Spatial Analysis
Methods

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Introduction

1. These groups of spatial analysis methods offer diverse tools for analyzing geographic data and addressing spatial problems.
2. Depending on the research question or problem, one or more of these methods can be applied to understand spatial patterns, relationships, and processes more effectively.

Overview

1. Point Pattern Analysis
2. Spatial Autocorrelation
3. Geostatistics
4. Spatial Interpolation
5. Network Analysis
6. Surface and Terrain Analysis
7. Spatial Regression and Econometrics
8. Cluster and Hotspot Analysis
9. Raster and Grid-Based Analysis
10. Spatial Simulation and Modeling
11. Multicriteria Decision Analysis (MCDA)
12. Time-Space Analysis

1. Point Pattern Analysis

- Objective:
  - To analyze the spatial distribution of discrete points (e.g., locations of schools, trees, or crime incidents) in space.
- Methods:
  - **Nearest Neighbor Analysis**: Measures how clustered or dispersed points are.
  - **Quadrat Analysis**: Divides the study area into smaller squares (quadrats) and counts the number of points in each to detect patterns.
  - **K-function** (Ripley's K): Examines point distribution at multiple scales to assess clustering or regularity.
  - **Kernel Density Estimation** (KDE): Creates a smoothed surface showing the density of point features over space.

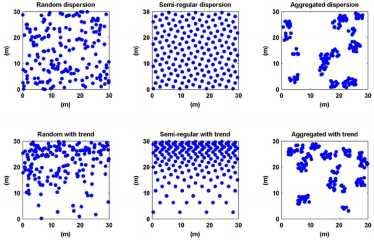


Figure 1: Point Pattern Analysis

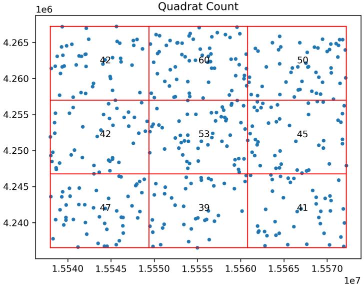


Figure 3: Quadrat Analysis

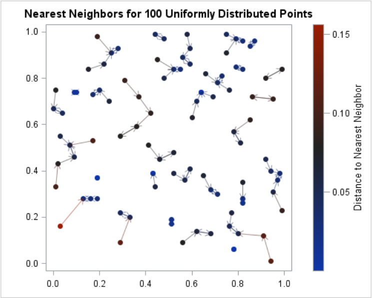


Figure 2: Nearest Neighbor Analysis

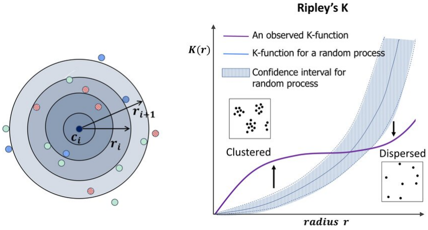


Figure 4: Ripley's K Function

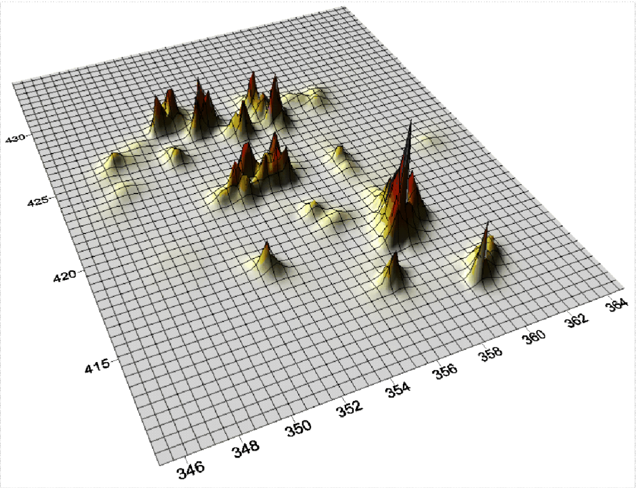


Figure 5: Kernel Density Estimation (KDE)

2. Spatial Autocorrelation

- Objective:
  - To measure the degree to which a set of spatial features (or values) are *similar/dissimilar* to each other in geographic space.
- Methods:
  - **Moran's I**: Measures the overall spatial autocorrelation of a dataset (global measure).
  - **Geary's C**: Measure of spatial autocorrelation, but focuses on differences between neighboring features (more sensitive to local variations).
  - **Getis-Ord G and G*** : Measures local *hotspots* (clusters) and *cold spots* in spatial data.

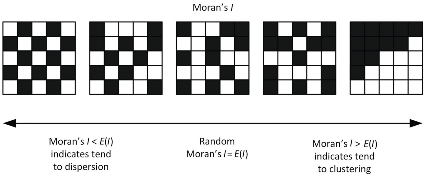


Figure 6: Moran's I

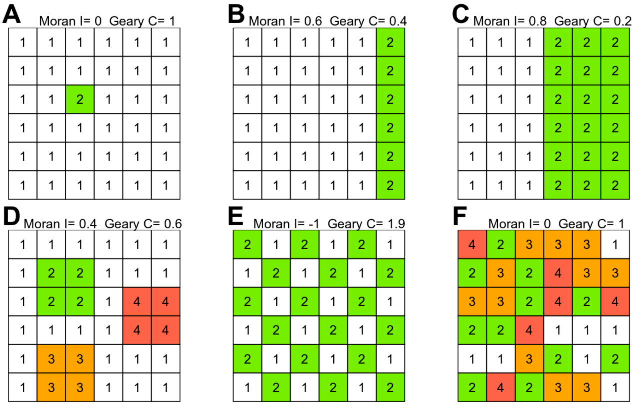


Figure 7: Moran's I & Geary's C

3. Geostatistics

- Objective:
  - To model and predict spatially continuous phenomena (e.g., elevation, pollution, temperature) based on sample data points.
- Methods:
  - **Kriging**: A method of interpolation that uses spatial autocorrelation to predict unknown values.
  - **Inverse Distance Weighting** (IDW): Estimates values at unknown points by averaging known values, with nearer points given more weight.
  - **Trend Surface Analysis**: Fits a polynomial surface to spatial data, capturing large-scale spatial variation.

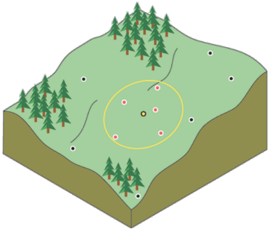


Figure 8: Kriging

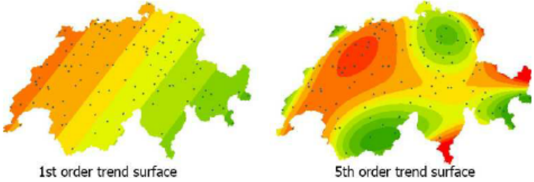
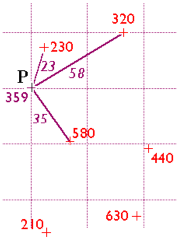


Figure 10: Trend surfaces



$$Z_P = \frac{\sum_{i=1}^{n} \left(\frac{z_i}{d_i}\right)}{\sum_{i=1}^{n} \left(\frac{1}{d_i}\right)}$$

$$= \frac{\frac{230}{23} + \frac{320}{58} + \frac{580}{35}}{\frac{1}{23} + \frac{1}{58} + \frac{1}{35}}$$

Figure 9: IDW

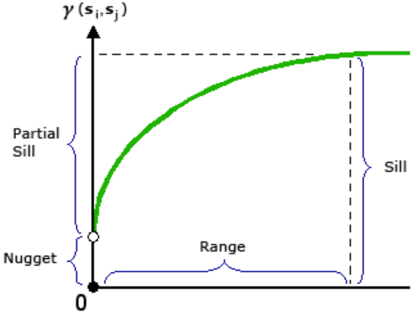


Figure 11: Semivariogram (Kriging)

4. Spatial Interpolation

- Objective: To estimate values at unmeasured locations using known values from surrounding locations.
- Methods:
  - **Thiessen Polygons** (Voronoi Diagrams): Assigns values to each location by associating it with the nearest known point.
  - **Spline Interpolation**: Fits a smooth surface through the known data points, minimizing curvature.
- Applications
  - Meteorology, Precision Agriculture, Rainfall estimation,

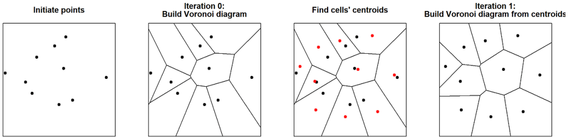


Figure 12: Voronoi

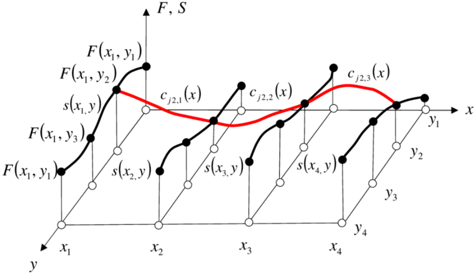


Figure 13: Bi cubic spline interpolation

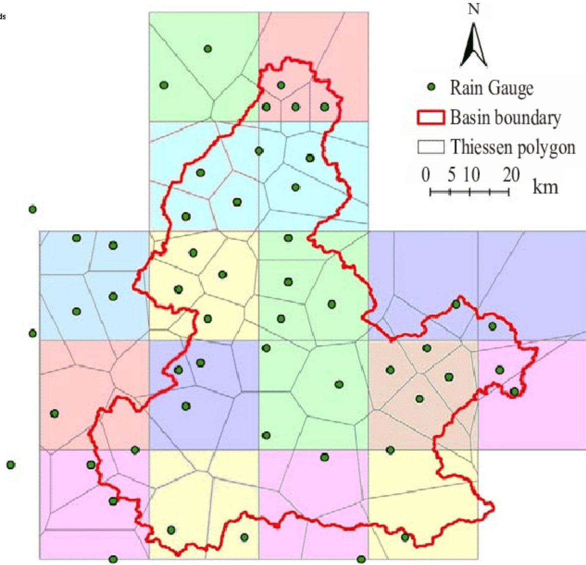


Figure 14: Thiesen interpolation

5. Network Analysis

- Objective:
  - To study and model spatial networks such as transportation, utility grids, or social networks.
- Methods:
  - **Shortest Path Analysis**: Finds the most efficient route between two points in a network.
  - **Service Area Analysis**: Defines regions accessible within a certain time or distance from a point.
  - **Flow Analysis**: Models the movement of goods, services, or people through a network.
  - **Network Optimization**: Seeks to improve the efficiency or effectiveness of spatial networks (e.g., traffic flow, utility networks).

6. Surface and Terrain Analysis

- Objective:
  - To analyze the properties and characteristics of geographic surfaces, often used in topographic and environmental studies.
- Methods:
  - **Slope and Aspect Analysis**: Determines the steepness and orientation of a surface, critical in hydrology, erosion, and solar exposure studies.
  - **Hillshade and Viewshed Analysis**: Calculates shadows and visibility from a certain point based on the terrain.
  - **Digital Elevation Model** (DEM) Analysis: Used to derive elevation, slope, and aspect from raster data.

7. Spatial Regression and Econometrics

- Objective:
  - To model relationships between spatial data variables, accounting for spatial dependence and heterogeneity.
- Methods:
  - **Spatial Lag Model**: Includes the spatially lagged dependent variable to account for autocorrelation in the data.
  - **Spatial Error Model**: Accounts for spatially autocorrelated error terms in regression.
  - **Geographically Weighted Regression** (GWR): Allows regression coefficients to vary across geographic space, providing localized models of spatial relationships.

8. Cluster and Hotspot Analysis

- Objective:
  - To detect clusters or patterns of high or low values in geographic data.
- Methods:
  - **Hotspot Analysis (Getis-Ord Gi*)**: Identifies statistically significant clusters of high or low values.
  - **DBSCAN** (Density-Based Spatial Clustering of Applications with Noise): Identifies clusters of points based on density and can detect outliers.
  - **K-means Clustering**: Groups spatial features into clusters based on similarity (e.g., socioeconomic data, land use).
  - Local Indicators of Spatial Association (LISA): Detects local spatial autocorrelation, identifying clusters or outliers within the data.
- Applications
  - Crime analysis, Epidemiology, Market analysis

9. Raster and Grid-Based Analysis

- Objective:
  - To analyze continuous data or surfaces often represented as grids (e.g., satellite imagery, climate data).
- Methods:
  - **Map Algebra**: A set of operations (e.g., addition, multiplication) applied to raster layers for spatial analysis.
  - **Reclassification**: Assigns new values to raster cells based on specific criteria.
  - **Overlay Analysis**: Combines multiple raster layers to evaluate relationships between different spatial phenomena.
  - **Cost Distance Analysis**: Determines the least-cost path over a surface by accounting for distance and resistance factors (e.g., topography, land cover).

10. Spatial Simulation and Modeling

- Objective:
  - To simulate spatial processes or predict future scenarios based on various inputs and conditions.
- Methods:
  - **Cellular Automata (CA)**: Models spatial changes through simple local rules applied to cells in a grid (e.g., urban growth modeling).
  - **Agent-Based Modeling (ABM)**: Simulates interactions of individual agents (e.g., people, vehicles) in space, useful in crowd dynamics, traffic simulations, or market behaviors.
  - **Land Use Change Models**: Predict changes in land use over time based on socio-economic and environmental factors.

11. Multicriteria Decision Analysis (MCDA)

- Objective:
  - To assist in decision-making by combining multiple spatial factors or criteria.
- Methods:
  - **Weighted Overlay**: Combines different spatial layers with assigned weights to determine optimal locations for activities (e.g., site selection for infrastructure).
  - **Analytic Hierarchy Process (AHP)**: Structures complex decisions into a hierarchy and assigns weights to various criteria for spatial decision-making.
  - **Suitability Analysis**: Evaluates the suitability of different areas for specific uses based on multiple factors (e.g., agriculture, conservation).

12. Time-Space Analysis

- Objective:
  - To analyze the interaction of time and space in data, particularly for dynamic processes such as human movements or environmental changes.
- Methods:
  - **Space-Time Cube**: A 3D representation of spatial phenomena where the vertical axis represents time, helping visualize temporal changes in geographic patterns.
  - **Time-Geography**: Focuses on tracking the movement of individuals or objects through space and time, often using time-space prisms to understand constraints.

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