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Research and Development in Cartography: A Geographical Perspective

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ABSTRACT: Cartography is the study and practice of making and using maps. Combining science, aesthetics and technique, cartography builds on the premise that reality (or an imagined reality) can be modeled in ways that communicate spatial information effectively.

The fundamental objectives of traditional cartography are to:

- Set the map's agenda and select traits of the object to be mapped. This is the concern of map editing. Traits may be physical, such as roads or land masses, or may be abstract, such as toponyms or political boundaries.
- Represent the terrain of the mapped object on flat media. This is the concern of map projections.
- Eliminate the mapped object's characteristics that are irrelevant to the map's purpose. This is the concern of generalization.
- Reduce the complexity of the characteristics that will be mapped. This is also the concern of generalization.
- Orchestrate the elements of the map to best convey its message to its audience. This is the concern of map design.

Modern cartography constitutes many theoretical and practical foundations of geographic information systems (GIS) and geographic information science (GISc).

KEYWORDS-cartography,maps,geography,design,generalization

I. INTRODUCTION

Maps of the Enlightenment period practically universally used copper plate intaglio, having abandoned the fragile, coarse woodcut technology. Use of map projections evolved, with the double hemisphere being very common and Mercator's prestigious navigational projection gradually making more appearances.

Due to the paucity of information and the immense difficulty of surveying during the period, mapmakers frequently plagiarized material without giving credit to the original cartographer. For example, a famous map of North America known as the "Beaver Map" was published in 1715 by Herman Moll. This map is a close reproduction of a 1698 work by Nicolas de Fer. De Fer, in turn, had copied images that were first printed in books by Louis Hennepin, published in 1697, and François Du Creux, in 1664. By the late 18th century, mapmakers often credited the original publisher with something along the lines of, "After [the original cartographer]" in the map's title or cartouche.[33]

In cartography, technology has continually changed in order to meet the demands of new generations of mapmakers and map users. The first maps were produced manually, with brushes and parchment; so they varied in quality and were limited in distribution. The advent of magnetic devices, such as the compass and much later, magnetic storage devices, allowed for the creation of far more accurate maps and the ability to store and manipulate them digitally.

Advances in mechanical devices such as the printing press, quadrant, and vernier allowed the mass production of maps and the creation of accurate reproductions from more accurate data. Hartmann Schedel was one of the first cartographers to use the printing press to make maps more widely available. Optical technology, such as the telescope, sextant, and other devices that use telescopes, allowed accurate land surveys and allowed mapmakers and navigators to find their latitude by measuring angles to the North Star at night or the Sun at noon.

Advances in photochemical technology, such as the lithographic and photochemical processes, make possible maps with fine details, which do not distort in shape and which resist moisture and wear. This also eliminated the need for engraving, which further speeded up map production.

In the 20th century, aerial photography, satellite imagery, and remote sensing provided efficient, precise methods for mapping physical features, such as coastlines, roads, buildings, watersheds, and topography. The United States Geological Survey has devised multiple new map projections, notably the Space Oblique Mercator for interpreting satellite ground tracks for mapping the surface. The use of satellites and space telescopes now allows researchers to map other planets and moons in outer space.[34] Advances in electronic technology ushered in another revolution in cartography: ready availability of computers and peripherals such as monitors, plotters, printers, scanners (remote and document) and analytic stereo plotters, along with computer programs for visualization, image processing, spatial analysis, and database management, have democratized and greatly expanded the making of maps. The ability to superimpose spatially located variables onto existing maps has created new uses for maps and new industries to explore and exploit these potentials. See also digital raster graphic.

In the early years of the new millennium, three key technological advances transformed cartography:[35] the removal of Selective Availability in the Global Positioning System (GPS) in May 2000, which improved locational accuracy for consumer-grade GPS receivers to within a few metres; the invention of OpenStreetMap in 2004, a global digital counter-map that allowed anyone to contribute and use new spatial data without complex licensing agreements; and the launch of Google Earth in 2005 as a development of the virtual globe EarthViewer 3D (2004), which revolutionised accessibility of accurate world maps, as well as access to satellite and aerial imagery. These advances brought more accuracy to geographical and location-based data and widened the range of applications for cartography, for example in the development of satnav devices.

Today most commercial-quality maps are made using software of three main types: CAD, GIS and specialized illustration software. Spatial information can be stored in a database, from which it can be extracted on demand. These tools lead to increasingly dynamic, interactive maps that can be manipulated digitally.

Field-rugged computers, GPS, and laser rangefinders make it possible to create maps directly from measurements made on site.

There are technical and cultural aspects to producing maps. In this sense, maps can sometimes be said to be biased. The study of bias, influence, and agenda in making a map is what comprise a map's deconstruction. A central tenet of deconstructionism is that maps have power. Other assertions are that maps are inherently biased and that we search for metaphor and rhetoric in maps.[36]

It is claimed that the Europeans promoted an "epistemological" understanding of the map as early as the 17th century.[36] An example of this understanding is that "[European reproduction of terrain on maps] reality can be expressed in mathematical terms; that systematic observation and measurement offer the only route to cartographic truth…".[36]

A common belief is that science heads in a direction of progress, and thus leads to more accurate representations of maps. In this belief, European maps must be superior to others, which necessarily employed different map-making skills. "There was a 'not cartography' land where lurked an army of inaccurate, heretical, subjective, valuative, and ideologically distorted images. Cartographers developed a 'sense of the other' in relation to nonconforming maps."[36]

Depictions of Africa are a common target of deconstructionism.[37] According to deconstructionist models, cartography was used for strategic purposes associated with imperialism and as instruments and representations of power[38] during the conquest of Africa. The depiction of Africa and the low latitudes in general on the Mercator projection has been interpreted as imperialistic and as symbolic of subjugation due to the diminished proportions of those regions compared to higher latitudes where the European powers were concentrated.[39]

Maps furthered imperialism and colonization of Africa in practical ways by showing basic information like roads, terrain, natural resources, settlements, and communities. Through this, maps made European commerce in Africa possible by showing potential commercial routes and made natural resource extraction possible by depicting locations of resources. Such maps also enabled military conquests and made them more efficient, and imperial nations further used them to put their conquests on display. These same maps were then used to cement territorial claims, such as at the Berlin Conference of 1884–1885.[38]

Before 1749, maps of the African continent had African kingdoms drawn with assumed or contrived boundaries, with unknown or unexplored areas having drawings of animals, imaginary physical geographic features, and descriptive texts. In 1748, Jean B. B. d'Anville created the first map of the African continent that had blank spaces to represent the unknown territory.[38]

II. DISCUSSION

In understanding basic maps, the field of cartography can be divided into two general categories: general cartography and thematic cartography. General cartography involves those maps that are constructed for a general audience and thus contain a variety of features. General maps exhibit many reference and location systems and often are produced in a series. For example, the 1:24,000 scale topographic maps of the United States Geological Survey (USGS) are a standard as compared to the 1:50,000 scale Canadian maps. The government of the UK produces the classic 1:50,000 (replacing the older 1 inch to 1 mile) "Ordnance Survey" maps of the entire UK and with a range of correlated larger- and smaller-scale maps of great detail. Many private mapping companies have also produced thematic map series.

Thematic cartography involves maps of specific geographic themes, oriented toward specific audiences. A couple of examples might be a dot map showing corn production in Indiana or a shaded area map of Ohio counties, divided into numerical choropleth classes. As the volume of geographic data has exploded over the last century, thematic cartography has become increasingly useful and necessary to interpret spatial, cultural and social data.

A third type of map is known as an "orienteering," or special purpose map. This type of map falls somewhere between thematic and general maps. They combine general map elements with thematic attributes in order to design a map with a specific audience in mind. Oftentimes, the type of audience an orienteering map is made for is in a particular industry or occupation. An example of this kind of map would be a municipal utility map.[40]

Topographic vs. topological

A topographic map is primarily concerned with the topographic description of a place, including (especially in the 20th and 21st centuries) the use of contour lines showing elevation. Terrain or relief can be shown in a variety of ways (see Cartographic relief depiction). In the present era, one of the most widespread and advanced methods used to form topographic maps is to use computer software to generate digital elevation models which show shaded relief. Before such software existed, cartographers had to draw shaded relief by hand. One cartographer who is respected as a master of hand-drawn shaded relief is the Swiss professor Eduard Imhof whose efforts in hill shading were so influential that his method became used around the world despite it being so labor-intensive.[41][42]

A topological map is a very general type of map, the kind one might sketch on a napkin. It often disregards scale and detail in the interest of clarity of communicating specific route or relational information. Beck's London Underground map is an iconic example. Although the most widely used map of "The Tube," it preserves little of reality: it varies scale constantly and abruptly, it straightens curved tracks, and it contorts directions. The only topography on it is the River Thames, letting the reader know whether a station is north or south of the river. That and the topology of station order and interchanges between train lines are all that is left of the geographic space.[43] Yet those are all a typical passenger wishes to know, so the map fulfills its purpose.[44]

Map design

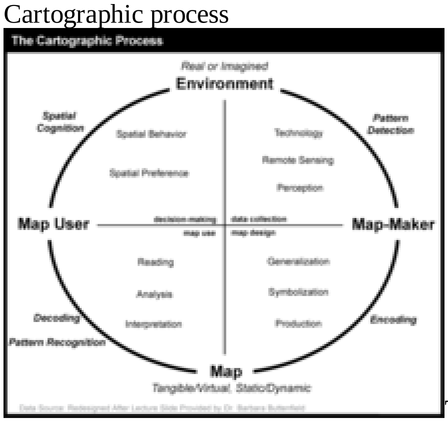
Illustrated map

Modern technology, including advances in printing, the advent of geographic information systems and graphics software, and the Internet, has vastly simplified the process of map creation and increased the palette of design options available to cartographers. This has led to a decreased focus on production skill, and an increased focus on quality design, the attempt to craft maps that are both aesthetically pleasing and practically useful for their intended purposes.

Map purpose and audience

A map has a purpose and an audience. Its purpose may be as broad as teaching the major physical and political features of the entire world, or as narrow as convincing a neighbor to move a fence. The audience may be as broad as the general public or as narrow as a single person. Mapmakers use design principles to guide them in constructing a map that is effective for its purpose and audience.

Cartographic process



The cartographic process

The cartographic process spans many stages, starting from conceiving the need for a map and extending all the way through its consumption by an audience. Conception begins with a real or imagined environment. As the cartographer gathers information about the subject, they consider how that information is structured and how that structure should inform the map's design. Next, the cartographers experiment with generalization, symbolization, typography, and other map elements to find ways to portray the information so that the map reader can interpret the map as intended. Guided by these experiments, the cartographer settles on a design and creates the map, whether in physical or electronic form. Once finished, the map is delivered to its audience. The map reader interprets the symbols and patterns on the map to draw conclusions and perhaps to take action. By the spatial perspectives they provide, maps help shape how we view the world.[45]

Aspects of map design

Designing a map involves bringing together a number of elements and making a large number of decisions. The elements of design fall into several broad topics, each of which has its own theory, its own research agenda, and its own best practices. That said, there are synergistic effects between these elements, meaning that the overall design

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process is not just working on each element one at a time, but an iterative feedback process of adjusting each to achieve the desired gestalt.

- Map projections: The foundation of the map is the plane on which it rests (whether paper or screen), but projections are required to flatten the surface of the earth. All projections distort this surface, but the cartographer can be strategic about how and where distortion occurs.[46]
- Generalization: All maps must be drawn at a smaller scale than reality, requiring that the information included on a map be a very small sample of the wealth of information about a place. Generalization is the process of adjusting the level of detail in geographic information to be appropriate for the scale and purpose of a map, through procedures such as selection, simplification, and classification.
- Symbology: Any map visually represents the location and properties of geographic phenomena using map symbols, graphical depictions composed of several visual variables, such as size, shape, color, and pattern.
- Composition: As all of the symbols are brought together, their interactions have major effects on map reading, such as grouping and visual hierarchy.
- Typography or labeling: Text serves a number of purposes on the map, especially aiding the recognition of features, but labels must be designed and positioned well to be effective.[47]
- Layout: The map image must be placed on the page (whether paper, web, or other media), along with related elements, such as the title, legend, additional maps, text, images, and so on. Each of these elements have their own design considerations, as does their integration, which largely follows the principles of graphic design.
- Map type-specific design: Different kinds of maps, especially thematic maps, have their own design needs and best practices.

III. RESULTS

Some maps contain deliberate errors or distortions, either as propaganda or as a "watermark" to help the copyright owner identify infringement if the error appears in competitors' maps. The latter often come in the form of nonexistent, misnamed, or misspelled "trap streets".[48] Other names and forms for this are paper towns, fictitious entries, and copyright easter eggs.[49]

Another motive for deliberate errors is cartographic "vandalism": a mapmaker wishing to leave their mark on the work. Mount Richard, for example, was a fictitious peak on the Rocky Mountains' continental divide that appeared on a Boulder County, Colorado map in the early 1970s. It is believed to be the work of draftsman Richard Ciacci. The fiction was not discovered until two years later.

Sandy Island in New Caledonia is an example of a fictitious location that stubbornly survives, reappearing on new maps copied from older maps while being deleted from other new editions.

With the emergence of the internet and Web mapping, technologies allow for the creation and distribution of maps by people without proper cartographic training are readily available. This has led to maps that ignore cartographic conventions and are potentially misleading.[50]

Professional and learned societies include:

- International Cartographic Association (ICA), the world body for mapping and GIScience professionals, as well as the ICA member organizations
- British Cartographic Society (BCS) a registered charity in the UK dedicated to exploring and developing the world of maps
- Society of Cartographers supports in the UK the practising cartographer and encourages and maintains a high standard of cartographic illustration
- Cartography and Geographic Information Society (CaGIS), promotes in the U.S. research, education, and practice to improve the understanding, creation, analysis, and use of maps and geographic information. The society serves as a forum for the exchange of original concepts, techniques, approaches, and experiences by

those who design, implement, and use cartography, geographical information systems, and related geospatial technologies.

- North American Cartographic Information Society (NACIS), A North American-based cartography society that is aimed at improving communication, coordination and cooperation among the producers, disseminators, curators, and users of cartographic information. Their members are located worldwide and the meetings are on an annual basis
- Canadian Cartographic Association (CCA)
- Modern Cartography Tools
- Today’s cartography tools have taken mapmaking to new heights, mostly in terms of detail and accuracy, but sometimes quite literally.
- Mapmaking can employ a huge variety of methods and tools. Here we'll cover a few of the most common tools: aerial photography, sensors, GPS, satellites, and GIS.[50]
- Aerial Photography
- Folks have been trying to get cameras into the sky for as long as those same cameras have existed. Early attempts at aerial photography included balloons, kites, and even rockets.
- In 1860, the oldest surviving aerial photograph was taken by James Wallace Black, tethered in a hot air balloon 2,000ft above Boston.
- Modern aerial photography now relies on advanced technology like helicopters and unmanned aerial vehicles (UAVs) - more colloquially known as drones.

- Phantom 3 Drone
- Able to reach impressive heights and controlled by a hand-held remote, drones are a fantastic tool for aerial photography. Especially for GIS mapping, large-scale, consistent visual records make surveying and change detection a breeze.
- Though drones are still fairly expensive, the barrier to entry is low enough that organizations and even most individuals can participate.

- Sensors
- Sensors detect events, changes, and physical characteristics of a given area by transforming stimuli (sound, light, heat, or motion) into electrical signals.
- Those signals are collected and then transmitted to another device, usually a computer. Put simply, sensors collect data about the Earth's surface.

- ZephIR 300M wind lidar device
- Examples of sensors include:
- Seisometers: Measure ground motion

  LIDAR: 3D laser-based aerial mapping

  Sonar: Detecting objects under water through sound propagation

- In terms of modern cartography, sensors contribute to the design and creation of detailed, high-fidelity maps.
- Because sensors can detect and log huge quantities of accurate data regularly, they are often used in change detection projects. Essentially, creating one map of an area, waiting for a specified amount of time, creating another, and then comparing for discrepancies.
- GPS
- The Global Positioning System (GPS) is a series of over 24 satellites that orbit Earth regularly, each transmitting a unique signal.
- GPS receivers intercept those signals and perform trilateration (distance based measurement between various points): enabling a highly accurate system of navigation.[39]

- Trimble Geo7x [Source]
- Primarily used for navigation in aircrafts, cars, boats, and mobile phones, GPS is also the primary tool for land surveying.

- Digital cartography has enabled the ubiquity of GPS systems. Users can employ GPS to track everyday trends like traffic, mark coordinates for landmarks, chart a path from one location to another, and find their own location within a map.

- Satellites

- Satellites serve a variety of purposes — from spying on foreign adversaries, to tracking weather and improving cell service, or as mentioned above - enabling the GPS network.[38]

- Satellite
- In terms of map making, satellites enable consistent, large-scale updates of Earth's surface.
- Think about modern applications like Google Earth or cloud GIS tools. These all rely on satellites for accurate geospatial data.
- Satellites have increased the speed and range at which mappable information can be collected. Surveys that once took months can now be done in minutes.
- By continually capturing footage of the Earth's surface, satellites have enabled the creation of thousands, if not millions, of maps - used in agriculture, forestry, utilities, earth sciences, regional planning, and much more.
- Geographic Information Systems (GIS)
- Sensors, GPS, and satellites are methods through which to collect data.
- These devices are quite advanced. However, as a general rule they lack the ability to display, organize, and manage the data they collect.
- GIS provides the ideal solution.[37]
- GIS is location-based software used to view, organize, visualize, and analyze geospatial data. GIS helps users wrangle their data, enabling a better understanding of positionally based patterns and relationships.

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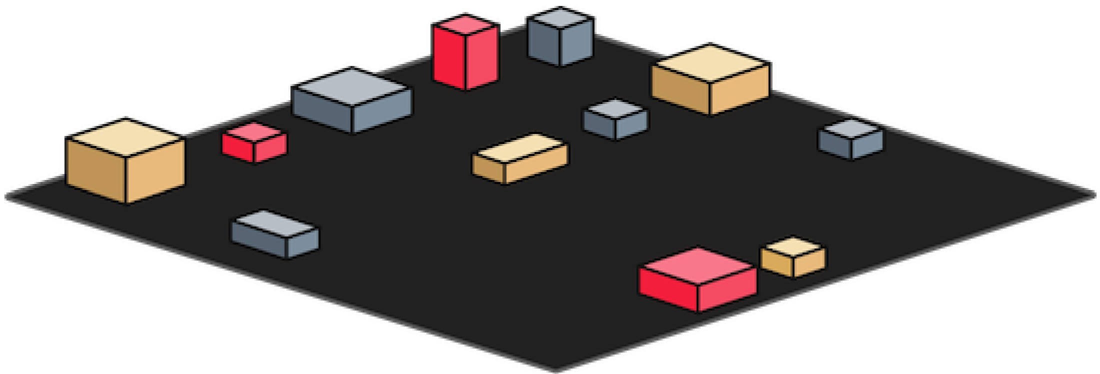
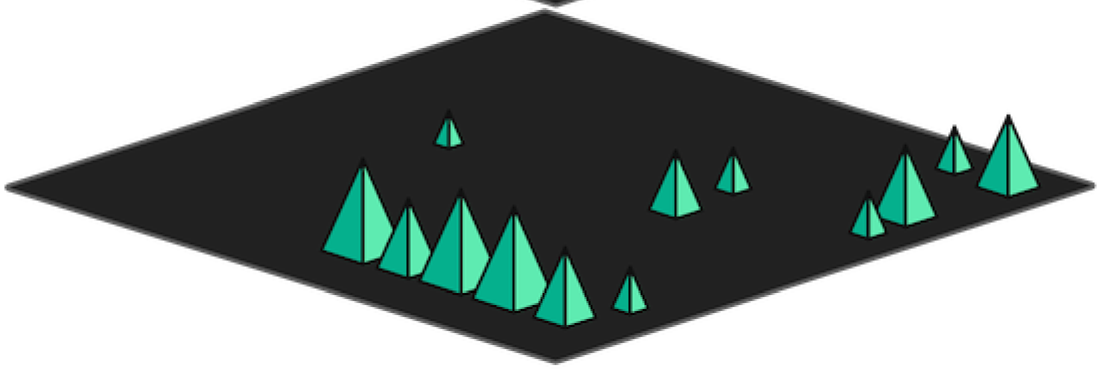
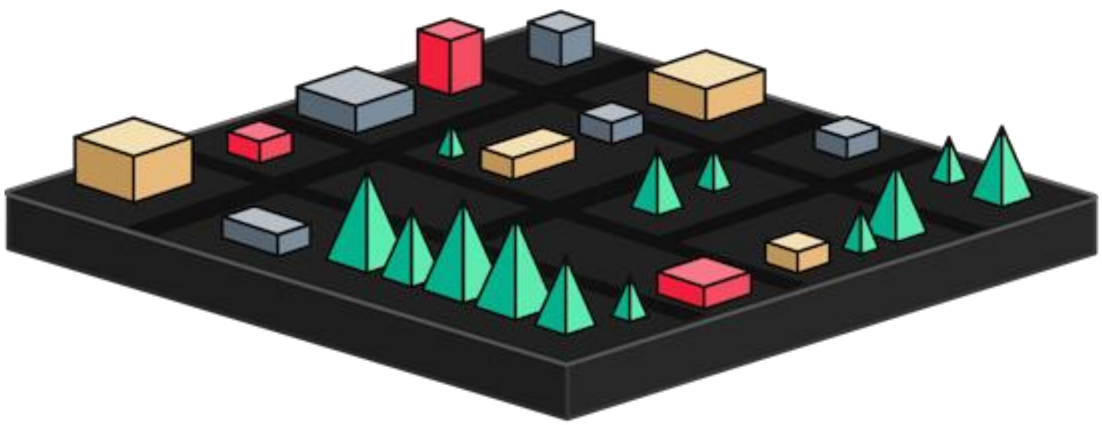
- 
- 
- 

- Legacy GIS platforms, originating in the 1980's, provide tools for high-level scientific analysis and data visualization. These programs are most often desktop based and require local installation - though some do offer mobile applications.

- In the last decade, cloud GIS systems have started to become more prevalent. Cloud GIS systems don't offer the same level of deep scientific analysis; however, they are significantly more mobile friendly - enabling users to take GIS with them wherever they go.

- See how GIS has transformed key industries in our blogs on utilities, oil & gas, construction, urban planning, and telecom.

- Practical Applications of Modern Cartography
- Most people interact with the products of modern cartography on a daily basis.
- Consider the many apps in your phone. How many of them rely on location-based services? Navigation apps like Google Maps and Waze, ride services like Uber or Lyft, and food delivery apps like DoorDash all have some kind of mapping component.
- That said, modern cartography goes far beyond simply finding your location on a map. Location intelligence, 3D modeling, and real-time map creation are all based in the application of modern cartographic tools.
- Location Intelligence[37]
- Location intelligence, also known as spatial intelligence, helps users derive insights and discover meaningful relationships within geospatial data.

- Location intelligence emerged from the foundation of GIS, and is used to help organizations and corporations understand positional data.
- Practical applications for location intelligence include risk assessment, delivery optimization, price configuration, and strategy development for acquisition or expansion.
- 3D Modeling
- LiDAR, one of the modern cartography tools mentioned above, is integral to creating 3D maps and models. LiDAR relies on laser light to measure distance.

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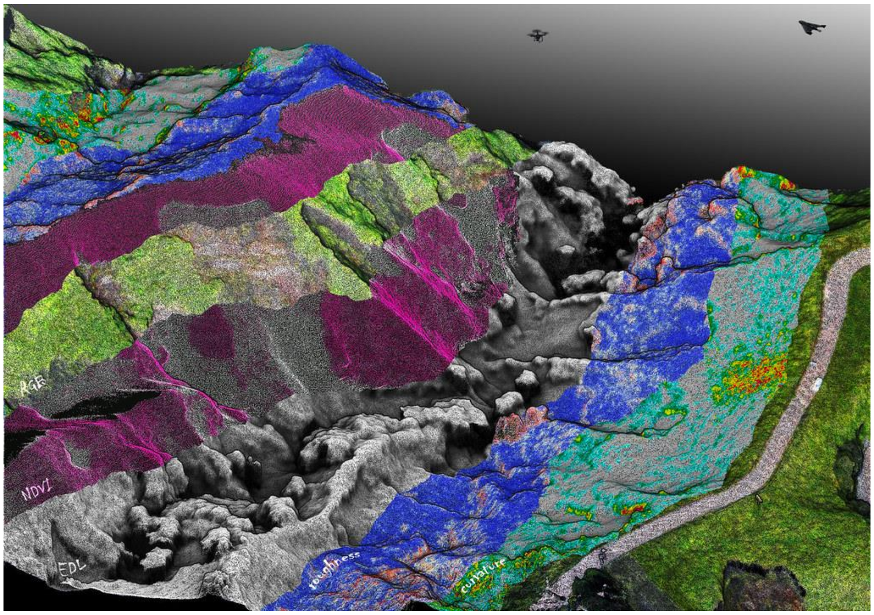

- Point cloud of slope failures in Sensuikyo Valley

- A laser pulse is released, travels outward, hits an object, and then bounces back. Similar to sonar, distance is measured by how long the pulses take to return.

- Because light travels incredibly fast and in all directions simultaneously, LiDAR scans produce point clouds.

- Consisting of millions of individual points, point clouds are basically highly-detailed 3D maps. The sheer number of data points means that LiDAR scans can create 3D maps of everything from a bustling metropolis to the Grand Canyon.

IV. CONCLUSION

- Real-time Map Making
- Cloud technology has enabled mapping in real time.

- In contrast to locally installed software, cloud-based GIS platforms can be accessed via any web browser. This means any device connected to the internet can be used to view and interact with a given program.

- Real-time digital mapping enables an incredible amount of activities - from tracking utility inspections, to watching as your Uber driver approaches the pick-up spot.

- Aside from the awesome number of applications, real-time mapping stands as perhaps the starkest indicator of how far cartography has come. From the earliest cave drawings to creating live maps to suit almost any purpose, the technological advances are truly astounding.[50]

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