Advanced Spatial Analysis

Lecture 02

Introduction to Spatial Analysis

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In Today's Class

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1. Spatial Analysis

- The process of examining the locations, attributes, patterns, and relationships of features in spatial data to address a question or gain useful knowledge.
- A method of advanced spatial modeling that assists with terrain modeling, finding suitable locations and routes, discovering spatial patterns, and performing hydrologic and statistical analysis.

- Spatial analysis is a set of techniques used to study, model, and interpret data based on geographical, topological, or geometric properties, transforming raw location data into actionable insights. By analyzing the "where" of data—such as points, lines, or polygons—it uncovers hidden patterns, spatial relationships, and trends that drive better decision-making in urban planning, business, and science.

2. GIS vs Spatial Analysis

GIS

- A Geographic Information System is a multi-component environment used to create, manage, visualize and analyze data and its spatial counterpart.

spatial analysis

focuses on the statistical examination of spatial patterns and the processes that may have generated them.

- For example, imagine you record the location of each tree within a well-defined study area. Mapping these locations is a typical GIS task. Once the trees are mapped, you may begin to draw inferences about the spatial pattern: Are the trees clustered or dispersed? Is tree density consistent across the study area? Could environmental factors such as soil type or slope have influenced the observed distribution? These are the kinds of questions addressed through spatial analysis, using quantitative and statistical techniques to explore and explain spatial patterns.

3. Importance in Real World

- Spatial analysis is crucial for transforming raw location data into actionable insights, enabling better decision-making in urban planning, logistics, environmental management, and business. By mapping relationships between data points, it uncovers trends—like disease hotspots, optimal service locations, or risk factors—that traditional analysis misses

- Urban Planning & Development: Optimizing city infrastructure, managing land use, and planning transportation corridors.
- Business & Real Estate: Site selection for new stores, analyzing customer demographics, and visualizing property surroundings to gauge value.
- Public Health & Epidemiology: Mapping disease outbreaks, identifying high-risk areas, and managing resources for healthcare facilities.

- Environmental Conservation: Monitoring, managing natural resources, and analyzing climate change impacts (e.g., in maritime spatial planning).
- Logistics & Asset Management: Optimizing supply chains, routing, and maintaining utility infrastructure.
- Disaster Management: Identifying flood-prone areas, planning evacuation routes, and rapid assessment of damage.

4. Fundamental Concepts in Spatial Analysis

- Fundamental concepts in spatial analysis revolve around understanding the location, distribution, and relationship of features on the Earth's surface to identify patterns and make predictions. Core principles include spatial dependence (nearby things are more related), distance decay, and scale effects. Key methods include mapping, spatial interpolation, proximity analysis, and spatial interaction.

- **Spatial Location and Distribution**: Identifying where things are (points, lines, polygons) and how they are arranged (e.g., clustered, dispersed, or uniform).
- **Spatial Dependence (Tobler's Law):** The concept that nearby locations are more similar than distant ones, fundamental for predicting values in unsampled areas (interpolation).
- **Spatial Interaction**: The movement or flow of people, goods, or information between places, which explains connectivity.

- **Proximity and Buffer Analysis**: Measuring distances and creating zones around features to analyze relationships (e.g., finding the best path or location).
- **Spatial Data Representation**: Modeling data using either vector (points, lines, polygons) or raster (grid cells) structures.
- **Scale and Modifiable Areal Unit Problem (MAUP)**: The understanding that spatial results depend on the size of the area units chosen (scale).

- **Spatial Autocorrelation**: A measure of the degree to which a set of spatial features and their associated data values tend to be clustered together (positive) or dispersed (negative)

5. raster vs vector data models

Vector data

- Vector data represents geographic features using precise coordinates and is ideal for representing discrete, well-defined, or sharp-boundary objects.
- Vector data structures represent specific features on the Earth’s surface, and assign attributes to those features. Vectors are composed of discrete geometric locations (x, y values) known as vertices that define the shape of the spatial object. The organization of the vertices determines the type of vector that we are working with is a point, line or polygon

Points

Each point is defined by a single x, y coordinate. There can be many points in a vector point file. Examples of point data include: sampling locations, the location of individual trees, or the location of cities (depending on the scale of a map).

Lines

- Lines are composed of many (at least 2) points that are connected. For instance, a road or a river stream may be represented by a line. This line is composed of a series of segments, each “bend” in the road or river stream represents a vertex that has defined x, y location.

Polygons

- A polygon consists of 3 or more vertices that are connected and closed. The outlines of survey plot boundaries, lakes, oceans, and states or countries are often represented by polygons. However, depending on the scale, if we ‘zoom-in’ a lot, we may represent rivers as polygons instead of lines since the water volume of a river stream covers a specific area (i.e. river width of 5 or 10 meters)

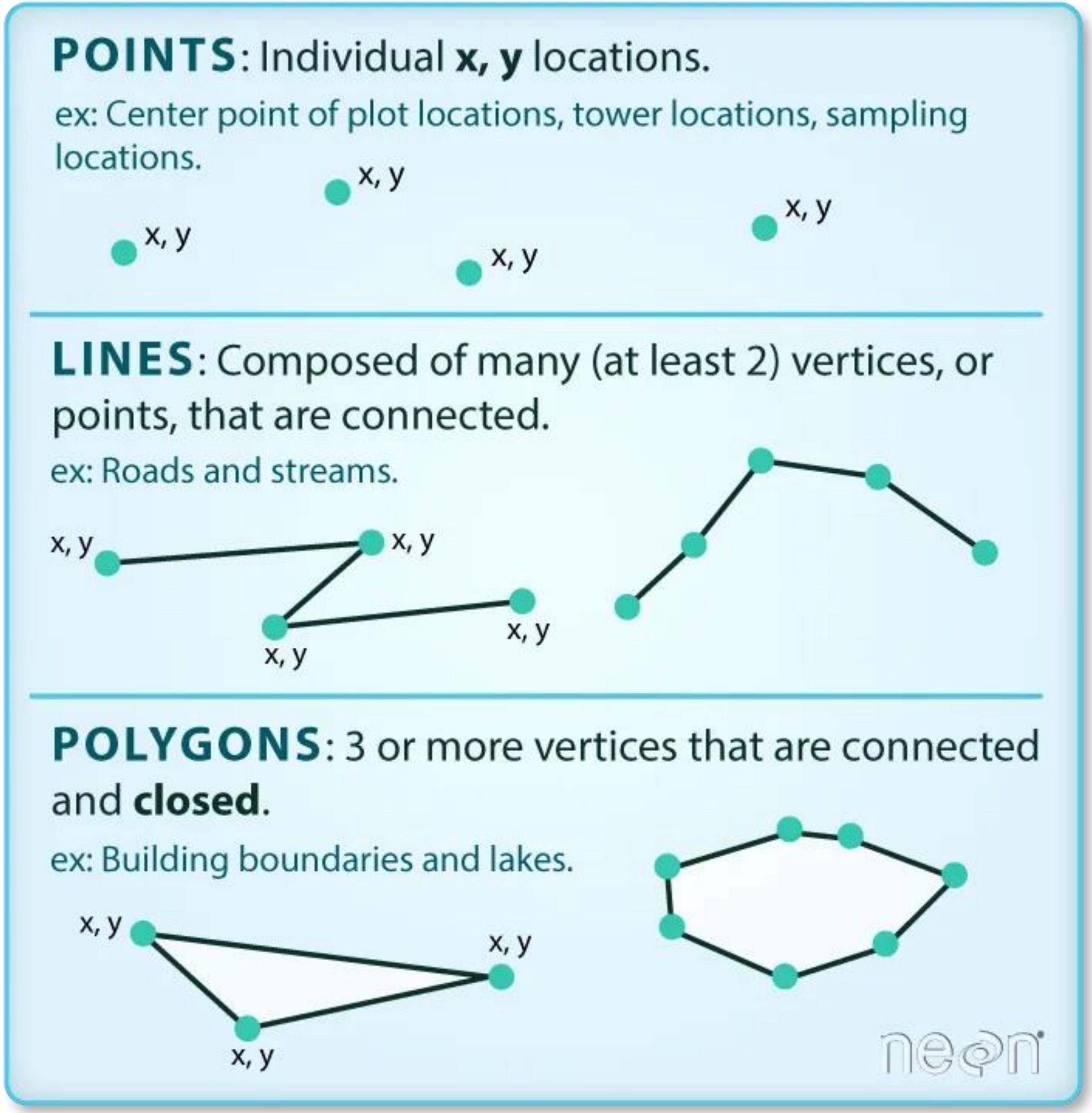

Image Source: National Ecological Observatory Network (NEON)

Raster data

- Raster data is any pixelated (or gridded) data where each pixel is associated with a specific geographical location. The value of a pixel can be continuous (e.g. elevation) or categorical (e.g. land use).
- A geospatial raster is only different from a digital photo in that it is accompanied by spatial information that connects the data to a particular location. This includes the raster's extent and cell size, the number of rows and columns, and its coordinate reference system (or CRS).

Some examples of continuous raster data include:

- Precipitation maps.
- Maps of tree height derived from LiDAR data.
- Elevation values for a region.

Some rasters contain categorical data where each pixel represents a discrete class such as a landcover type (e.g., “forest” or “grassland”) rather than a continuous value such as elevation or temperature. Some examples of classified maps include:

- Landcover / land-use maps.
- Tree height maps classified as short, medium, and tall trees.
- Elevation maps classified as low, medium, and high elevation.

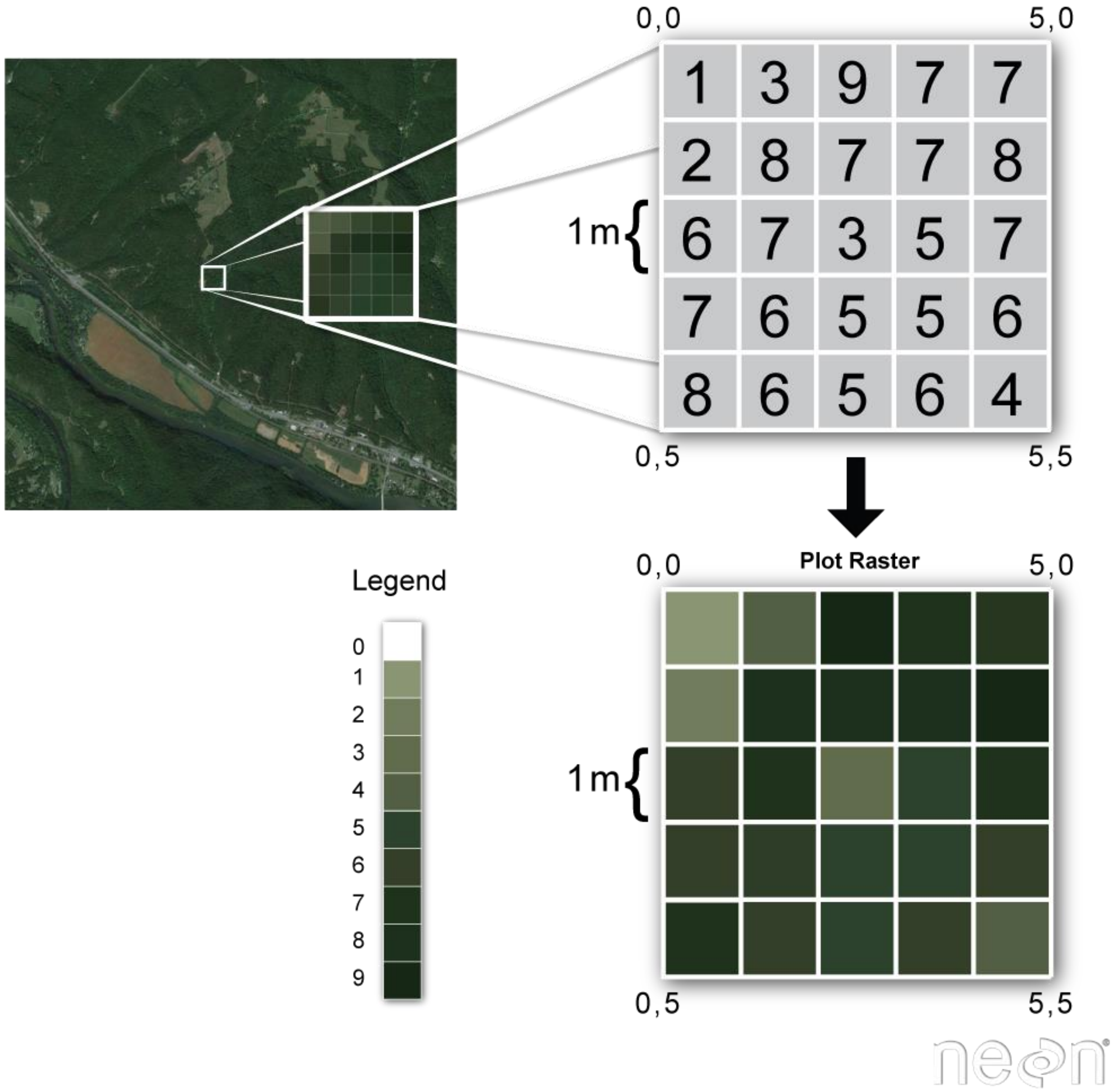

Image Source: National Ecological Observatory Network (NEON)

6. Types of Spatial Analysis

Core Spatial Analysis

- GIS operations/methods comprise data input, management, and spatial analysis to manipulate and analyze geographic information
- GIS methods provide the means to extract meaningful insights from spatial data, aiding decision-making processes.

Remote Sensing based Spatial Analysis

- While GIS features (like the ones you mentioned) focus on the vector relationships between points, lines, and polygons, Remote Sensing (RS) spatial analysis focuses on the pixel (raster) data and the electromagnetic spectrum.

Core Spatial Analysis

Buffer Analysis

- Buffer analysis is a fundamental spatial analysis technique used in GIS. It involves creating a zone or an area around a geographic feature, such as a point, line, or polygon, to represent a specified distance or range from that feature. This zone is referred to as a buffer zone.

Shortest Path Analysis

- Shortest path analysis is a fundamental operation in GIS and graph theory. It involves finding the shortest path or route between two points or locations within a network, considering factors such as distance, travel time, cost, or other attributes associated with the network.

Cluster Analysis

- Cluster analysis is a statistical technique used to group a set of objects in such a way that objects in the same group, called clusters, are more similar to each other than to those in other groups. The goal of cluster analysis is to identify inherent patterns or structures in the data without prior knowledge of any group memberships.

Nearest Neighborhood Analysis

- Nearest Neighbor Analysis (NNA) is a spatial analysis technique used in GIS to identify patterns and relationships within spatial data. It focuses on determining the proximity of features to one another based on their spatial locations.

Overlap Analysis

- Overlap analysis, also known as overlay analysis or spatial intersection analysis, is a GIS technique used to identify and analyze areas where different spatial datasets intersect or overlap. The primary goal of overlap analysis is to understand the spatial relationships between different geographic features and to derive insights from the intersections of these features.

Spatial Interpolation

- Spatial interpolation is a technique used in GIS and spatial analysis to estimate the values of unknown locations within a study area based on known values from surrounding locations. It’s particularly useful when dealing with irregularly distributed data points or when trying to create continuous surfaces or maps from point data.

Remote Sensing Based Spatial Analysis

Spectral Indices Analysis

- This is one of the primary applications in remote sensing. It involves calculating ratios between different spectral bands to highlight specific physical properties.
- Vegetation Analysis: Using indices like NDVI (Normalized Difference Vegetation Index) to assess plant health.
- Water & Moisture: NDWI (Water Index) or NDMI (Moisture Index) to delineate water bodies or drought stress.
- Burn Severity: NBR (Normalized Burn Ratio) used after wildfires to map the intensity of the burn.

Digital Surface & Elevation Modeling (DSM/DEM)

- Remote sensing allows us to analyze the "vertical" dimension of the earth using Stereo Imagery, LiDAR, or Radar (InSAR).
- Viewshed Analysis: Determining what is visible from a specific pixel location.
- Hydrological Modeling: Identifying flow direction, accumulation, and watershed boundaries based on the terrain.
- Slope and Aspect Analysis: Calculating the steepness and orientation of the land for agricultural or construction suitability.

Change Detection (Temporal-Spatial Analysis)

- This measures how a specific geographic area has changed between two or more points in time.
- Pixel-to-Pixel Comparison: Subtracting values of an older image from a newer one to find differences.
- Post-Classification Comparison: Comparing two classified maps to see how land use transitioned (e.g., "Forest" to "Urban").
- Time-Series Trend Analysis: Using long-term data (like Landsat) to detect gradual degradation or recovery of ecosystems.

Image Segmentation & Object-Based Image Analysis (OBIA)

- Unlike traditional GIS that starts with defined shapes, OBIA creates them by grouping neighboring pixels with similar spectral and spatial properties.
- Feature Extraction: Automatically identifying building footprints, road networks, or individual tree crowns from high-resolution imagery.
- Texture Analysis: Using the "roughness" or "smoothness" of pixels to distinguish between classes that look spectrally similar (e.g., distinguishing a forest from a grassy field).

Land Surface Temperature (LST) Retrieval

- Using thermal infrared bands to calculate the actual temperature of the earth's surface.
- Urban Heat Island (UHI) Analysis: Mapping how cities stay warmer than surrounding rural areas.
- Geothermal Mapping: Identifying underground thermal activity.

Atmospheric & Aerosol Analysis

- Remote sensing isn't just for the ground; it’s for the volume of air above it.
- AOD (Aerosol Optical Depth): Mapping the spatial distribution of smoke, dust, and pollution (PM2.5) in the atmosphere.
- Gas Plume Detection: Using hyperspectral sensors to identify the exact spatial source of methane leaks from pipelines or factories.

Thank you!