unmanned underwater vehicles (UUVs), underground vehicles and space vehicles.

This technique can also be used with handheld 3D mobile mapping systems such as the ZEB devices or Hovermap (see below). In all cases, it is possible to simultaneously map a location and locate the device itself within that mapped area.

A SLAM device may use sensors such as ultrasonic rangefinders, LIDAR (light detection and ranging), radar and other technologies to map the surrounding environment.

SLAM provides 3D maps both indoors and outdoors in real-time by the use of sensors.

When a GPS signal is not available, a SLAM device can establish its position with the use of an inertial measurement unit, which contains three-axis accelerometers and gyroscopes (and possibly magnetometers), to provide data for a relative position fix.

To provide maximum accuracy with SLAM, it is desirable to "close the loop", ie. return to the starting point, so that the mapping algorithm can correct for any drift or slippage of the calculated position.

The China GPS offset problem

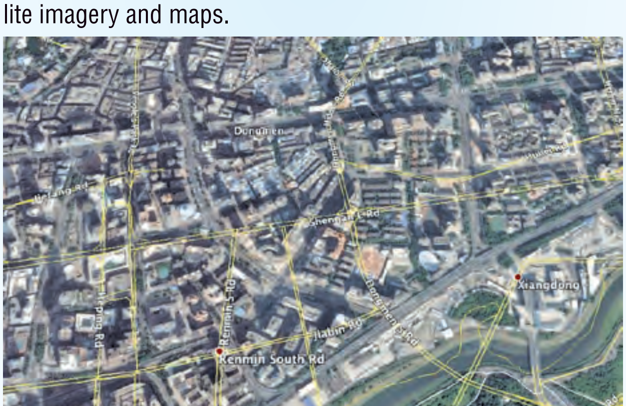
For reasons supposed linked to national security, mapping and other geographic data in China is under state control and many GPS equipped cameras won't geotag photos in China (as I experienced myself, with a Panasonic camera).

Crowd-sourced mapping such as Open Street Maps is illegal in China (but happens anyway) and there is a random offset between the position as determined by a GPS receiver and official Chinese street maps, of 100-700m (see below).

Street maps supplied under Chinese Government control use a unique coordinate (datum) system known as GCJ-02 that contains random offsets from real coordinates, with the English name of "Topographic map non-linear confidentiality algorithm". The rest of the world mostly uses WGS-84 or a similar real coordinate system.

To make GPS usable in China, GCJ-02 coordinates will work with GCJ-02 maps, but there is no direct correspondence with WGS-84 coordinates (the real position). Despite the secrecy of the algorithm behind GCJ-02, it has been reversed-engineered by various people, and there are open-source projects to convert between GCJ-02 and WGS-84.

Google Earth and Google Maps intended for use outside China will not display correctly in China due to this offset. Still, a version of Google Maps made in conformity with Chinese laws for use in China uses the GCJ-02 datum and works for both satellite imagery and maps.



A comparison of real satellite imagery and official Chinese maps (overlaid in yellow), showing the lack of correspondence of the map with reality.
Source: *https://geoawesomeness.com*

Fig.28: a drone with the Hovermap payload attached (the black box at the bottom with a white LIDAR device). Image courtesy CSIRO.

SLAM technology can be used for mapping underground structures including tunnels, caves, mines and more. This can be done using a handheld scanning device or with a similar device carried by an autonomous drone.

Australian CSIRO Zebedee Scanner

The Zebedee three dimensional handheld SLAM LIDAR mapping system was invented by the CSIRO and is now licensed to be manufactured by UK company GeoSLAM (https://geoslam.com/).

Commercial versions of the Zebedee include the ZEB Discovery, ZEB Pano, ZEB Revo and ZEB Horizon. Zebedee technology can also overlay historical data over newly captured data.

See the following videos on Zebedee:

- Early 2013 CSIRO video of the technology, *"Mobile mapping indoors and outdoors with Zebedee"* at https://youtu.be/jyt4-Wz3JC8
- *"CSIRO Zebedee 3D Mapping"* at https://youtu.be/gKPp2MYBYX0
- *"Zebedee 3D laser scanning in Val de Loire"* at https://youtu.be/k8q5xr_eLgk
- *"Real science from caves to the classroom"* at https://youtu.be/jt38pF_TJvY

The Australian CSIRO Hovermap

Hovermap was developed by CSIRO researchers and commercialised by Brisbane-based company Emersent (https://emesent.io). Hovermap uses SLAM technology and is the world's first 3D mapping payload for attachment to drones that works indoors or outdoors, and without the need for GPS (see Fig.28).

It can work underground, inside storage tanks, inside buildings or under bridges.

See the following videos:

- *"Hovermap - World's first autonomous LIDAR mapping payload"* at https://youtu.be/2zadTtCadeI
- *"Hovermap UAV LIDAR mapping payload"* at https://youtu.be/_Gu6Fx7Jt5A
- *"Autonomous underground drone flight beyond line-of-sight using Hovermap payload"* at https://youtu.be/S0HIeDxqevQ

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The Los Angeles city GeoHub

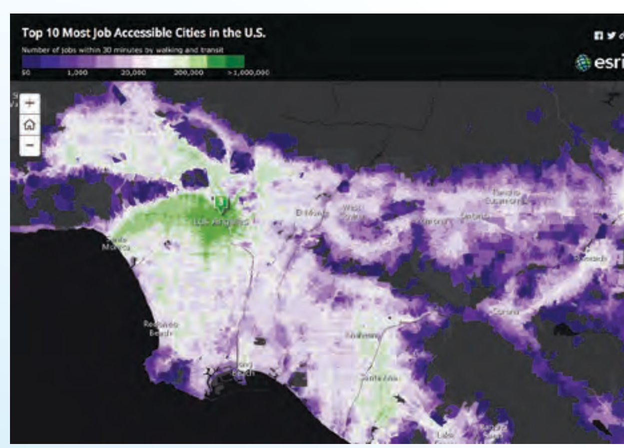
The Los Angeles GeoHub (http://geohub.lacity.org/) is an initiative of the City of Los Angeles and Jack Dangermond from Esri. It is a digital mapping portal capable of delivering immense amounts of information in real-time or near-real-time to a wide variety of people, including the general public.

It is probably one of the most advanced such systems in the world. When the portal was opened, the LA Mayor gave a few examples of how this system could be used. One was a firefighter who, after an earthquake, needs to know the location of fire hydrants, sewer lines, electrical equipment, building infrastructure and even the current location of other emergency workers.

Or social workers might want to see if there is a correlation between the location of homeless encampments and liquor store locations and police patrol activities.

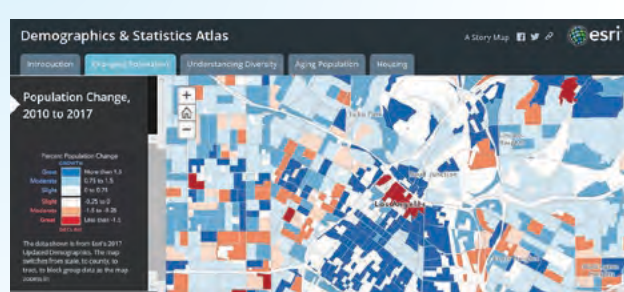
It has numerous possible uses in the areas of business; boundaries of various districts, fire zones etc; health; infrastructure; planning; recreation and parks; safety; schools; transportation and others.

You don't need to have an account or even be a resident of LA or the USA to use the system.



An example of data visualisation from the Los Angeles GeoHub, showing the number of jobs within 30 minutes walking or transit distance from specified areas.

An example map from the Los Angeles GeoHub, showing aircraft noise around Los Angeles International Airport.



A map of the population change in areas of Los Angeles from 2010 to 2017.