



Monitoring Pistachio Orchards

MAPPING FUNDAMENTALS

About

Syllabus

[Introduction to Spatial Data and Mapping](#) (1 hour lecture)

- Definitions of terms (maps, mapping, geography, geodata, spatial data)
- Overview of mapping and its applications

[History of Mapping](#) (3 hours lecture)

- Early maps and cartography
- Key developments in the history of mapping

[Types of Maps](#) (3 hours lecture)

- Physical, political, thematic maps, topographic maps

[Map Elements](#) (3 hours lecture, 1 hour exercises)

- Labels, annotations, symbols and their meanings, legends and scale bars

[Map Projections and Coordinate Systems](#) (2 hours lecture, 2 hour exercises)

- Types of map projections
- Distortions and their implications
- Geographic vs. cartesian coordinate systems

[Spatial Data Acquisition Methods](#) (2 hours lecture, 2 hour exercises)

- Ground surveying techniques, GNSS and Remote sensing basics
- Aerial photography, satellite imagery, LiDAR (Light Detection and Ranging)

[Using Maps](#) (3 hours exercises)

- Reading and interpreting maps
- Map navigation skills
- Application of maps in various fields (e.g. urban planning, environmental management)

The homework will include: 20 hrs literature analysis, mapping terminology, and individual study.

Objectives and Competences

Course Objectives:

- To provide foundational knowledge of spatial data and mapping.

- To introduce students to the various types of maps and their uses.
- To teach the principles of coordinate systems and map projections.
- To explore the history and evolution of mapping.
- To familiarise students with the methods and technologies used in spatial data acquisition.

Competences:

- Ability to interpret and create maps using appropriate symbols and labels.
- Understanding of coordinate systems and the ability to apply map projections.
- Knowledge of the different types of maps and their specific applications.
- Proficiency in basic spatial data acquisition techniques.

Intended Learning Outcomes

Students that will successfully attend the course will be able to:

- Explain the fundamental concepts of spatial data and mapping.
- Identify and use different types of maps and their elements (labels, symbols).
- Describe the history and development of mapping.
- Apply coordinate systems and map projections.
- Differentiate between various spatial data acquisition methods.
- Utilise maps effectively for various applications.

Course content

Introduction to Spatial Data and Mapping

Geography is the study of places, landscapes, environments, and the relationships between people and their environments.

Data are facts and statistics collected together for reference or analysis.

Spatial data refers to data which cover more than one spatial dimension (2D, 3D, ...).

Geographic data (shortly **geodata**) are data representing features or phenomena related to the Earth.

Map is a downscaled and simplified drawing of the earth's surface, or part of that surface.

Mapping in this context means a process of making a map. Beware that this word may have different meanings in different fields, like in mathematics.

Mapping can be also described as the process of creating visual representations of geographic data, transforming raw facts and statistics into understandable, spatially-organised information. It is invaluable for studying geography, as it helps illustrate the relationships between people, places and environments. By representing spatial data and geodata in the form of maps, mapping makes it easier to analyse and interpret the Earth's features and phenomena. Applications of mapping are diverse, including urban planning, environmental conservation, transportation logistics, disaster response and resource management, all of which benefit from clear, accessible visualisations of complex geographic data.

Quiz

match a term with its description

map	downscaled or simplified drawing of the earth's surface, or part of that
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	surface
mapping	a process of making a map
spatial data	data which cover more than one spatial dimension
geography	the study of places, landscapes, environments, and the relationships between people and their environments
geographic data	data representing features or phenomena related to the Earth

History of Mapping

We have already learned a definition of what a map is. But how do we distinguish a map from a plan or a sketch, or a simple drawing? That is a rather philosophical question. What is known is that people used to draw maps (or plans, geographical sketches, ...) long before the word “map” was even introduced. One of these oldest relics which we may call a map, is an engraving on a Mammoth tusk – a plan of meanders of river Thaya in the south Moravia, also depicting a camp of the indigenous people. This engraving probably dates at least 20 000 years into history.

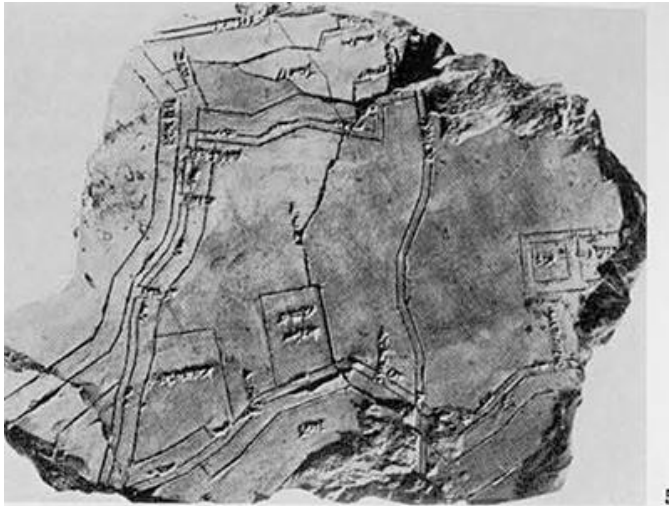


Mammoth tusk engraving map, Petr Novák, Wikipedia

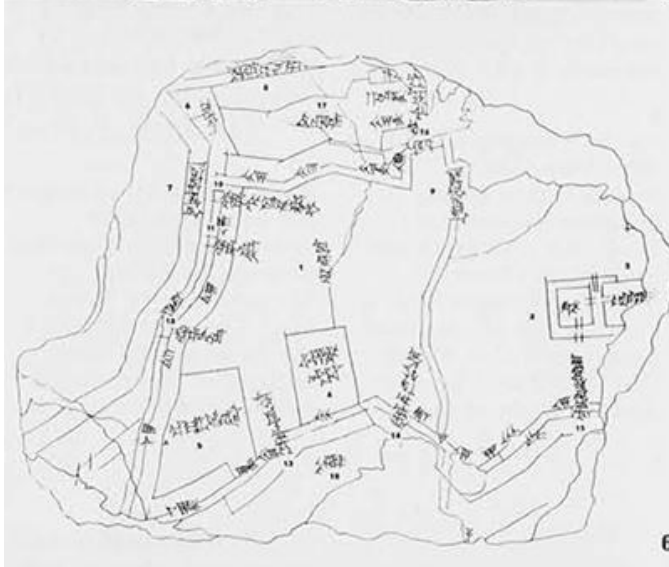
One notable example of a very old map (or “map”), is the so-called *Mappa di Bedolina* – one of the earliest maps, which survived till the current era. As with other very old maps, it is hard to tell its actual age, due to its unknown date of origin. It is believed that it was created around 1000 BCE. *Mappa di Bedolina* is a 4 metres length plan of the valley around Bedolina, Lombardy. Another example of a map this old is a city plan of Babylonian city Nippur.



Mappa di Bedolina, Luca Giarelli / CC-BY-SA 3.0



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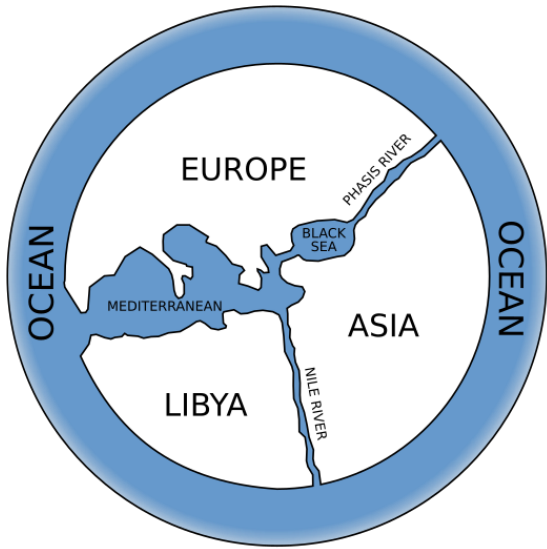
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Map of the Babylonian city of Nippur. <https://imgur.com/map-of-babylonian-city-of-nippur-ca-1500-bce-this-is-earliest-known-city-map-drawn-to-scale-1WuI7RR>

If the aforementioned old maps had a scale, we could call them all large-scale or middle-scale maps – they only covered a small piece of the Earth’s surface. That is due to the fact that the area known to their authors was quite limited. Since then, as the human population grew and the ancient civilizations expanded, maps covering larger areas have appeared. As a result of the continuous discovery of the Earth by these civilizations, first maps of the known world were created.

Notable is the Anaximandros’ map of the world. The actual map was not preserved to the current times, but it is known that its shape and design affected many maps created afterwards. We call them “round maps”, as they have a circular shape.

One of these maps, which survived until the current era, is the *Hereford Mappa Mundi* map, created around 1280. It depicts known continents – Europe, Asia and Africa. It has Jerusalem in the centre of the map and it is oriented such that east is on the top of the map and north is on the left side. The Hereford Mappa Mundi depicts locations from Ganges river in the east to the Strait of Gibraltar to the west and from the Baltic sea in the north to the River Nile in the south.



Anaximander world map. Probable reconstruction.



Hereford Mappa Mundi.

The eastern orientation of the old “world” maps was typical, due to the east was considered the direction to heaven. The northern orientation of maps, which is common nowadays, emerged later. Mediaeval maps called Portolan charts were using the northern orientation. These maps were produced from the 13th century onward. Their purpose was for nautical navigation. They are known for their precise depiction of coastlines and for the fact that loxodromes (rhumb lines) are displayed as straight lines on the map. Oldest known of these Portolan charts is *Carta Pisana*.



Carta Pisana. The preserved piece.

In the late 15th century, Martin Behaim created his globus, a spherical depiction of the earth surface. It was not the first globus ever created, it is known that globes existed in the antique times, but the globe by Martin Behaim is the oldest one which was preserved until today.



"Erdapfel" – the globe of Martin Behaim.

https://commons.wikimedia.org/wiki/File:Behaims_Erdapfel.jpg

In the 16th century, cartography was significantly influenced by the mathematician **Gerhard Mercator**. Mercator created a number of maps, globes and atlases. He is also considered the author of the word "atlas" in the cartographic meaning – a collection of maps sharing a similar composition and reflecting a certain shared theme or describing a certain region. Gerhard Mercator has also set

First map with isolines was created by Edmond Halley. Isolines are lines which connect places with the same value of a certain phenomenon. Halley's map was depicting a magnetic variation. The method of isolines then gained popularity. Alexander von Humboldt used the isolines to show places with the equal temperate, thus creating a first map with isotherms. Phillippe Buache then made a map of France on which contours were first used – isolines connecting places with equal height. Before Buache's innovation, the height on maps was shown with a simple method of "hills" or "forests" or the slope was illustrated with hatching.



Edmond Halley's New and Correct Chart Shewing the Variations of the Compass

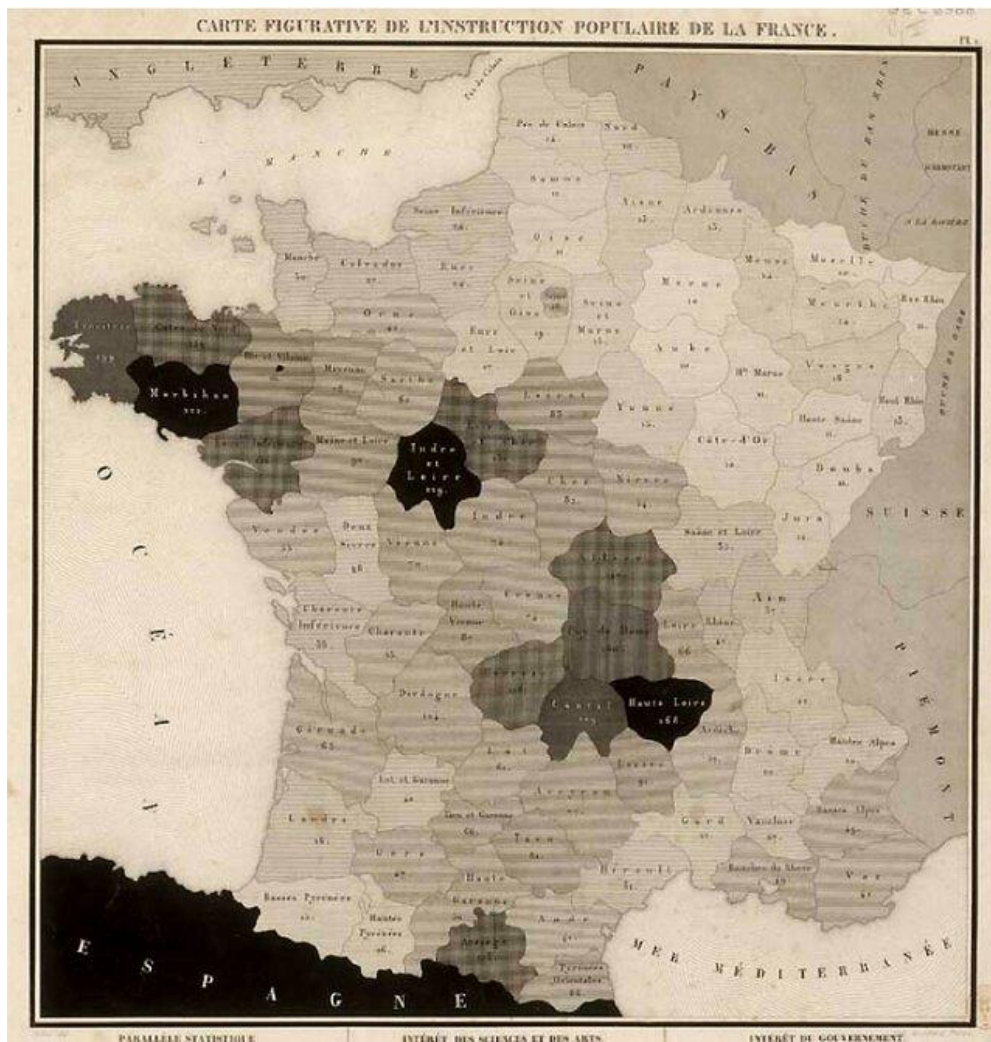
Another significant development which affected the cartographic works, was the invention of coloured print in the 18th century.

Notable colourful map is a geological map of Britain by William Smith from 1851. Geological maps were created before, but this one is the basis for nowadays geological maps.



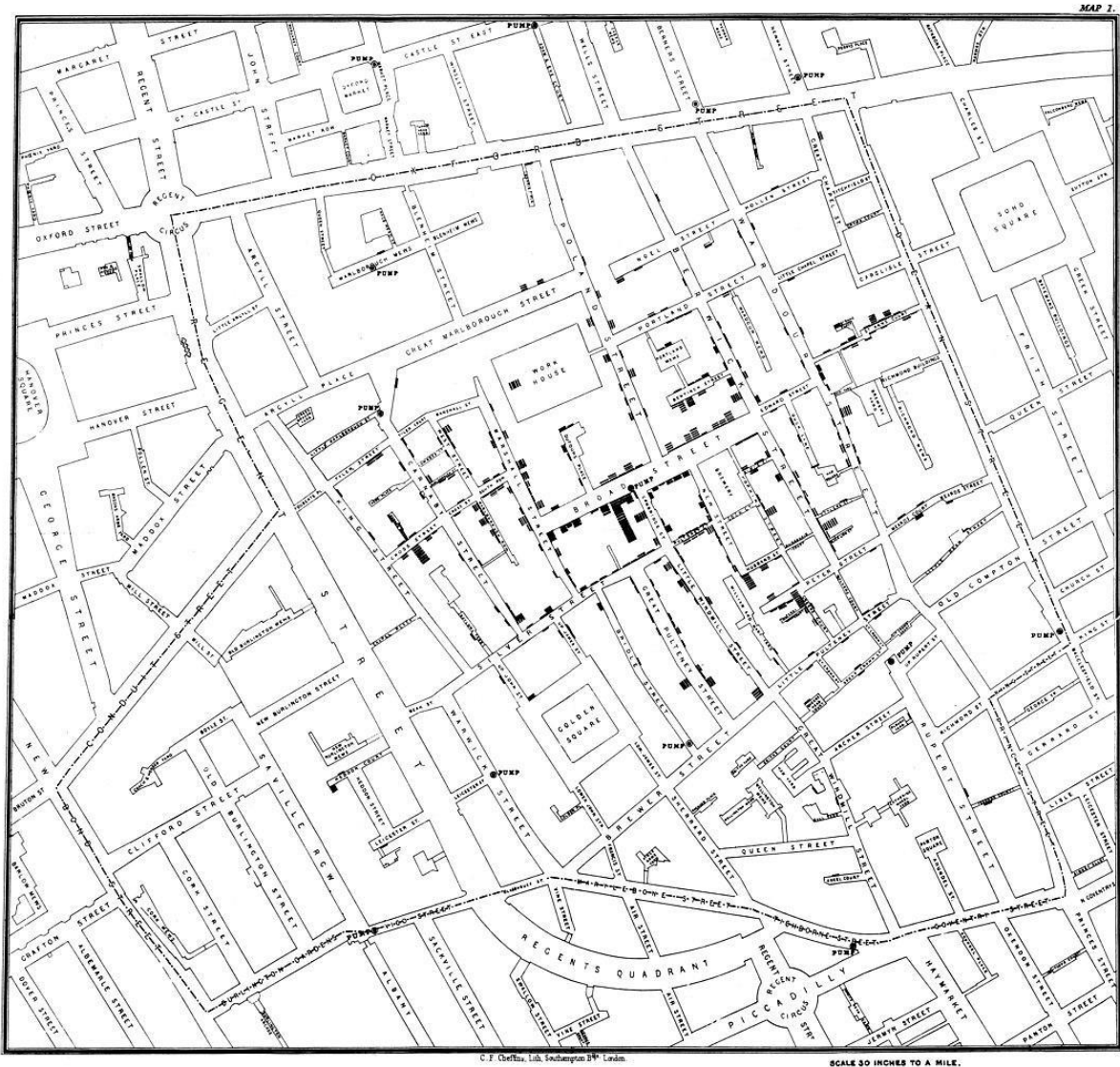
William Smith's geological map. <https://www.nhm.ac.uk/discover/first-geological-map-of-britain.html>

Pierre Charles Francois Dupin is the author of the first modern statistical map. It depicts education and literacy in France and was published in 1826. The method used by Dupin, colourizing regions with a different tint of colour based on a relative value, is known as a choropleth map. Dupin then created more statistical maps of France for other socio-economic phenomena, while using other methods of thematic cartography like graduated symbols.



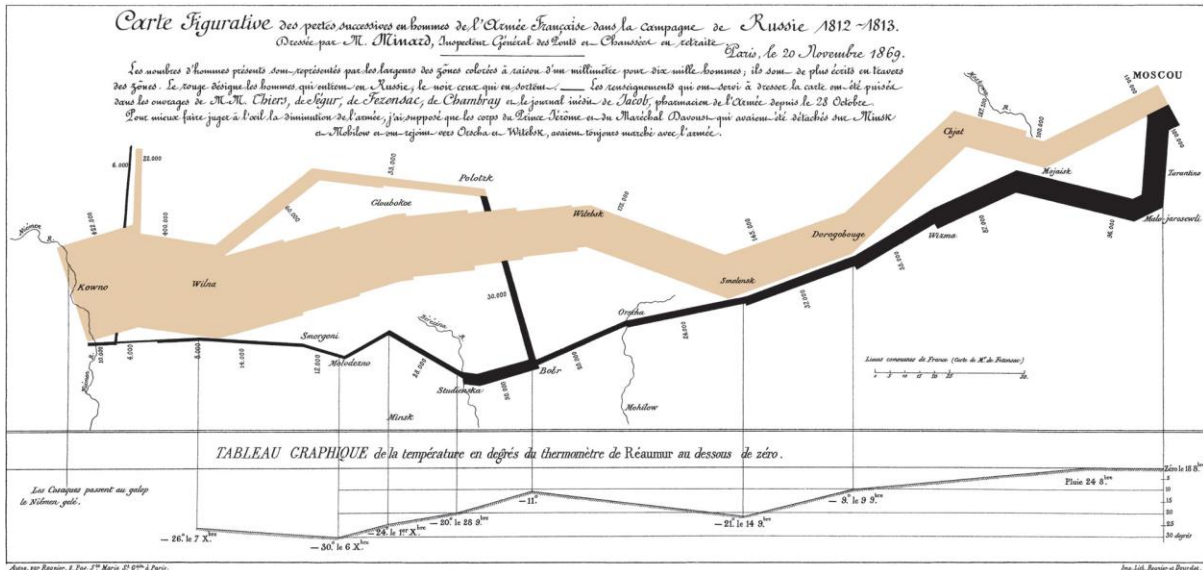
Statistical (choropleth) map by Pierre Charles Francois Dupin.
<https://www.researchgate.net/publication/269498551>

Several years later, in 1854, John Snow created his famous dot map. This map shows cholera cases during the disease outbreak in London as individual dots. When created, it helped localise poisoned wells and even uncovers the spatial relation between water wells and cases of disease. That cholera event and the work done by John Snow are considered the basics of epidemiology.



John Snow's map from "On the Mode of Communication of Cholera".

An innovative approach in creating thematic maps was introduced by Charles Joseph Minard in 1869. He portrayed Napoleon's march against Russia as a single line changing its thickness. The thickness represents the number of soldiers in Napoleon's army in a given place and time. This type of map was later called a flow map and Minard's map was one of the first.



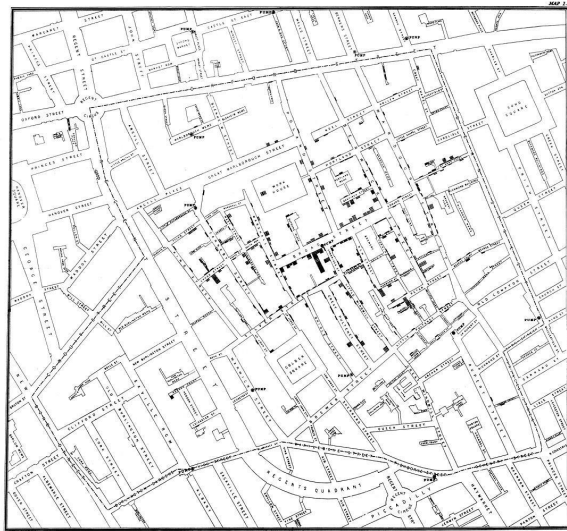
Charles Minard's chart of Napoleon's campaign against Russia in 1812.

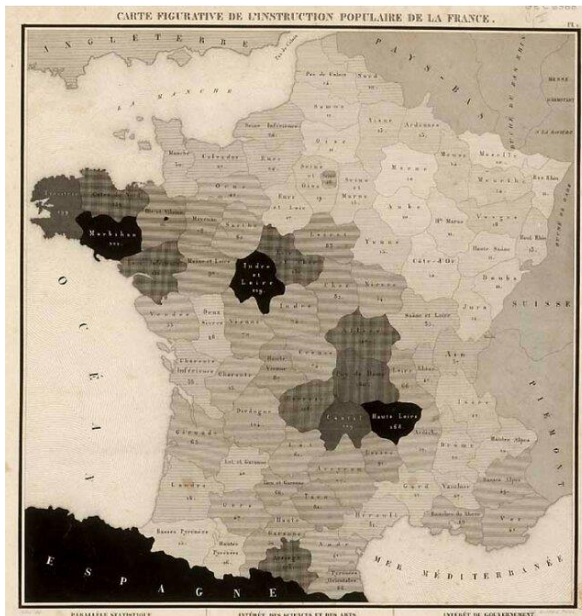
From the mid 18th to the mid 19th century, many cadastral maps were produced in Europe. These detailed maps of land were often based on very precise geodetic measurements, notably in Austria-Hungary. Along with the cadastral maps, detailed maps for military purposes were also produced.

Quiz

Recognise the following significant old maps:

- Mappa di Bedolina
- John Snow's dot map
- Hereford map
- Pierre C. F. Dupin's statistical map





Types of Maps

Maps can be divided into two major groups: Reference (base) maps and thematic maps. The primary difference between reference maps and thematic maps is in their purpose and the information they convey.

Reference maps are designed to show the location of geographic features, such as boundaries, cities, and physical landscapes, providing a general understanding of an area's layout; examples include political, physical, and topographic maps.

In contrast, **thematic maps** highlight a specific theme or topic over a geographic area, such as temperature, population density, or resource distribution, by overlaying this data onto a base map. While reference maps emphasise locations and boundaries, thematic maps focus on communicating patterns or trends related to a particular subject.

Physical maps are designed to show the natural landscape features of Earth. They are best known for showing topography, either by colours or as shaded relief.



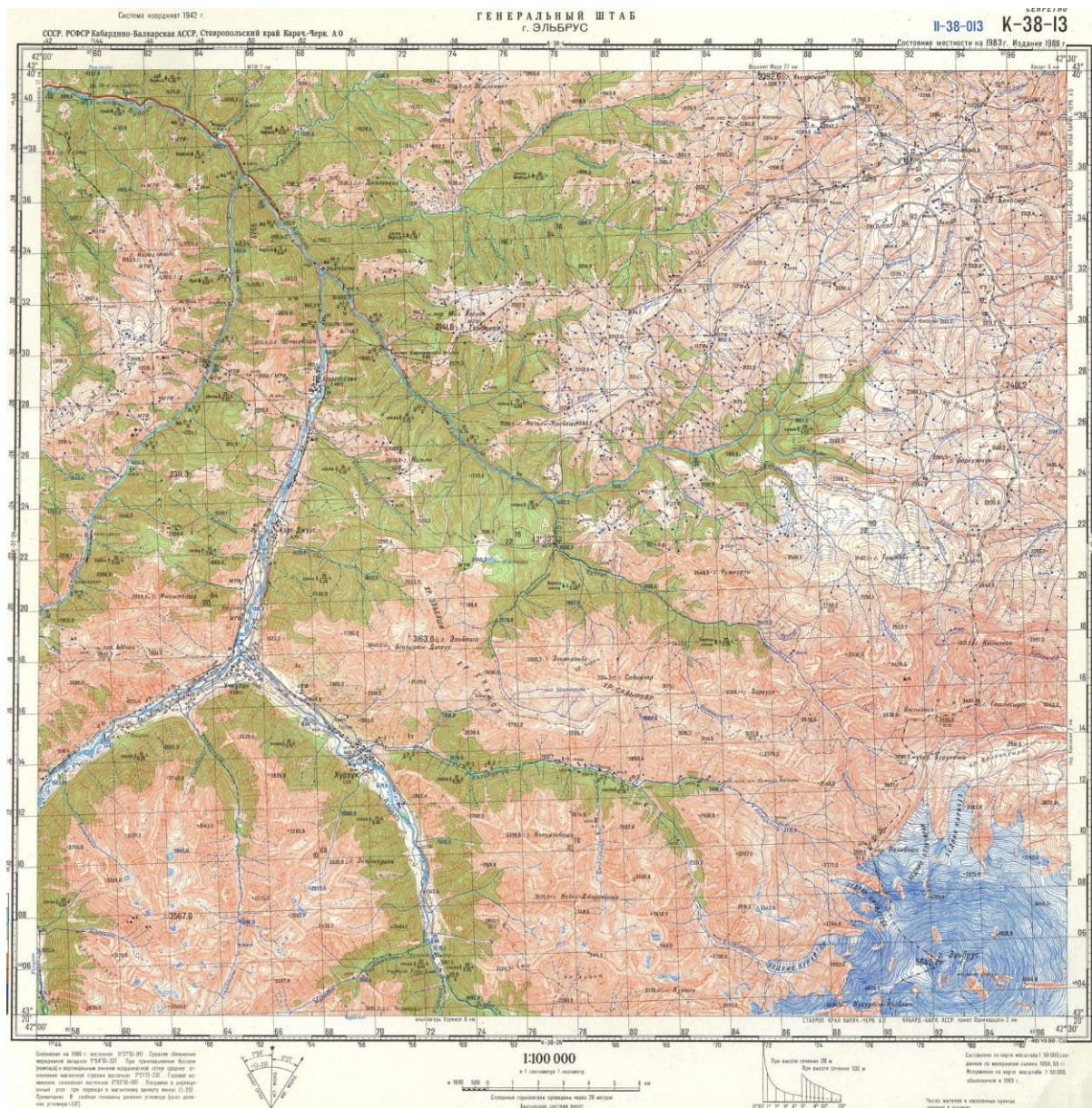
Physical map of North America, Mapswire / CC-BY 4.0

Political maps are among the most widely used reference maps. They show the geographic boundaries between governmental units such as countries, states, and counties. To distinguish the governmental units, each unit is painted in a different colour. Political maps may show roads, cities and major water features such as oceans, rivers and lakes. Political maps help people understand the geography of the world. They are mounted on the walls of classrooms throughout the world and they are usually the first type of map that students are introduced to in school.



Political map of North America. <https://www.burningcompass.com/continents/north-america/north-america-political-map.html>

Topographic maps are reference maps that show the shape of Earth's surface. They usually do this with lines of equal elevation known as "contour lines", but elevation can also be shown using colours (second map), colour gradients, shaded relief and a number of other methods. Topographic maps also show other important natural features such as lakes, rivers and streams. Important cultural features are also shown on topographic maps. These include roads, trails, buildings, place names, bench marks, cemeteries, churches, schools and much more. A standardised set of special symbols has been developed for this use. Topographic maps have traditionally been printed on large sheets of paper with their four boundaries being lines of longitude and latitude.



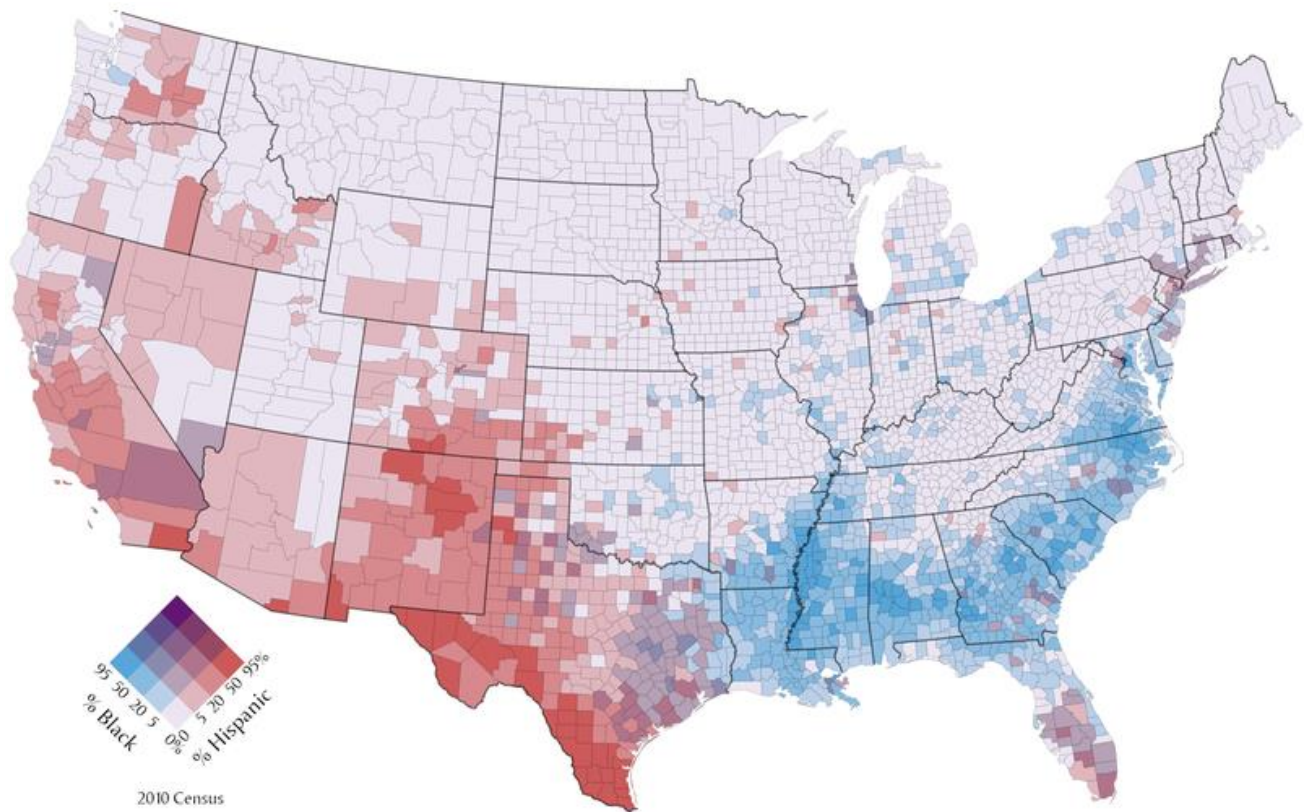
Soviet military mapping – topographic map of the Elbrus mountain.
<https://maps.vlasenko.net/smtm100/k-38-013.jpg>

An **orthophotomap** is a high-resolution aerial photograph that has been geometrically corrected, or "orthorectified," so that it accurately represents the Earth's surface, with uniform scale throughout. Unlike standard aerial photographs, which can have distortions due to camera angles, terrain, or elevation, orthophotomaps align with a specific map projection, allowing for precise measurements of distance, area, and angles directly from the image. These maps combine the visual detail of a photograph with the spatial accuracy of a map, making them useful for applications in urban planning, environmental monitoring, and geographic analysis.



Orthophotomap of a town in Czechia.

A **thematic map** is a type of map that portrays the geographic pattern of a particular subject matter (theme) in a geographic area. This usually involves the use of map symbols to visualise selected properties of geographic features that are not naturally visible, such as temperature, language, or population.



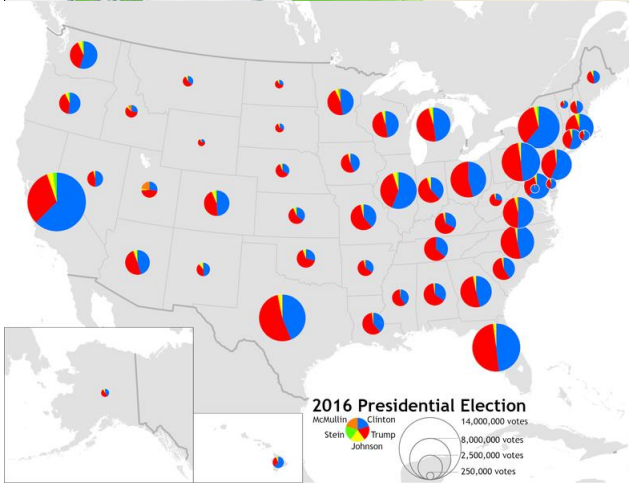
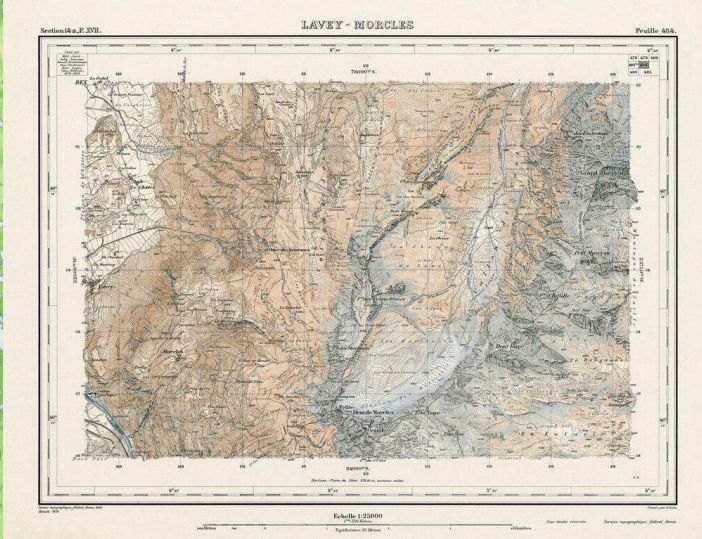
A thematic (choropleth) map visualising proportion of black and hispanic population in the United States as of 2010. Bplewe / CC-BY-SA 4.0

Source for this lecture: <https://geology.com/maps/types-of-maps>

Quiz

Categorise maps by image

- Orthophoto
- Political map
- Physical map
- Topographic map
- Thematic map



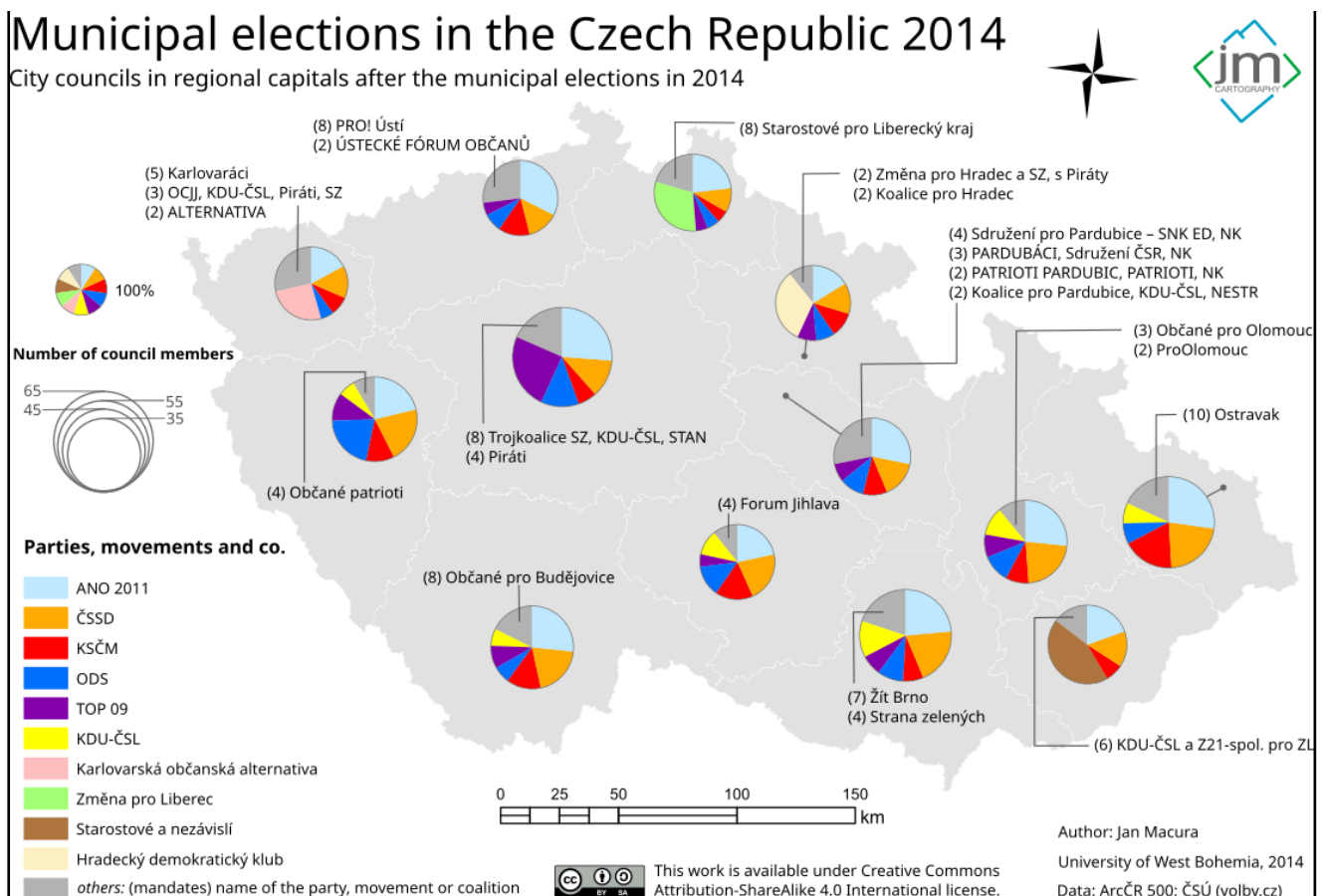
Map Elements

A proper map consists at least of:

- map image,
- title,
- scale,
- legend,
- north arrow,
- imprint.

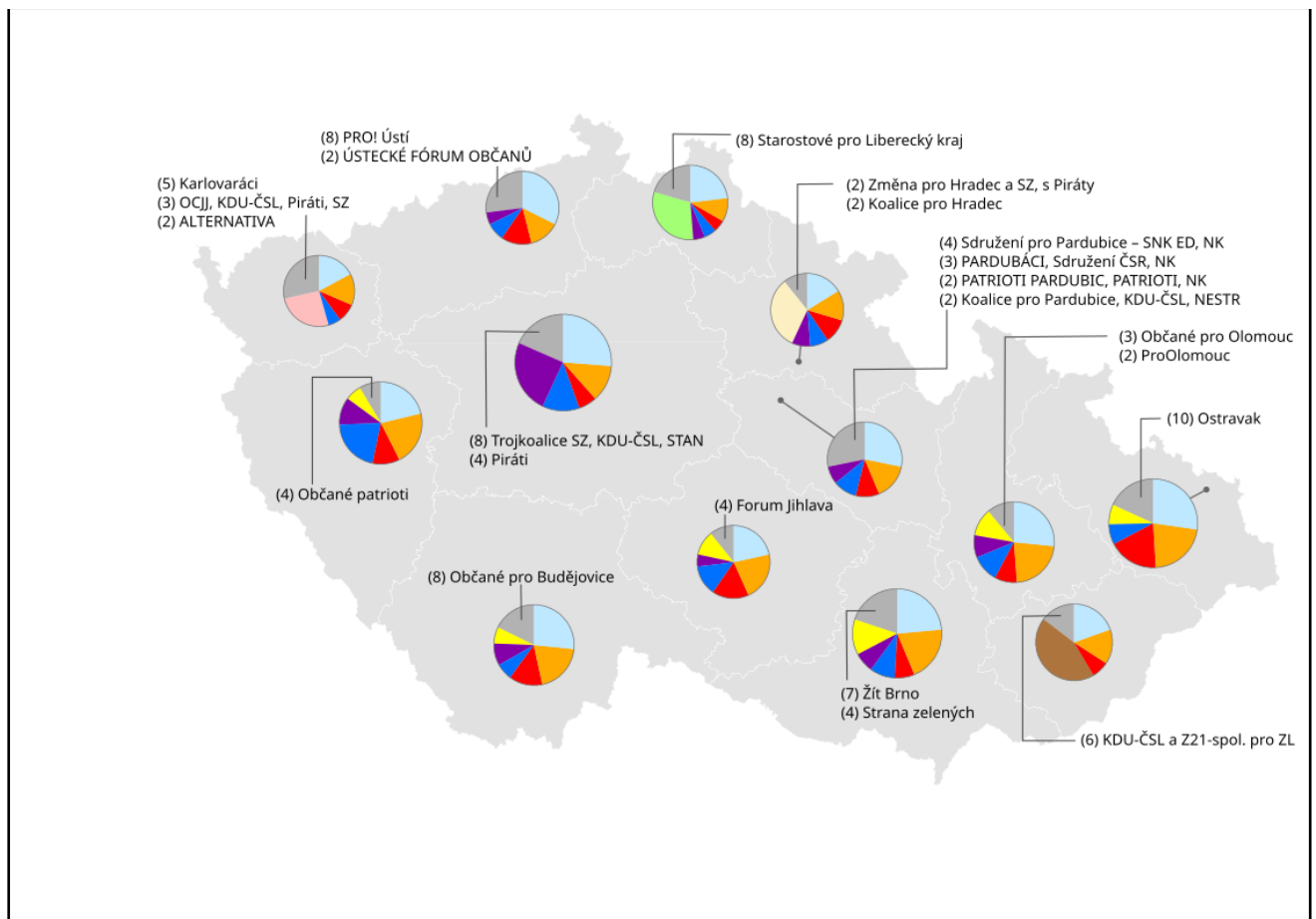
These are the so-called composition elements and together they form a map layout, also known as a map composition.

We are going to investigate an example map and decompose it into individual elements.



A map with proper composition: Map image, title, scale, legend, imprint and north arrow.

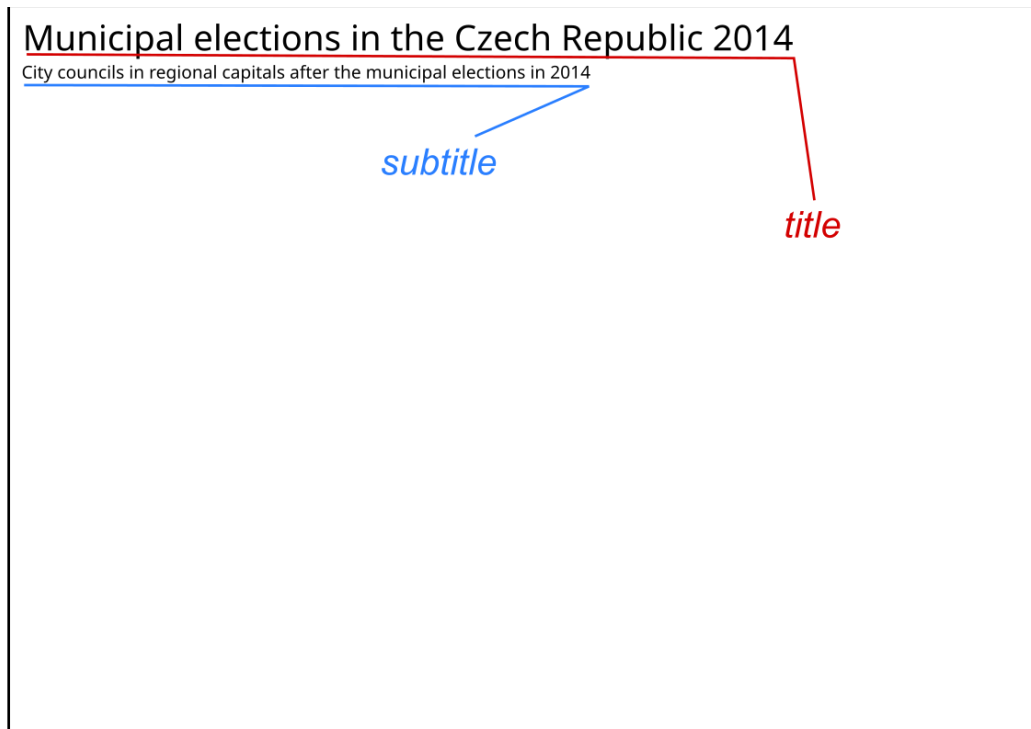
Map image is the core part of the whole map. It is the spatial data interpreted with a certain cartographic technique to convey an information, a message or a point of view. Yet the map image itself cannot convey any meaningful information on its own. As you can see on the picture below, if the map image is not accompanied with other elements, the content of the map would be a pure guess.



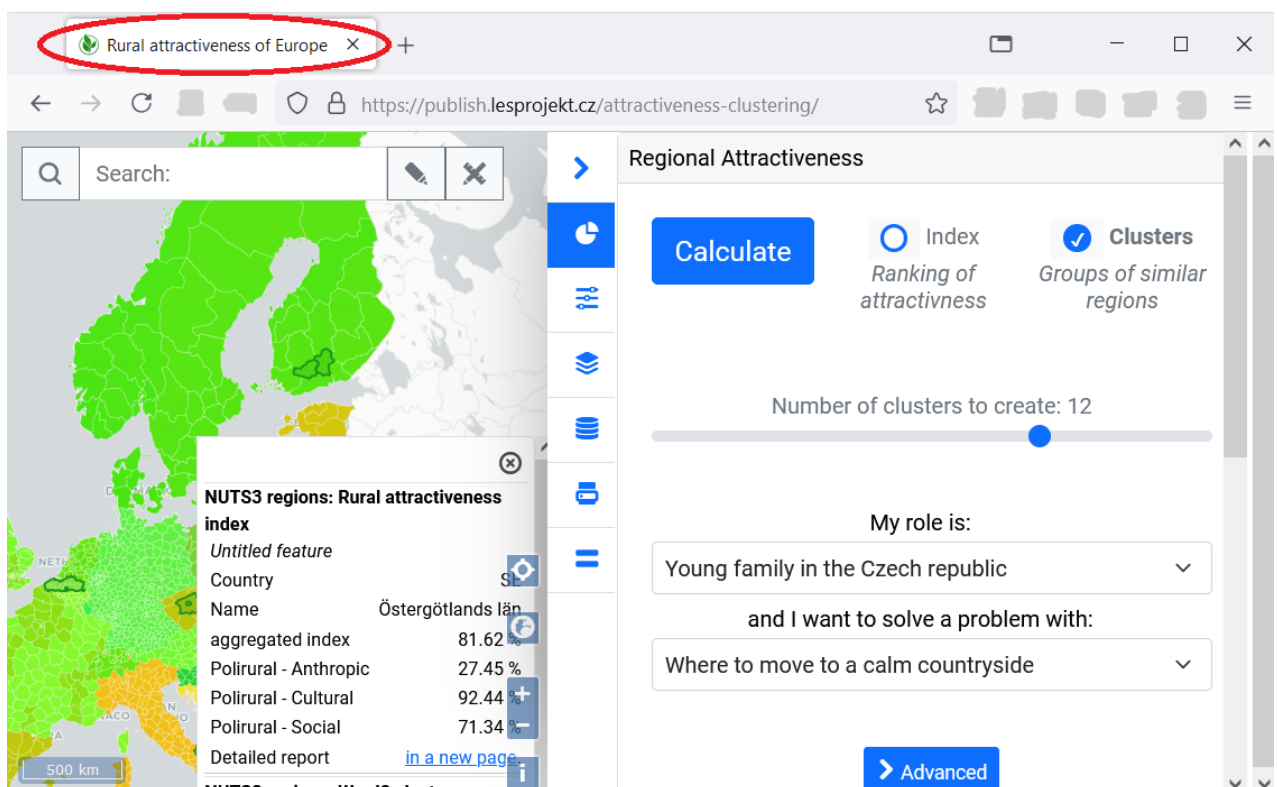
Map image without any other composition elements.

The first element that helps the map reader to understand the content of the map is a **title**. Title shall be brief but also descriptive and specific. Typically, there is no reason for the map to have the word “map” in its title. A good title might be e.g. “Crop production in Benin in 2020” or “Trujillo from satellite”, while bad examples might be “Map of crop production” or “What a detail! The image from the sky shows every street of our city. Can you find your house?”.

If the title would be too long, it is a good idea to split the headline, so it is displayed as a title and a subtitle. In such a case, the title gives the reader a coarse idea of what is the topic of the map and the subtitle specifies the topic in a little more detail. In the digital era, maps are often presented as web pages. In such a case, map title can be displayed as a regular page title in the web browser.

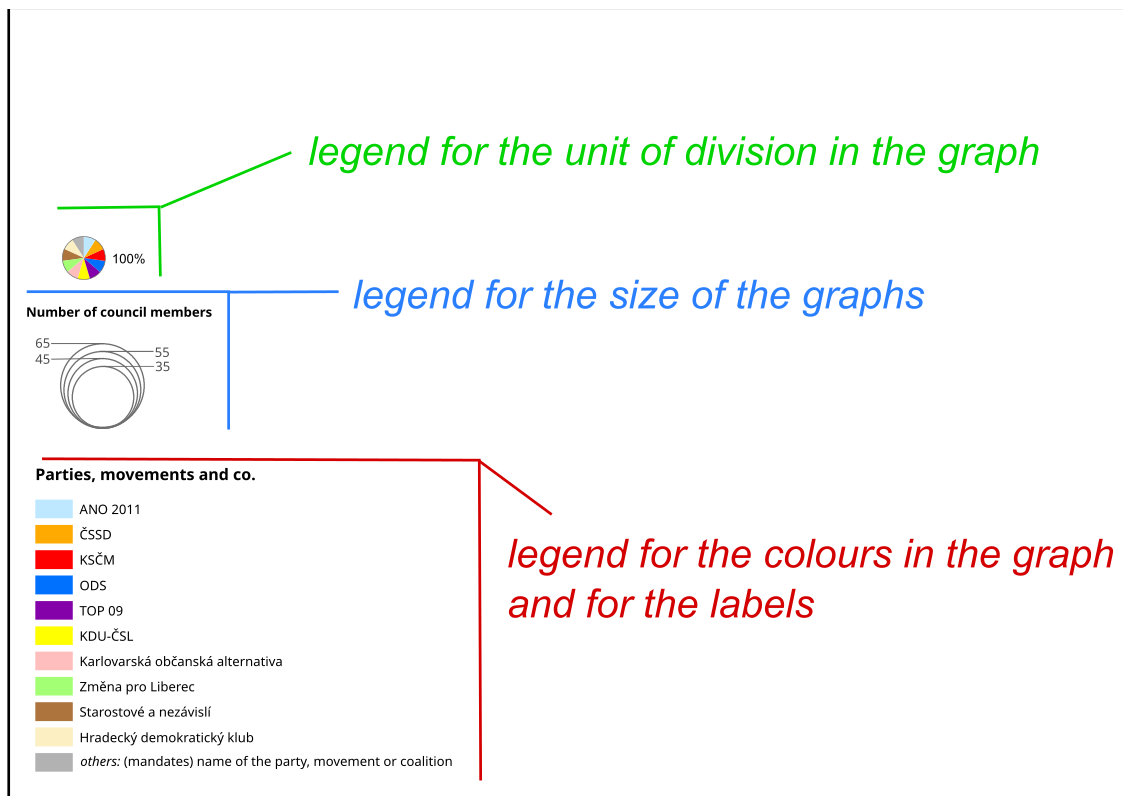


A brief title gives a coarse idea what the topic of the map is. It is further specified in the subtitle.



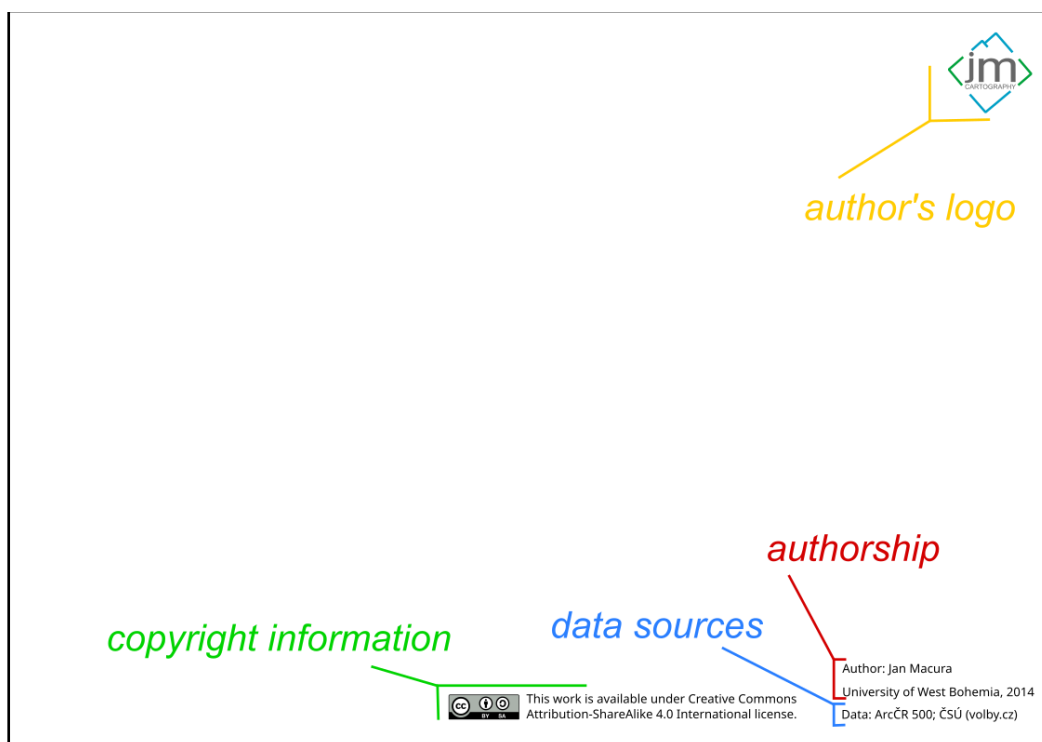
Interactive digital map presented as a web page with title highlighted.

While a title explains *what* is displayed in the map, **legend** explains *how* it is displayed. Through the charts, textual explanations and map symbols, the reader shall understand all the content visible on the map. With the use of the legend, the reader shall be ultimately able to *read* the map and to *understand* it. Usually, there is no good reason to headline a legend with the word “Legend”.



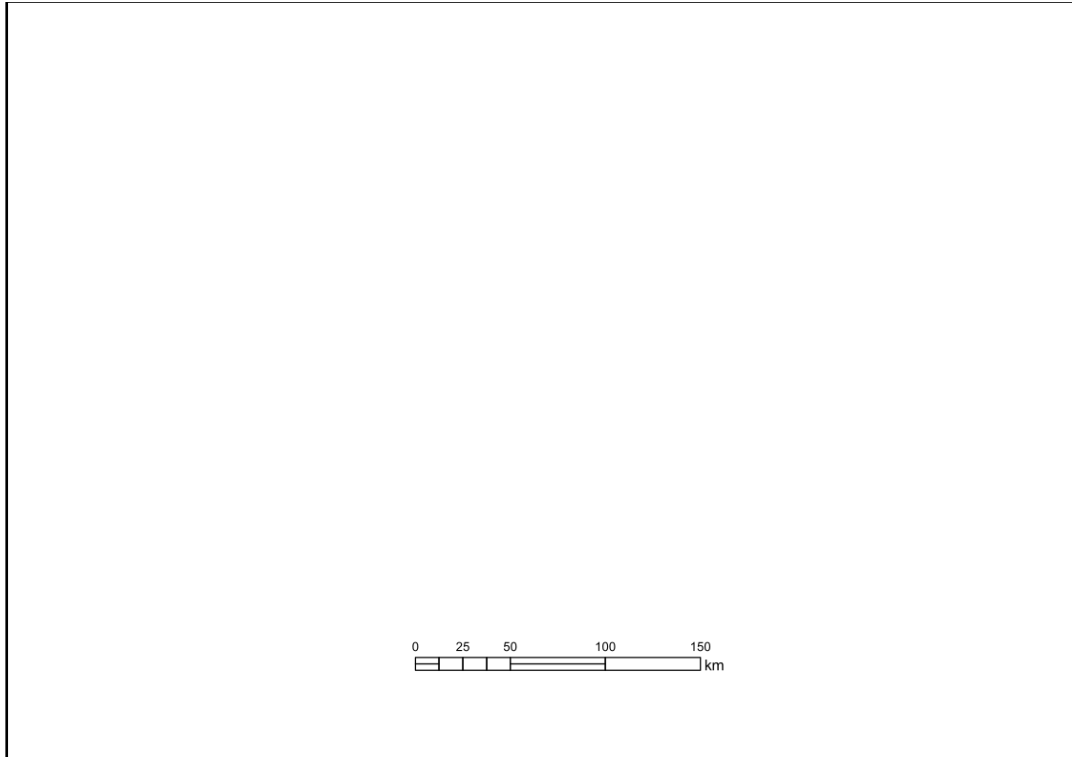
The example map contains three legends as it displays three types of information: a) the ratio of the council seats each party occupies depicted as a fraction of a circle (graph), b) the size of the city council as a number of seats represented as as size of the circle (graph) and c) specific parties represented by their associated colour in the graphs.

Imprint is a brief description of the map's author, date of creation, source of map's spatial data, copyright, etc. In the digital world, imprint is usually replaced with metadata records.



The imprint of the example map is quite generous.

The **scale** of a map is the ratio of a distance on the map to the corresponding distance on the ground. Scale can be represented as a numeric value (e.g. 1:10 000) or as a graphical scale-bar. Rarely, it can be described using words. Scale and north arrow can be omitted if a geographic graticule is present over the map. Numerical scale is also not appropriate for largely distorted maps (see lecture “Map Projections and Coordinate Systems”).



On the example map, the scale is depicted as a graphical bar.

As mentioned in the lecture “History of Mapping”, the orientation of maps has evolved. Nowadays, we can generally see two orientations:

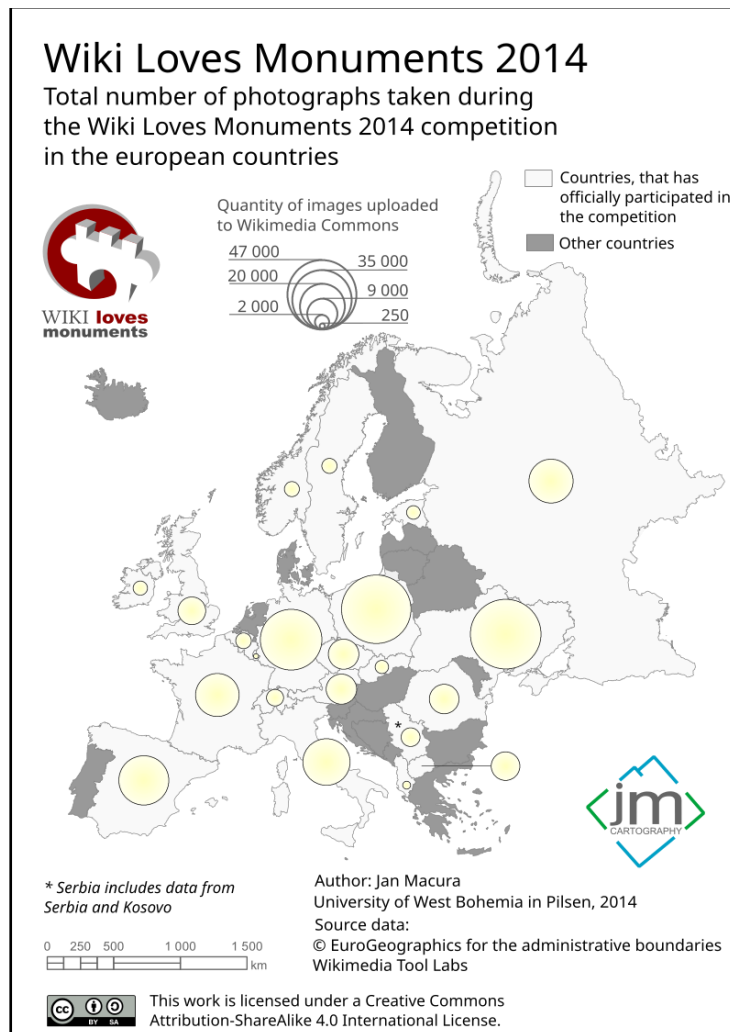
- to the north or
- to the direction of the viewer.

The former is the most common orientation of printed maps, while the latter is a popular option for digital interactive maps in handheld devices like mobile phones or smart watches. Especially in the case the map is static (printed), a **north arrow** is an important element, as it helps the reader to *orient* the map into a direction which corresponds with the world around them. North arrow can be displayed in various shapes from a simple arrow to more complex symbols. It might be accompanied with a letter “N” or the word “north”. Some maps do not contain a north arrow, when they display the whole world or continent, which is expected to be known to any potential reader, especially with the standard orientation having the north on the top. In cases like this, a north arrow is considered redundant.



An example of a north arrow.

Additionally, the map layout can be enriched with other composition elements like images, charts, texts, inset maps, etc.



This map has one additional composition element: an illustration (image / logo) to the topic.

Map image itself usually comprises various elements: labels, annotations, symbols. The set of all symbols, marks and colours used in the map is called a **symbolology** of the map and is explained through the map legend.

Quiz

Match element with its graphic representation

- title,
- scale,
- legend,
- north arrow,
- imprint.

Map Projections and Coordinate Systems

Map projection is a technique used to display the spherical shape of the Earth on a flat surface. It's a conversion of the 3D shape of Earth to 2D form. There are endless variants of how a map projection

can project the earth surface on a plane. Every map projection must grow or diminish some characteristics, including size, shape, distance, direction, and/or scale.

Maps inherently involve distortions because it is impossible to perfectly unfold the surface of a three-dimensional globe onto a two-dimensional plane. When a globe is projected onto a flat surface, some aspects of the map must be distorted, whether it be shape, area, distance, or direction. Different map projections preserve different metrics to suit specific purposes. However, no single projection can preserve all these properties simultaneously, which is why different projections are used depending on the map's intended purpose.

There are three main groups of projections depending on a property they preserve:

- **Conformal projections** (like the Mercator projection) preserve **angles and shapes** locally, making them useful for navigation.
- **Equal-area projections** (like the Mollweide projection) maintain **area** accuracy, ensuring that the relative size of regions is correct.
- **Equidistant projections** (like Plate carée) preserve **distances** along certain lines.

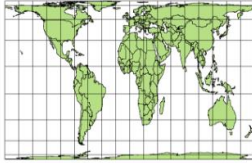
Beside that, a map projection can be constructed in such a way that none of the above-mentioned properties are preserved, but distortions of all of these are somewhat minimized. These are called **compromise projections**.



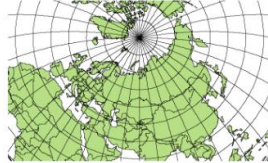
Mollweide-Projektion



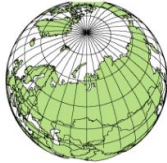
Mercator-Projektion



Peters-Projektion



Längentreue Azimuthalprojektion



Senkrechte Umgebungsperspektive



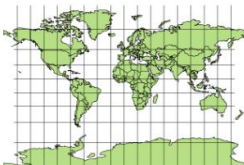
Robinson-Projektion



Gnomonische Projektion



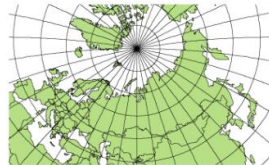
Flächentreue Kegelprojektion



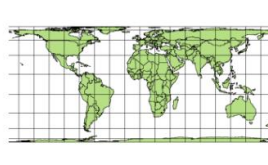
Zylinderprojektion nach Miller



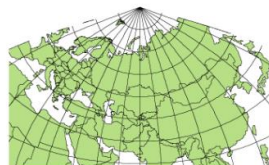
Hammer-Aitoff-Projektion



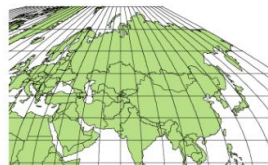
Stereographische Projektion



Behrmann-Projektion



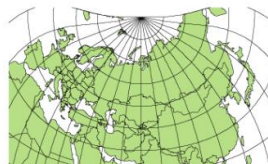
Hotine Oblique Mercator-Projektion



Sinusoidale Projektion



Transverse Mercator-Projektion

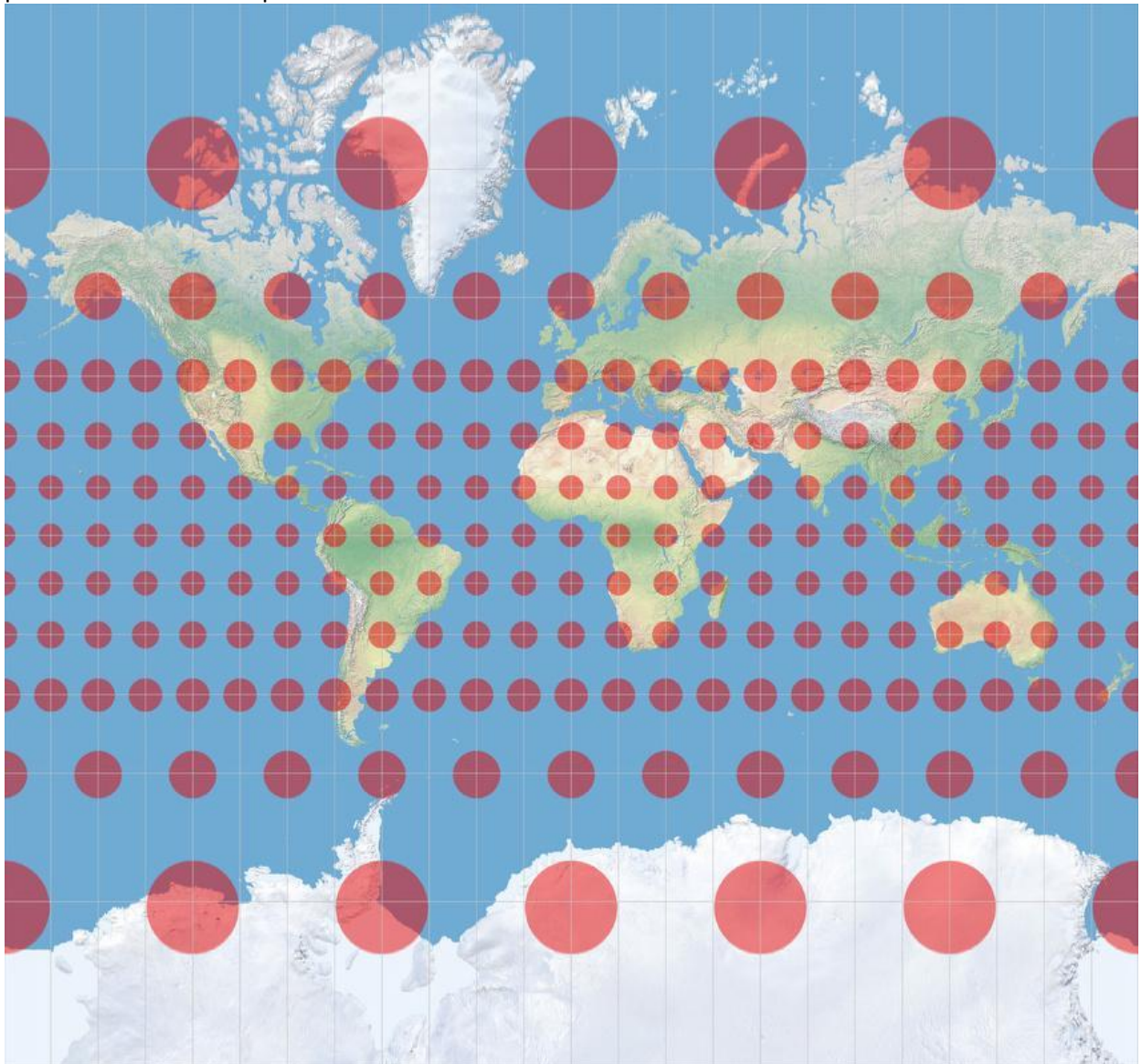


Cassini-Soldner-Projektion

Some common map projections / Maximilian Dörrbecker, CC BY-SA 3.0.

How a certain projection distorts shapes can be observed on a circle with a fixed diameter when drawn on multiple places over the map. Such a circle is called a *Tissot indicatrix*. Under conformal

projections, the Tissot's indicatrix remains circle, but its size is variable across the map. Under equal-area and equidistant projections, the Tissot's indicatrix can be a circle on certain places, but in most places distorts to an ellipsis.



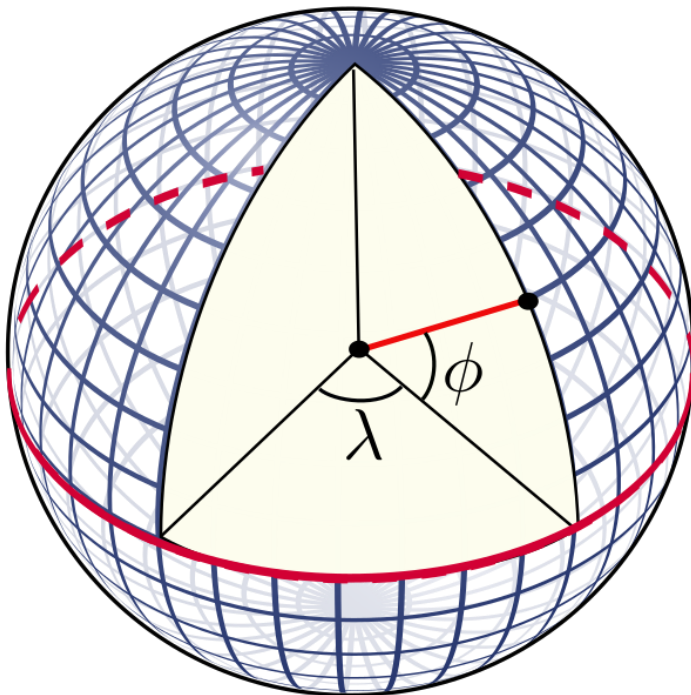
Mercator projection with Tissot's indicatrix. <https://map-projections.net/tissot.php>

A **coordinate system** is a method used to identify the exact position of a point in space using numbers called coordinates. In simple terms, it assigns a set of values (commonly marked as "x", "y", ...) to each point, helping us locate where something is. For example, in a 2D space, the "x" coordinate tells us how far left or right a point is, and the "y" coordinate tells us how close or far away.

A **spatial reference system (SRS)** or **coordinate reference system (CRS)** is a framework used to precisely measure locations on the surface of Earth as coordinates. A particular SRS specification comprises a choice of Earth ellipsoid, horizontal datum, map projection, origin point and unit of measure. As possibilities of how an Earth's surface can be projected to a plane are endless, there are endless ways to define a spatial reference system. Thousands of various SRS have been specified for use around the world or in specific regions and for various purposes. As a consequence, transformations between different SRS are often required.

We can divide spatial reference systems into two groups depending on whether they work with geographic (spherical) coordinates or if they work in projected space with cartesian coordinates. A **geographic coordinate system** represents the Earth as a perfect sphere and any place on the Earth surface can be described by two numbers denoted by greek letters λ and ϕ . λ is called longitude and ϕ is called latitude. Longitude and latitude are angles in degrees and can only take on certain values. Longitude values are restricted from -180 to 180, while latitude values are restricted from -90 to 90. In this representation, negative longitude represents the western hemisphere and positive longitude represents the eastern hemisphere. Similarly, negative latitude represents the southern hemisphere and positive latitude represents the northern hemisphere. Alternatively, the hemisphere can be denoted by a big letter after the value like 49° N stands for latitude 49 degrees north or 15° S means latitude 15 degrees south. A point exactly in the cross-section of the main meridian and the equator is on neither hemisphere and its geographic coordinates are [0,0]. This point can be theoretically anywhere, but in the most commonly used geographic coordinate system WGS84, it is in reality inside of an Atlantic ocean, thus it does not point to any special place.

A great circle with a constant longitude is called a meridian. A prime meridian is a meridian with longitude equal to 0. Most widely known is the Greenwich prime meridian, yet others have been in use historically and even nowadays. A great circle with latitude equal to 0 is an equator. Circles parallel to the equator are called parallels or circles of latitude.



Earth as a sphere with meridians and parallels in blue, equator as a red line and latitude and longitude angles in black.

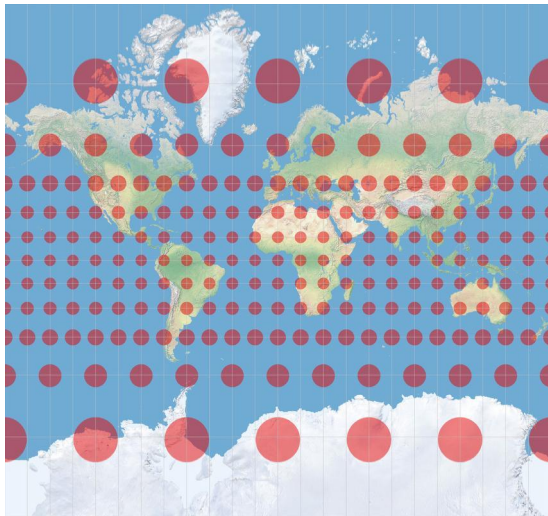
Most commonly used SRS with a geographic coordinate system is WGS84, a realisation of the World Geodetic System standard.

While a geographic coordinate system defines locations on a spherical surface, a **cartesian coordinate system** (also known as projected coordinate system) represents locations on a flat, two-dimensional surface. The Earth's surface (or a piece of it) is *projected* on a plane using one of the map projections. Most common cartesian coordinate systems are based on a Mercator projection, like the **UTM (Universal Transverse Mercator)** or **Web Mercator**. Even a **Pulkovo 1942** system is a cartesian coordinate system using Gauss-Krüger projection, which is also a variant of Mercator projection.

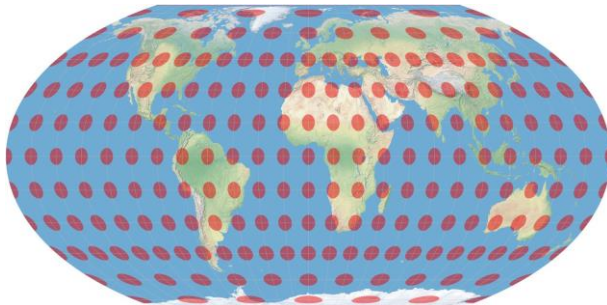
To identify coordinate systems (both geographic and cartesian), projections and mutual transformation without confusion, a unique database called EPSG exists. It references all common coordinate systems, projections etc. by an “EPSG:” string followed by a numeric code. E.g. WGS84 system has EPSG code EPSG:4326, while Web Mercator has code EPSG:3857 and Pulkovo 1942 has code EPSG:4284. These codes are used to identify coordinate systems in geographic information systems (GIS) but also elsewhere.

Quiz

Match a projection with its description



- Preserves angles, distorts sizes



- Preserves sizes, distorts lengths

Spatial Data Acquisition Methods

From all spatial data acquisition methods, **ground surveying** has the longest history. As mentioned in the chapter “History of Mapping”, first measurements of the Earth involved measuring distances between not so distant places. A groundbreaking measurement was done by Eratosthenes of Cyrene in the 3rd century BCE. Eratosthenes used only primitive tools available at that time: a *gnomon* and a wheel. Gnomon is a simple pole placed perpendicular to the earth surface. By measuring the revolutions of a wheel of Eratosthenes carriage and the length of a shadow casted by gnomon on two different places, Eratosthenes was able to calculate quite precisely the Earth’s circumference more than 2200 years ago. His approach inspired much later measurements in 16th century France.

When better and more precise instruments were invented, the measurements of earth also improved. Josef Liesgang in the 18th century used a telescope to measure angles between objects on an observable horizon. By also measuring a distance in several places, he was able to construct imaginary triangles of known sizes. Vertices of these triangles were well identified locations on hills or at build-up structures, like a cathedral tower. In principle, the same method is used up until today. An instrument named *theodolite* was a principal tool for measuring angles in the 19th and 20th century and is still used for simple tasks at construction works today. Theodolites were lately superseded by electronic *total stations*, an instrument capable of measuring both angles and distances at the same time. Nowadays total stations are robotic, meaning they can turn in a desired direction by a remote control. They are also often combined with GNSS apparatuses in order to calculate the most accurate results in the field, without further post-processing, which is essential for smooth work on construction sites.

Global Navigation Satellite Systems (GNSS) work by determining the precise location of a receiver on Earth through the use of satellite signals. The basic principle behind GNSS relies on measuring the time it takes for a signal to travel from a satellite to a receiver. Each GNSS satellite continuously transmits signals that include the satellite's position and the precise time the signal was sent. The receiver on the ground records the time at which the signal was received. By calculating the time difference between when the signal was emitted and when it was received, the receiver can determine its distance from that satellite.

Since the receiver only knows its distance from the satellite (and not the direction), it could be located anywhere on a sphere with that radius. To accurately pinpoint its location, the receiver needs signals from at least four satellites. When data from these satellites are combined, the receiver calculates its position through a process called trilateration. The intersection of spheres from multiple satellites allows the receiver to determine its exact position in three dimensions (latitude, longitude, and altitude). This process accounts for time discrepancies by solving for both the receiver's position and the receiver's clock error, making GNSS an accurate and reliable method for global positioning.

First GNSS system was an American military system NAVSTAR GPS or shortly just GPS. Its positional accuracy was initially obscured for civil usage and location with sub-metre accuracy was only available for military applications. Civil receivers were only able to determine its location with a precision of several metres. This obfuscation of NAVSTAR GPS was removed in 2000. With the evolution of GNSS receivers for public geodetic users, a positional accuracy of several centimetres is possible. This is thanks to the approach of using phase measurements of the GNSS carriage wave. As of 2024, four GNSS systems are fully operable worldwide. Beside the american-based NAVSTAR GPS, it is a russian system GLONASS, chinese system Beidou and european system Galileo. Japan is building a GNSS system specifically suited for the east Asian region. These GNSS systems not only vary in the country in which its operation centre resides and which government funds its operation, it also differs in the technical aspects like the frequency of the carriage wave, the number, height and angle (inclination) of the satellites on the Earth's orbit, the speed in which the satellites orbit the Earth, number of waves they transmit and others.

Where the NAVSTAR GPS signal was not ideal or better precision was required, systems for local enhancement of GPS, named SBAS systems, were developed. From these systems, European EGNOS is notable, as the predecessor of EU's own Galileo system.

Generally, an acquisition of spatial information from distance, without making a physical contact with the observed area, is called **remote sensing**. Collecting spatial data remotely involves aerial photography, satellite imagery or LiDAR (Light Detection and Ranging) techniques.

Taking photographs from aircrafts belongs to older remote sensing techniques. The process of acquisition of precise survey photographs is called **photogrammetry**. Aerial photography can provide images with a high resolution, but collecting data for a large area is slow and expensive. Satellite images usually provide worse resolution, but a wider area can be covered. Nowadays, satellite images cover a whole world and are often used as base-layers in popular online maps like Google Maps. Recently, unmanned aerial vehicles (UAVs) allowed to take very detailed photographs of a small area, while being cheap. Photographs acquired using these techniques can be processed into orthophotos, orthophoto maps and even 3D models of terrain.

Imagery from aerial, satellite and UAV photogrammetry does not have to capture visible spectrum of light like common cameras do. Information obtained from near-infrared, infrared and other parts of the spectrum are useful for applications in forestry, agronomy and elsewhere.

LiDAR technique is based on targeting an object or a surface with a laser. The time travelled by the reflected light back to the receiver is calculated to distance. As a laser can emit the light beam to thousands of points in a second, the output of LiDAR is usually a large set of distances between the laser device and the observed object or terrain. Consequently, the distances are transformed into points in locations where the laser beam has been reflected. The set of these points is called a point cloud. A process of collecting laser data is called **laser scanning**.

Quiz

Match a spatial data acquisition technique with its description:

- Remote sensing – acquisition of spatial information from distance
- Laser scanning – capturing precise 3D information about objects or terrain in the form of dense point clouds
- Ground surveying – measuring of angles and distances in order to represent features by specific points and lines
- GNSS technique – determining precise locations on Earth by receiving signals from multiple satellites

Using Maps

Quality maps and accurate map use are essential in many everyday fields, including but not limited to:

- **Navigation and Transportation:** For driving directions, public transit planning, and logistics, maps help people and goods get from point A to B efficiently. Beyond basic navigation, spatial data and map data are essential in **traffic management and congestion prediction** within transportation. By analysing real-time traffic patterns and historical data on traffic flow, transportation departments can identify congestion hotspots, monitor traffic incidents, and adjust signals or implement detours to alleviate bottlenecks. Spatial data also supports **infrastructure planning**, helping planners decide where to add new roads, bike lanes, or pedestrian paths to improve mobility and reduce travel times across urban areas.
- **Urban Planning:** Maps support city planners in designing layouts for roads, green spaces, and utilities to optimise land use and improve quality of life. A specific example of how maps support city planners is the use of **heat maps** to identify urban "heat islands"—areas where buildings, roads, and infrastructure cause higher temperatures due to limited vegetation. By overlaying temperature data on city maps, planners can pinpoint neighbourhoods that would benefit from additional green spaces, like parks, green roofs, or tree-lined streets. This mapping not only helps reduce local temperatures and improve air quality but also

enhances residents' quality of life by creating cooler, more pleasant areas for recreation and reducing energy costs for cooling in nearby buildings.

- **Disaster Management:** Maps help emergency responders plan for and respond to natural disasters, ensuring they can reach affected areas and allocate resources effectively. An example is the use of **flood risk maps** by emergency responders during hurricane season to plan evacuations and allocate resources. These maps, which combine elevation data, rainfall predictions, and historical flood patterns, help responders identify areas most likely to flood and the severity of potential impacts. By pinpointing high-risk zones, emergency teams can prioritize evacuations, position rescue teams and supplies nearby, and set up shelters on higher ground. During the response, these maps are updated with real-time data, guiding teams to the hardest-hit areas and helping coordinate the delivery of resources like food, water, and medical aid.
- **Agriculture:** Farmers and agricultural companies use maps to plan crop layouts, manage soil quality, and monitor resources like water availability. A specific example is the use of **soil nutrient maps** created from satellite and drone data to help farmers manage crop layouts and optimise fertiliser use. These maps display varying nutrient levels across a field, allowing farmers to apply fertilisers only where they're needed rather than uniformly across the entire field. This targeted approach, known as **precision agriculture**, improves crop yields, reduces waste, and minimises environmental impact by preventing nutrient runoff into nearby water sources.
- **Environmental Conservation:** Maps are crucial for tracking wildlife habitats, managing natural resources, and planning conservation efforts to protect ecosystems. For example **migration maps**, created with GPS tracking data, are used to monitor animal movements, such as those of African elephants. Conservationists use these maps to identify critical migration corridors and feeding grounds, allowing them to prioritise areas for habitat protection and create safe passages across human-altered landscapes. This data can also reveal where elephants encounter threats like poaching or habitat fragmentation. By understanding these migration patterns, conservation teams can work with local governments to designate protected areas, implement anti-poaching patrols, and establish wildlife corridors that connect fragmented habitats.
- **Retail and Marketing:** Businesses use maps to find the best locations for stores, analyse customer demographics, and plan delivery routes. One specific example is how *Starbucks* uses geographic information systems (GIS) to choose new store locations. By layering maps with customer demographic data, such as income levels, age groups, and spending habits, they identify areas with high potential customer density and suitable purchasing power. GIS also helps analyse foot traffic and proximity to other businesses, like office complexes or universities, where coffee demand is typically higher.

Exercise 1: Creating a Soil Nutrient Map

Objective: Use soil nutrient data to create a map in QGIS.

Steps:

1. **Load the Data:**
 - Open QGIS and create a new project.
 - Go to **Layer > Add Layer > Add Vector Layer** to load field boundary data (e.g. shapefile or GeoJSON).
 - Load soil nutrient data as a raster or tabular file (e.g. CSV with latitude, longitude, and nutrient levels).

2. **Visualise the Field Boundaries:**
 - Right-click the field boundary layer > **Properties** > **Symbology**.
 - Choose a suitable outline or fill colour for easy visibility.
3. **Create a Soil Nutrient Raster (if data is tabular):**
 - Use **Processing Toolbox** > **Interpolate Points**.
 - Select the nutrient column as the input field.
 - Choose **IDW** (Inverse Distance Weighted) or **Kriging** as the interpolation method.
 - Save the output as a raster layer.
4. **Style the Nutrient Map:**
 - Right-click the nutrient raster > **Properties** > **Symbology**.
 - Select **Singleband pseudocolor**.
 - Set a colour gradient to represent low-to-high nutrient values (e.g. red for low, green for high).
 - Adjust the legend to clearly show nutrient ranges.
5. **Add a Legend:**
 - Go to **Project** > **Layout Manager** to create a new layout.
 - Insert the map and a legend using the **Add Legend** tool.
6. **Export the Map:**
 - Save the layout as a PDF or PNG for future use.

Exercise 2: Analysing and Deciding Fertiliser Zones

Objective: Use the nutrient map to identify areas for targeted fertiliser application.

Steps:

1. **Classify the Nutrient Map:**
 - Right-click the nutrient raster > **Properties** > **Symbology**.
 - Use **Classified** symbology to group nutrient levels into 3–5 ranges (e.g. Very Low, Low, Medium, High, Very High).
2. **Draw Fertiliser Zones:**
 - Add a new vector layer:
 - Go to **Layer** > **Create Layer** > **New Shapefile Layer**.
 - Select **Polygon** geometry.
 - Use the **Add Polygon Feature** tool to draw polygons around areas requiring fertiliser.
3. **Label the Zones:**
 - Right-click the new vector layer > **Properties** > **Labels**.
 - Enable labelling and set the nutrient level range as the label text.
4. **Export the Results:**
 - Save the fertiliser zone layer for use in subsequent exercises.
 - Export the map layout showing the nutrient zones and recommended fertiliser areas.

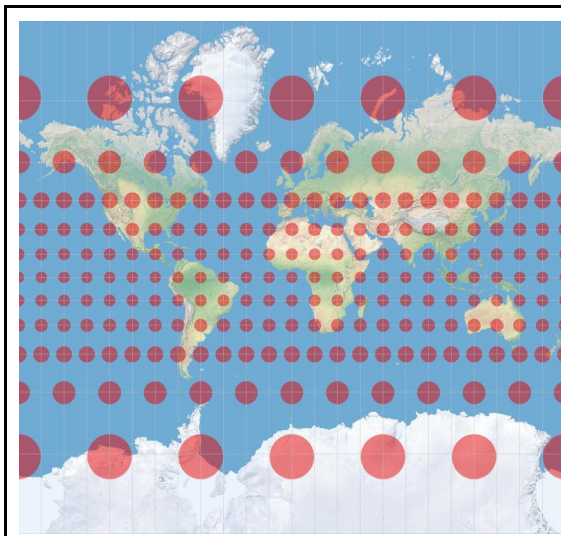
Course Final Quiz

1. Match a term with its description

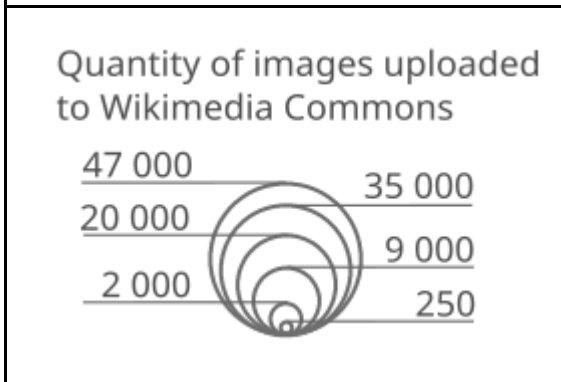
map	downscaled or simplified drawing of the earth's surface, or part of that
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	surface
geographic data	data representing features or phenomena related to the Earth
laser scanning	capturing precise 3D information about objects or terrain in the form of dense point clouds
GNSS technique	determining precise locations on Earth by receiving signals from multiple satellites

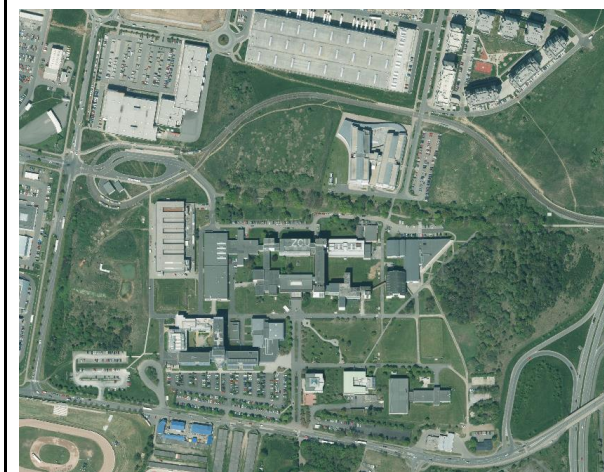
2. Match an image with the most suitable description



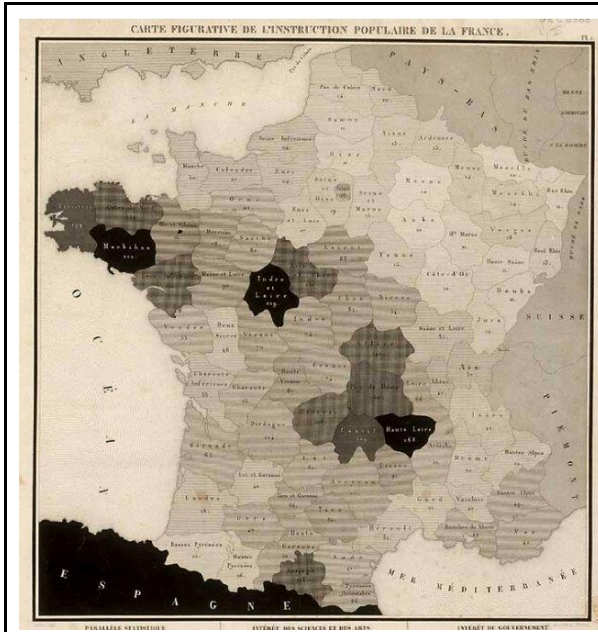
A projection which preserves angles but distorts sizes.



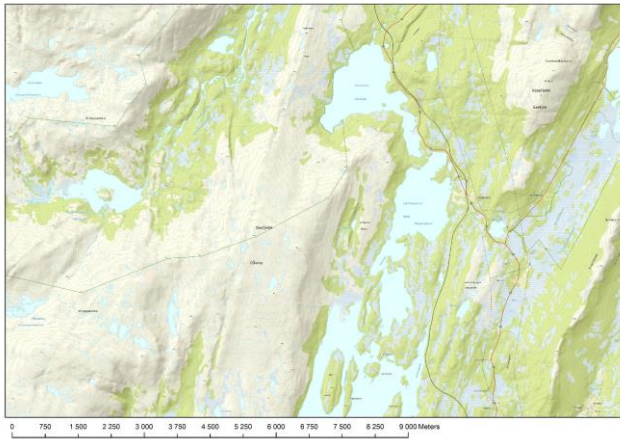
Map legend



Orthophoto



Statistical map by Pierre C. F. Dupin



Topographic map

3. Look at the following map and answer questions:
 - a. Which ecoregion is presented in yellow color? (Great Plains, Arctic Cordillera, Tropical Dry Forests)
 - b. Which ecoregion(s) stretches most to the north? (Arctic Cordillera, Tundra, Hudson Plain)
 - c. In which part of the continent Tropical Dry Forests can be found? (south, north, west)

ecoregions

of North America



Water	Hudson Plain	Eastern Temperate Forests	Southern Semiarid Highlands
Arctic Cordillera	Northern Forests	Great Plains	Temperate Sierras
Tundra	Northwestern Forested Mountains	North American Deserts	Tropical Dry Forests
Taiga	Marine West Coast Forest	Mediterranean California	Tropical Wet Forests

Source: Iva Brunec via X.com