Methods in Spatial Analysis
PS | LV.Nr. 856.141

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Lecturer

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- Head of Research Group Geoinformation

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Publons: https://publons.com/a/1231051/

Google Scholar: https://scholar.google.at/citations?user=kthtbDYAAAAJ&hl=de

https://twitter.com/Joe_GISc

@Joe_GISc@mastodon.online

… who are you?

- Please introduce yourself!

Introduction

- The students should become familiar with and understand state-of-the-art spatial analysis methods. In particular we focus on the nature of analysis methods and the impact on the analysis results. Through integrated practical examples, students are able to understand the methods & concepts and apply them to real-world problems in spatial analysis.

- Objectives
  - Students should be familiar with the basic concepts and terminology used in spatial analysis contexts.
  - Students are able to reflect on the most recent technological and methodological advancements.
  - Students understand the nature spatial analysis techniques and are able to apply them to real world problem in an appropriate way.

PS Overview and Contents

Date	Where & When	Content
10-Oct-2023	GI-Lecture | 0900-1500	Administration, Introduction to Spatial Analysis, Basics
17-Oct-2023	GI-Lecture | 0900-1500	Distance Analysis Selection & Aggregation
24-Oct-2023	Online | 0900-1100	Network Analysis
07-Nov-2023	Online | 0900-1100	Spatial Interpolation
14-Nov-2023	Online | 0900-1100	Terrain Analysis
21-Nov-2023	Online | 0900-1100	Visibility Analysis
28-Nov-2023	Online | 0900-1100	Calculating Solar Potential
05-Dec-2023	Online | 0900-1100	Hydrological Modelling (Surface Runoff)
12-Dec-2023	Online | 0900-1100	Weighted Overlay
09-Jan-2024	GI-Lecture | 0900-1500	Cost Surface Analysis, Concluding Remarks

Lecture details

- Where do we meet:
  - Lecture Hall > GI-Lecture
    - Tuesday 0900 – 1500
  - Online
    - Tuesday 0900 – 1100
    - Meeting Links are provided in Blackboard

- Blackboard shows a collection of:
    - Transparencies (PDFs)
    - Books
    - Papers
    - Online resources

Grading

- **Hand-ins of Assignments**
  - 3 Assignments
  - Concerned with Spatial Analysis using ArcGIS online
  - Report has to be handed in (using Blackboard)

- **Assessment criteria**
  - Active participation in the course (10%)
  - Each assignment (30%)

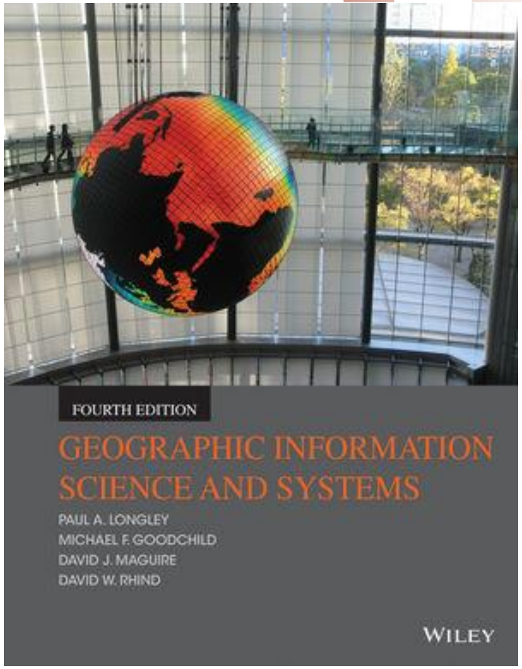
- Grading schema for each assignment & course:
  - 100 - 91 points: 1 (sehr gut)
  - 90 - 81 points : 2 (gut)
  - 80 - 71 points : 3 (befriedigend)
  - 70 - 61 points : 4 (genügend)
  - <= 60 points: 5 (nicht genügend)

Literature

- Bartelme, N. (2005). Geoinformatik - Modelle, Strukturen, Funktionen. Springer-Verlag, Berlin, Heidelberg.
  - Available in the library

- Longley, P.A., Goodchild, M.F., Maguire, D.J., Rhind, D.W. (2015). Geographic Information Science and Systems, 4th Edition, Wiley.
  - Available in the library

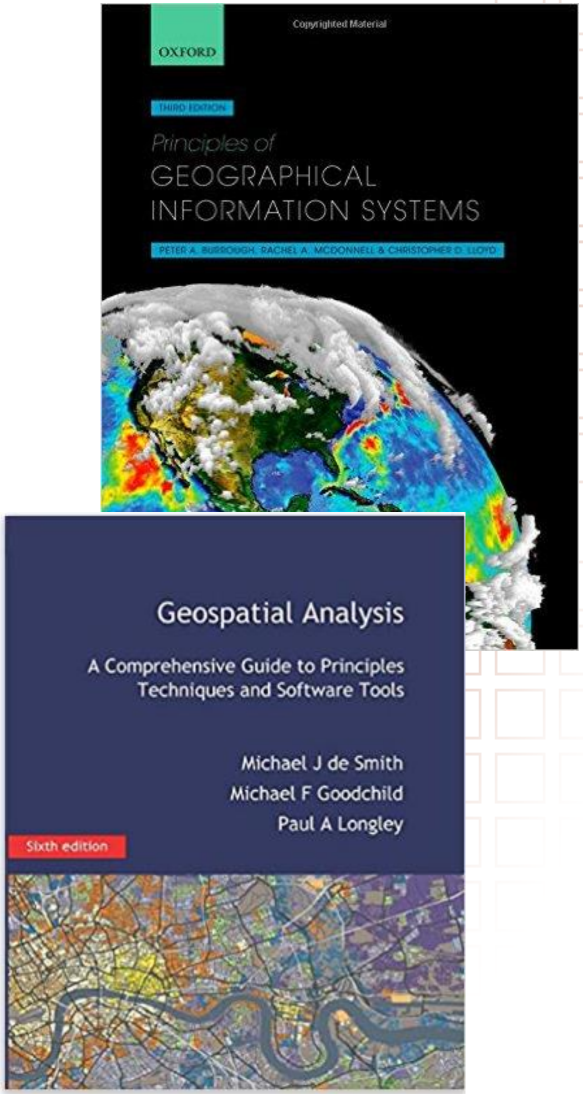
  >> I strongly recommend buying this book!



Literature

- Burrough, P.A., McDonnell, R.A., Lloyd, C.D. (2015). Principles of Geographical Information Systems. Oxford University Press.

- De Smith, M. J., Goodchild, M. F., & Longley, P. (2018). *Geospatial analysis: a comprehensive guide to principles, techniques and software tools*. Troubador Publishing Ltd.



Questions?

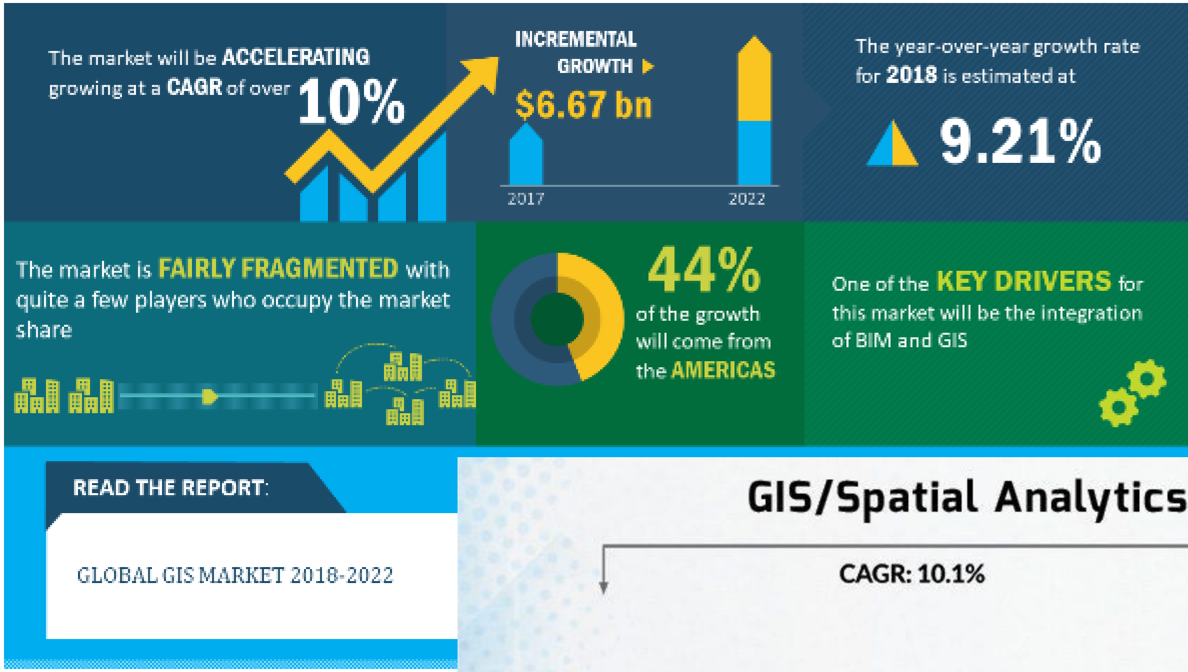
Intro & Basics

Geoinformation ?

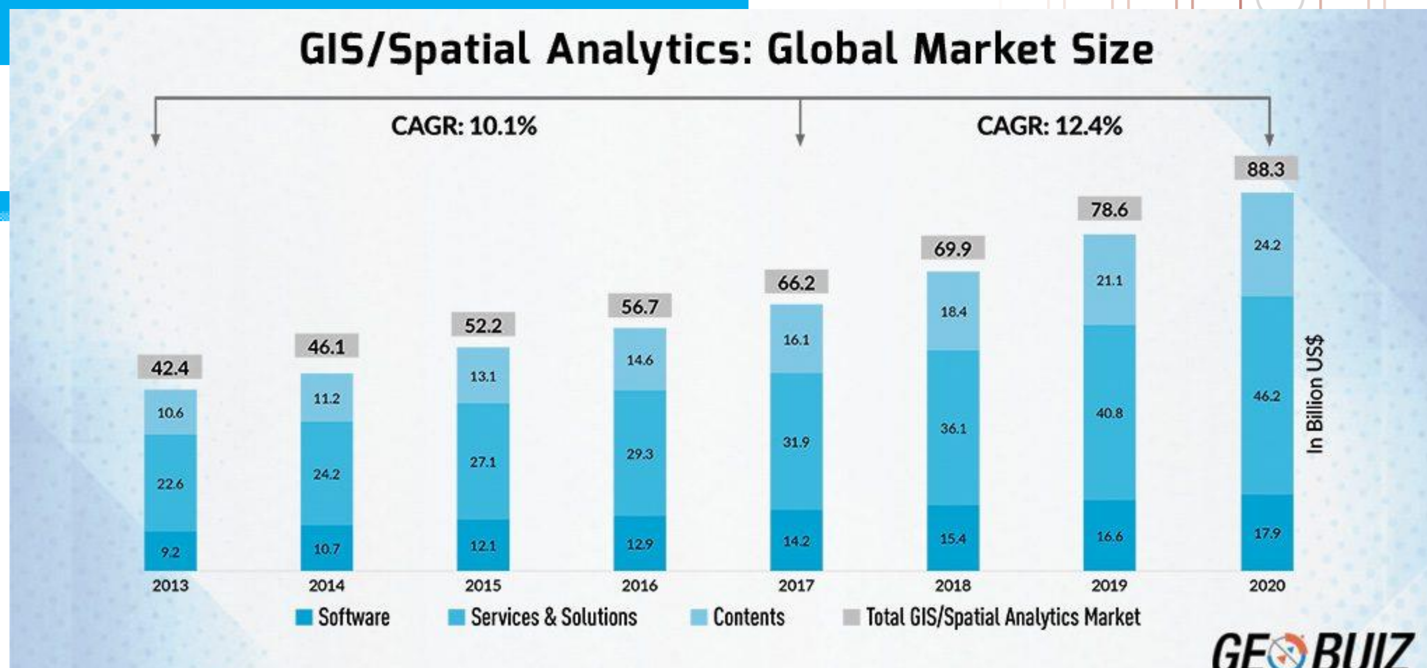
- **Geoinformation** deals with any kind of ***information systems*** that *integrate*, *store*, *edit*, *analyze*, *share* and *visualize* **geographic information.**

Geoinformation and YOU?

GEO INFORMATION



https://www.technavio.com/report/global-gis-market-analysis-share-2018



https://www.geospatialworld.net/blogs/gis-and-spatial-analytics-market/

How does GIS work?

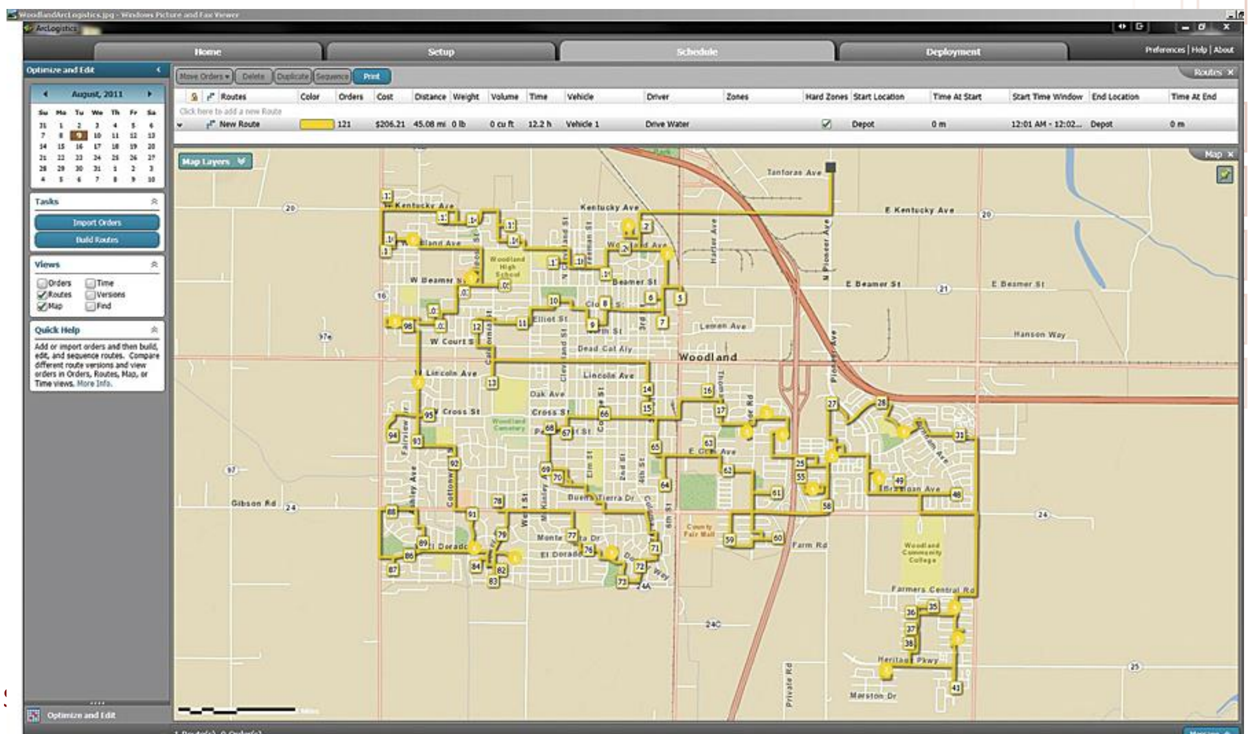
- **80% of all data** present have a **spatial dimension**

- **A Geographic Information System (GIS) lets us visualize, question, analyze, and interpret data to understand relationships, patterns, and trends.**

- Five-step process to apply Geographical Information System (GIS) to any problem that requires a geographic decision
  - Ask
  - Acquire
  - Examine
  - Analyze
  - Act

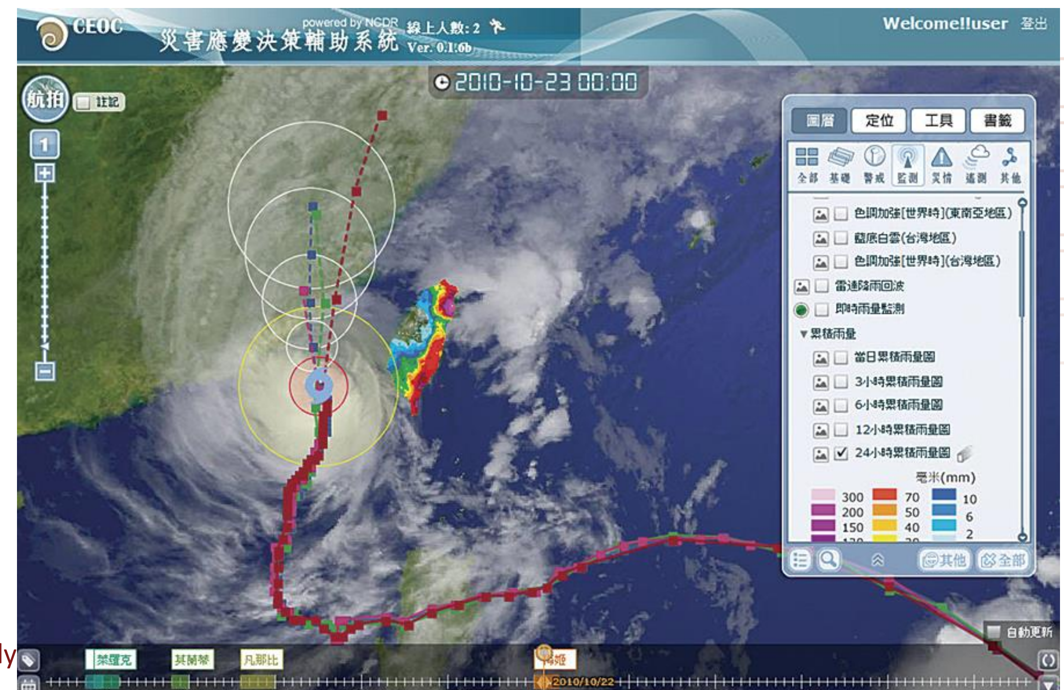
Benefits from Geoinformation?

- Cost savings from greater efficiency
  - GIS is widely used to optimize maintenance schedules and daily fleet movements. Typical implementations can result in a savings of 10 to 30 percent in operational expenses through reduction in fuel use and staff time, improved customer service, and more efficient scheduling.



Benefits from Geoinformation?

- Better decision making
  - GIS is the go-to technology for making better decisions about location. Common examples include real estate site selection, route/corridor selection, evacuation planning, conservation, natural resource extraction, etc. Making correct decisions about location is critical to the success of an organization.

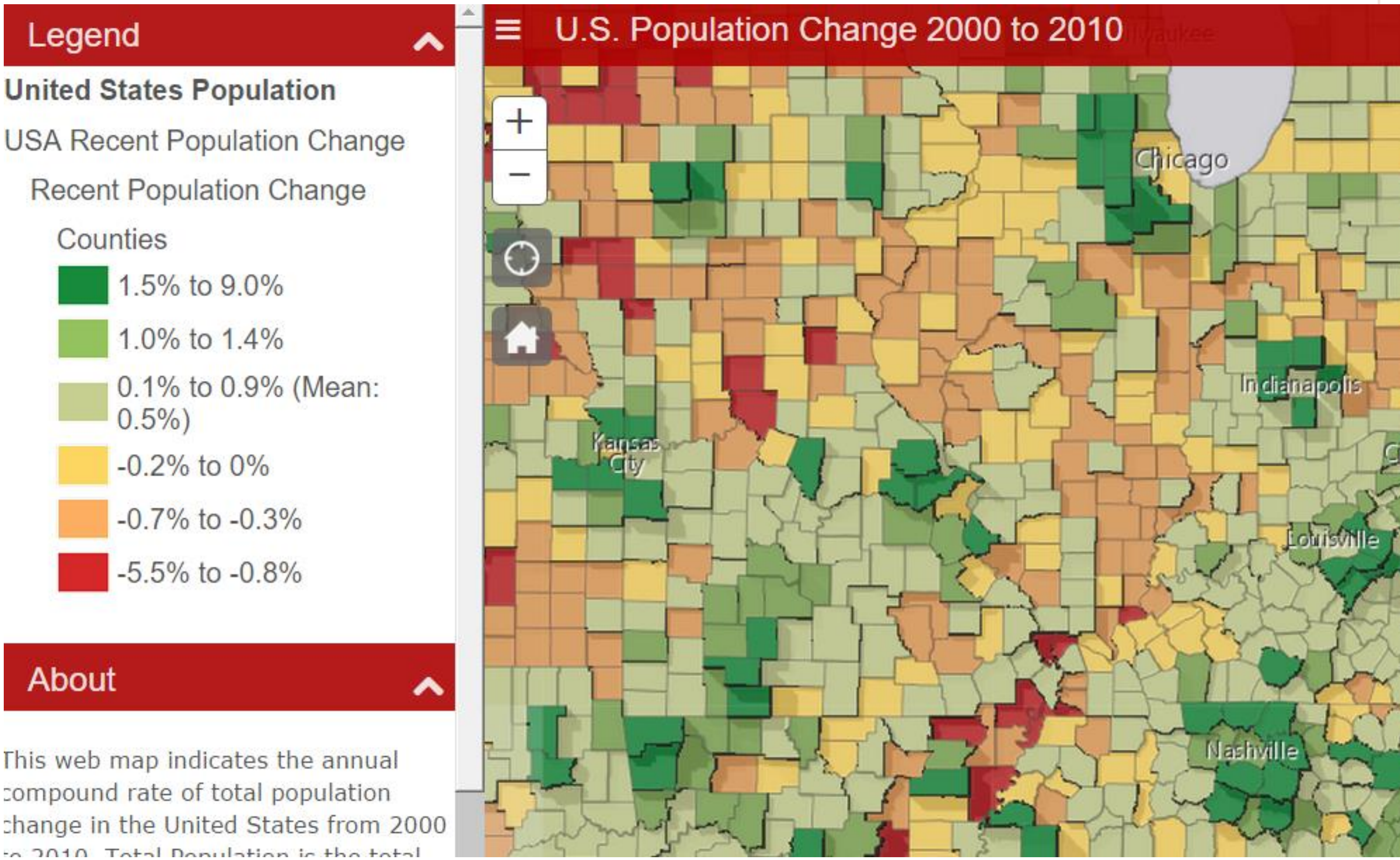


Benefits from Geoinformation?

- Improved communication
  - GIS-based maps and visualizations greatly assist in understanding situations and in storytelling. They are a type of language that improves communication between different teams, departments, disciplines, professional fields, organizations, and the public.

Benefits from Geoinformation?

- Improved communication



Benefits from Geoinformation?

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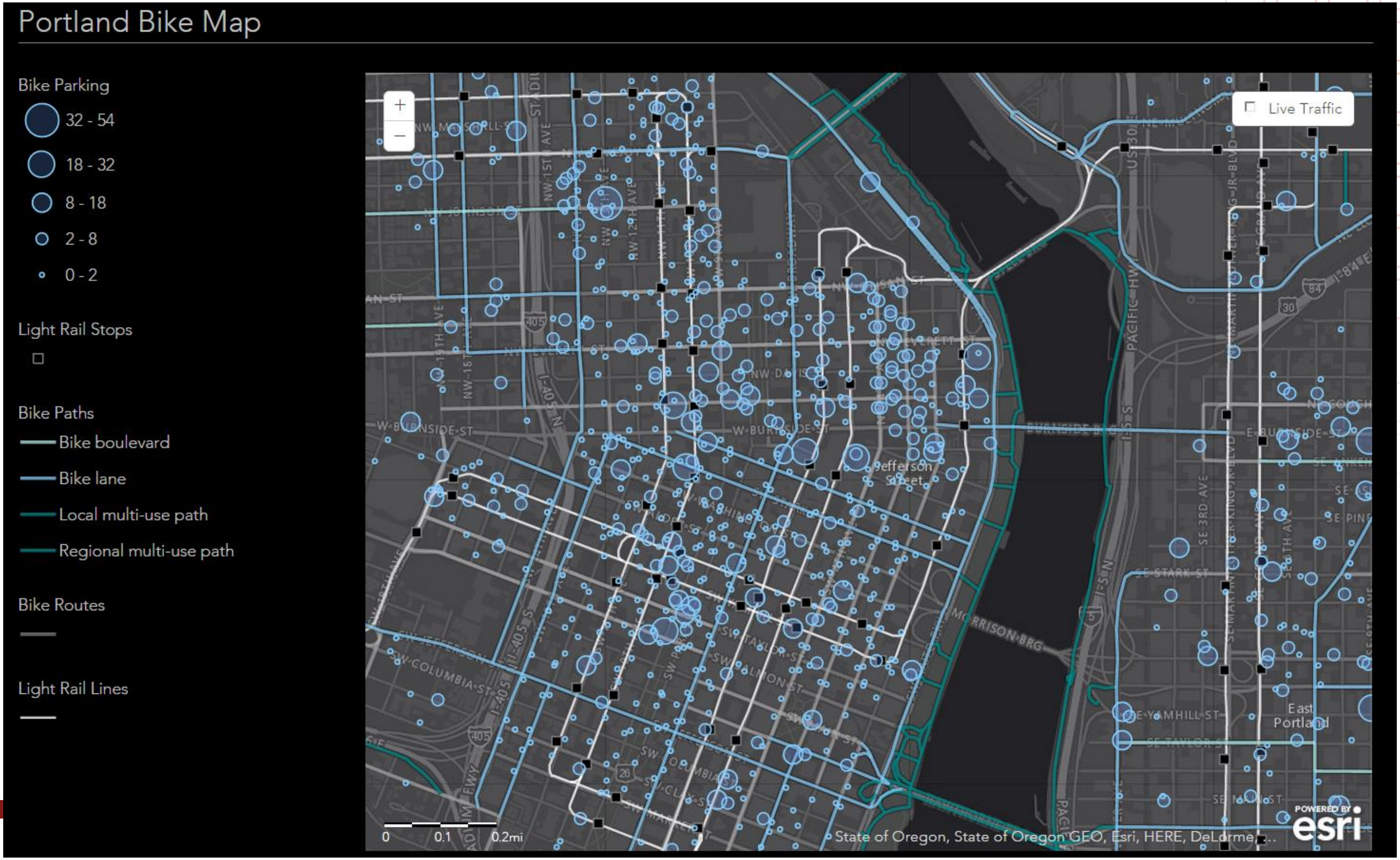
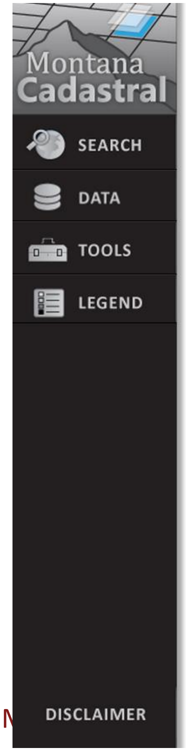


Benefits from Geoinformation?

- Improved communication

Benefits from Geoinformation?

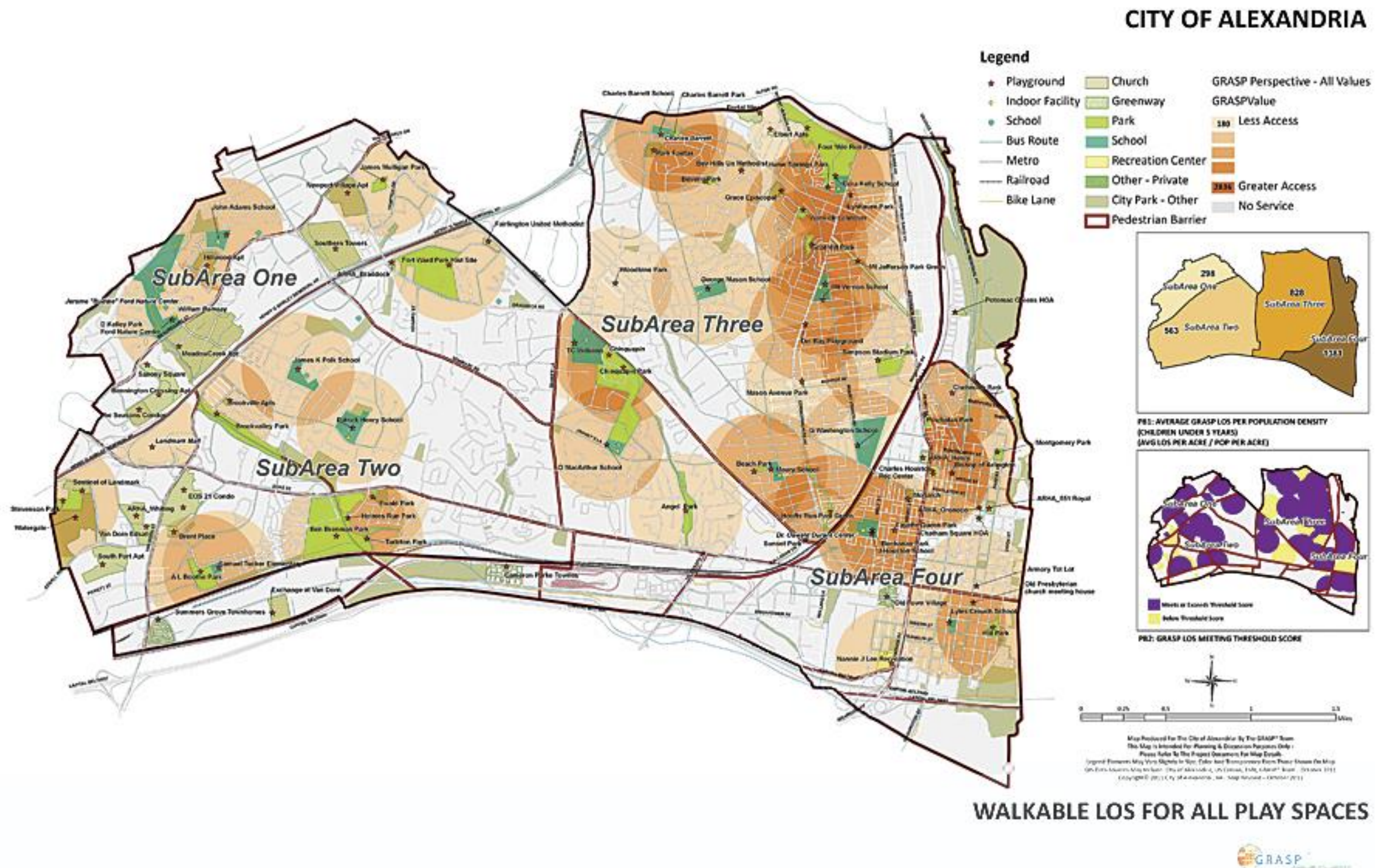
- Better record keeping
  - Many organizations have a primary responsibility of maintaining authoritative records about the status and change of geography. GIS provides a strong framework for managing these types of records with full transaction support and reporting tools.



Benefits from Geoinformation?

- Managing geographically
  - GIS is becoming essential to **understanding what is happening** and **what will happen** in **geographic space**. Once we understand, we can **prescribe action**. This new approach to management—managing geographically—is transforming the way organizations operate.

Benefits from Geoinformation?



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Application Areas

- … and many more:

- http://gisgeography.com/gis-applications-uses/

„Spatial Analysis“ || Overview

Get creative!

- **What is Spatial Analysis for you?**

  - Prepare a quick pitch (of about 2 mins)!
  - Maybe create a supporting drawing

  - Present in front of the class!

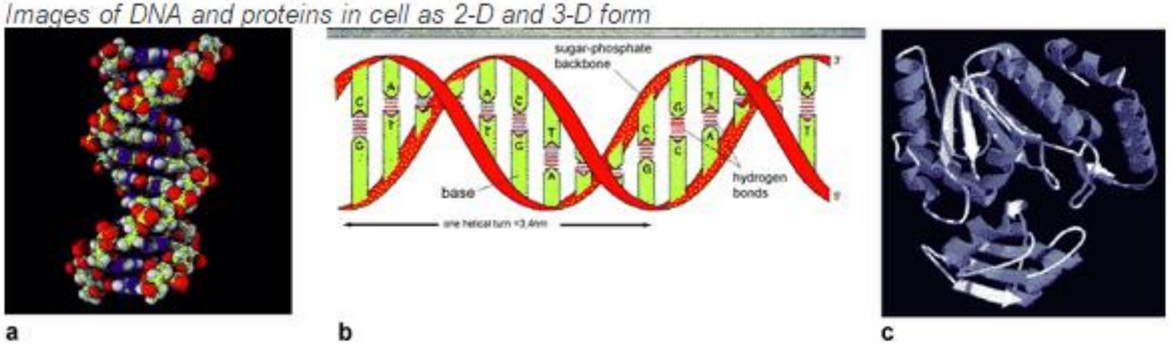
Definition

- Spatial Analysis:
  - Formal methods and techniques that analyze spatial objects – with respect to their
    - topological
    - geometrical
    - geographic
  - ... properties
  - … to solve a specific question e.g.:
    - Identify regions with high crime rate
    - Best location for a new store
    - Best locations for a advertising a certain product
    - …

Definition

- Spatial Analysis:
  - Other definiton (closely related to Geography):
    - Techniques & Methods for analyzing phenomena on (or closely around) the Earth‘s surface, in particular with the help of spatial data
  - Why spatial analysis and not geographic analysis?
    - Theory can be applied to spatial data in general, not only to geographical space (e.g. Bioinformatics).

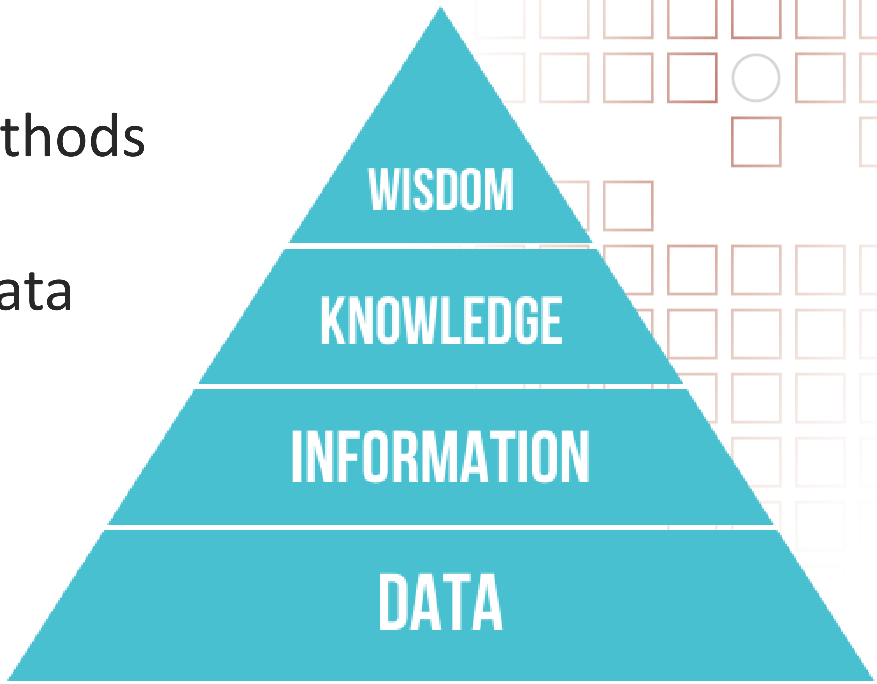
Images of DNA and proteins in cell as 2-D and 3-D form



Spatial Analysis: statements

- Spatial analysis is a symbiosis of humans and computer.
  - A strong computer is not enough!
  - Humans are excellent at detecting patterns and correlations!

- Spatial analysis is the set of methods that create an added value to spatial data and that transfer data into information & knowledge.



Spatial Questions

- Nyerges (1991) suggests that spatial questions should be categorized, according to the topic they cover:
  - location and extent
  - distribution and pattern or shape
  - spatial association
  - spatial interaction and
  - spatial change.

- Solutions strategy for spatial questions:
  - Analyze the questions and collect data necessary for to answer the question
  - Data processing (i.e. spatial analysis)
  - Try to find generalizations and implement them
  - Evaluate the result

Spatial Questions?

- Where is it?
- Where does it occur?
- What is there?
- Why is it there?
- Why is it not elsewhere?
- What could be there?
- Could it be elsewhere?
- How much is there at that location?
- Why is it there rather than anywhere else?
- How far does it extend already?
- Why does it take a particular form or structure that it has?
- Is there regularity in its distribution?
- What is the nature of that regularity?
- Why should the spatial distributional pattern exhibit regularity?
- Where is it in relation to others of the same kind?
- What kind of distribution does it make?
- Is it found throughout the world?
- Is it universal?
- Where are its limits?
- What are the nature of those limits?
- Why do those limits constrain its distribution?
- What else is there spatially associated with that phenomenon?
- Do these things usually occur together in the same places?
- Why should they be spatially associated?
- Is it linked to other things?
- Has it always been there?
- When did it first emerge or become obvious?
- How has it changed spatially (through time)?
- What factors have influenced its spread?
- Why has it spread or diffused in this particular way?
- What geographic factors have constrained its spread?

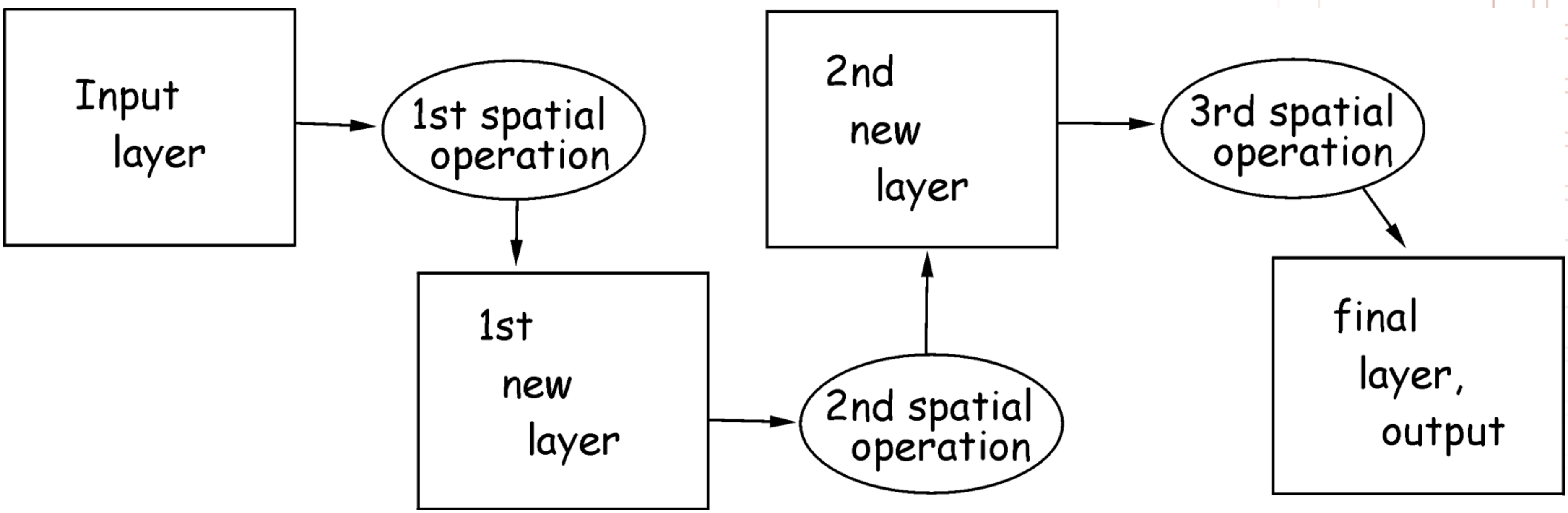
https://gisgeography.com/gis-applications-uses/

Definition recap

- Spatial Analysis:
  - Operations on data
    - Boolean algebra, mathematical operations, trigonometric operations, statistical function
  - Operations applied to data lead to new insights
  - Operations may be applied in sequential order
    - Result of one/more operation(s) is input to the following operation

>> Sequence of spatial/non-spatial operations

Begriff recap



Quelle: Bolstad (2015)

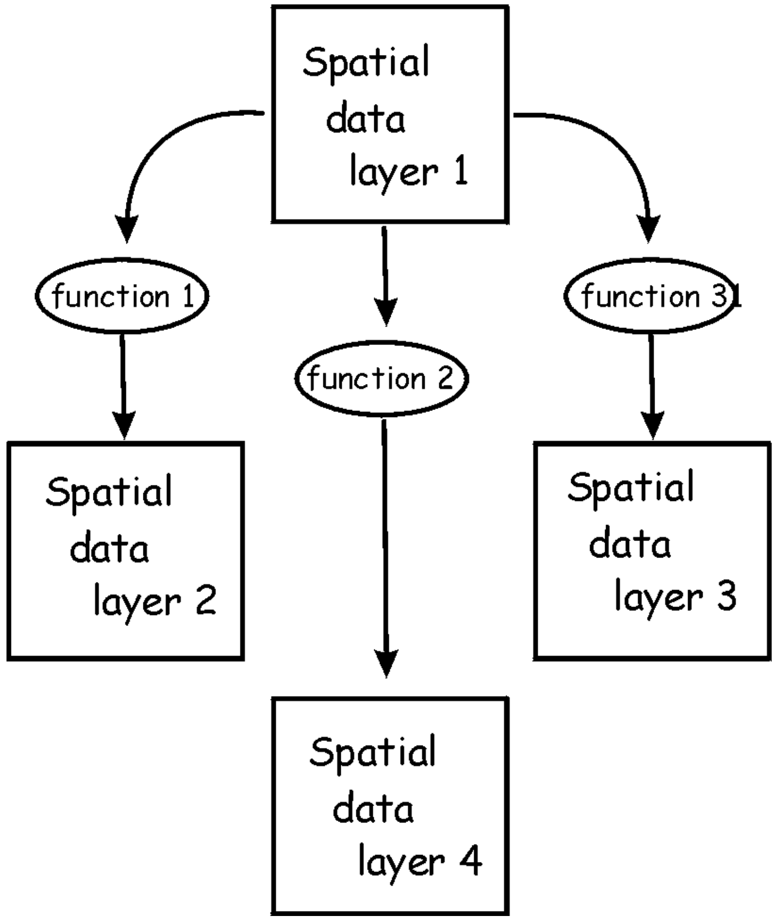
Input, Output, Operations

- Spatial analysis uses 1, …, n layer as input to create some output.

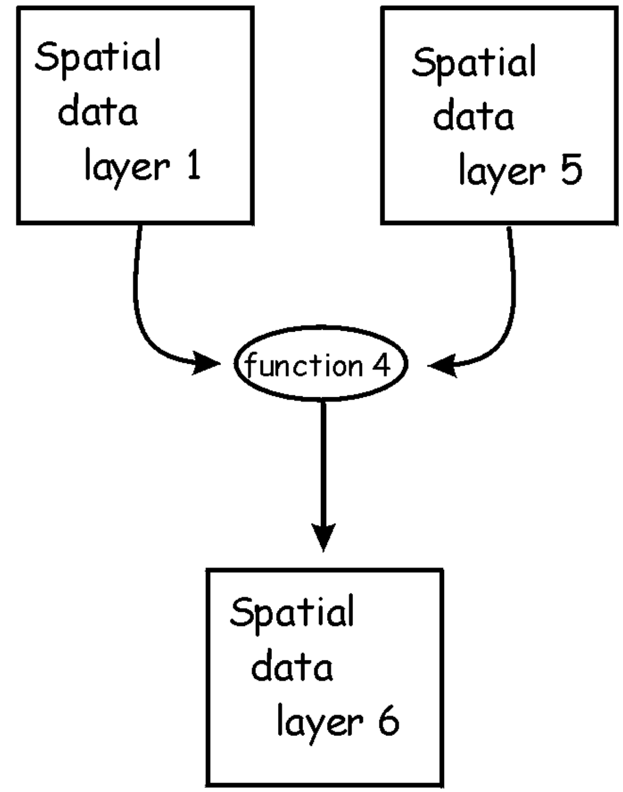
- Analysis can look as follows:
  - A single opertion or a sequence of operations
  - … applied to one or more layers
  - … several output layer can result from one input layer (e.g. terrain analysis)
  - …

Input, Output, Operations

One Input - Many Outputs



Many Inputs - One Output



Quelle: Bolstad (2015)

Input, Output, Operations

- Output:
  - May be spatial or non-spatial:
    - Non-spatial: e.g. skalar, list, table; area, list of LULC types, # trees, …
    - Spatial
      - Layer: point, polyline, polygone

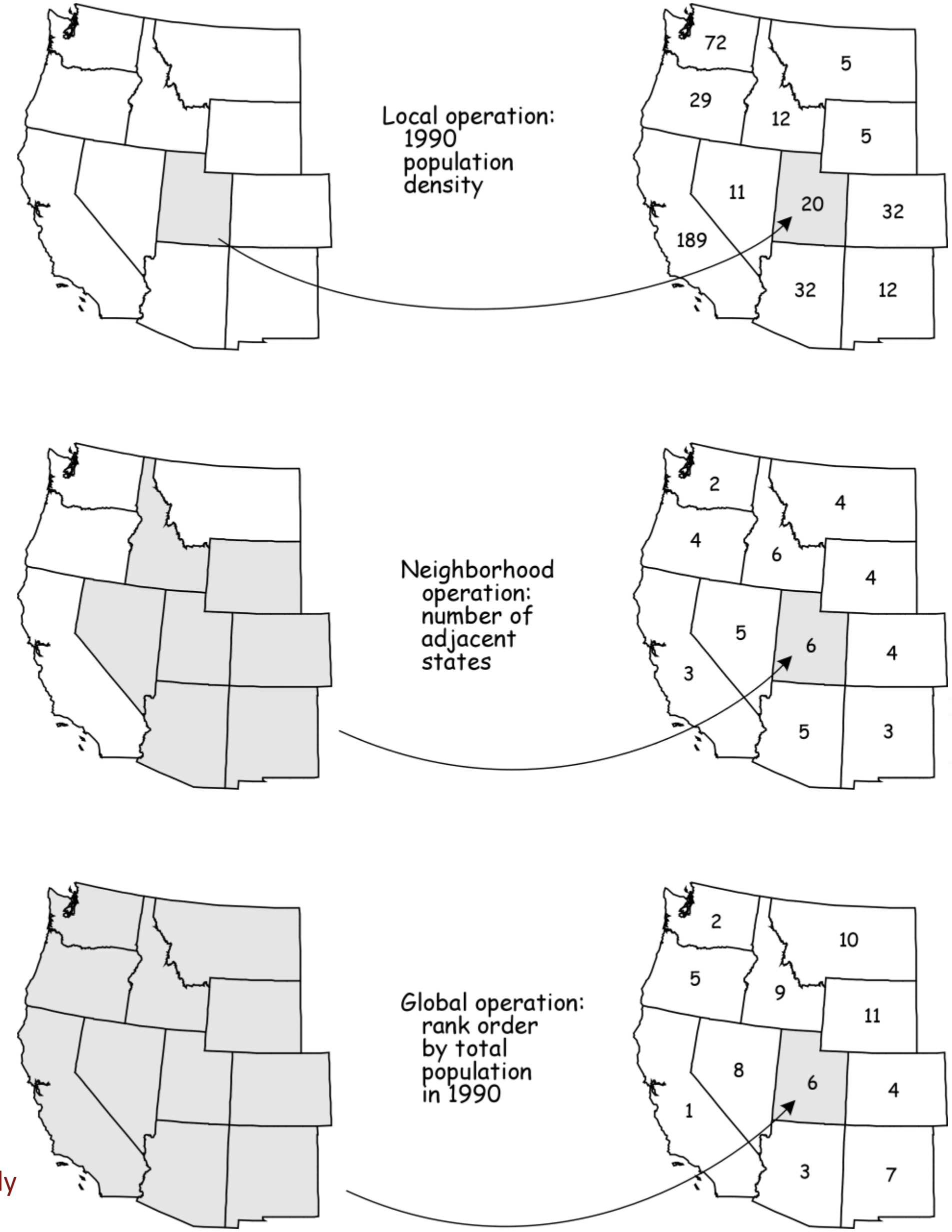
>> Combination of spatial and non-spatial output also possible

Operations - Scope

- Spatial scope of operations:
  - Describes the spatial scope of the operations with respect ot the input data

  - Values:
    - **Local**: only data from one input position/one object are used in order to calculate an analysis output on exactly the same position
    - **Neighborhood**: uses all direct neighboring areas as input for a spatial operation on a specific position.
    - **Global**: all data of the input layer as used as input for the spatial operation in order to create a result at a specific position

Operationen - Scope



Quelle: Bolstad (2015)

The Fundamental Problem

- “Our behavior in space often reflects past patterns of behavior”
  - thus it is one-dimensional, need only look in the past, whereas spatial events can potentially have consequences anywhere in two-dimensional or even three-dimensional space.
- How and why does spatial and temporal context affect what we do?

Waldo Tobler: First Law of Geography

"Everything is related to everything else, but near things are more related than distant things.“ [Tobler, 1970, p.236]

Spatial Autocorrelation

- Understanding of ***spatial autocorrelation*** aids generalization from sample observations
  - becomes easier to build good generalized representations of spatial distributions

- Spatial autocorrelation measures attempt to deal simultaneously with similarities in the location of spatial objects and their attributes

- Measures of spatial and temporal autocorrelation are *scale dependent*

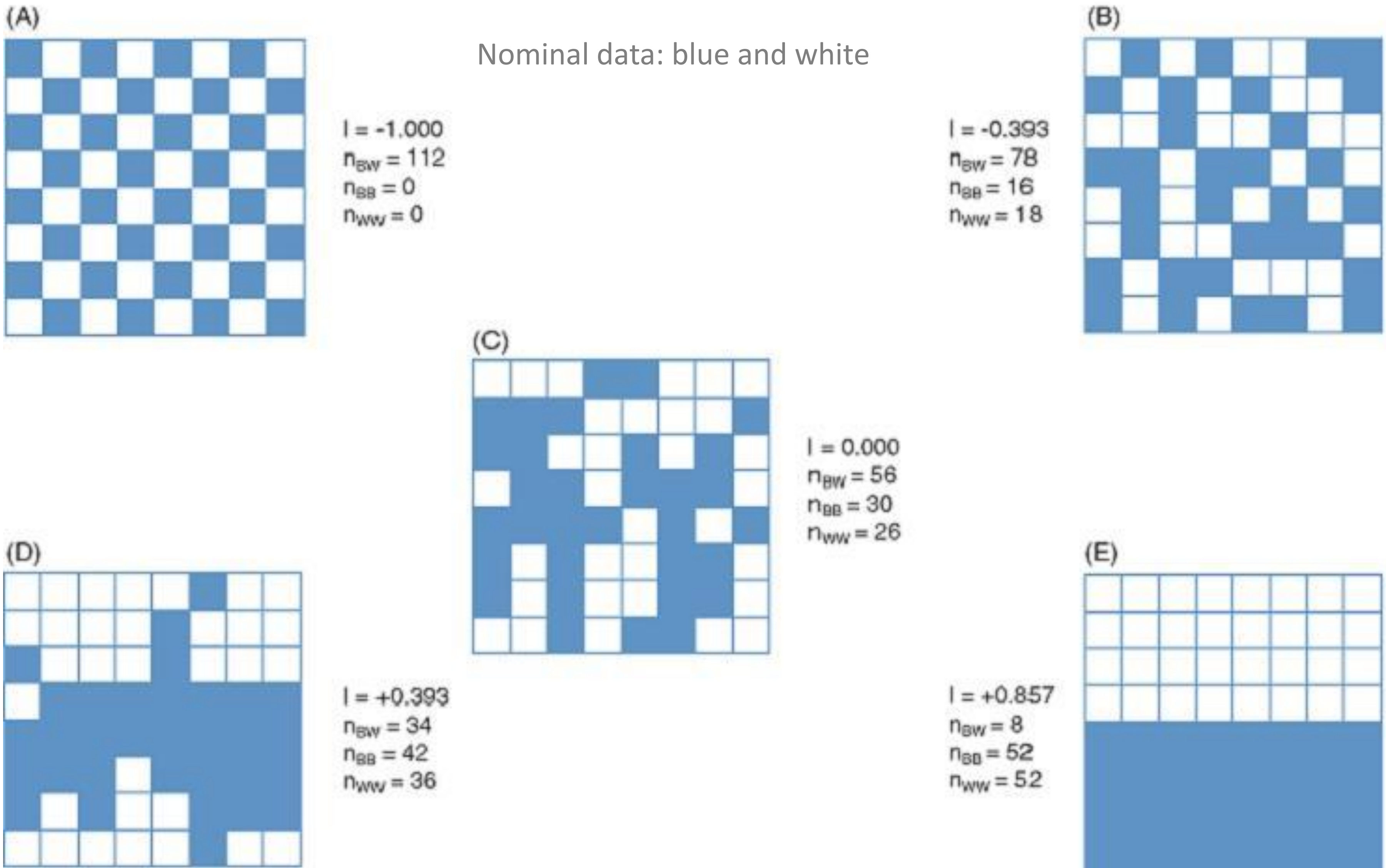
Spatial Autocorrelation

- Spatial autocorrelation is determined both by **similarities in position**, and by **similarities in attributes**
- Possible Values: **positive**, **zero**, or **negative**
  - If features that are similar in location are also similar in attributes, then the pattern as a whole is said to exhibit *positive spatial autocorrelation.*

- **Lots of different indexes**
  - Moran's I
  - Geary's C
  - Ripley's K

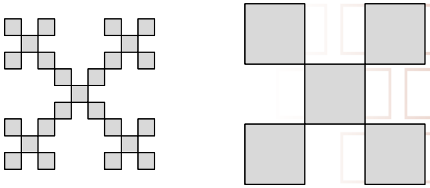
Spatial Autocorrelation

Nominal data: blue and white



Spatial Autocorrelation

- Some things to consider:
  - **Measurement scales** and assessment of **neighborhood**
  - Issue of **sampling intervals**
    - rhythm of temporal activities and spatial patterning
  - **Self-similarity** of spatial and temporal structure
    - Extent that patterns are replicated across scales



Fine scale Coarse scale

Measurement scales

- Variables are numbers, but may be of **qualitative nature** as well. This fact results in different measurement scales (Stevens 1946).

- Measurement scales determine
  - which mathematical operations can be applied to a data set!

  Expecially interesting when **combining different data sets**!
    - When combining 2 or more datasets: The lower measurement scale defines the possible mathematical operations!

Measurement Scales

Categorical		Scalar	
Nominal	**Ordinal**	**Interval**	**Ratio**
• Presence/absence • Counting • Diff. in degree or quality • Equality of category	• Sequence • Rel. position < , > , =	• Differences • Arbitrary Zero + , -	• Ratio • Real Zero * , /
Classification	Ordering	Measuring	
name of city type of land use name of highway	large city wettest soil primary highway	angle or bearing in degrees (cycle)	number of people, # of passengers distance

(see Laurini and Thompson, p.70)

Measurement scales

- **Nominal scale**
  - Data on the nominal scale have the lowest information level.
  - Mostly categories that can be represented by numbers
  - Examples: Sex (1 male, 2 female) or city (1 : Zurich, 2 : Bern, 3 : Basel), animal species, player number (soccer)
  - Nominal variable with only two classes (e.g. 0/1) is called dichotomous variable.

  - **Operations: =, ≠**

Measurement scales

- **Ordinal scale**
  - Data on the ordincal scale have a clear ordering

    >> ordinal scaled data allow the ordering of the data
  - Ordering does not tell anything about the absolute difference
  - Examples: marks, Leaderboard of a race (just positions), or Mohs' scale.
  - **Operations: =, ≠, >, <**

Measurement scales

- **Interval scale**
  - Here we can measure the absolute distance between single values!
  - The scale has an equal intervals along the scale, but no defined zero.
  - Example: temperature in degrees Celsius.
    - Difference between -15 and 4 °C is equal to the difference between 14 and 33 °C. But: 40°C is not „two times warmer“ than 20°C – due to the fact that the scale has an arbitrary zero (freezing of water).
  - **Operations: =, ≠, >, <, +, -**

Measurement scales

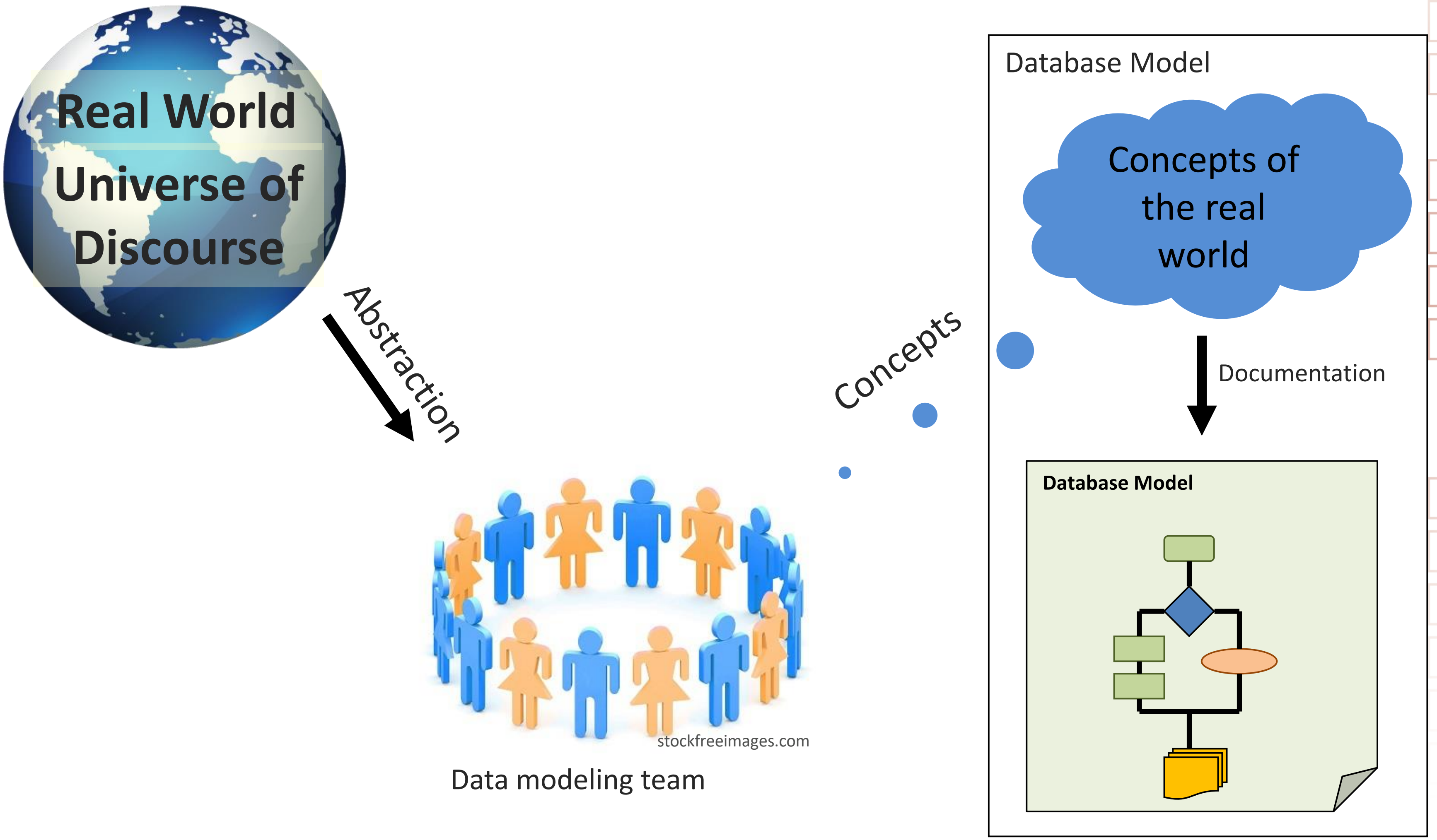
- **Ratio scale**
  - Ratio scale data have a **defined real zero value**.
  - We can calculate the ratio between values.
    - Person being 1.8m in height is double the height of a kid with 90 cm.
    - Temperature in °Kelvin > has an defined real null point (Absolute Null - thermodynamics).
  - Examples:
    - Age, monetary values (income) or height
  - **Operations: =, ≠, >, <, +, -, *, /**

Measurement scales

Scale	Interpretation of Observations	possible Operations	Examples
Nominal Scale	Equality (or non-equality), counting of occurrence	=, ≠	Color, Phone number, Feelings
Ordinal Scale	Equality (or non-equality), number of occurrence greater/lower Relation, counting of occurrence	=, ≠ , <, >	Sports tournament results., military ranks, energy efficiency rating, grades in school
Interval Scale	Equality (or non-equality), number of occurrence greater/lower Relation, counting of occurrence Absolute differences (incl. Equality of differences)	=, ≠, <, >, +, -	date, temperature in Celsius, IQ-scale
Ratio Scale	Equality (or non-equality), number of occurrence greater/lower Relation, counting of occurrence Absolute differences (incl. Equality of differences), Gleichheit von Verhältnissen, Nullpunkt	=, ≠, <, >, +, -, *, /	Velocity, length, temperature in Kelvin, age

Representation of Reality

Modeling Reality



Discrete Objects and Continuous Fields

- In the ***discrete object/entity*** view, the world is empty, except where it is occupied by **objects** with **well-defined boundaries** that are instances of generally recognized categories.
  - Objects can be counted
  - Objects have dimensionality: 0-dimension (points), 1-dimension (lines), 2-dimensions (areas)

- The ***continuous field*** view represents the **real world** as a **finite number of variables**, each one defined at every possible position.
  - Continuous fields can be distinguished by what varies, and how smoothly.

Discrete Objects and Continuous Fields

Entity

- discrete, occupies space
- described by its attributes
- position mapped in a coordinate system
- e.g. building, road, river, lake...

Field

- values of an attribute vary over space
- represented by some continuous mathem. function (or field)
- e.g. temperature, air pressure, elevation...

Discrete Objects and Continuous Fields

Bears are easily conceived as discrete objects, maintaining their identity as objects through time and surrounded by empty space.

Examples of field-like phenomena

(A) Image of part of the Dead Sea in the Middle East. The lightness of the image at any point measures the amount of radiation captured by the satellite's imaging system.

(B) A simulated image derived from the Shuttle Radar Topography Mission. The image shows the Carrizo Plain area of Southern California, with a simulated sky and with land cover obtained from other satellite sources.

Discrete Objects and Continuous Fields

Lakes are difficult to conceptualize as discrete objects because it is often difficult to tell where a lake begins and ends, or to distinguish a wide river from a lake.

Vector and Raster

- … are fundamental geographic data models
- … are formalized concepts used by people to perceive geographical phenomena
- are used to reduce geographic phenomena to forms that can be coded in computer databases
- assumption that phenomena can be
  - uniquely identified
  - location can be registered
  - resolution of observation/measurement determined

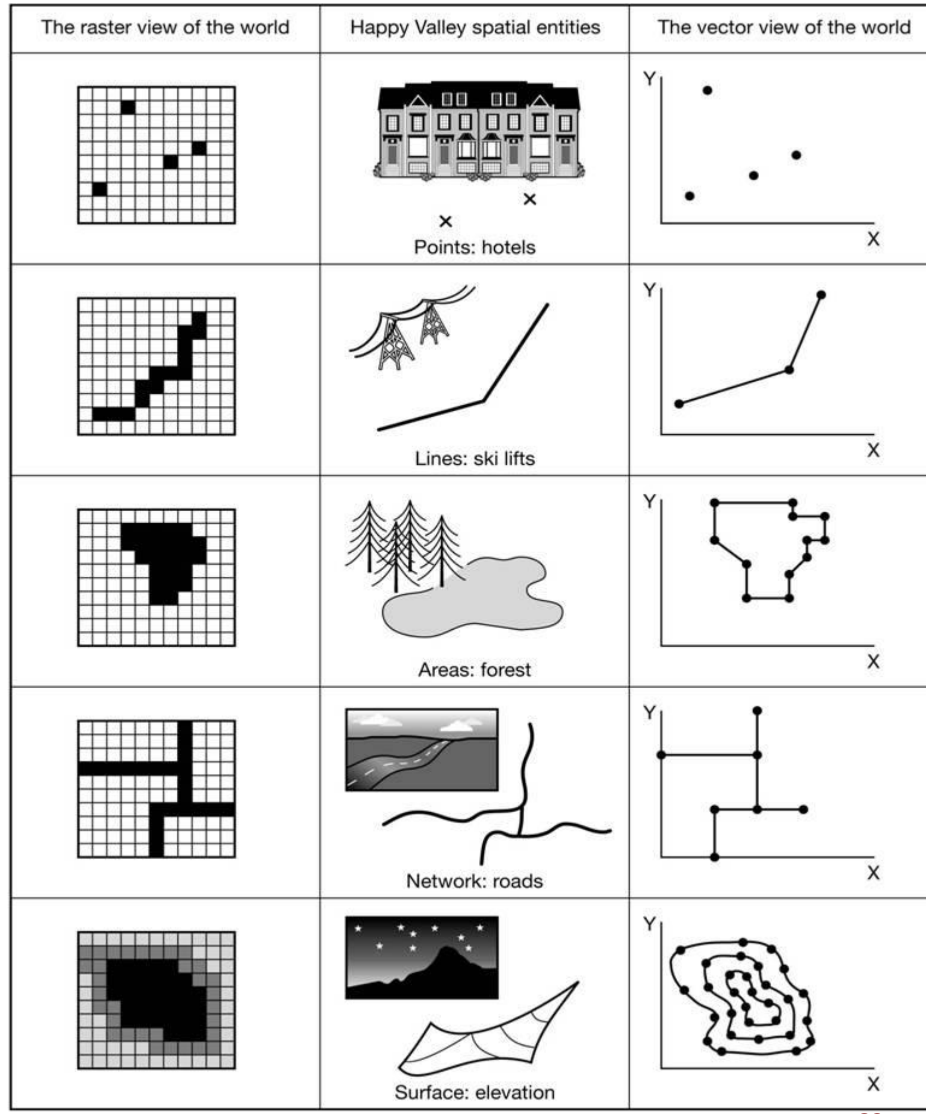
- In principle, each can be used to code both fields and discrete objects, but in practice there is a strong association between raster and fields, and between vector and discrete objects.

Vector and Raster

- In a raster representation geographic space is divided into an array of cells, each of which is usually square, but sometimes rectangular.
  - All geographic variation is then expressed by assigning properties or attributes to these cells.
  - The cells are sometimes called pixels (short for *picture elements*).

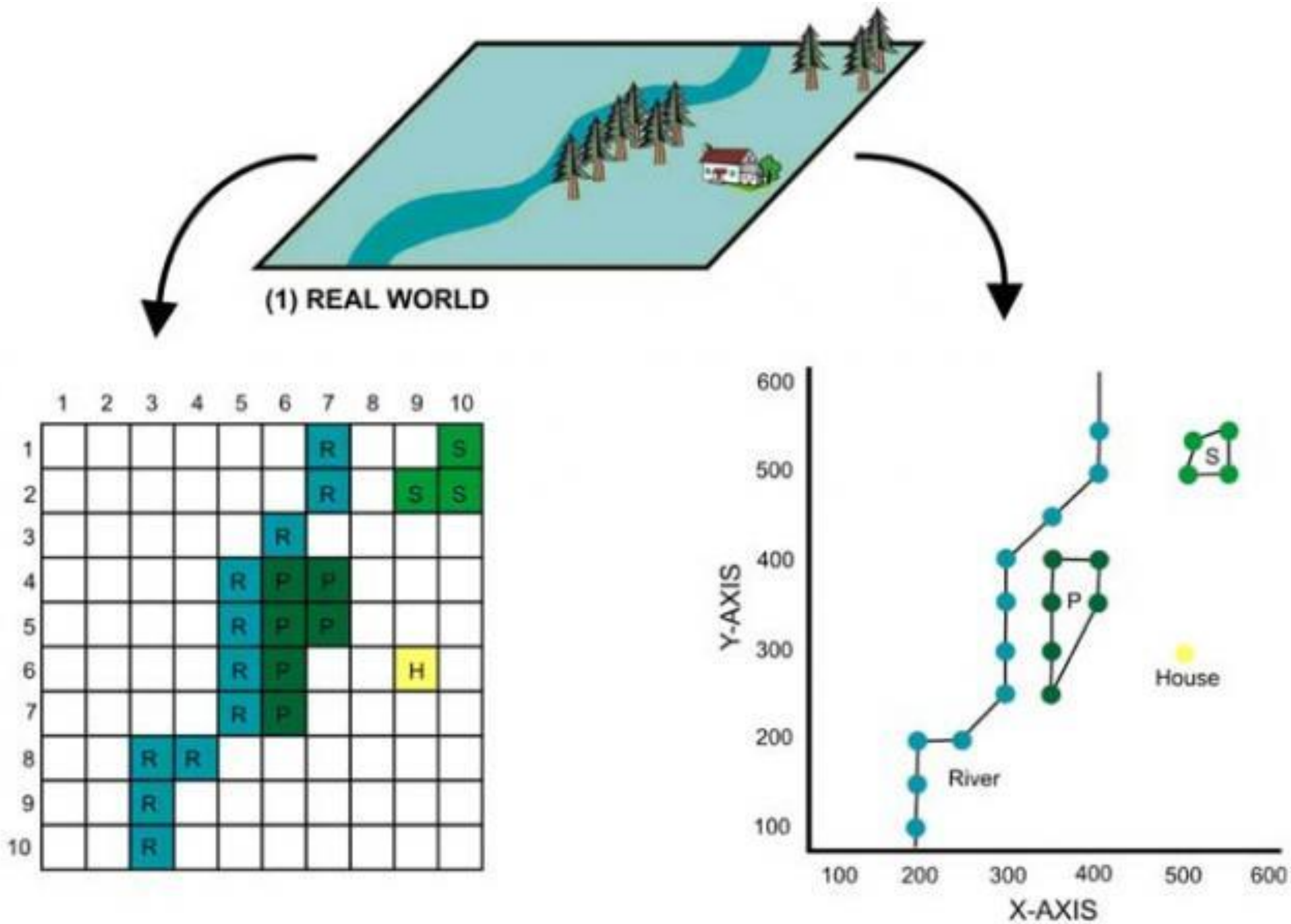
Representation of Reality

- Comparison of the respresentation of the real world: raster vs. vector.
- Digital Elevation Models (DEMs) are field data models, but are mostly stored as with the help of vector models!



Representation of Reality

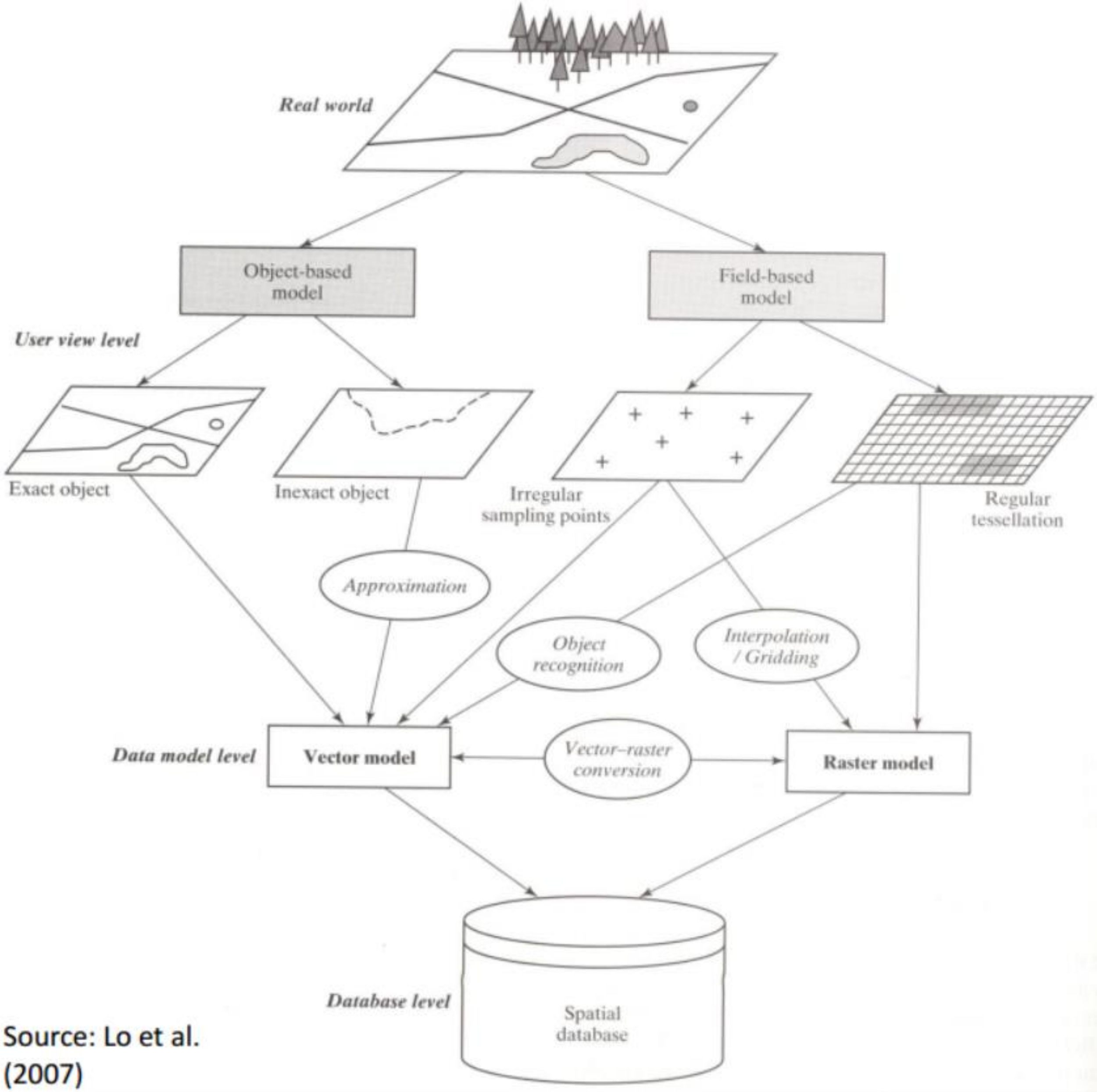
- **Raster vs. vector:**



(2) RASTER REPRESENTATION

(3) VECTOR REPRESENTATION

Representation of Reality



Source: Lo et al. (2007)

Raster vs. Vector models

RASTER

- Simple data structure
- Attributes may manipulated easily
- High number of spatial analysis methods (math. modeling is easy)

+

- Huge data quantities
- Coarse resolution > loss of accuracy
- Coordinate transformation is cumbersome
- Network analysis not possible
- Mostly regular sampling of spatial phenomena

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VECTOR

- Well suited for entity models
- Compact data structure
- Explicit topology (neighborhood)
- Coordinate transformation is easily possible
- Accurate spatial representation (coordinates), scale-indepentent
- Query, update and generalisation possible

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- Complex data structure
- Any data operation may be complex & time-consuming
- Visualization and print is complex
- Spatial analysis >> complex

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