GEOM20013
Applications of GIS

1

2 L7: Multicriteria Decision Making with GIS

2

Recap

- You are aware of different methods that allow to capture spatial data
- You know how to represent spatial data in a GIS
- You realise the inherent limitations of any data representation: resolution (precision), and accuracy
- You appreciate the complexity of storing and managing spatial data (geometries and attributes)
- You have learnt basics of proper spatial data presentation in maps

3

3

Learning objectives

- Understand the main concepts that underpin spatial data analysis and decision making with GIS
- Understand and be able to explain the concept of modelling and the inherent simplification and abstraction it involves;
- Be able to explain and critically investigate how a model operationalizes often vague assumptions and statements about a phenomenon;
- Reason about the different influences on the accuracy of the outcomes of the models, in particular with respect to the combined influence of multiple factors.

4

4

Recall: Nature of Spatial Data [chpt 1.2]

- **Nature of space**
  - **Spatial proximity:** *..all things are related, but close things are more related than distant things. (Tobler's law)*
    - **Corollary**: things are heterogeneous in space.
  - **Spatial variation**: things vary in space, and some things covary (depend on each other)
- **Nature of spatial data**
  - Spatial scale (level of detail): how we **represent** things will impact on the **outcomes** of reasoning;
  - Aggregation imposes assumptions/limitations on data;
  - Our data are *samples* from the phenomena (incomplete knowledge)

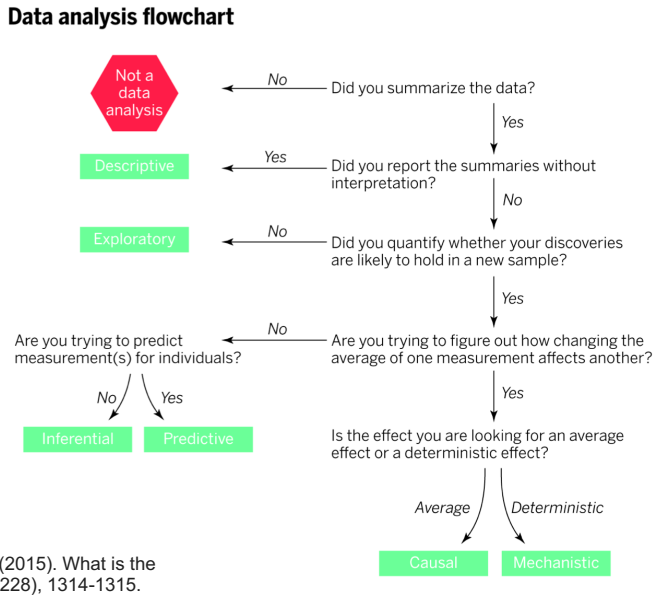
5

5

6 (Scientific) Analytical process

6

Analysis typology



Leek, J. T., & Peng, R. D. (2015). What is the question?. *Science*, *347*(6228), 1314-1315.

7

7

From conceptual model to model specification

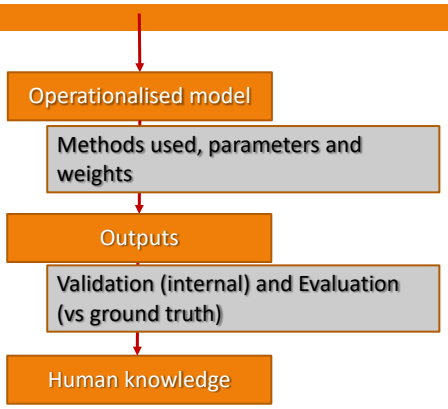
Problem & Research Question

Human knowledge Is the information trustworthy? Does it apply to my situation?	Papers, interviews with experts, legal codes, guidelines
Conceptual model What simplifications have I made? Are they adequate?	Mathematical formulas, DB models, diagrams, schematic drawings
Selection of input data Fitness for use?: Accuracy, Resolution, Recency, Source, Completeness…	Accuracy, Resolution, Recency, Source, Completeness, Bias, Coding of input values
Operationalised model Methods used, parameters and weights	What approximations do the methods make? What (default) parameters do they use?
Output datasets	

8

8

From conceptual model to model specification



What approximations do the methods make?
What (default) parameters do they use?

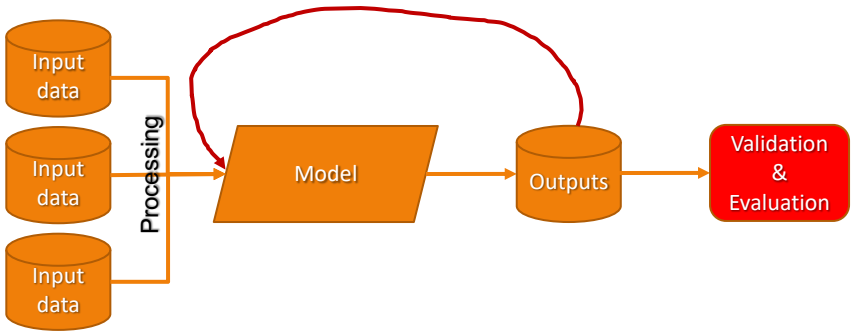
How do I find out if the assumptions and data were plausible?
How can I measure this independently?

Papers, reports, presentations (and peer review)

9

9

Data + Analysis



Limitations

Assumptions	Idealisation	Accumulation of errors	Ground truth
Bias (Coverage,…)	Simplification	Transferrability & overfitting	Marginal conditions
Sampling	Parametrisation	Precision and resolution	
Accuracy			

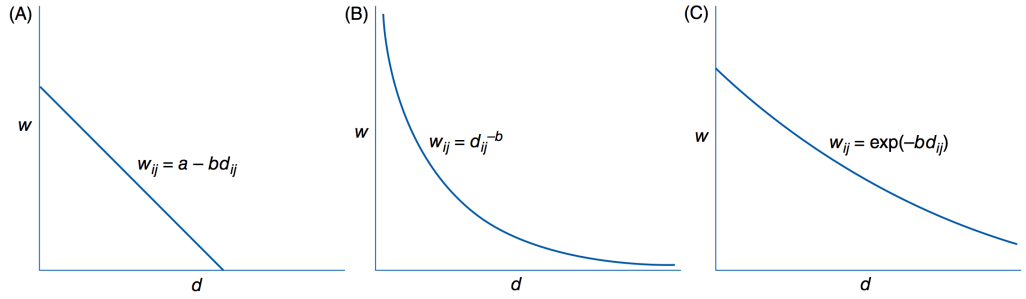
10

10

Model simplifications

- **Distance decay**

Figure 2.8 The attenuating effect of distance: (A) linear distance decay, $w_{ij} = a - bd_{ij}$; (B) negative power distance decay, $w_{ij} = d_{ij}^{-b}$; and (C) negative exponential distance decay, $w_{ij} = e^{-bd_{ij}}$.



Longley, P.A., Goodchild, M., Maguire, D., Rhind, D. *Geographic Information Science and Systems, 4th Edition*. Wiley, 2015-02-26.

11

11

12 Spatial Data Analysis

12

Spatial data analysis

- **Main characteristics of spatial data**
  - Geometry/location
  - Topology
  - Theme
- **Analysis – identifying subset of data that meets conditions** (qualitative and quantitative):
  - Conditions on Geometry – "near", "within 3km", "at least 5km", "north of"
  - Conditions on Topology – "inside", "connected to", "between"
  - Conditions on Theme – "affordable", "fast", "less than $1mil"

13

13

Thematic variables levels of measurement

- **Nominal**
  - Meadow, Forest, Built up area
  - Lygon St, Grattan St, Queensberry St
  - Bus, car, motorbike, other
  - Carlton, Parkville, 24600 (City of Melbourne)
- **Ordinal**
  - Very good, good, ok, bad, very bad
  - Very high, high, low, very low
- **Interval**
  - 10ºC, 20ºC, 35ºC,-3ºC, 0ºC
- **Ratio**
  - 15km/h, 30km/h
  - 10ºK, 0ºK, 273,15ºK
  - 20%, 60%

More statistical operations possible

- **The level of measurement (or measurement scale) determines what operations we can do with the data!**

Stevens, S. S. (1946). On the Theory and Scales of Measurement. *Science, 103*(2684), 677-680.

14

14

Sampling

- **We cannot measure everything everywhere**
- **Selection** is important
- **We approximate** regions of interest and then **fill in data:**
  - Interpolation
  - Smoothing

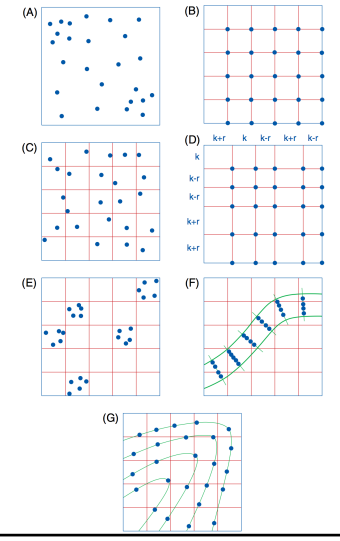
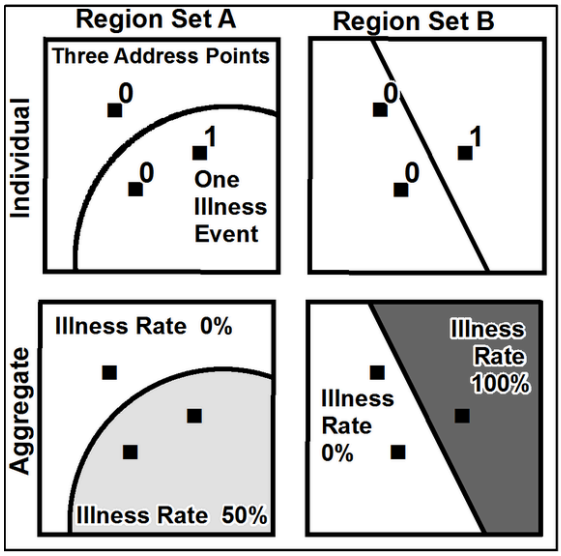


Figure 2.4 Spatial sample designs: (A) simple random sampling, (B) stratified sampling, (C) stratified random sampling, (D) stratified sampling with random variation in grid spacing, (E) clustered sampling, (F) transect sampling, and (G) contour sampling.

Longley, P.A., Goodchild, M., Maguire, D., Rhind, D. *Geographic Information Science and Systems, 4th Edition*. Wiley, 2015-02-26.

15

Aggregation



The effects of scale and aggregation are generally known as the Modifiable Areal Unit Problem (MAUP). (Longley 123)

Figure: https://en.wikipedia.org/wiki/Modifiable_areal_unit_problem

16

16

Operationalisation of a model

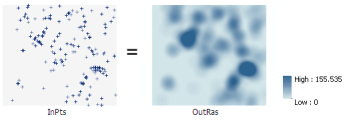
- **Operators and parameters (descriptive and generative)**
  - **Operations on Geometry**: distance, length, buffer, boundary,
  - **Operations on Topology**: intersects, inside, meets, intersection,
  - **Operations on Theme**: <val, == val, *,/,+,-,mean, mode, median
  - **Operations on Sets**: union, difference, and/or/not,…

17

17

Parametrisation of a model

- Parameters (or arguments) modify the behavior of an operation;
- The choice of parameters defines the output of the operation – responsibility of the analyst;
- Some operations often offer default parameters – the analyst MUST evaluate their suitability;
- Sometime the default parameters are not disclosed – impacts on the ability to replicate results in other systems



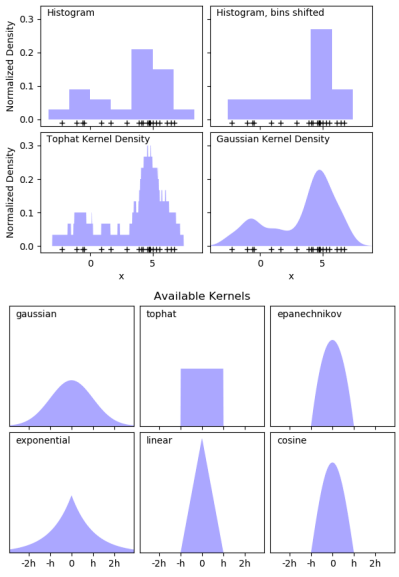
The default search radius (bandwidth) is calculated based on the spatial configuration and number of input points. This approach corrects for spatial outliers—input points that are very far away from the rest—so they will not make the search radius unreasonably large

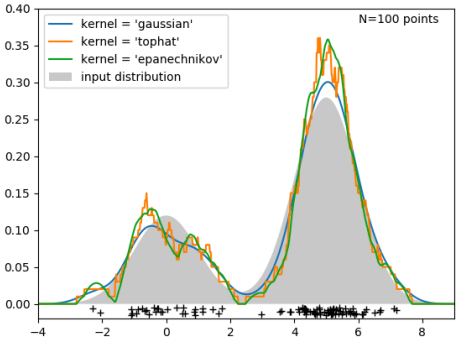
http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/kernel-density.htm

18

18

Example: Kernel density estimation





http://scikit-learn.org/stable/auto_examples/neighbors/plot_kde_1d.html 19

19

20 Multicriteria Decision Making

20

Multicriteria decision making

Many decisions depend on identifying relevant factors and adding their appropriately weighted values. (Longley 353)

Longley, P.A., Goodchild, M., Maguire, D., Rhind, D. *Geographic Information Science and Systems, 4th Edition*. Wiley, 2015-02-26.

21

21

Greater Glider

- chooses habitat in higher in regions of montane forest containing manna gum (*E. viminalis*) and mountain gum (*E. dalrympleana*, *E. obliqua*), the presence of *E. cypellocarpa* appears to improve the quality of habitat in forests dominated by *E. obliqua*.
- Another factor is elevation. Optimal levels are 845 m above sea level.
- Within a forest of suitable habitat, they prefer overstorey basal areas in old-growth tree stands.

https://en.wikipedia.org/wiki/Greater_glider

22

22

Greater Glider

https://en.wikipedia.org/wiki/Greater_glider

23

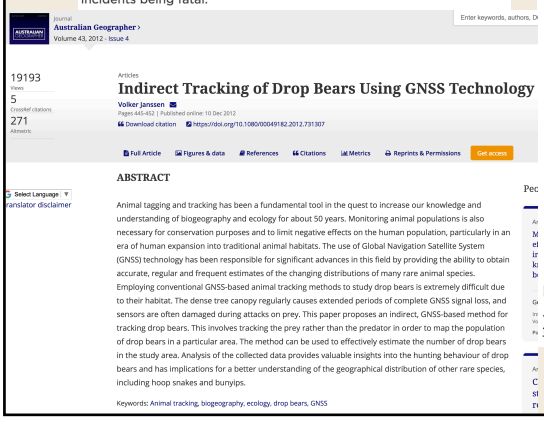
Drop bear (*Thylarctos plummetus*)

Distribution

Drop Bears can be found in the densely forested regions of the Great Dividing Range in South-eastern Australia. However there are also some reports of them from South-east South Australia, Mount Lofty Ranges and Kangaroo Island.

Danger to humans and first aid

Bush walkers have been known to be 'dropped on' by drop bears, resulting in injury including mainly lacerations and occasionally bites. Most attacks are considered accidental and there are no reports of incidents being fatal.



Australian Geographer

Volume 43, 2012 - Issue 4

19193 Views

5 CrossRef citations

271 Altmetric

Articles

Indirect Tracking of Drop Bears Using GNSS Technology

Volker Janssen

Pages 445-452 | Published online: 10 Dec 2012

Download citation https://doi.org/10.1080/00049182.2012.731307

Full Article | Figures & data | References | Citations | Metrics | Reprints & Permissions | Get access

ABSTRACT

Animal tagging and tracking has been a fundamental tool in the quest to increase our knowledge and understanding of biogeography and ecology for about 50 years. Monitoring animal populations is also necessary for conservation purposes and to limit negative effects on the human population, particularly in an era of human expansion into traditional animal habitats. The use of Global Navigation Satellite System (GNSS) technology has been responsible for significant advances in this field by providing the ability to obtain accurate, regular and frequent estimates of the changing distributions of many rare animal species. Employing conventional GNSS-based animal tracking methods to study drop bears is extremely difficult due to their habitat. The dense tree canopy regularly causes extended periods of complete GNSS signal loss, and sensors are often damaged during attacks on prey. This paper proposes an indirect, GNSS-based method for tracking drop bears. This involves tracking the prey rather than the predator in order to map the population of drop bears in a particular area. The method can be used to effectively estimate the number of drop bears in the study area. Analysis of the collected data provides valuable insights into the hunting behaviour of drop bears and has implications for a better understanding of the geographical distribution of other rare species, including hoop snakes and bunyips.

Keywords: Animal tracking, biogeography, ecology, drop bears, GNSS

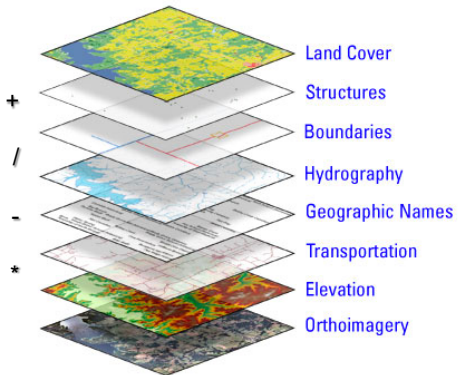
https://australianmuseum.net.au/drop-bear

Further Reading

Janssen, V. 2012. Indirect tracking of drop bears using GNSS technology. Australian Geographer, 43 (4). pp. 445-452.

24

Layered model of GIS



https://commons.wikimedia.org/wiki/File:USGS_The_National_Map.jpg

A layer is a collection of geographic entities of the same geometric type (e.g., points, lines, or areas, rasters). (Longley 155)

In analysis, we combine information from multiple layers, even across different geometric types.

25

25

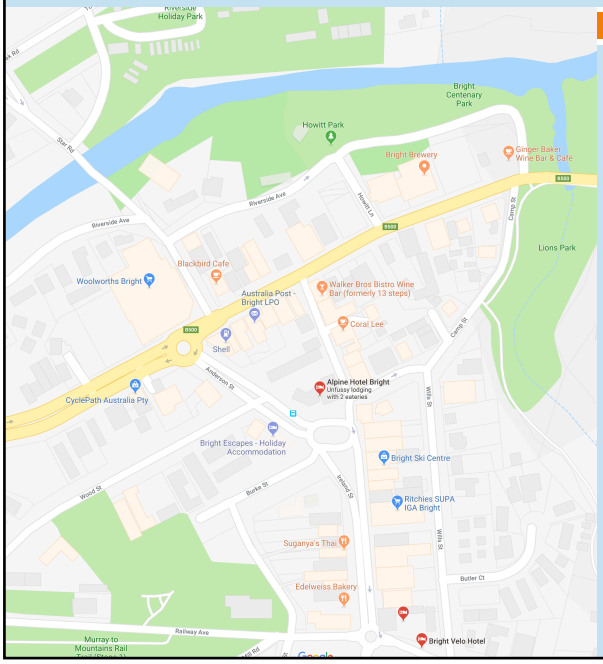
Not all criteria are made equal

- **Soft vs Hard**
  - Must be satisfied vs good to have
- **Priorities and weights**
  - How preferred is one criterion relative to another
  - What weight does one criterion have compared to another

26

26

I want a house…

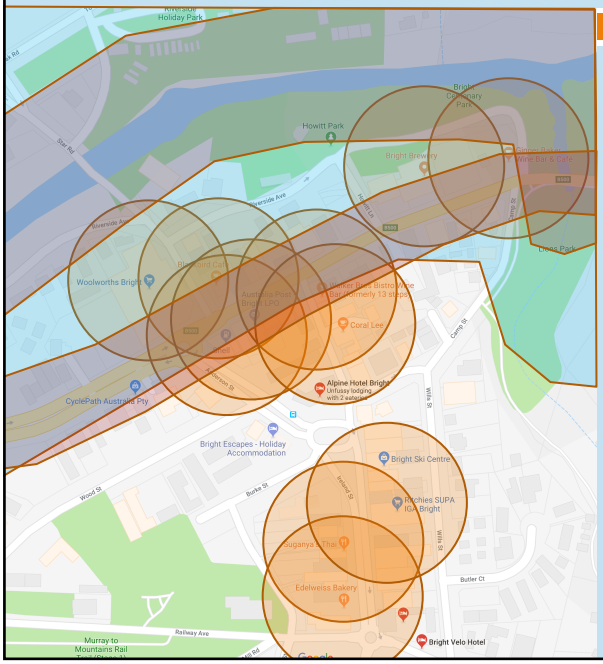


- Near cafés and shops
- Not on a main road
- Close to a river
- …but not in danger of being flooded
- and affordable

27

27

I want a house…

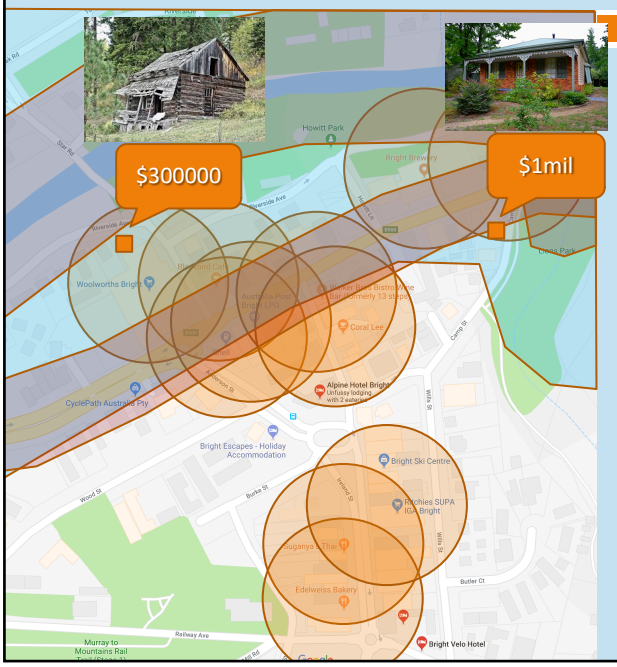


- Near cafés and shops
- Not on a main road
- Close to a river
- …but not in danger of being flooded

28

28

I want a house…



- Near cafés and shops
- Not on a main road
- Close to a river
- …but not in danger of being flooded
- and affordable

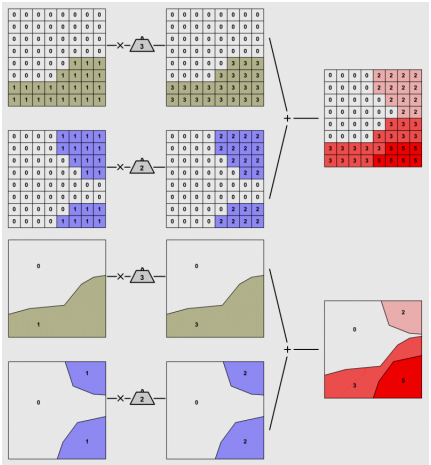
29

29

Approaches

- **Boolean overlay**
  - Data either meet, or do not meet all conditions
  - The *house* must meet all of the criteria noted
  - How do you operationalize *close*, *affordable*?
- **Weighted overlay**
  - Some criteria are more important than others
  - Still, each factor is part of the decision making
  - The impact of some factor may vary in space

http://www.gitta.info/Suitability/en/html/WeightOverla_learningObject1.html

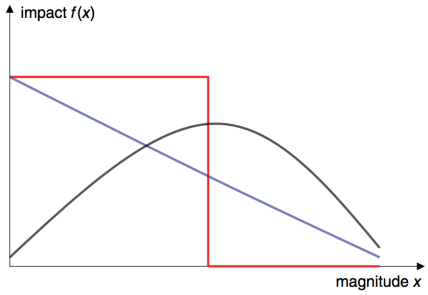


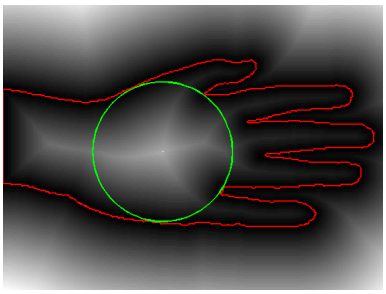
30

The varying criterion

- **The weight of a criterion may vary in space**
  - (possibly anisotropicaly – differentially by direction)

Figure 15.13 Three possible impact functions: (red) the step function used to assess slope in Figure 15.5; (blue) a decreasing linear function; and (black) a function showing impact rising to a maximum and then decreasing.





https://www.mathworks.com/matlabcentral/fileexchange/30805-maximum-inscribed-circle-using-distance-transform

31

31

How do you decide

- **Weight factors (criteria), their variation and weights**
  - What factors should be considered
  - How do they vary in space
  - What weight (importance for the decision) is each of them assigned

32

32

Weighting factors

- **Capture each stakeholder's view** of the appropriate weights to give to each impact factor.
- **The impact of each factor is expressed as a function** (see before);
- **Each stakeholder then compares factors**
- **Assessments are combined into final model weights**

- **Weighting:**
  - Ranking
  - Rating
  - Pairwise comparison (AHP)

Each stakeholder in a decision may have his or her own assessment of the importance of each relevant factor. (Longley 353)

http://www.gitta.info/Suitability/en/html/unit_Normalisatio.html

33

33

Analytical hierarchical process (by T. Saaty, 1980)

- **Each stakeholder assesses compares each pair of factors (with n factors there are n(n – 1)/2 pairs) and assesses their relative importance in ratio form (symmetrical).**

Table 15.1 An example of the weights assigned to three factors by one stakeholder. For example, the entry "7" in Row 1 Column 2 (and the 1/7 in Row 2 Column 1) indicates that the stakeholder felt that Factor 1 (slope) is seven times as important as Factor 2 (land use).

	Slope	Land use	Distance from stream
Slope		7	2
Land use	1/7		1/3
Distance from stream	1/2	3	

Longley, P.A., Goodchild, M., Maguire, D., Rhind, D. *Geographic Information Science and Systems, 4th Edition*. Wiley, 2015-02-26.

34

34

AHP – cont.

- **Weights are calculated from the binary comparisons**

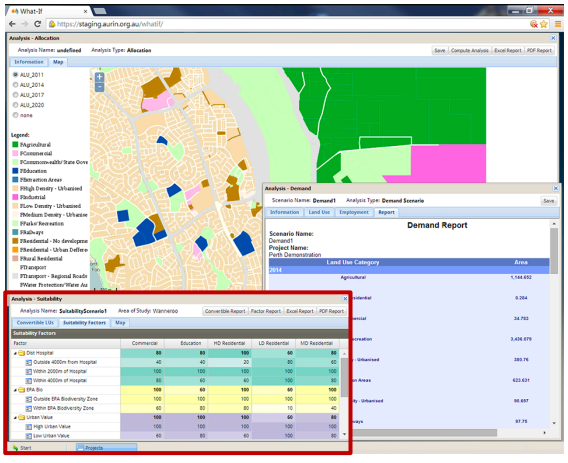
Definition	Index	Definition	Index
Equally important	1	Equally important	1/1
Equally or slightly more important	2	Equally or slightly less important	1/2
Slightly more important	3	Slightly less important	1/3
Slightly to much more important	4	Slightly to way less important	1/4
Much more important	5	Way less important	1/5
Much to far more important	6	Way to far less important	1/6
Far more important	7	Far less important	1/7
Far more important to extremely more important	8	Far less important to extremely less important	1/8
Extremely more important	9	Extremely less important	1/9

35

35

Use-case: Land use planning

- **Land use planning needs to compromise views of diverse stakeholders** (Environmental protection, developers, transport, …);
- **This process can be assisted by GIS-based tools:** e.g., the AURIN What-if tool
  - Suitability > Demand > Allocation



https://aurin.org.au/projects/portal-and-infrastructure/what-if/

36

36

Accuracy and Validity

- **Whenever you are modelling something, you should think of validation and evaluation**
  - Each model is a simplification – how do you assess that your results are plausible?

http://wiki.gis.com/wiki/index.php/Confusion_matrix

https://en.wikipedia.org/wiki/Greater_glider

Results from computers tend to carry innate authority. **(Longley 354)**

37

37

Accuracy and Validity

- **Whenever you are modelling something, you should think of validation and evaluation**
  - Each model is a simplification – how do you assess that your results are plausible?

"The confusion matrix represents how often the model correctly places a species in a given area or recognizes that it will not be found in the area."

wiki.gis.com

http://wiki.gis.com/wiki/index.php/Confusion_matrix

Confusion matrix (one option)

	Recorded Present	Recorded Absent
Predicted Present	A (true positive)	B (false positive)
Predicted Absent	C (false negative)	D (true negative)

38

38

L5: Summary

- You are now able to explain and undertake a spatial modelling task, based on often vague statements about a phenomenon;
- You are able to justify the abstractions and simplifications in a model and its operationalization;
- You are able to undertake the process of multi-criteria decision making with GIS, based on an informed choice of factors (criteria), a model of how their influence varies in space (spatial function), and their relative weights;
- You are able to critically think of the limitations and devise means to evaluate the results of your modelling.

39