ANALYTICAL MODELLING

PROCESS MODELLING

Classification of Process Models

- Process model simulates real-world processes.
- It is a relatively simple task to classify process models into one of two types: *a priori or a posteriori.*

Natural and scale analogue models

- A natural analogue model uses actual events or real world objects as a basis for model construction.
- A natural analogue model to predict the formation of avalanches in the previously unstudied area

Scale Analogue & Conceptual Model

- Scale analogue models such as topographic maps and aerial photographs, which are scaled down and generalized replicas of reality.
- Conceptual process models are usually expressed in verbal or graphical form, and attempt to describe in words or pictures quantitative and qualitative interactions between real-world features.

Mathematical models

- Mathematical process models use a range of techniques including deterministic, stochastic and optimization methods.
- In deterministic models, there is only one possible answer for a given set of inputs.
- Stochastic models recognize that there could be a range of possible outcomes for a given set of inputs, and express the likelihood of each one happening as a probability.
- Optimization models are constructed to maximize or minimize some aspect of the model’s output.

MODELLING PHYSICAL AND ENVIRONMENTAL PROCESSES

- In a spatial context, one of the most challenging tasks for physical and environmental modellers is *forecasting what may happen in the* future under a given set of conditions.
- For example, predicting when and where a flood may occur or where an avalanche may take place is a difficult task.

MODELLING PHYSICAL AND ENVIRONMENTAL PROCESSES

- Forecasting is inherently time-dependent. Unfortunately GIS data models handle the time dimension poorly.
- Most applications that involve making predictions or forecasts are based around some non-GIS model.

MODELLING PHYSICAL AND ENVIRONMENTAL PROCESSES

- Forecasting models tend to be dynamic, with one or all of the input variables changing over time.
- For example, in the case of a forest fire, as time elapses from the start of the fire the prevailing weather conditions will change, as will the amount of forest still left to burn.

MODELLING PHYSICAL AND ENVIRONMENTAL PROCESSES

- The rate of diffusion of the fire from its starting point is based on the spatial characteristics of the neighbourhood.

- One approach to modelling fire behaviour. Their method involved three stages:
- A raster approach
- Aspatial Fire modelling program known as BEHAVE
- The modelling capabilities of GIS

MODELLING PHYSICAL AND ENVIRONMENTAL PROCESSES

- A recent development in forecasting models has been to couple GIS with artificial intelligence (AI) techniques such as neural networks.

MODELLING PHYSICAL AND ENVIRONMENTAL PROCESSES

- Several problems make accurate forecasting very difficult. It is generally accepted that the accuracy of forecasts decreases with the length of the prediction.

- The introduction of random or stochastic processes, as advocated by proponents of chaos theory may play an increasingly important role in improving the accuracy of longer-term predictions, especially models of natural systems like weather and climate.

MODELLING HUMAN PROCESSES

- Spatial interaction models are used to help understand and predict the location of activities and the movement of materials, people and information.

- For example: To predict the flow of people from their home to shops.

- The 'attractiveness' of a store can be represented in a spatial interaction model as an attractiveness index.

MODELLING HUMAN PROCESSES

- The concepts of supply and demand are also important for spatial interaction modelling.
- Distance between an origin and a destination does not have a fixed effect on spatial interaction. The effect of distance depends on the type of activity and customers.

MODELLING HUMAN PROCESSES

- The effects of distance and attractiveness can be studied using *gravity models. These* use a distance-decay function (derived from Newton’s law of gravitation) to compute interactions given the relative attractiveness of different destinations.

- GIS can also be used to display the results of the modelling process as a series of accessibility contours for both origin and destination locations, or as interaction probability surfaces

MODELLING THE DECISION MAKING PROCESS

- Outputs from process models of both human and physical systems are the raw information that will be required to assist various types of decision-making.

- Map overlay is the traditional technique for integrating data for use in spatial decision making.
- For example, in siting nuclear waste facilities
- Overlay analyses suffer from certain limitations when dealing with decision-making problems of a less well-defined nature.

MODELLING THE DECISION MAKING PROCESS

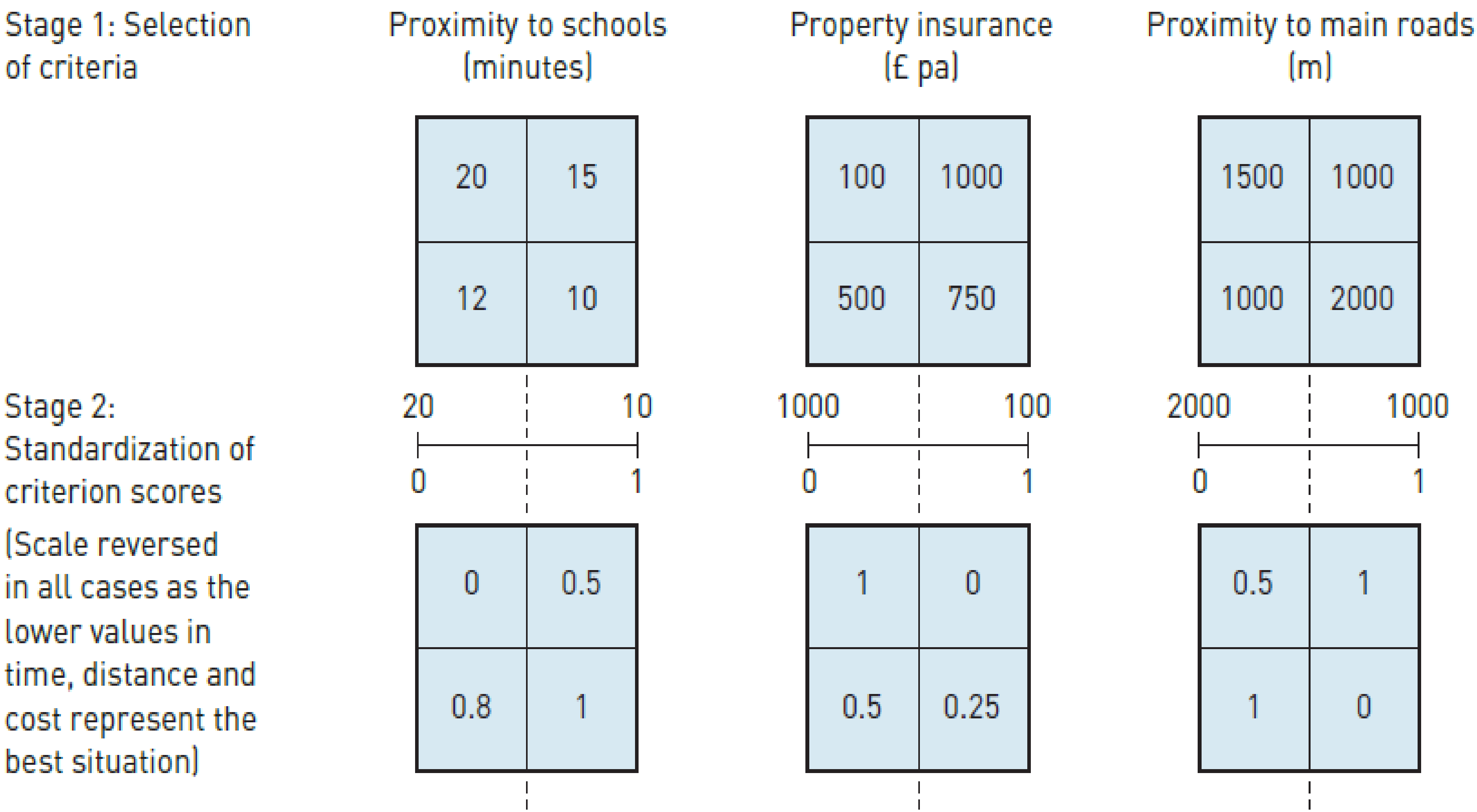
1. Digital map overlays
2. Most overlay procedures in GIS
3. When mapping variables for overlay analysis

- One way to address these problems is to use *multicriteria evaluation (MCE) techniques to either supplement* or replace standard map overlay in GIS.

MODELLING THE DECISION MAKING PROCESS

4. MCE is a method for combining data according to their importance in making a given decision.
5. MCE techniques are numerical algorithms that define the 'suitability' of a particular solution

MCE algorithm is the weighted linear summation technique.



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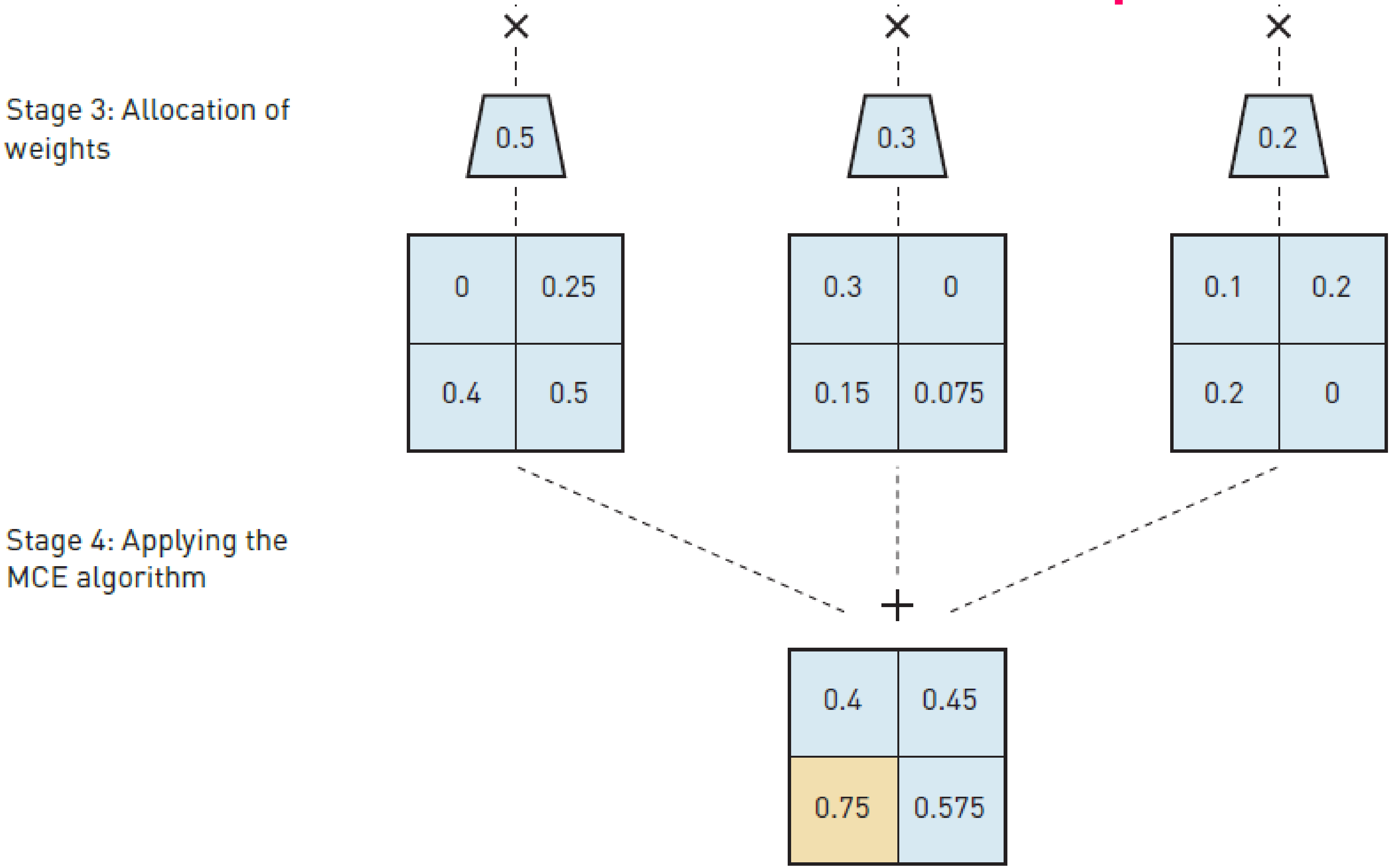


MODELLING THE DECISION MAKING PROCESS

- GIS is an ideal framework in which to use MCE to model spatial decision-making problems as it provides the data management and display facilities lacking in MCE software.

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- The use of GIS to facilitate the development of spatial process models is not without problems.
- There are otherconceptual problems, These include:
- The quality of source data for model calibration;
- The availability of data for model validation;
- The implementation within a GIS;

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- The complexity of modelling reality; and
- The conceptual and technical problems of building multi-dimensional models.

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- Similarly, models that have been developed in a non-spatial context may require detailed data inputs which, again, do not exist as spatial data sets.
- Example is the Universal Soil Loss Equation, which has often been applied within a GIS context.
- The equation is written as:

$$A = R \times K \times LS \times C \times P$$

- where: A = *average annual soil loss;* R = *rainfall* factor; K = *soil erodibility factor;* LS = *slope* length–steepness factor; C = *cropping and management* factor; and P = *conservation practices factor.*

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- Extending the measurements to a large study area, where the controlling factors can vary by orders of magnitude, is difficult.
- For example, spatial variations in evapotranspiration may be estimated by combining previous field studies on different vegetation types and weather with land cover information derived from satellite imagery.

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- The main GIS problem associated with validating spatial process models is therefore lack of appropriate spatial data.
- Implementation of process models within GIS enforces a spatial context. When models were originally developed for non-spatial applications this can create conceptual and operational problems.

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- The human and physical worlds are extremely complex and interlinked. Theories of environmental determinism suggest that human development is strongly influenced (if not determined) by the physical environment.

- Agriculture is a good example. A crop may not grow naturally in an area that receives a low rainfall, so a more drought-tolerant crop may be grown instead.

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- As the model becomes more comprehensive, there will be greater data requirements, increased complexity of intra-model interactions, greater opportunity for errors in both model data and model processes, and an increased likelihood that the model outputs will have little relevance to reality.

PROBLEMS WITH USING GIS TO MODEL SPATIAL PROCESSES

- Limitations of standard GIS data models regarding their handling of time and 3D data.
- Current GIS data models employ a 'flat Earth' approach. Although most GIS packages allow surface modelling of some description (2.5D) and some even permit true solid 3D modelling.

OUTPUT

From new maps to enhanced decisions

Maps as Output

- Users must be aware of the different forms of output such as maps, statistics and tables of numbers.
- The term 'output' is used to describe the ways in which information can be presented.

Map as Output

- It will influence the decision-making process.
- The most common form of output is a map.
- GIS output may be a 3D.

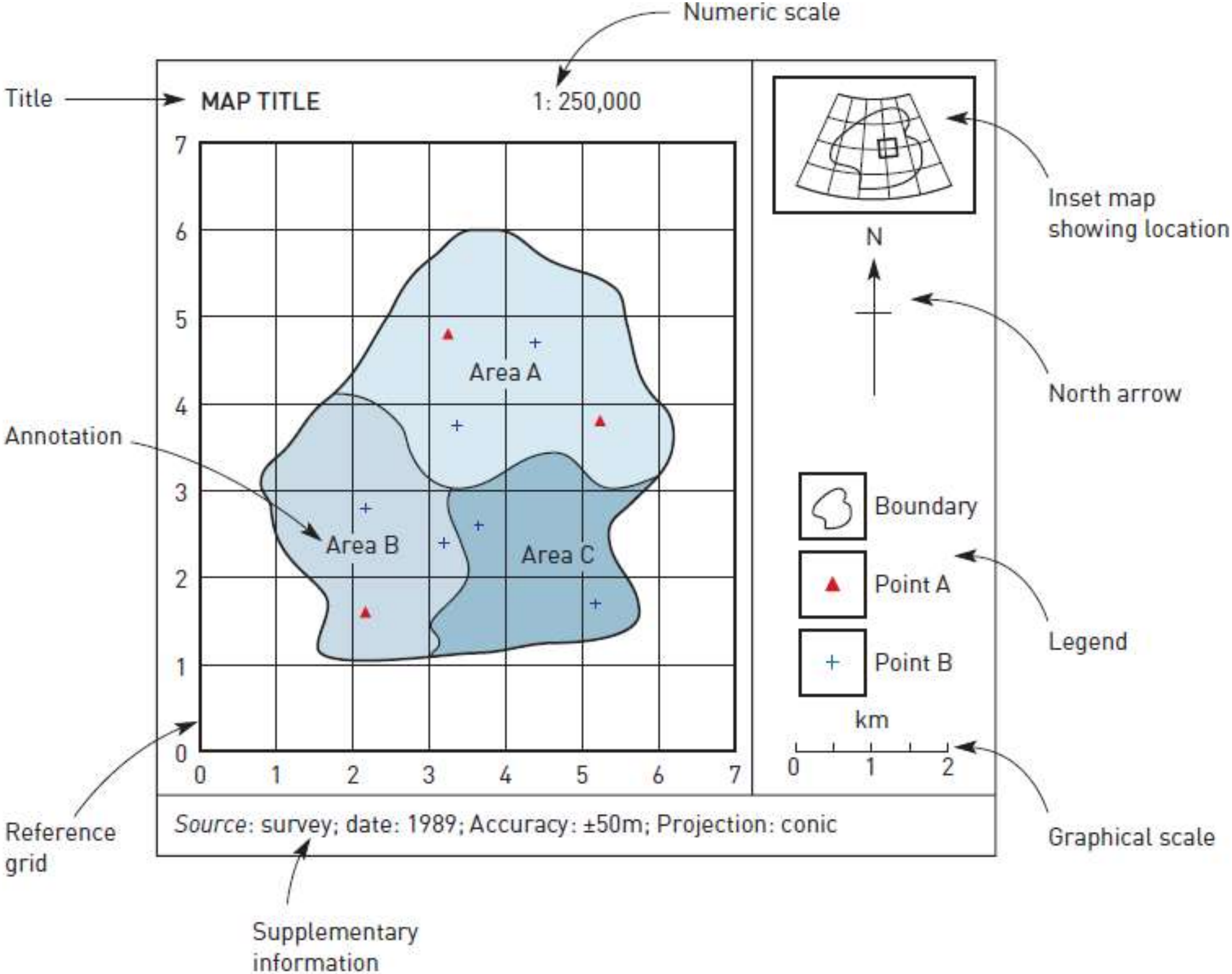
Maps as Output

- The role is to communicate to user.
- It is necessary to consider a design elements.
- These include:
  - the frame;
  - the projection;
  - the features;
  - the generalization;
  - annotation; and
  - symbolism.

Maps as Output

- It needs some form of spatial referencing.
- A number of graphic and non-graphic devices are used.
- The spacing and labelling of the grid lines provide information and the orientation

MAP COMPONENTS



Maps as Output

- An inset map showing the location of the main map area.
- For large-scale maps of small areas, planar co-ordinates derived from a local projection system.

Maps as Output

- Maps are communication devices for spatial information.

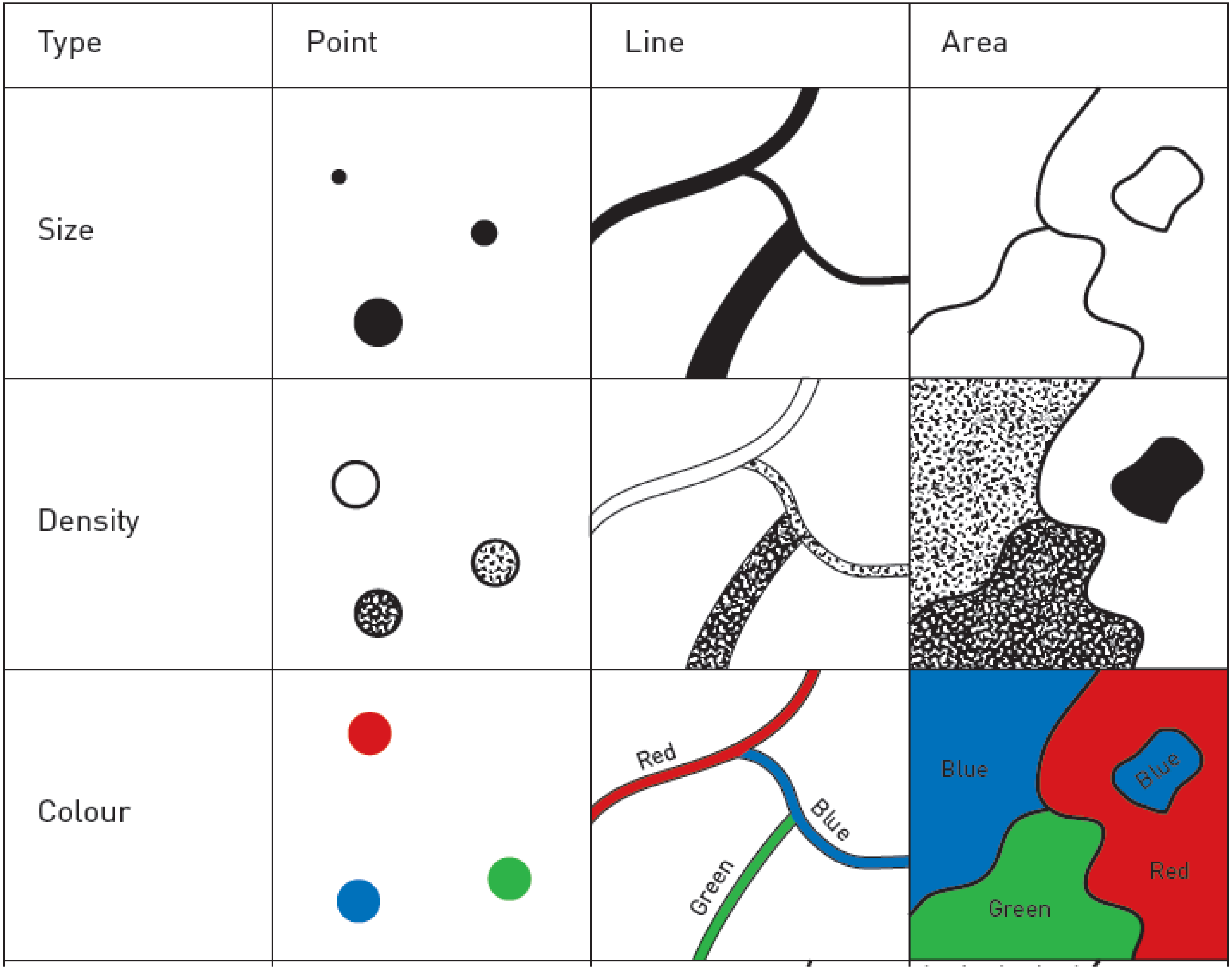
MAPS AS OUTPUT

- In creating quality cartographic output, it is necessary to consider both the level of detail and the relative positions.

MAPS AS OUTPUT

- The high level of precision does not help.
- For example, in a map showing the road network

Cartographic symbolism



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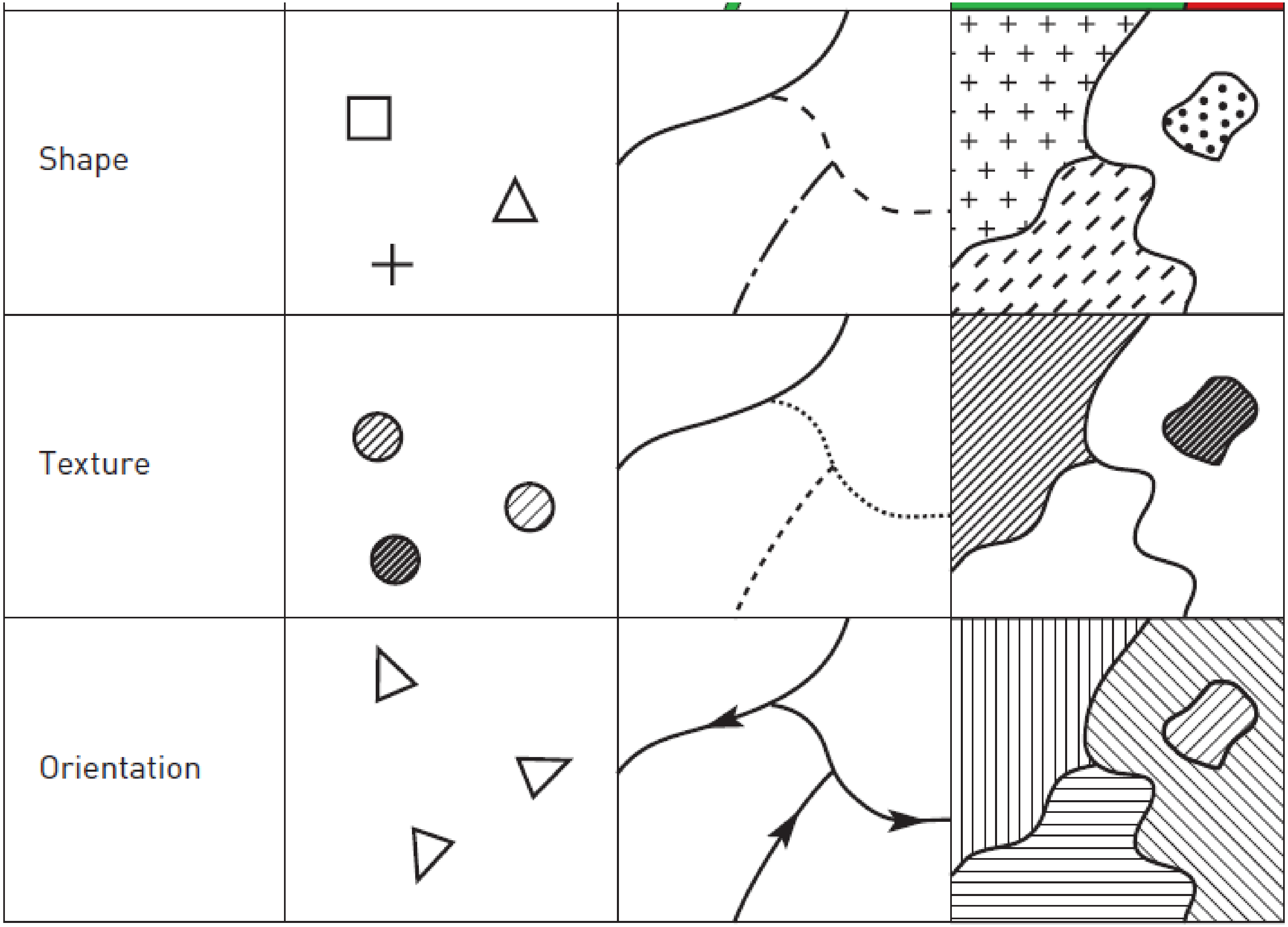

MAPS AS OUTPUT

- It is necessary to generalize the detail of main roads
- The roads and railway lines that follow close and parallel.
- To avoid confusion between the two features we need to add a slight offset.

MAPS AS OUTPUT

- Generalizing map information may be done.
- Map symbolism can also be important.
- Each symbol can differ in size, shape, density, texture, orientation and colour.

MAPS AS OUTPUT

- The standard international colour scheme is green (easy), blue (intermediate), red (advanced), black (expert).
- Colour is important in the understanding of the map.

MAPS AS OUTPUT

- Black and white maps that use differently shaped symbols and shading patterns.
- The shape and pattern used to bear some relation to the feature.
- For example: use an anchor symbol to show the location of an airport and a lighthouse symbol to show the location of a public telephone.

MAPS AS OUTPUT

- Our road and rail example:
- Railway lines are plotted as (– – – – – – –)
- Main roads as black lines with short perpendicular hatching (++++++).
- Careful choice of shape and pattern of symbolism.

MAPS AS OUTPUT

- Finally, density and texture of shading can affect the impression given by a map.
- Monochrome choropleth map.
- Thematic map.

MAPS AS OUTPUT

- Annotation is textual and graphical information
- The visual and numeric guides is a form of annotation.

MAPS AS OUTPUT

- For example, information on a map showing the geography of the ‘Great Solar Eclipse’ of 14 July 1748. This is referred to as ‘metadata’.

MAPS AS OUTPUT

- The primary objective of the map's theme(s).
- This involves technical decisions, generalization, positioning , colour and symbolism.

Alternative forms of cartographic output

- Maps are drawn as plan views, 3D views and animation.

Alternative forms of cartographic output

- A common use of cartograms is for drawing maps. This type of cartogram is known as a *routed line cartogram*.

Alternative forms of cartographic output

- Routes are plotted as generalized lines.
- Space distorted from a central point on the basis of time taken. These are known as *central point linear cartograms*.

Alternative forms of cartographic output

- Another use of cartograms is to depict the size of non-spatial relative areas. These are referred to as *area cartograms.*
- Popular method of visualization (3D).

Alternative forms of cartographic output

- Animation can be useful for a strong temporal element.
- ‘played back’ as a series of frames, the change of pattern over time.
- This technique has proved for identifying temporal patterns.

Alternative forms of cartographic output

- Animation may be used in a similar way to display spatio-temporal processes.
- By combining 3D mapping and animation, GIS packages can create realistic animation.
- This is a powerful means of simulators.

OUTPUT

Non-Cartographic, Spatial Multimedia, Delivery, Spatial Decision Support

NON-CARTOGRAPHIC OUTPUT

- Tables and charts containing spatial and non-spatial attribute forms of output.
- Numerical or character information are displayed as tables or in charts.
- In many cases the output may be a single number or character string.

NON-CARTOGRAPHIC OUTPUT

- A recent development is the *linked display*.
- *This* approach makes use of the dynamic linking.

SPATIAL MULTIMEDIA

- Some GIS packages offer facilities of multimedia.
- Photographic images, text, graphics, sound and video can be linked to displays.

SPATIAL MULTIMEDIA

- GIS output to inform users about environmental problems.
- Sound can be used to add value to mapped information.

MECHANISMS OF DELIVERY

- GIS output, ranging from maps to animated ‘fly-through’ visualizations and multimedia presentations.
- Two basic types of output medium can be defined: permanent, and ephemeral.

MECHANISMS OF DELIVERY

- Dot-matrix printers, bubble-jet and ink-jet printers, laser printers, pen plotters, thermal printers, photographic image setters and electrostatic colour plotters.
- Ephemeral output is essentially based around the computer screen.

MECHANISMS OF DELIVERY

- Map based information is being served using wireless technology to users.
- Screen types include cathode ray tubes (CRT) and liquid crystal displays (LCD).
- Screens may be monochrome (black-and-white or green-screen) or colour.

MECHANISMS OF DELIVERY

- Image as a grid of pixels (picture elements).
- New types of screen include flexible screens, low power consumption devices, and head up displays.

MECHANISMS OF DELIVERY

- Allowing the user to choose display and/or analysis options and carry out spatial search and query operations.
- Recent research has focused on the development of *virtual reality (VR) displays.*
- Web using the virtual reality modelling language (VRML).

Virtual reality GIS

- Virtual Reality GIS (VRGIS) simulates the real world using a GIS database.
- Some of the features of are:
- Realistic representation.
- Free movement of the user.
- Standard GIS capabilities.
- A visibility function

Serving maps on the web

- GIS-based websites allow users to interrogate map data.

GIS AND SPATIAL DECISION SUPPORT

- GIS provides six distinguishing characteristics of DSS are:

1. Decision-support systems are used to tackle ill-structured or semi-structured problems.
2. They are accessible through a user-friendly graphic user interface (GUI).

GIS AND SPATIAL DECISION SUPPORT

3. They enable users to make full use of the data and models.
4. Users of decision-support systems develop a solution procedure using models.
5. They are designed for flexibility of use and ease of adaptation.
6. Decision-support systems are developed interactively and recursively.

GIS AND SPATIAL DECISION SUPPORT

- GIS has been referred to as a special kind of decision support system dealing with problems that involve a high degree of spatiality.
- This is perhaps not entirely an accurate view, as GIS *does not meet all the six characteristics of a decision* support system.
- GIS can provide a framework for the development of ‘spatial decision-support systems’ (SDSS), particularly when either loosely or tightly coupled with other modelling software.

GIS AND SPATIAL DECISION SUPPORT

- SDSS are an extension of DSS. They share the same characteristics.

Maps as decision tools

- Maps were used as a form of decision-support tool.
- Which is the best route to take between one place and another?
- What is the best means of transport?
- What will I need to take with me?

Maps as decision tools

- In many cases digital spatial information is being used through either GIS or custom-designed software.
- Recent developments have linked web-based GIS methods.

Methods

Handling Spatial Data

Introduction

- Many of the developments in GIS have been technology or application-led.

- Developments have often been the result of cooperation and integration, matching the integrating nature of the technology.

Introduction

- Many different disciplines :
- computer mapping, databases, computer science, geography, remote sensing, data processing, mathematics and statistics.
- Methods were used before computers were commonly available are examined.

HANDLING SPATIAL DATA MANUALLY

- In the 1940s or 1950s, Spatial data were encountered as maps.
- Maps could be found in most households, shops and businesses.
- Maps were used for many applications: identifying areas, routing, planning walks, targeting services.

HANDLING SPATIAL DATA MANUALLY

- Sieve mapping were introduced.
- In the early days, colour pens and shading patterns to represent values.
- The techniques were planning agencies, nature conservation agencies.

HANDLING SPATIAL DATA MANUALLY

- Manual sieve mapping is inaccurate.
- Use of maps: route finding, planning deliveries or an emergency evacuation.
- Measuring shortest distances by hand is a tedious process.

HANDLING SPATIAL DATA MANUALLY

- The string is used to trace the route.
- There are many problems: inaccurate, difficult, and time-consuming.
- It is difficult to check alternative routes.

HANDLING SPATIAL DATA MANUALLY

- Calculating areas is more difficult.
- An innovative technique involved cutting out polygons and weighing to measure of relative area.

HANDLING SPATIAL DATA MANUALLY

- These manual techniques share many problems.
- These include the slow speed of update, access, difficulties in extracting, difficulties in analyzing, inaccuracies and analysis, and the inflexibility.

HANDLING SPATIAL DATA MANUALLY

- With all these problems associated with spatial data handling and analysis, it was hardly surprising that cartographers and other spatial data users were keen to exploit and explore computer technology.

Methods

Handling Spatial Data

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HANDLING SPATIAL DATA MANUALLY

- Calculating areas from maps is even more difficult
- Tracing areas onto graph paper and then ‘counting squares’.
- An innovative technique is used by the US Bureau of Census.

HANDLING SPATIAL DATA MANUALLY

- Manual techniques were in widespread use until computers
- Slow speed, difficulties in extracting, inaccuracies, and the inflexibility.
- Other problems associated with the media.
- Stretch and shrink), inconsistencies, destroyed, considerable space and difficult to transport.

HANDLING SPATIAL DATA MANUALLY

- Other spatial data, printed census
- Birth and death records, marriage certificates and other documents
- Inconsistencies and changes

THE DEVELOPMENT OF COMPUTER METHODS FOR HANDLING SPATIAL DATA

- Graphics technology,
- Data access and storage,
- Digitizing,
- Programming and interfaces; and
- Developments.

THE DEVELOPMENT OF COMPUTER METHODS FOR HANDLING SPATIAL DATA

- Areas of prime importance
- Hardware developments
- Areas of cartography

THE DEVELOPMENT OF COMPUTER METHODS FOR HANDLING SPATIAL DATA

- Harvard Graphics Laboratory played a role in the development of GIS(1991).
- In 1960s little commercial development.
- (CAD) and (AM/FM).

The systems approach

- Problem solving and decision making.
- Macroscopic view (1971).

The systems approach

- Boulding (1956), Von Bertalanffy (1968), Churchman (1968) and Ackoff (1971).
- Systems theory is the conceptual approach

The systems approach

- (Reeve, 1997)
- (Goodchild, 1995).
- (Burrough, 1986; Aronoff, 1989);

The systems approach

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- Methodological framework.
- Two approaches, hard and soft systems analysis

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- some of the major developments:
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- 1966
- 1967
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- DIME assisted efficient digitizing and

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- 2002
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- (Maguire, 1989).
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- (Goodchild and Rhind, 1990; Masser, 1990).

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- the development of similar activities.

DATA QUALITY ISSUES

Data quality and errors – Sources of error in GIS – Finding and modeling errors of GIS – Managing GIS error

INTRODUCTION

- Quality is a word in a dictionary define that ‘degree of excellence’.
- In GIS, *data quality is used to give an indication* of how good data are.

INTRODUCTION

- In many industries, quality control is everything.
- GIS users strive for quality products from their systems.

INTRODUCTION

- Errors can enter a GIS in many different ways.
- For example:
- A mistake in digitizing a field boundary.
- A mistake in the transcription of a grid reference.
- Misinterpretation of satellite imagery.

INTRODUCTION

- But what is a high-quality product?
- What exactly are good quality data?
- How can we describe and recognize poor quality output?

INTRODUCTION

- Two issues are:
- First, the terminology, and
- Second, the sources, propagation and management.
- Describing data problems in GIS is difficult since many of the words used are also common in everyday language.
- Words such as quality, accuracy and error not only mean different things to different people but also have precise technical definitions.

INTRODUCTION

- The terms used for data error and quality are introduced to solve problems.
- The types and sources of errors to recognize and deal with problems.

INTRODUCTION

- Techniques for modelling and managing errors are.
- A few data sets are error-free.
- GIS users should document the limitations.

INTRODUCTION

- Earlier in the book we compared the fuel in a car to data in a GIS.
- In the same way that a poor quality fuel may cause problems with the running of the car, poor quality data will introduce errors into your GIS.

DESCRIBING DATA QUALITY AND ERRORS

- In GIS, *data quality is used to give an indication* of good data.

DESCRIBING DATA QUALITY AND ERRORS

- Issues such as *error, accuracy, precision and bias can help to assess the quality*.
- In addition, the *resolution and generalization*.

DESCRIBING DATA QUALITY AND ERRORS

- A systematic error would have occurred.

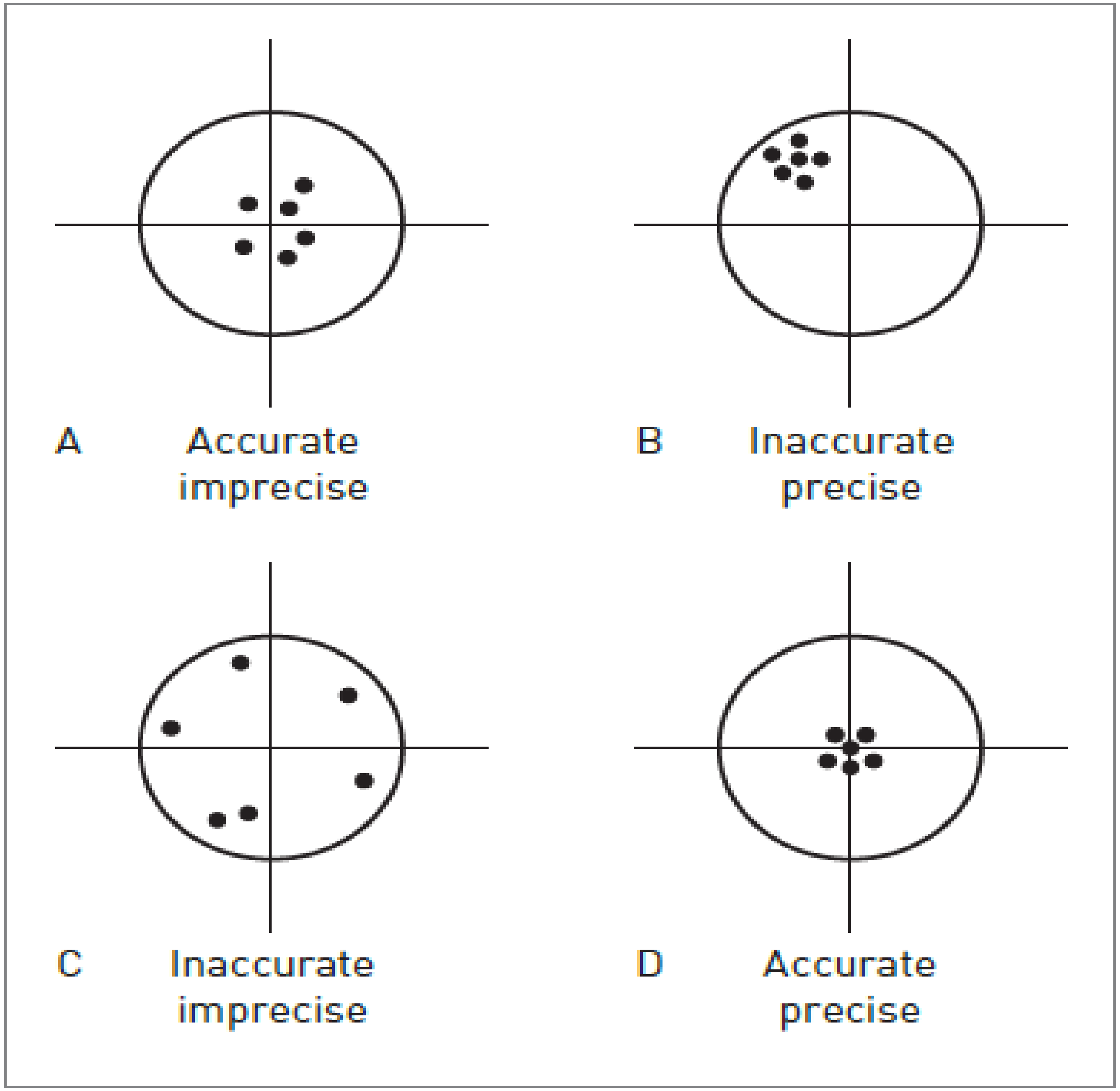
DESCRIBING DATA QUALITY AND ERRORS

- Accuracy of reality.

DESCRIBING DATA QUALITY AND ERRORS

- Precision is the recorded.

The difference between accuracy and precision is Shown:



DESCRIBING DATA QUALITY AND ERRORS

- Bias in GIS data is the systematic variation of data

Resolution and generalization of raster datasets

(a) 25m resolution vegetation map

(b) 5m resolution colour aerial photograph

DESCRIBING DATA QUALITY AND ERRORS

- Generalization is the process of simplifying the complexities.

DESCRIBING DATA QUALITY AND ERRORS

- *Completeness, compatibility, consistency and applicability are introduced here.*
- A complete will cover period of interest.

DESCRIBING DATA QUALITY AND ERRORS

- Maps containing data measured in different scales of measurement cannot be combined easily.

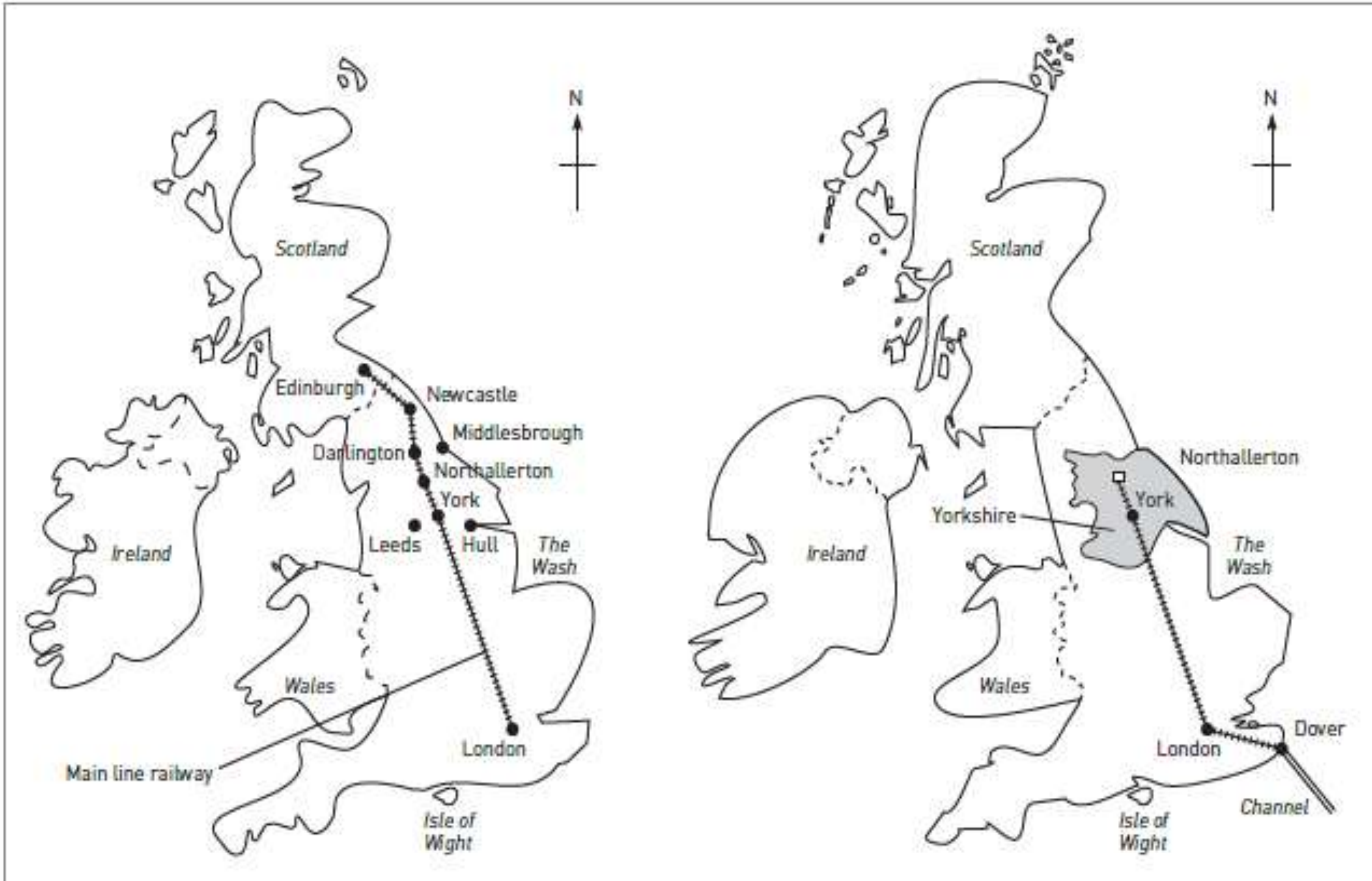
DESCRIBING DATA QUALITY AND ERRORS

- Consistency applies not only to separate data sets but also within individual data sets.

SOURCES OF ERROR IN GIS

- Spatial and attribute errors can occur at any stage

MENTAL MAPS


N
Scotland
Edinburgh
Newcastle
Middlesbrough
Darlington
Northallerton
York
Leeds
Hull
The Wash
Ireland
Wales
London
Main line railway
Isle of Wight
N
Scotland
Northallerton
York
Yorkshire
The Wash
Ireland
Wales
Dover
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Channel
Isle of Wight

Errors arising from our understanding and modelling of reality

- Our perception of reality influences our definition of reality.

Errors arising from our understanding and modelling of reality

- Consider the problem of defining a common geographical feature such as a mountain in a GIS.

Finsteraarhorn, Switzerland (4273m)

The Finsteraarhorn, Switzerland (4273 m)

Terrain model of Mount Everest (8849 m)

Terrain model of Mount Everest and its surrounding area based on photogrammetric survey data. 3D vizualization of Mount Everest (*Source*: Martin Sauerbier/Institute of Geodesy and Photogrammery)

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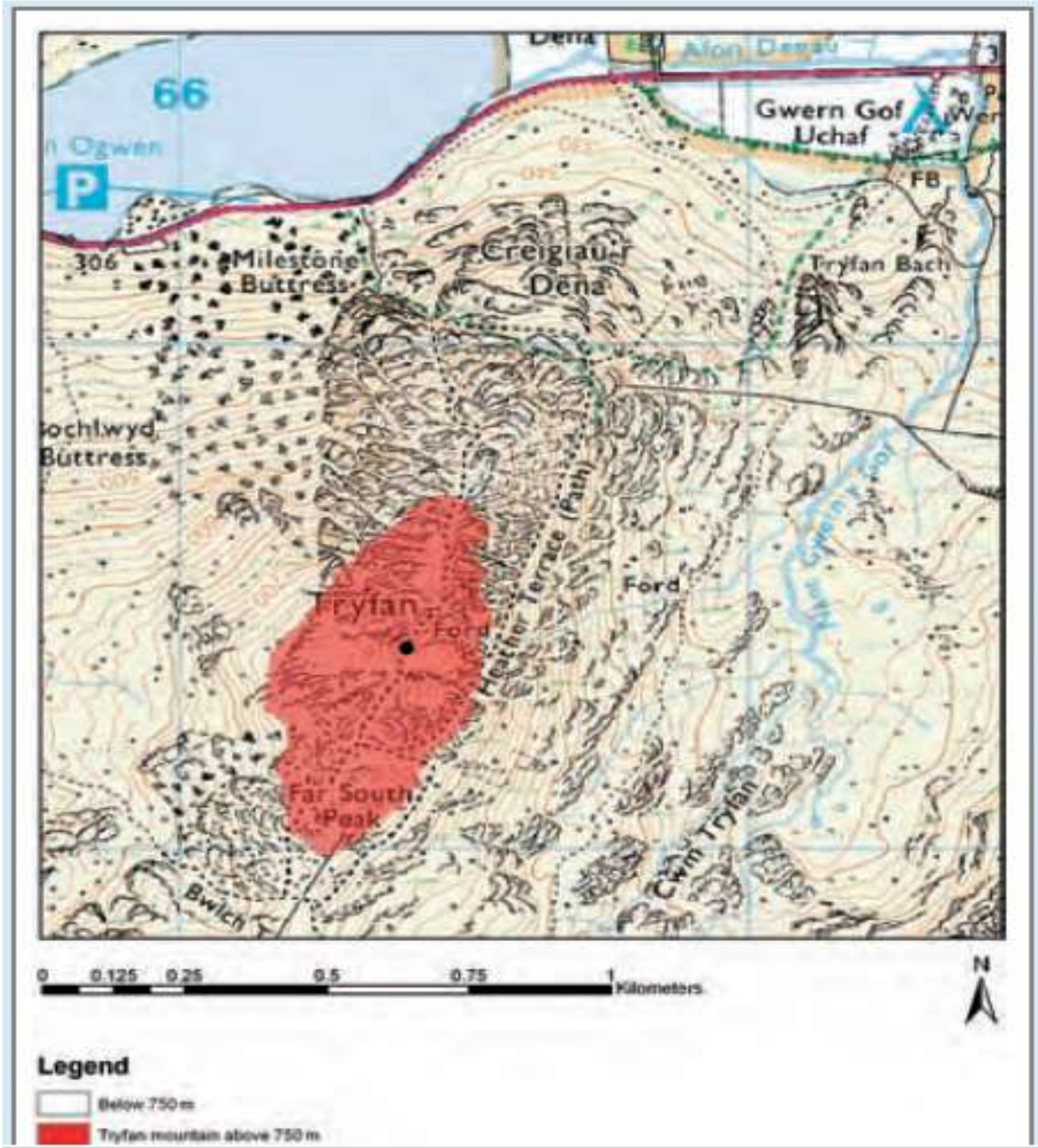
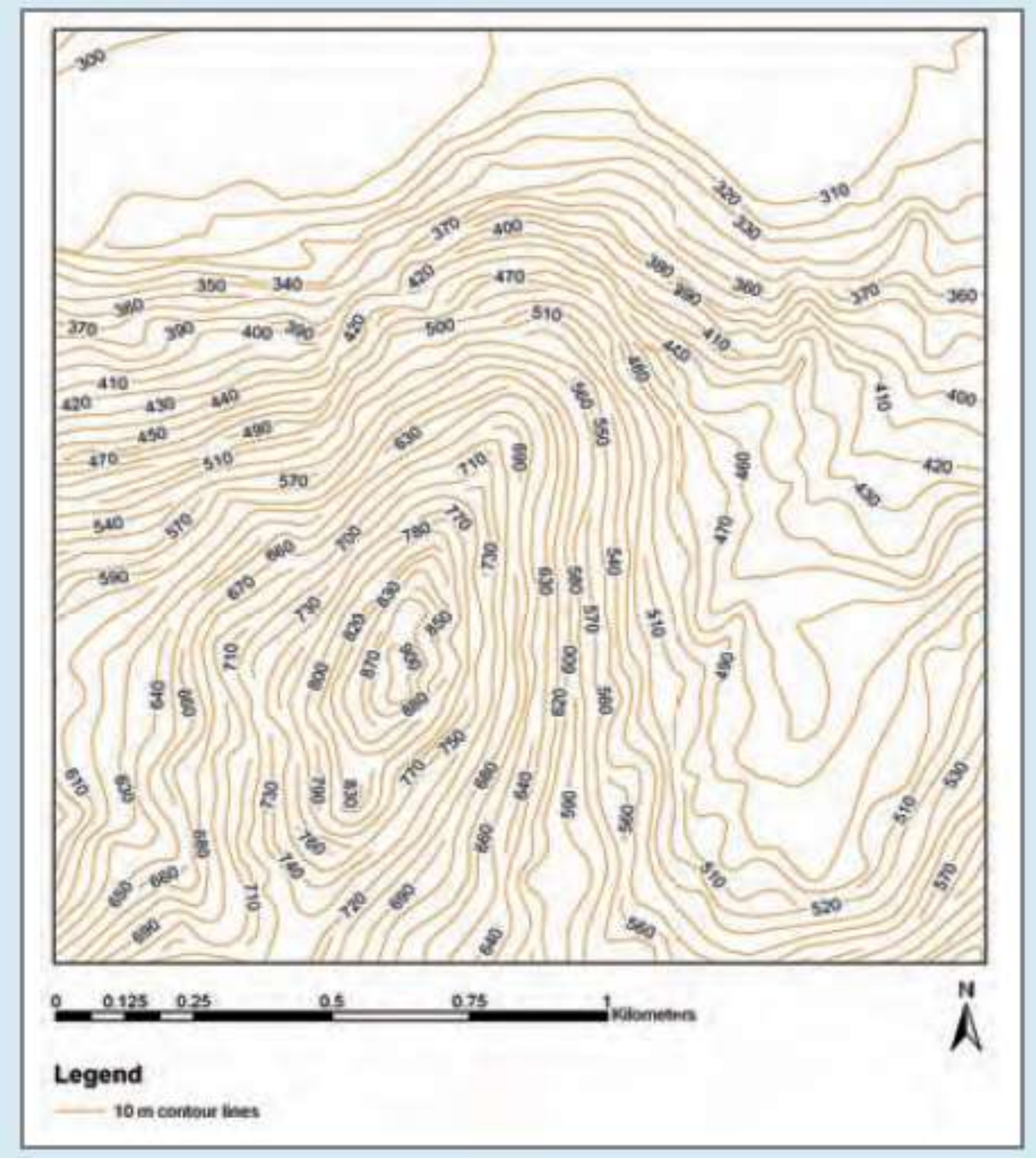
Visualize the problem for Tryfan; a mountain in north Wales.

Photograph of Tryfan

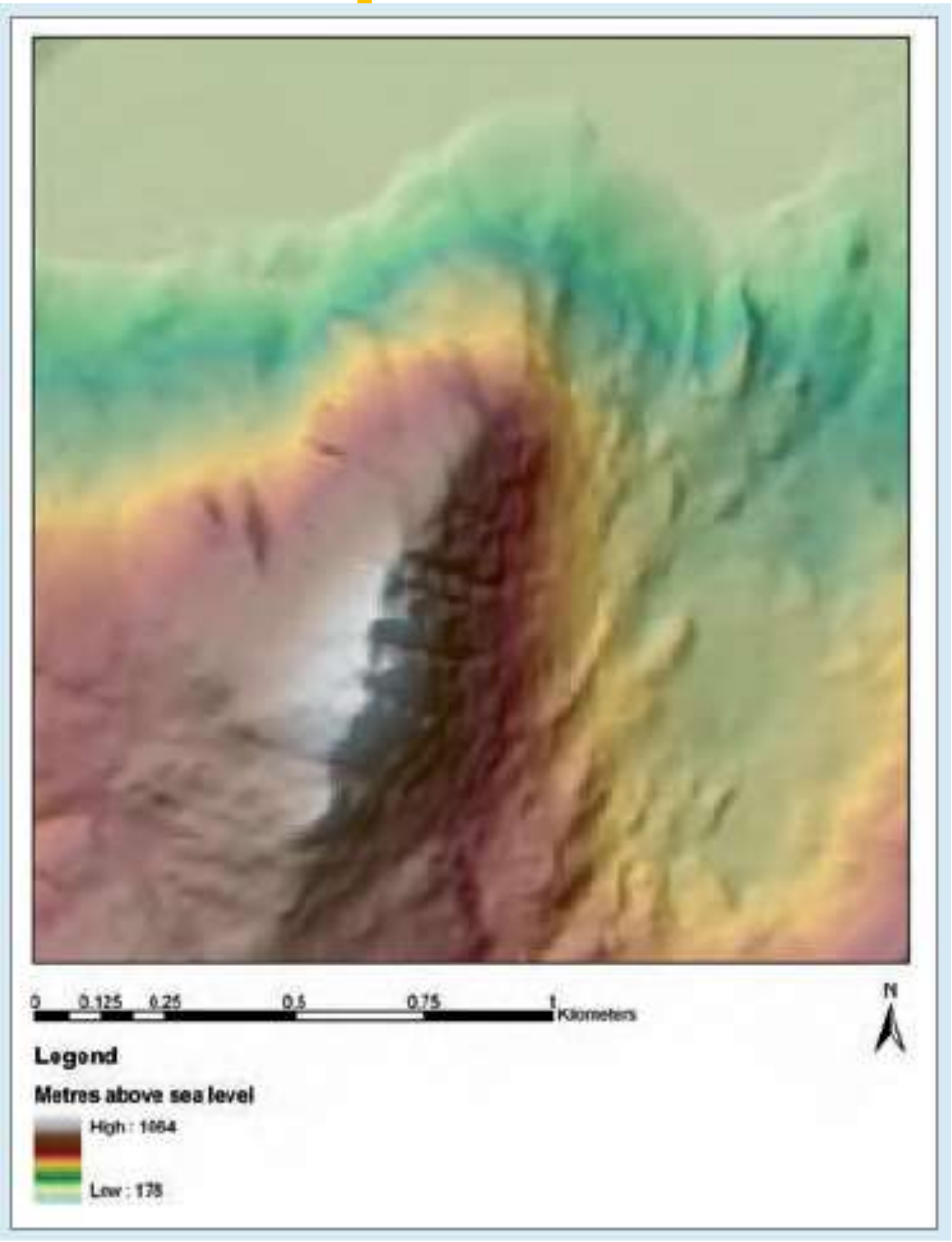
Ordnance Survey 1:50,000 topographic map showing area above 750m



Contour map



DEM Representation



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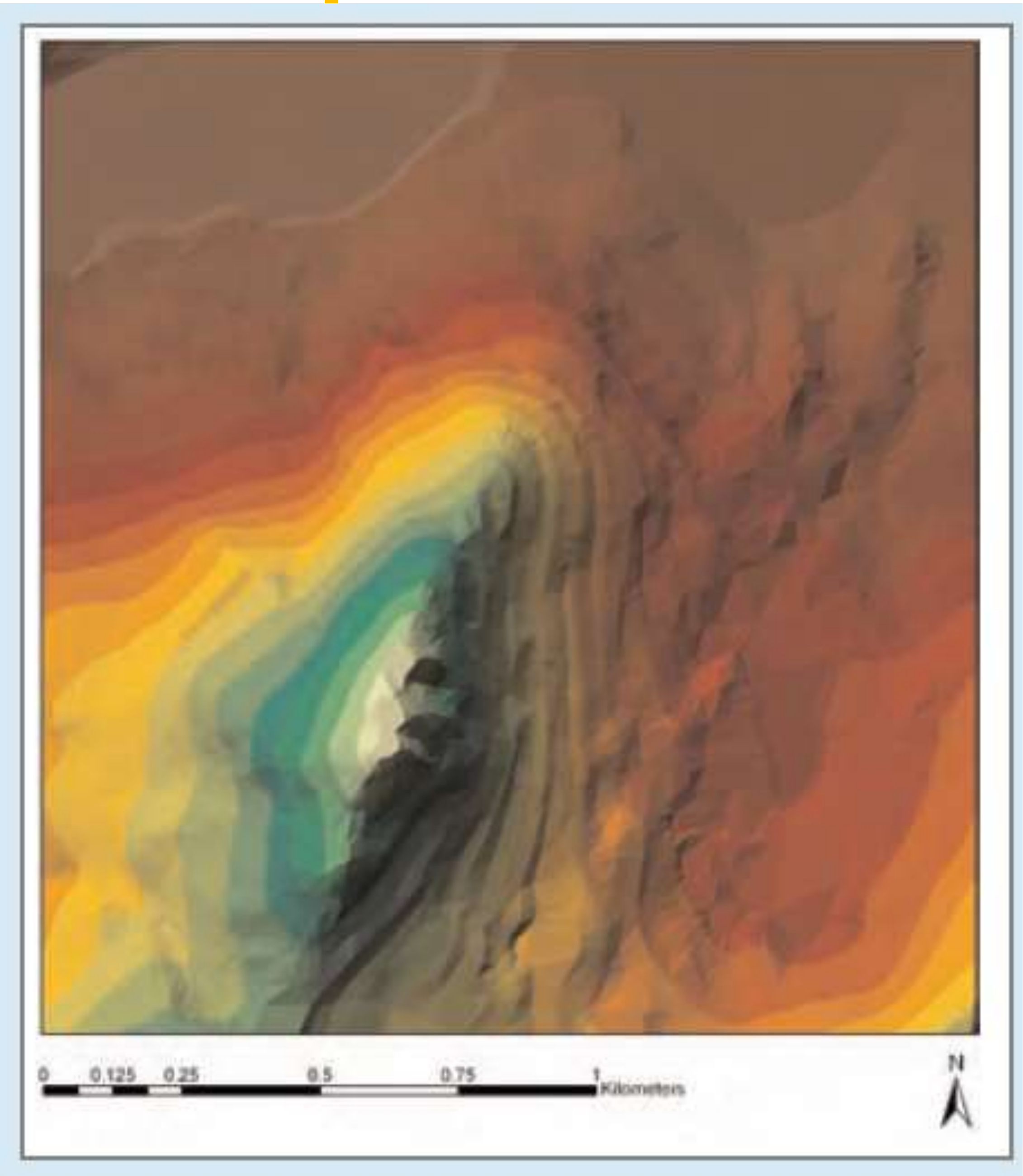
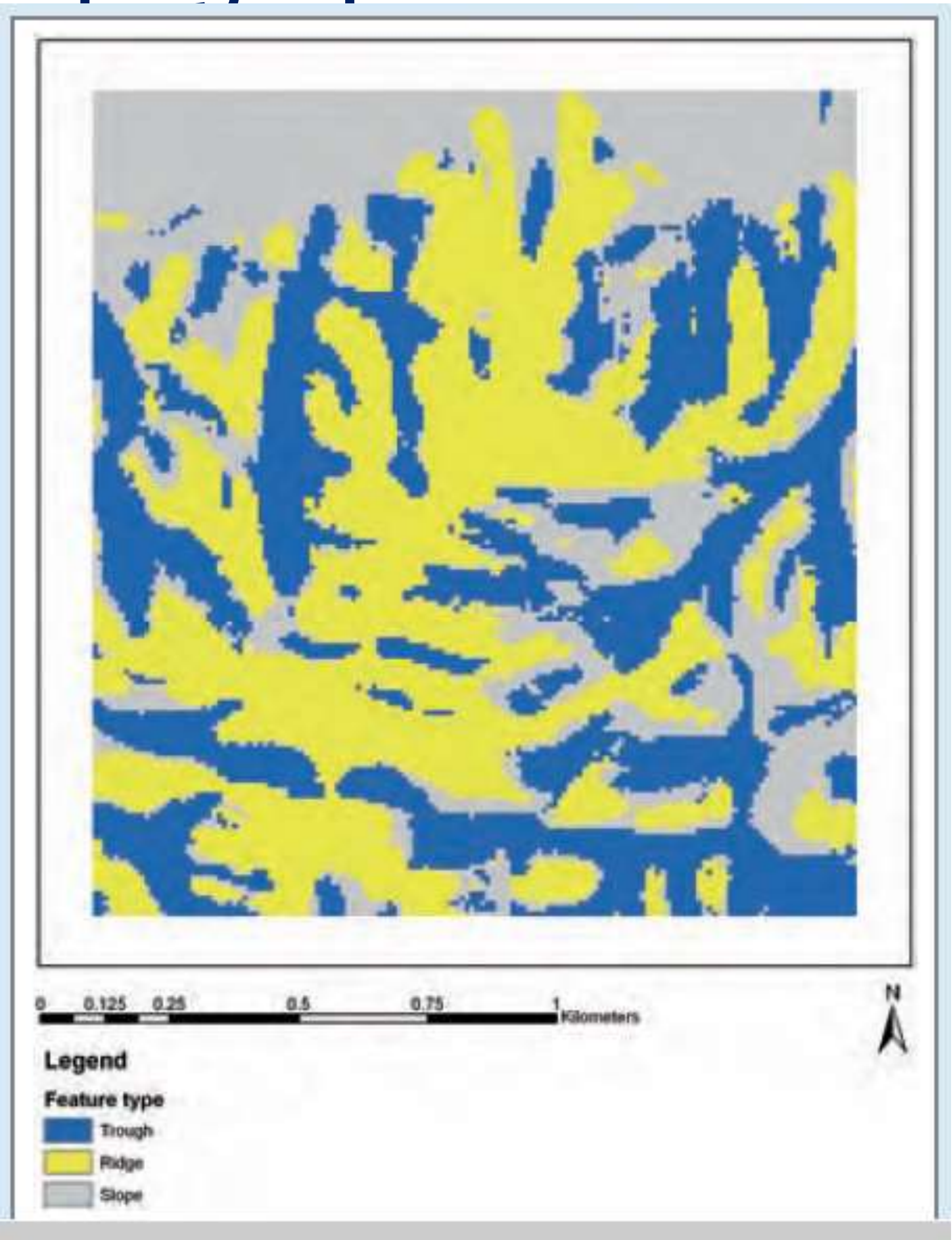


Topographic features



Errors in source data for GIS

- **All sources of spatial** and attribute data are likely to include errors.

Errors in source data for GIS

- Cartographic data sources error are:
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  - FUZZY BOUNDARIES
  - MAP SCALE
  - MAP MEASUREMENTS

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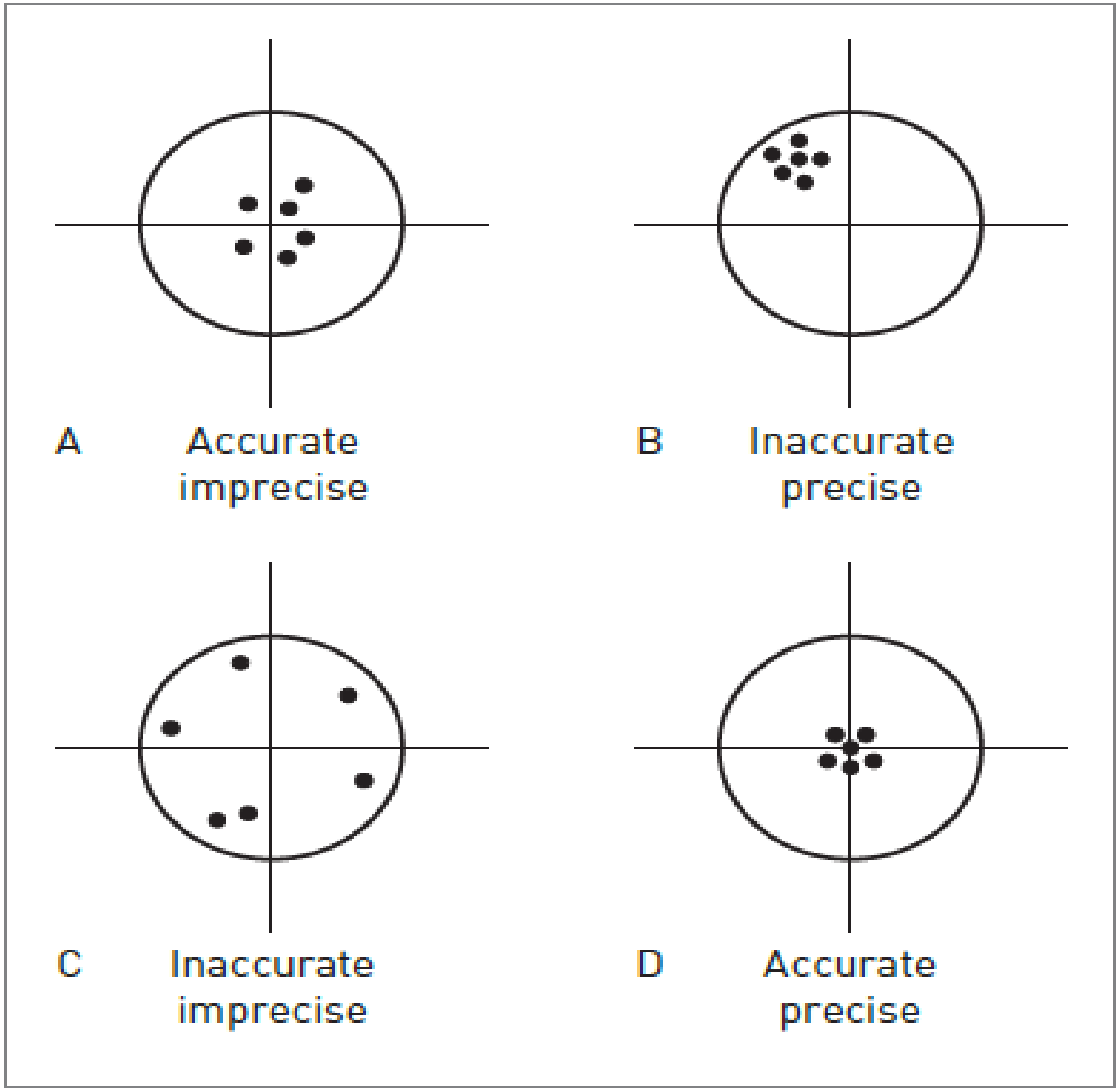

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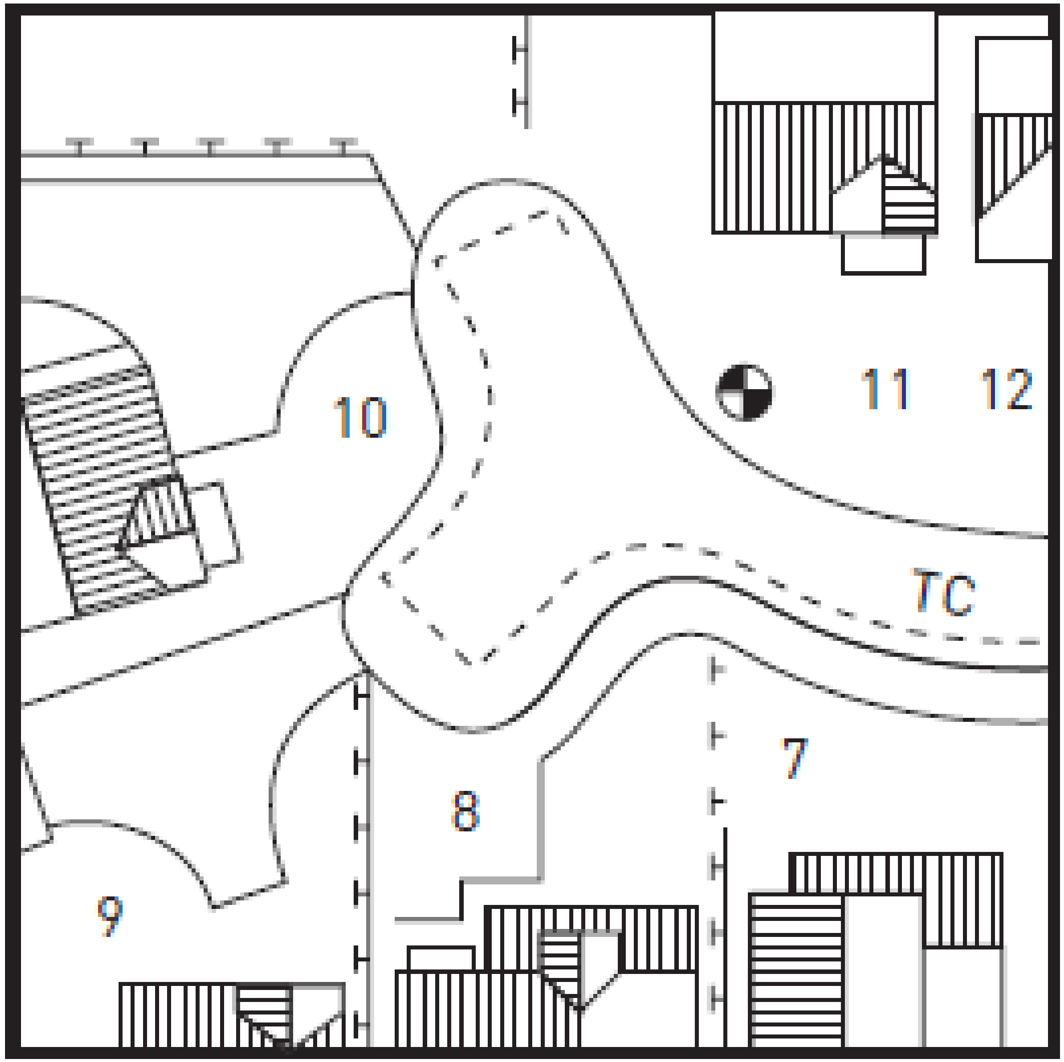
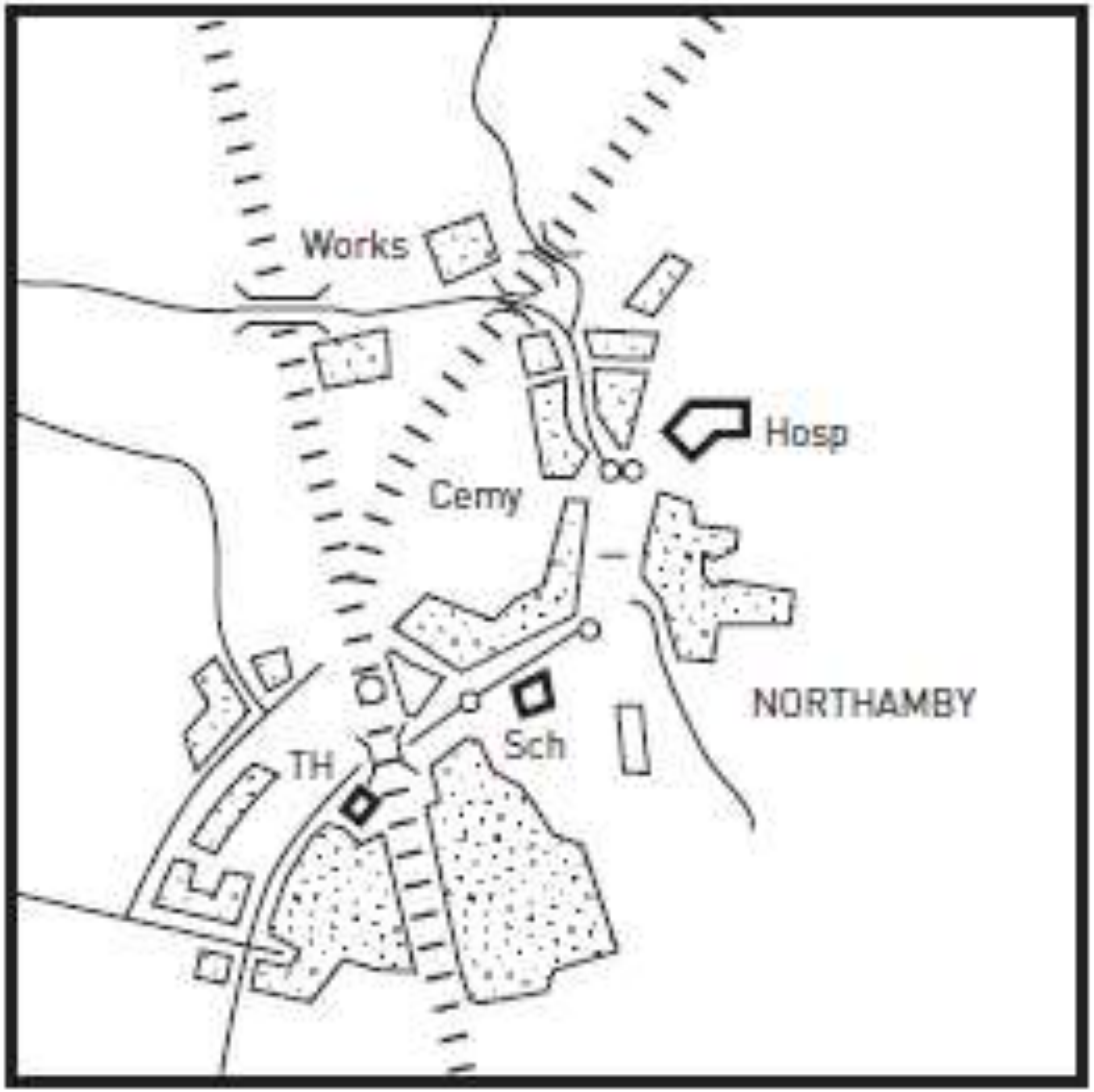


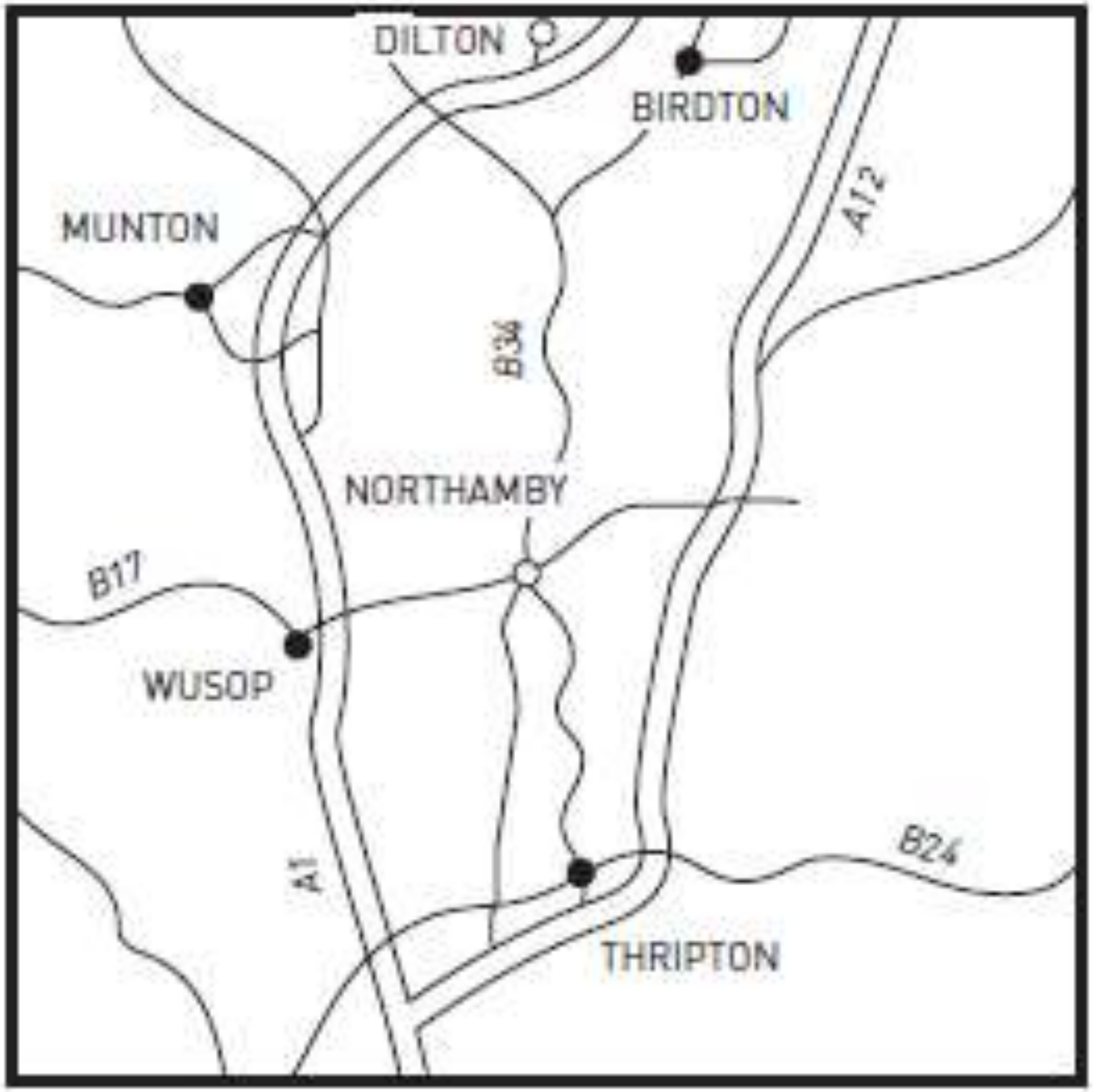
1:10,000

Scale-related generalization



1:50,000

Scale-related generalization



1:500,000

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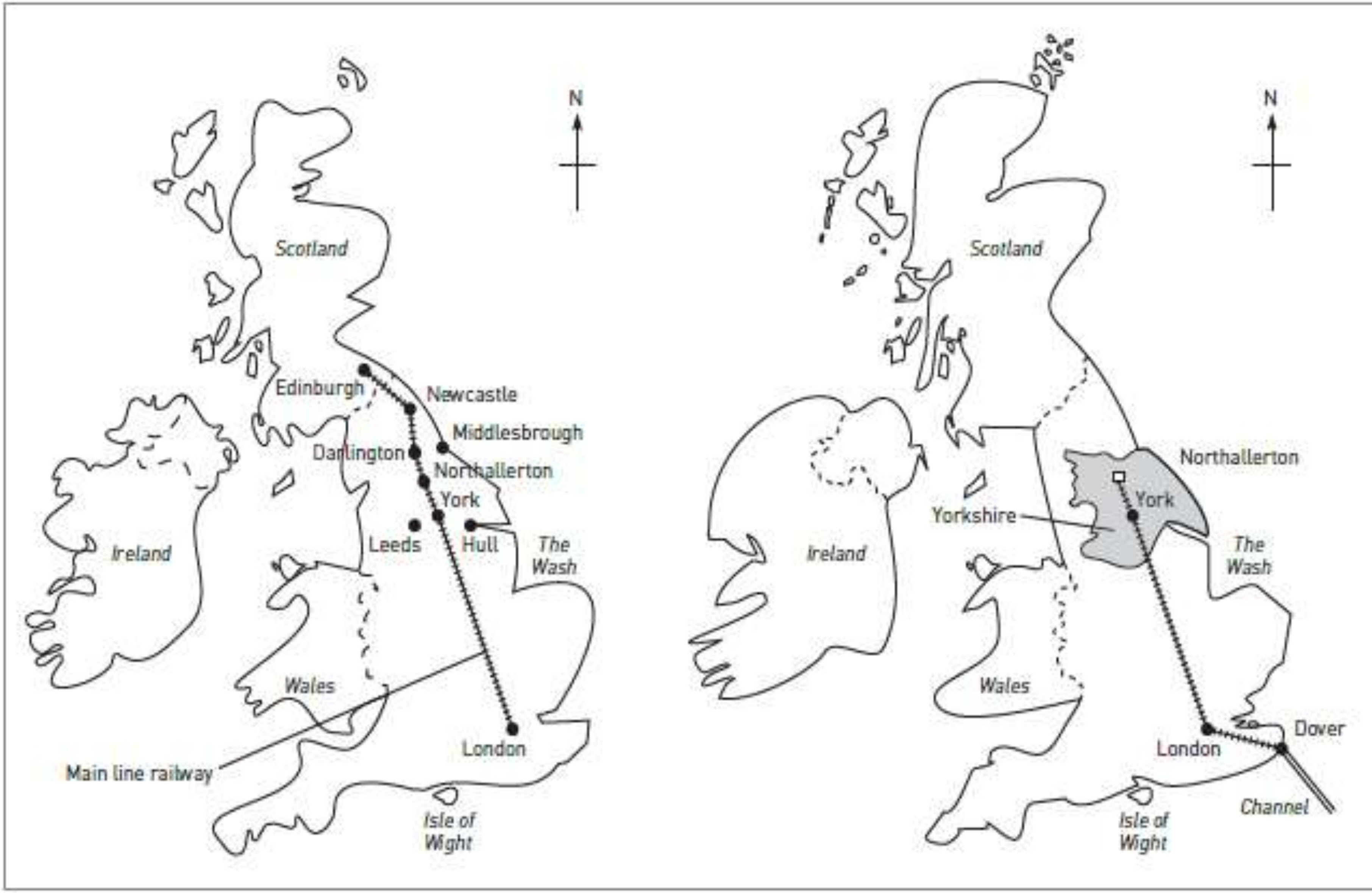
N
Scotland
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Wales
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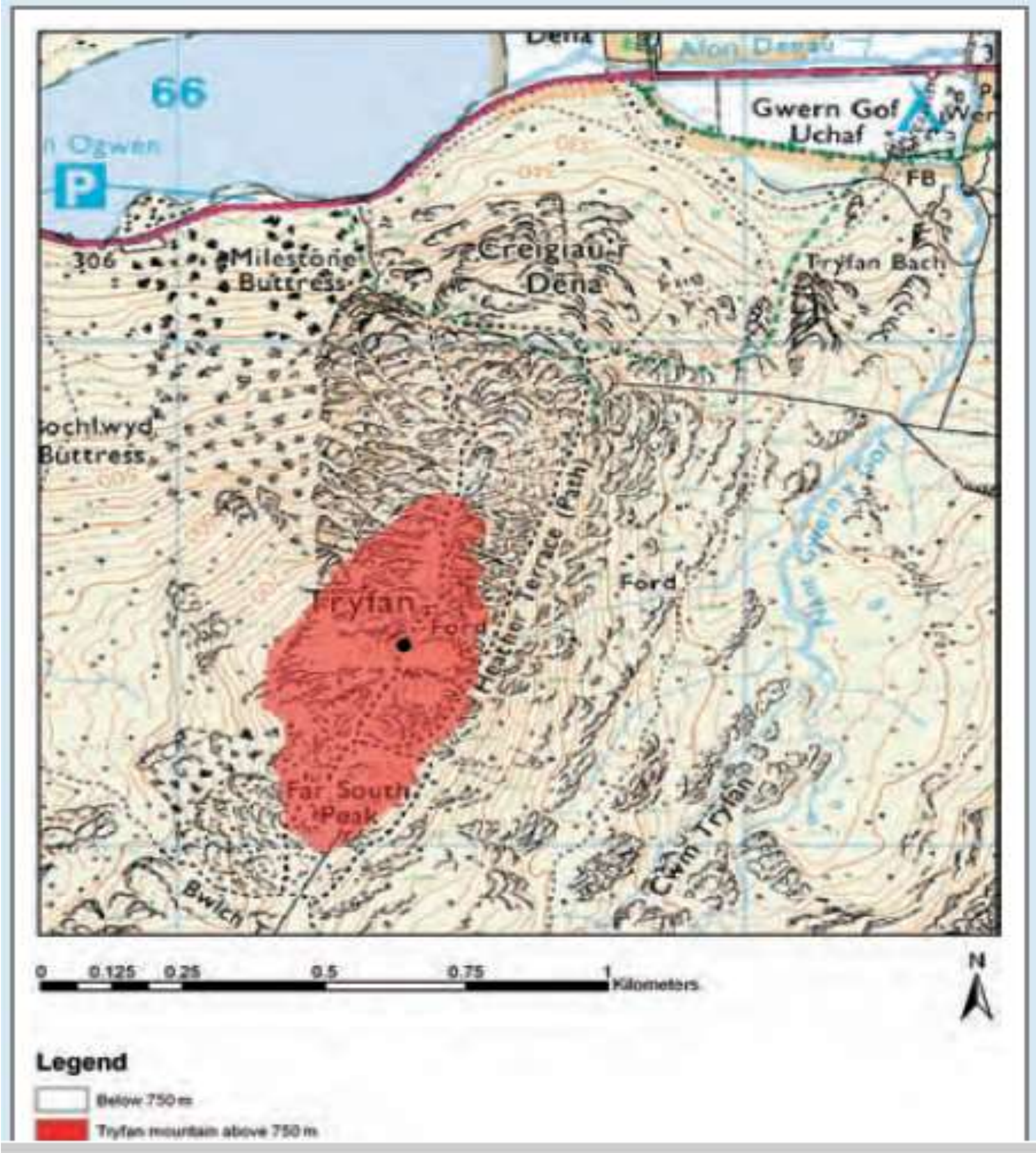

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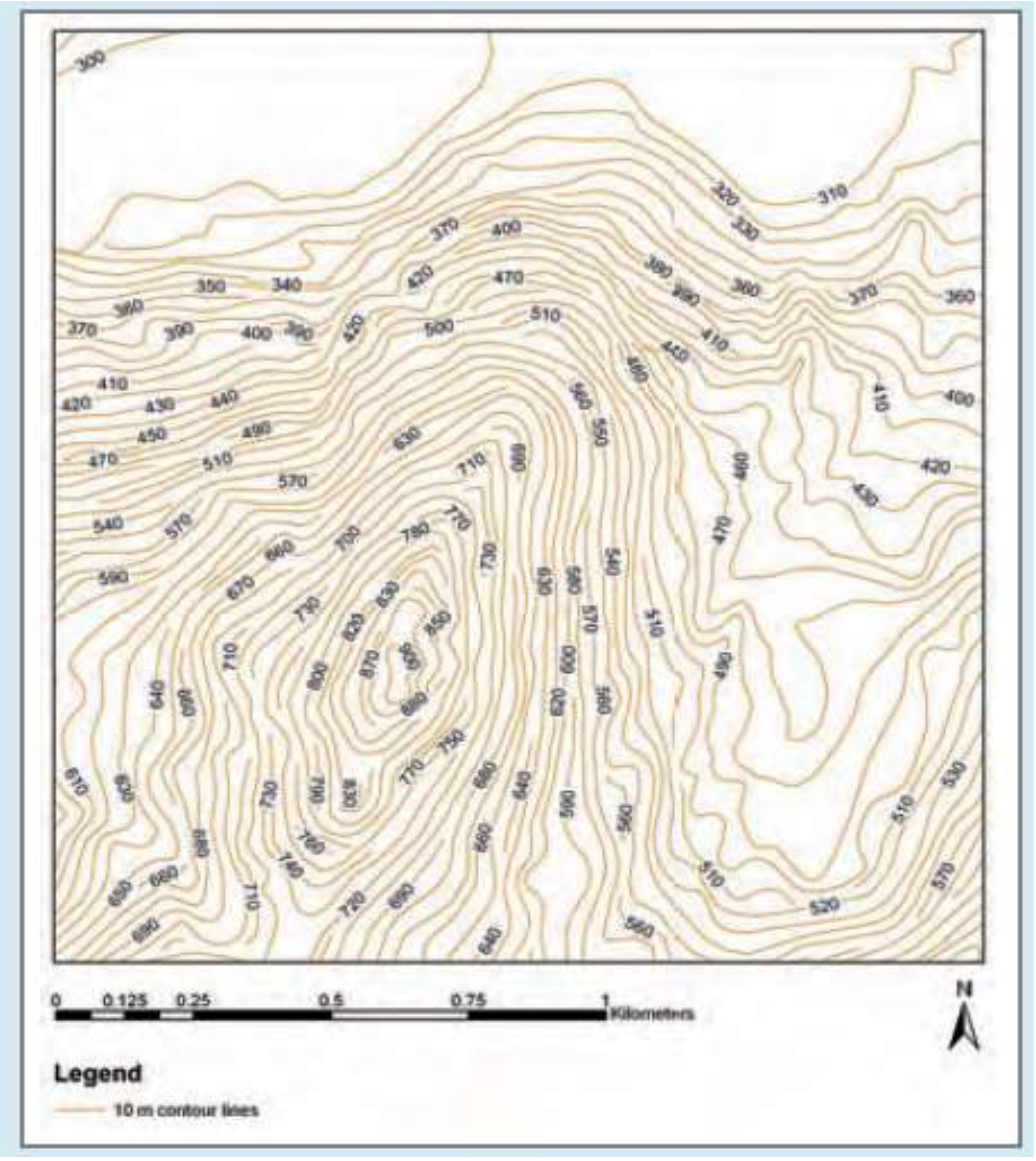

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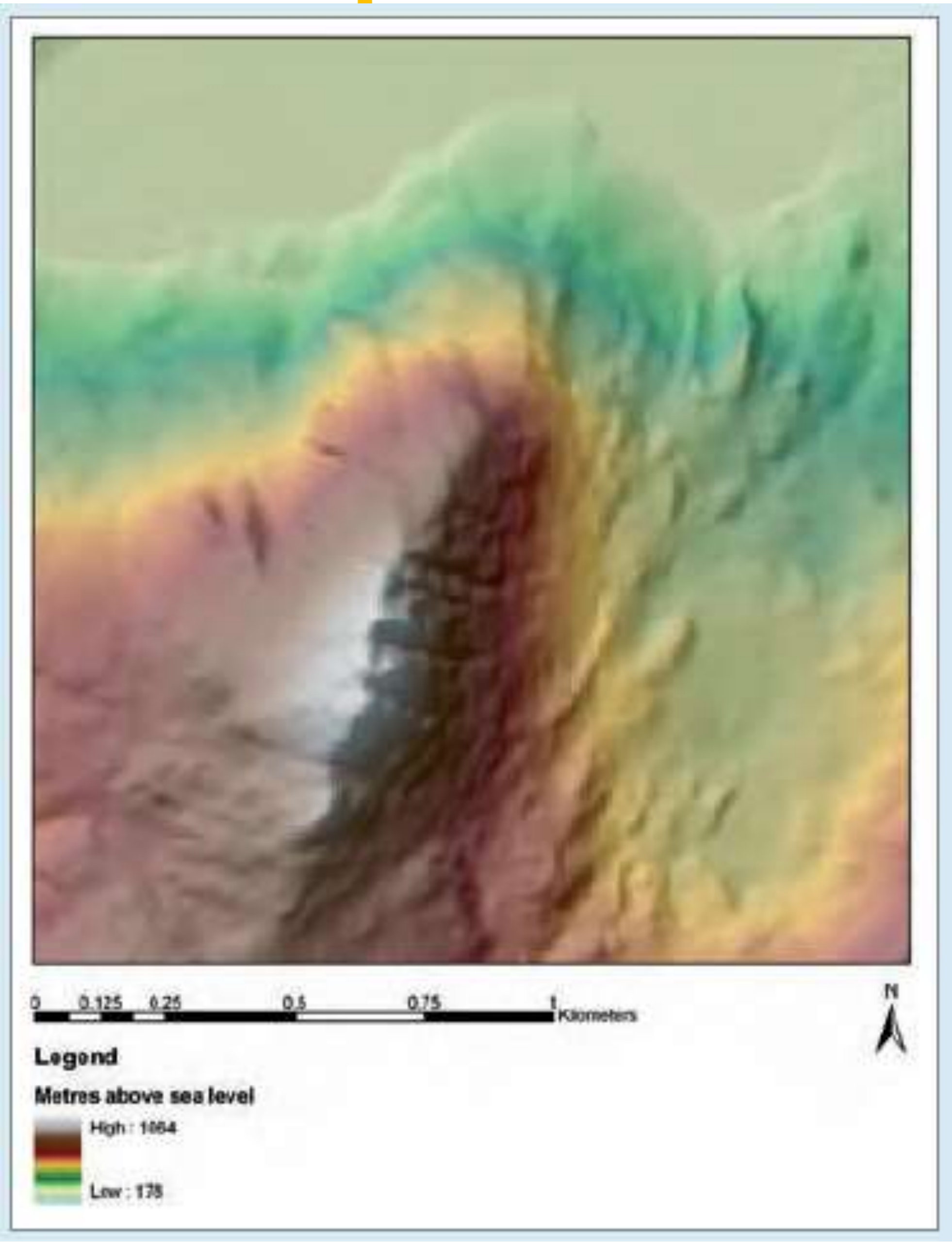

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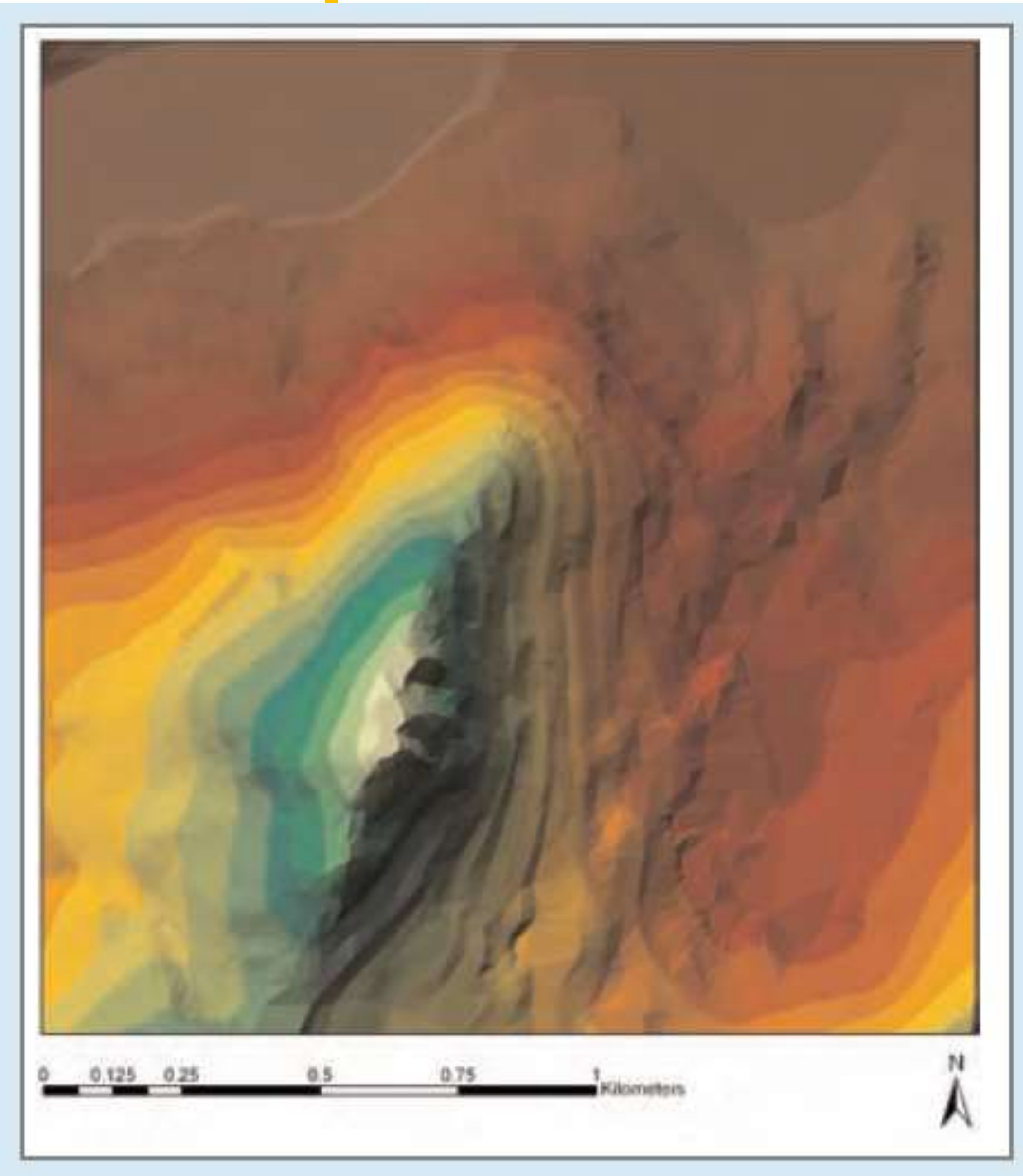

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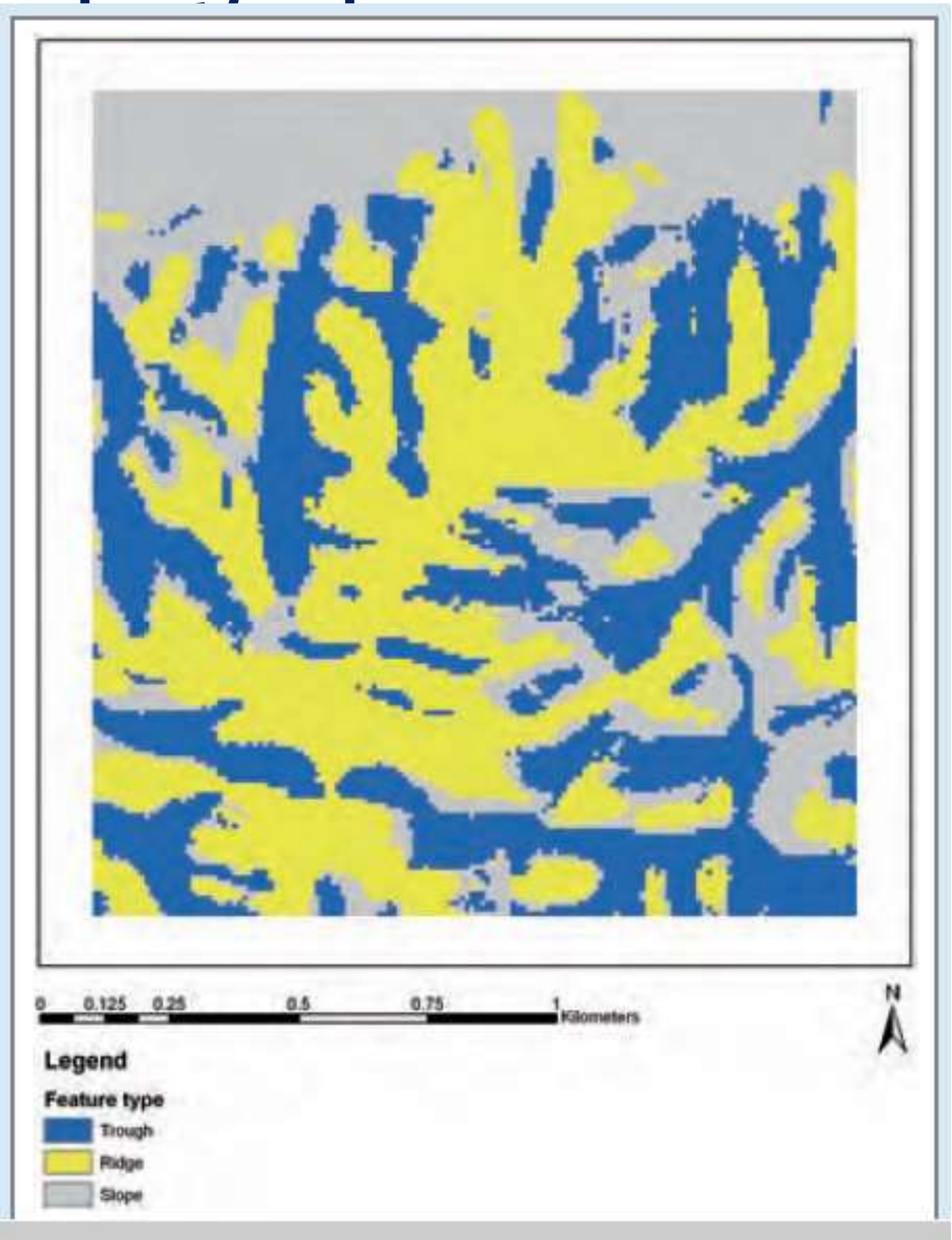

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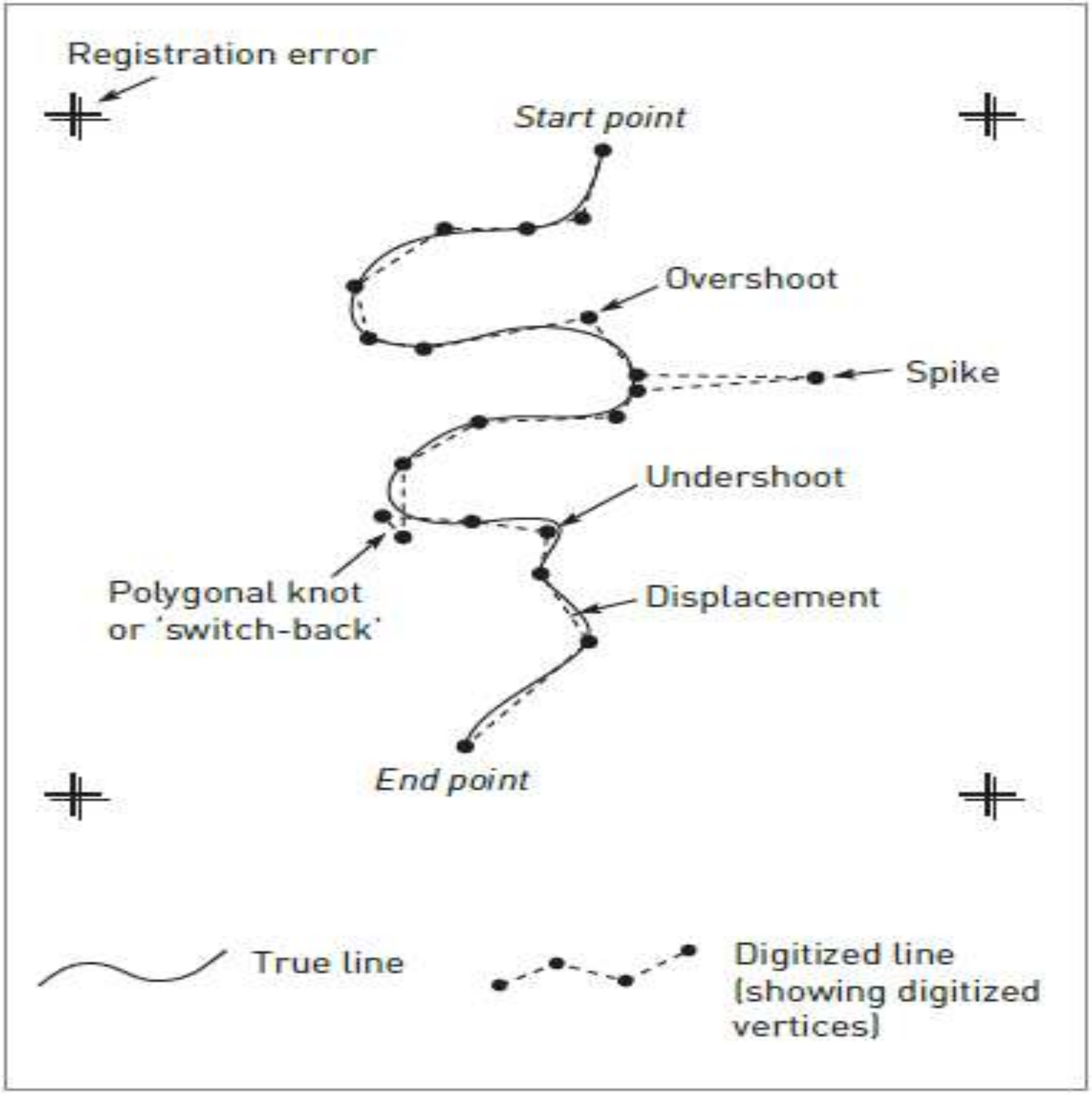
Errors in data encoding

- Data encoding is the process by which data are transferred from some non-GIS source.

Errors in data encoding

- Two main types:
- source map error and
- operational error.
- Categorizes human digitizing error into two types:
  - **psychological and**
  - **physiological.**

Operational errors



Operational errors

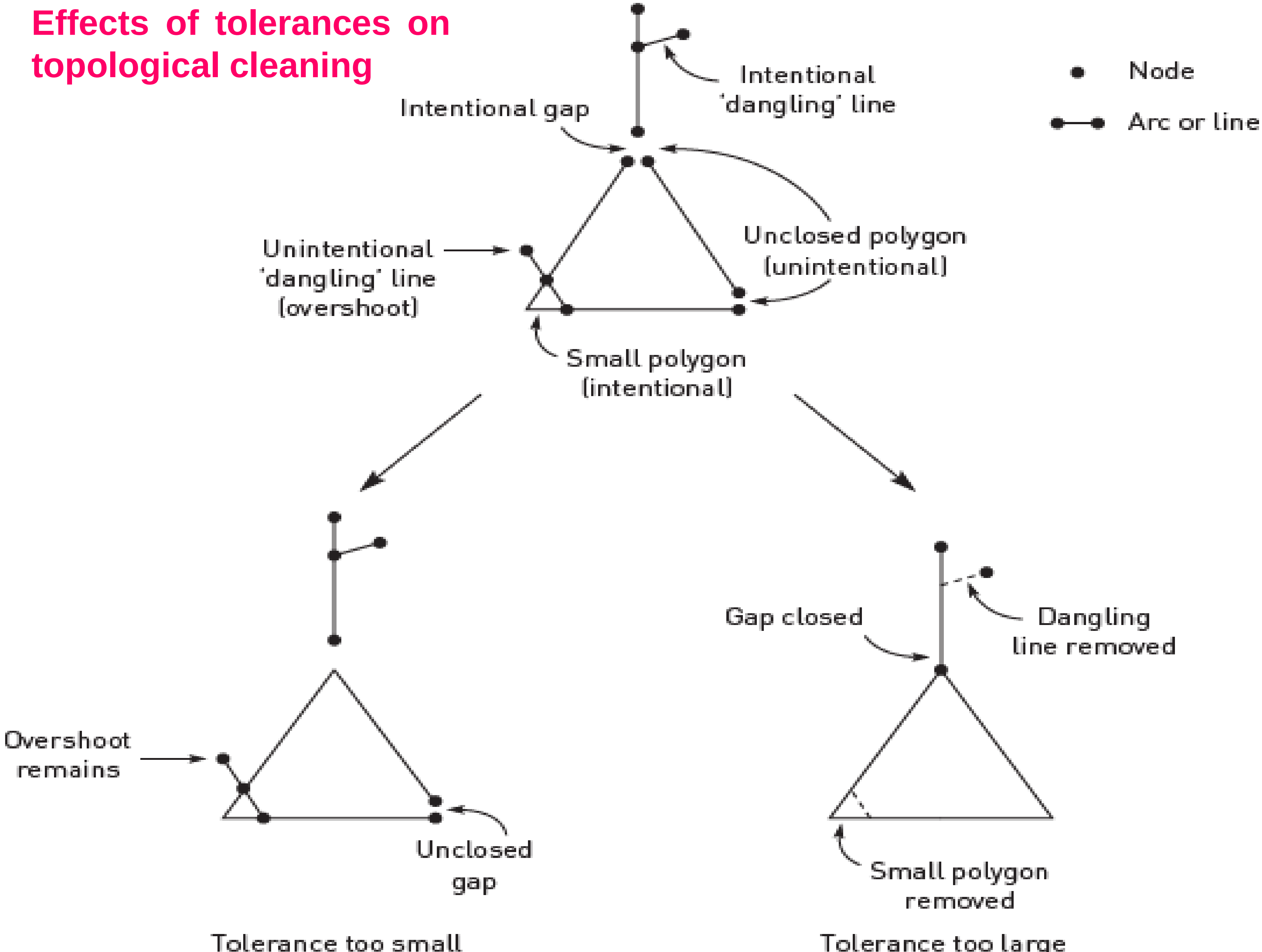
- 3 *Line thickness.*
- 4 *Method of digitizing. Two methods* :
  - point mode and
  - stream mode.

Errors in data editing and conversion

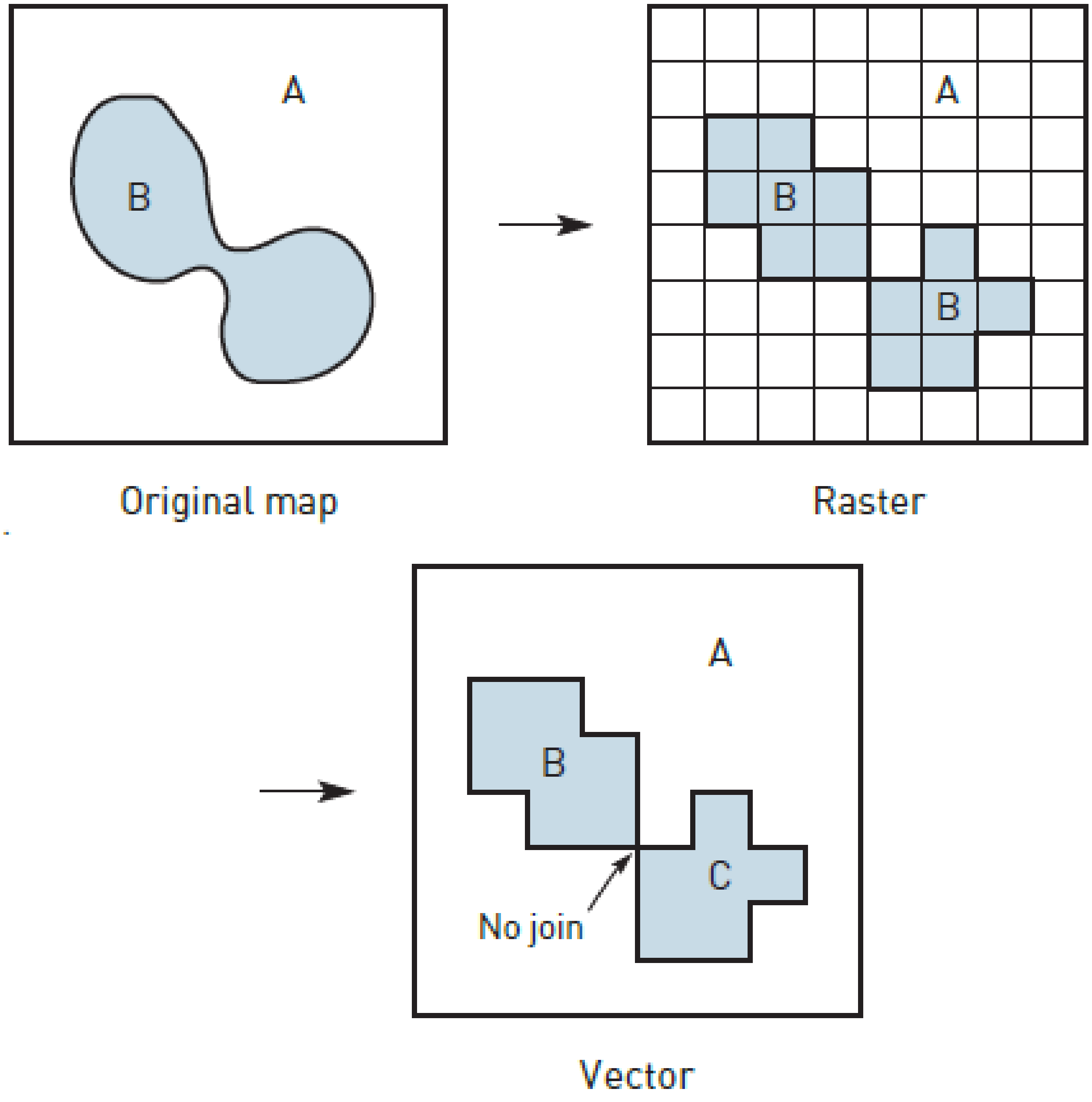
- After data encoding is complete, cleaning and editing.

Topological errors in vector GIS

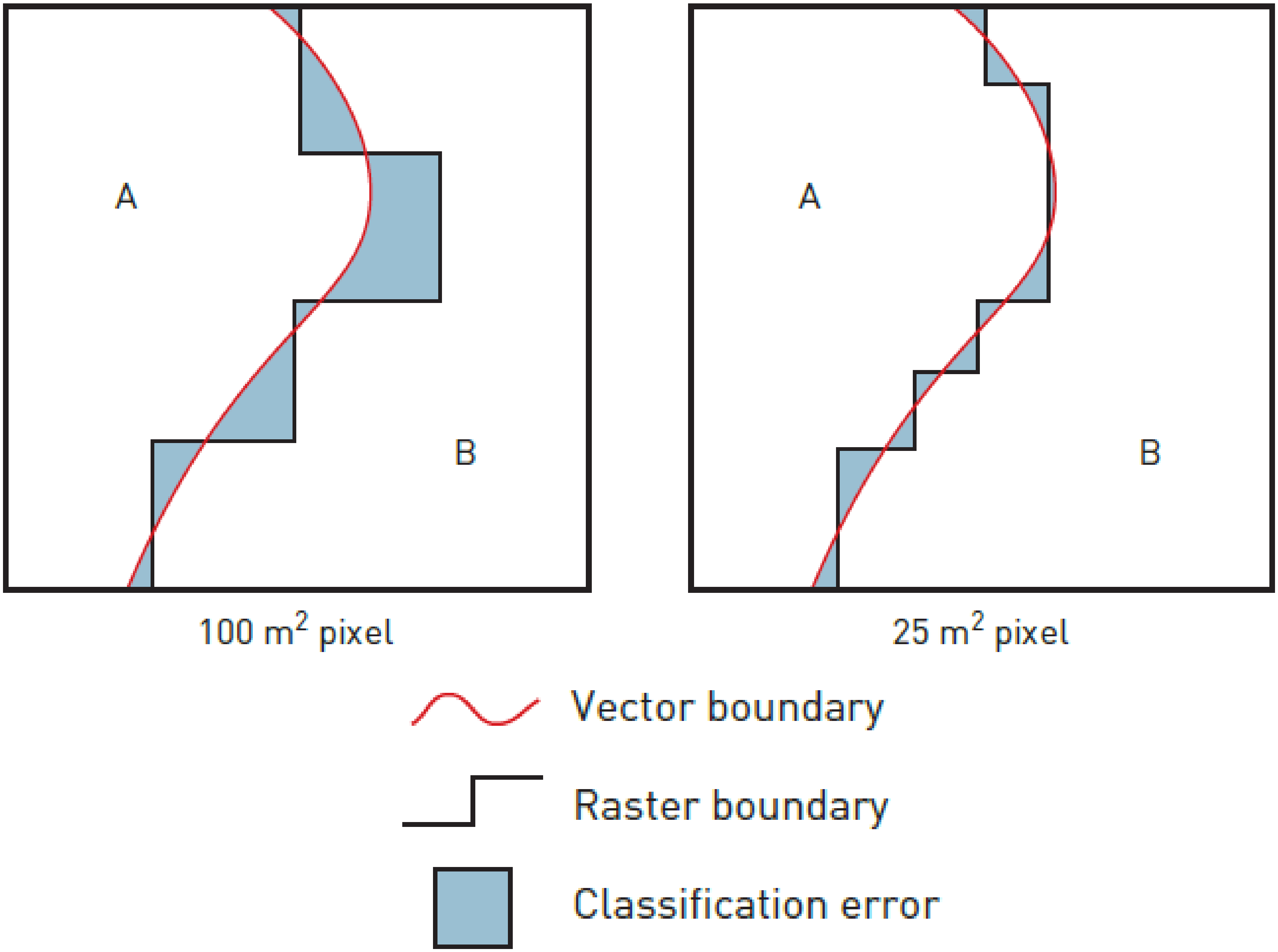
Effects of tolerances on topological cleaning



Topological ambiguities in raster to vector conversion



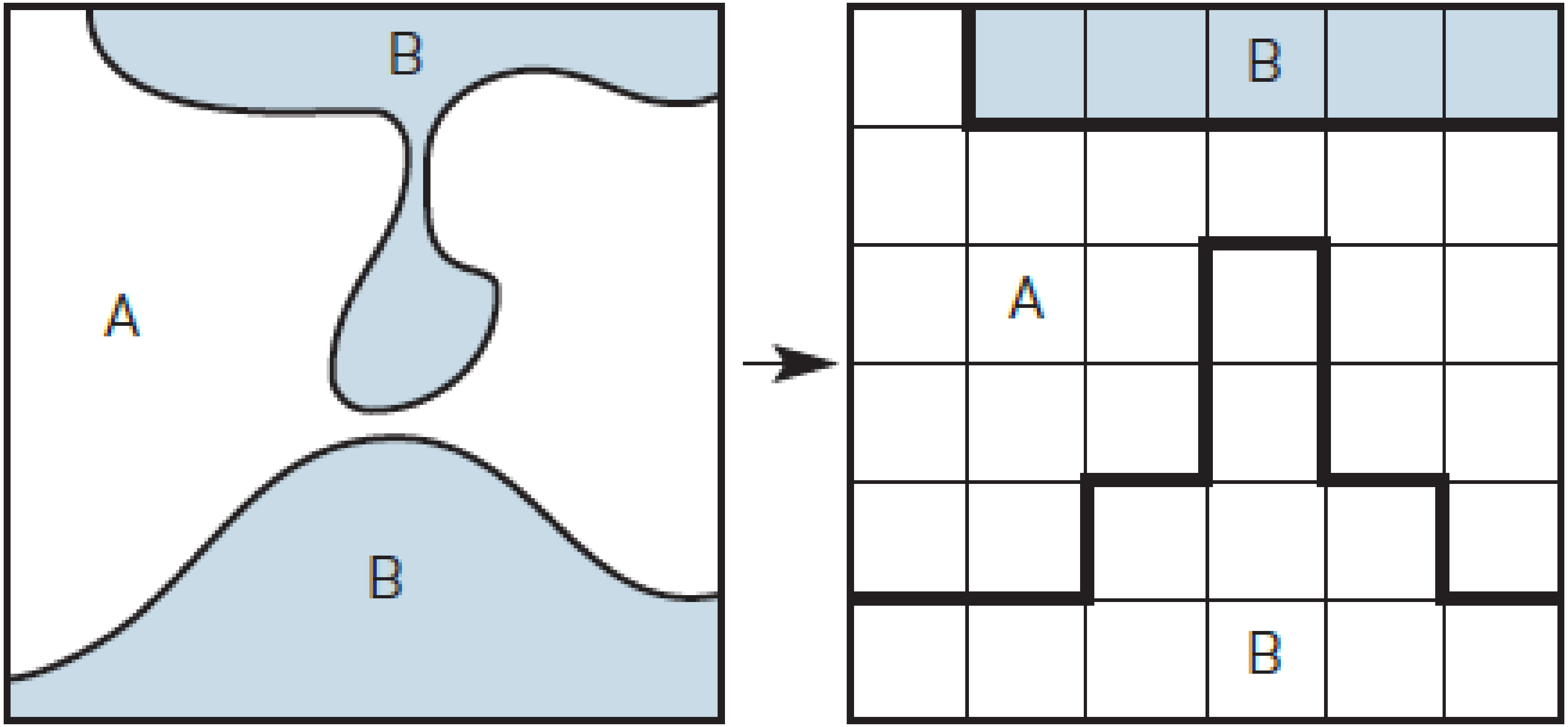
Vector to raster classification error



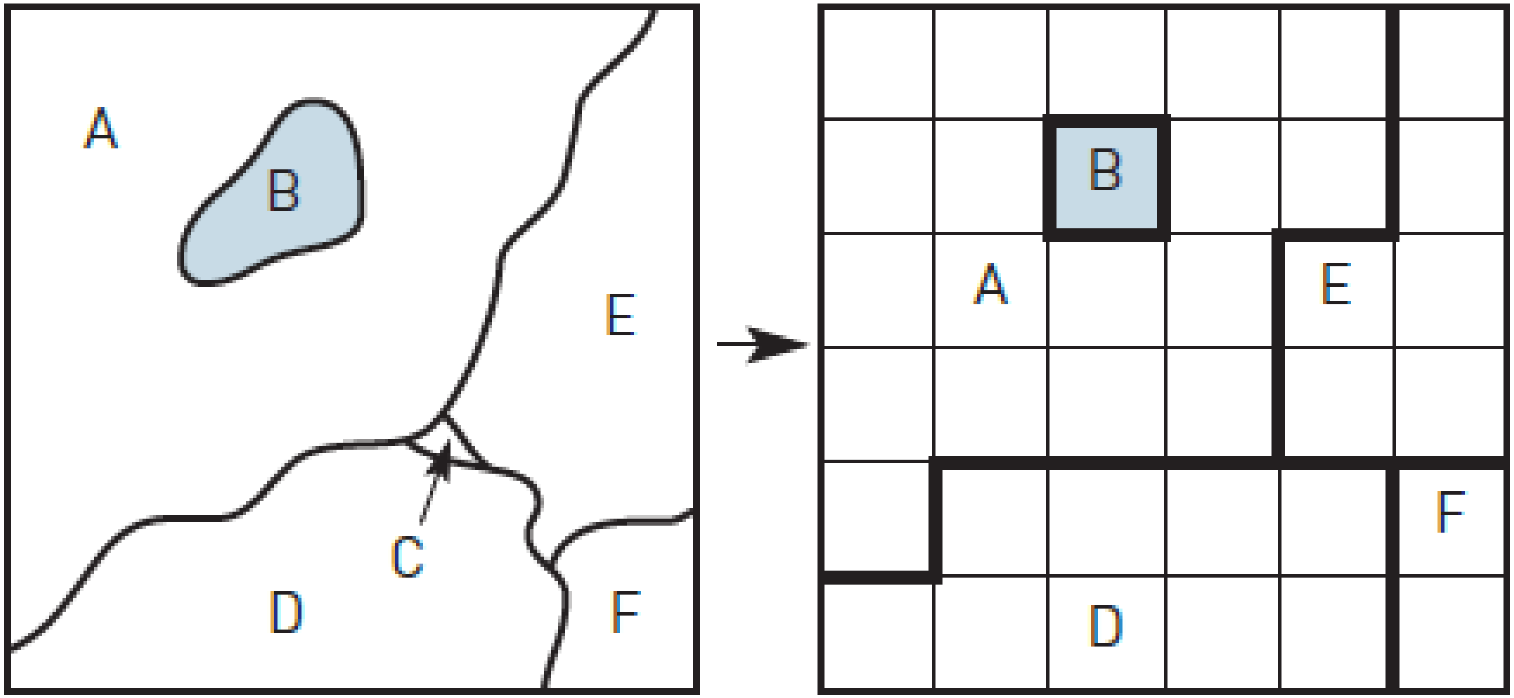
Rasterization errors

- Vector to raster conversion.
- For example:
- 1 *Topological errors.*
- *2 Loss of small polygons.*
- 3 *Effects of grid orientation.*
- 4 *Variations in grid origin and datum.*

Loss of connectivity and creation of false connectivity



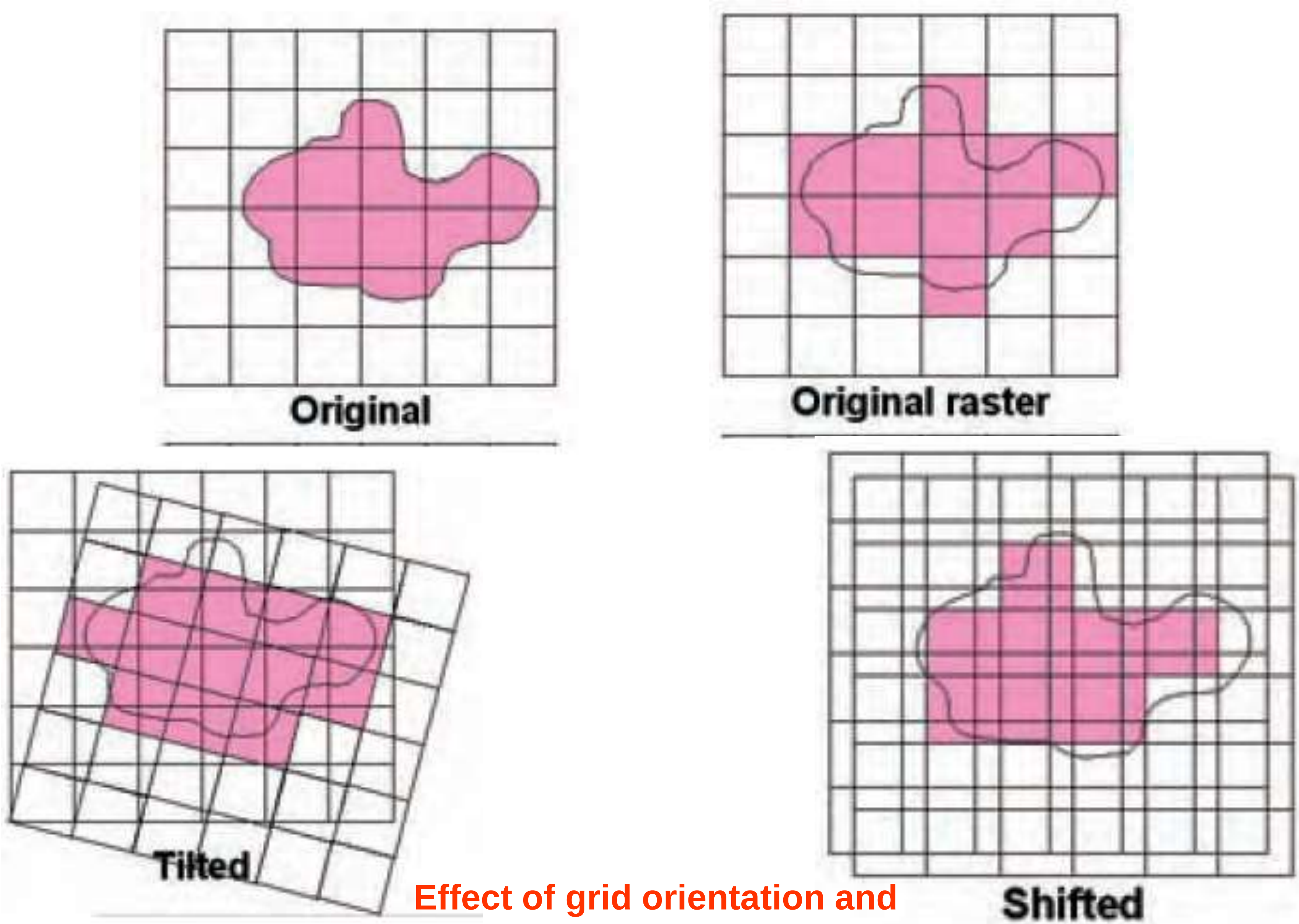
Loss of Information



(b)

What happened to 'C'?

Effect of grid orientation



Effect of grid orientation and origin on rasterization

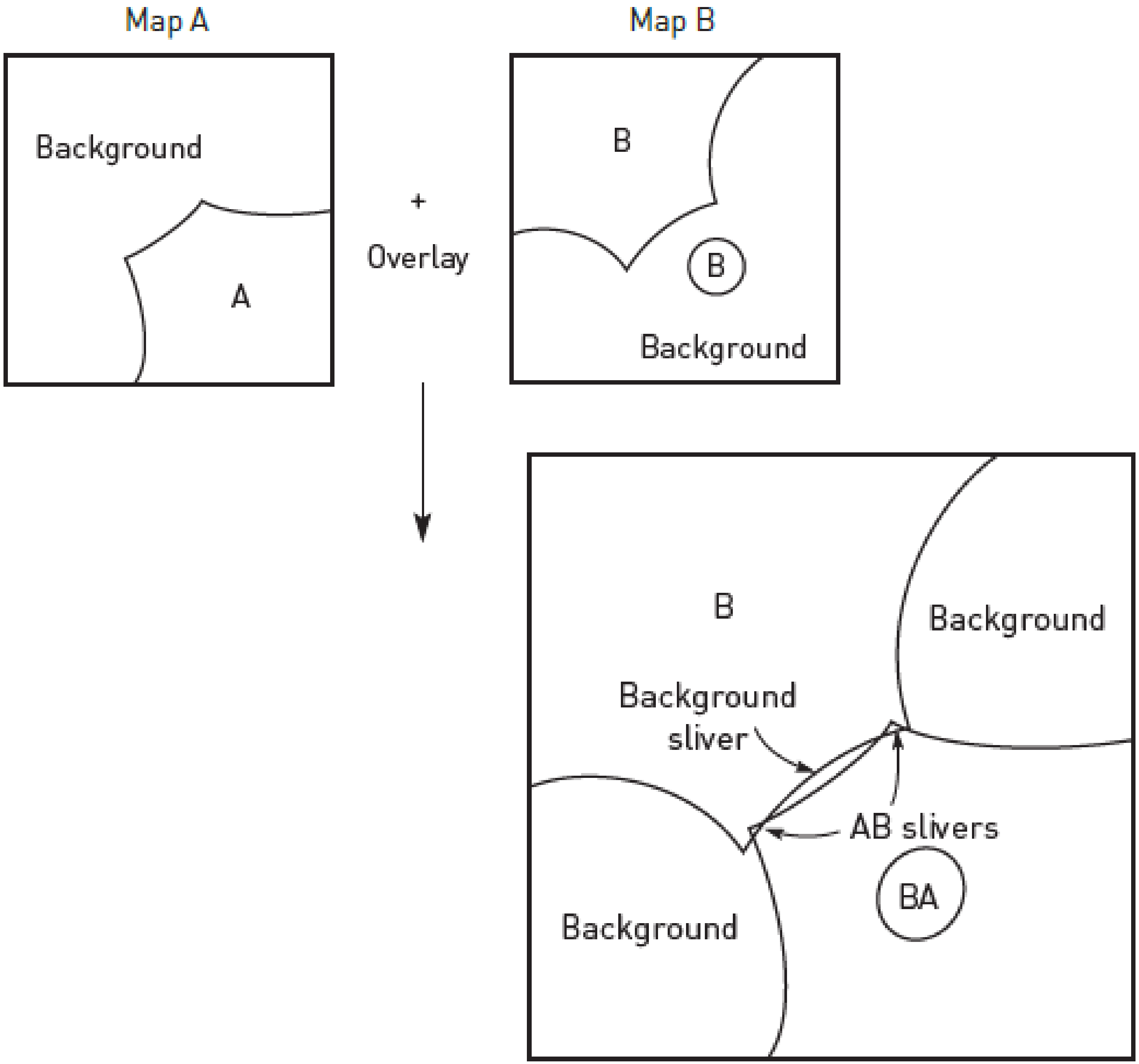
Errors in data processing and analysis

- Errors may be introduced during the manipulation and analysis of the GIS database.
- For example: Are the data suitable for this analysis? Are they in a suitable format? Are the data sets compatible?
- Are the data relevant? Will the output mean anything? Is the proposed technique appropriate to the desired output?

Errors in data processing and analysis

- Classification errors also affect raster data.
- Classified satellite images provide a reflectance value
- Raster maps of environmental variables, present the reflectance values.

Generation of sliver polygons



Composite (A + B) with sliver polygons