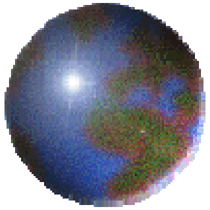


6. Uncertainty

Geographic Information Systems and Science

SECOND EDITION

Paul A. Longley, Michael F. Goodchild, David J. Maguire, David W. Rhind

Overview

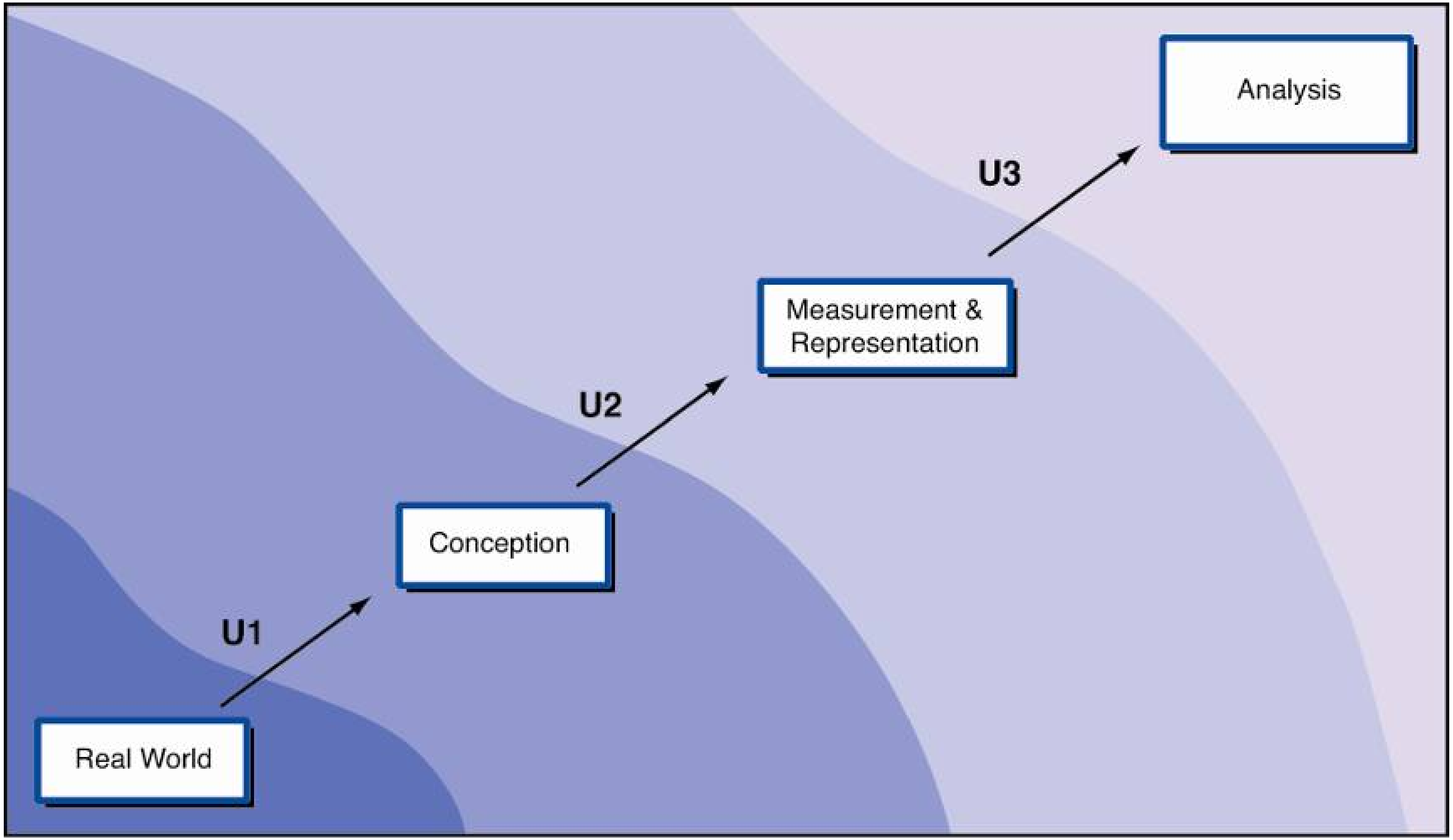
- Definition, and relationship to geographic representation
- Conception, measurement and analysis
- Vagueness, indeterminacy accuracy
- Statistical models of uncertainty
- Error propagation
- Living with uncertainty

Introduction

- Imperfect or *uncertain* reconciliation
  - [science, practice]
  - [concepts, application]
  - [analytical capability, social context]
- It is impossible to make a perfect representation of the world, so uncertainty about it is inevitable

Sources of Uncertainty

- Measurement *error*: different observers, measuring instruments
- Specification *error*: omitted variables
- *Ambiguity*, *vagueness* and the *quality* of a GIS representation
- A catch-all for ‘incomplete’ representations or a ‘quality’ measure

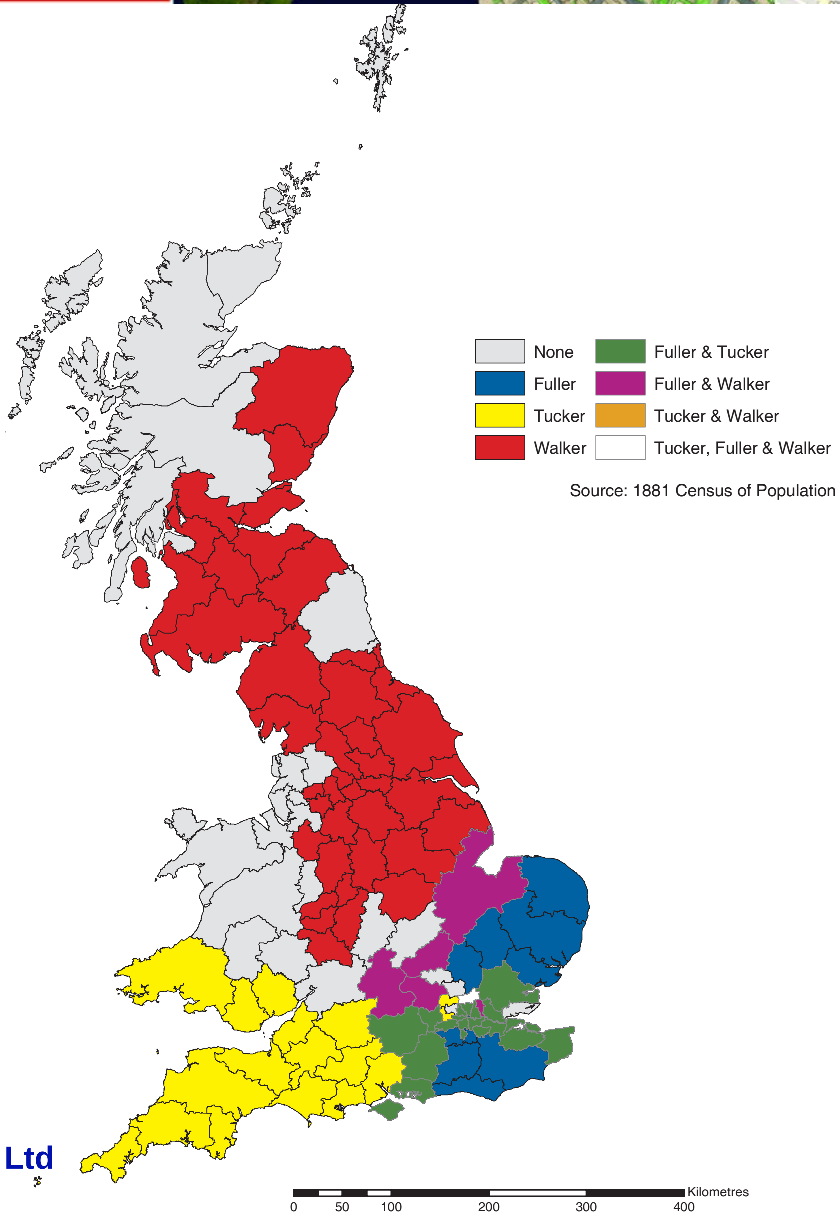

Analysis
U3
Measurement &
Representation
U2
Conception
U1
Real World

U1: Conception

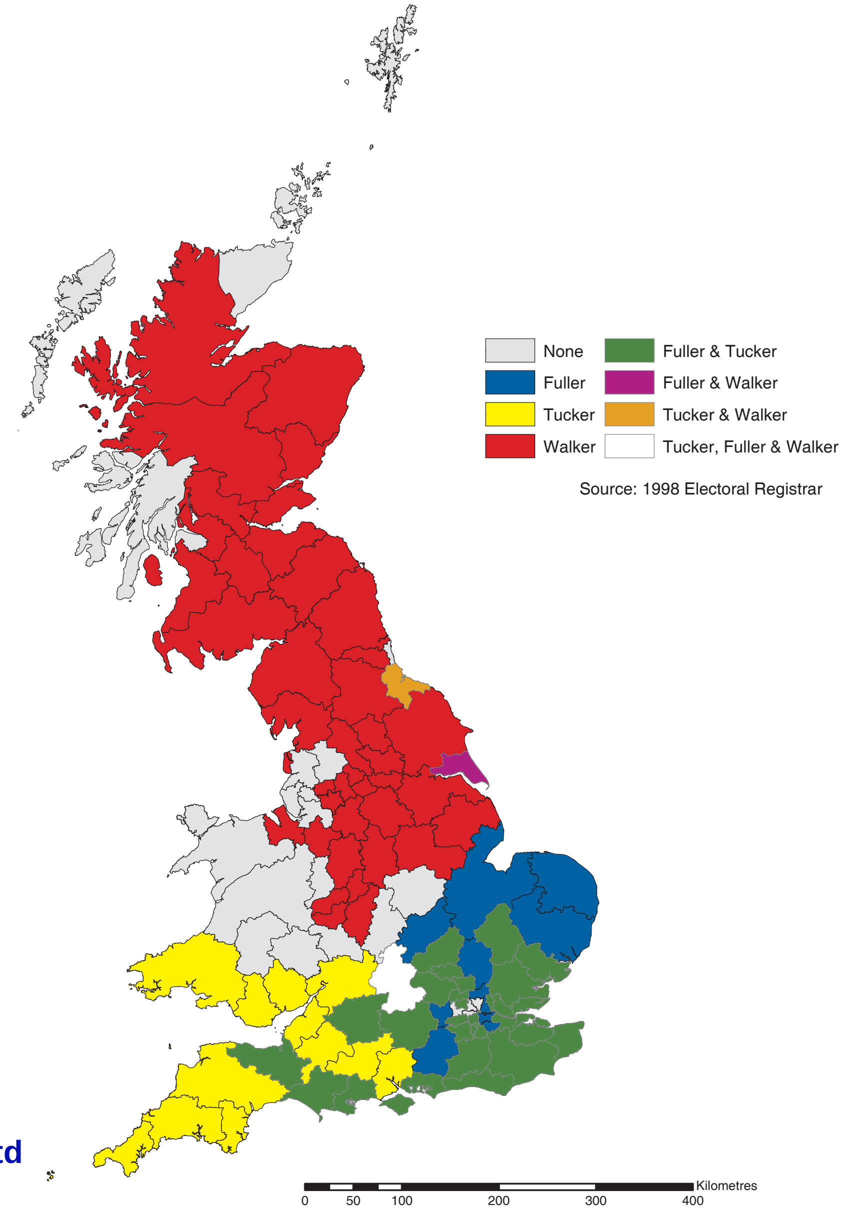
- Spatial uncertainty
  - *Natural* geographic units?
  - Bivariate/multivariate extensions?
  - Discrete objects
- Vagueness
  - Statistical, cartographic, cognitive
- Ambiguity
  - Values, language

Scale & Geographic Individuals

- Regions
  - Uniformity
  - Function
- Relationships typically grow stronger when based on larger geographic units

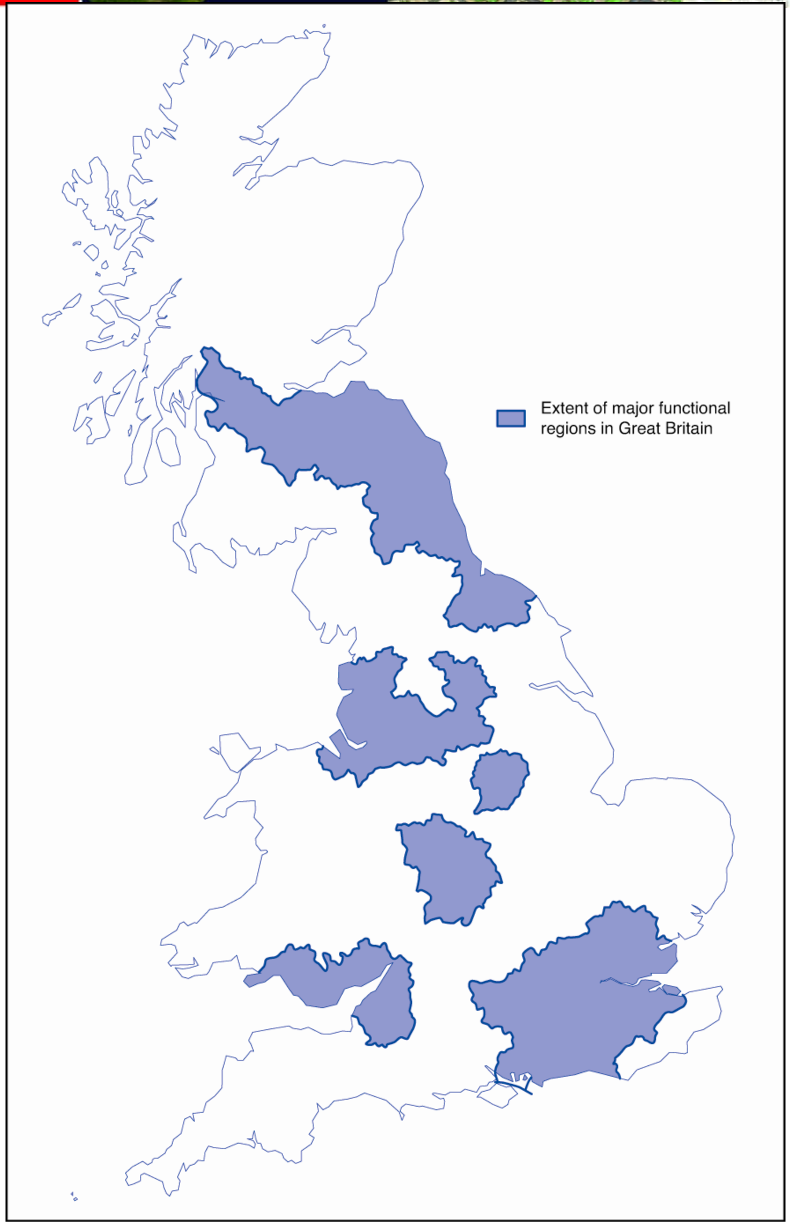


Source: 1881 Census of Population


None
Fuller
Tucker
Walker
Fuller & Tucker
Fuller & Walker
Tucker & Walker
Tucker, Fuller & Walker
Source: 1998 Electoral Registrar
Kilometres
0
50
100
200
300
400

Fuzzy Approaches to Uncertainty

- In fuzzy set theory, it is possible to have partial membership in a set
  - membership can vary, e.g. from 0 to 1
  - this adds a third option to classification: yes, no, and maybe
- Fuzzy approaches have been applied to the mapping of soils, vegetation cover, and land use

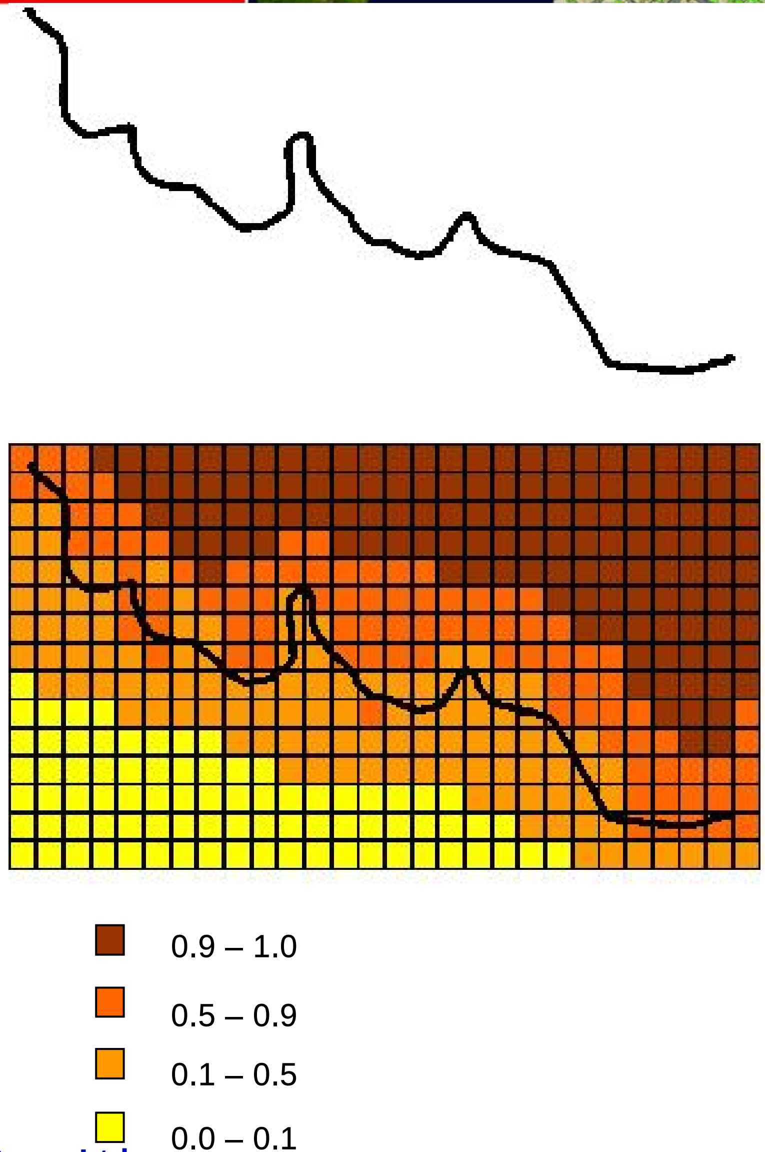

Extent of major functional regions in Great Britain

Scale and Spatial Autocorrelation

No. of geographic areas	**Correlation**
48	.2189
24	.2963
12	.5757
6	.7649
3	.9902

U2: Measurement/representation

- Representational models filter reality differently
  - Vector
  - Raster


0.9 – 1.0
0.5 – 0.9
0.1 – 0.5
0.0 – 0.1

Statistical measures of uncertainty: nominal case

- How to measure the accuracy of nominal attributes?
  - e.g., a vegetation cover map
- The confusion matrix
  - compares recorded classes (the *observations*) with classes obtained by some more accurate process, or from a more accurate source (the *reference*)

Example of a misclassification or confusion matrix. A grand total of 304 parcels have been checked. The rows of the table correspond to the land use class of each parcel as recorded in the database, and the columns to the class as recorded in the field. The numbers appearing on the principal diagonal of the table (from top left to bottom right) reflect correct classification.

	A	B	C	D	E	Total
A	80	4	0	15	7	106
B	2	17	0	9	2	30
C	12	5	9	4	8	38
D	7	8	0	65	0	80
E	3	2	1	6	38	50
Total	104	36	10	99	55	304

Confusion Matrix Statistics

- Percent correctly classified
  - total of diagonal entries divided by the grand total, times 100
  - 209/304*100 = 68.8%
  - but chance would give a score of better than 0
- Kappa statistic
  - normalized to range from 0 (chance) to 100
  - evaluates to 58.3%

Sampling for the Confusion Matrix

- Examining every parcel may not be practical
- Rarer classes should be sampled more often in order to assess accuracy reliably
  - sampling is often stratified by class

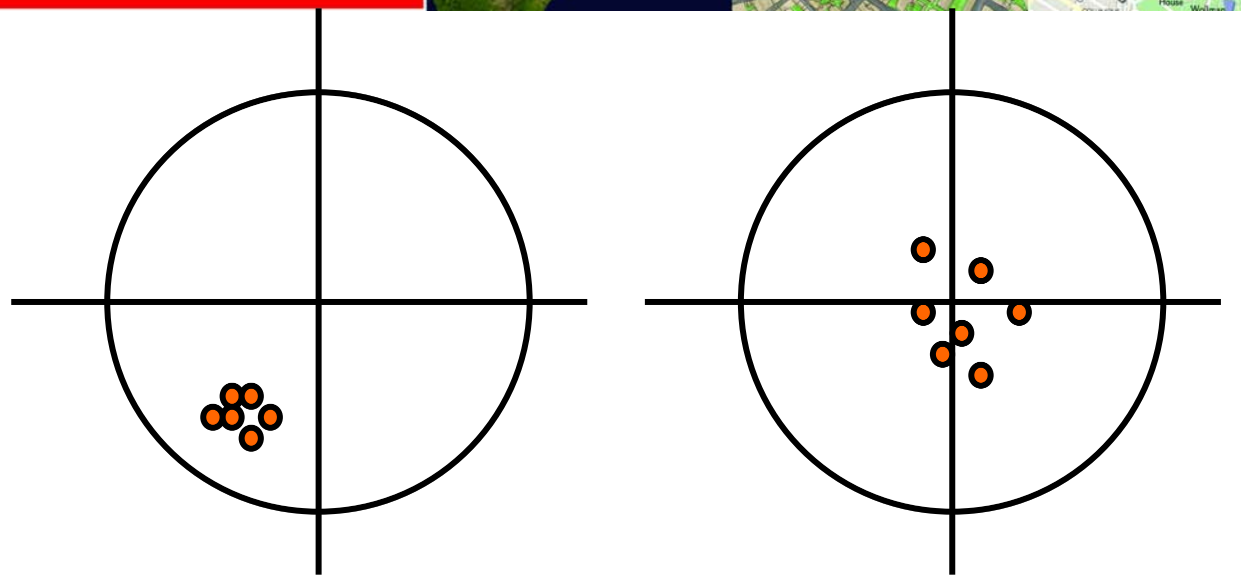
Per-Polygon and Per-Pixel Assessment

- Error can occur in both attributes of polygons, and positions of boundaries
  - better to conceive of the map as a field, and to sample points
  - this reflects how the data are likely to be used, to query class at points

An example of a vegetation cover map. Two strategies for accuracy assessment are available: to check by area (polygon), or to check by point. In the former case a strategy would be devised for field checking each area, to determine the area's correct class. In the latter, points would be sampled across the state and the correct class determined at each point.

Interval/Ratio Case

- Errors distort measurements by small amounts
- Accuracy refers to the amount of distortion from the true value
- Precision
  - refers to the variation among repeated measurements
  - and also to the amount of detail in the reporting of a measurement



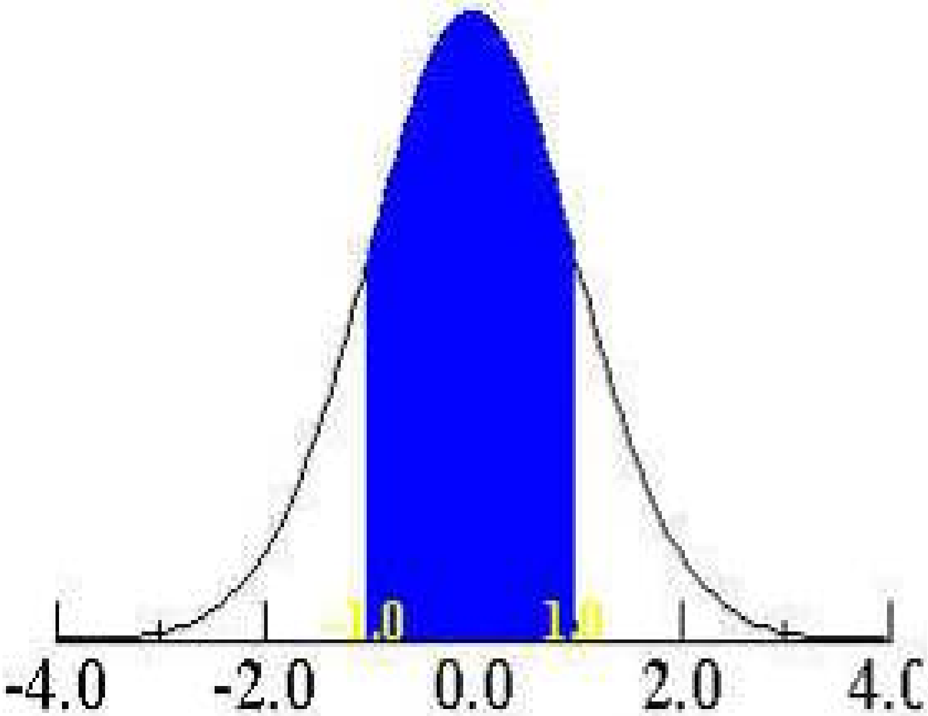
The term *precision* is often used to refer to the repeatability of measurements. In both diagrams six measurements have been taken of the same position, represented by the center of the circle. On the left, successive measurements have similar values (they are *precise*), but show a bias away from the correct value (they are *inaccurate*). On the right, precision is lower but accuracy is higher.

Reporting Measurements

- The amount of detail in a reported measurement (e.g., output from a GIS) should reflect its accuracy
  - “14.4m” implies an accuracy of 0.1m
  - “14m” implies an accuracy of 1m
- Excess precision should be removed by rounding

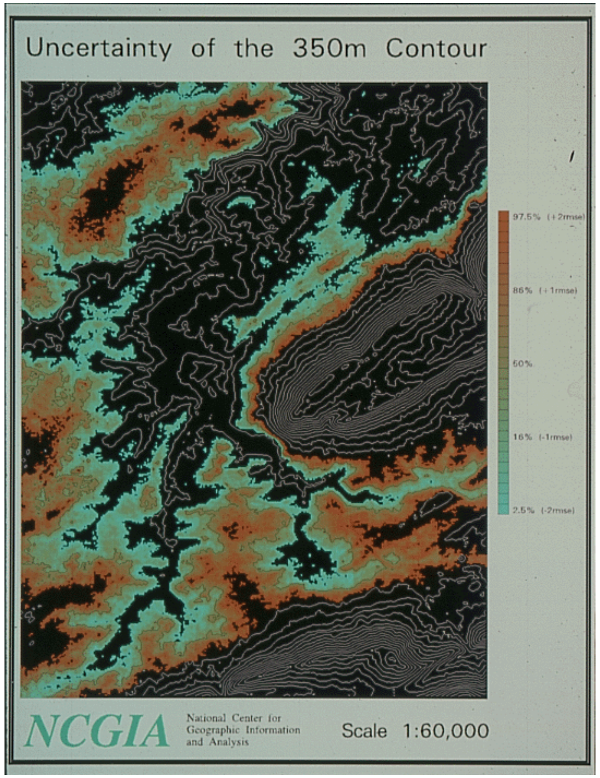
Measuring Accuracy

- Root Mean Square Error is the square root of the average squared error
  - the primary measure of accuracy in map accuracy standards and GIS databases
  - e.g., elevations in a digital elevation model might have an RMSE of 2m
  - the abundances of errors of different magnitudes often closely follow a Gaussian or normal distribution



The **Gaussian** or **Normal** distribution. The height of the curve at any value of *x* gives the relative abundance of observations with that value of *x*. The area under the curve between any two values of *x* gives the probability that observations will fall in that range. The range between –1 standard deviation and +1 standard deviation is in blue. It encloses 68% of the area under the curve, indicating that 68% of observations will fall between these limits.

Plot of the 350 m contour for the State College, Pennsylvania, U.S.A. topographic quadrangle. The contour has been computed from the U.S. Geological Survey's digital elevation model for this area.



Uncertainty in the location of the 350 m contour based on an assumed RMSE of 7 m. The Gaussian distribution with a mean of 350 m and a standard deviation of 7 m gives a 95% probability that the true location of the 350 m contour lies in the colored area, and a 5% probability that it lies outside.

A Useful Rule of Thumb for Positional Accuracy

- Positional accuracy of features on a paper map is roughly 0.5mm on the map
  - e.g., 0.5mm on a map at scale 1:24,000 gives a positional accuracy of 12m
  - this is approximately the U.S. National Map Accuracy Standard
  - and also allows for digitizing error, stretching of the paper, and other common sources of positional error

A useful rule of thumb is that positions measured from maps are accurate to about 0.5 mm on the map. Multiplying this by the scale of the map gives the corresponding distance on the ground.

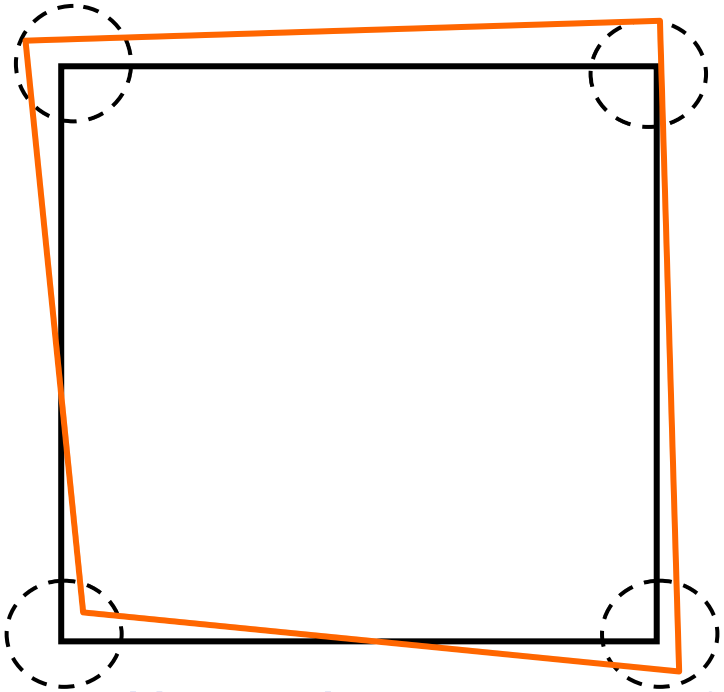
Map scale	Ground distance corresponding to 0.5 mm map distance
1:1250	62.5 cm
1:2500	1.25 m
1:5000	2.5 m
1:10,000	5 m
1:24,000	12 m
1:50,000	25 m
1:100,000	50 m
1:250,000	125 m
1:1,000,000	500 m
1:10,000,000	5 km

Correlation of Errors

- *Absolute* positional errors may be high
  - reflecting the technical difficulty of measuring distances from the Equator and the Greenwich Meridian
- *Relative* positional errors over short distances may be much lower
  - positional errors tend to be strongly correlated over short distances
- As a result, positional errors can largely cancel out in the calculation of properties such as distance or area

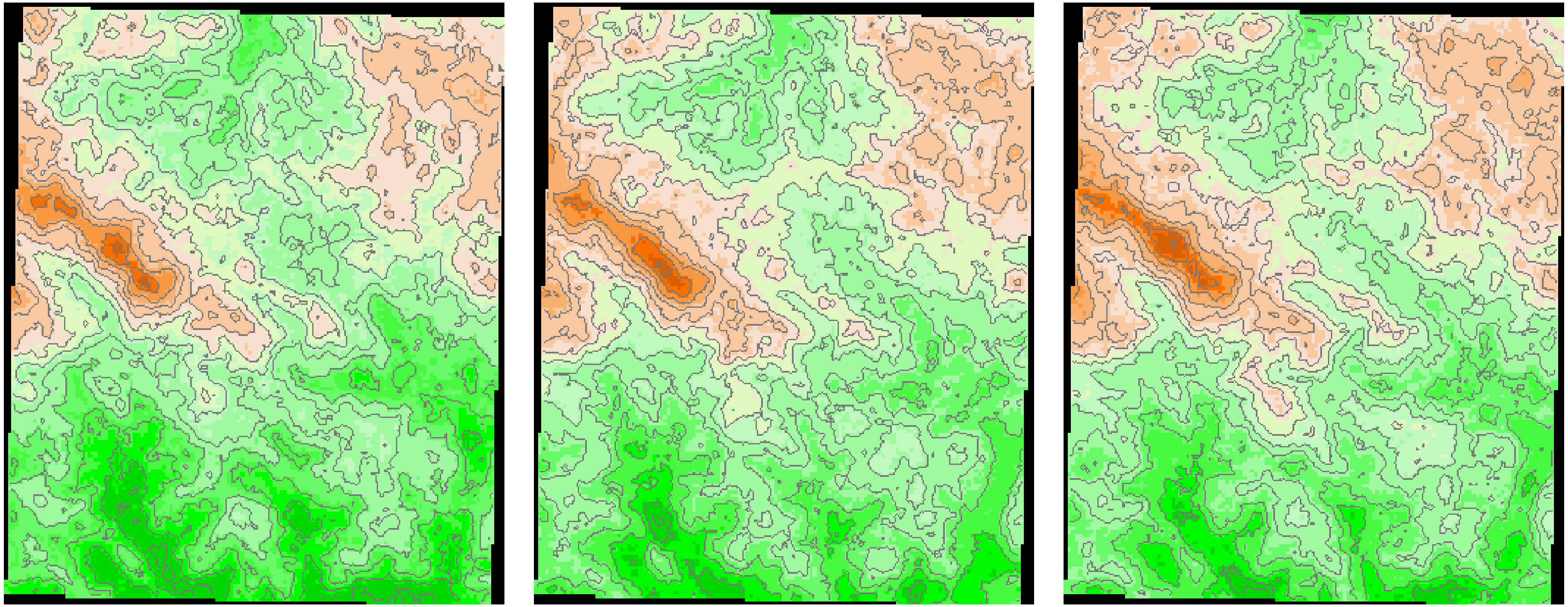
U3: Analysis. Error Propagation

- Addresses the effects of errors and uncertainty on the results of GIS analysis
- Almost every input to a GIS is subject to error and uncertainty
  - In principle, every output should have confidence limits or some other expression of uncertainty

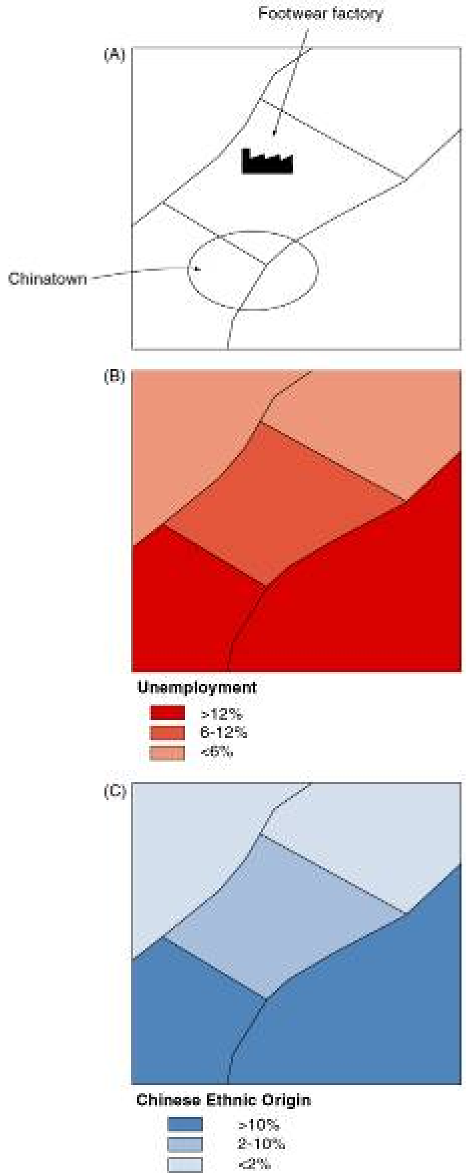


Error in the measurement of the area of a square 100 m on a side. Each of the four corner points has been surveyed; the errors are subject to bivariate Gaussian distributions with standard deviations in *x* and *y* of 1 m (dashed circles). The red polygon shows one possible surveyed square (one *realization* of the error model).

In this case the measurement of area is subject to a standard deviation of 200 sq m; a result such as 10,014.603 is quite likely, though the true area is 10,000 sq m. In principle, the result of 10,014.603 should be rounded to the known accuracy and reported as as 10,000.

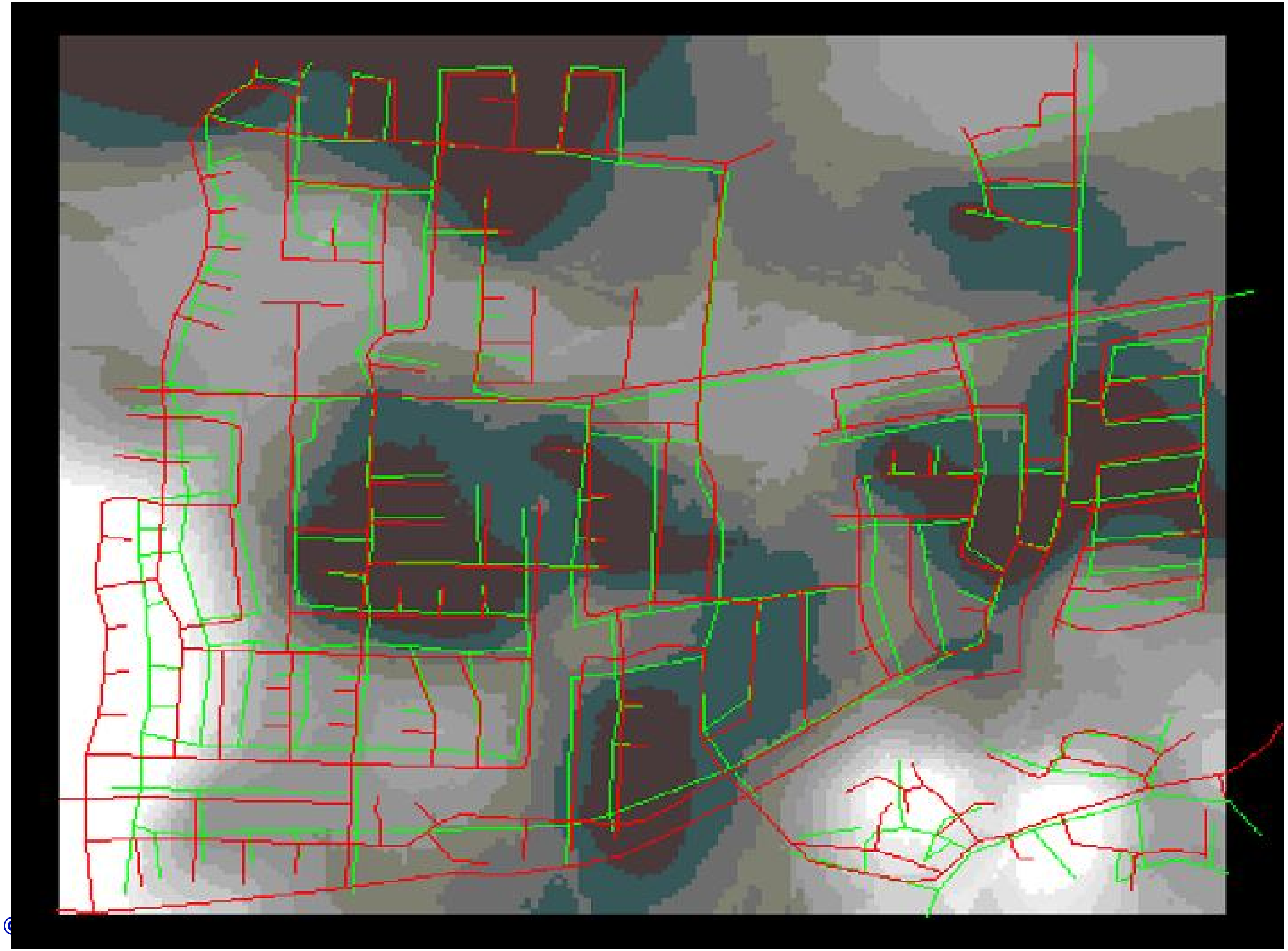


Three realizations of a model simulating the effects of error on a digital elevation model. The three data sets differ only to a degree consistent with known error. Error has been simulated using a model designed to replicate the known error properties of this data set – the distribution of error magnitude, and the spatial autocorrelation between errors.



Footwear factory
(A)
Chinatown
(B)
Unemployment
>12%
6-12%
<6%
(C)
Chinese Ethnic Origin
>10%
2-10%
<2%


UPPER WEST SIDE



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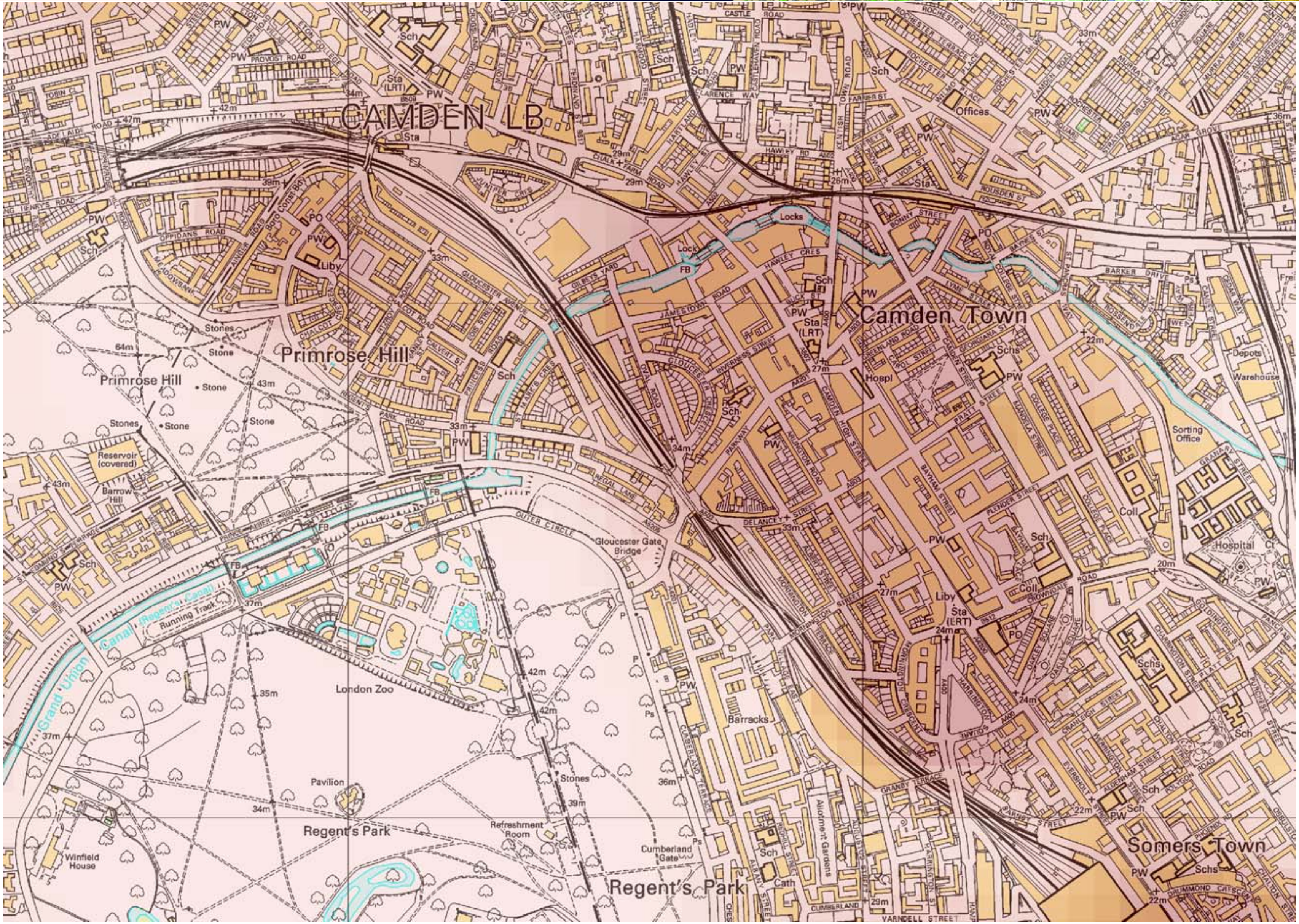
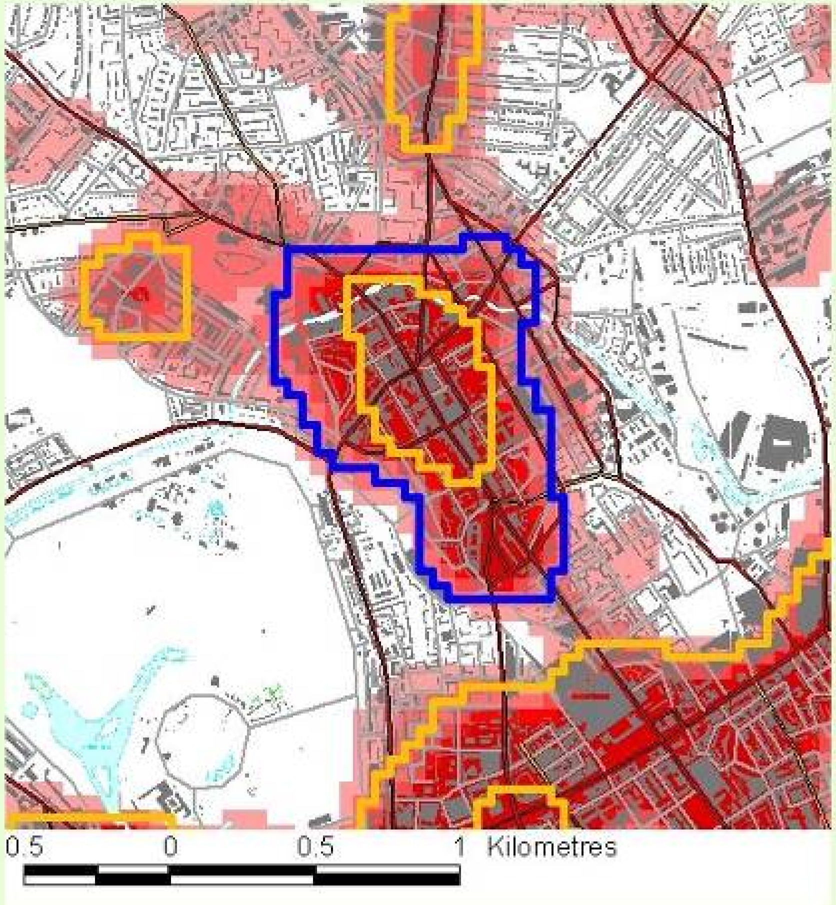
MAUP

- Scale + aggregation = MAUP
  - can be *investigated* through simulation of large numbers of alternative zoning schemes



CAMDEN LB
Camden Town
Primrose Hill
Primrose Hill
London Zoo
Regent's Park
Regent's Park
Somers Town
Grand Union Canal (Regent's Canal)
Gloucester Gate Bridge
Sorting Office
Hospital
Barracks
Cumberland Gate
Winfield House

Area of Town Centre Activity: Camden Town, LB Camden



Employment (Persons)	
Convenience retail	1,143
Comparison retail	1,008
Service retail	1,750*
Offices	5,852
Civic and Public Administration	412
Restaurants & Licensed Premises	1,335
Arts, Culture and Entertainment	408

Turnover (£000s)	
Convenience retail	130,336
Comparison retail	89,475
Service retail	Disclosive
Restaurants & Licensed Premises	40,015
Arts, Culture and Entertainment	35,399

Floorspace (Sq m)	
A1	55,496
A2	6,726
A3	12,967
Retail	81,278
Offices	147,663

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Back to Camden map

Printer friendly Version

*** Indicates possible unreliability in the marked data**

Production date: 21 Jun 2002

Living with Uncertainty

- It is easy to see the importance of uncertainty in GIS
  - but much more difficult to deal with it effectively
  - but we may have no option, especially in disputes that are likely to involve litigation

Some Basic Principles

- Uncertainty is inevitable in GIS
- Data obtained from others should never be taken as truth
  - efforts should be made to determine quality
- Effects on GIS outputs are often much greater than expected
  - there is an automatic tendency to regard outputs from a computer as the truth

More Basic Principles

- Use as many sources of data as possible
  - and cross-check them for accuracy
- Be honest and informative in reporting results
  - add plenty of caveats and cautions

Consolidation

- Uncertainty is more than error
- Richer representations *create* uncertainty!
- Need for *a priori* understanding of data and sensitivity analysis