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Chapter 16: Introduction to Geographic Information Systems

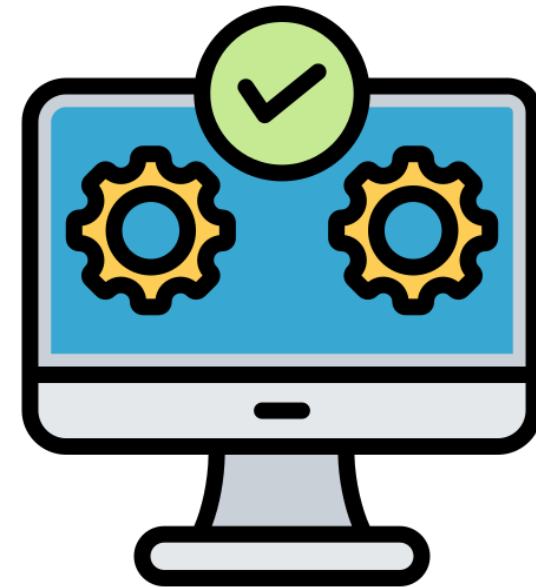


Information Systems (IT372)



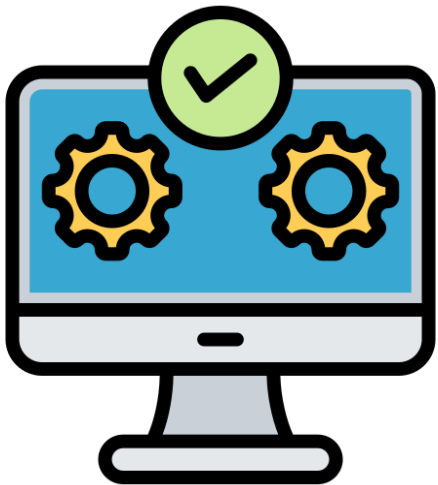
Introduction to Geographic Information Systems

- What is a GIS?
- Geographic Information System
- Importance of GIS
- Representations
- Raster
- Vector Data
- Geospatial Data Types
- Raster vs Vector

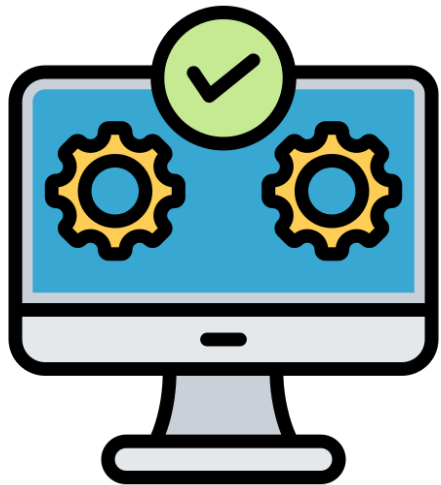




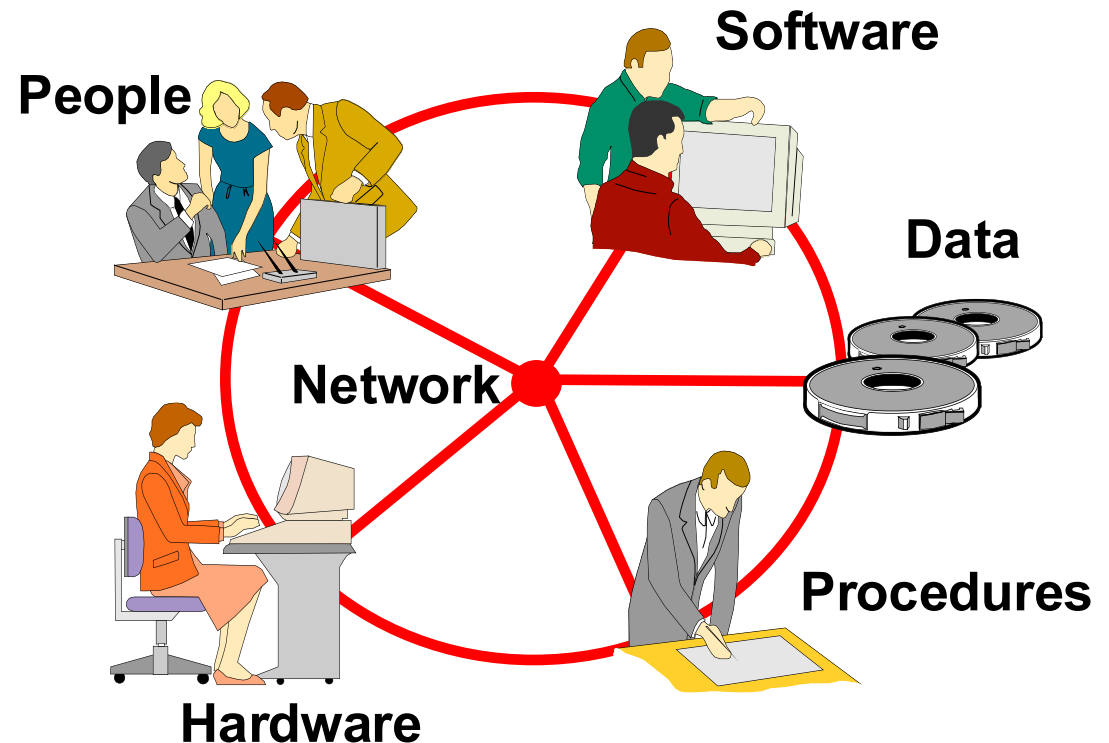
What is a GIS?

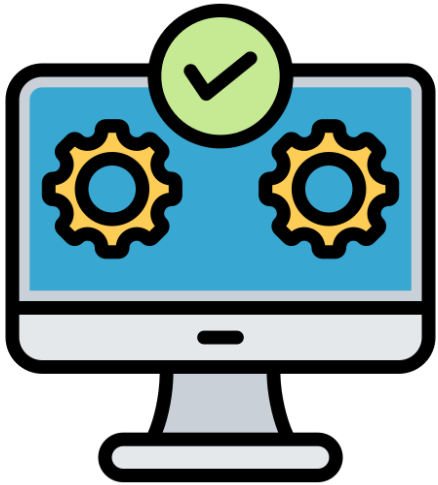


- A computer system capable of holding and using data describing places on the earth's surface.
- An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.
- GIS stands for Geographic Information System
- GIS is a computer-based system that captures, stores, manages, analyzes, and visualizes spatial data, including maps, satellite imagery, and other geospatial information
- GIS allows for the integration and analysis of data from multiple sources, helping to understand patterns, relationships, and trends in geographic data

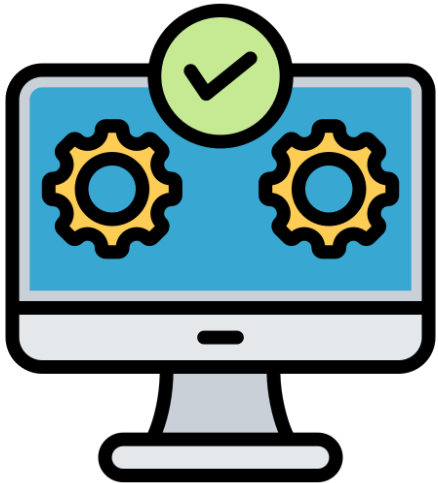


- Organized collection of
 - Hardware
 - Software
 - Network
 - Data
 - People
 - Procedures

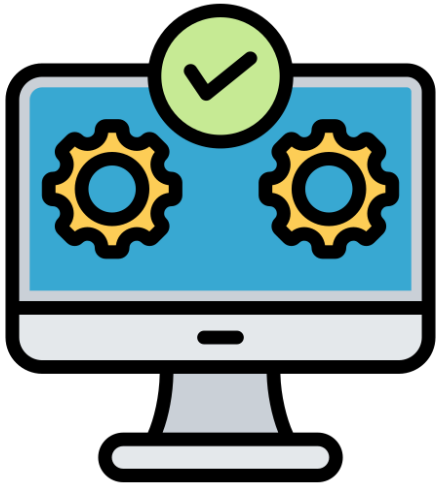




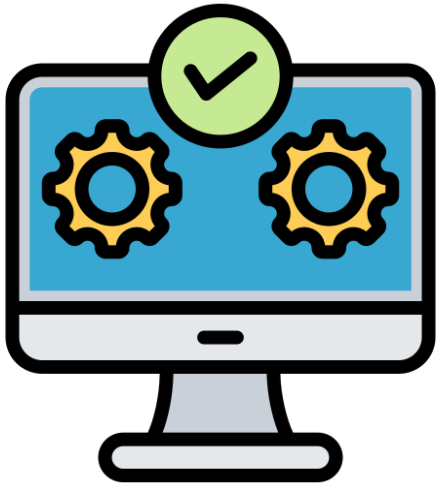
- **Data:** The foundation of GIS is data, including
 - ✓ spatial data (e.g., geographic features, locations) and
 - ✓ attribute data (e.g., characteristics, and attributes associated with spatial data)
- **Software:** GIS software enables the creation, management, analysis, and visualization of spatial data. e.g., ArcGIS, QGIS, and Google Earth
- **Hardware:** GIS requires hardware, such as computers, servers, and GPS devices, to process and store data
- **People:** Skilled GIS professionals are needed to operate and analyze GIS data, interpret results, and make informed decisions



- **Improved Decision Making:**
 - ✓ by providing visualizations, analysis, and insights from spatial data.
- **Spatial Analysis and Modeling:**
 - ✓ overlay analysis, proximity analysis, and network analysis.
- **Data Integration and Management:**
 - ✓ satellite imagery, aerial photography, GPS data, and other spatial datasets.
- **Visualization and Communication:**
 - ✓ maps, charts, and other graphical representations of spatial data.
- **Cost and Time Savings:**
 - ✓ GIS helps in optimizing resources, reducing costs
- **Environmental and Social Impact Assessment:**
 - ✓ infrastructure development, land use planning, and natural resource management.



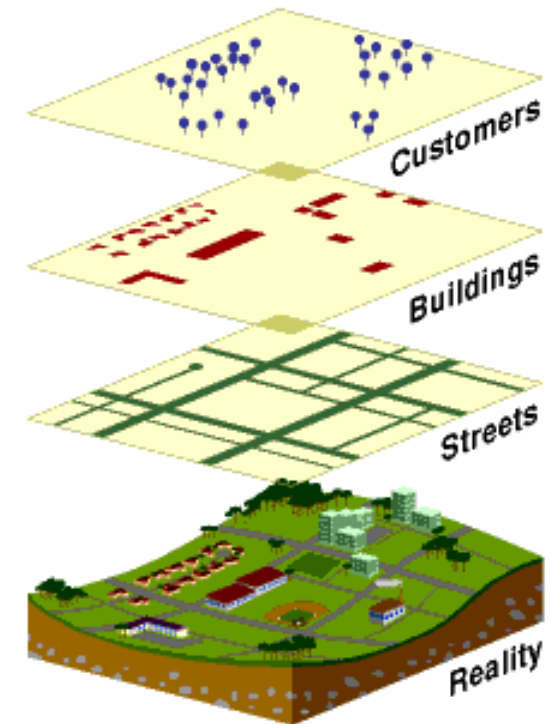
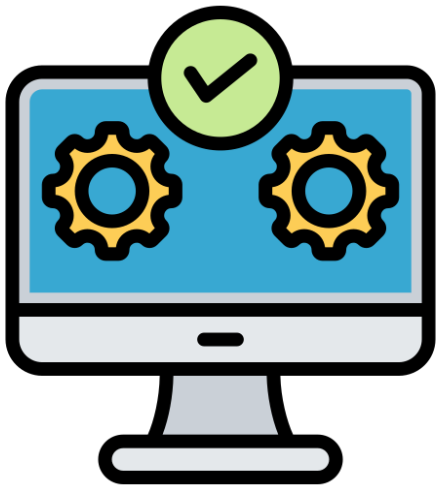
A GIS is a computer-based tool for mapping and analyzing things and events that are spatially located.



A GIS integrates common database operations with visualization and geographic analysis through the use of maps.

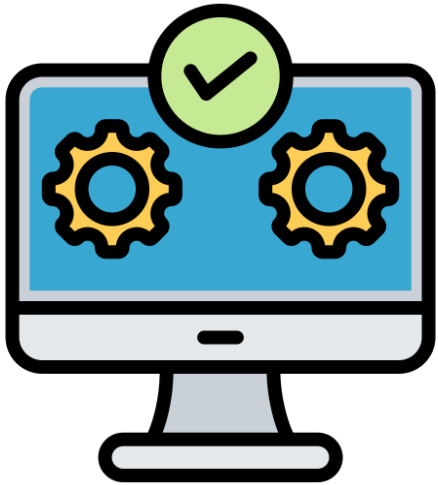


A GIS stores information as a collection of thematic layers that can be linked together by geography





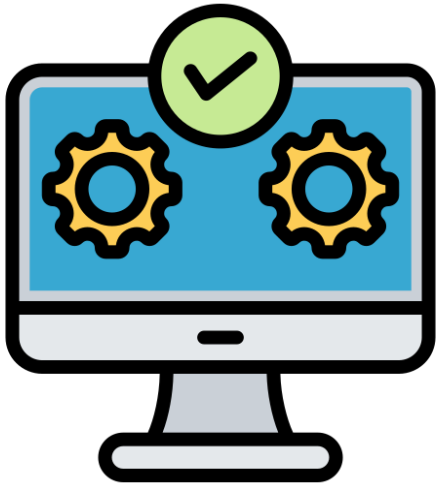
GIS helps people to:



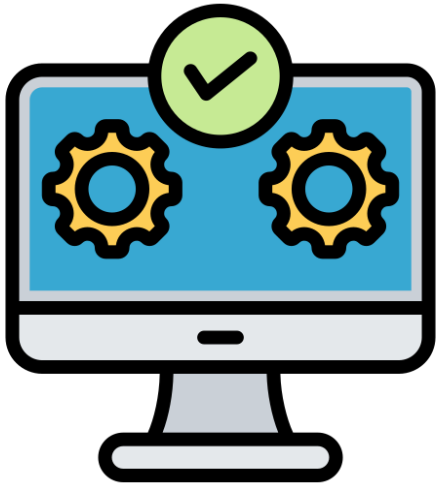
- Integrate information
- Visualize scenarios
- Solve complicated problems
- Present powerful ideas
- Develop effective solutions



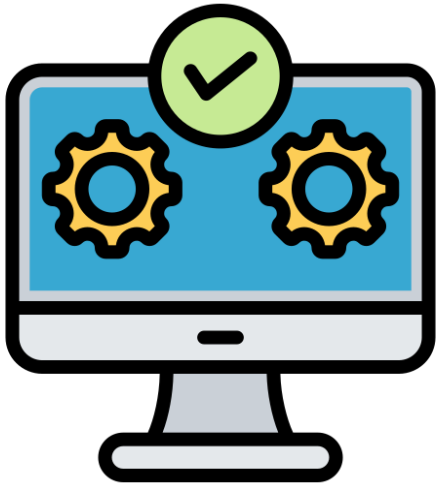
Representations Occur:



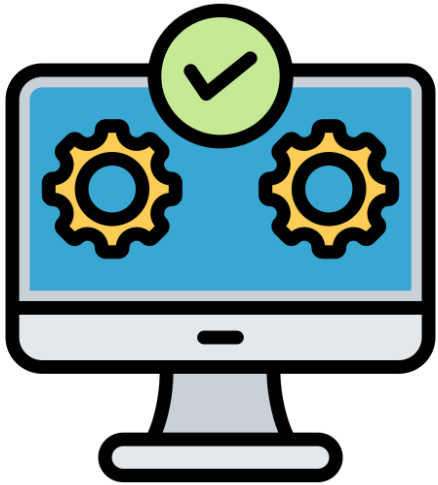
- In the human mind, when information is acquired through the senses and stored in memory
- In photographs, which are two-dimensional models of light received by the camera
- In written text, when information is expressed in words
- In numbers that result from measurements



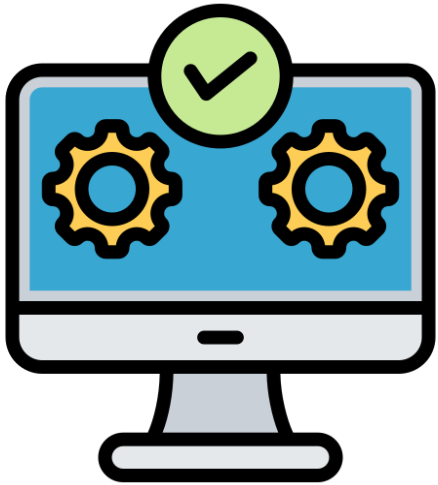
- Spatial data refers to data that has a geographic or spatial component, such as location, shape, and attributes associated with geographic features
- Spatial data can be represented as points, lines, polygons, or raster images, and can be stored in various formats, such as vector and raster
- Spatial data is the foundation of GIS, and it can be collected, created, and analyzed using GIS tools and techniques



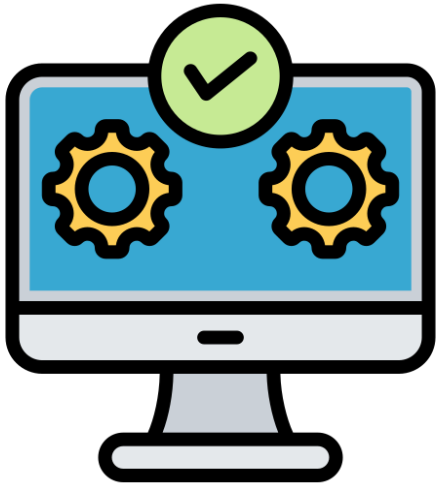
- How can we represent geographic information, conceptually and digitally?
- What are rasters and vectors?
- What are attributes?



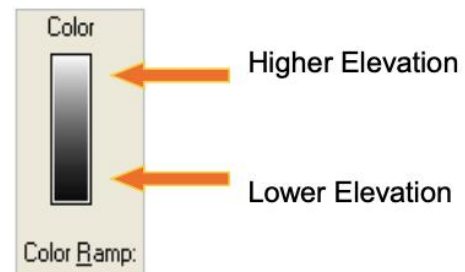
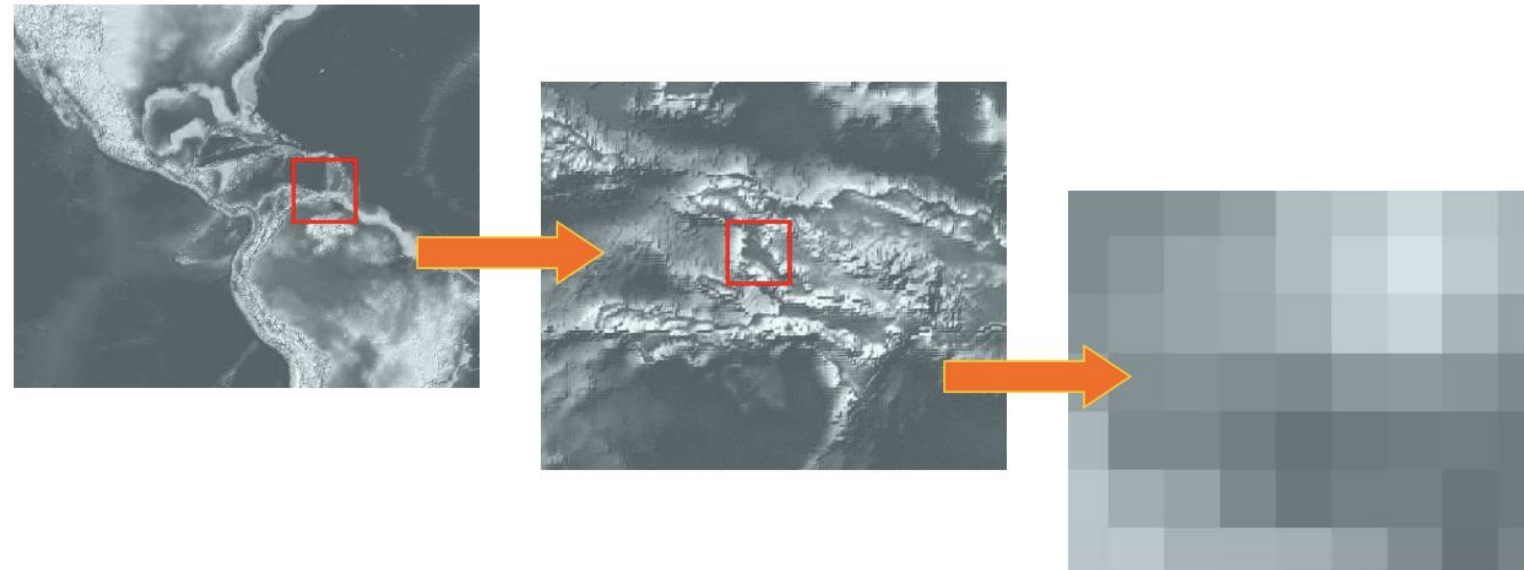
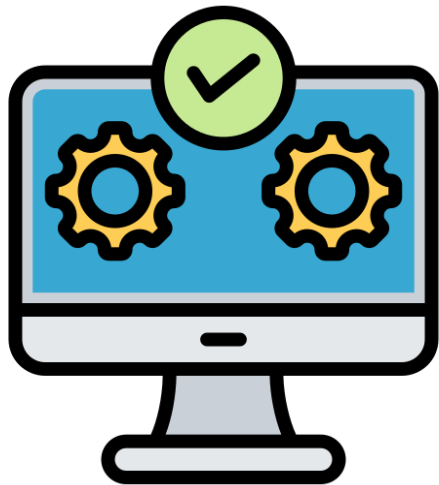
- Distributed through space
- Can be observed or described in the real world and identified by geographical location
- Change through space and time



- **GIS data can be categorized into two main types:**
 - ✓ **Vector data**
 - ✓ **Raster data**
- Vector data represents geographic features as points, lines, or polygons, and is used to represent discrete and well-defined features such as roads, buildings, and land parcels
- Raster data represents geographic features as a grid of cells, where each cell contains a value that represents an attribute or characteristic and is used to represent continuous data such as elevation, temperature, and precipitation

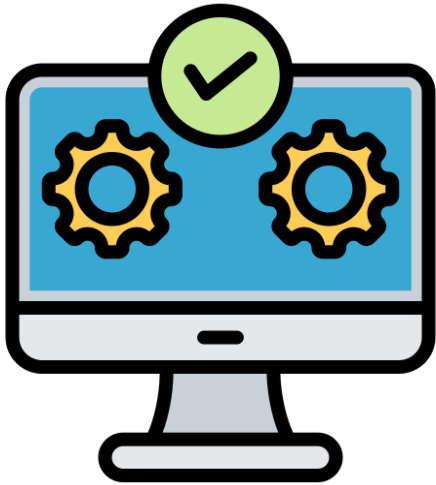


- How to represent phenomena conceived as fields or discrete objects?
- Raster
 - Divide the world into square cells
 - Register the corners to the Earth (known positions)
 - Represent discrete objects as collections of one or more cells
 - Represent fields by assigning attribute values to cells
 - More commonly used to represent fields than discrete objects





A raster data model uses a grid



- One grid cell is one unit or holds one attribute.
- Every cell has a value, even if it is “missing.”
- A cell can hold a number or an index value standing for an attribute.
- A cell has a resolution, given as the cell size in ground units.

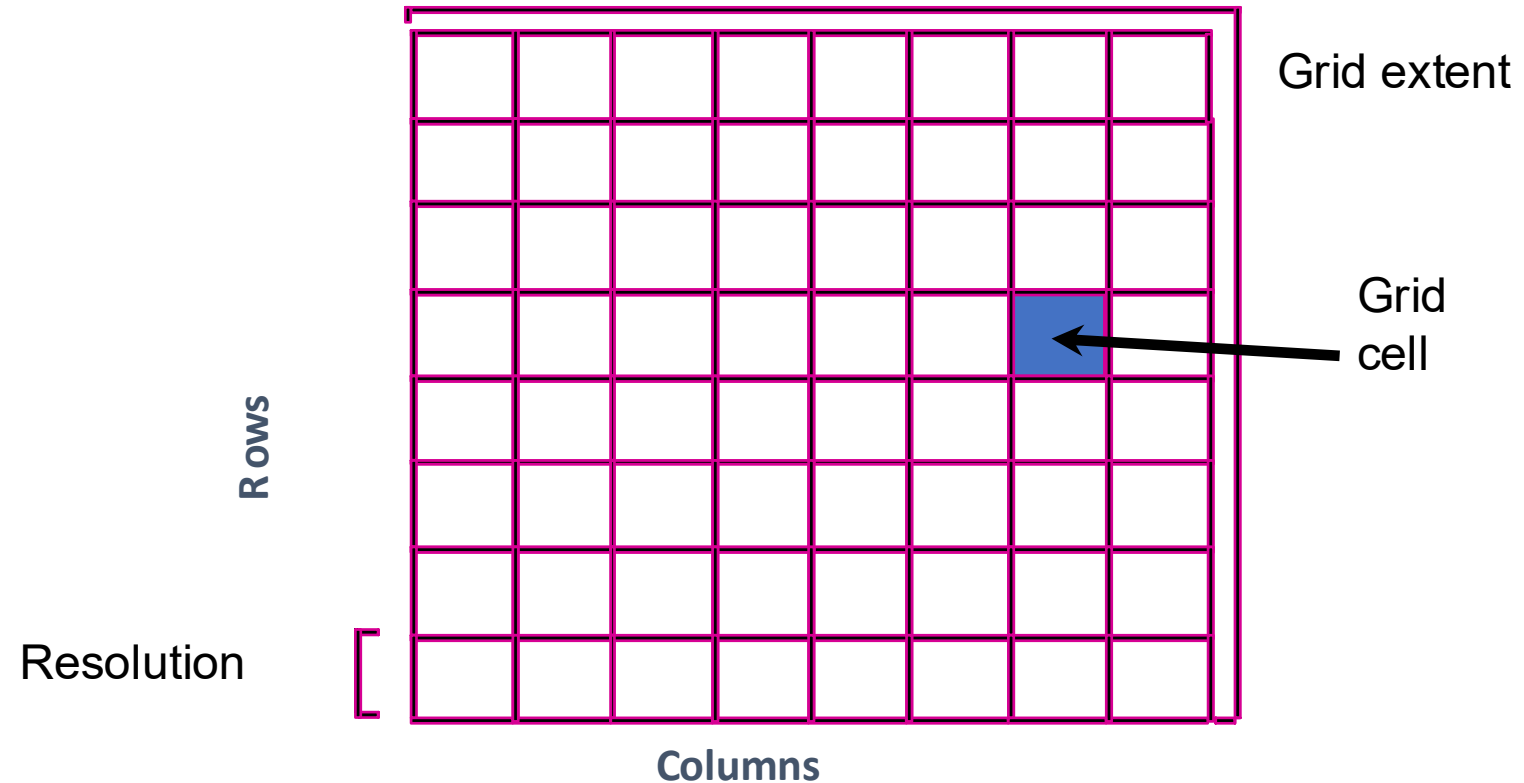
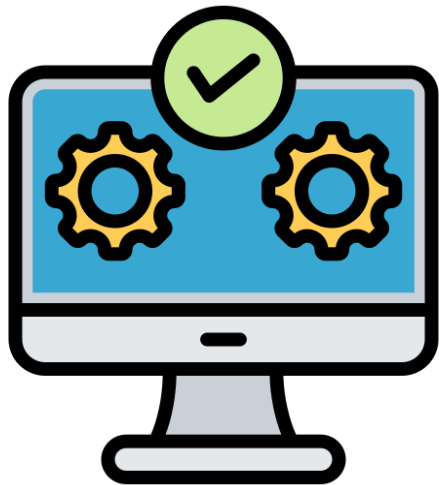
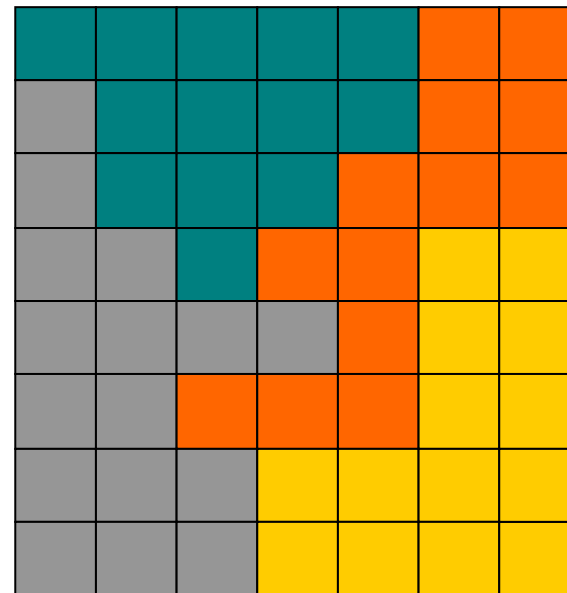
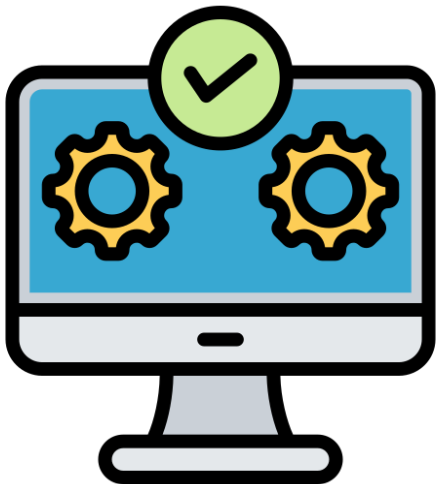


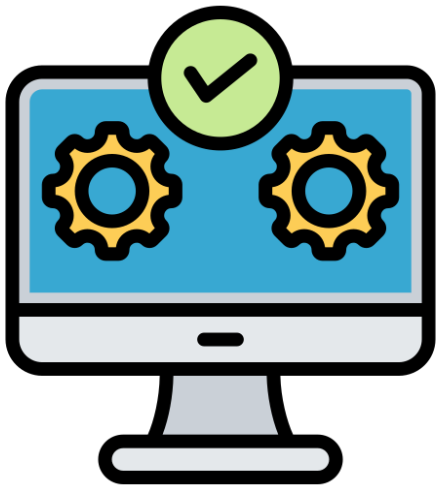
Figure 3.1 Generic structure for a grid.



Legend

-  **Mixed conifer**
-  **Douglas fir**
-  **Oak savannah**
-  **Grassland**

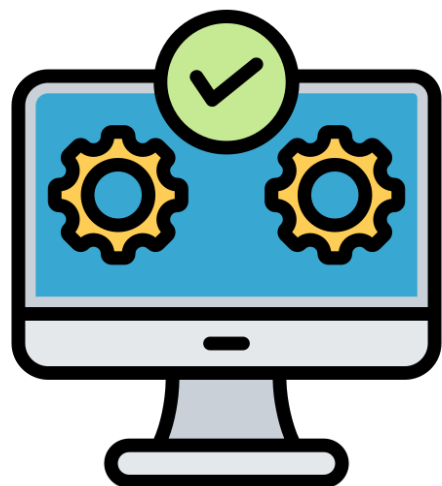
Raster representation. Each color represents a different value of a nominal-scale field denoting land cover class.



- Pixel size
 - The size of the cell or picture element, defining the level of spatial detail
 - All variation within pixels is lost!
- Assignment scheme
 - The value of a cell may be an average over the cell, or a total within the cell, or the commonest value in the cell
 - It may also be the value found at the cell's central point



The mixed pixel problem



Water

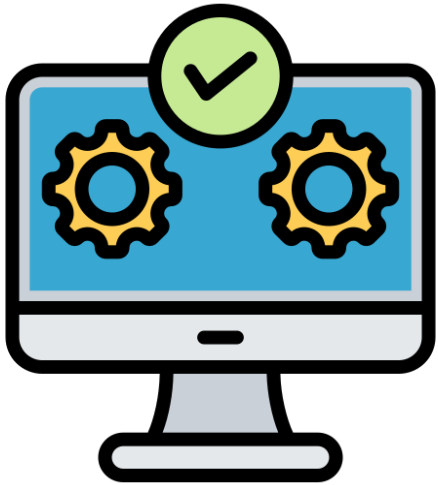
W	W	G
W	W	G
W	W	G

Water

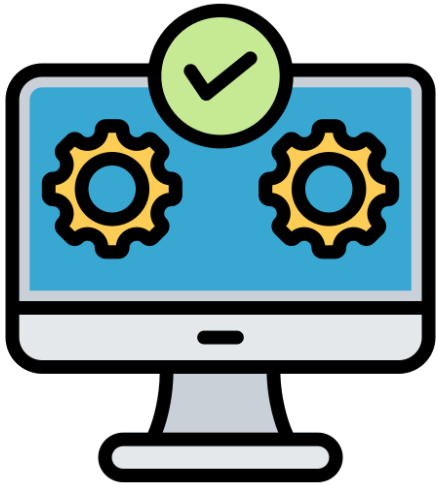
W	G	G
W	W	G
W	G	G

Edge

W	E	G
W	E	G
E	E	G



- Used to represent points, lines, and areas
- All are represented using coordinates
 - One per point
 - Areas as polygons
 - Straight lines between points, connecting back to the start
 - Point locations recorded as coordinates
 - Lines as *polylines*
 - Straight lines between points



Polygon

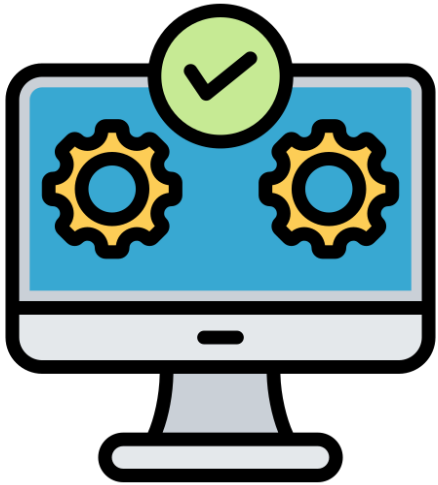
Line

Point

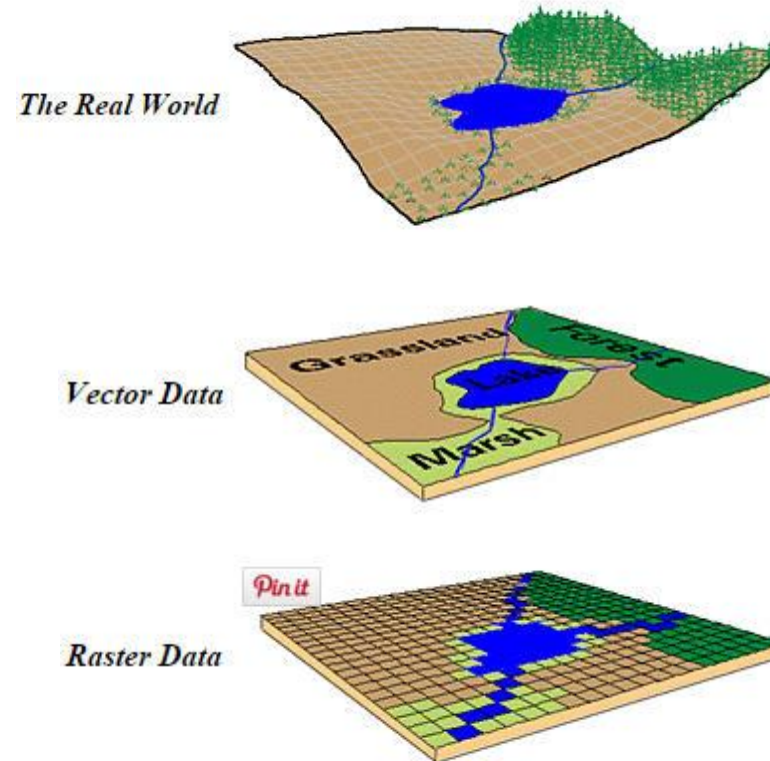
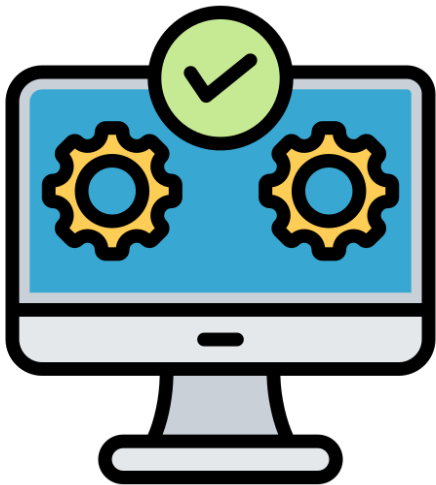
Vector data
are also
called
Shapefiles



The Vector Model



- A vector data model uses points stored by their real (earth) coordinates.
- Lines and areas are built from sequences of points in order.
- Lines have a direction to the ordering of the points.
- Polygons can be built from points or lines.
- Vectors can store information about topology.



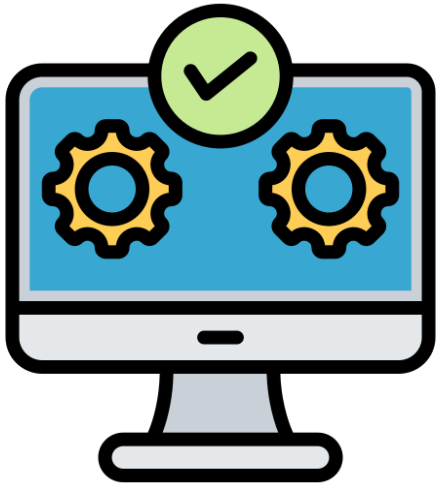
Geospatial or coordinate data can be represented in two different data formats:

Vector:

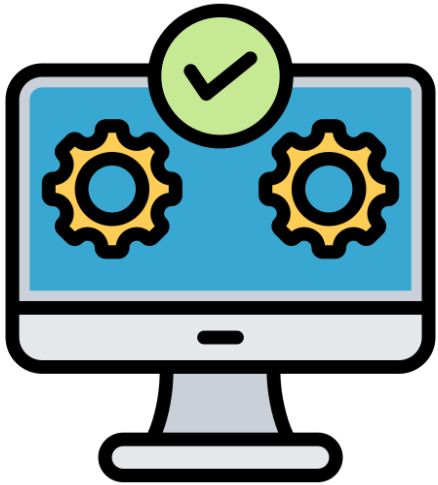
e.g. points, lines, and polygons

Raster:

e.g. row and column matrix



- Volume of data
 - Raster becomes more voluminous as cell size decreases
- Source of data
 - Remote sensing, elevation data come in raster form
 - Vector favored for administrative data (boundaries)
- Software
 - Some GIS better suited to raster, some to vector



- Simple geographic features can be used to build more complex ones.
- Areas are made up of lines, which are made up of points represented by their coordinates.
- Areas = {Lines} = {Points}

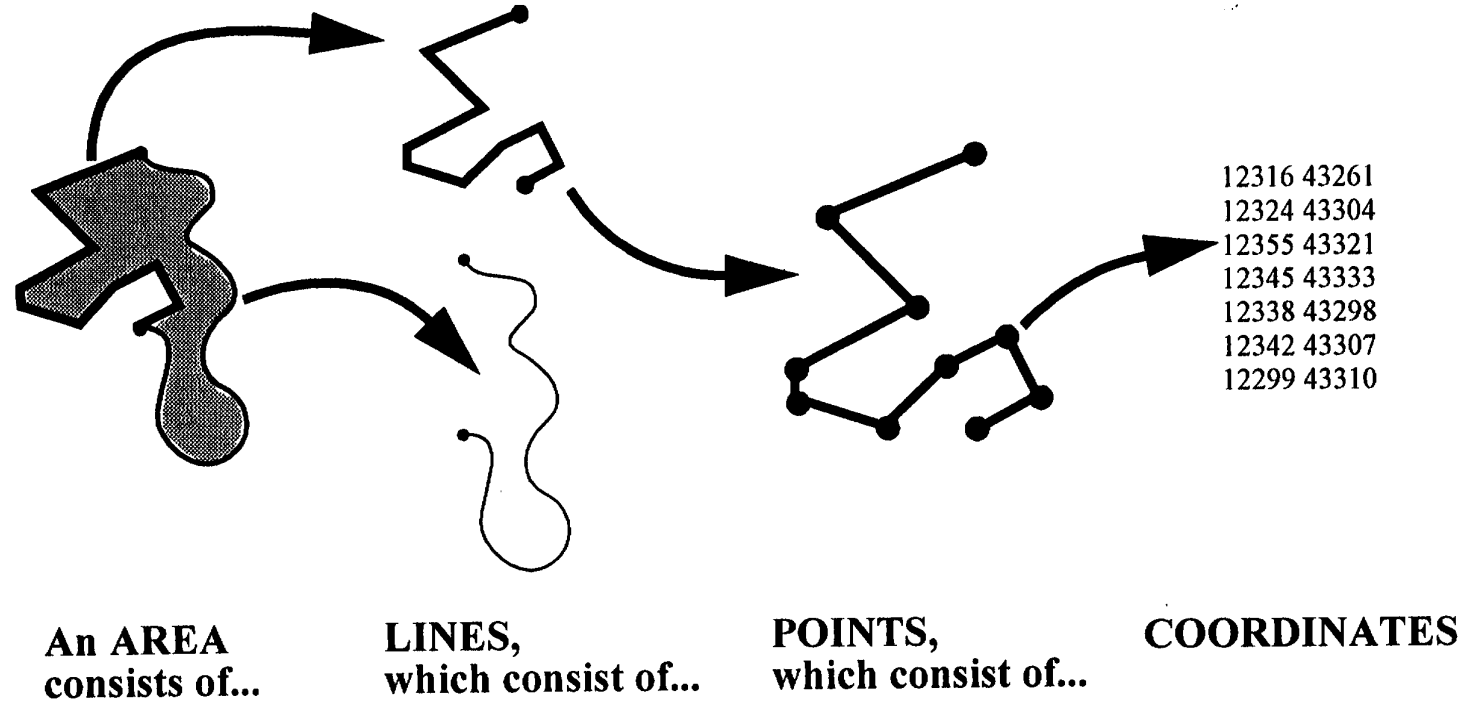
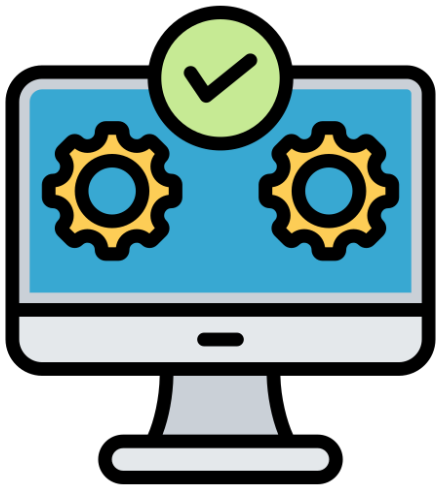
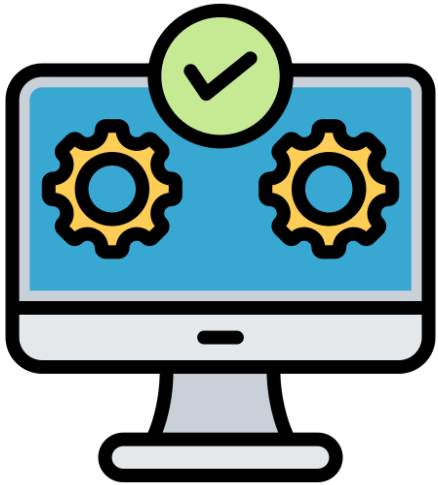
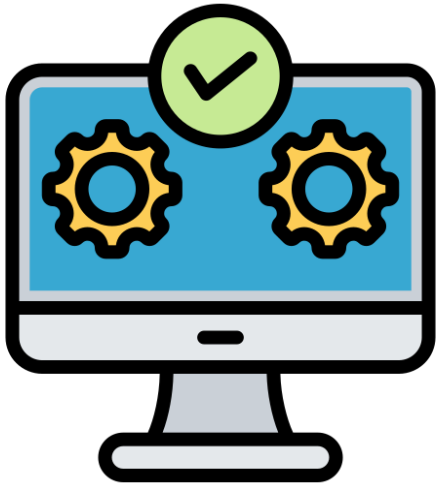


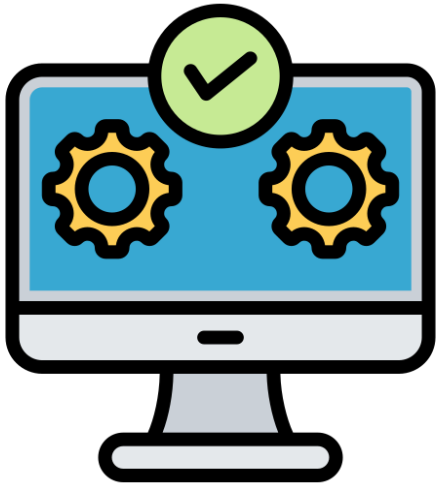
Figure 2.16 Geographic information has *dimension*. Areas are two-dimensional and consist of lines, which are one-dimensional and consist of points, which are zero-dimensional and consist of a coordinate pair.



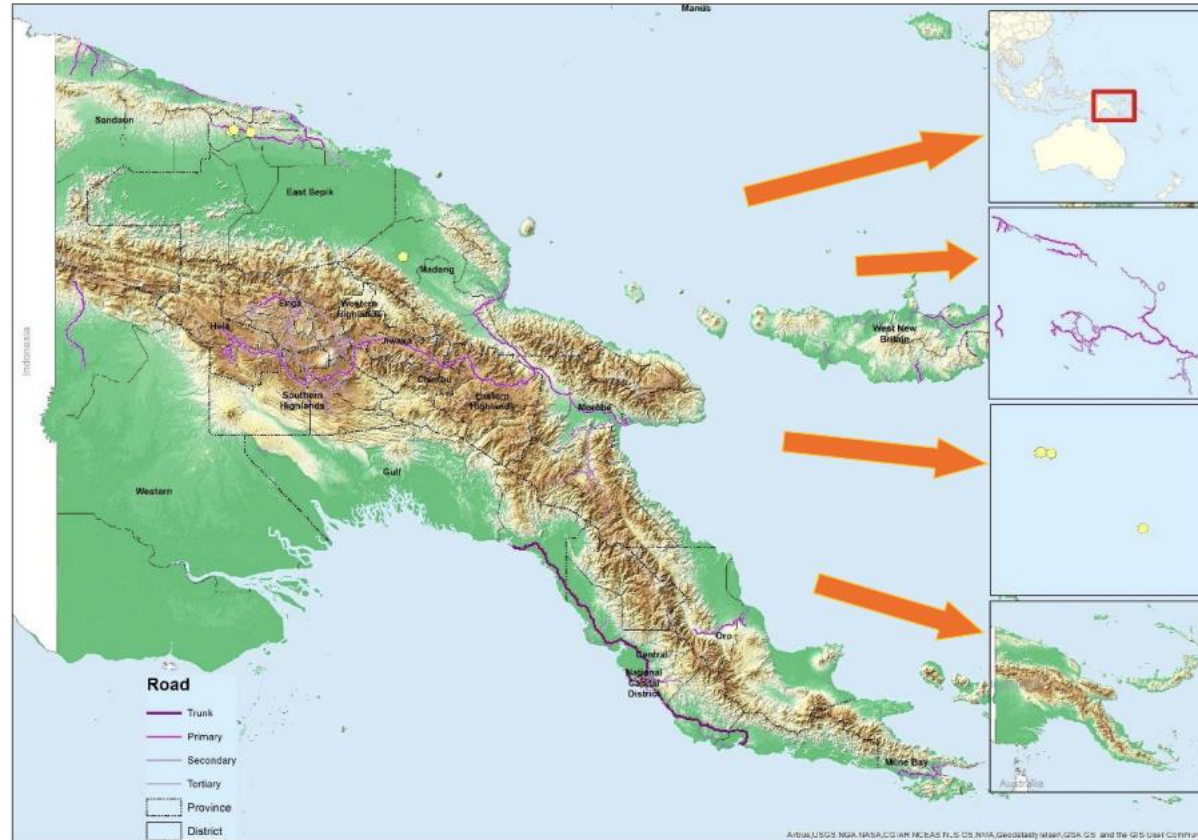
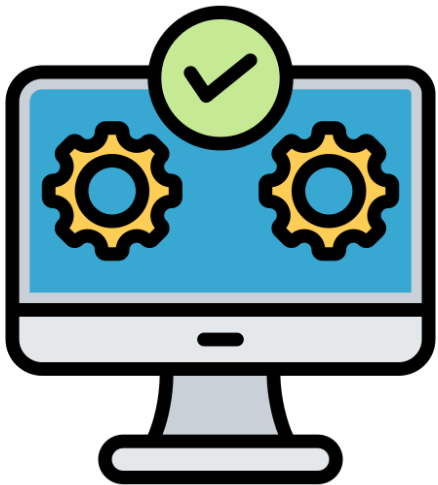
- The **vector** model: information about points, lines and polygons are encoded and stored as a collection of x,y coordinates.
- The **raster** model: made up of a collection of grid cells, each holding a piece of information.



- Layers are the building blocks of GIS, and they represent different thematic information that can be stacked on top of each other to create a map
- Layers can include features such as roads, buildings, rivers, and land parcels, each represented as a separate layer with its own attributes and properties
- Layers can be added, removed, and manipulated in GIS software to create complex spatial analyses and visualizations

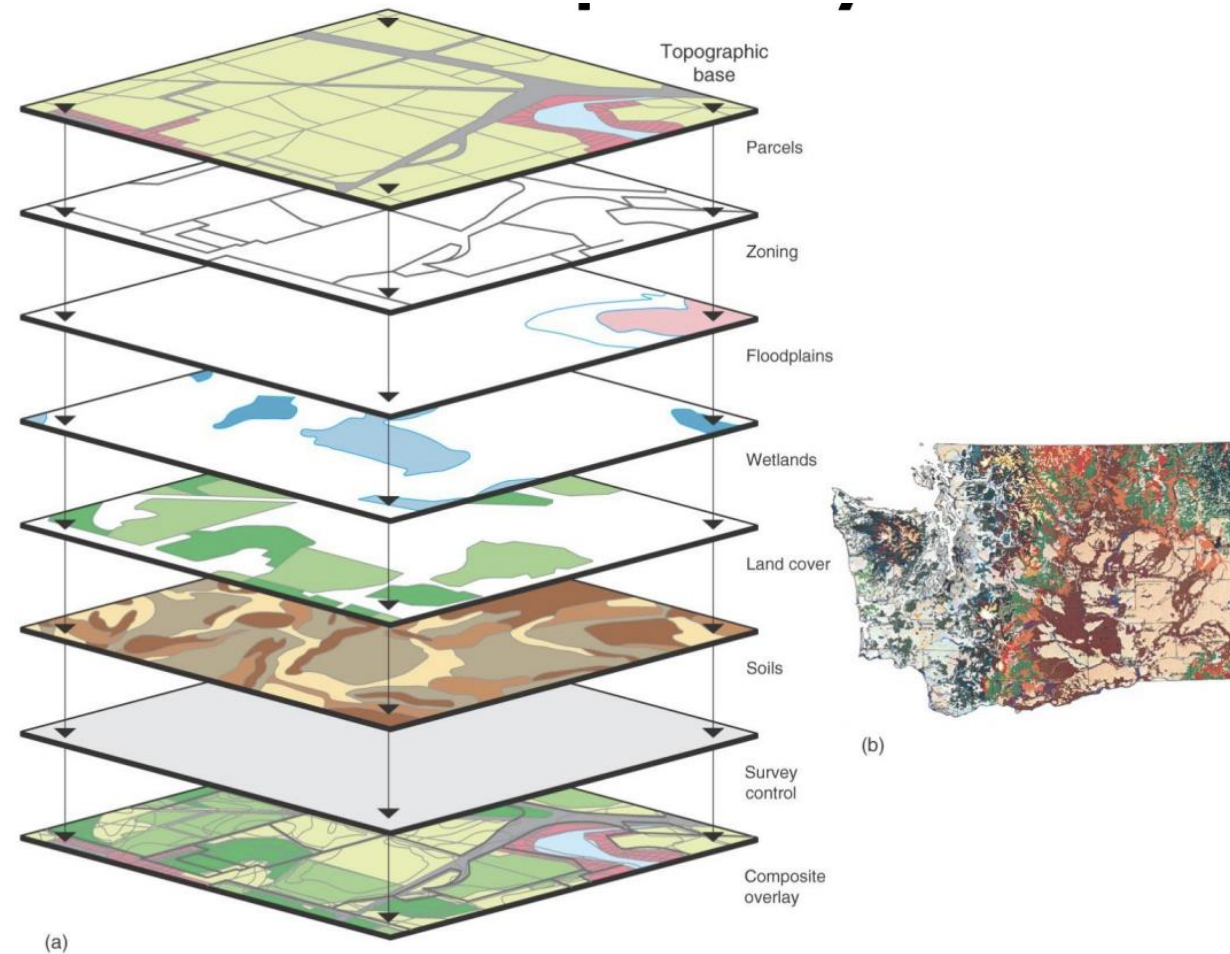
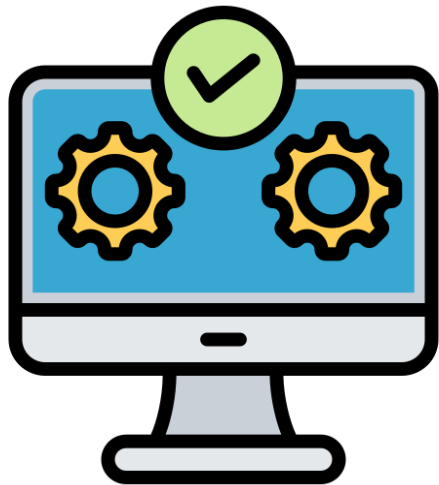


- A Map is made up of Layers or Shapefiles
- Layers contain Features
- Features can take the form of Points, Lines and Polygons, and are known collectively as Vector Data
- Layers contain Features, and each Feature is linked to a row of information in the Attribute table

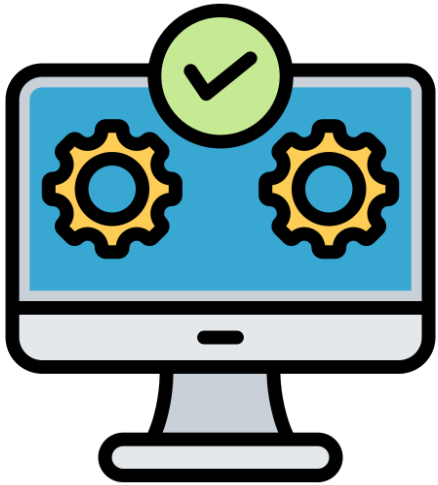




Each map is a system of layers



Each layer will have either Vector Data or Raster Data



- size
- distribution
- pattern
- contiguity
- neighborhood
- shape
- scale
- orientation.

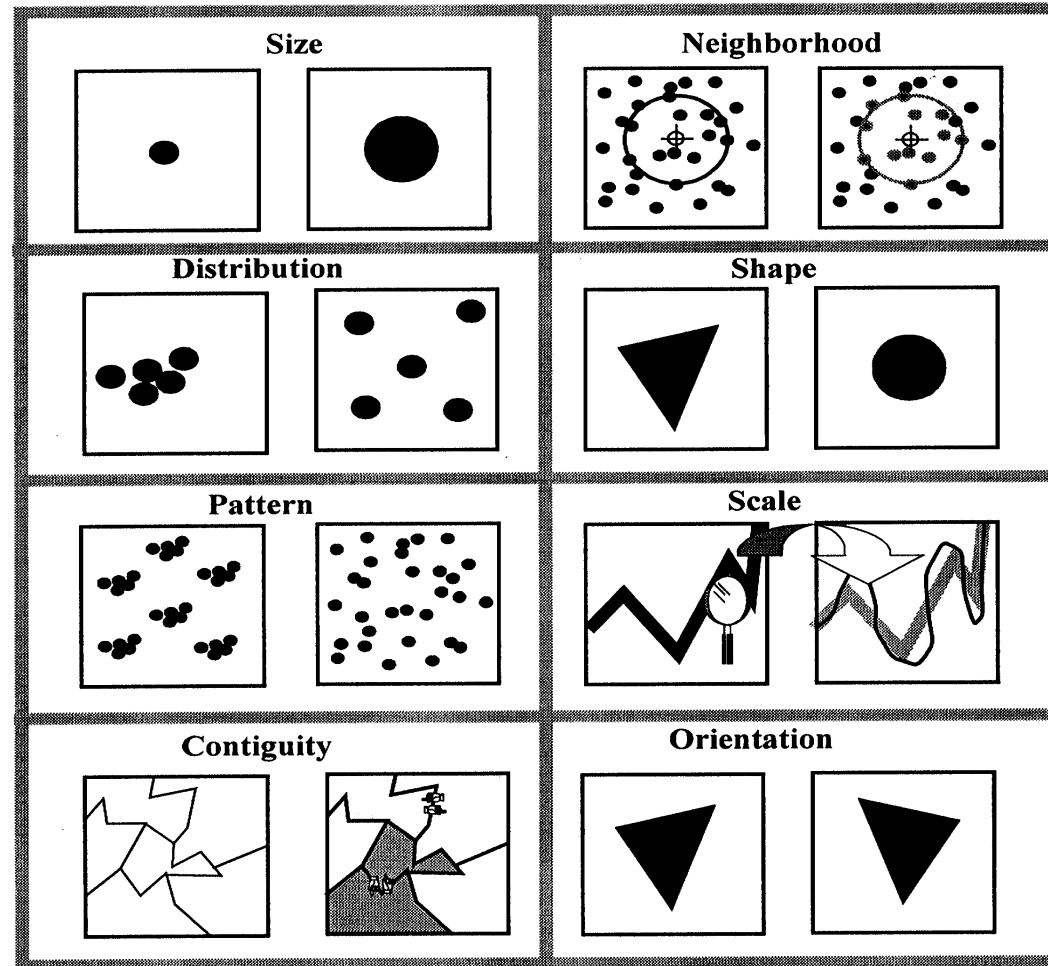
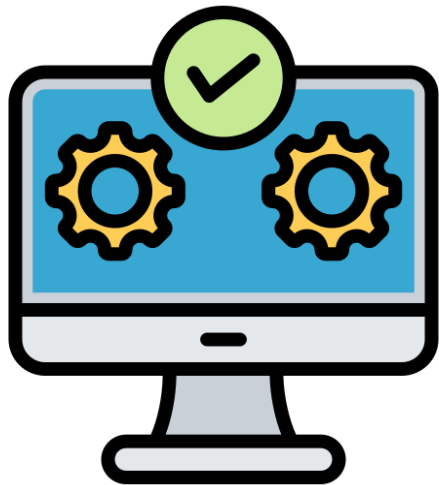
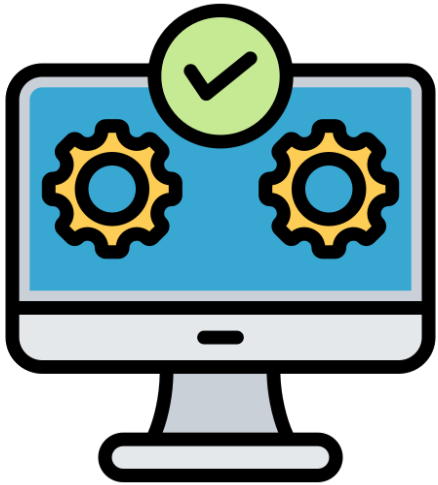


Figure 2.17 Basic properties of geographic features.

Basic
properties
of
geographic
features



Types of attributes

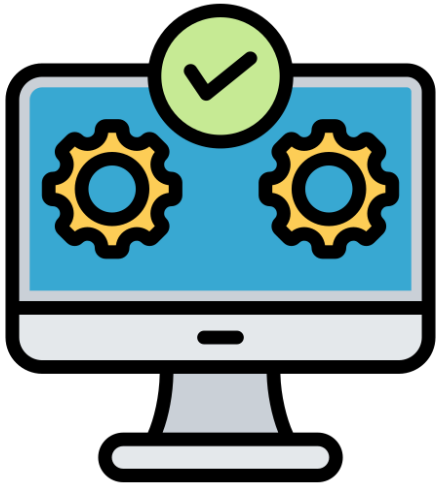


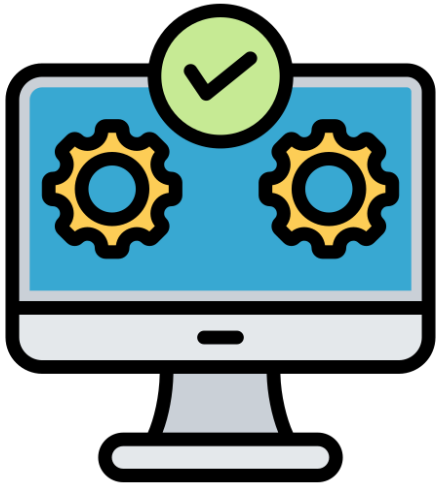
- Nominal (named, e.g., placenames, ID numbers, colors)
- Ordinal (ranked, e.g., soil quality, income category)
- Interval (differences between values are real)
- Ratio (100 kg is twice as much as 50 kg)
- Cyclic (e.g., compass direction, longitude, months) – problematic in GIS?



In an infinitely complex world...

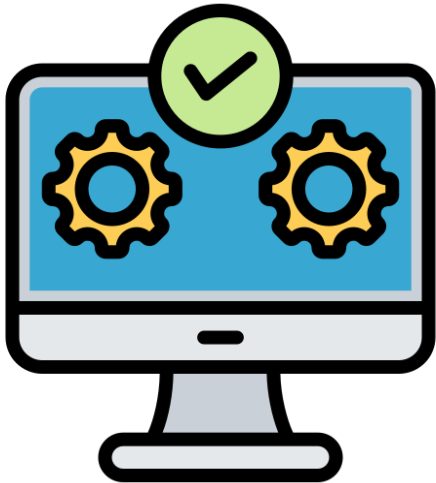
- representation must be partial (limited detail)
- it is necessary to generalize



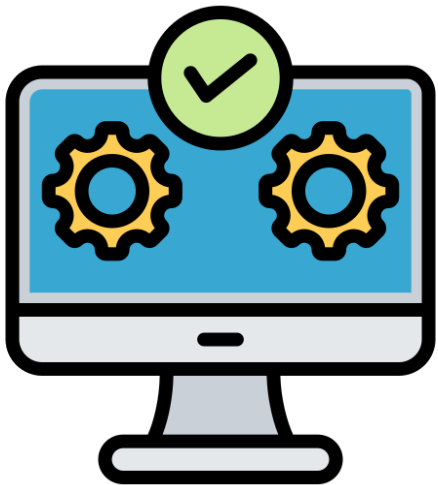


- Simplification
- Smoothing
- Aggregation
- Amalgamation
- Merging
- Collapse
- Refinement
- Exaggeration
- Enhancement
- Displacement

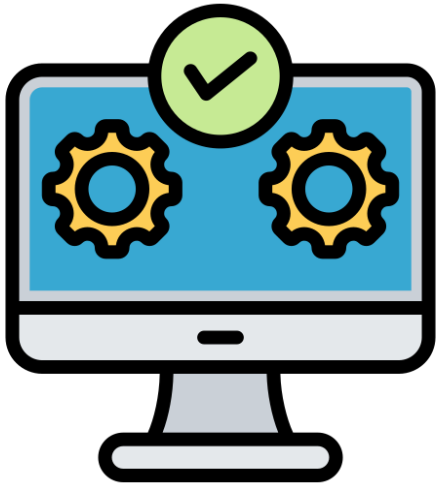
Each technique resolves a specific problem of display at a coarser scale to result in an acceptable version



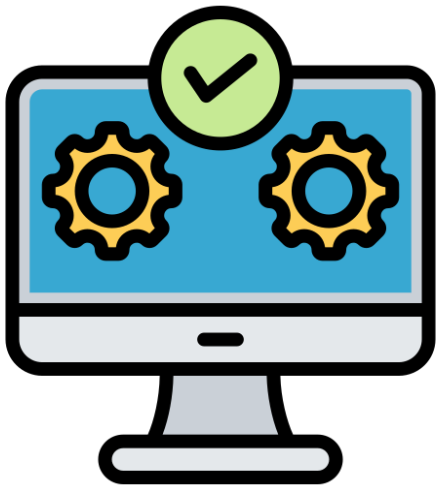
Category	Latest Tools	Key Features
Professional GIS	ArcGIS Pro (Esri), QGIS 3.38+, MapInfo Pro 2024	3D mapping, AI-powered analytics, cloud collaboration
Web GIS / Cloud GIS	ArcGIS Online, Google Earth Engine, Mapbox, Carto, Kepler.gl	Cloud-based data hosting and visualization
Open-source & AI Integration	GRASS GIS, PostGIS, GeoPandas, Rasterio, AI4EO (ESA)	Python/AI integration, spatial database analysis
Real-time & IoT GIS	Esri ArcGIS Velocity, AWS Location Service, Azure Maps, Google Maps Platform APIs	Real-time geolocation and sensor data integration



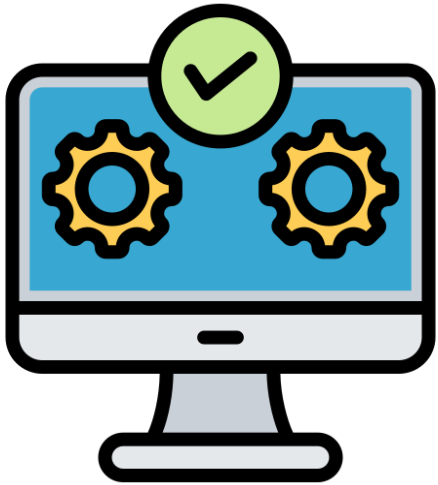
- Modern GIS now incorporates **multi-source, multi-resolution datasets**:
- **Drones (UAVs)** → High-resolution aerial imagery for mapping and 3D terrain modeling.
- **Satellites (e.g., Sentinel, Landsat 9, PlanetScope)** → Near real-time earth observation data.
- **IoT Sensors** → Environmental, traffic, and weather data streams.
- **LiDAR (Light Detection and Ranging)** → Precise 3D elevation and vegetation structure mapping.
- **Crowdsourced Data** → OpenStreetMap, citizen science platforms.



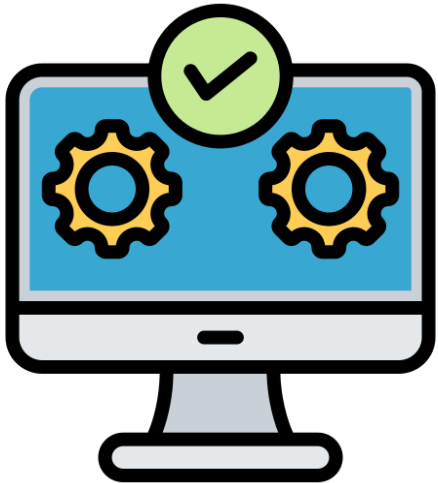
- New technologies improve how these data types are processed:
- **Cloud-Optimized GeoTIFFs (COGs)** – optimized for streaming large raster files online.
- **3D & 4D Vector Tiles** – used for interactive maps in platforms like Mapbox and CesiumJS.
- **Spatio-temporal modeling** – integrates time as a fourth dimension to track changes over time (e.g., climate change, urban growth).



- Recent advances include:
- **GeoAI (Geospatial Artificial Intelligence)** – applies machine learning to spatial data for pattern recognition, anomaly detection, and predictive analytics.
- **Deep Learning for GIS** – tools like **ArcGIS Deep Learning Studio** and **TensorFlow Geospatial** analyze satellite imagery automatically.
- **Big Data GIS** – distributed computing with platforms like **Spark Geo**, **Google Earth Engine**, and **AWS SageMaker Geo**.



- Today's GIS ecosystems are cloud-first:
- **ArcGIS Online** and **Google Earth Engine** – enable collaborative, browser-based GIS.
- **Serverless GIS** – uses cloud computing for dynamic scaling and real-time data analytics.
- **API-based Mapping** – Mapbox GL JS, Leaflet, and Deck.gl allow developers to embed interactive maps in web apps.



- To align it with **modern GIS**, focus on:
- **AI + GIS integration (GeoAI)**
- **Cloud-based GIS platforms (ArcGIS Online, Google Earth Engine)**
- **Big Data and real-time analytics**
- **3D/4D and Digital Twin modeling**
- **Interoperable, open standards for global collaboratio**



Thank You