THE UNIVERSITY OF MELBOURNE

GEOM90007

SPATIAL VISUALISATION

Week 6:

CARTOGRAPHY 2: MULTIVARIATE

REVISION (Lecture 5)

Cartography 1:

- Cartography process diagram
- Basic communication model – noisy channels
- Sensing; perception; cognition – mental image
- Generalisation
  - Abstraction
    - Operators
  - Representation
    - Spatial dimensions, data types
    - Visual variables for cartography, visualising uncertainty
- Map types
  - Topographic
  - Thematic
  - Schematic

TODAY (Lecture 6)

Cartography 2:

- Creating a thematic map
  - Data modelling/selection
    - Classification
      - Techniques (theory)
  - Revision: (1) Scale (aggregation) problem, (2) MAUP and (3) Gestalt principles

- Cartographic design process
  - Elements, hierarchies,
  - Design principles in cartography, e.g., Gestalt
  - Cartographer's communication process (links back to model)

CLARIFYING CONCEPTS

Phenomenon:
A real-world physical object or process

Property:
A quality of a phenomenon

Feature:
An abstraction of a phenomenon

CLARIFYING CONCEPTS

Observation:
The act of observing a property*

*Note: The goal of an observation may be to measure (or otherwise determine) the value of a property

Measurement:
The operation (or set of operations) to determine the value of a property such as height, angle or colour

Data:
The results of observing a property

CLARIFYING CONCEPTS

Observation → Measurement

Formal description: Observations and Measurements

http://www.opengeospatial.org/standards/om

CLARIFYING CONCEPTS

Value can be **measured** using a variety of scales

Four **levels of measurement** scale identified by Stevens (1946)*

Scale	Properties	Description	Operators	Examples	Statistical analyses
Nominal	Categorisation	Unknown increments between categories	$=, \neq$	Male, Female	Mode Chi Square
Ordinal	Categorisation + Ordering	Known increments between categories (equal or unequal)	$=, \neq, <, >$	High, medium, low	Median Percentiles
Interval	Ordering + Explicit intervals	Equal intervals with an arbitrary zero point	$=, \neq, <, >,$ $+, -$	Celsius or Fahrenheit	Mean Standard deviation
Ratio	Ordering + Explicit intervals	Equal intervals with a non-arbitrary zero point	$=, \neq, <, >,$ $+, -, \times, \div$	Kelvin Weight Length	Coefficient of variation

CLARIFYING CONCEPTS

Data is the result of observing phenomena

Beware domain specific types

Data type	Corresponding Level of Measurement	Visualisation
Qualitative	Nominal	Geometry or visual variable indicates membership in a non-numeric class
*	Ordinal	Geometry or visual variable must be capable of being visually ordered (e.g., a sequence using lightness)
Quantitative	Interval Ratio	Geometry or visual variable relationships must express a relationship

Value message

*Categories may be encoded differently depending on the application, therefore data may be qualitative or quantitative.
In cartography ordinal data is typically quantitative.

CLARIFYING CONCEPTS

Content Scaling Level	Defining Relations	FORM OF CARTOGRAPHIC SYMBOL		
		POINT	LINE	AREA
Nominal	Equivalence	Wholesale and Retail Establishments	Highway Connectivity	Land Ownership
Ordinal	Equivalence Greater than	Small Medium Large Population Centers	Roads by Degree of Improvement	Yield
Interval	Equivalence Greater Than Ratio of Intervals	45 89 72 60 42 Spot Elevations	Latitude/ Longitude Grid	1845 1820 1862 Date of First Settlement
Ratio	Equivalence Greater Than Ratio of Intervals Ratio of Scale Values	Area Proportional to Population	20 20 10 Population Density Isopleths	Darkness Proportional to Population Density

Image: Clarke (1995), redrawn from Robinson and Sale (1969)

CLARIFYING CONCEPTS

DATA TYPES

	Point	Line	Area	Volume
Nominal	City	Road	Name of Unit	Precipitation or soil type
Ordinal	Large City	Major Road	Rich County	Heavy precip. Good soil
Interval / Ratio	Total Population	Traffic Flow	Per Capita Income	Precip. in mm or Cation Exchange

MAP TYPES

	Point	Line	Area	Volume
Nominal	Dot Map	Network Map	Colored Area Map	Freely Colored Map
Ordinal	Symbol Map	Ordered Network Map	Ordered Colored Map	Ordered Chromatic Map
Interval / Ratio	Graduated Symbol Map	Flow Map	Choropleth Map	Contour Map

Image: BOM (2016)

Table (image): Clarke (1995), based on Unwin (1981)

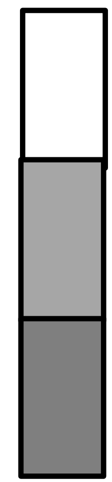
REVISITING STANDARDISATION

REVISITING STANDARDISATION

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

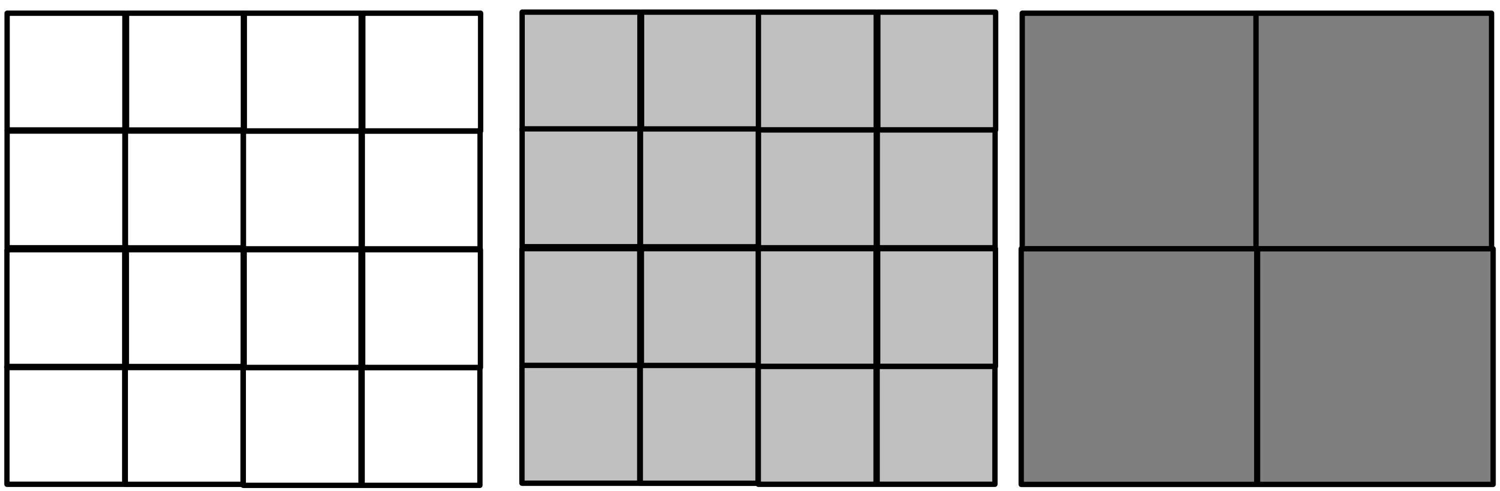
16	16	16	16
16	16	16	16
16	16	16	16
16	16	16	16

64	64
64	64



Homogenous wheat yield

1. Visualise raw totals of wheat only

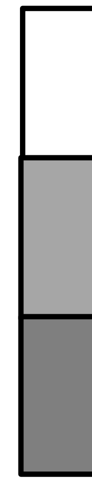


REVISITING STANDARDISATION

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

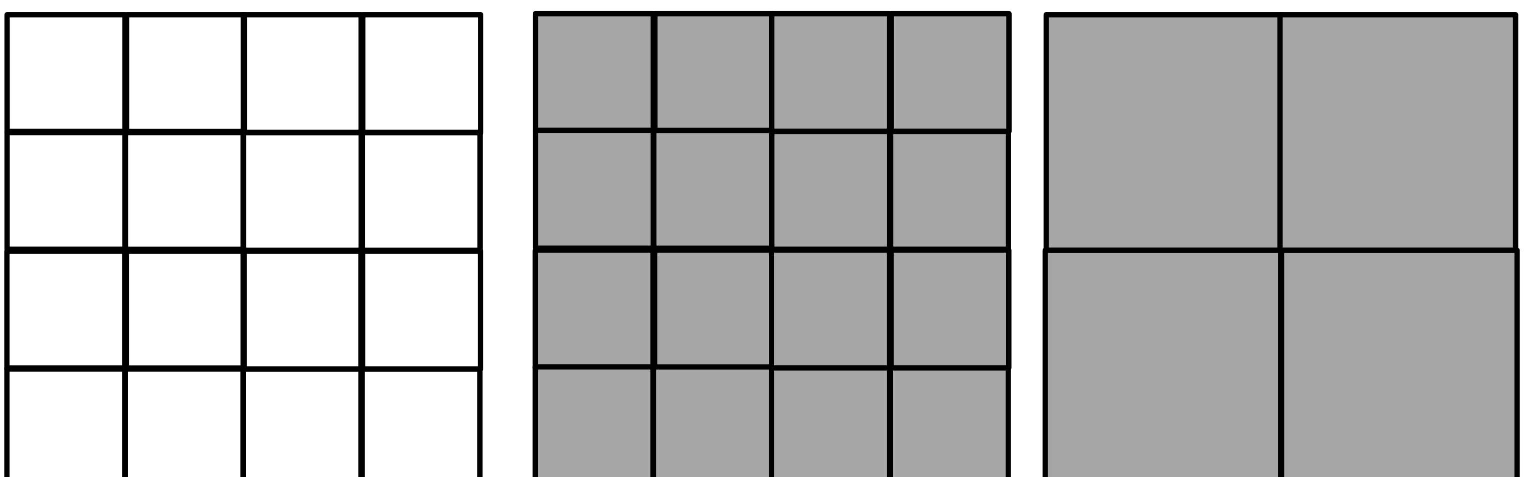
16/1	16/1	16/1	16/1
16/1	16/1	16/1	16/1
16/1	16/1	16/1	16/1
16/1	16/1	16/1	16/1

64/4	64/4
64/4	64/4



Standardise by adjusting for the size of the enumeration unit (hectares)

2. Visualise the proportion (percentage) of wheat yield



UNDERSTAND STANDARDISATION – Important

Understanding the size and shape of enumeration units is key to creating a statistical map!

A choropleth map is ideal if phenomena are...

But how about population densities: ACT vs. Western Australia?

- Uniform vs non-uniform distributions
- Larger state may have larger visual impact (potentially more colour) – but may have the largest error of representation*

UNDERSTAND STANDARDISATION

1. Proportion

$$\frac{total\ (areal)}{total\ (areal)}$$ **e.g.** $$\frac{64\ hectares\ yield}{64\ hectares\ land}$$

2. Density

$$\frac{counts\ (not\ areal)}{total\ (areal)}$$ **e.g.** $$\frac{19\ tonnes\ of\ wheat}{64\ hectares\ land}$$

3. Rate

$$\frac{counts\ (not\ areal)}{maximum(not\ areal)}$$

e.g. Cancer deaths $$\frac{Cancer\ deaths\ in\ state}{Population\ of\ state} = \frac{Number\ of\ cancer\ deaths}{100{,}000}$$

4. Summary statistics for each numeration unit

e.g. *standard deviation, etc.*

CARTOGRAPHY 2: Towards multivariate mapping

1. Univariate mapping – displaying one attribute (or variable)

2. Bivariate mapping

3. Multivariate mapping

4. Cluster analysis for classification and visualisation

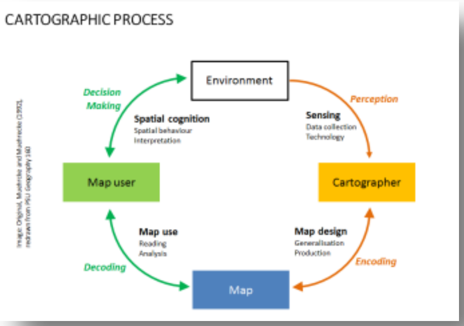
VISUALISATION PIPELINE: COMPLEX MAPPING

Data modelling and selection for mapping:

- Investigate summary statistics (variance/covariance)
- Examine distributions (e.g., normal or skewed)
- Observe patterns
- Determine message
- Consider whether to classify data (or not)

Graphic representations:

1. Univariate maps
2. Bivariate maps
3. Multivariate maps



1. TWO-UP COMPARISON (UNIVARIATE) EXAMPLE

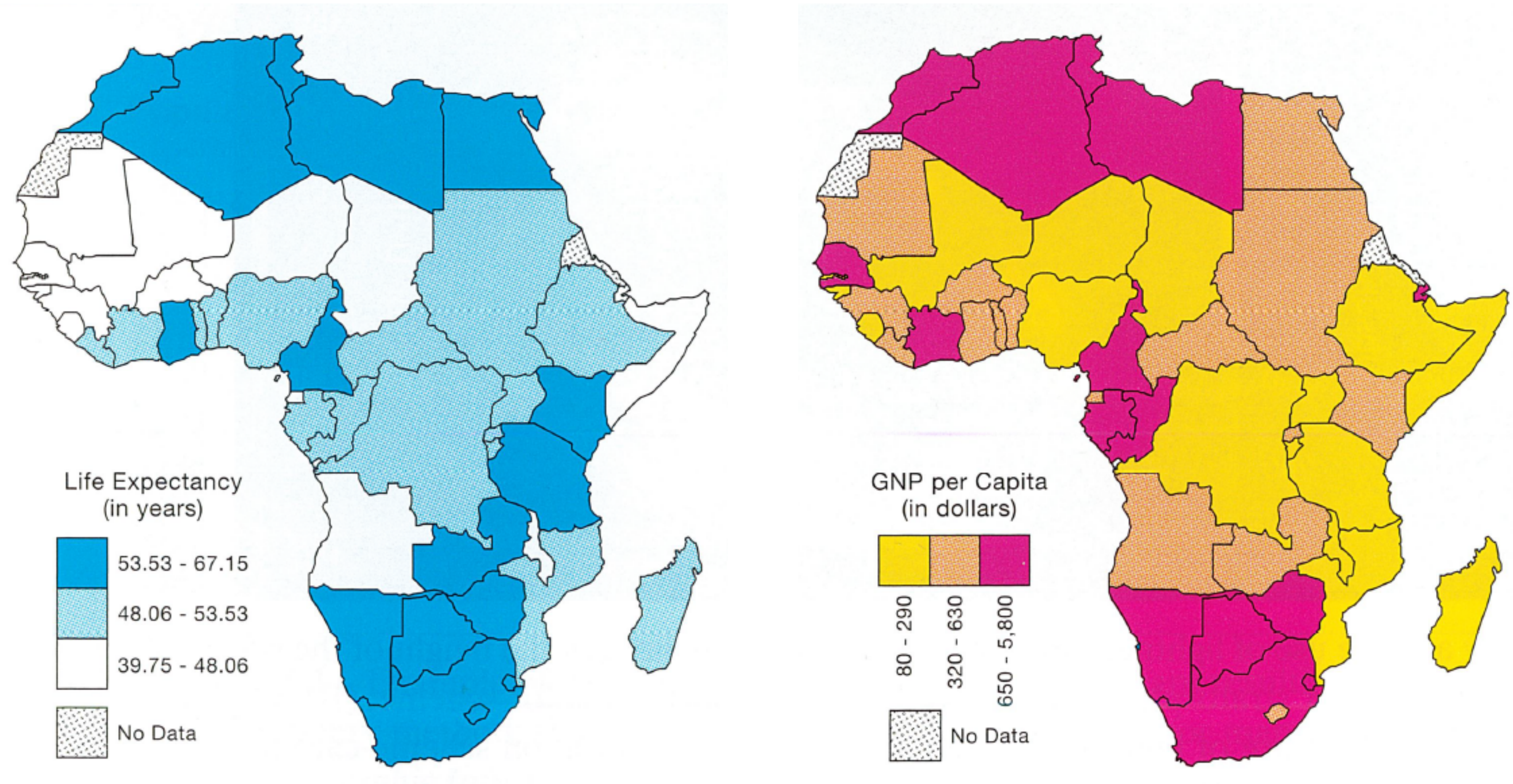


Image: Slocum et al. (2009)

TWO-UP COMPARISON (UNIVARIATE) EXAMPLE

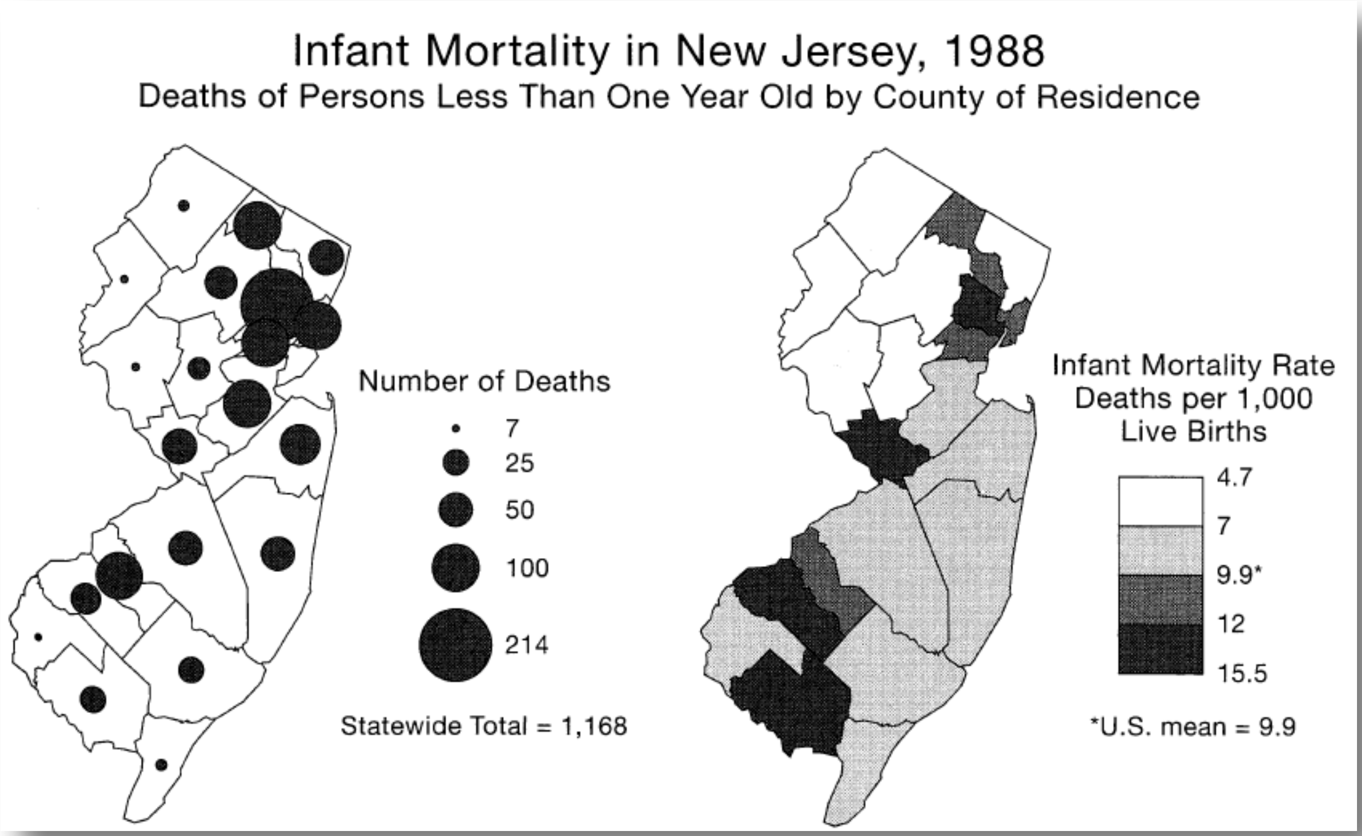


Image: Slocum et al. (2009), redrawn from Monmonier (1993)

Proportional symbols: Symbols vary by size in proportion to the data

-*Line* symbols are more accurate but less usable with large data ranges

-*Area* symbols (e.g. circles scaled using the square root of data vales) are more compact and easier to associate with location

Important: Draw smaller symbols over larger ones to aid map reading

Brewer (2006)

MAP SERIES (UNIVARIATE) EXAMPLE

To aid comparison, classification techniques must be the same using the same class breaks.
Techniques include: qantiles, equal areas or mean-std. deviation (both must be normal)

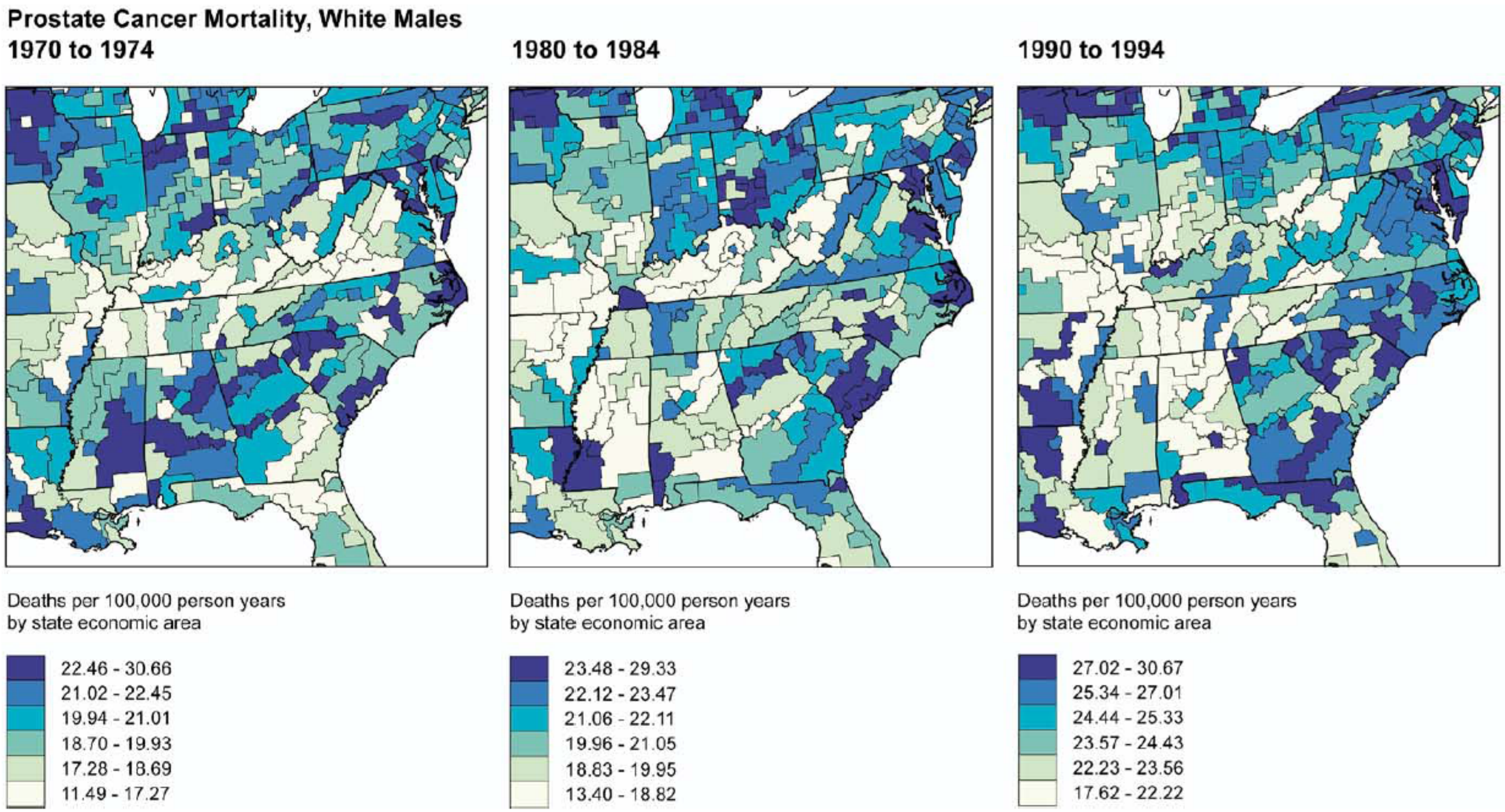


Image: Brewer (2006)

2. BIVARIATE MAPPING

Mapping that combines variables into one representation

Can make covariation visible

Category/category:
e.g., shape for one variable, colour hue for category

Quantity/category
e.g., size for the quantitative variable, colour hue for category

Quantity/quantity
e.g., size for one variable, lightness of the other

VARIABLE CONJUNCTIONS

A **conjunction** of two visual variables can be applied, combinations divided into two groups:
-Separable
-Integral

Why use conjunctions?

a) Strengthens the graphic encoding of one attribute
b) Represents multiple attributes in a bivariate or multivariate display

Refer geometry + visual variables examples introduced in Lecture 5

1. TWO-UP COMPARISON (UNIVARIATE) EXAMPLE

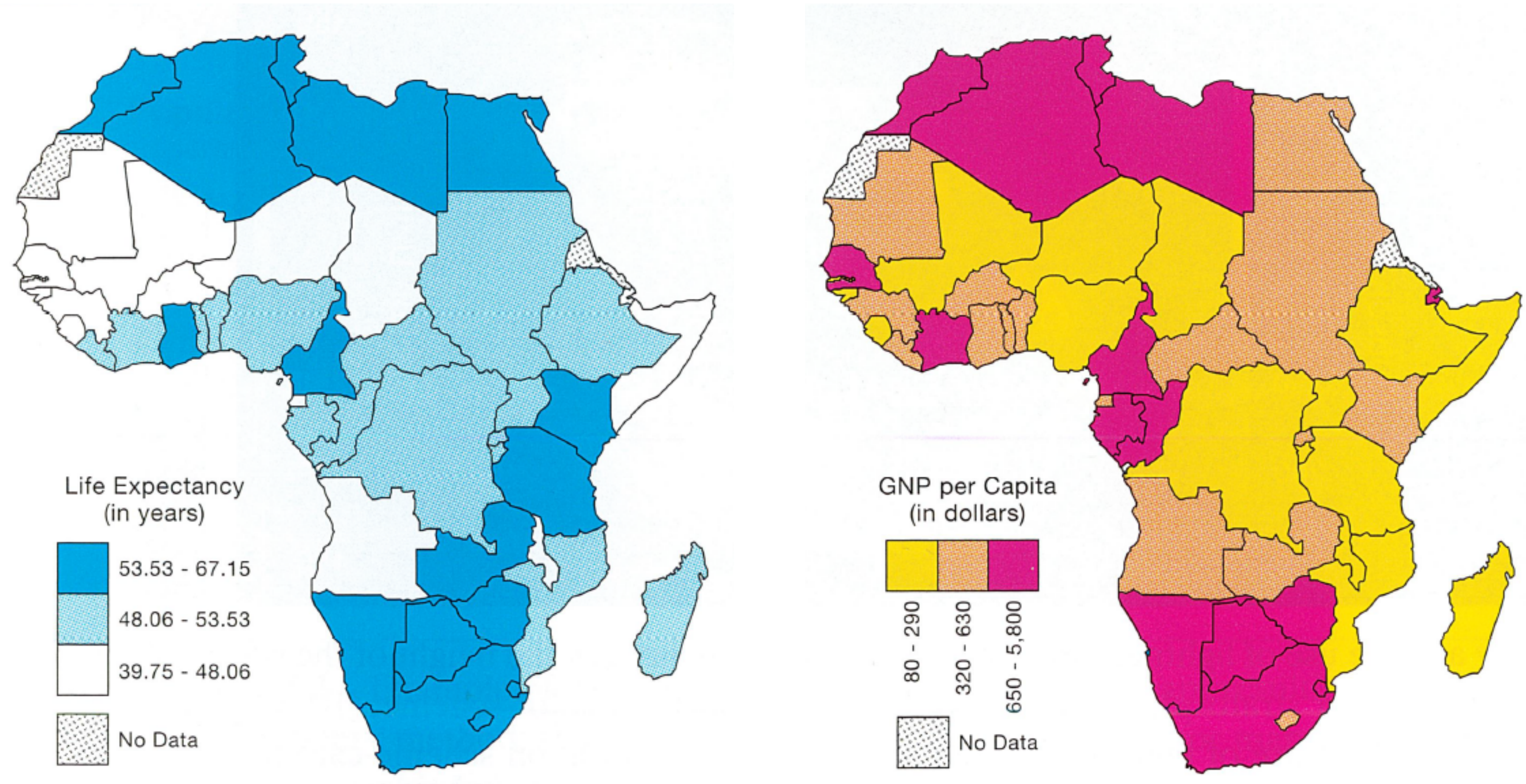


Image: Slocum et al. (2009)

2. BIVARIATE CHOROPLETH MAP EXAMPLE

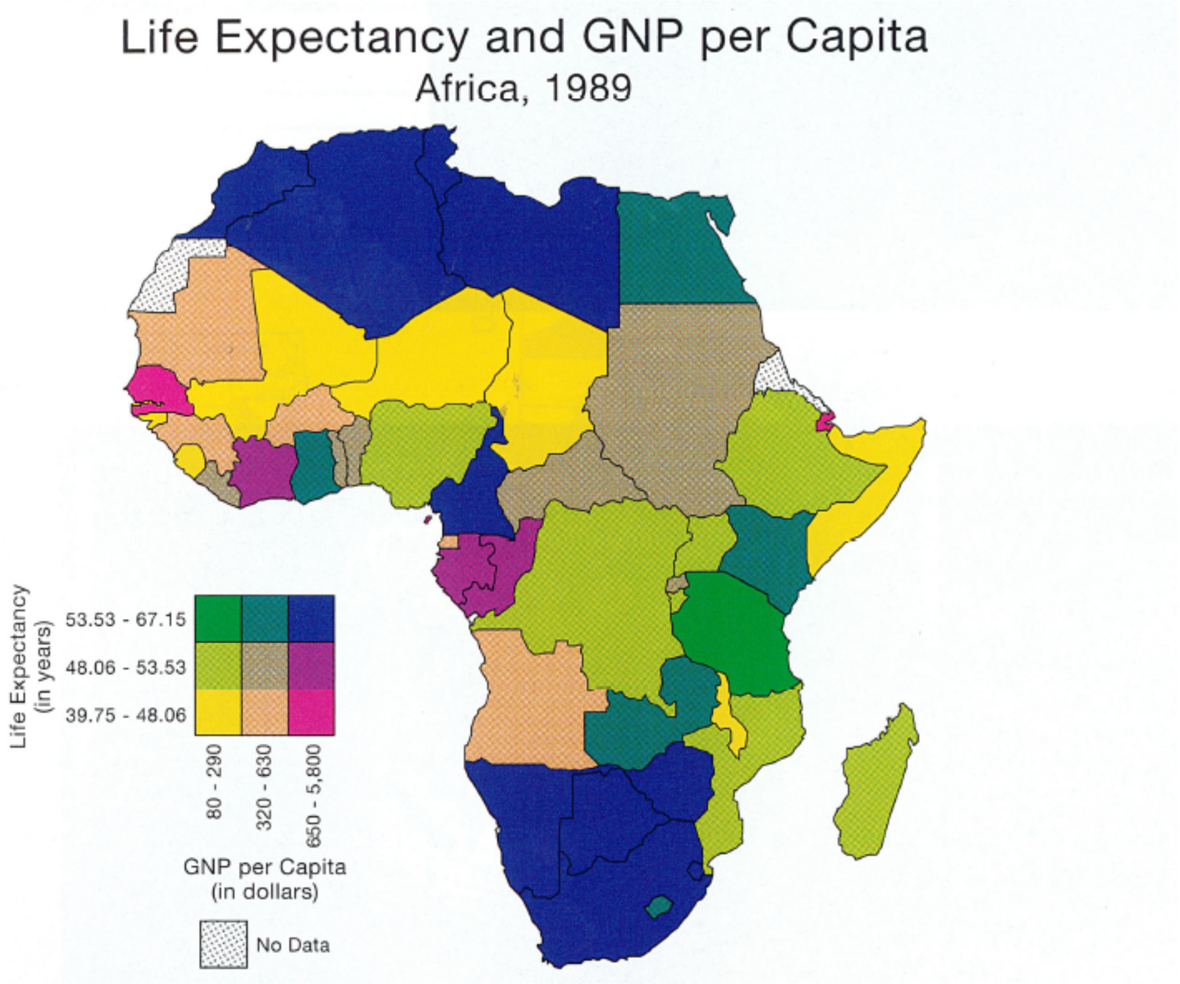


Image: Slocum et al. (2009)

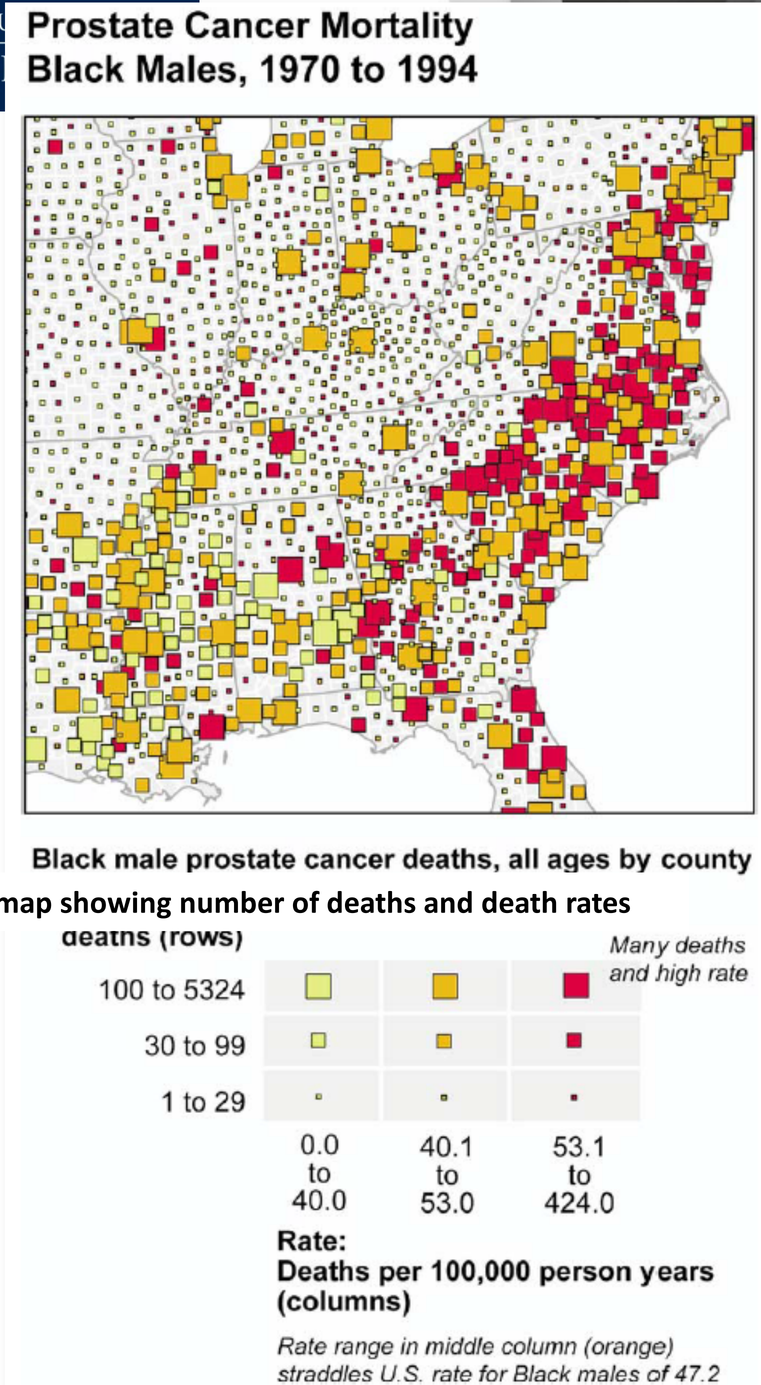
Separable symbols:

Size and colour are called separable visual variables as they can be understood as separate concepts

Combinations:

- Colour hue, Shape
- Colour hue, Size
- Colour hue, Orientation
- Colour value*, Shape
- Colour value*, Size

Nelson (2000)
*HSV colour



Bivariate map showing number of deaths and death rates

Image: Brewer (2006)

Quantity/quantity bivariate map:
Number of deaths and death rates

Size: Used for the count variable (row; larger symbols for more deaths)

Colour hue and Lightness:
Used for death rates
(columns; light yellow to dark red)

Combination of smaller size and lighter colour reduces salience

Separable symbols: Colour hue/Size

3x3 classes

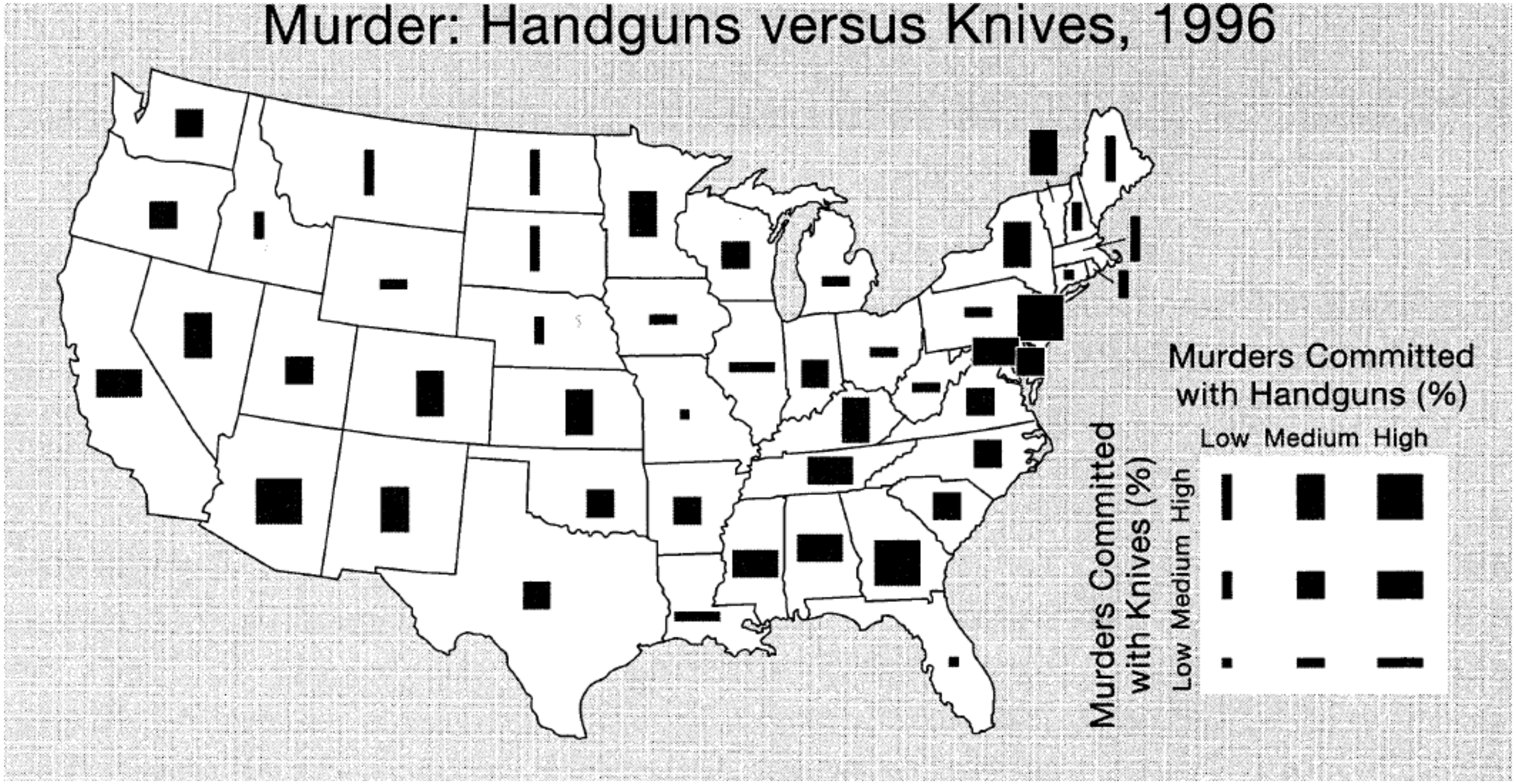
Integral symbols:
Visual variables that can not be easily separated, but allow patterns (e.g. covariance) to be visible.

Combinations:

- Size (height), Size (width) (rectangular symbols)
- Colour saturation, Colour value

Nelson (2000)

Image: Slocum et al., (2009)



Quantity/quantity bivariate map:

Number of deaths and death rates

Size (width):

% murders using handguns

Size (height):

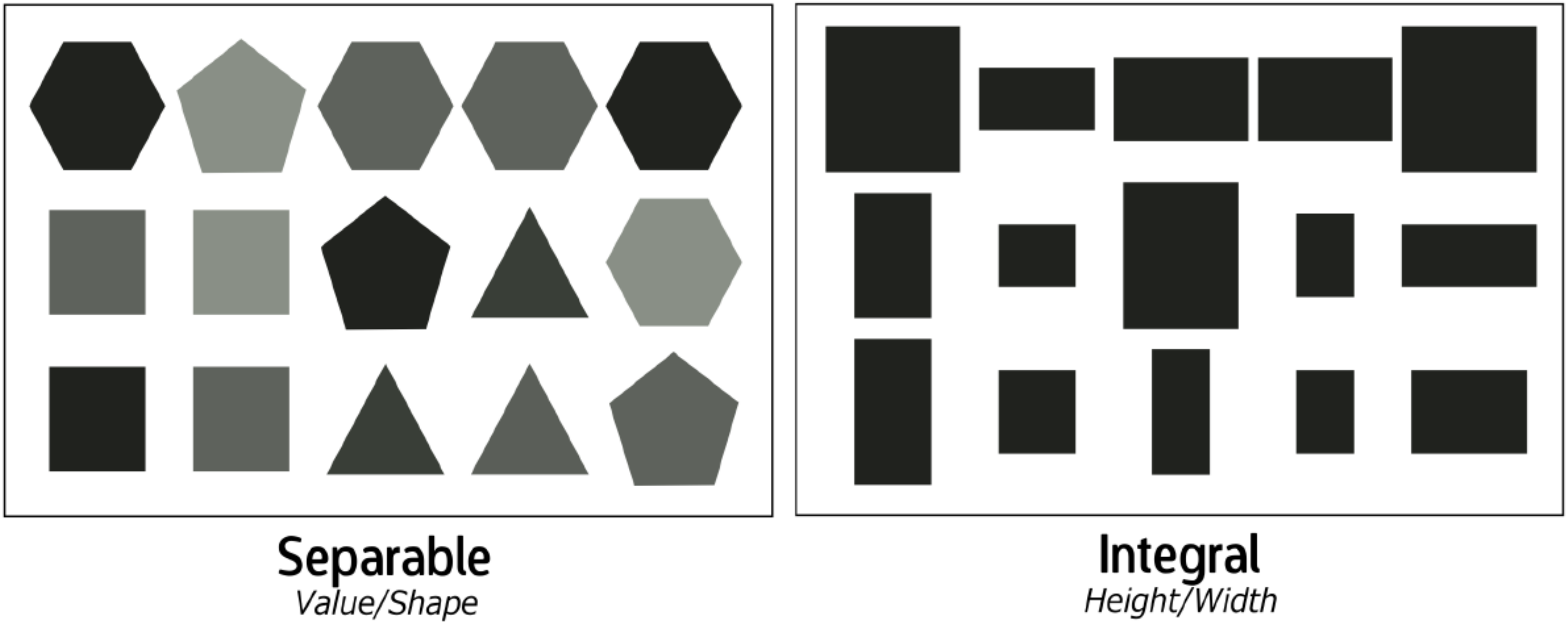
% murders using knives

Integral symbols: Size (height, width)

3x3 classes

Comparing separable and integral

Image: Melmer (2012)



Both series represent the same data.

What can you see? Which do you find easier?

2. BIVARIATE MAP EXAMPLE – 5x5 classes

Trends in Europe’s climate (change in temperature and precipitation over 30 year period) using different models

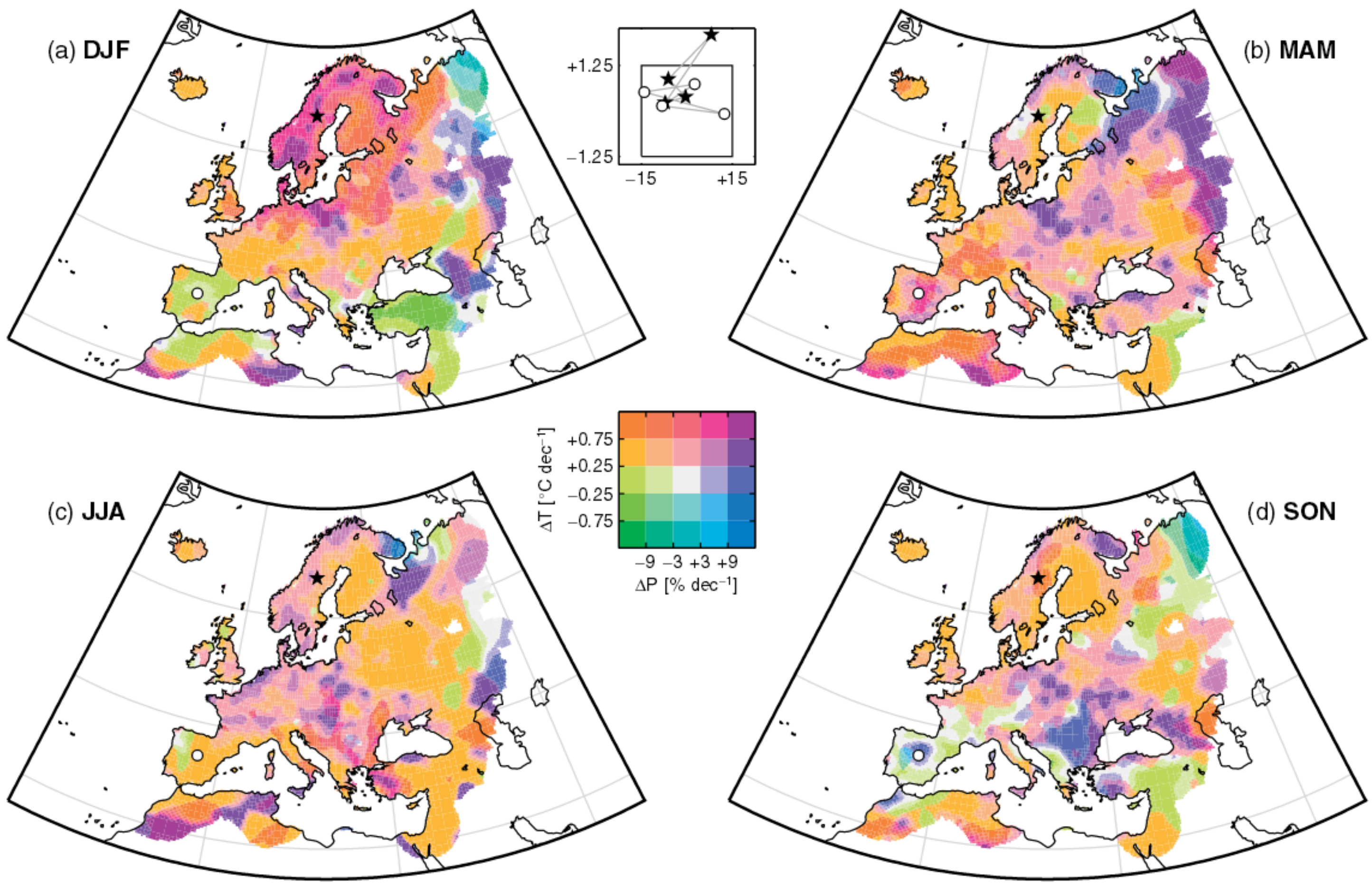


Image: Teuling et al. (2010)

2. BIVARIATE MAP EXAMPLE

Data Modelling: Choosing classes to represent data
3×3 recommended by Leonowicz (2003)
4×4 becoming too complicated (Olson, 1981)

A “visual puzzle” or “crypto-graphical mystery” (Tufte, 1983)

But what if the data is highly complex? **CLIMATE DATA**

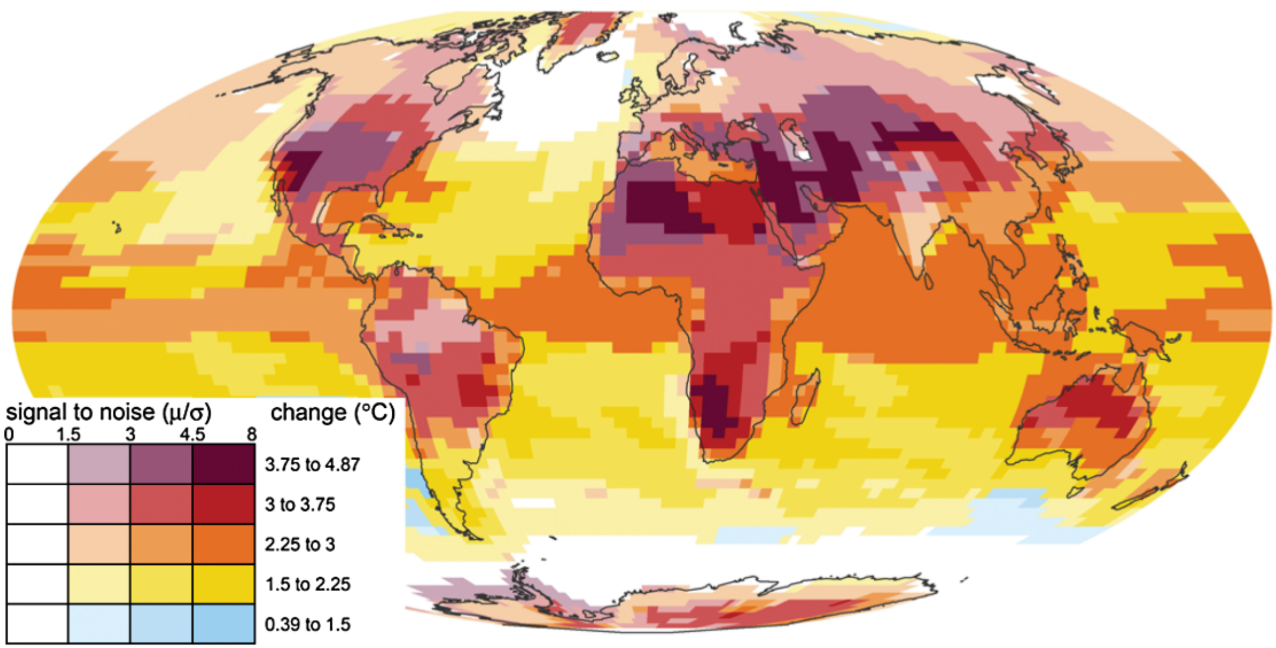


Image: Kaye et al. (2012)

TOO MANY CLASSES? Remember simultaneous brightness contrast

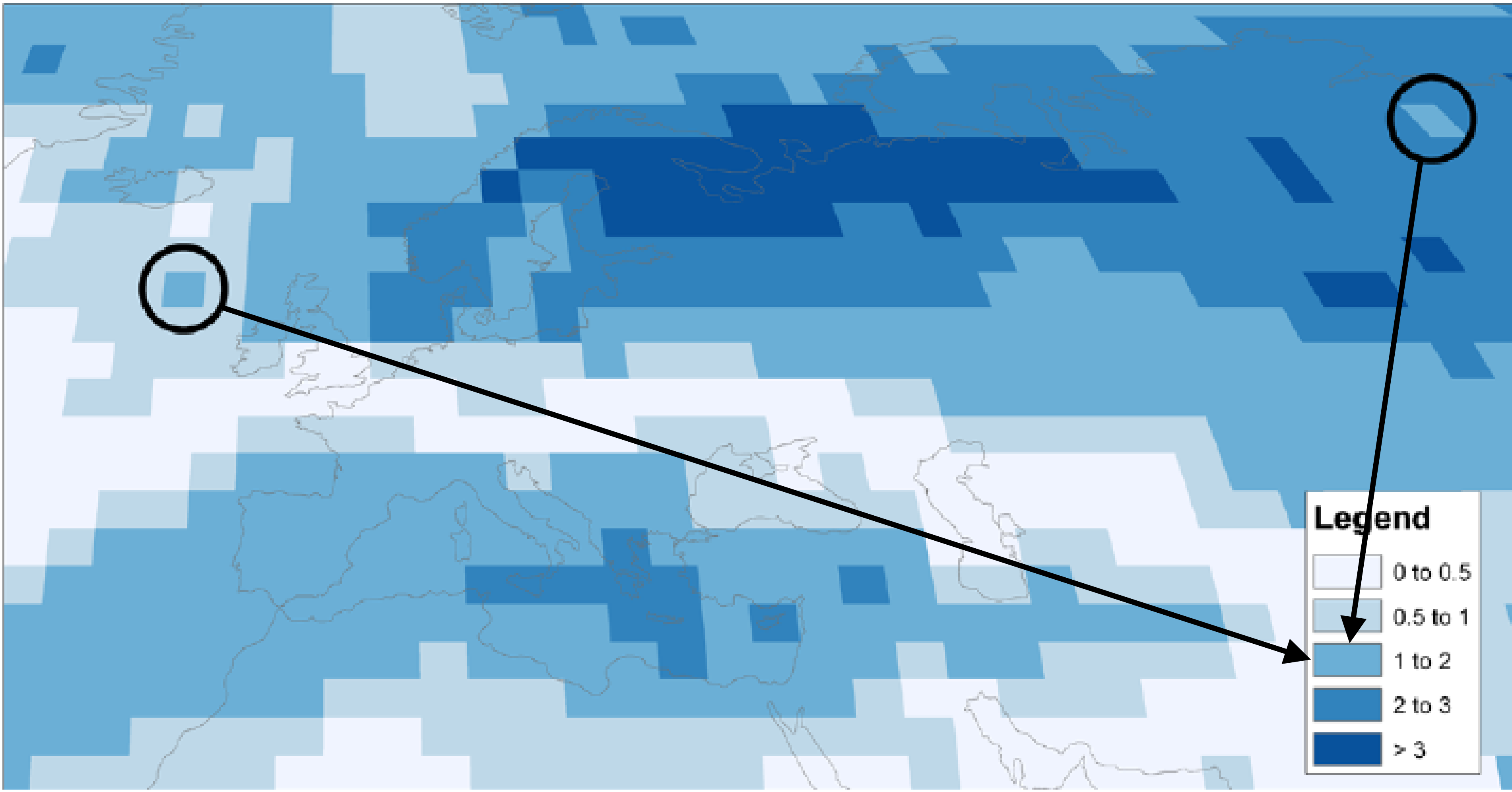


Image: Kaye et al. (2012)

2. BIVARIATE MAP EXAMPLS – Colour hue, certainty

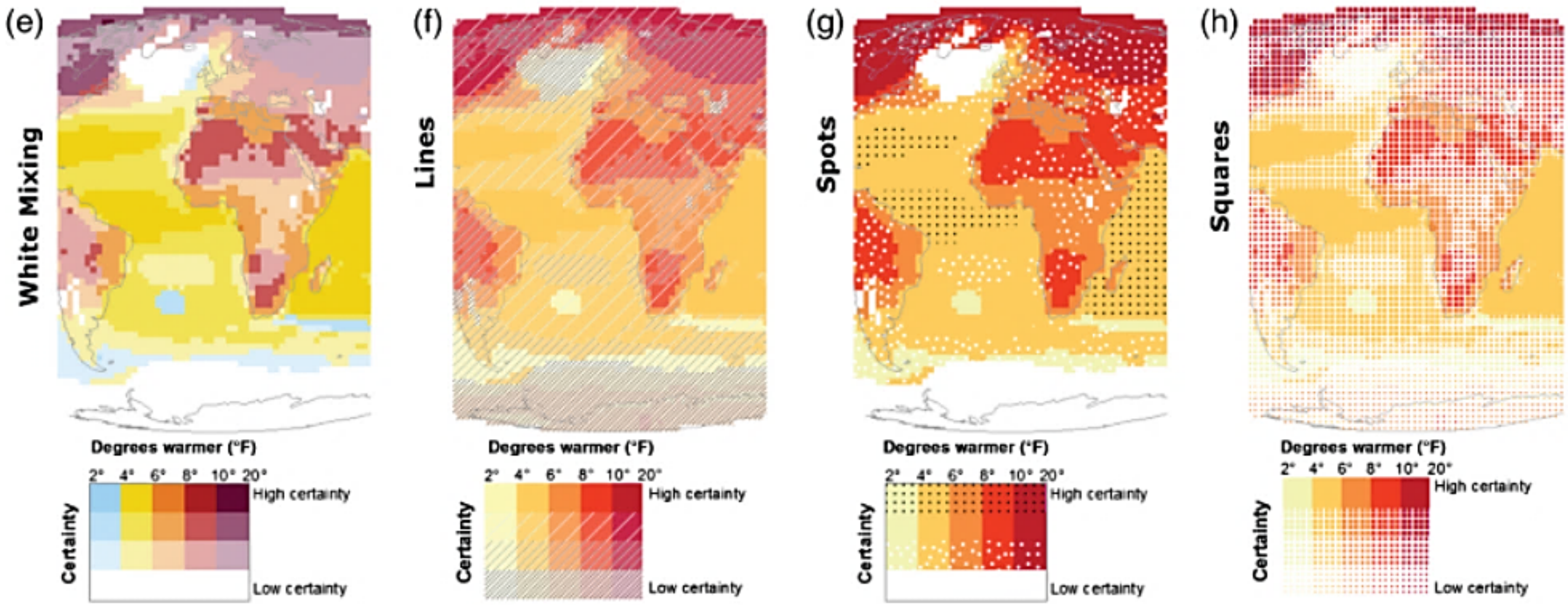


Image: Retchless and Brewer (2015)

3. MULTIVARIATE MAPPING:

Extension from bivariate

Using colour

e.g., dot map (different attributes)

e.g., trivariate (overlay three coloured attributes CMY, RGB)

Using pattern (texture)

Substitute for smooth, colour tones

Using glyphs + choropleth

Univariate choropleth map with multivariate glyph

Beware of obscuring data and 'information overload'

USING COLOUR: MULTIVARIATE DOT MAPPING

Race/ethnicity

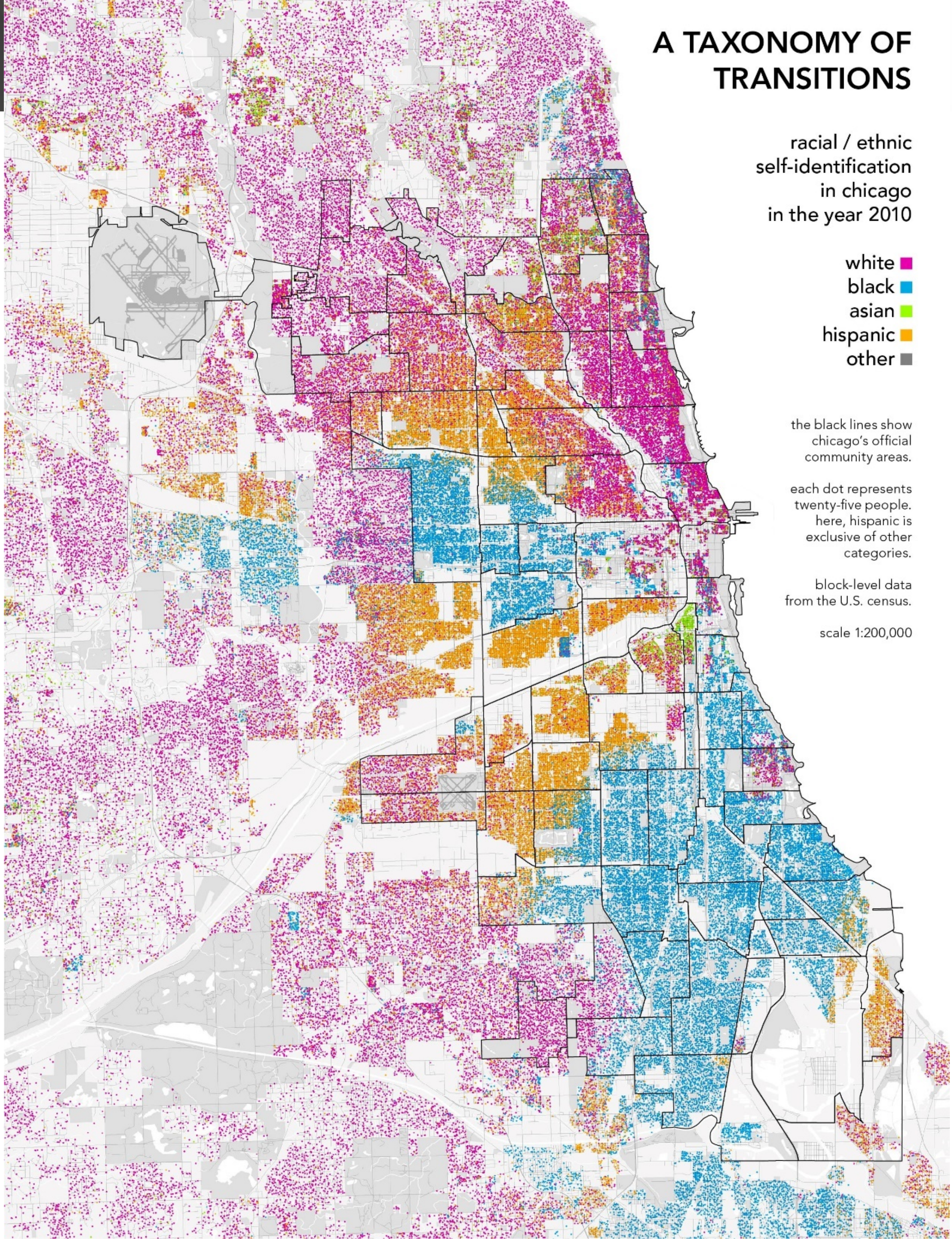
- 5 categories

25 persons per dot

Reflects the 1920s delimitation of Chicago's official “community areas”

e.g., http://encyclopedia.chicagohistory.org/pages/3889.html

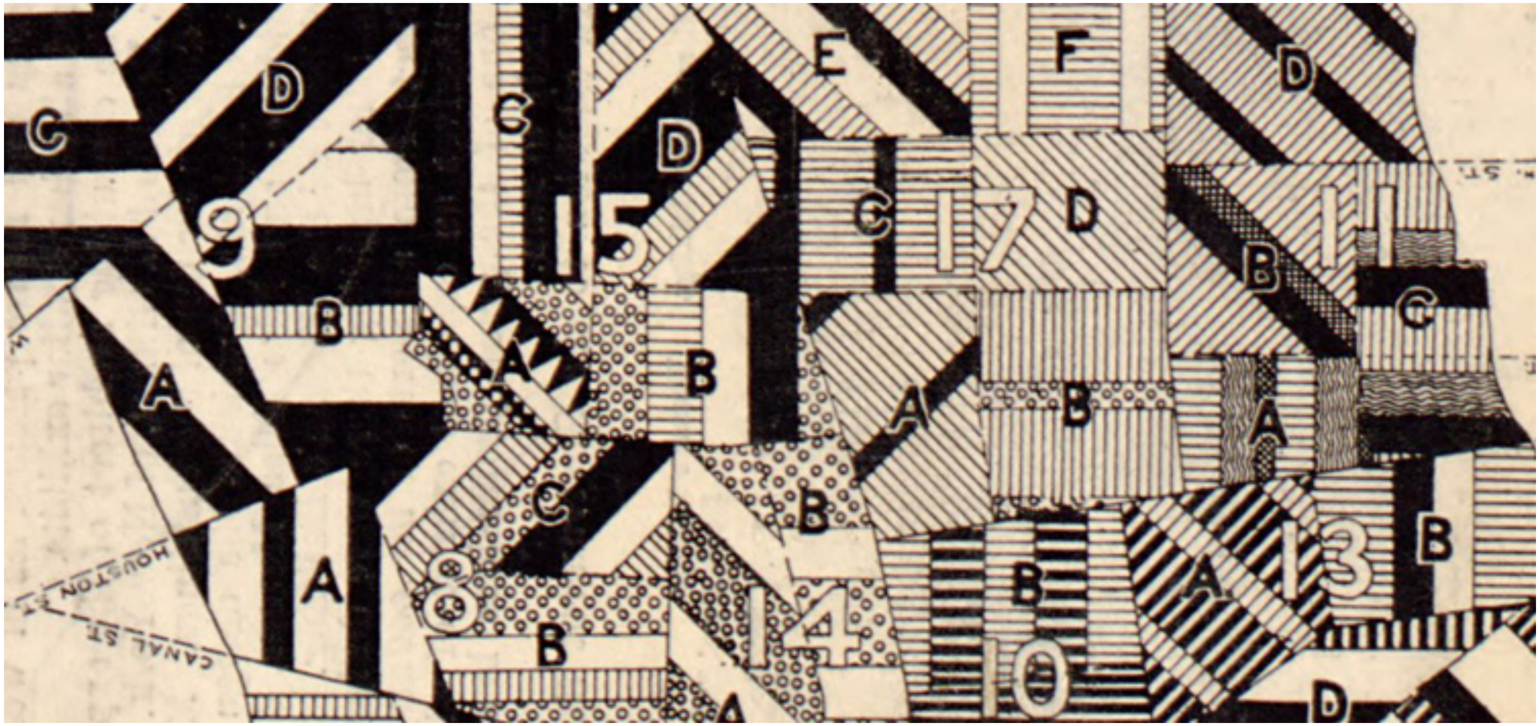
Source: Bill Rankin http://www.radicalcartography.net/index.html?chicagodots

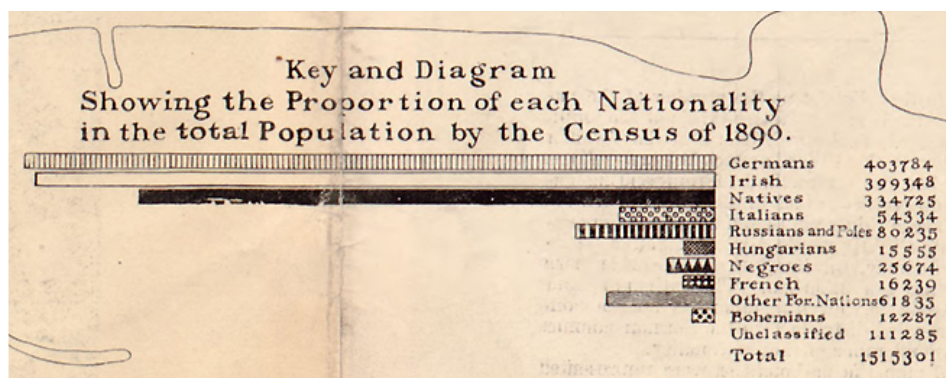


USING COLOUR: TRIVARIATE MAPPING

https://www.good.is/infographics/america-s-richest-counties-and-best-educated-counties#open

USING PATTERN (TEXTURE)





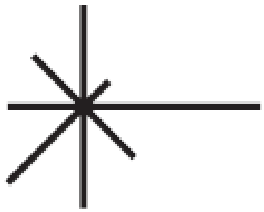
Map of New York City

Nationalities per district

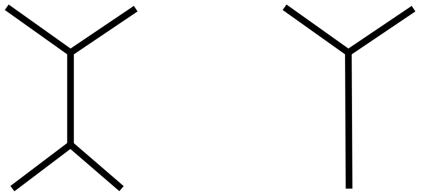
Image: Harper's Weekly (1894)

EXAMPLE MULTIVARIATE GLYPHS

- Ray glyph (or star, multi-dimensional whisker plot



- Stick figures



- Wind barb

Image:
Pilar and Ware (2013)

- Pie chart

- Chernoff face

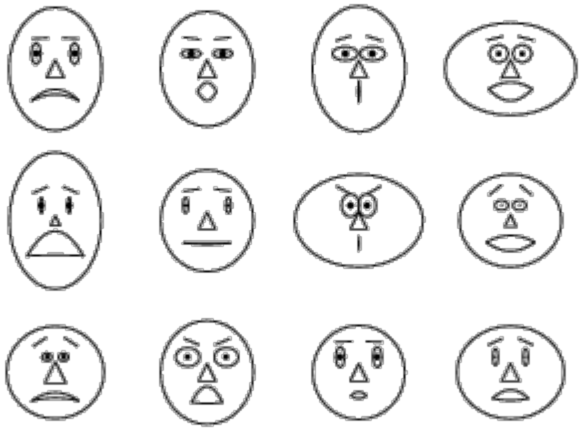


Image: Wolfram's Mathworld (2016)

MULTIVARIATE GLYPHS – Pie chart overlaid on provinces

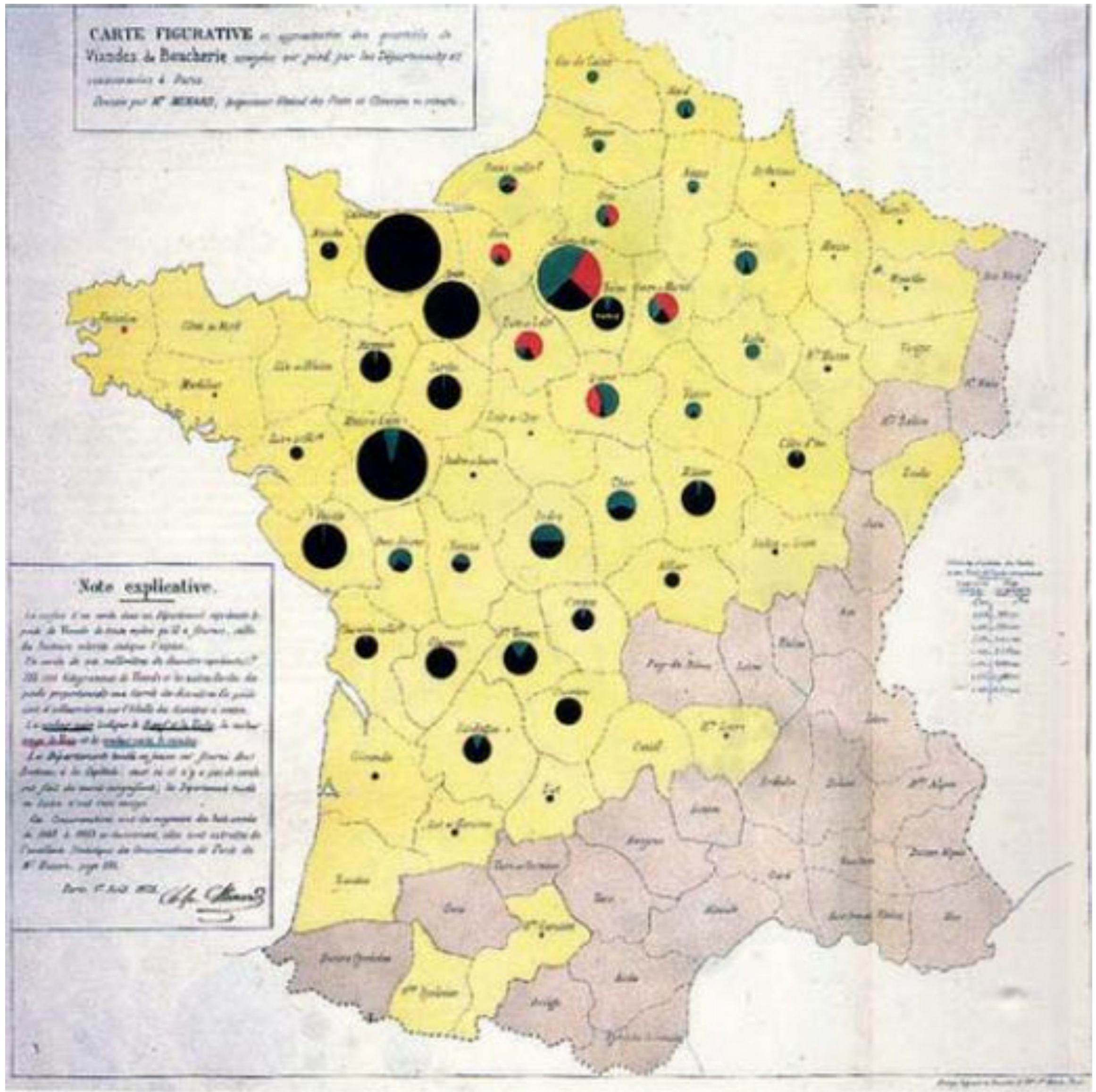


Image: Minard (1958)

USING MULTIVARIATE GLYPHS – Overlaid on choropleth map

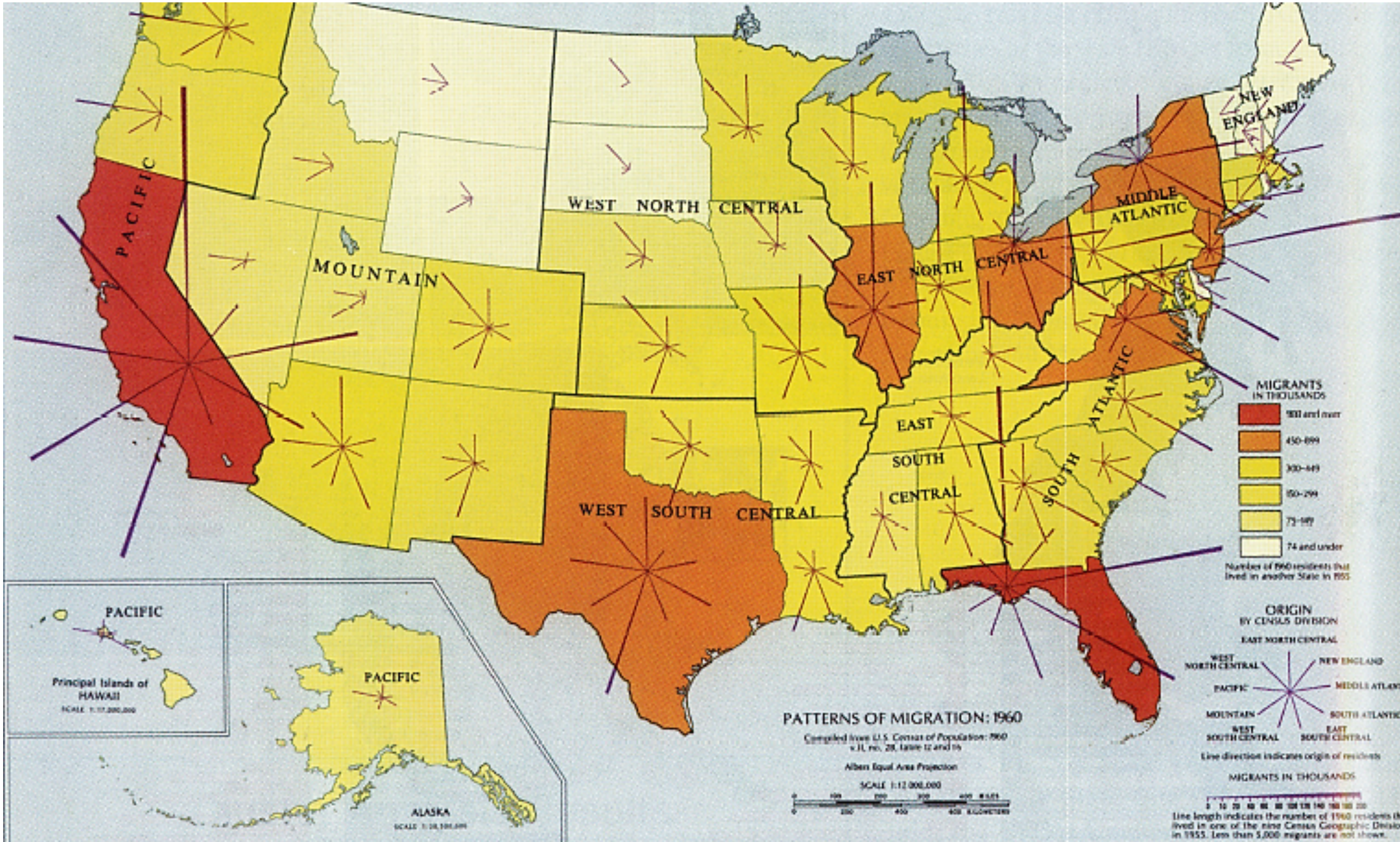


Image: USGS (1970)

MULTI-MODAL MULTIVARIATE MAPPING

Use of visual and non-visual variables (e.g. sound or vibration)

Can be used to increase redundancy or representation of data

Example: Fisher's use of sound

Used different frequencies of sound to represent the reliability of classification in remote sensing

More information: Fisher, P. F., (1994), Visualization of the reliability in classified remotely sensed images. *Photogrammetric Engineering and Remote Sensing*, 60(7), pages 905-910.

4. CLUSTER ANALYSIS FOR CLASSIFICATION AND VISUALISATION

Previous classification only using univariate data

Cluster analysis to classify multiple numerical variables

Methods can be either **hierarchical** or **non-hierarchica**l

Process:

1. Collect appropriate data
2. Standardise data
3. Compute coefficients
4. Cluster the data
5. Determine appropriate number of classes

SUMMARY

Data modelling and selection is critically important.

What is your message?

How do you classify the data?

What graphic representation is needed to communicate your message?

NEXT LECTURE

- Cartography 3: Coordination systems and projections

READING

Choengsa-ard et al. (2013). Effective Graphic Features for Multivariate Symbol Mapping. *The Cartographic Journal*, 50(1). Link: http://www.tandfonline.com.ezp.lib.unimelb.edu.au/doi/full/10.1179/1743277412Y.0000000025

Retchless, D. P. and Brewer, C. A. (2015), Guidance for representing uncertainty on global temperature change maps, *International Journal of Climatology*, 36(3). Link: http://onlinelibrary.wiley.com/doi/10.1002/joc.4408/full