The Language of spatial ANALYSIS

esri

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FOREWORD

Watching the GIS industry grow for more than 25 years, I have seen innovation in the problems we solve, the people we can reach through technology, the stories we tell, and the decisions that help make our organizations and the world more successful. However, what has not changed is our longstanding goal to better understand our world through spatial analysis.

Traveling the world I have met people from many diverse cultures who work in a wide range of industries. However, as I listen to their mission and challenges, there is a common pattern: we all speak the same language—it is the language of spatial analysis.

This language consists of a core set of questions that we ask, a taxonomy that organizes and expands our understanding, and the fundamental steps to spatial analysis that embody how we solve spatial problems.

I encourage each of you to learn and communicate to the world the power of spatial analysis. Learn the definition, learn the vocabulary and the process, and most important, be able to speak this language to the world. The greatest potential for change and success occurs when we all understand and speak the same language—the language of spatial analysis.

— Christopher Cappelli, Esri

HOW TO USE THIS BOOK

The Language of Spatial Analysis is designed as an interactive workbook that allows you to create and add your own sample questions of spatial analysis (from your industry or domain expertise), which can add to your vocabulary when explaining spatial analysis to others. To take advantage of this capability, make sure to read the book with the latest version of Adobe Reader and add your own comments.

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CHAPTER 1

An introduction to spatial analysis

When did you first learn how to perform spatial analysis? Perhaps you recall your first job or the first time you used a geographic information system (GIS) in college. Or maybe it was the day you joined the Army, and you were given a topographic map.

However, in reality, you learned about spatial analysis at a much earlier age. For most of you, the beginning of your spatial analysis education was around age two and the time you started walking. The cognitive development of geography and subsequently spatial analysis actually began as soon as you became aware of your geographic surroundings and you started to become mobile.

More often than not, the first step in spatial analysis is *understanding where*. At two years old, you became aware of where you were—in the bedroom or in the kitchen. Your skills then started to expand into the second development phase—*navigation*. How do you go from one room to the next, and then how do you go from home to school? You did not need to take a class in spatial analysis, but it was becoming very much ingrained in your everyday life.

The third step in cognitive development is understanding *spatial relationships and patterns*—looking at the world around you, asking questions, and attempting to make sense of your surroundings and how they affect your actions.

Each of us has gone through these stages in our understanding of spatial analysis and in cognitive development. Most people are very well versed in understanding where they are, many are good at navigation, but it is the last phase of development that opens the way to solving the harder challenges of the world—this last phase is also the most expansive in terms of opportunities and benefits. It is not just where you are, or how you get there, that most people are trying to figure out—usually it is a much bigger question or a much larger challenge that needs to be addressed.

Welcome to the world of spatial analysis.

DEFINITION

Spatial analysis—how we understand our world—mapping where things are, how they relate, what it all means, and what actions to take.

There are many definitions of spatial analysis. However, the best place to start is with a practical definition that everyone can understand. Spatial analysis is how we understand our world—mapping where things are, how they relate, what it all means, and what actions to take. Whether you are talking about the small child standing in the kitchen looking around wondering where to go next or the GIS professional analyzing the implications of a new building on the landscape, the same practical definition applies.

Whenever we look at a map, we inherently start turning that map into information by finding patterns, assessing trends, or making decisions. This is spatial analysis, and it's what our minds do naturally whenever we look at a map.

Spatial analysis is a diverse and comprehensive capability that includes the simple visual analysis of maps and imagery, computational analysis of geographic patterns, finding optimum routes, site selection, and advanced predictive modeling. This process happens every day in the human brain. However over the last four decades, our ability to solve complex spatial problems has grown exponentially with technologies that include global positioning systems, real-time sensors, navigation systems, and most important, GIS.

As you grow past childhood, you discover that detecting patterns and relationships isn't always obvious by looking at a map. Often, there's too much data to sift through and present coherently on a map, and the way data is displayed on the map can change the patterns you see. GIS provides the spatial analysis tools to help us better discover, quantify, and understand geographic phenomena and determine what actions to take.

The language of spatial analysis

Now that we have a practical definition of spatial analysis, how do we *think* about spatial problems, and how can we *explain* these concepts to others?

Before answering these two questions, try the following challenge:

> Close your eyes and *think* about something—anything—for one minute.
> *And try to think about it without using words—without using a language.*

Most people will find that their thoughts are comprised of unspoken words. The truth is, even the simplest thoughts are difficult without language, without the vocabulary that you've been building up your entire life. Language is the key not only to communication and speech, but also to thinking and reasoning.

Now apply this idea to spatial analysis. How can we *think* spatially, and how can we *explain* the concepts of spatial analysis to others? The answer is with a vocabulary and with a language of spatial analysis.

CHAPTER 2

The language of spatial analysis

With an endless list of spatial questions that need to be answered, it is helpful to classify and group these questions in order to establish a common language. The resulting classification, or taxonomy, provides the structure that can help us better learn, understand, and communicate to the world how spatial analysis is a critical part of problem solving.

The taxonomy of spatial analysis includes six high-level categories that classify and group related analytical questions.

The six categories of spatial analysis

- **Understanding where**
- **Measuring size, shape, and distribution**
- **Determining how places are related**
- **Finding the best locations and paths**
- **Detecting and quantifying patterns**
- **Making predictions**

Each category reflects a set of related question types. Learning the 26 question types provides the vocabulary necessary to speak the language of spatial analysis.

One of the best ways to learn a new language is through association and practice. As a result, each type of question is illustrated with a series of examples from different disciplines and industries. Using these as a guide, you have the opportunity to practice applying them to your specific domain by writing your own sample questions.

Understanding where

If you don’t know where you are, you are lost. Understanding where is about putting the world in context. Where are you? What is around you? Very similar to when you were two years old, your journey of spatial analysis requires an understanding of how you fit into your geography.

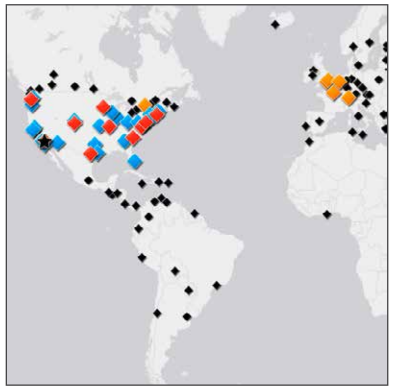
Understanding where includes geocoding your data, putting it on a map, and symbolizing it in ways that can help you visualize and understand your data. Within the taxonomy of spatial analysis, the first category of understanding where contains three types of questions.

TYPES

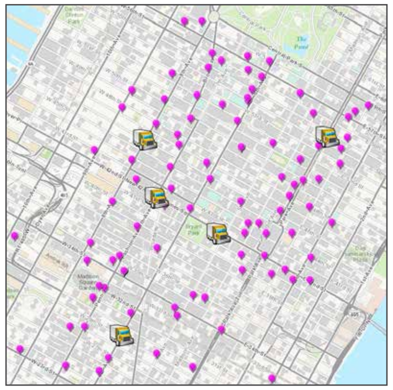
1. Understanding where things are (location maps)
2. Understanding where the variations and patterns in values are (comparative maps)
3. Understanding where and when things change

1. Understanding where things are (location maps)

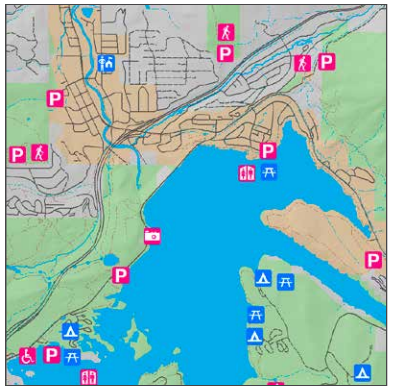
One of the simplest questions we can answer with spatial analysis is, where are things located? This could be a simple store directory map at the mall or a more sophisticated map showing real-time positions of moving vehicles and events. The map is often the visualization medium, and the human brain does the analysis. However, it is rare to just want to know where things are located; there is usually a greater need behind the question that drives further analysis.



Sample: Where are my offices located?
Use coordinates, address geocoding, and place finding to accurately locate your data on a map.



Sample: Where are the coffee shops and the delivery trucks?
Map data by single symbol type (static and real-time locations) and/or use attribute queries to subset relevant data.



Data courtesy of Summit County, Colorado.

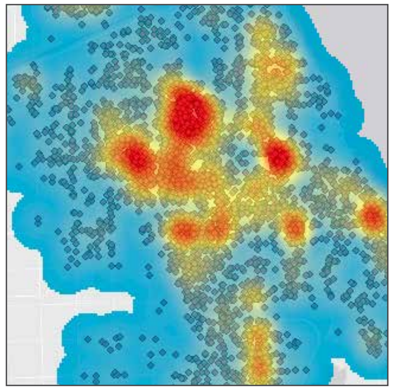
Sample: Where are the recreational opportunities? Where are all the electric assets by type?
Use thematic mapping to visualize different categories or attribute queries to select subsets of features.

Exercise: Write three or more sample questions illustrating different types of analyses that help you understand where things are.

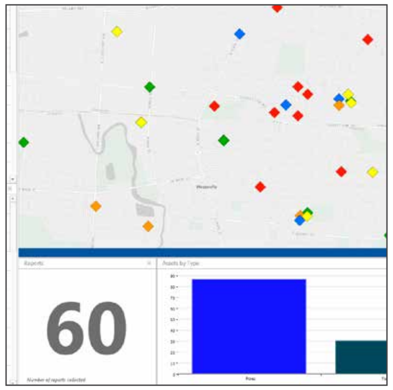
2. Understanding where the variations and patterns in values are (comparative maps)

Behind each location is usually a wealth of additional variables. Comparative maps take advantage of different approaches to symbology (color, size, dot density, charts) and allow you to analyze and further understand spatial variations. With comparative mapping you can visualize the highs and lows and their distribution across space. These comparative analyses can be accomplished using historical, current, and even real-time analytical maps.

Sample: Where are the highest levels of retail spending? Where are the largest camps of internally displaced people?
Use thematic mapping of values to represent variations with colors, symbols, charts, and dot densities.



Sample: Where are the greatest concentrations of crimes in the city?
Understand the concentration of point data using density surfaces and heat maps.



Sample: Where are the power outages happening by service areas?
Use continuous visualization, monitoring, and alerts from real-time data to understand changing patterns and situations.

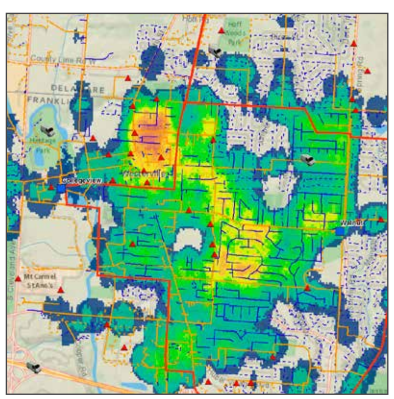
Exercise: Write three or more sample questions illustrating different types of analyses that help you understand the variations and patterns in values.

3. Understanding where and when things change

The world is constantly changing. Mapping the changing conditions in a place over time, such as loss of vegetation, can help us anticipate future conditions and implement policies that will positively impact our world.

Data courtesy of Hawkeye UAV.

Sample: Where has the city grown? How is the new highway or facility construction project progressing?
Understand change using multiple comparative maps; perform image classification, image interpretation, and map algebra to calculate change.



Sample: What is the current status of the electric grid, and how are changing weather conditions affecting field crew safety?
Integrate real-time data to react to changing conditions.

Exercise: Write sample questions illustrating different types of analyses that help you understand where and when things are changing or have changed.

Measuring size, shape, and distribution

The task of measuring size and shape is a common requirement in the spatial analysis process. You may want to know how large an object is, or you may want to describe an object in terms of its geometric properties, such as area, perimeter, length, height, and volume.

When there are multiple objects, the set of objects takes on additional properties, including extent, central tendency, and other characteristics that collectively define the distribution of the entire dataset.

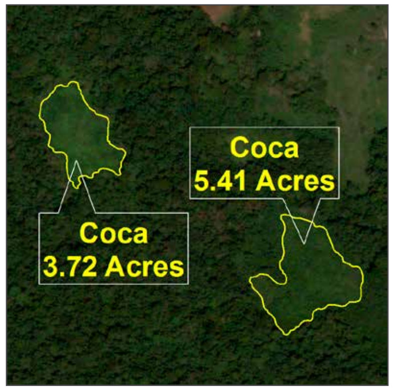
The process of measuring and describing these characteristics constitutes the second category of spatial analysis questions.

TYPES

4. Calculating individual feature geometries
5. Calculating geometries and distributions of feature collections

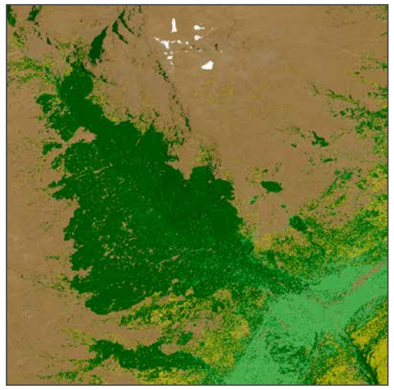
4. Calculating individual feature geometries

Spatial analysis is not just about understanding where things (features) are located, it is also about the spatial characteristics of these features. For example: How big is the lake? How long is the trail? How high is the mountain? The process of calculating these characteristics, although simple, is a form of spatial analysis. Calculating building heights from satellite imagery, calculating the volume of a lake, and calculating the slope of a bike path are all examples of spatial analysis.

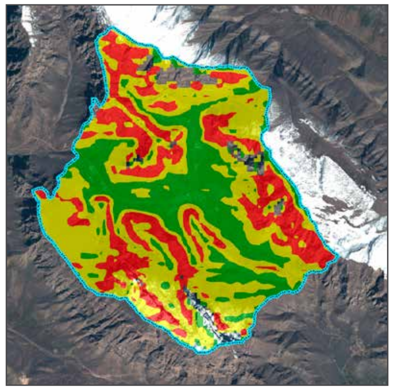


Data courtesy of DigitalGlobe.

Sample: How large are the coca fields? How long is the river? How tall is the building?
Calculate individual feature geometries to describe physical properties such as area, length, height, centroid, and so on.


Data courtesy of DigitalGlobe.

Sample: How many acres in the forest are undisturbed wilderness areas?
Use image classification and analysis techniques to determine feature geometries; compute and create features and their geometries from remotely sensed data.

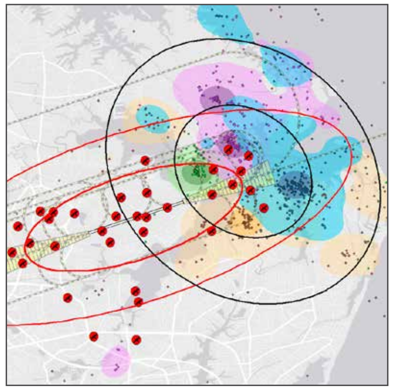

Data courtesy of DigitalGlobe.

Sample: What is the slope, aspect, and curvature of a drainage basin (terrain)?
Use surface functions to describe the properties of continuous surfaces.

Exercise: Write sample questions illustrating different types of analyses that require the geometric properties of individual features.

5. Calculating geometries and distributions of feature collections

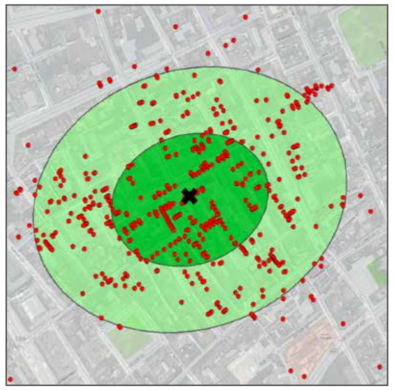
Although individual features have their own geometric properties (size and shape), a collection of features takes on additional properties such as extent and distribution. Think about gang graffiti and how its extent delineates a gang territory and the distribution can create conflict with other gangs. Measuring these geometric properties can often lead to a more detailed understanding of the geography.



Data courtesy of USDA.

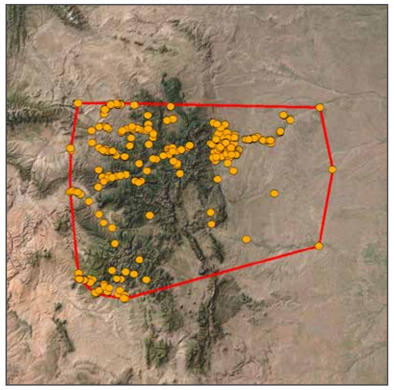
Sample: Are there directional trends within osprey home ranges and airplane bird strikes?

Calculate the directionality of a collection of features using linear directional mean or standard deviation ellipses.



Sample: What is the center of the disease outbreak?

Calculate the centrality of the data using mean center or median center methods.



Data courtesy of Colorado Parks and Wildlife.

Sample: What is the extent of bald eagle nests?

Calculate the areal extent of a collection of features using tools such as convex hull, minimum bounding rectangle, or standard deviational ellipses.

Exercise: Write sample questions illustrating different types of analyses that calculate the geometric properties of a collection of multiple features.

Determining how places are related

Answering spatial questions often requires not only an understanding of context (understanding where), but also an understanding of the relationships between features. Take any two objects: How are they related in space? How are they related in time? These relationships in space and time include associations such as proximity, coincidence, intersection, overlap, visibility, and accessibility.

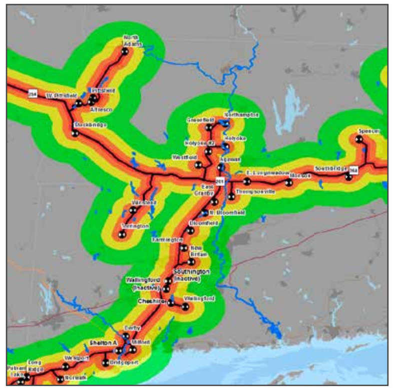
Determining how places are related includes a set of questions that help describe and quantify the relationships between two or more features.

TYPES

6. Determining what is nearby or coincident
7. Determining and summarizing what is within an area(s)
8. Determining what is closest
9. Determining what is visible from a given location(s)
10. Determining overlapping relationships in space and time

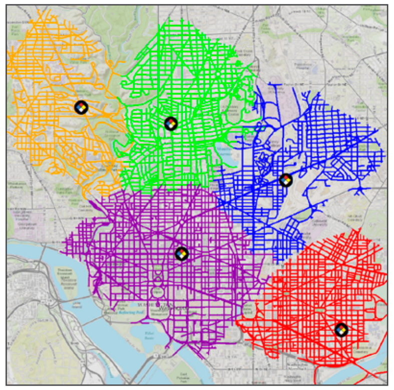
6. Determining what is nearby or coincident

Take two places. How are they related? Are they coincident, nearby, close, far away, accessible? Understanding the spatial relationship of distance or proximity is a common spatial analysis process. Distances can be measured, and features can be selected based on their distance characteristics.

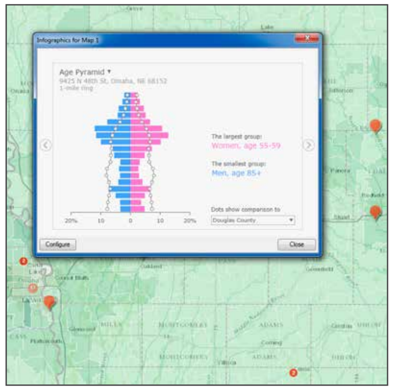


Data courtesy of El Paso Pipeline.

Sample: Which rivers are within 10 miles of a pipeline? How many customers are within one, five, and 10 miles? Are there other crimes at the same location?
Use spatial queries and buffers to select nearby features; collect events to determine coincidence; calculate distance between features to determine proximity.



Sample: What locations are within four-minute drive times of hazardous-materials response units?
Model proximity along linear networks using drive time rings and service areas.

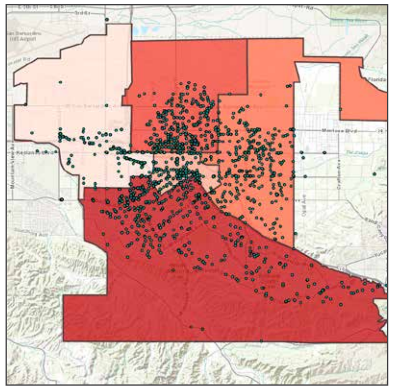


Sample: What are the environmental landscape conditions around a farm? What are the demographics around a store?
Gain an understanding of your surroundings by computing a summary of what is around you, also known as geoenrichment.

Exercise: Write sample questions illustrating different types of analyses that determine relationships such as nearby or coincident.

7. Determining and summarizing what is within an area(s)

We often look at a map and ask, how much of this is in that? How many stores are in the city? How many miles of pipeline cut across the county? How many acres of my farm are in the flood zone? Spatial aggregation provides a mechanism to count and summarize data over geographic areas. The process may be as simple as counting points in polygons, or it may require a more advanced analytical routine to overlay, divide, and assign variables proportionately across polygons.



Data courtesy of the Redlands Police Department.

Sample: How many crimes are in each police beat?

Use spatial joins to summarize data within a geographic area and calculate statistics (counts, min, max, mean, etc.).

Data courtesy of the City of San Luis Obispo, California.

Sample: What is the percentage of each parcel that is in a floodplain? How many miles of bike paths are in each neighborhood?

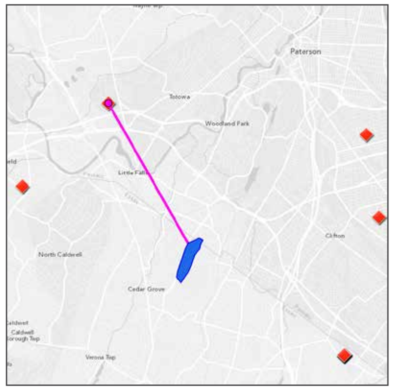
Perform overlays (identity, intersect, union) to apportion and assign variables from one feature to another.

Exercise: Write sample questions illustrating different types of analyses that involve summarizing data. Be sure to include examples that use apportionment.

8. Determining what is closest

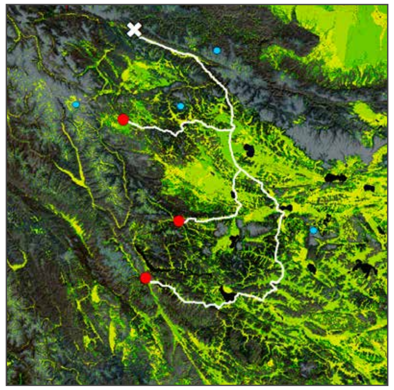
How do you determine what is closest? Do you want distances determined as the crow flies (straight-line distances)? Perhaps you want drive times along the road? What if you have a tank, or another type of off-road vehicle, that has different operating constraints?

For each of these examples, the determination of closest requires different sets of criteria and analytical tools. All these examples are valid, using different spatial analysis approaches to determine what is closest in space or time.



Sample: What is the closest industrial site to a water reservoir (straight-line distance)?
Calculate the distance between features to determine the closest one.

Sample: What are the three closest post offices along a road network?
Using a network, calculate the optimal routes using travel times and traffic to determine the closest facilities.

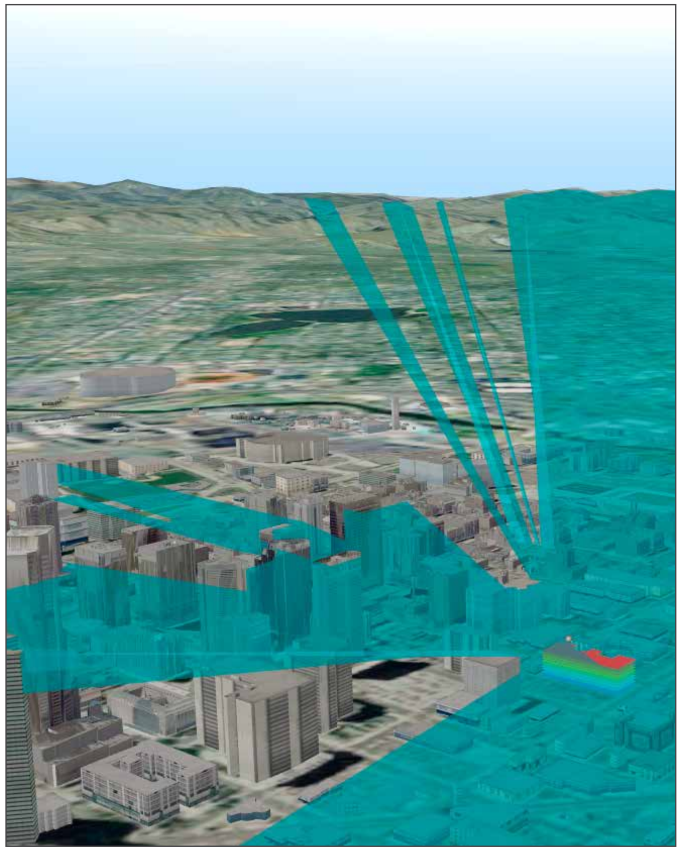


Sample: Where are the three closest military units across open terrain?
Determine proximity relationships across open geographies (air, land, sea) using cost surfaces when you have a vehicle that is not restricted to a linear network.

Exercise: Write sample questions illustrating different types of analyses that determine what is closest (as the crow flies, along a linear network, and across open terrain).

9. Determining what is visible from a given location(s)

Can you see the Golden Gate Bridge from your hotel room? Wouldn't you like to know this ahead of time? An important relationship between places is intervisibility—the ability to calculate sight lines and viewsheds, taking into account terrain, the built environment, and the earth's curvature. There are many types of three-dimensional visibility analyses that can help us understand our world and help us make better decisions.



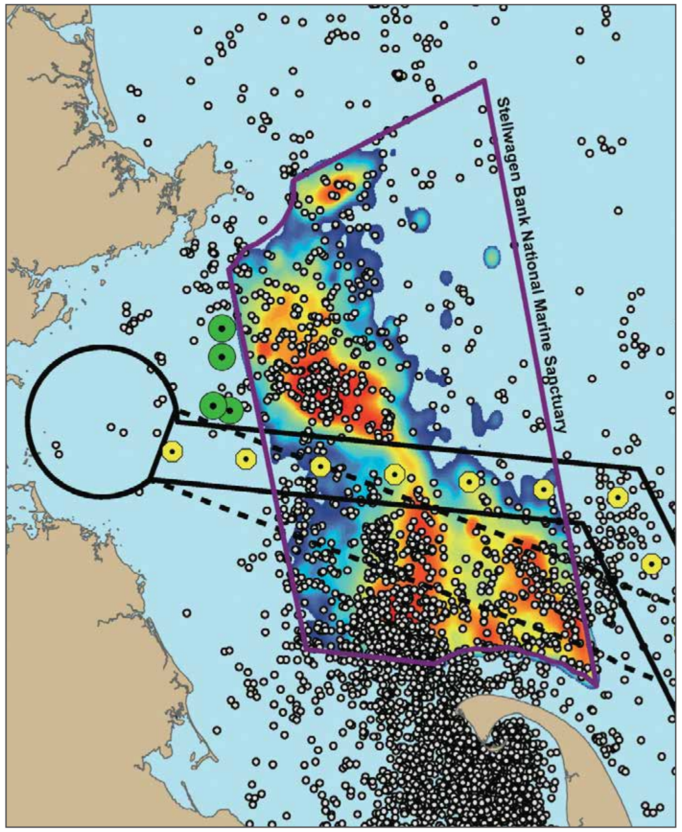
Data courtesy of the City and County of Denver, Colorado; CyberCity 3D; and Sanborn.

Sample: What buildings have direct line of sight to a new radio tower? Can you see the forest timber harvests from the scenic corridor? Determine sight lines and visibility using terrain, physical objects or obstructions, and observer/target properties.

Exercise: Write sample questions illustrating different types of analyses that show examples of determining visibility.

10. Determining overlapping relationships in space and time

Two or more features can have a variety of relationships in space. Are they close, nearby, visible, accessible, and so on? However, the world is not static—locations, properties, and relationships may change over time. Bringing time into the analysis adds yet another dimension to all the relationships discussed so far.



Map courtesy of NOAA.

Sample: When and where will the whale migration paths intersect with maritime shipping routes? Determine the intersection of objects in space and time with temporal queries and visualization. Compare the results of computational tools such as standard deviational ellipses and overlays over time.

Exercise: Write sample questions illustrating different types of analyses that require understanding the intersection of space and time.

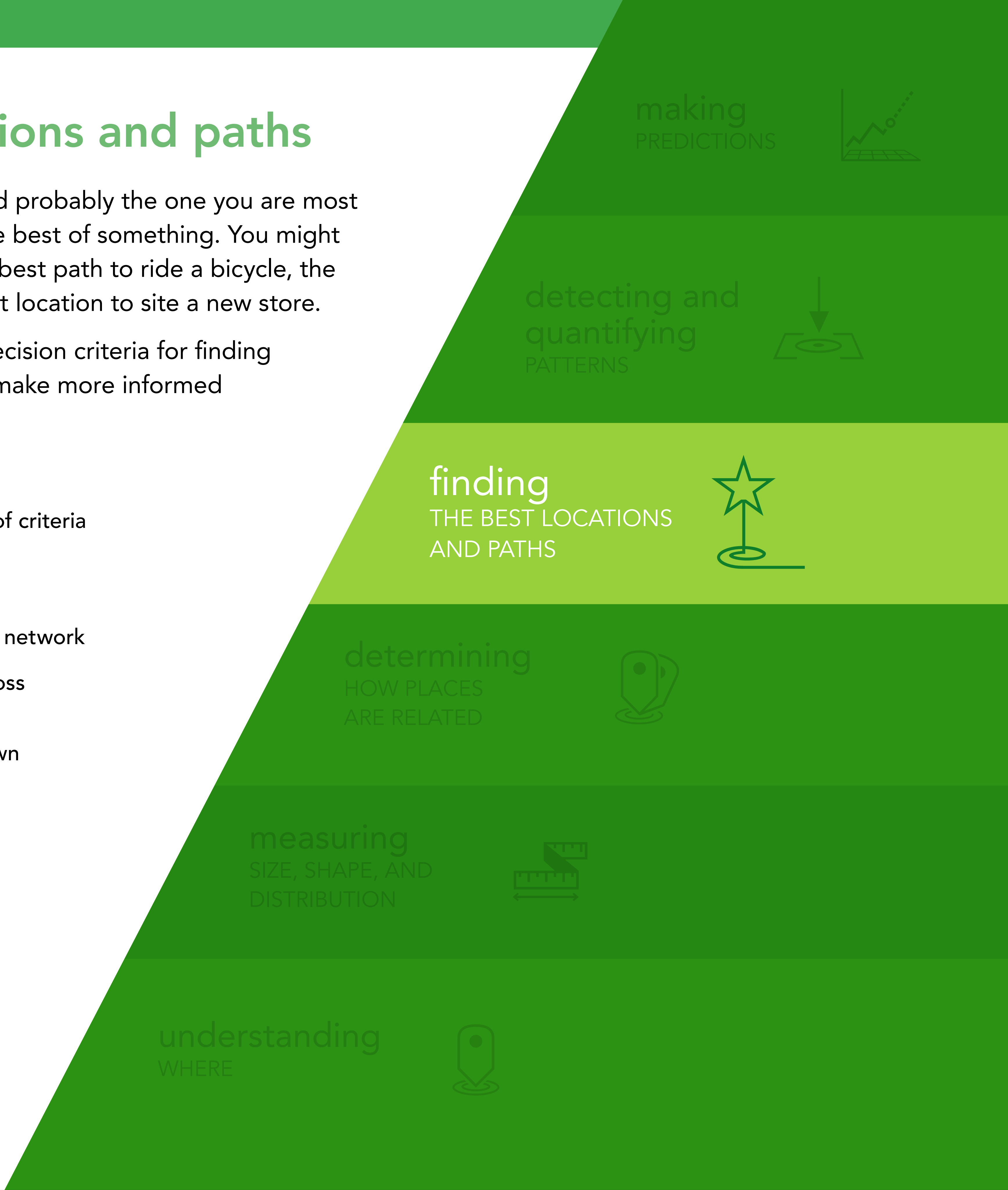
Finding the best locations and paths

A very common type of spatial analysis, and probably the one you are most familiar with, is optimization and finding the best of something. You might be looking for the best route to travel, the best path to ride a bicycle, the best corridor to build a pipeline, or the best location to site a new store.

Using multiple input variables or a set of decision criteria for finding the best locations and paths can help you make more informed decisions using your spatial data.

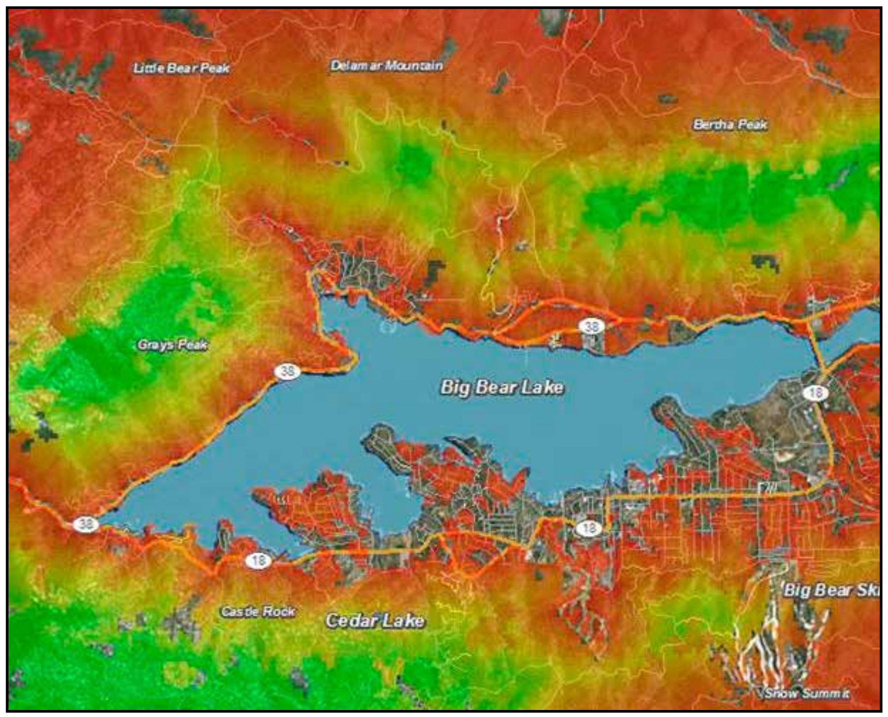
TYPES

11. Finding the best locations that satisfy a set of criteria
12. Finding the best allocation of resources to geographic areas
13. Finding the best route, path, or flow along a network
14. Finding the best route, path, or corridor across open terrain
15. Finding the best supply locations given known demand and a travel network



11. Finding the best locations that satisfy a set of criteria

What makes a location the “best location”? Most likely, it meets a set of requirements, given a certain objective. The best place for a new coffee shop has requirements including demographics, accessibility, and disposable income. If you can describe the desired characteristics, the spatial overlay process can be used to combine all the inputs to help prioritize and select the best location(s).



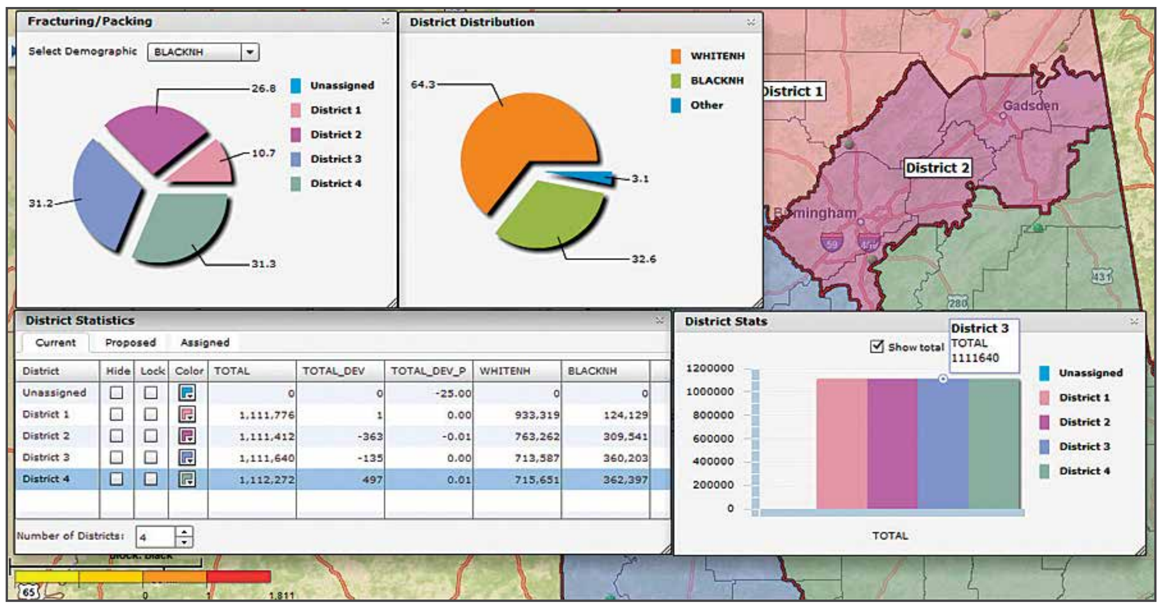
Sample: Where is the best location to create a new wildlife conservation area?

Prioritize and find the optimal location(s), also known as site suitability modeling, using weighted overlays, fuzzy overlays, map algebra, and geodesign.

Exercise: Write sample questions illustrating different types of analyses that find the best location(s) considering many different input variables.

12. Finding the best allocation of resources to geographic areas

Students are assigned to school districts. Voters report to election precincts. The assignment and balancing of resources within geographic areas is often a redistricting problem. The goal is to delineate geographic areas with similar capacity.



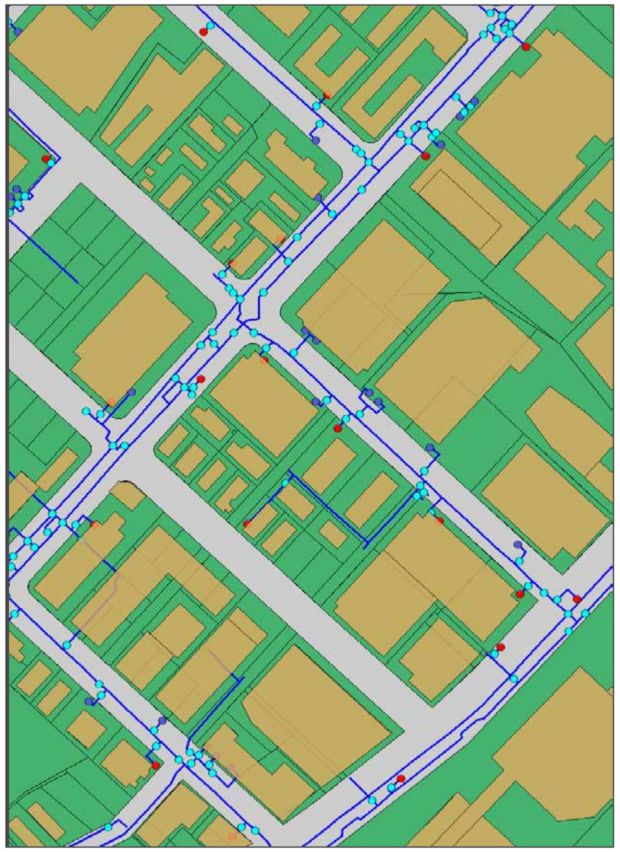
Sample: Where should boundaries for sales territories be placed so that sales staff and opportunities are balanced?

Assign and create territories through selection, proximity, compactness, and redistricting of resources.

Exercise: Write sample questions illustrating different types of analyses that require redistricting or assigning objects to territories.

13. Finding the best route, path, or flow along a network

What is the best route to drive from Los Angeles to San Francisco? What is the best walking path in New York City? How does water flow through a storm sewer system? These are all analyses that compute optimal paths along linear networks. There may be costs, restrictions, and barriers to flow, but the basic principles are the same—modeling flow along a system of connected linear features.



Data courtesy of the City and County of Honolulu, Hawaii.

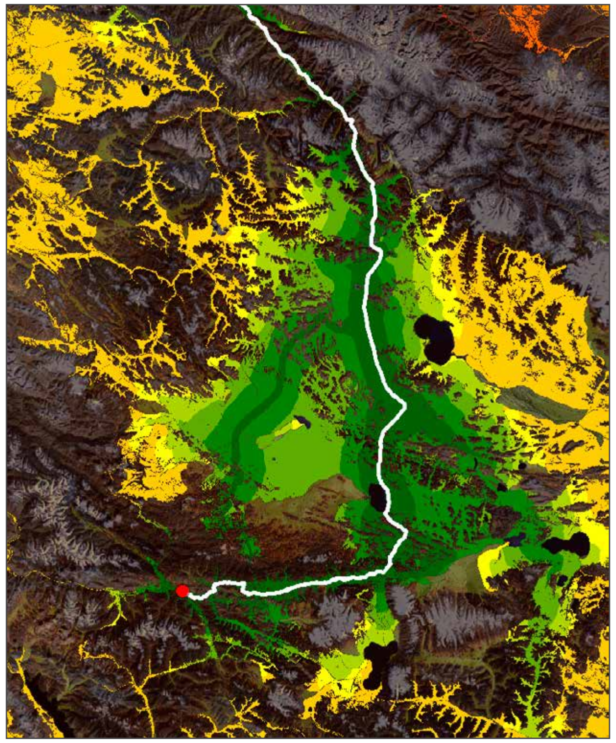
Sample: What is the best way to get from point A to point B? How will water flow through a water or sewer network?

Find the least-cost paths (distance, time, and cost) through linear networks using network analysis tools, geometric network tracing, and vehicle routing algorithms.

Exercise: Write sample questions illustrating different types of analyses that require finding the best path along linear networks.

14. Finding the best route, path, or corridor across open terrain

Moving objects (vehicles, animals, people) are not always restricted to traveling along networks. A ship on the ocean can go in many directions, as opposed to a car on a street that must follow the restrictions of the road. A lost hiker can walk in any direction through a national park and does not always stay on the trail. However, in all these examples, there are costs, obstacles, and resistances that can be used to understand flow across continuous geographies.



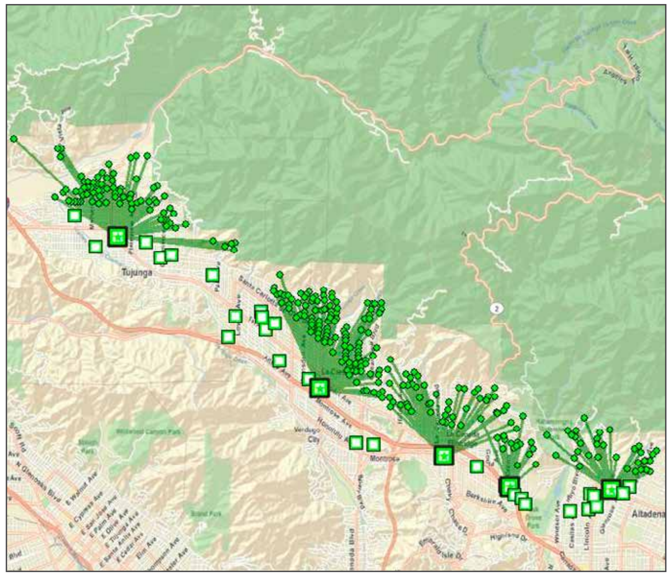
Sample: What is the best path to drive an off-road vehicle across the mountains? What is the best route to build a pipeline across a region?

Using cost surfaces, find the optimal route and corridors without the constraints of linear networks.

Exercise: Write sample questions illustrating different types of analyses requiring route optimization where you are not constrained to follow a linear network and that take into account multiple cost variables.

15. Finding the best supply locations given known demand and a travel network

Locating new resources is often facilitated by understanding the relationships between supply and demand and evaluating the infinite number of possible travel routes between these origins and destinations. Location-allocation models evaluate a series of existing or planned supply centers against a set of demand points to determine the optimal locations needed to meet the supply/demand requirements. The analysis can be based on minimizing total travel costs or by finding the most equitable solution whereby everyone has to travel an acceptable distance, even if the total travel costs increase.



Sample: What is the best location to build a new library that best serves the public or the best location for wildfire evacuation centers? Find the best location(s) that minimizes distances or costs between supply and demand points using location-allocation principles.

Exercise: Write sample questions illustrating different types of analyses that optimize supply locations based on both minimizing travel and assuring equitable travel.

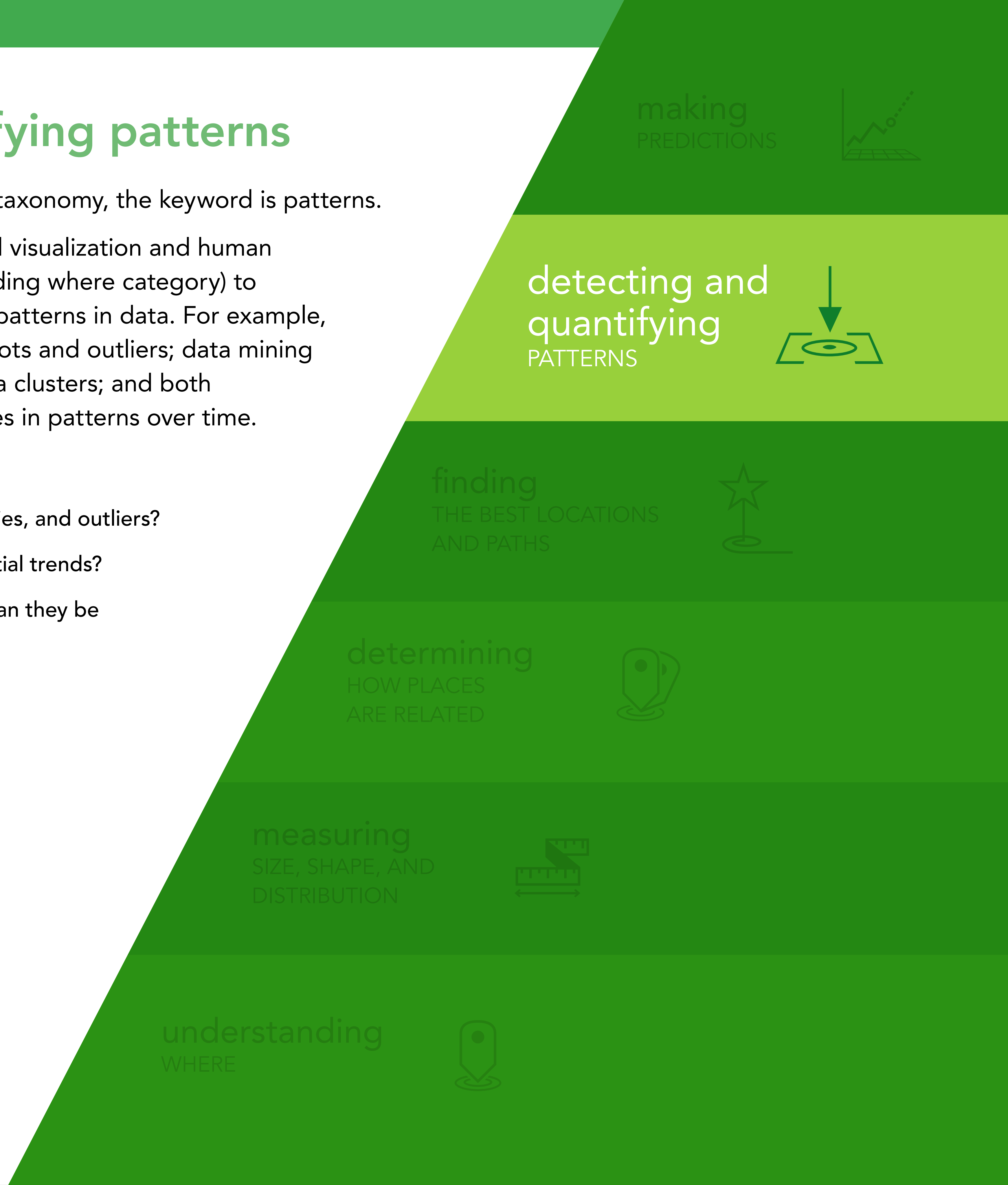
Detecting and quantifying patterns

In the fifth category of the spatial analysis taxonomy, the keyword is patterns.

These spatial analysis questions go beyond visualization and human interpretation of data (from the understanding where category) to mathematically detecting and quantifying patterns in data. For example, spatial statistics can be used to find hot spots and outliers; data mining techniques can be used to find natural data clusters; and both approaches can be used to analyze changes in patterns over time.

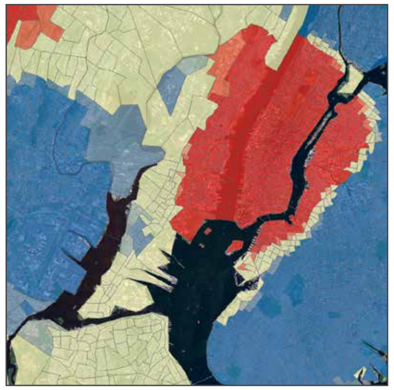
TYPES

16. Where are the significant hot spots, anomalies, and outliers?
17. What are the local, regional, and global spatial trends?
18. Which features/pixels are similar, and how can they be grouped together?
19. Are spatial patterns changing over time?



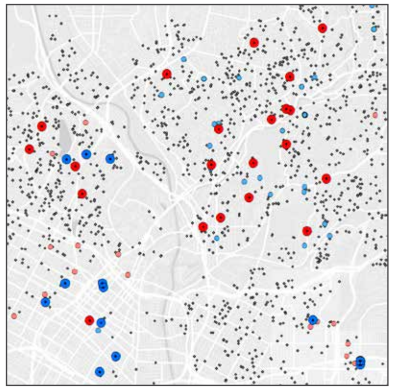
16. Where are the significant hot spots, anomalies, and outliers?

Visualizing spatial patterns is an important part of spatial analysis, but often we want to go beyond simple visualization to detect and quantify the patterns that we see (or don't see). It is common to look at a map and see clusters of high values and low values or areas that stand out as being different from their neighbors. We can use spatial analysis techniques, including spatial statistics, to gain confidence that these hot spots, cold spots, and outliers are significant before we make decisions based on these observed patterns.



Sample: Where are clusters of high expenditures on electronic goods? Where are the hot spots of cancer deaths?

Quantify statistically significant hot spots and cold spots of incidents, or data values, using spatial statistics such as hot spot analysis.



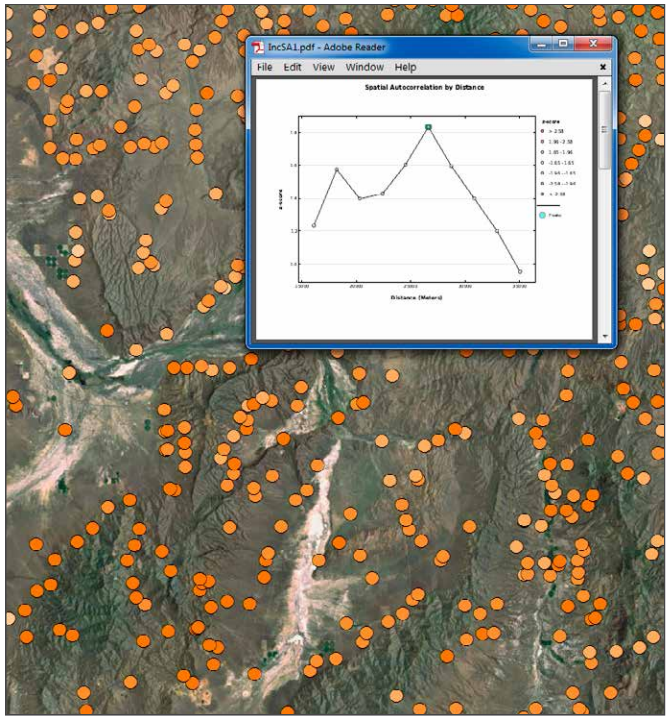
Sample: Where are homes being sold at prices much higher than their neighbors?

Find spatial outliers (low values surrounded by high values or high values surrounded by low values) using spatial statistics such as cluster and outlier analysis and exploratory spatial data analysis (ESDA).

Exercise: Write sample questions illustrating different types of analyses that require detecting and quantifying hot spots, anomalies, or outliers in spatial data.

17. What are the local, regional, and global spatial trends?

How do you choose an appropriate scale for your analysis? This is one of the most important components of an analysis, and sometimes the data holds the key. Things that are closer together are more related than things that are farther apart (Tobler's First Law of Geography). Detecting the local, regional, and global trends in data can help quantify the scale at which the relationships diminish and the scale at which they are the most pronounced.



Data courtesy of USGS, Central Minerals and Environmental Resources Science Center.

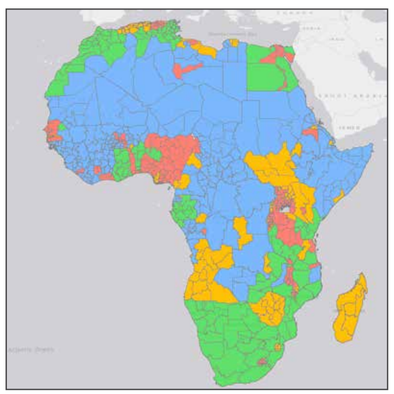
Sample: How does the clustering of gold concentrations vary at increasing scales from a valley, to a state, to the world?

Quantify the local, regional, and global trends using incremental spatial autocorrelation, Ripley's K-function, exploratory spatial data analysis, and geostatistics.

Exercise: Write sample questions illustrating different types of analyses where the relationships between values need to be quantified at different scales.

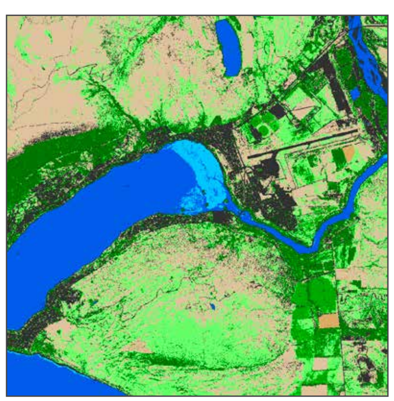
18. Which features/pixels are similar, and how can they be grouped together?

The wealth of attribute information associated with spatial features enables us to go beyond simple visualization and into the world of data mining. By combining location information and multiple variables, we are able to find natural groupings or clusters in our data. We can use these techniques to find places that have similar characteristics based on a range of attribute values and create groups or classifications that help us understand our data in new ways.



Data courtesy of the Robert S. Strauss Center for International Security and Law.

Sample: What are the areas with similar vulnerability characteristics based on socioeconomic status, governance, population density, and climate change? Using one or more variables, as well as location, find and quantify distinct clusters in data using grouping analysis.



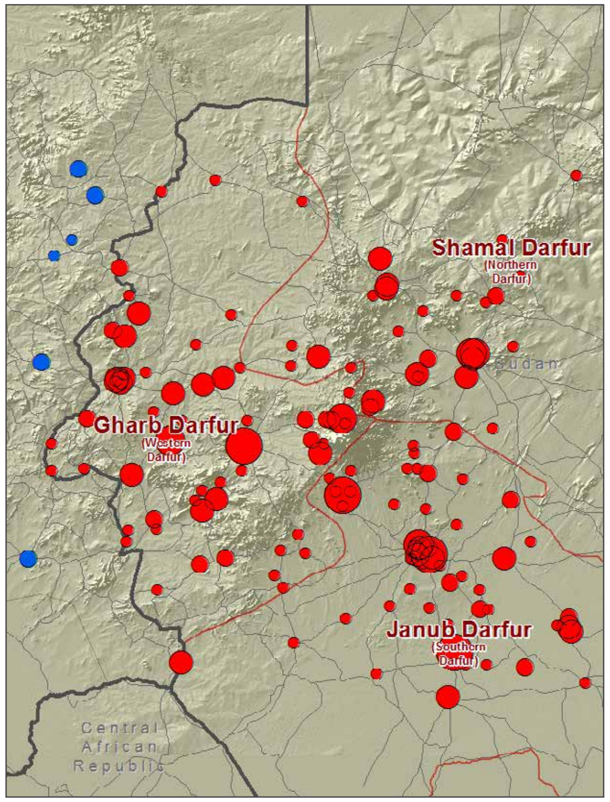
Data courtesy of DigitalGlobe.

Sample: Using satellite imagery, what are the areas that have similar land-cover types? Use image classification approaches to group pixels in remotely sensed data into distinct groups based on the values of multiple bands.

Exercise: Write sample questions illustrating different types of analyses that take raw data (points, lines, polygons, pixels) and identify unique clusters or groups in the data.

19. Are spatial patterns changing over time?

Although the spatial patterns that we detect and quantify are valuable on their own, we often gain additional insight by analyzing how they change over time. A hot spot analysis of childhood obesity provides policy makers with valuable insight, but knowing how the hot spot has grown over time provides additional insight that can help guide decision making. Each of the techniques in the detecting and quantifying patterns category can be applied temporally to answer a different set of questions.



Data courtesy of United Nations Office for the Coordination of Humanitarian Affairs and ReliefWeb.

Sample: Are rich and poor communities becoming more or less clustered over time? Over the last decade, have the hot spots of pine beetle outbreaks grown or shrunk? Through time, how are the camps with internally displaced people changing? Use the pattern detection tools iteratively, across time, and identify changing patterns in both time and space.

Exercise: Write sample questions illustrating different types of analyses where changing patterns in space and time provide critical information in the decision-making process.

Making predictions

The last category of the taxonomy includes those questions that use powerful modeling techniques to make predictions and aid understanding. These techniques can be used to predict and interpolate data values between sample points, find the factors related to complex phenomena, and make predictions in the future or over new geographies. Many specialized modeling approaches also build on the physical, economic, and social sciences to predict how objects will interact, flow, and disperse.

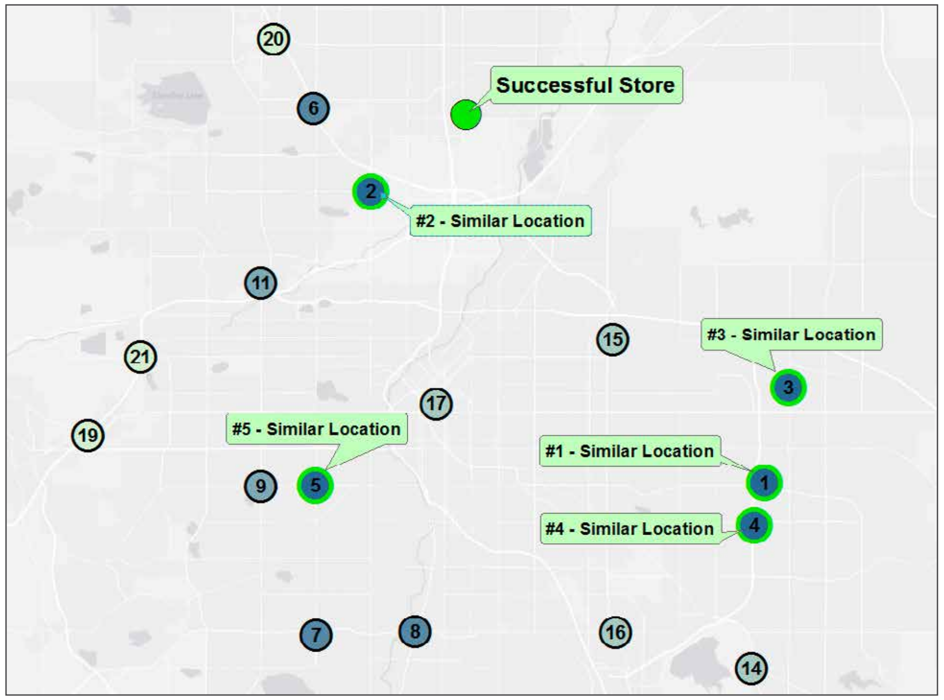
Despite their differences, all these questions share the same principles: they are used to predict behavior and outcomes and to help us better understand our world.

TYPES

20. Given a success case, identifying, ranking, and predicting similar locations
21. Finding the factors that explain observed spatial patterns and making predictions
22. Interpolating a continuous surface and trends from discrete sample observations
23. Predicting how and where objects spatially interact (attraction and decay)
24. Predicting how and where objects affect wave propagation
25. Predicting where phenomena will move, flow, or spread
26. Predicting what-if

20. Given a success case, identifying, ranking, and predicting similar locations

We often want to replicate success and avoid failure. Given a set of successful locations, we can find other locations, with similar characteristics, that are likely to succeed; and we can assess which locations are more likely to fail. Assessing similarity is a useful process in making predictions and benchmarking performance.



Sample: Given a successful store location, how would potential locations for a new store rank based on their similarity to the successful store in terms of population, demographics, and market potential?

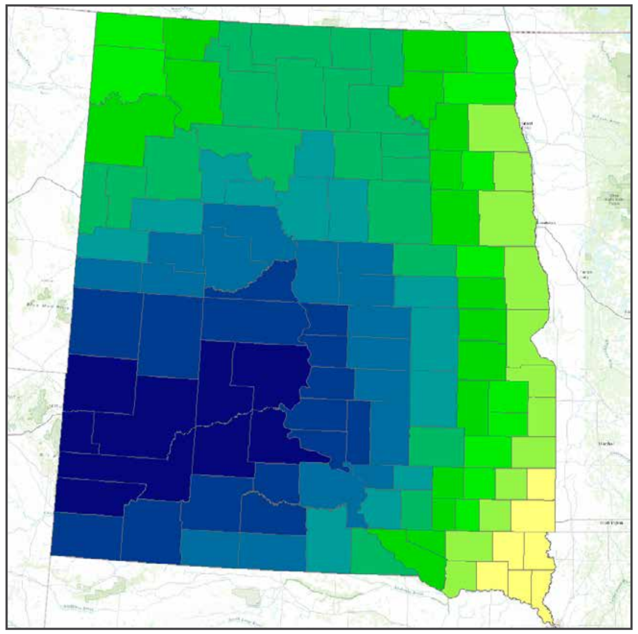
Use a similarity search to look at multiple input variables of a success case and find other similar candidates where a successful outcome can be predicted.

Exercise: Write sample questions illustrating different types of analyses where you have a target case and you would like to find similar candidates.

21. Finding the factors that explain observed spatial patterns and making predictions

As we try to understand the factors related to an observed pattern, it is often necessary to explore a number of variables, test their significance, and then analyze various combinations so that we can use these models to predict the same phenomena in other areas or other times.

These types of workflows are commonly referred to as regression analysis and encompass a variety of traditional and spatial regression approaches that provide statistical confidence in making predictions, and understanding our world, so we can implement effective policies.



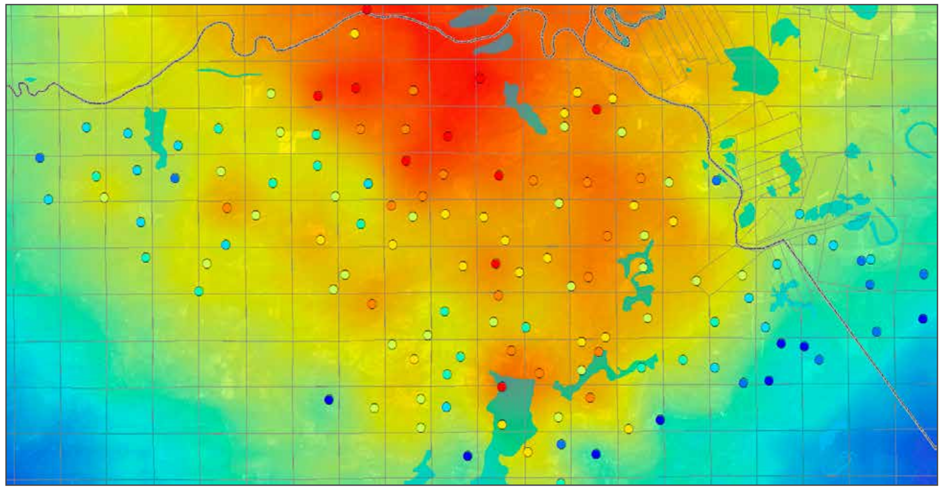
Sample: What factors contribute to people dying young, where should we focus intervention, and what will the impact be? Use linear, geographically weighted, and exploratory regression approaches to identify relevant factors and make predictions.

Exercise: Write sample questions illustrating different types of analyses where you want to understand the underlying factors and make predictions.

22. Interpolating a continuous surface and trends from discrete sample observations

What do you do when you have sample data that does not cover the entire area of interest? Predictive spatial analysis can be used to predict, or interpolate, between discrete data points to create a continuous surface.

A variety of interpolation techniques can be used to estimate the values in between sample points. More advanced geostatistical methods can also be used to measure the certainty, or uncertainty, of the results.



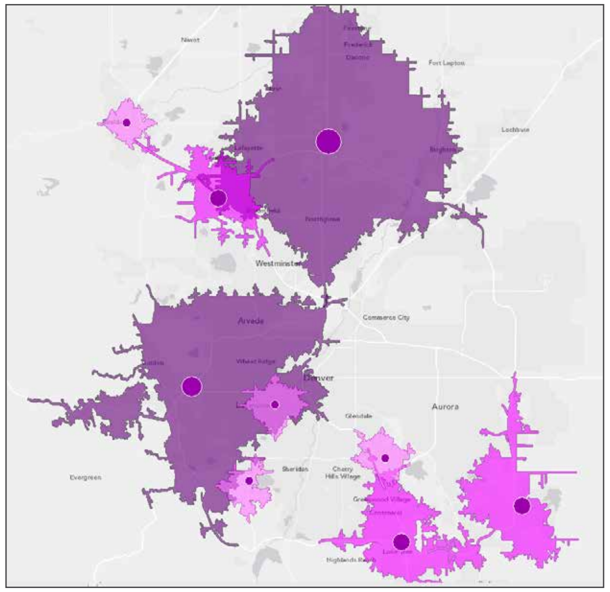
Sample: Given a set of oil well production points (samples) across an area, what are the estimated production values in unmeasured locations?

Use kriging, spline, and inverse distance weighted methods to predict data values across a continuous surface from discrete sample points.

Exercise: Write sample questions illustrating different types of problems where interpolation is needed between discrete point locations.

23. Predicting how and where objects spatially interact (attraction and decay)

Modeling and predictive analysis often use physical and geographic principles as a foundation. For example, gravity predicts how two objects will attract and come together via gravitational force. Think of a big-box retail store—the larger the store, and the better the prices, the more attractive this store will be to pull customers from farther away and from other smaller stores. Call it gravitational force. These predictive models use the concept of mass and gravity to predict the behavior of supply and demand for retail site selection and for other application areas.



Sample: How will store size and travel distance attract or detract customers? Use spatial interaction (gravity models), travel distances, and characteristics about the supply location to predict demand as well as cannibalization of other resources.

Exercise: Write sample questions illustrating different types of analyses where human or other behavior can be modeled using gravity and attraction.

24. Predicting how and where objects affect wave propagation

In physics, a wave is a disturbance or oscillation that travels through space and matter, accompanied by a transfer of energy. When we think of waves, the most common forms include light, sound (acoustic), electromagnetic, and ocean waves. With all waves, physical objects can disrupt, alter, or block their propagation. A tree blocks sunlight; a break wall disrupts an ocean wave, and temperature variations in the ocean can affect the acoustic noise propagation of a submarine.

Waves travel in predictable ways across space and time, making it possible to use spatial analysis techniques to model many of these interactions.

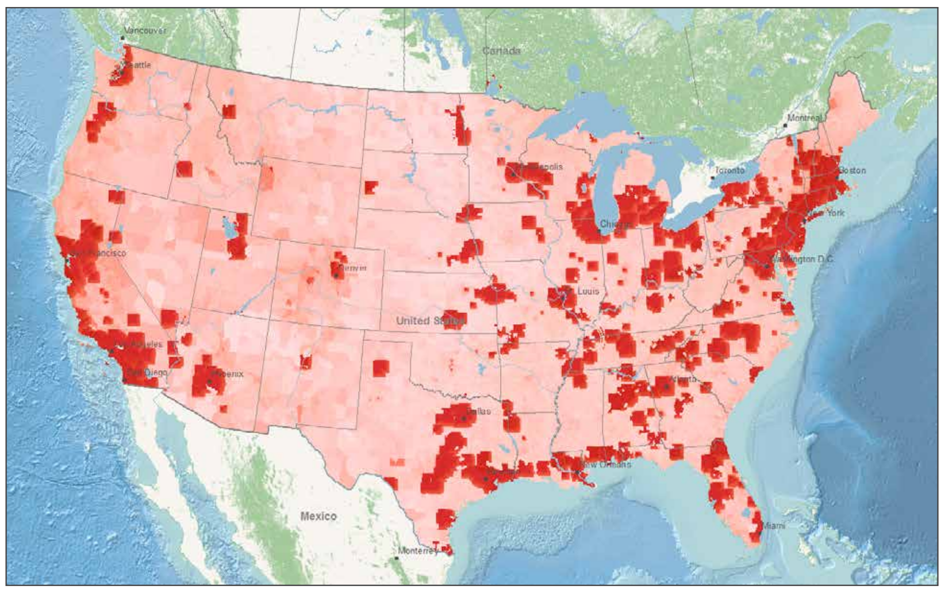
Data courtesy of the City of Portland, Oregon.

Sample: How will buildings cast shadows or reflect sunlight? Combine tools such as line of sight and shadow analysis with more complex modeling and simulation techniques to predict wave propagation.

Exercise: Write sample questions illustrating different types of analysis that use wave propagation modeling.

25. Predicting where phenomena will move, flow, or spread

Many geographic phenomena have the ability to move, flow, or spread—a forest fire, a disease outbreak, a chemical contamination, or a marketing campaign. Predicting how these phenomena move in space and time is an important type of spatial analysis that involves modeling complex systems, interactions, behaviors, and responses.



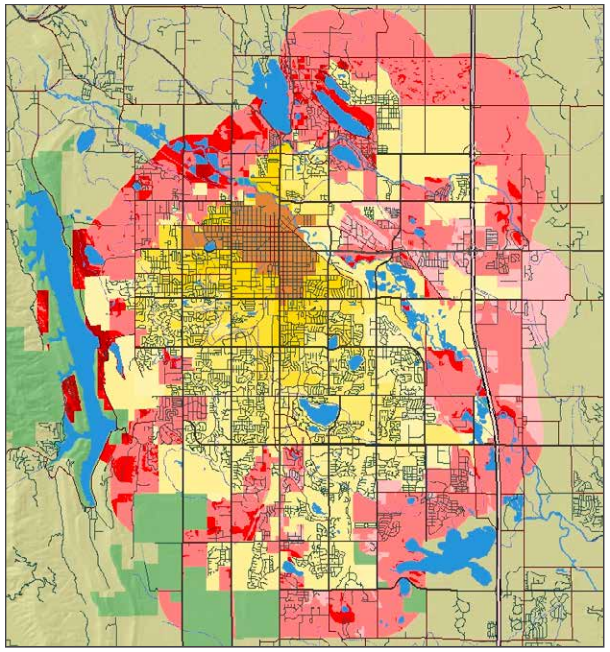
Sample: How will illegal drug use grow and spread? How will a forest fire spread based on vegetation and wind? How will a disease spread based on social interaction? How fast will a pollutant disperse in the ocean?

Use dispersion modeling, flow direction, and cost surfaces to predict how phenomena change size, shape, and location.

Exercise: Write sample questions illustrating different types of analyses that require modeling how phenomena will move, flow, or spread.

26. Predicting what-if

Models are used to predict outcomes, help us understand our world, and help people make informed decisions. One of the most valuable aspects of modeling is the ability to test and evaluate potential actions and their resulting impacts. Using a what-if, iterative approach, many different scenarios can be evaluated before taking action.



Data courtesy of the City of Fort Collins, Colorado.

Sample: How will different urban development scenarios impact sprawl? What if we create a new mixed-use town center? What if we build a major sports complex? What if we increase high-occupancy lanes?

Use modeling and prediction, applied repeatedly, to assess different outcomes.

Exercise: Write sample questions illustrating different types of what-if analyses.

The seven steps to successful spatial analysis

With the taxonomy of spatial analysis, we now have a language for communication. However, the individual questions in the taxonomy are just the building blocks that make up our vocabulary. How we choose to put these building blocks together is a function of the real-world problem that we're trying to solve.

Combining these questions takes us from learning the language of spatial analysis to understanding the process of spatial analysis. Successful spatial analysis requires a seven-step approach that begins with asking the questions and ends with making a decision. It is important to emphasize that spatial analysis is not just running a tool, or a model, but rather is a workflow and an approach to problem solving. At right are the seven steps to successful spatial analysis.

1. **Ask questions:** Formulate hypotheses and spatial questions.
2. **Explore the data:** Examine the data quality, completeness, and measurement limitations (scale and resolution) to determine the level of analysis and interpretation that can be supported.
3. **Analyze and model:** Break the problem down into solvable components that can be modeled. Quantify and evaluate the spatial questions.
4. **Interpret the results:** Evaluate and analyze the results in the context of the question posed, data limitations, accuracy, and other implications.
5. **Repeat as necessary:** Spatial analysis is a continuous and iterative process that often leads to further questions and refinements.
6. **Present the results:** The best information and analysis becomes increasingly valuable when it can be effectively presented and shared with a larger audience.
7. **Make a decision:** Spatial analysis and GIS are used to support the decision-making process. A successful spatial analysis process often leads to the understanding necessary to drive decisions and action.

CHAPTER 4

The benefits of spatial analysis

As we formulate spatial analysis solutions, it is important to keep in mind not only the goals that need to be achieved, but also the benefits that result from successful spatial analysis. Regardless of the domain or industry (government, commercial retail, petroleum, utilities, and so on), the purpose of spatial analysis is to use our data and increased understanding to make better decisions. Each problem may have a different objective, but the focus should always be on solving the underlying real-world problem.

WHY SPATIAL ANALYSIS?

- Achieve objectives
- Improve program outcomes
- Reduce costs
- Avoid costs
- Increase efficiency and productivity
- Increase revenue
- Assure revenue
- Protect staff and citizens (health and safety)
- Support regulatory compliance
- Improve customer service
- Enhance customer satisfaction
- Enhance competitive advantage

The vocabulary of spatial questions is not the endgame, it is rather akin to the single moves in a chess game. The game is never won with a single move, but only with a strategy that combines many moves together.

Similarly, a single spatial question will rarely solve the real-world problem. The true masters of spatial analysis can look at a real-world problem and bring together many types of questions, across categories, to reach their true objective. Those people who speak the language of spatial analysis will not only be able to think through spatial questions, but will also be able to communicate the power of spatial analysis to the world.

Spatial analysis offers a unique way to understand our world and meet our challenges. Most of the time, solving the problems will require answering a series of questions and developing a step-by-step workflow. It is through this process that we gain understanding and find out not only where things are, but how they relate, what it all means, and what actions to take.

Bringing it all together to solve the problem

In an effort to keep our city safe, the police department is instituting a policy that deploys additional police officers. Rather than the police just driving patrol cars, many officers will be redeployed on bicycles. The goals are for the police officers to get to know the communities, for the communities to get to know the police officers, and to reduce crime and improve public safety.

To accomplish these goals, the city needs to make sure it uses its limited resources as effectively as possible by deploying bicycle patrols in neighborhoods that are most in need of their services.

The police department needs to answer a number of common spatial analysis questions to begin to solve this problem:

1. Where have all the crimes occurred in the last year? (Location map)
2. Where are existing community resources located? (Location map)
3. Where are areas with concentrated vulnerable populations, including young children and the elderly? (Comparative map)

Once they answer these questions, they have several additional questions that need to be analyzed and modeled in order to make an informed decision:

4. Where are the areas that have statistically significant crime clusters? (Hot spot analysis)
5. How have crime patterns changed over time? (Changing spatial patterns over time)
6. How have demographics of the community changed, and where are vulnerable populations? (Changing spatial patterns over time)

7. What is the relationship between law enforcement efforts and crime rates? Where could the proposed bicycle patrols have the most impact? (Regression analysis)
8. Using the analysis about the demand for bicycle patrols both now and in the future, where are the best neighborhoods and routes for the officers to patrol so they can allocate their resources both effectively and equitably? (Location allocation and routing)

By interpreting these analytical results, the police department can determine whether this proposed plan will help citizens, reduce crime, and meet police and community objectives. If not, the process can be repeated, exploring other options. Once a suitable plan has been decided upon, the information can be presented and shared with the command staff and the public, and the officers can be redeployed accordingly.

Exercise: Write your own real-world analysis questions

Instead of looking at each type of question individually, start with a real-world problem in your domain and determine how many different questions can be combined to solve this problem. Think holistically about what the true endgame of the spatial analysis problem is.

Many problems will cut across the six categories:

- Understanding where
- Measuring size, shape, and distribution
- Determining how places are related
- Finding the best locations and paths
- Detecting and quantifying patterns
- Making predictions

Real-world problem and analysis questions

A quick guide to spatial analysis

Understanding where

1. Understanding where things are (location maps)
2. Understanding where the variations and patterns in values are (comparative maps)
3. Understanding where and when things change (change maps)

Measuring size, shape, and distribution

4. Calculating individual feature geometries
5. Calculating geometries and distributions of feature collections

Determining how places are related

6. Determining what is nearby or coincident
7. Determining and summarizing what is within an area(s)
8. Determining what is closest
9. Determining what is visible from a given location(s)
10. Determining overlapping relationships in space and time

Finding the best locations and paths

11. Finding the best locations that satisfy a set of criteria
12. Finding the best allocation of resources to geographic areas
13. Finding the best route, path, or flow along a network
14. Finding the best route, path, or corridor across open terrain
15. Finding the best supply locations given known demand and a travel network

Detecting and quantifying patterns

16. Where are the significant hot spots, anomalies, and outliers?
17. What are the local, regional, and global spatial trends?
18. Which features/pixels are similar, and how can they be grouped together?
19. Are spatial patterns changing over time?

Making predictions

20. Given a success case, identifying, ranking, and predicting similar locations
21. Finding the factors that explain observed spatial patterns and making predictions
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23. Predicting how and where objects spatially interact (attraction and decay)
24. Predicting how and where objects affect wave propagation
25. Predicting where phenomena will move, flow, or spread
26. Predicting what-if

ADDITIONAL RESOURCES

Explore the following additional Esri Press books:

Mitchell, A. 2001. *The Esri Guide to GIS Analysis, Volume 1: Geographic Patterns and Relationships.* Redlands, CA: Esri Press.

Mitchell, A. 2005. *The Esri Guide to GIS Analysis, Volume 2: Spatial Measurements and Statistics.* Redlands, CA: Esri Press.

Mitchell, A. 2012. *The Esri Guide to GIS Analysis, Volume 3: Modeling Suitability, Movement, and Interaction.* Redlands, CA: Esri Press.

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