Introduction to GeoVisualization {and Visual Analytics}

Special focus: spatio-temporal and movement data

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http://geoanalytics.net

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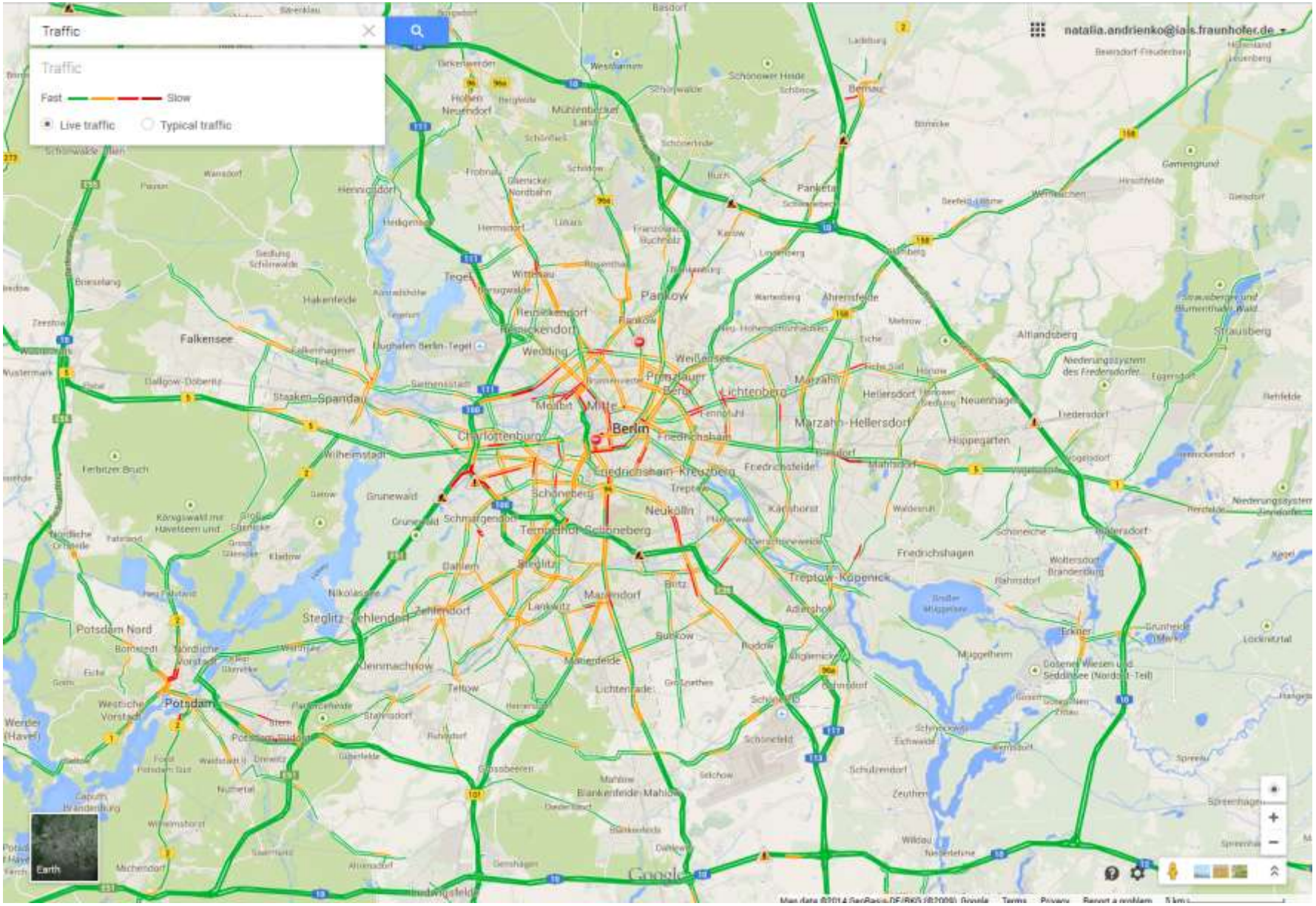

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{Geo} Information Visualization, basic principles

- Interactive Maps and Multiple Coordinated Views

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Maps: not only for orientation!

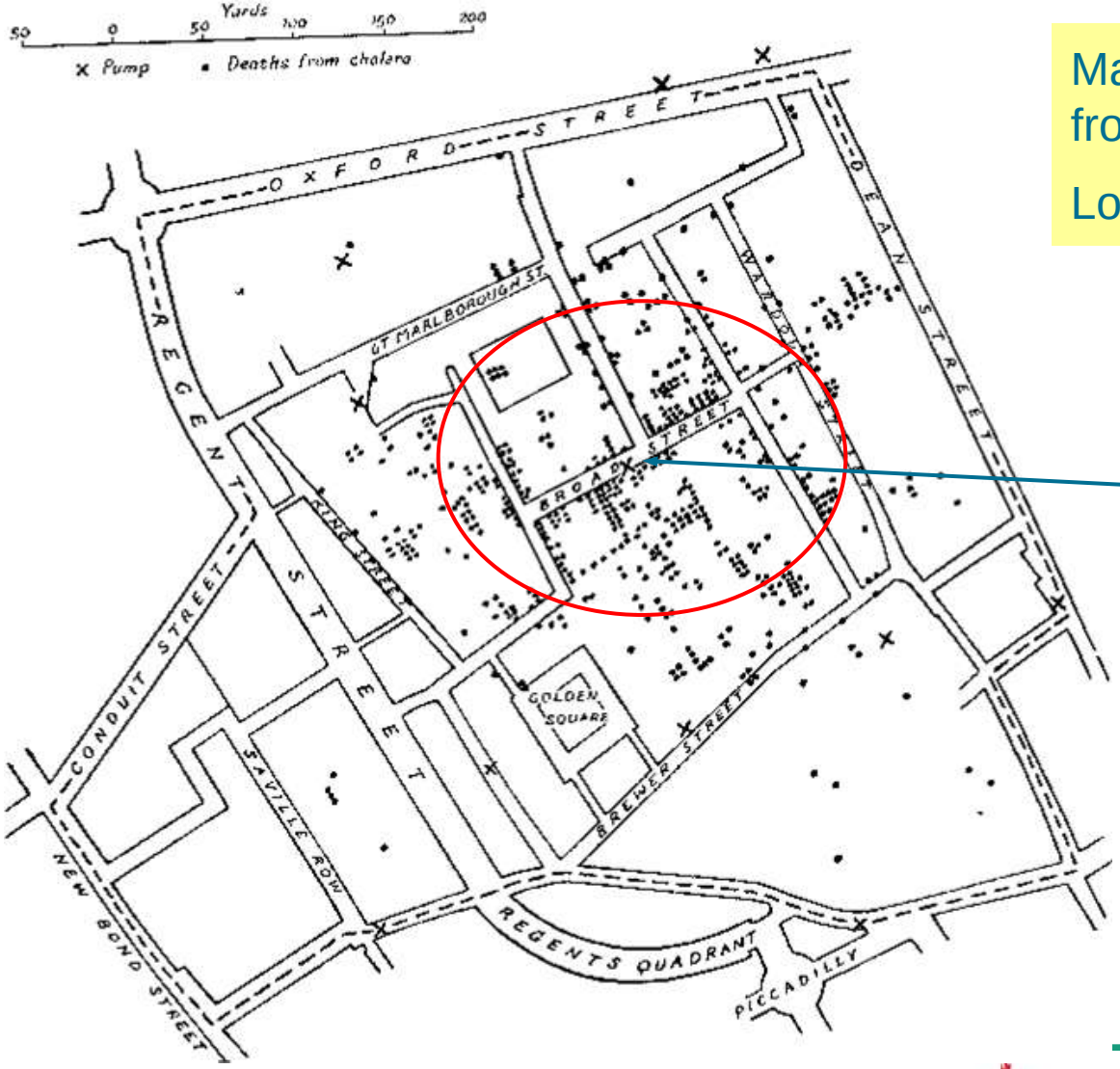
People live in geographical space.
Most of people's decisions and actions depend on

- where the things are;
- how are their locations related.

Maps allow people to perceive the space beyond the directly observable extent.

A map serves as a model of reality and helps to detect patterns existing in the reality

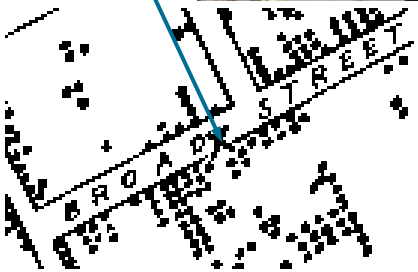
Example: Dr. John Snow's discovery



Map of locations of deaths from cholera

London, September 1854

infected water pump



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Interactive maps

Interactive maps can change in response to user's actions

Many interactive maps are available on the Web, e.g. street maps, tourist maps, election maps, …

Interaction techniques are used to

- compensate for the display deficiencies, e.g. limited size (zoom and pan, showing additional information related to mouse position, …)
- increase the display expressiveness
- enable more sophisticated analyses

Typical interactive operations

Select information layers, e.g. on a tourist map: accommodation, museums, restaurants, nightlife

Select time moments or intervals in displays of time-related information, e.g. election year

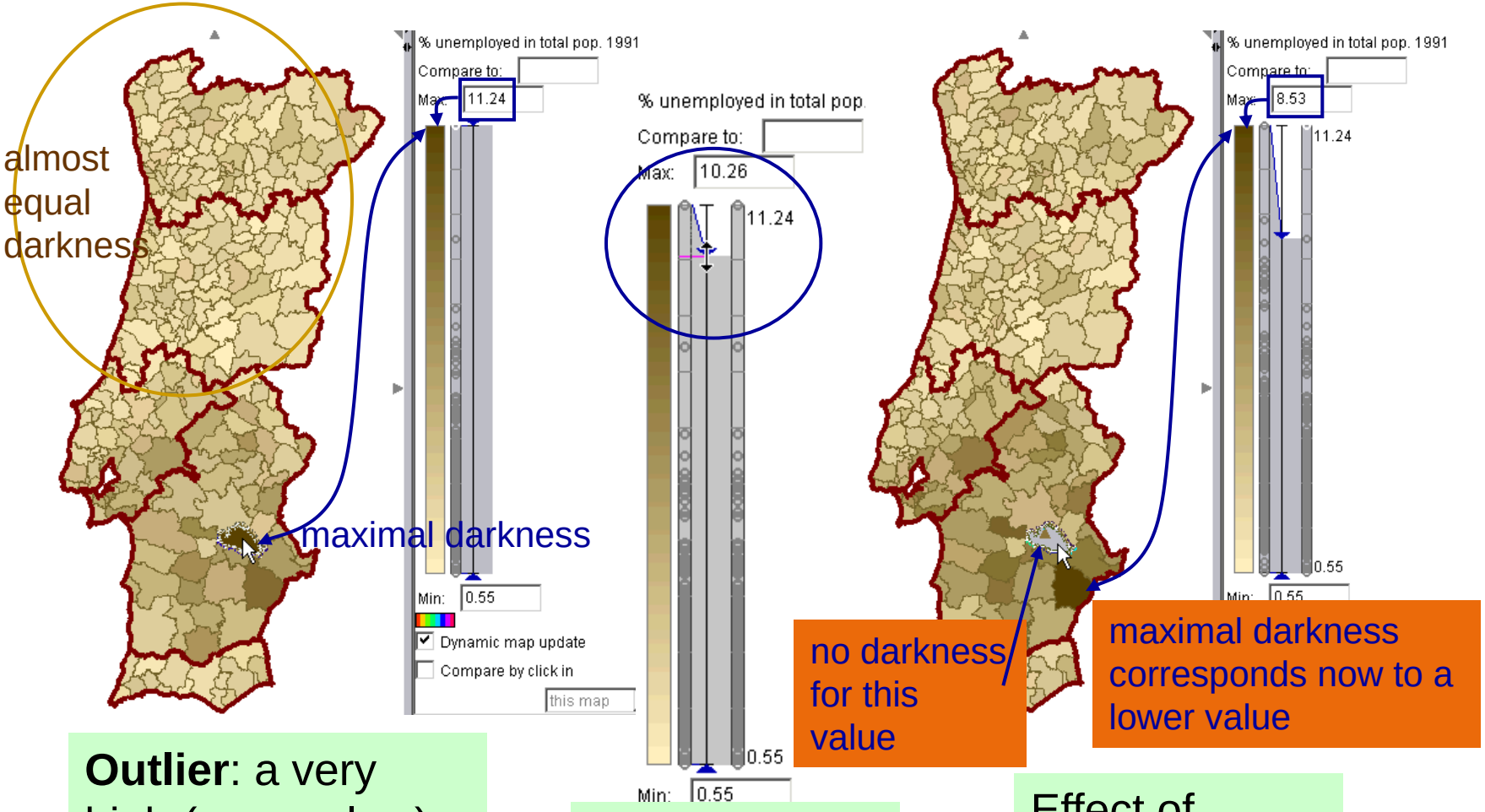
Change the spatial scale, e.g. states or counties

Change the theme, e.g. president elections or governor elections, absolute values or differences in comparison to the previous time

Choose the visualization method, e.g. area painting or proportional symbols

Examples of analytical interactions

Removing Outliers (1)



Outlier: a very high (or very low) value, far apart from others

Interactive outlier removal

Effect of outlier removal

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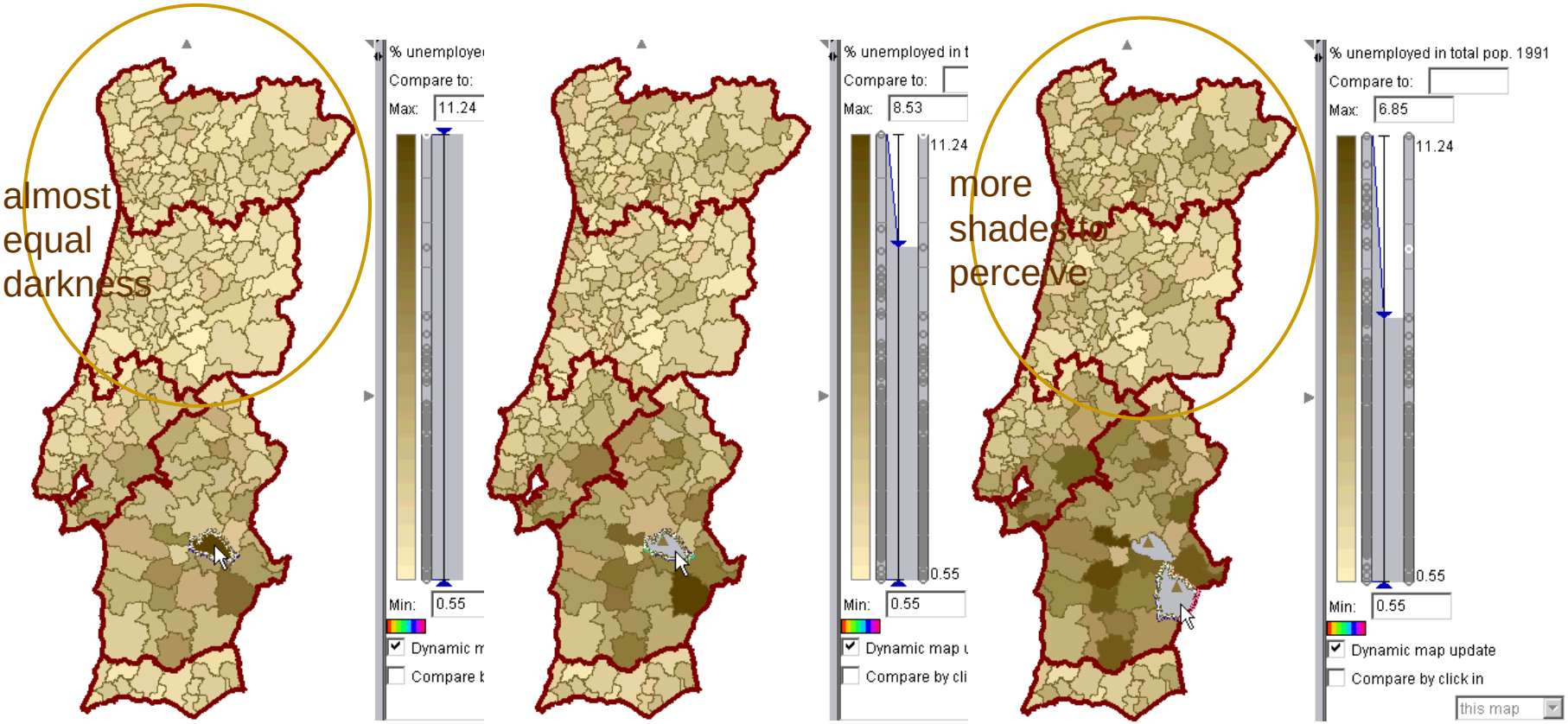
Removing Outliers (2)



After the removal of two outliers, the differences are better seen

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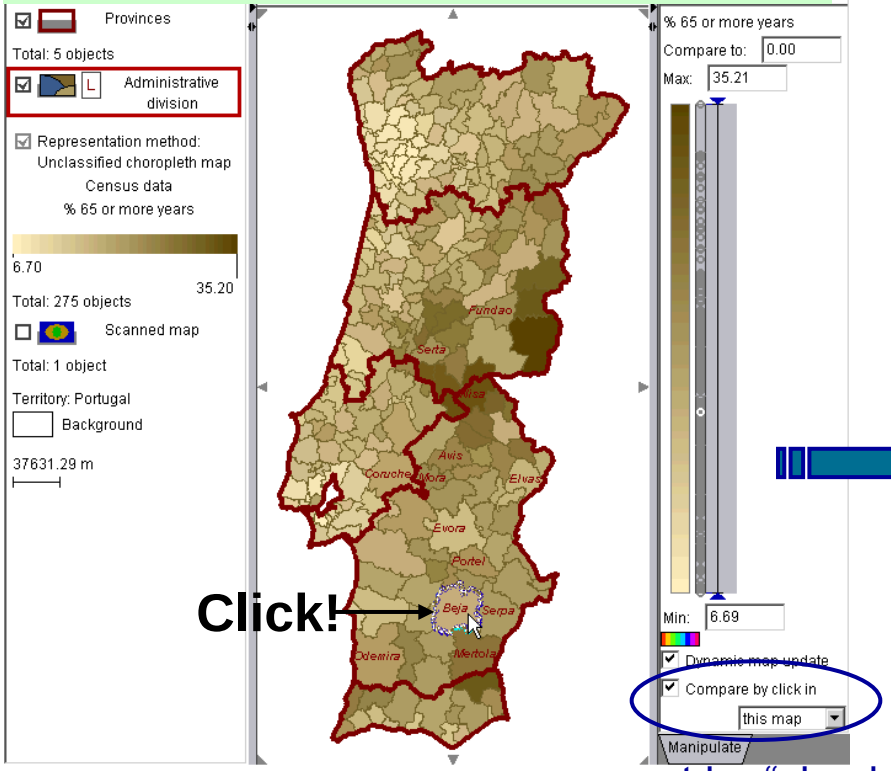
Object Comparison

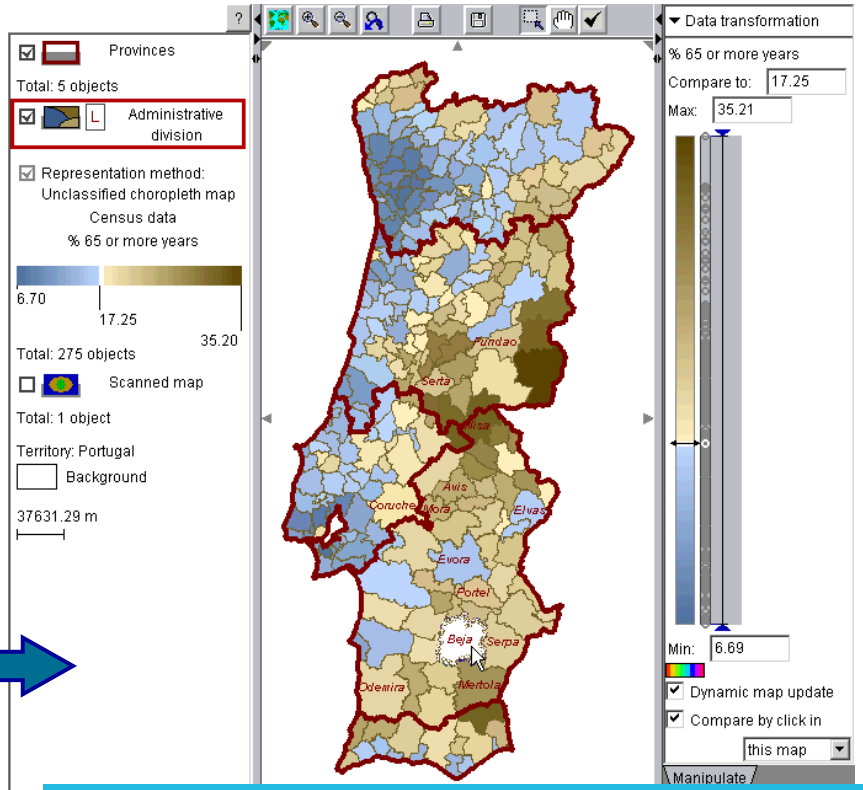
The diverging colour scale allows us to compare an object with all others:



Click!

CommonGIS 1998-2003: Portugal census 1981 and 1991

must be "checked"



After clicking on Beja:

lower values than in Beja → blue

higher values than in Beja → brown

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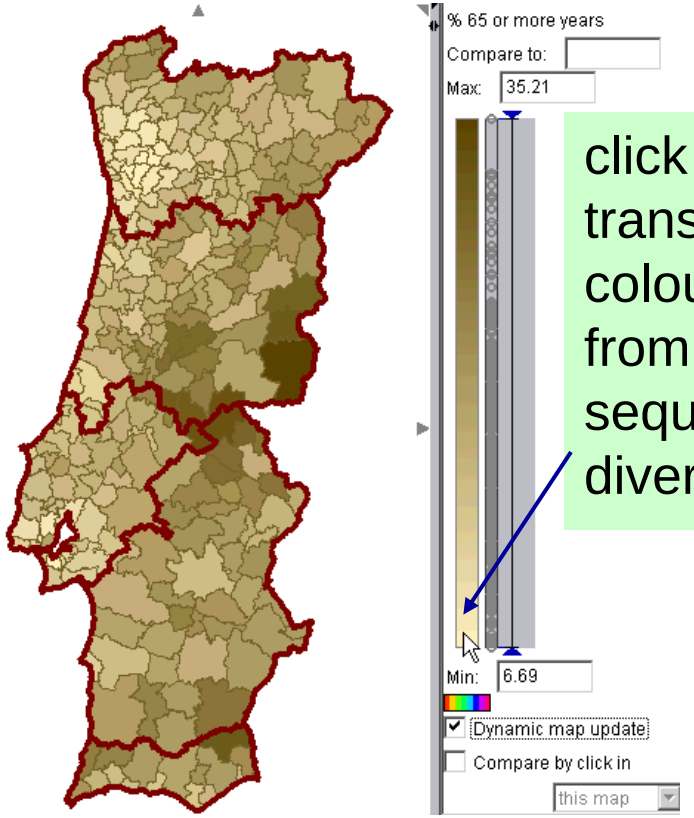
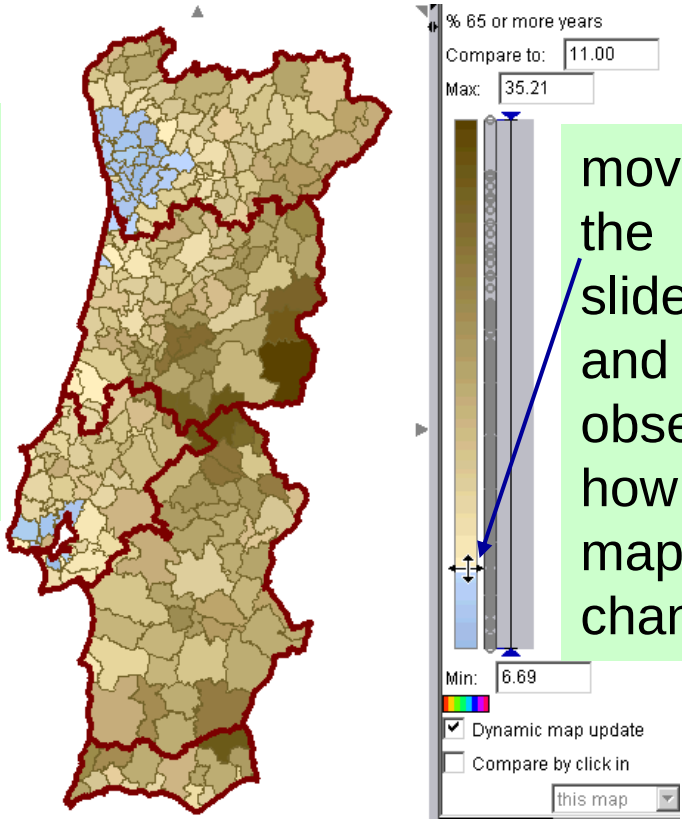
Pattern Investigation (1)



click here to transform the colour scale from sequential to diverging



move the slider and observe how the map changes

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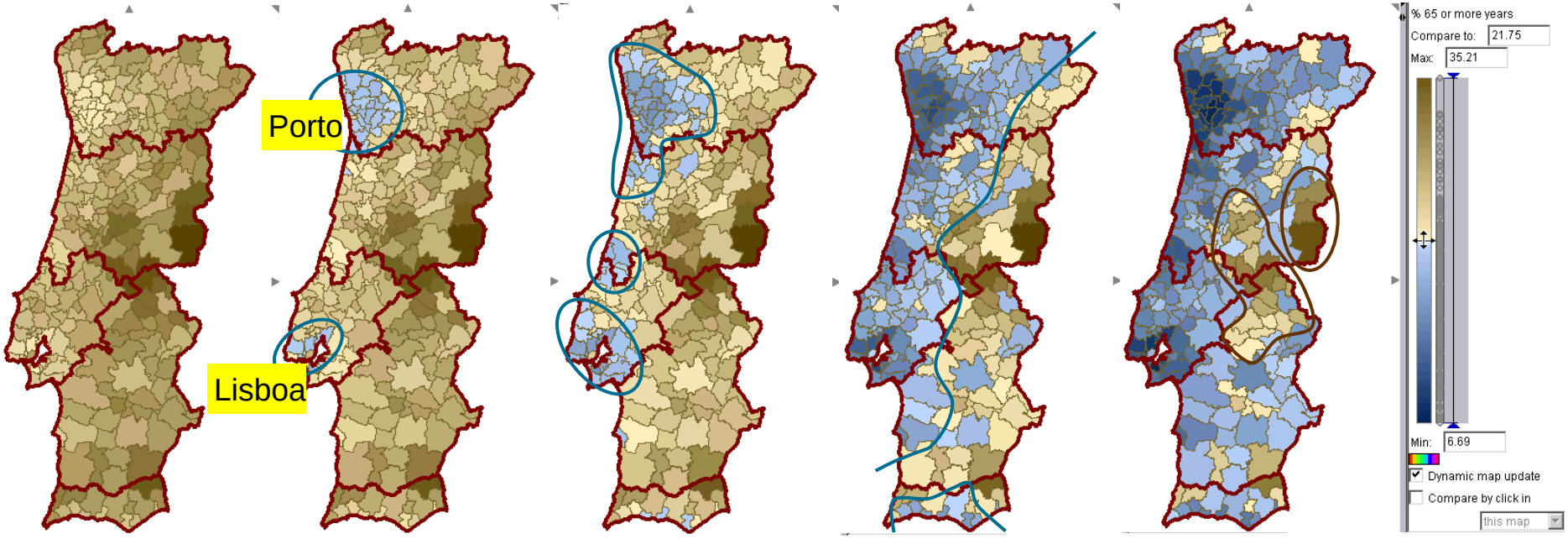
Pattern Investigation (2)

By moving the slider, we see more patterns and gain more understanding of value distribution



West-to-east increase

Clusters of low values around Porto and Lisboa

One more cluster of low values

Coast-inland contrast

Clusters of high values in central-east

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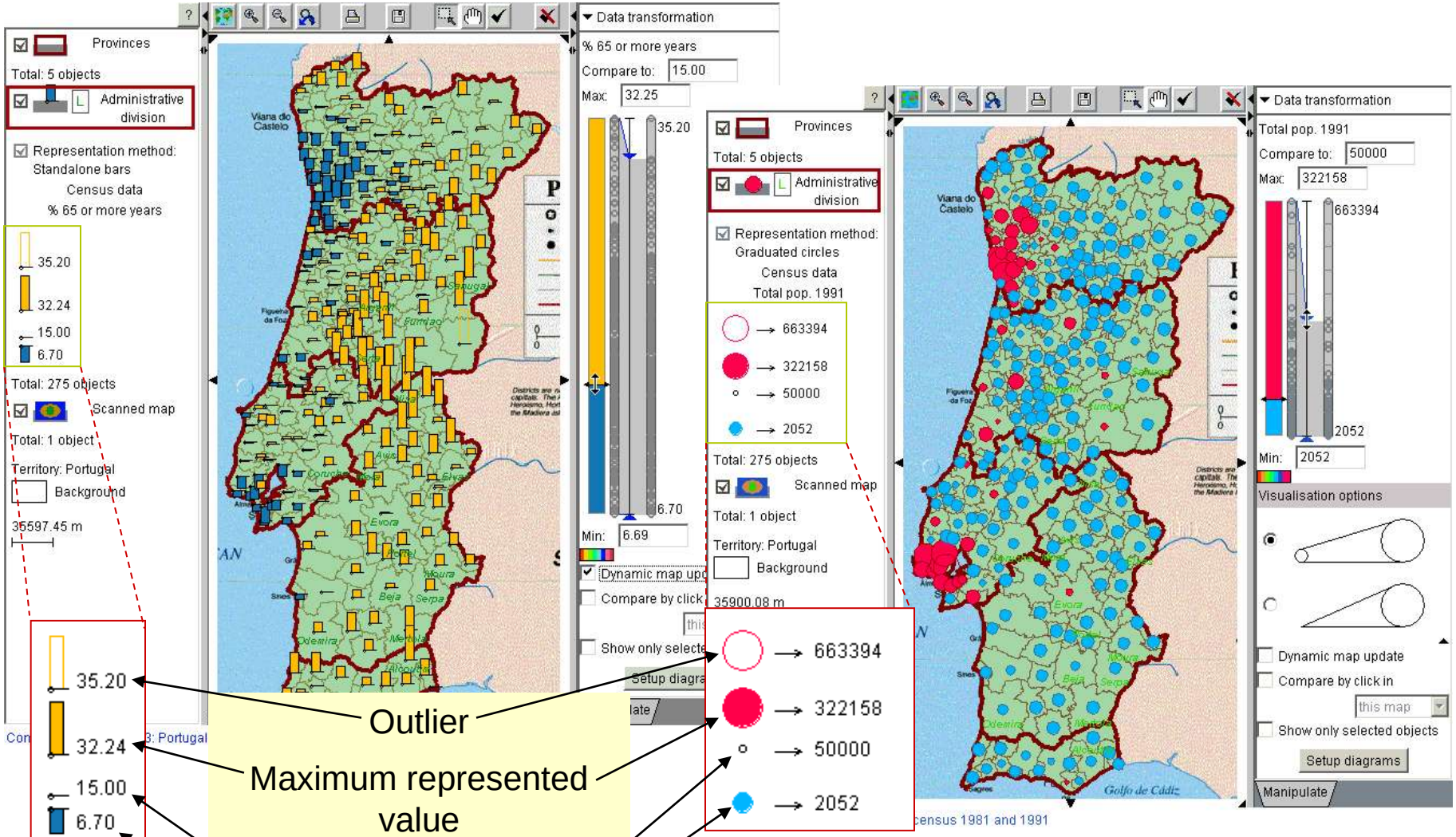
Focusing and Visual Comparison on Other Map



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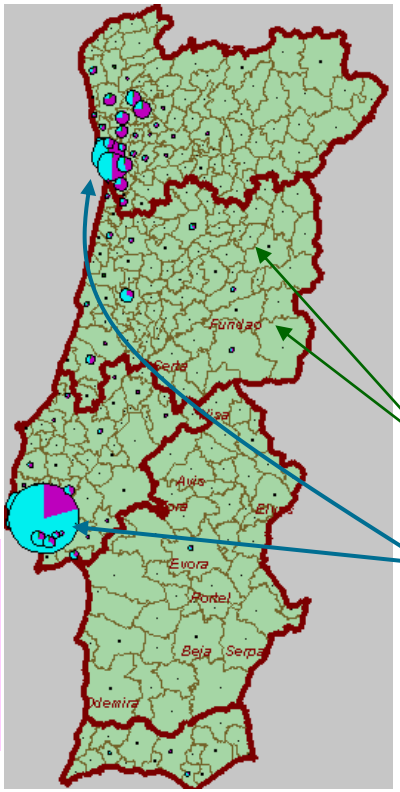
Piechart Map

Applicable to several attributes that together give some meaningful whole

"Pie" size is proportional to the total (sum of the attribute values)

The division into slices shows proportion of each attribute in the total



Here the population is very small in comparison to the large cities. Therefore, the pies are too small to be seen

However, the map often looks like this:

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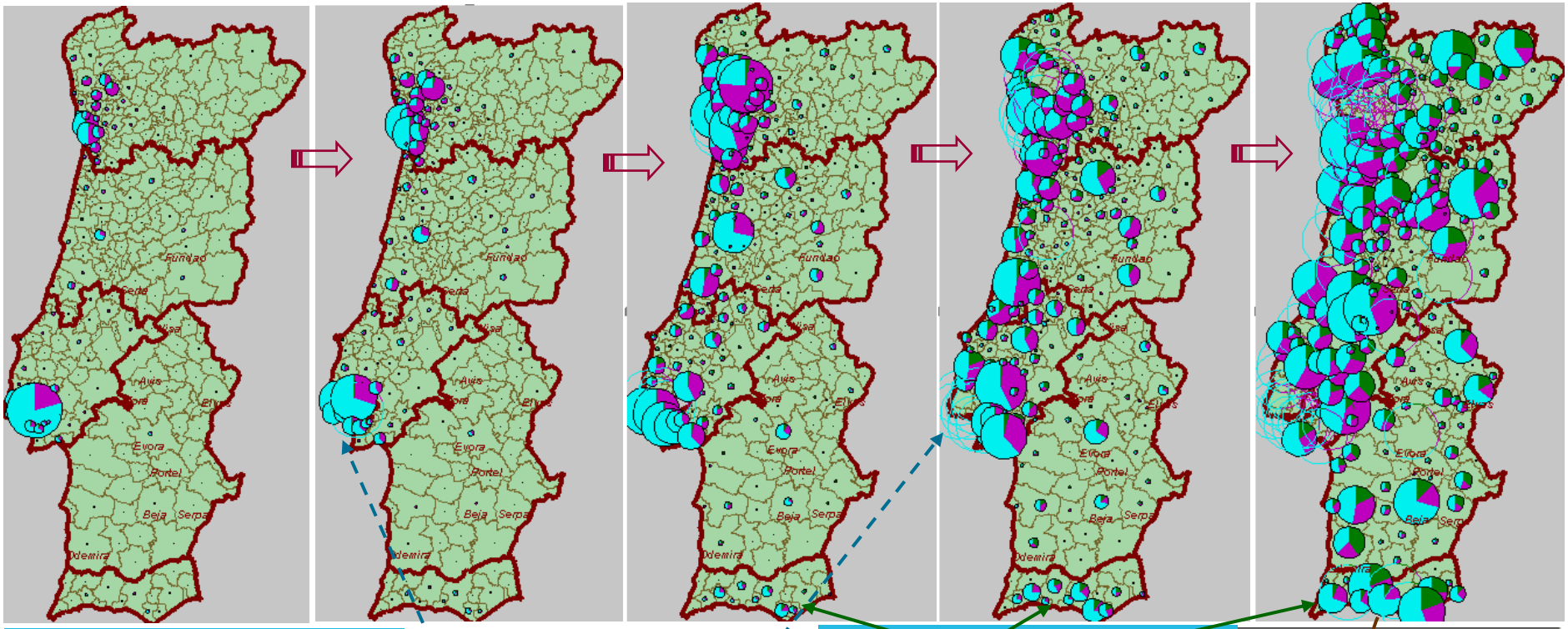
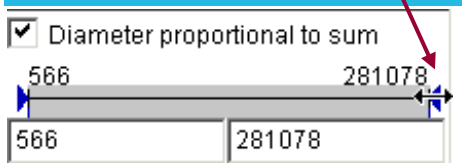
Piechart Map: Focusing

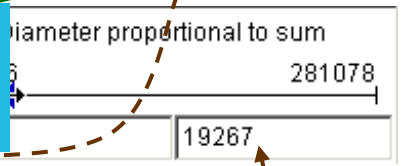


Move this delimiter to the left



The largest pies are gradually removed (replaced by hollow circles)

The remaining pies become larger



Now the maximum pie size corresponds to this value

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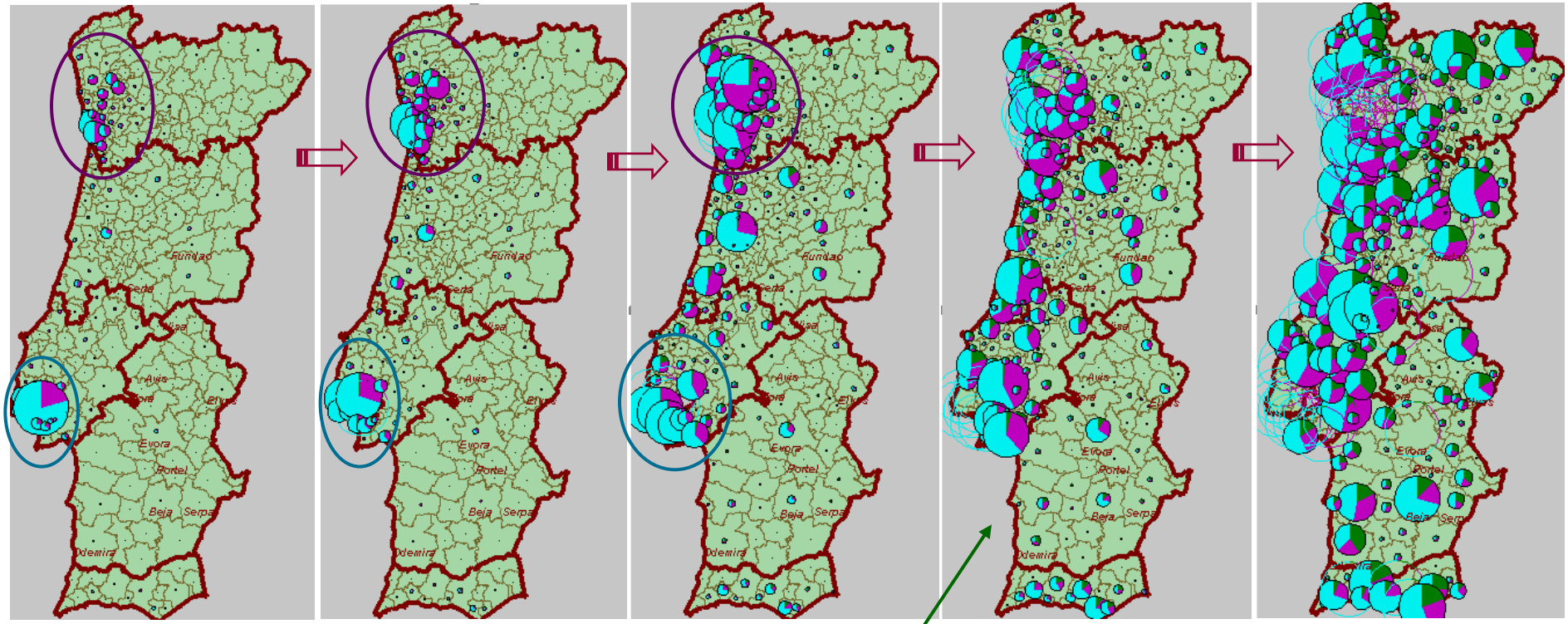
Focusing and Data Investigation



In districts with much population people work in industry (magenta) and services (cyan).

Northwest: more industry

Centre-west: more services

At this stage, the agricultural part (green) becomes visible

In districts with little population considerable proportion of people works in agriculture, but services still prevail

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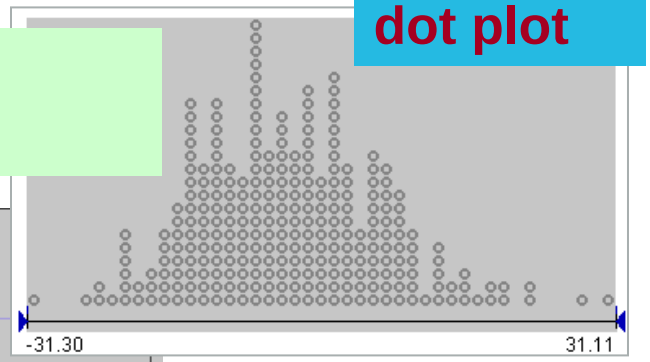
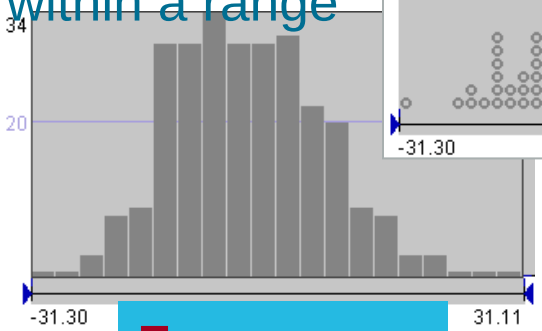
Why to Use Multiple Views?

Dot plot

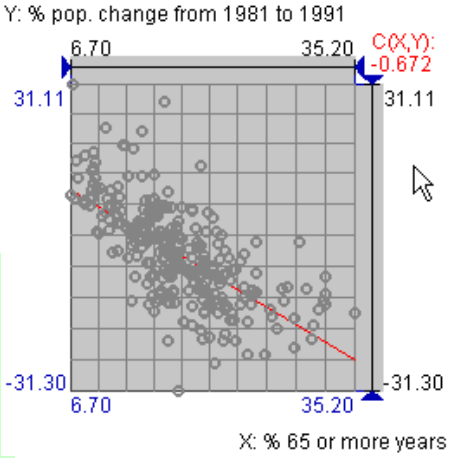
Stacked dot plot

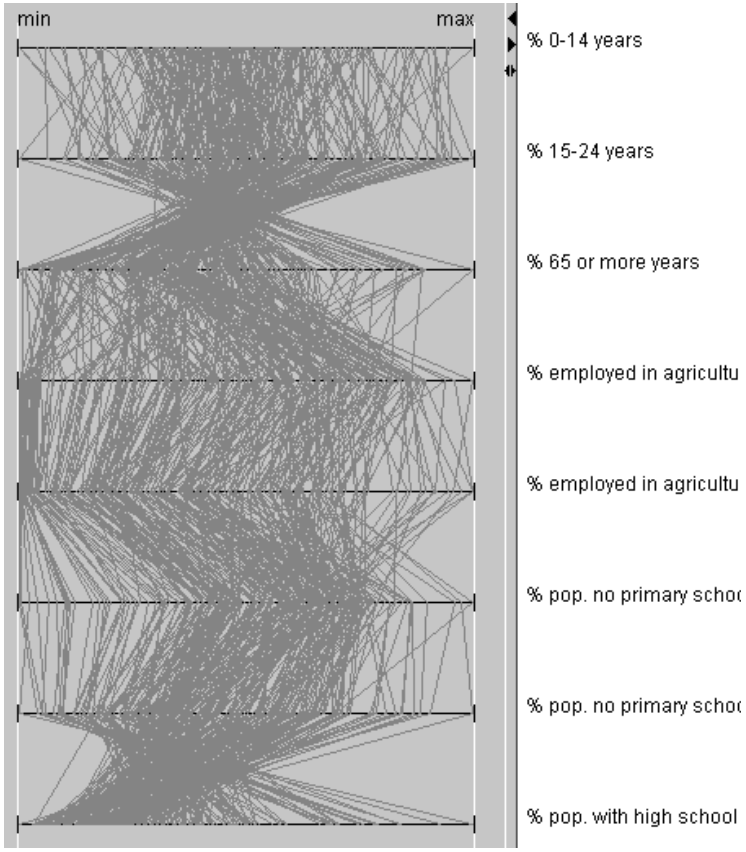


Distribution of attribute values within a range



Frequency histogram





Scatter plot: shows how two attributes are related

Parallel coordinates: object characteristics profiles; relationships between attributes (look at line slopes)

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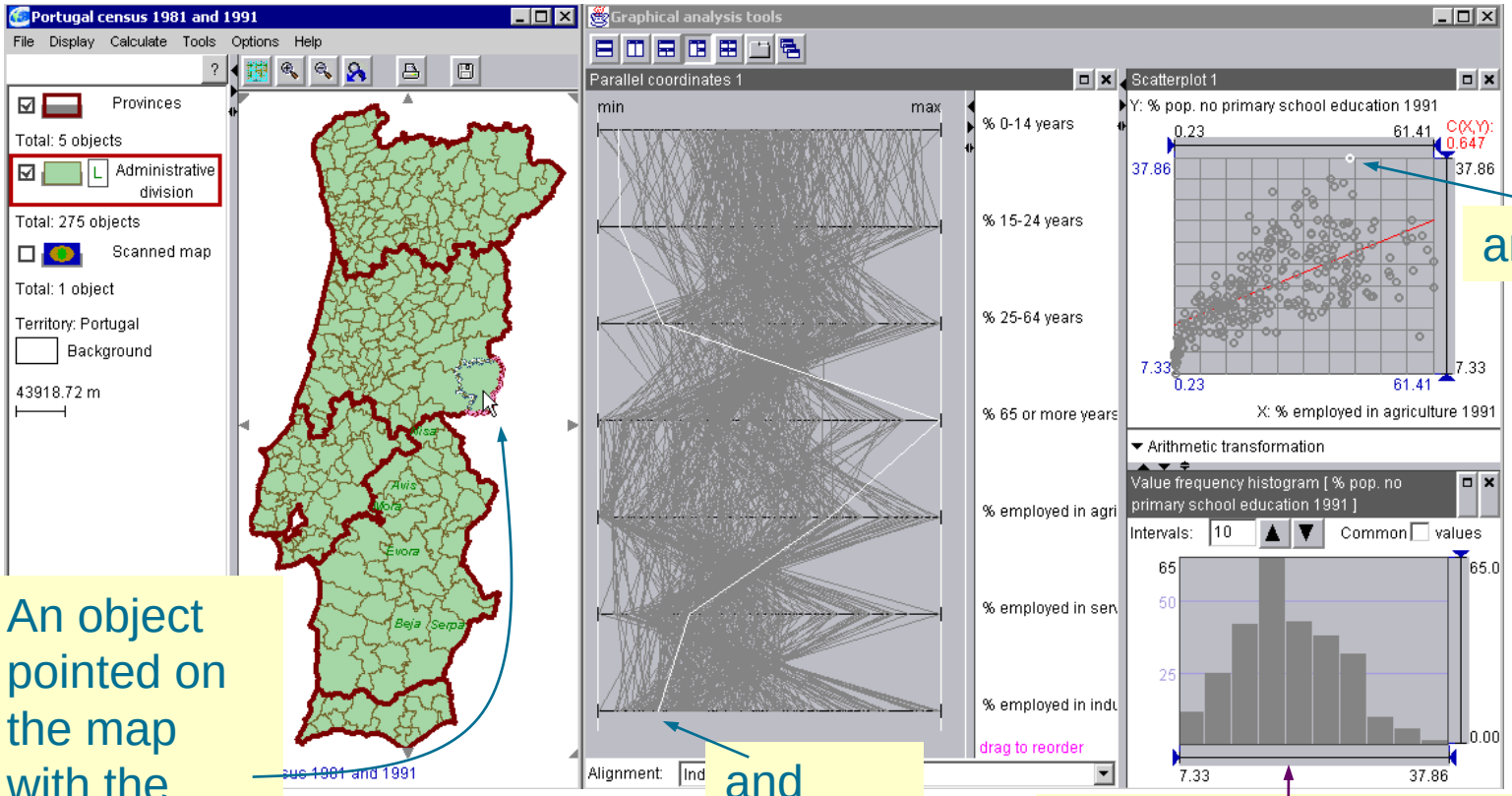
Display Linking by Highlighting



An object pointed on the map with the mouse

is simultaneously highlighted here,

and here,

and here,

but not here: this is an aggregated view that does not show individual objects

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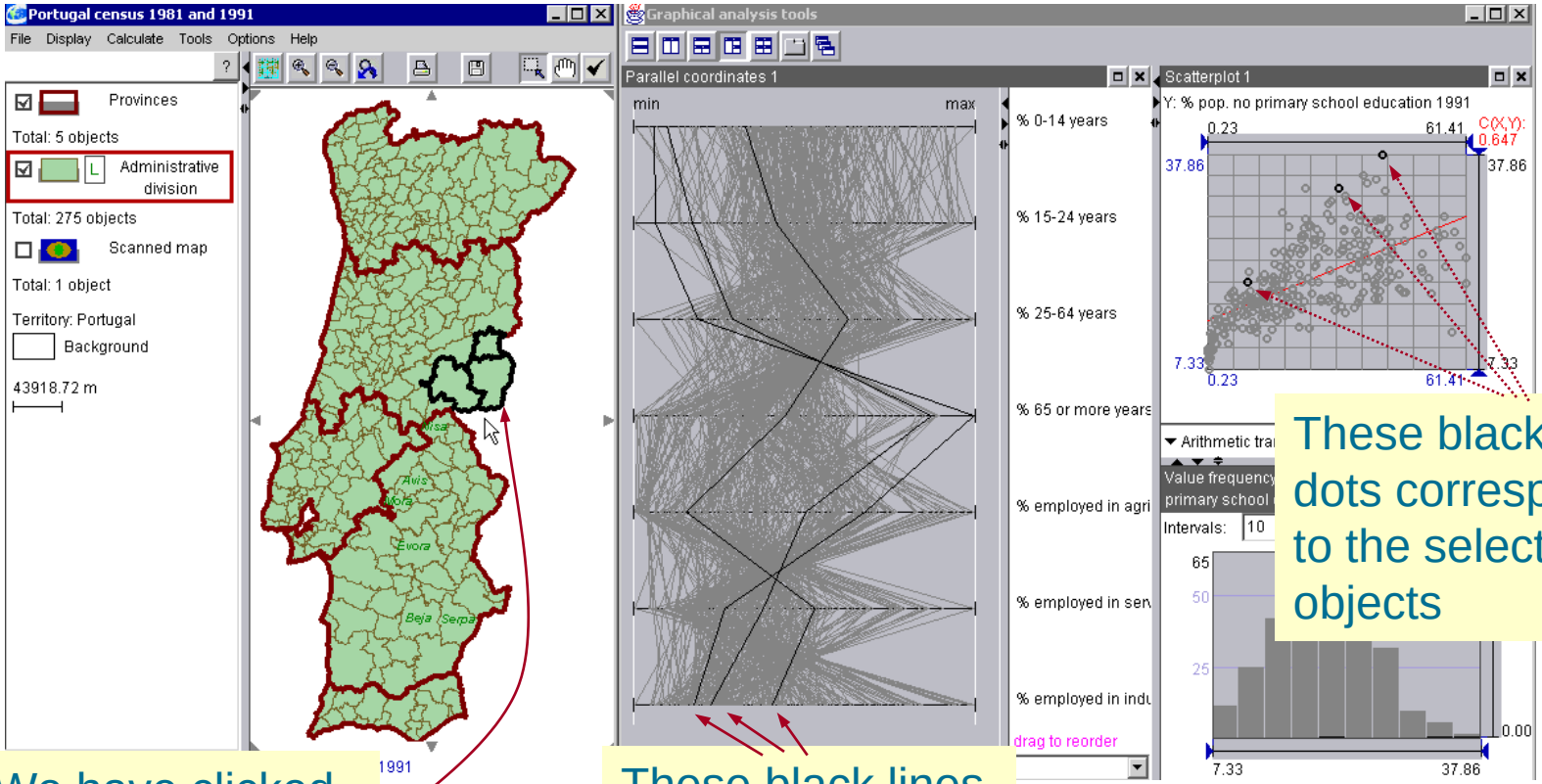
Display Linking by Selection

Selection (durable highlighting) does not disappear after the mouse is moved away. One or more objects may be selected e.g. by mouse-clicking on them.



We have clicked on each of these 3 objects

These black lines correspond to the selected objects

These black dots correspond to the selected objects

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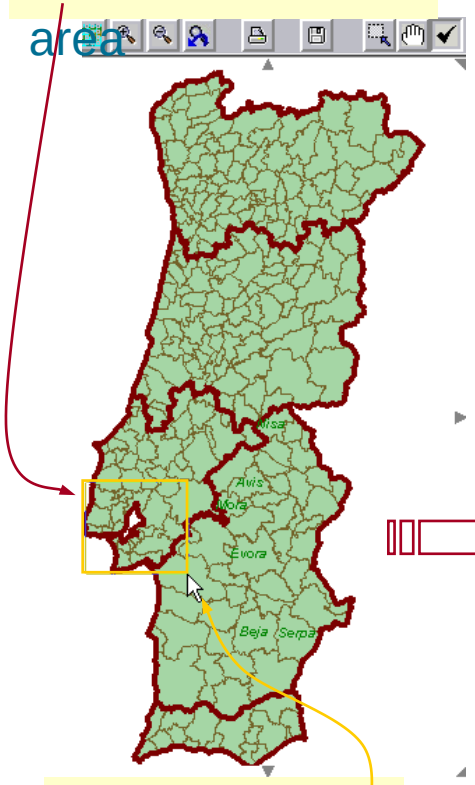
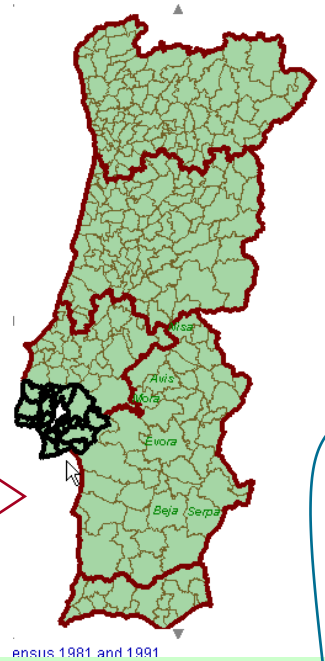
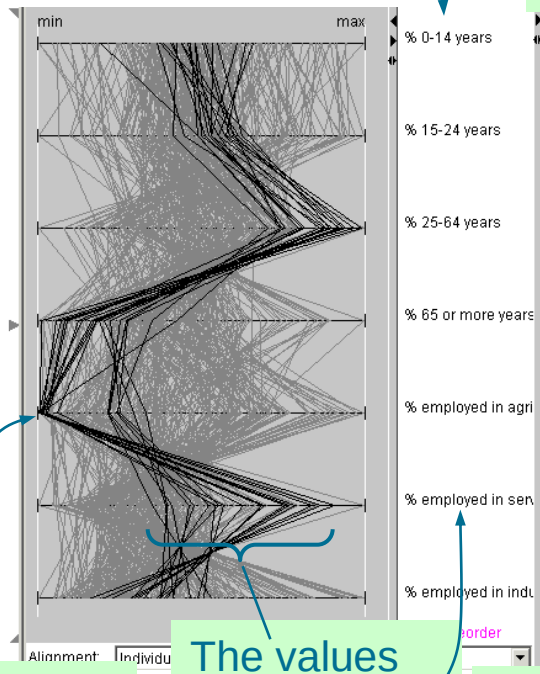
Using Display Linking (1)

Let us examine characteristics of districts in this area

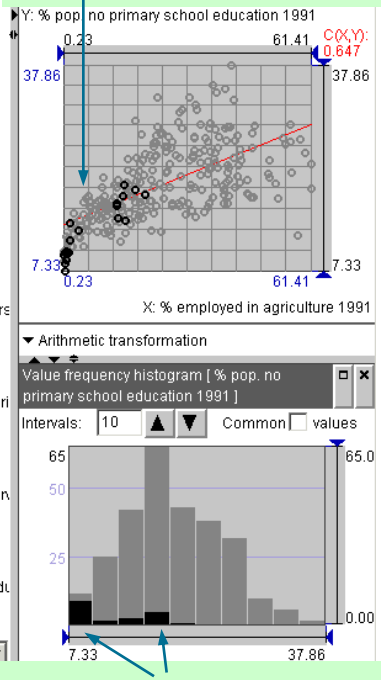




The characteristics in terms of the upper 4 attributes are rather coherent



Two distinct clusters in the value space of these two attributes



Enclose the area in a frame

The values of this attribute are split in two groups with a gap between

The values of this attribute greatly vary

The districts fit in the left half of the histogram, mostly in bars 1 and 4

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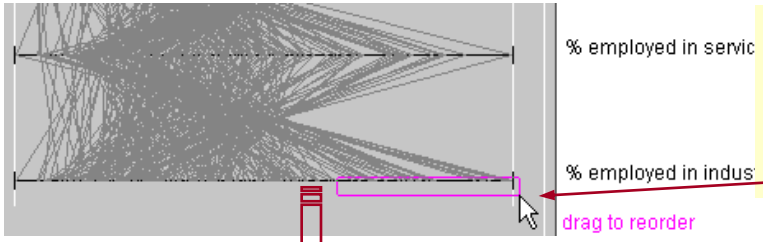
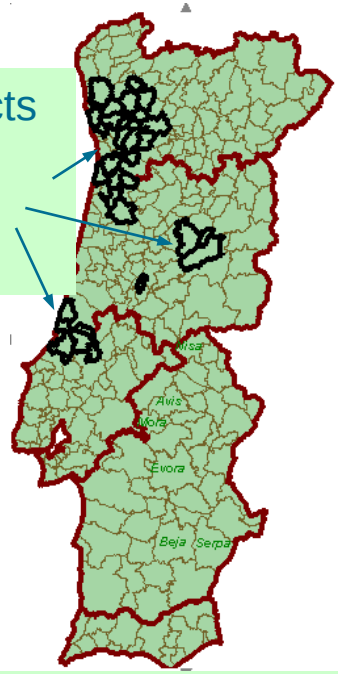
Using Display Linking (2)

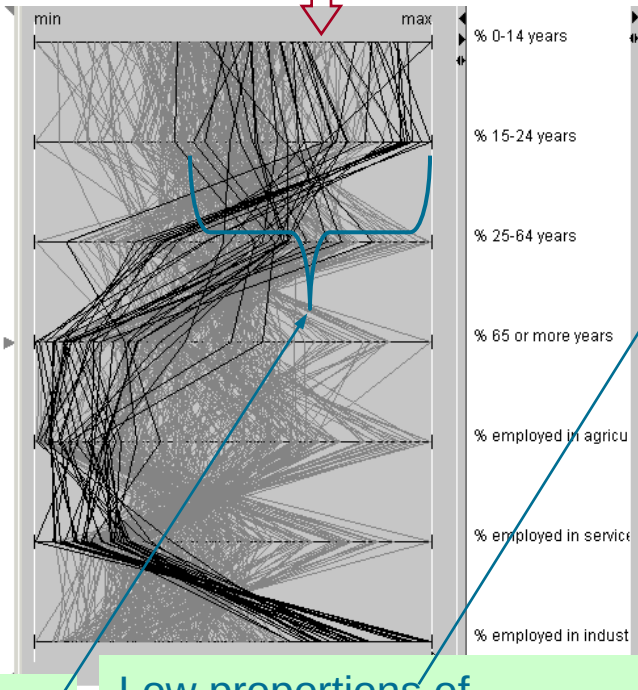
Let us look at the districts with high % employed in industry:

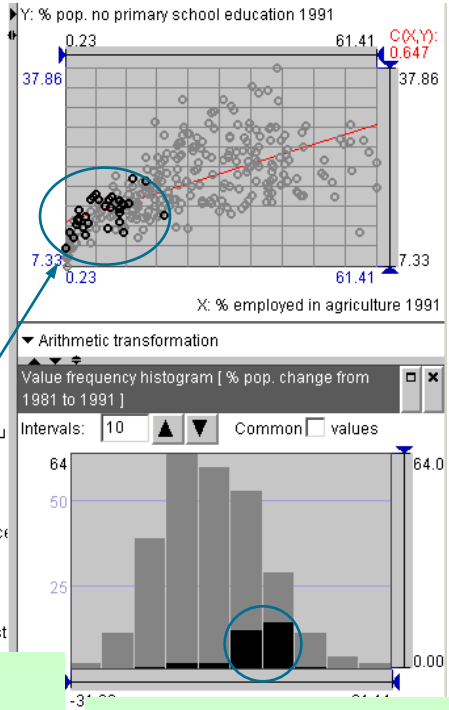


Select high values by drawing a frame

The districts form 3 spatial clusters







The districts have average or high proportions of children and young

Low proportions of agricultural workers and people without primary school education

Population change: mostly between –0.1% and 12.4%

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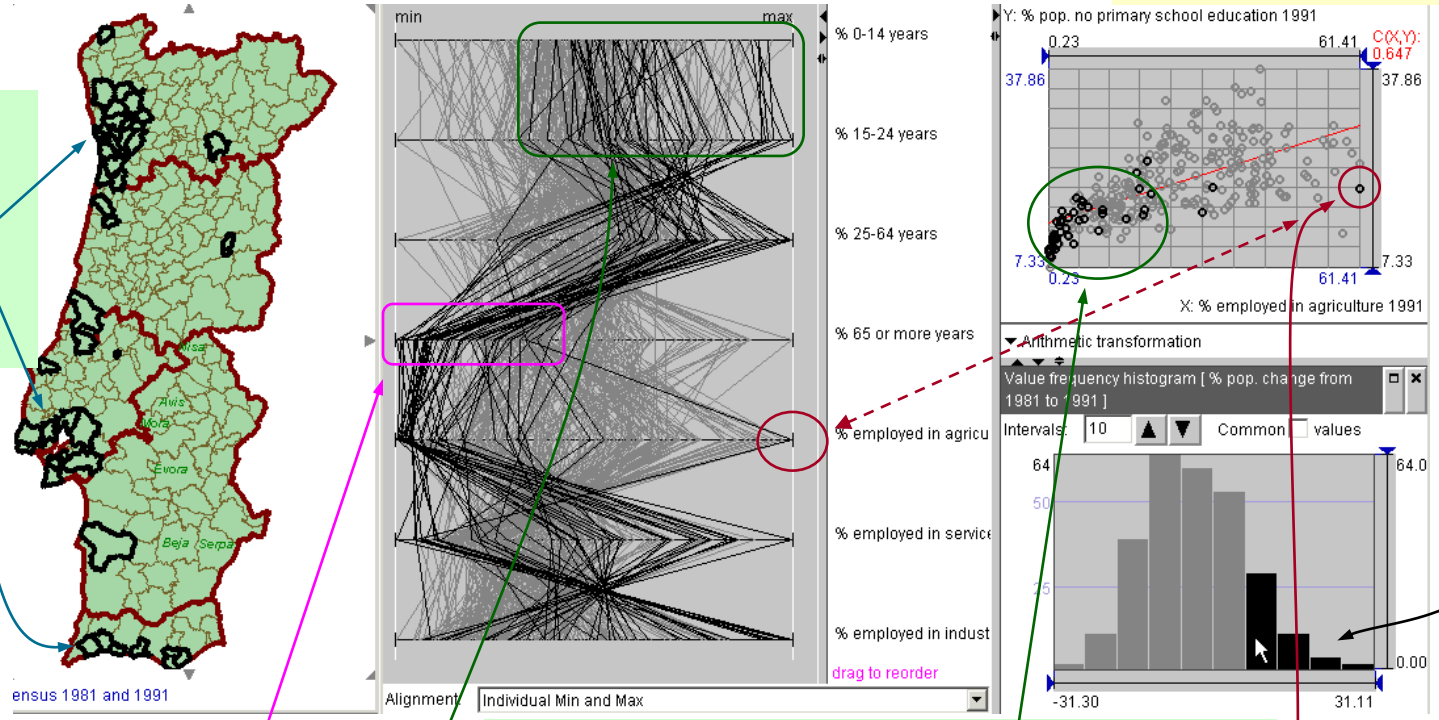
Using Display Linking (3)

Let us look at the districts with the highest population growth:

Click on the rightmost bars in the histogram

The districts form some spatial clusters



The districts have average or high proportions of children and young and low proportions of old people

The proportions of agricultural workers and people without primary school education are mostly low, but there is an outlier

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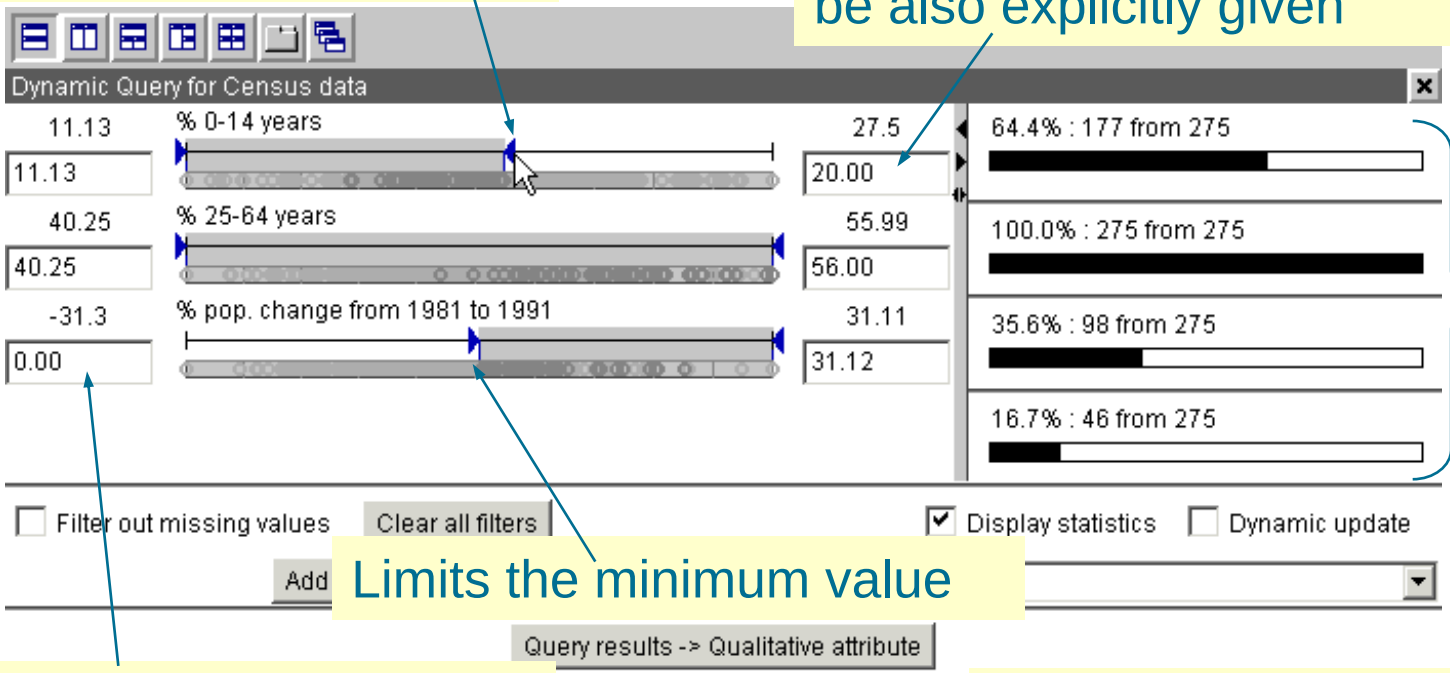
Dynamic Query

Dynamic query allows us to set constraints on attribute values

Limits the maximum value

The maximum limit can be also explicitly given



Limits the minimum value

The minimum limit can be also explicitly given

Statistics of constraint satisfaction

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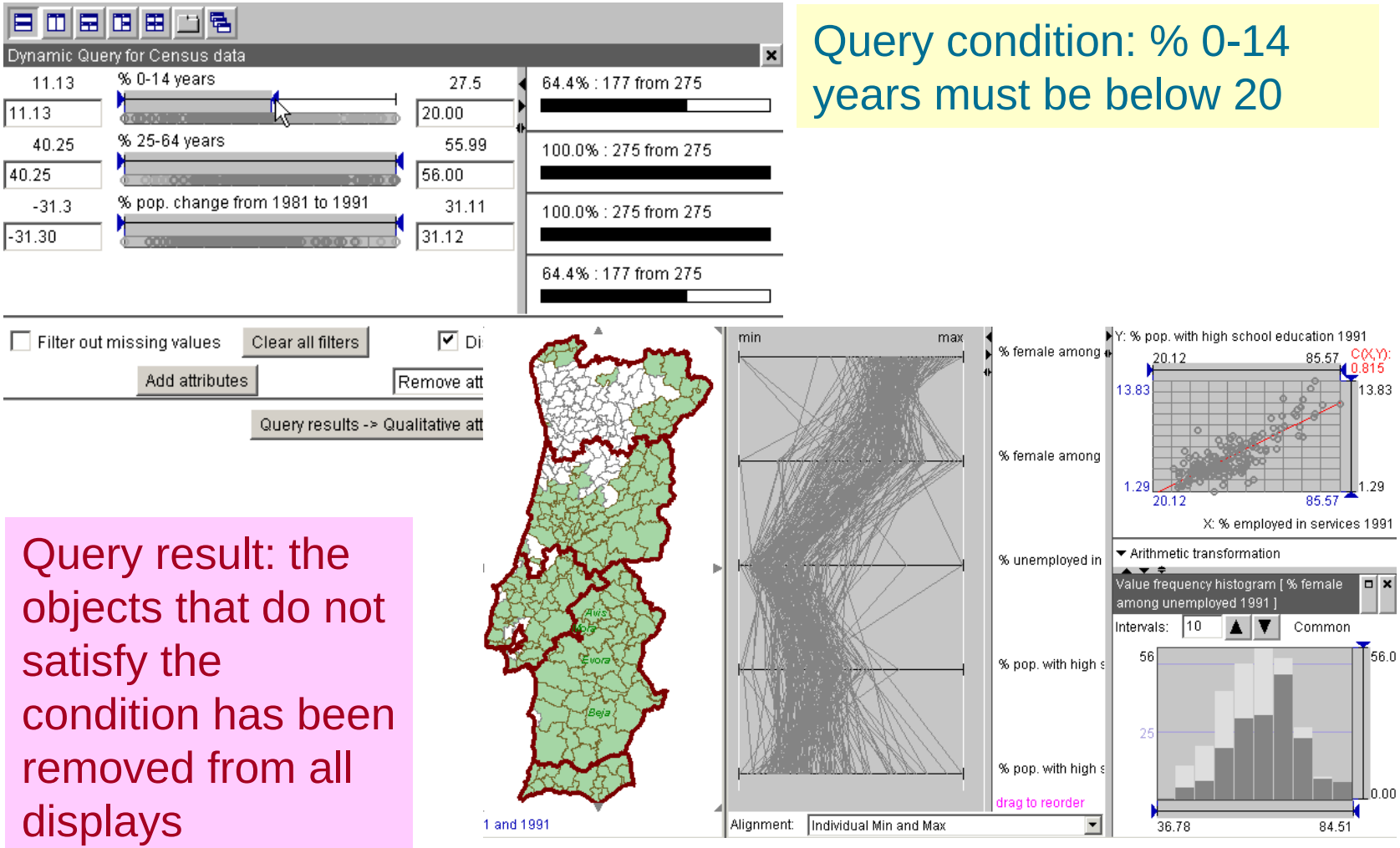
Dynamic Query in Action (1)



Query condition: % 0-14 years must be below 20

Query result: the objects that do not satisfy the condition has been removed from all displays

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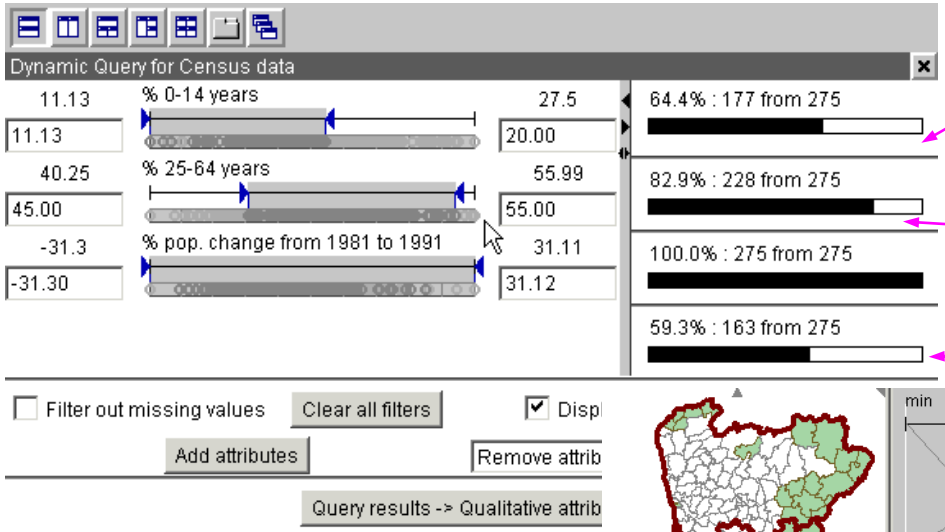
Dynamic Query in Action (2)

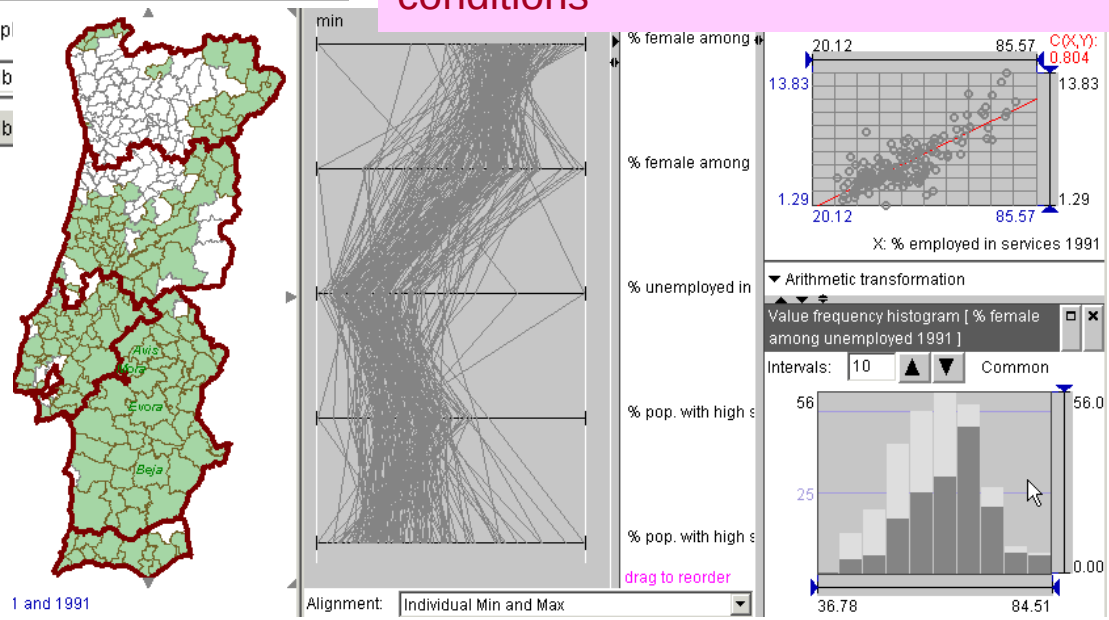
A second query condition added: % 25-64 years must be between 45 and 65



177 objects (64%) satisfy the 1st condition

228 objects (83%) satisfy the 2nd condition

163 objects (59%) satisfy both conditions



Query result changed: the objects that do not satisfy <u>both conditions</u> has been removed from all displays

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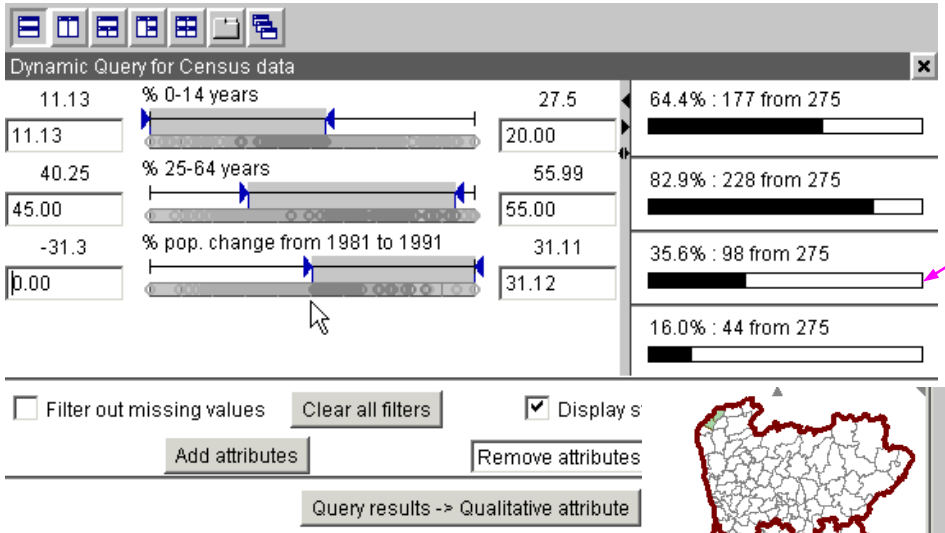
Dynamic Query in Action (3)

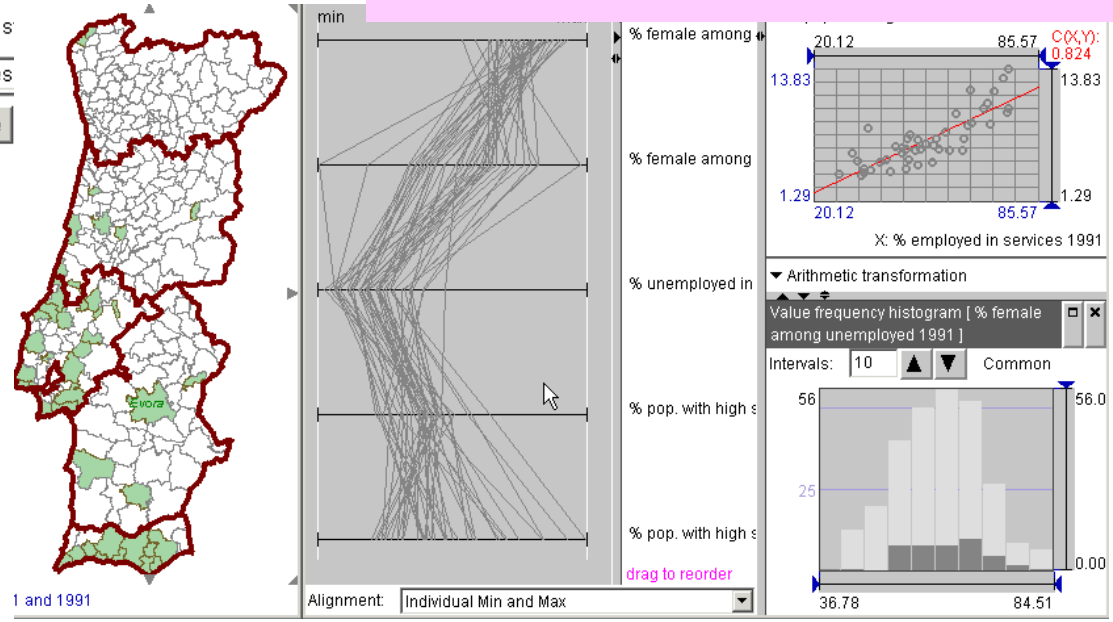
One more query condition added: % pop. change from 1981 to 1991 must be positive



…

98 objects (36%) satisfy the 3rd condition

44 objects (16%) satisfy all 3 conditions



Now the objects that do not satisfy <u>all 3 conditions</u> has been removed from all displays

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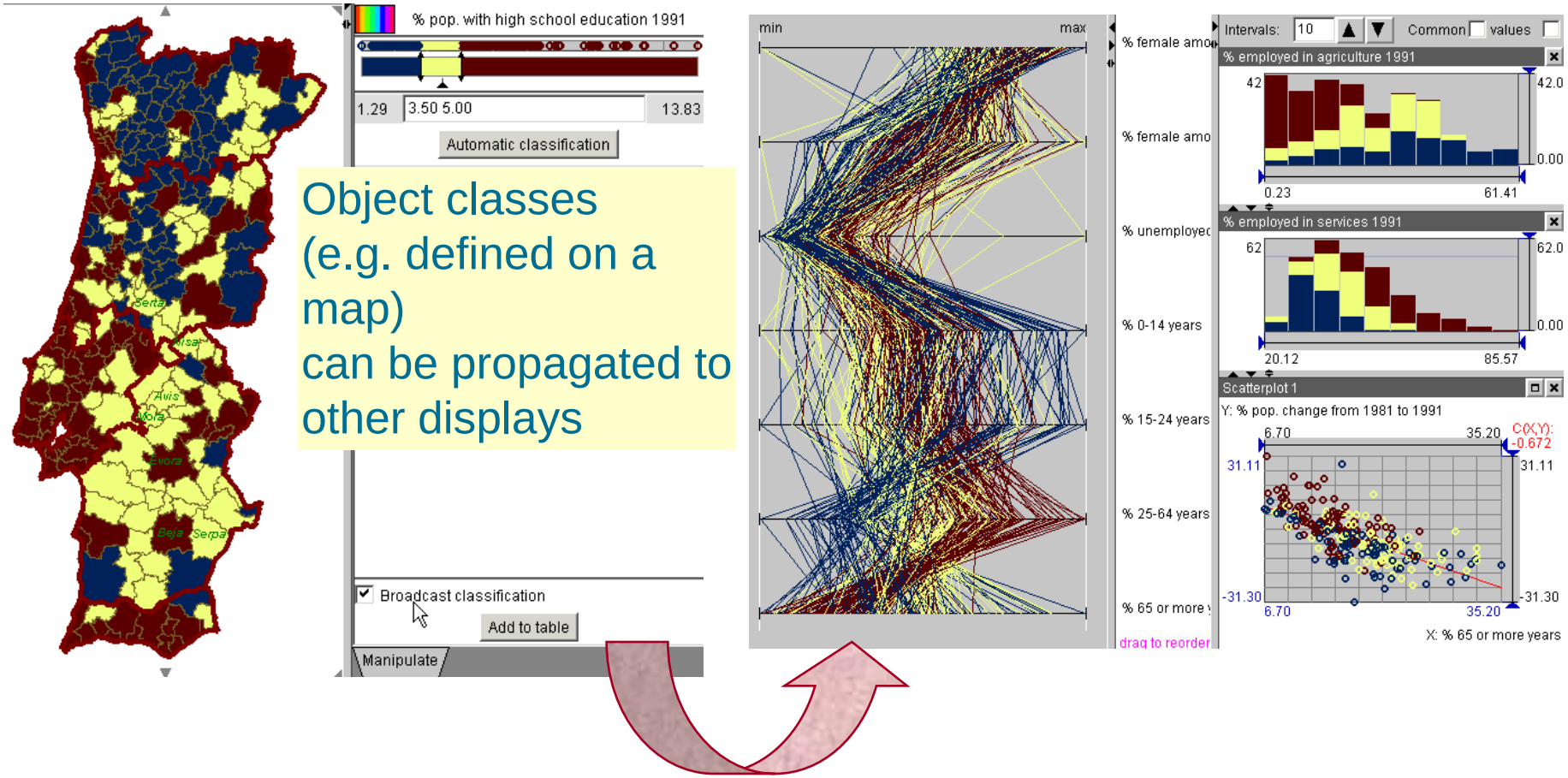
Propagation of Object Classes



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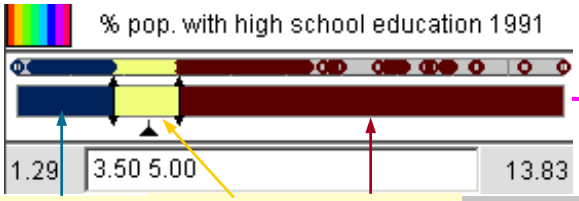
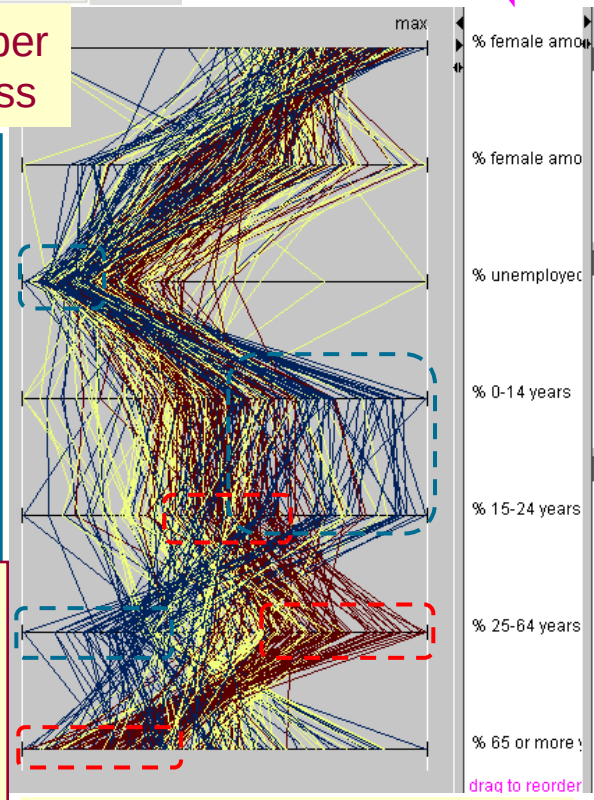
Propagation of Object Classes: Use Example

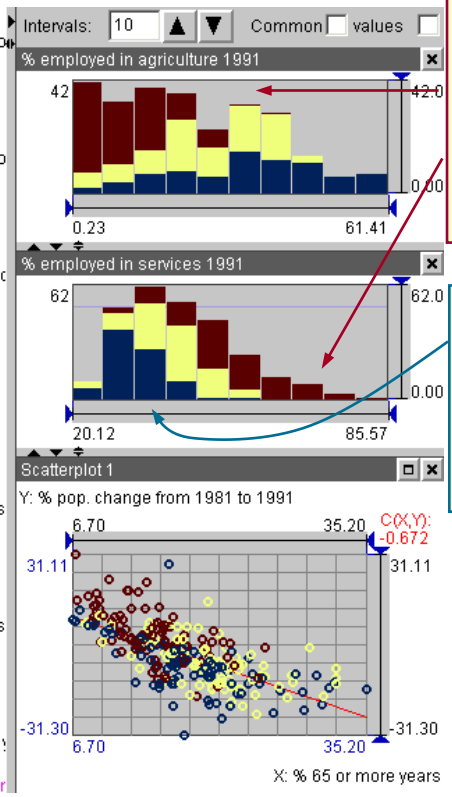


lower class | middle class | upper class

Lower class prevails among districts with low % unemployed, average or high % 0-14 years and % 15-24 years, and low % 25-64 years

Upper class prevails where % 25-64 years is high and % 65 or more years is low. It occupies mostly the middle part of the axis % 15-24 years.





Upper class co-occurs with low % employed in agriculture and average to high % employed in services

Lower class co-occurs with low % employed in services

Characteristics of the middle class are highly variant

In districts with high % employed in agriculture the proportion of people with high school education is low (mostly below 3.5%). For % employed in services we see the opposite relationship

Table View and Table Lens (1)

Click for sorting

Table cell shading shows the relative position of the values between the minimum and maximum values of the respective attributes

identifiers	Pop. density 1981	Pop. density 1991	% pop. no primary school education 1981	% pop. no primary school education 1991	% pop. with primary school education 1981	% pop. with primary school education 1991	% pop. with high school education 1981	% pop. with high school education 1991
Lisboa	9636.423	7912.43	37.26	8.51	39.49	25.45	7.675	11.11
Porto	7858.089	7260.49	37.32	8.83	39.97	26.22	8.756	9.84
Amadora	6895.481	7454.641	40.41	9.68	38.66	25.18	9.941	10.80
Oeiras	3257.592	3301.527	37.89	7.33	32.80	18.69	10.444	13.83
Barreiro	2796.012	2723.485	40.64	10.01	39.09	28.16	10.089	9.85
Matosinhos	2190.979	2434.703	42.45	11.01	40.12	29.08	9.857	7.78
Almada	2110.581	2169.072	40.58	10.26	38.49	25.99	8.813	10.66
Sao Joao da Madeira	2027.62	2275.216	41.12	10.21	39.62	28.59	9.658	7.68
Espinho	1513.025	1631.933	44.68	11.37	35.82	27.50	10.919	7.56
Cascais	1457.75	1579.276	39.37	8.92	34.97	21.13	9.718	12.95
Loures	1419.716	1654.349	40.84	10.29	39.32	27.12	9.950	10.09
Vila Nova de Gaia	1324.968	1455.128	43.66	11.61	39.18	29.86	10.352	7.07
Gondomar	981.172	1074.426	43.20	12.31	39.93	29.72	10.493	6.93
Maia	975.854	1112.915	44.45	11.71	39.08	30.47	10.406	7.07
Moita	966.594	1181.663	46.27	14.50	37.64	26.61	9.123	7.71
Seixal	952.844	1249.3	41.18	10.15	38.33	24.60	10.375	11.15
Valongo	880.038	1016.194	42.80	11.90	39.94	30.70	11.492	6.40
Entroncamento	874.161	1038.394	38.51	9.10	40.18	26.73	7.952	11.22

Sort by: Pop. density 1981 | Descending | ☑ TableLens | ☐ condensed | Attribute...

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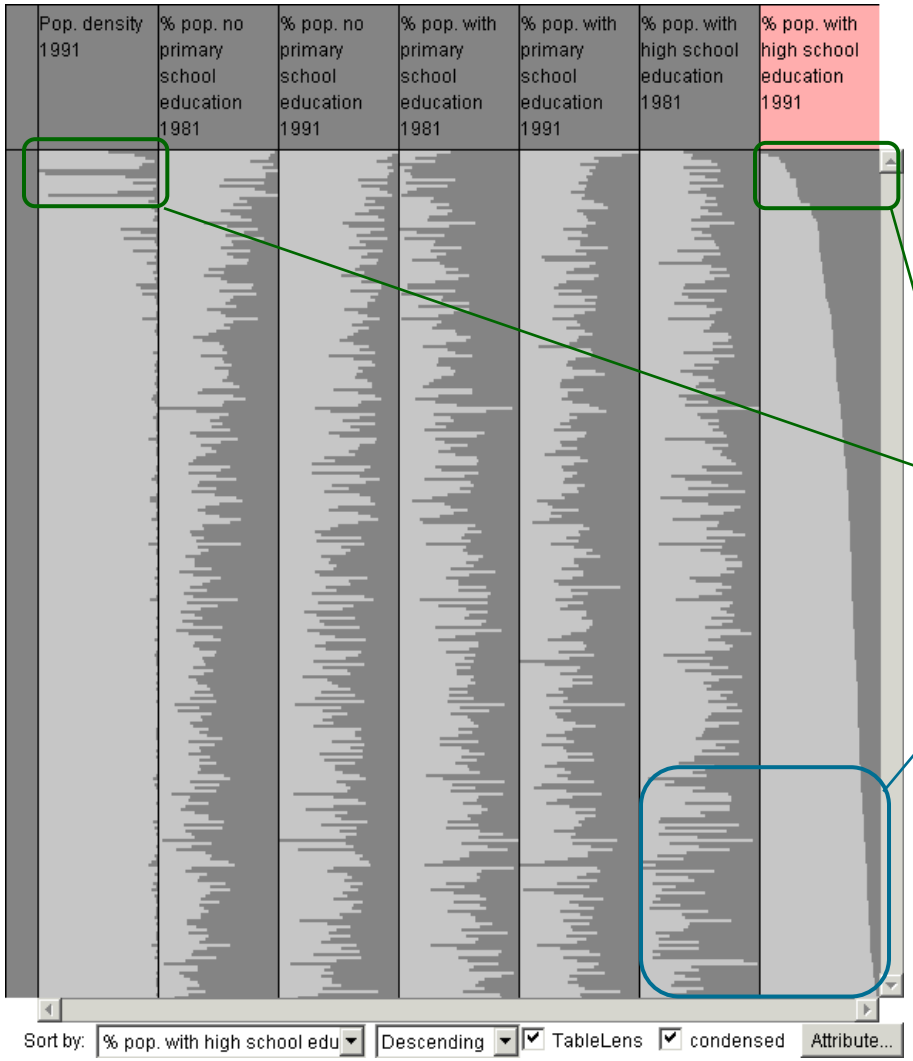
Table View and Table Lens (2)



The same information can be represented in a “condensed” form. We do not see the details about particular objects but get an overall impression about value variation and relationships between attributes.

High proportions of people having high school education often co-occur with high population density

Surprisingly, the districts with the lowest proportions of people having high school education in 1991 had much higher proportion of such people in 1981

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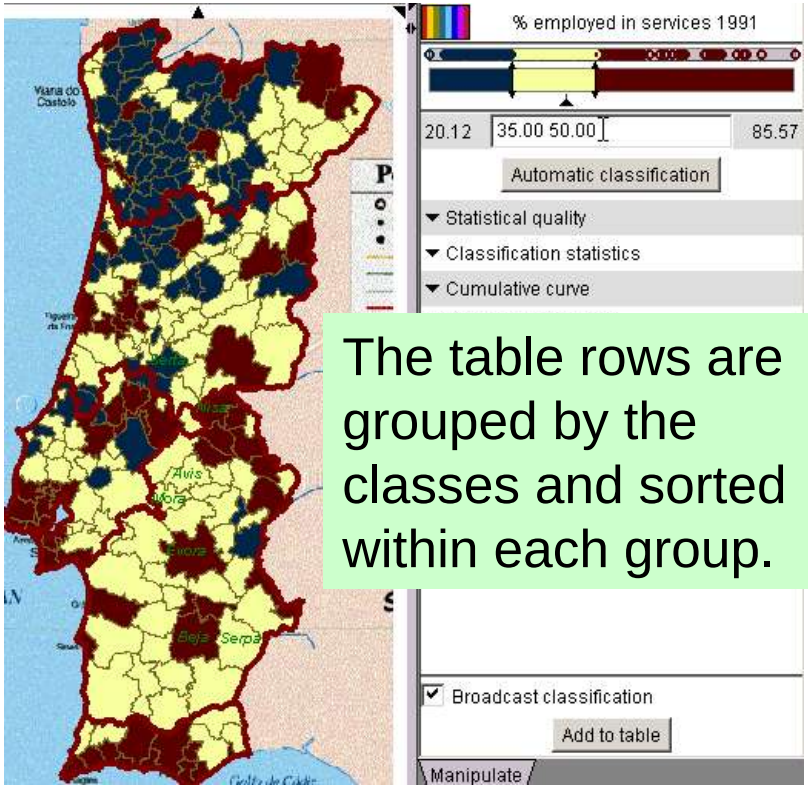
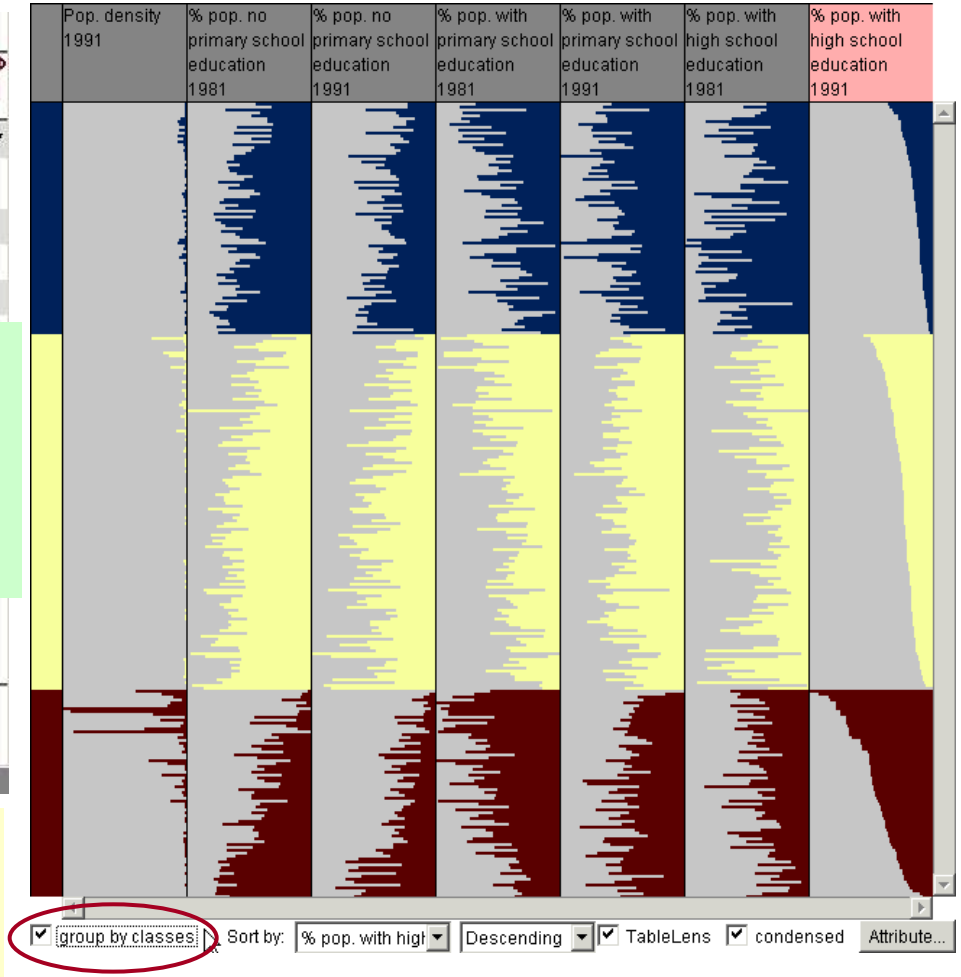
Class Propagation to Table View (1)



The table rows are grouped by the classes and sorted within each group.



These linked views show us, for example, that the general educational level tends to be higher in districts with high proportion of people employed in services

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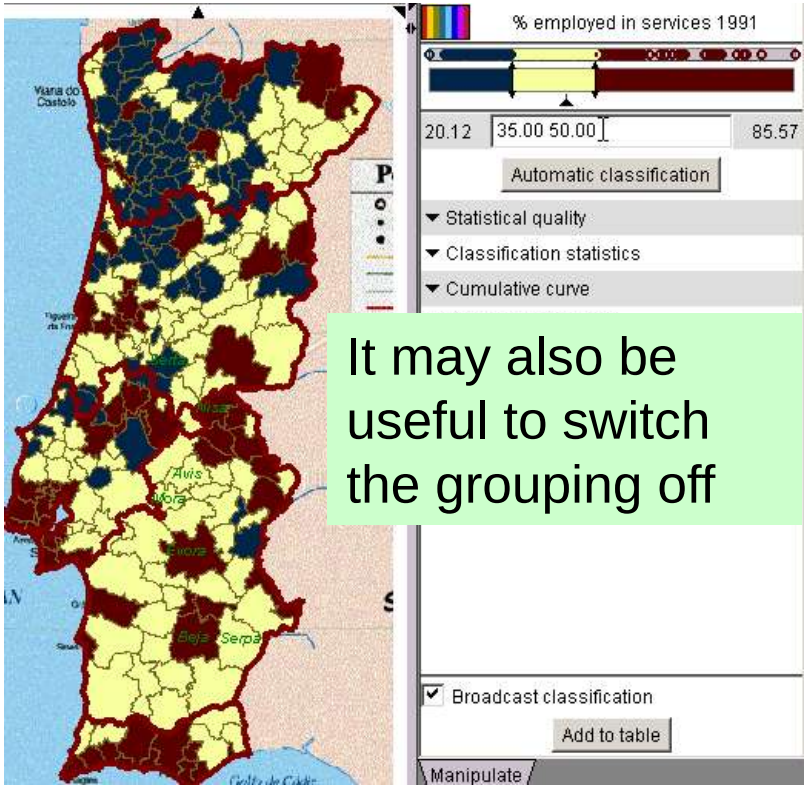
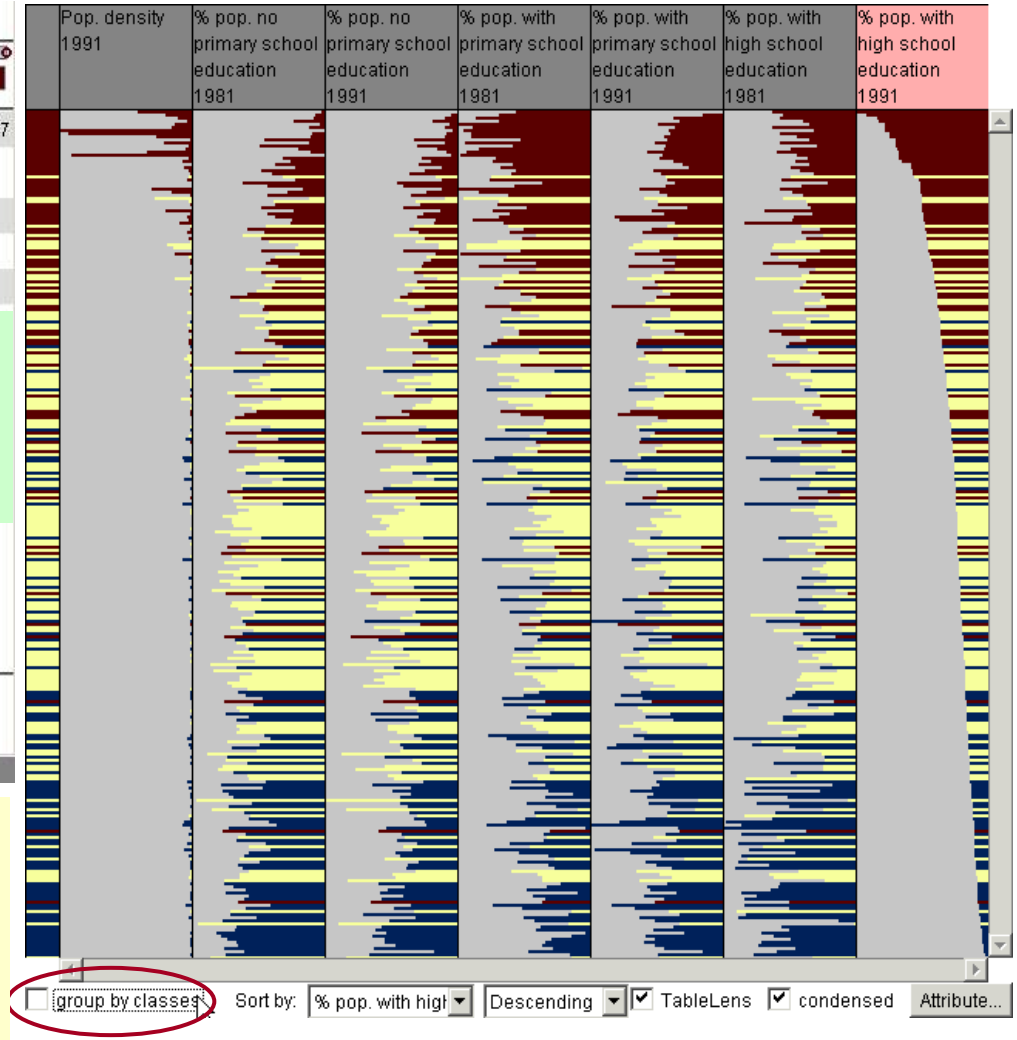
Class Propagation to Table View (2)



It may also be useful to switch the grouping off



We see that the red rows occur mostly at the top of the table and blue ones at the bottom. Note that the rows are sorted according to % people with high school education in 1991.

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Summary

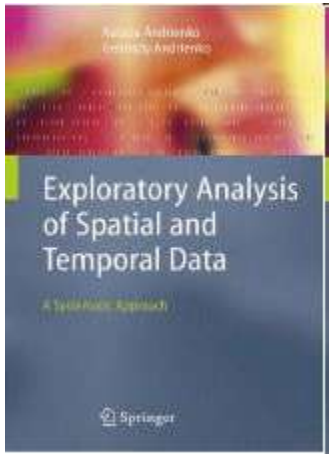
This lecture was supposed to

- introduce the concept of analytical interactive maps
- stress the importance of exploring various aspects of data using multiple views
- demonstrate some types of non-cartographic displays useful in analysis of geodata
- demonstrate various techniques of display linking
- show how to use this in data analysis

See also

- Natalia and Gennady Andrienko
  Exploratory Analysis of Spatial and Temporal Data
  A Systematic Approach
  Springer-Verlag, December 2005

  section 4.8, pp.428-449



Data structure

So far:

- Id, x, y, attribute(s)

Let’s add one more special component: **time**

- Id, x, y, **t**, attribute(s)

Overview

Types of Analysis Tasks on Spatio-Temporal Data

Three primary task foci (target information)

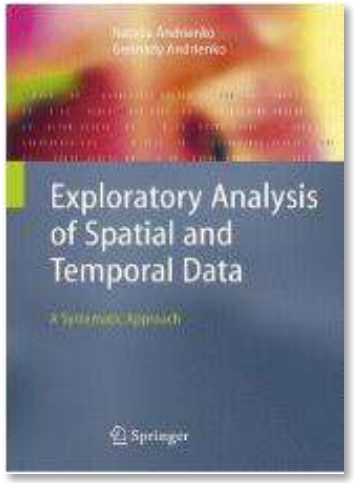
- Focus on *objects*
- Focus on *space*
- Focus on *time*

Two types of task subject

- Characteristics
- Relations

Two levels of analysis

- *Elementary*: focus on one or more elements of a set
- *Synoptic*: focus on a set as a whole, disregard individual elements
- Task may be elementary w.r.t. one subject and synoptic w.r.t. another



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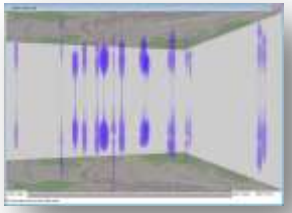
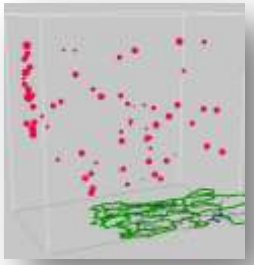
Data Types and Transformations

Methods & Techniques for Different Spatio-Temporal Data



Spatial time series



Events

Trajectories

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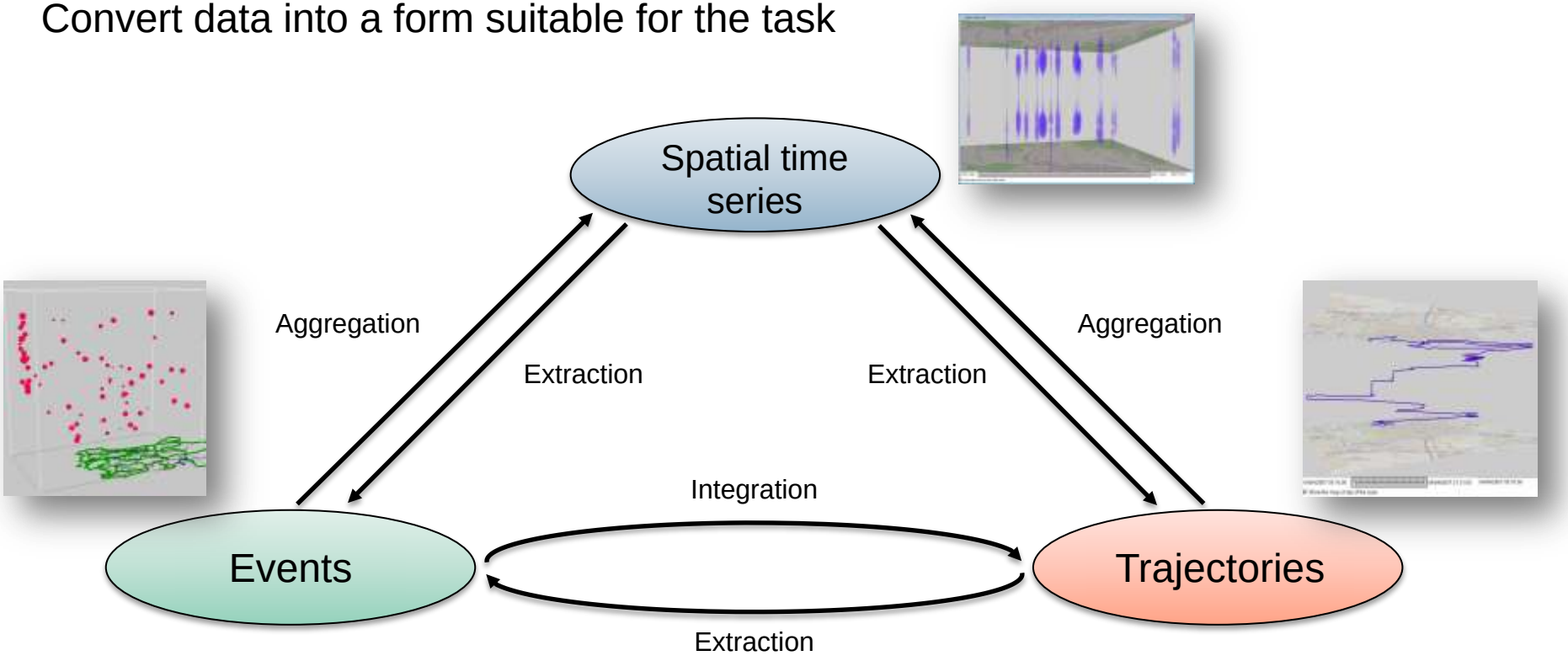
Data Types and Transformations

Methods & Techniques for Different Spatio-Temporal Data

Representation forms offer different conceptual views on ST data

Convert data into a form suitable for the task



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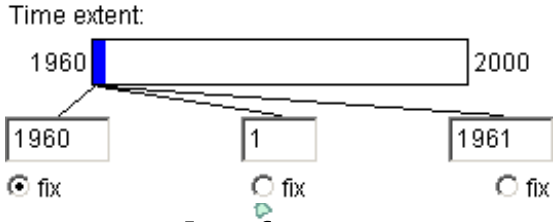
Spatial Time Series

Data structure

Spatial references: states of the USA



Temporal references: years from 1960 till 2000 (41)

Attributes: population + various crime rates

Population	Index offense rate	Violent Crime rate	Murder and nonnegligent manslaughter rate	Forcible rape rate	Robbery rate	Aggravated assault rate	Property crime rate	Burglary rate	Larceny-theft rate	Motor vehicle theft rate

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High level analysis questions

Spatial Time Series (STS)

How are attribute values distributed over the territory at a given time moment?

How do the attribute values at a given place vary over time?

How does the overall spatial pattern of value distribution evolve over time?

How are different behaviour patterns distributed over the territory? Are there spatial clusters of similar behaviours?

Spatial Time Series

Methods & Techniques for Different Spatio-Temporal Data I

Visualization methods

- Animated maps
- „Layman techniques": (animated) charts embedded in maps (bar charts, pie charts, …)
- "Small multiples" map displays
- Time Graphs and their transformations

Spatial Time Series

Methods & Techniques for Different Spatio-Temporal Data I

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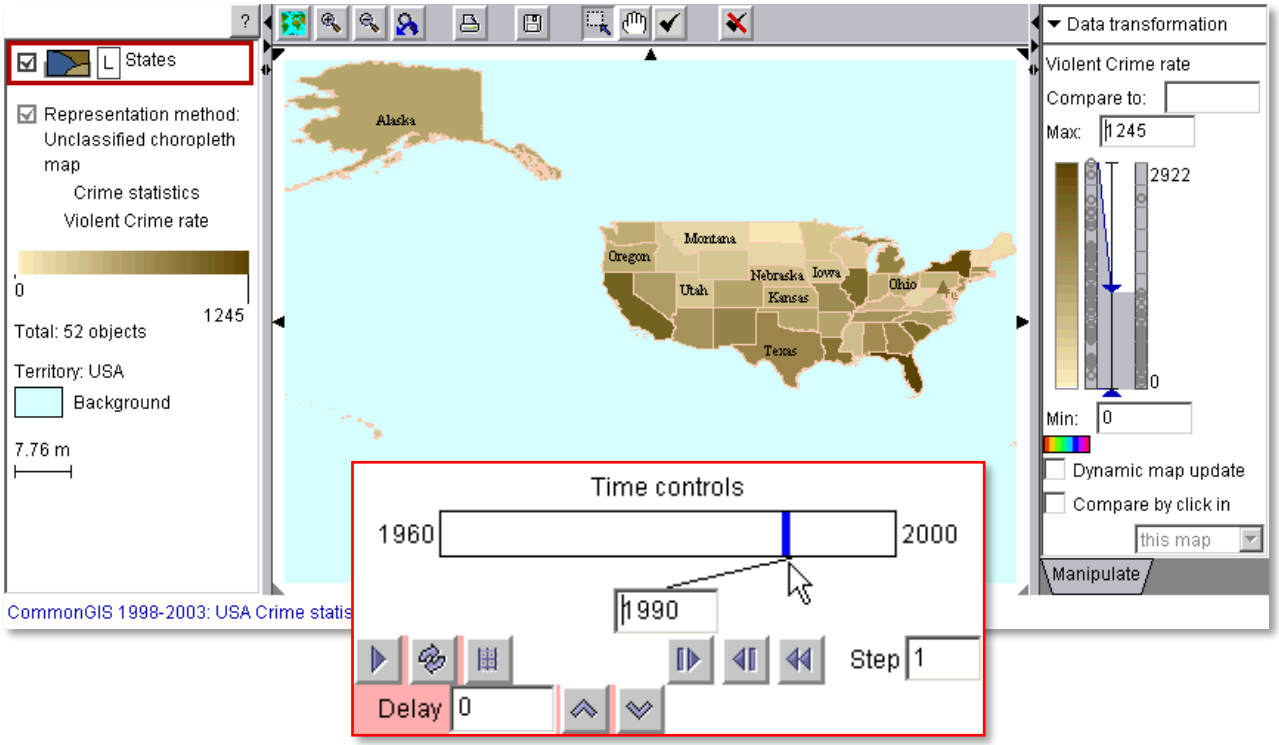
- Time Graphs and their transformations

Time Map

Spatial Time Series: Basic Visualization Methods I



For a time map, one can use any representation method suitable for static data. <u>Choropleth maps</u> are good for exploring *spatial distribution patterns.*

Time-dependent data may be represented on a <u>time map</u>, which is manipulated through time controls and, in particular, allows animation

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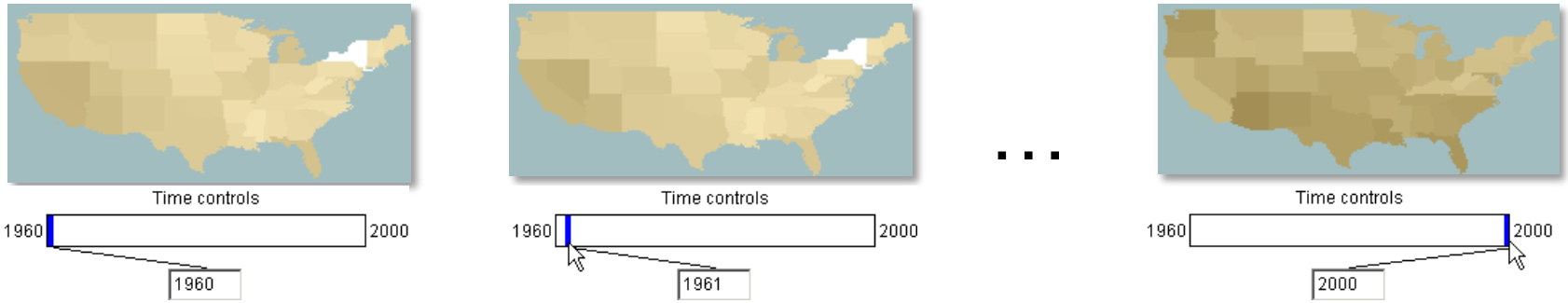
When time map is useful

Spatial Time Series: Basic Visualization Methods I



How did the spatial distribution pattern develop over time?

At moment *t*, how were the values distributed over the whole space?

At what time moment were the values distributed over the space in the given manner?

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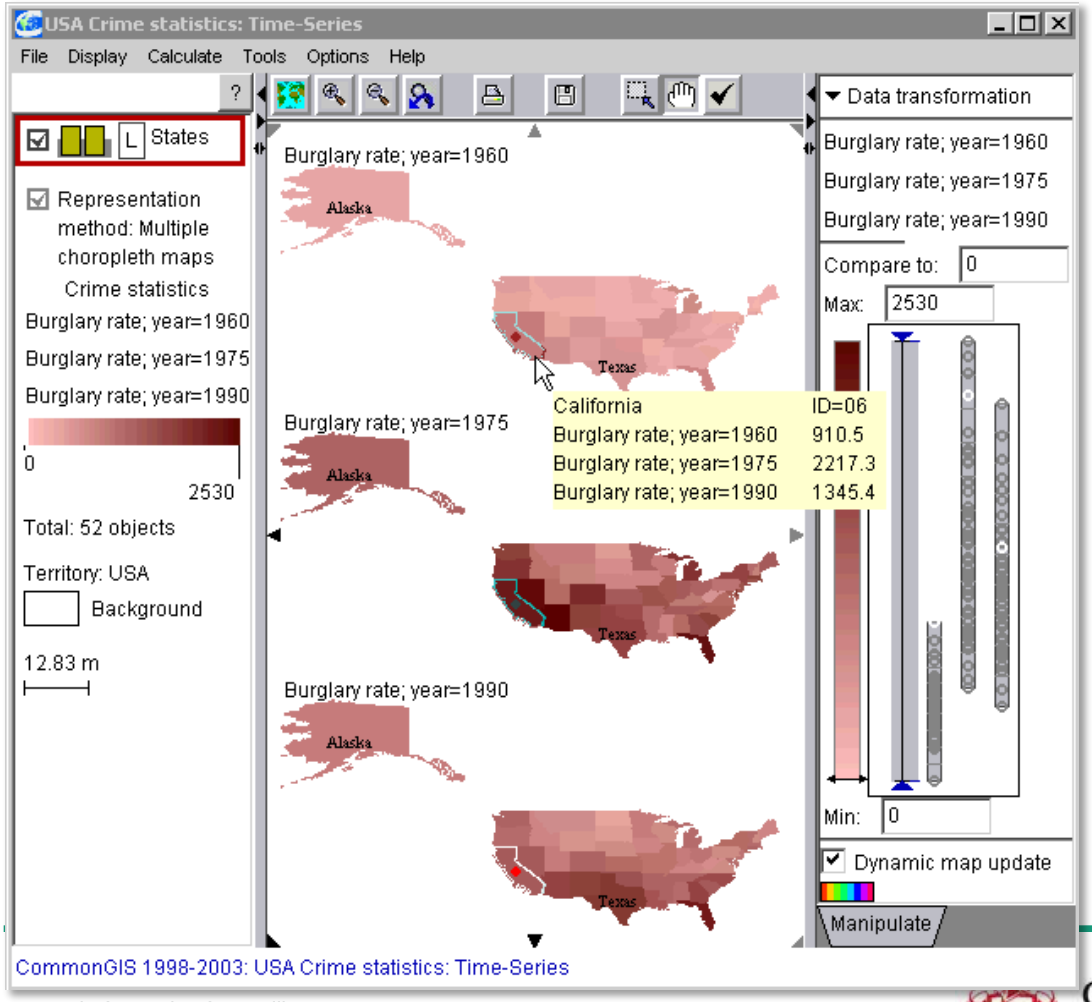
Map Series

Spatial Time Series: Basic Visualization Methods I



To compare the spatial distributions of attribute values at two or more time moments, we need to see these distributions simultaneously. Best of all is to use multiple maps displayed in a common panel and manipulated through a common set of controls.

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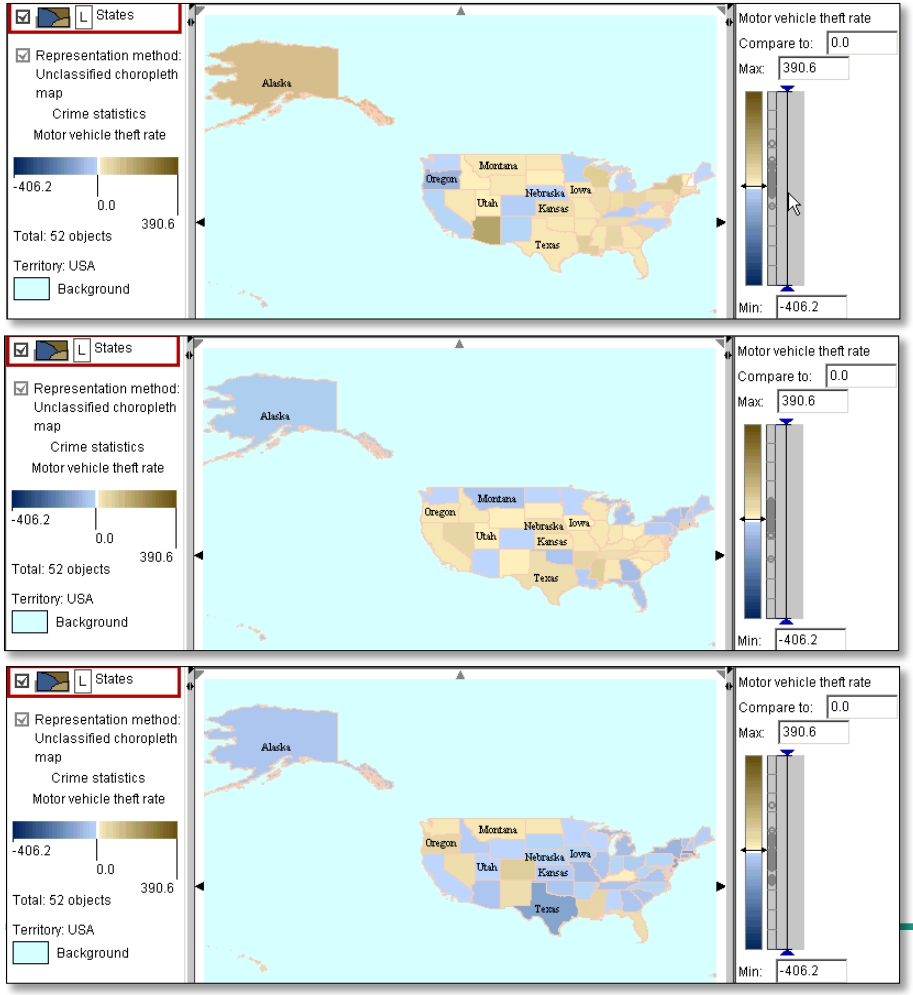
Exploring the Distribution of Changes

Spatial Time Series: Data Transformations



Instead of original attribute values, a time map or map series can represent <u>changes</u>, that is, differences or ratios to the previous moment or to any selected moment

Here the maps correspond to years 1990, 1991, and 1992 and represent differences to the previous years. Positive differences (i.e. increased values) are shown in brown and negative differences (i.e. decreased values) in blue

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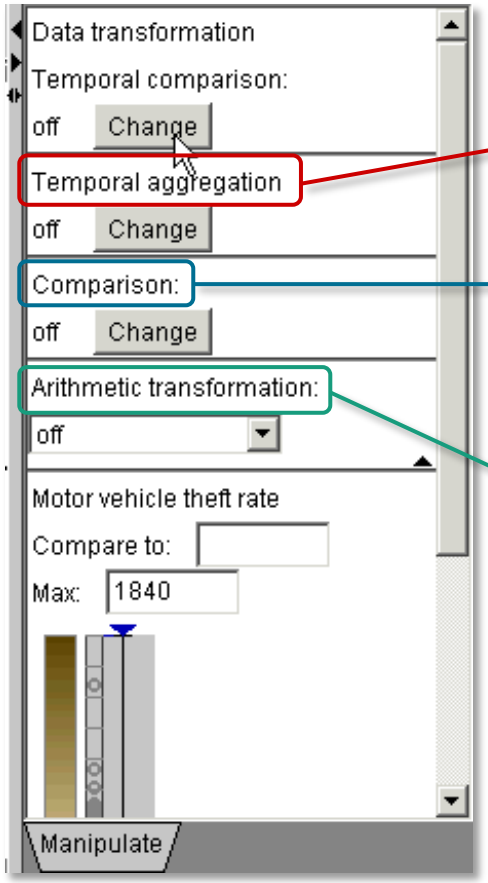
Map Series: Useful Transformations

Spatial Time Series: Data Transformations



Temporal smoothing and computing of residuals

For each time moment computes differences or ratios to a particular object or value or to the mean or median among all objects at this moment

Value scale transformation, e.g. logarithmic

Comparison to country's median

Spatial Time Series: Data Transformations

Build map series with transformed data:
relative difference to median value

Spatial distribution patterns of attribute values may become more vivid

Value and patterns evolution over time can be seen more easily

Spatial Time Series

Methods & Techniques for Different Spatio-Temporal Data I

Visualization methods

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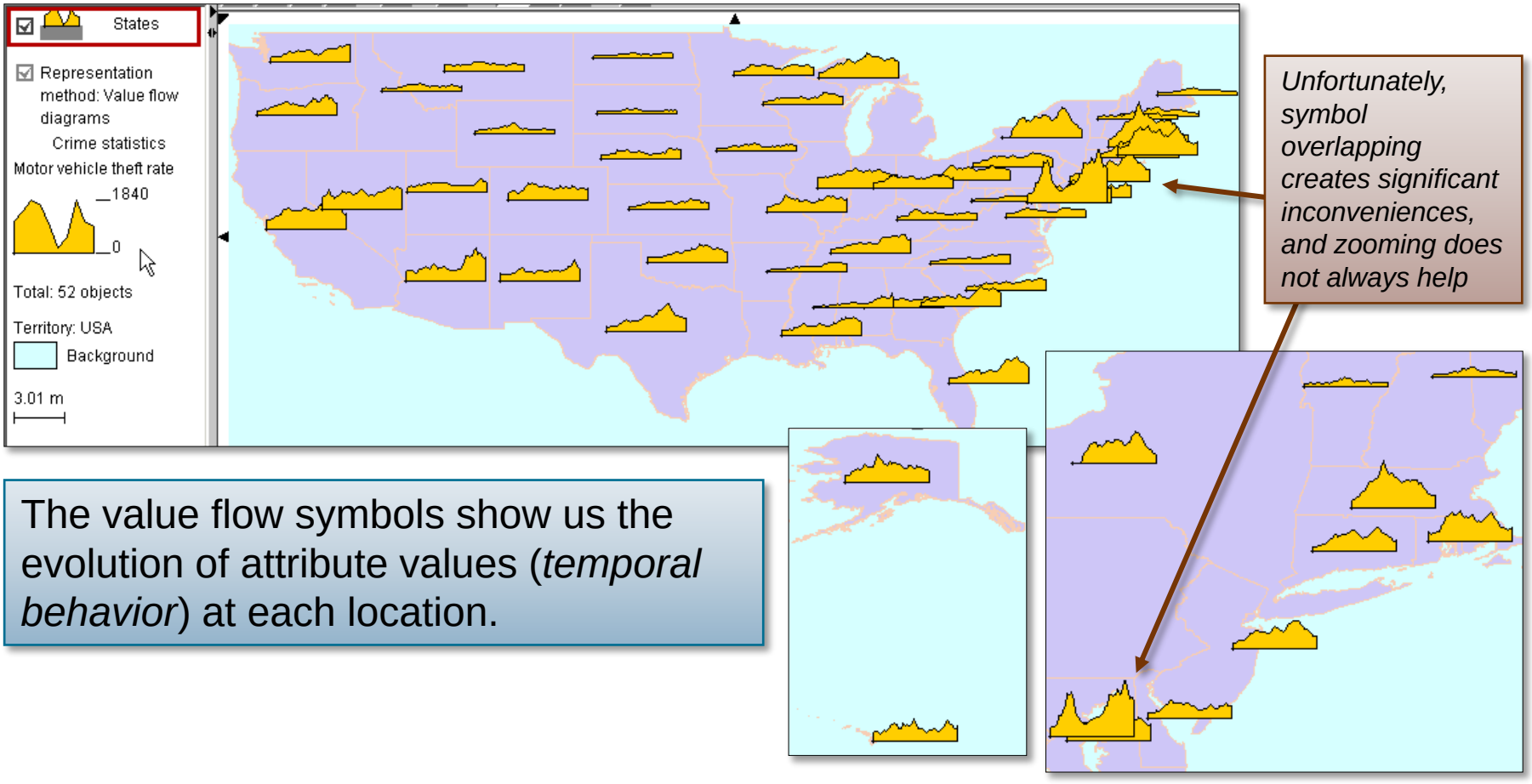
Value Flow Map

Spatial Time Series: Basic Visualization Methods II



Unfortunately, symbol overlapping creates significant inconveniences, and zooming does not always help

The value flow symbols show us the evolution of attribute values (*temporal behavior*) at each location.

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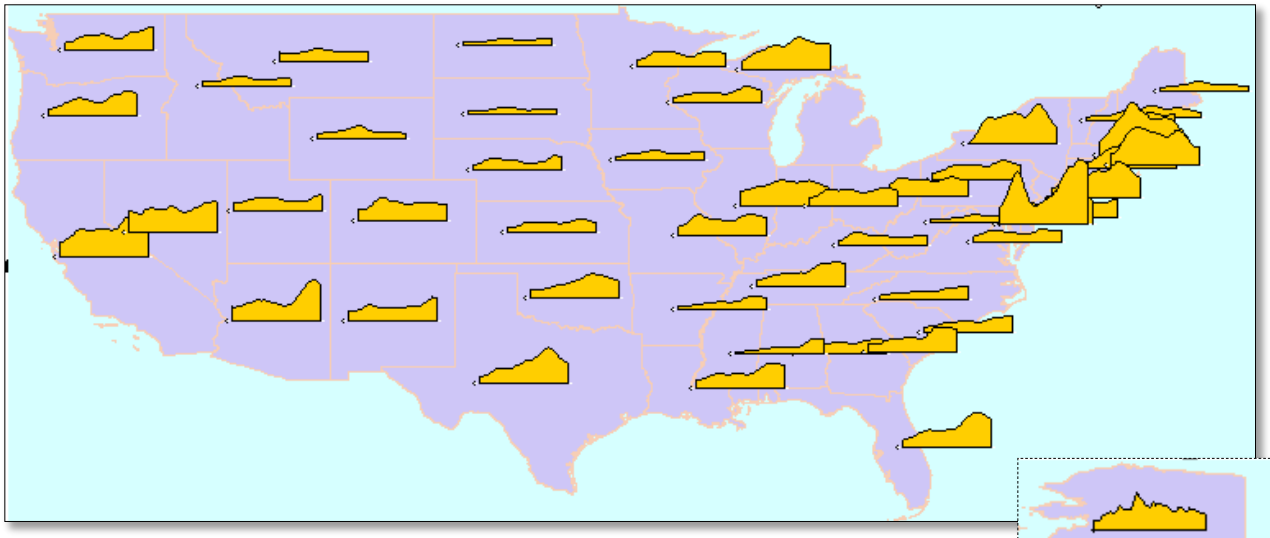
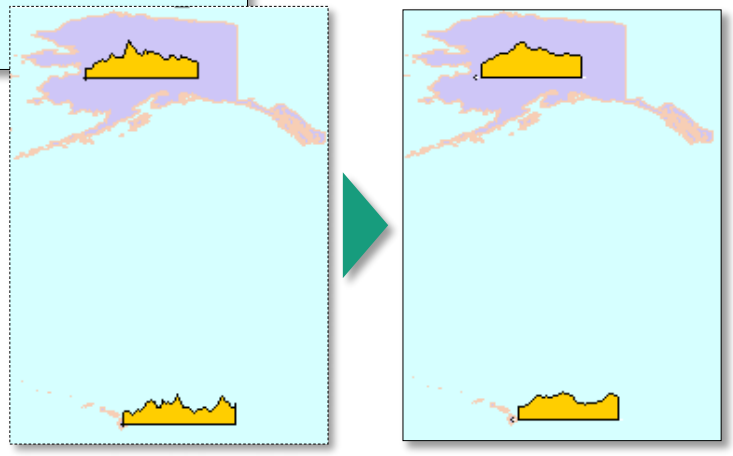
Value Flow Map (2)

Spatial Time Series: Basic Visualization Methods II



Temporal smoothing allows to disregard small fluctuations and see overall trends.

Here the values for each year have been replaced by 5-year means. You can compare to the previous variant and see the effect of the smoothing.



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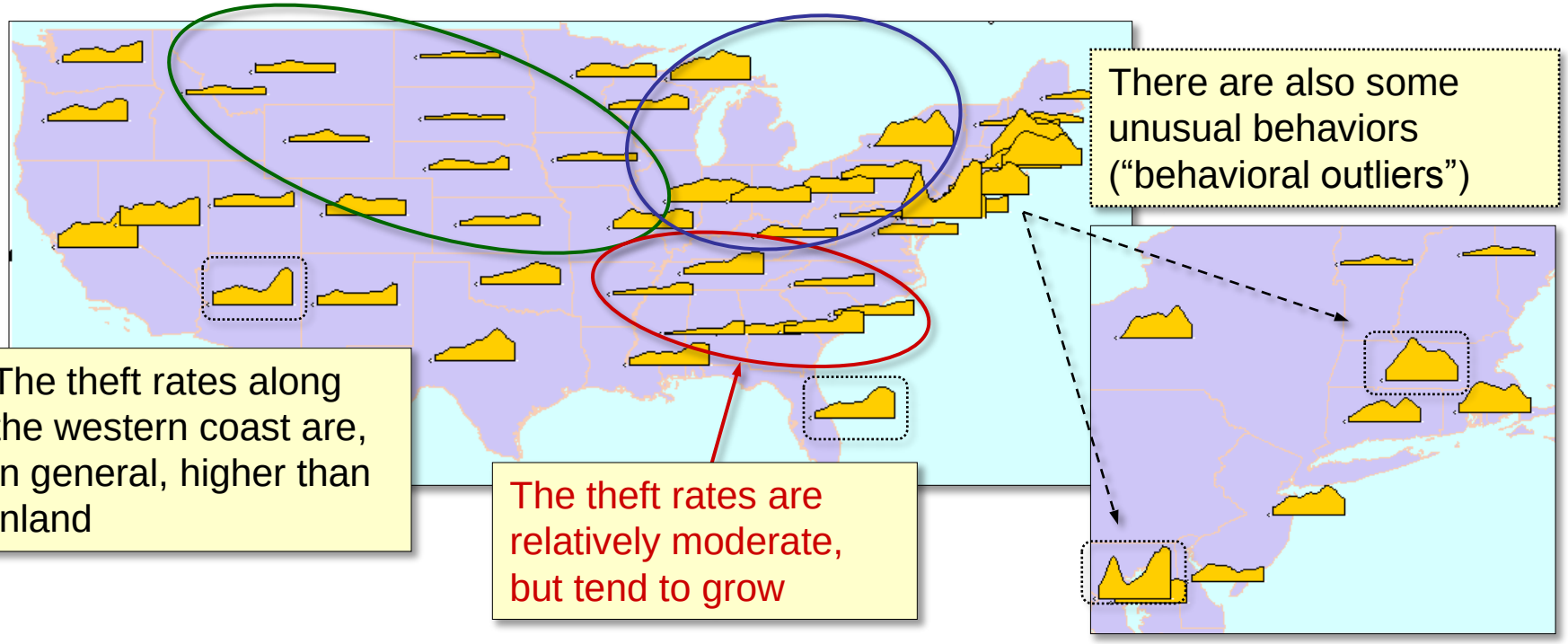
Value Flow Map (2)

Spatial Time Series: Basic Visualization Methods II

This appears to be a spatial cluster of similar behaviors

Around the Great Lakes, the theft rates were high, but tended to decrease in last years



There are also some unusual behaviors (“behavioral outliers”)

The theft rates along the western coast are, in general, higher than inland

The theft rates are relatively moderate, but tend to grow

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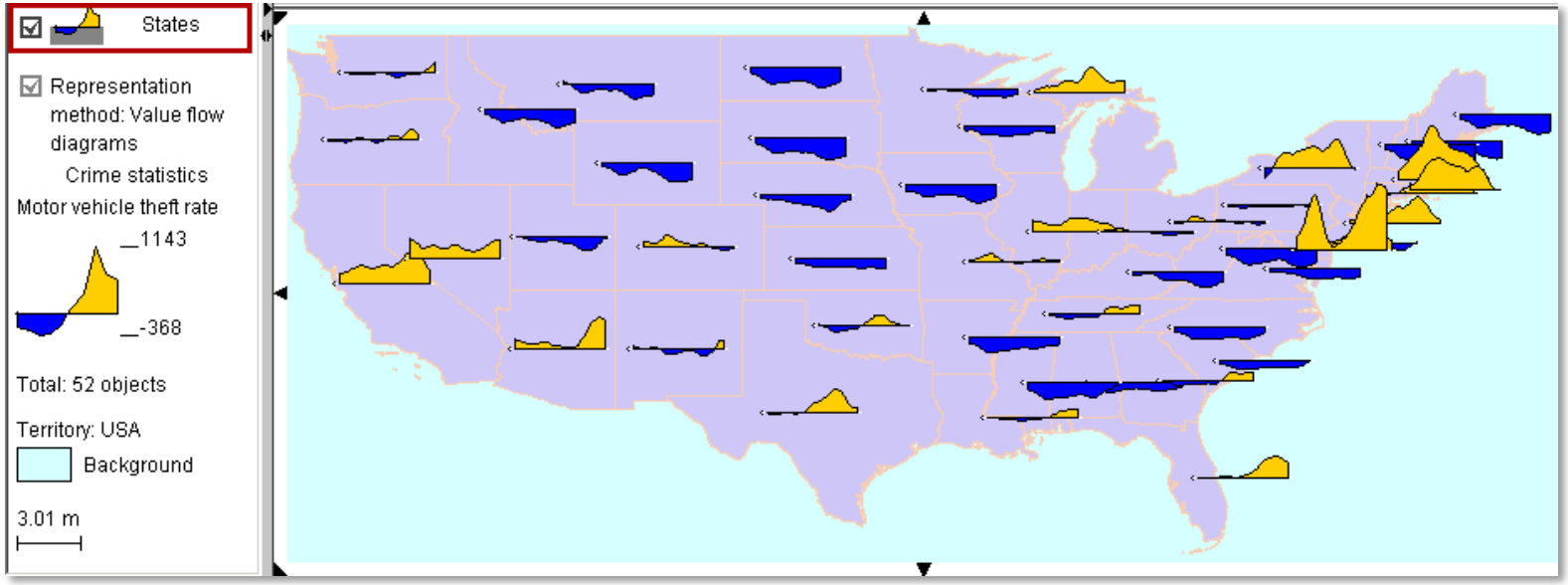
Temporal Behavior Exploration

Spatial Time Series: Data Transformations

As with time maps, various transformations can be applied to value flow maps



Here: comparison to each country's mean

- For every time moment, each state's values is replaced by its difference to the country's overall mean value at that moment
- Yellow color corresponds to positive differences, and blue – negative

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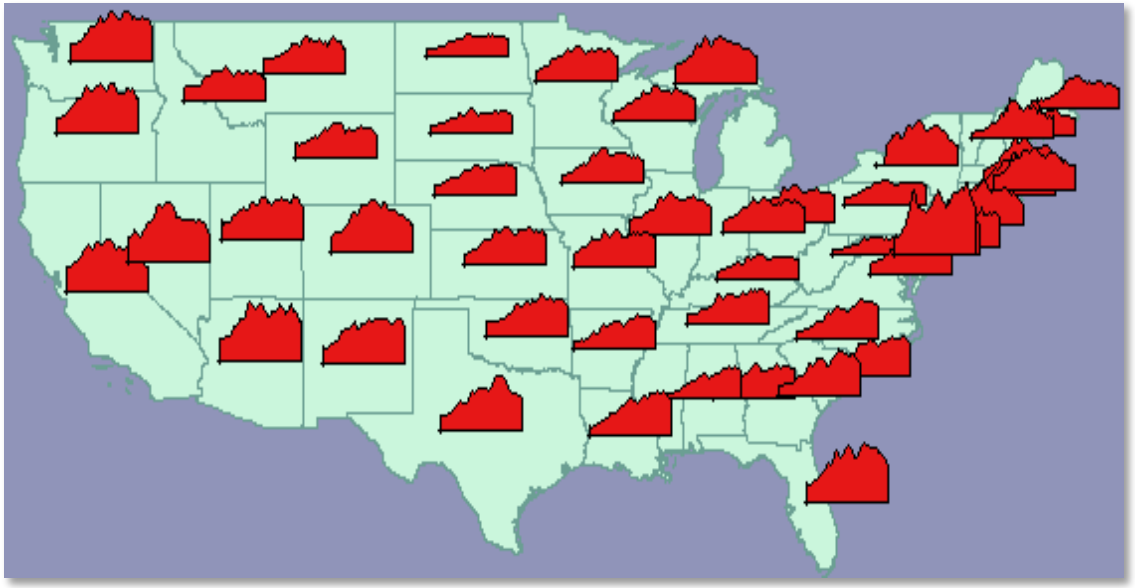
Value Flow Map Disadvantages

Spatial Time Series: Basic Visualization Methods II



- ✓ seeing the temporal behaviors in their spatial context
- × seeing all behaviors at once
- × detecting behaviors with particular features
- × noticing what sorts of features exist in the data

The diagrams are perceived as separate entities → the map must be scanned and cannot be grasped as a single image

Absence of ordering complicates seeking for specific behaviour patterns

Diagram overlapping is a serious problem

Spatial Time Series

Methods & Techniques for Different Spatio-Temporal Data I

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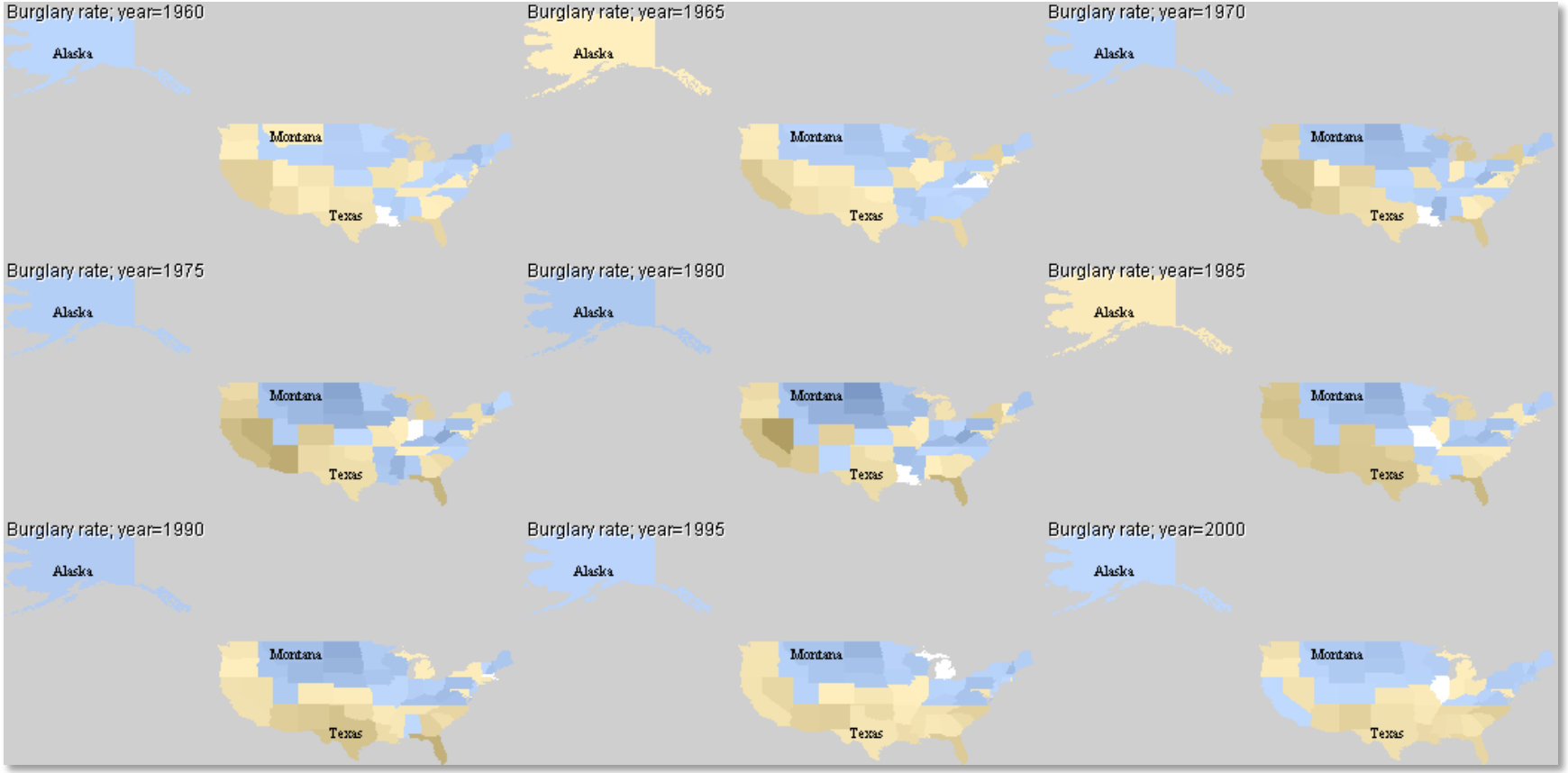
Comparison to country's median

Spatial Time Series: Data Transformations



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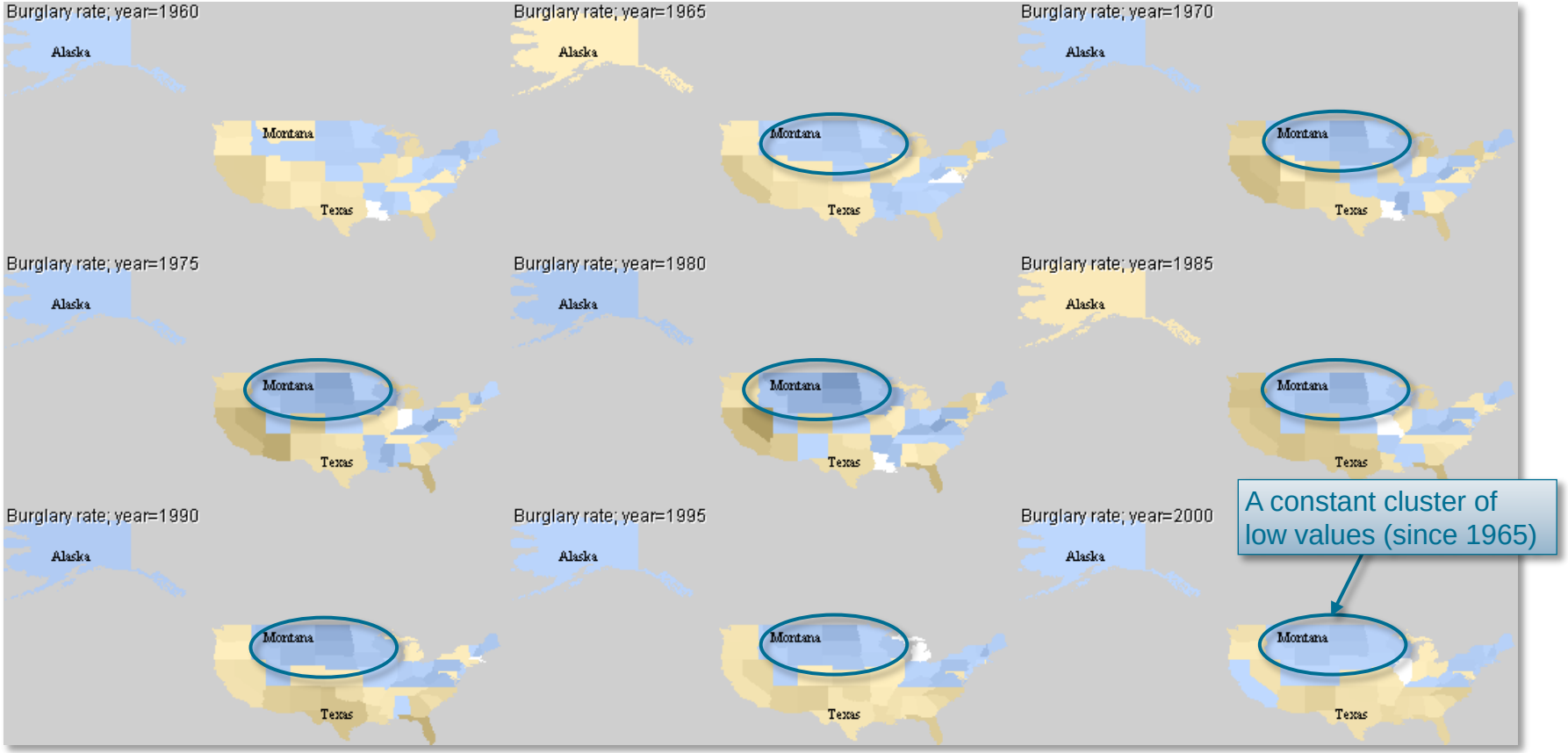
Comparison to country's median

Spatial Time Series: Data Transformations



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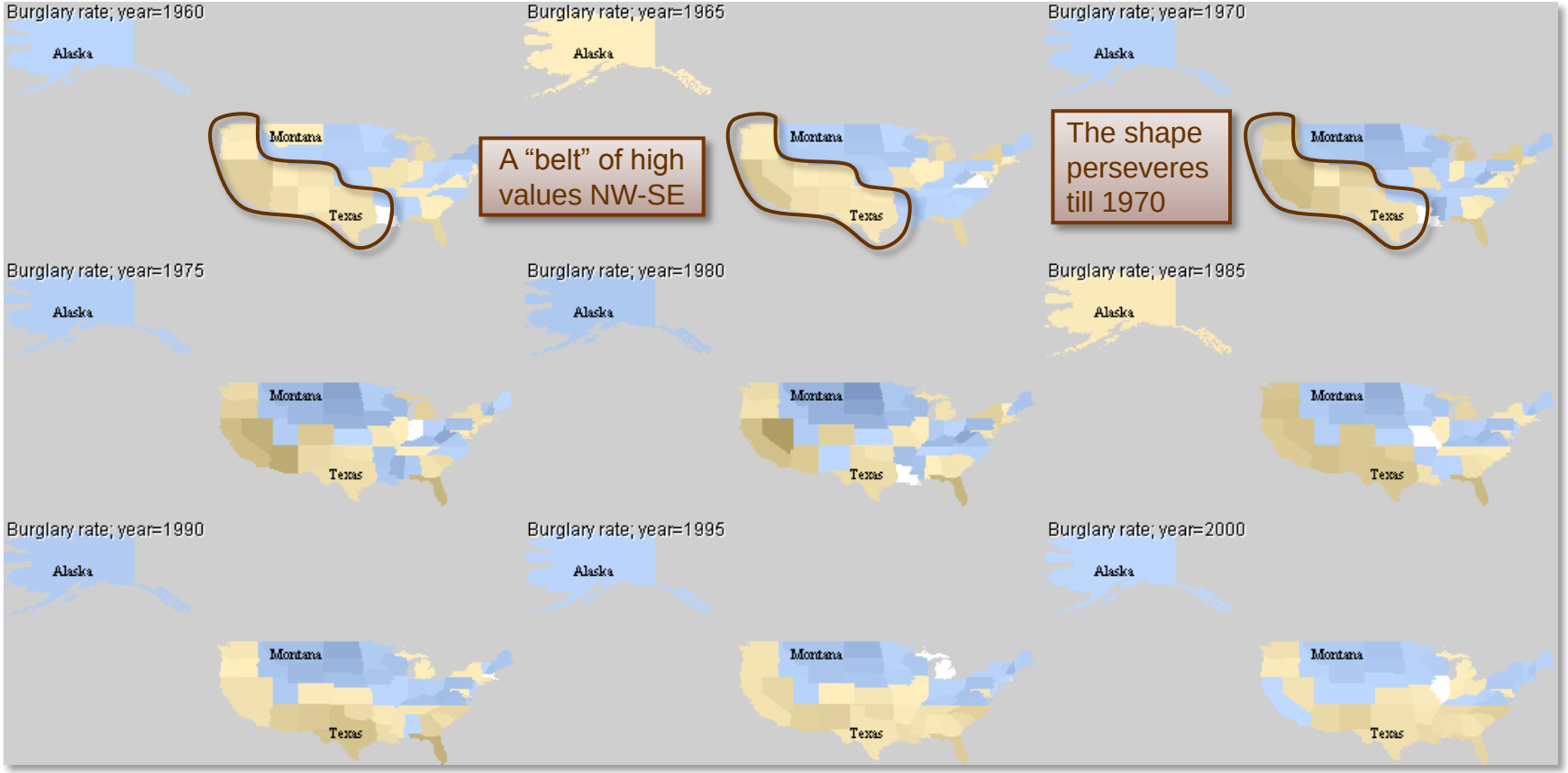
Comparison to country's median

Spatial Time Series: Data Transformations



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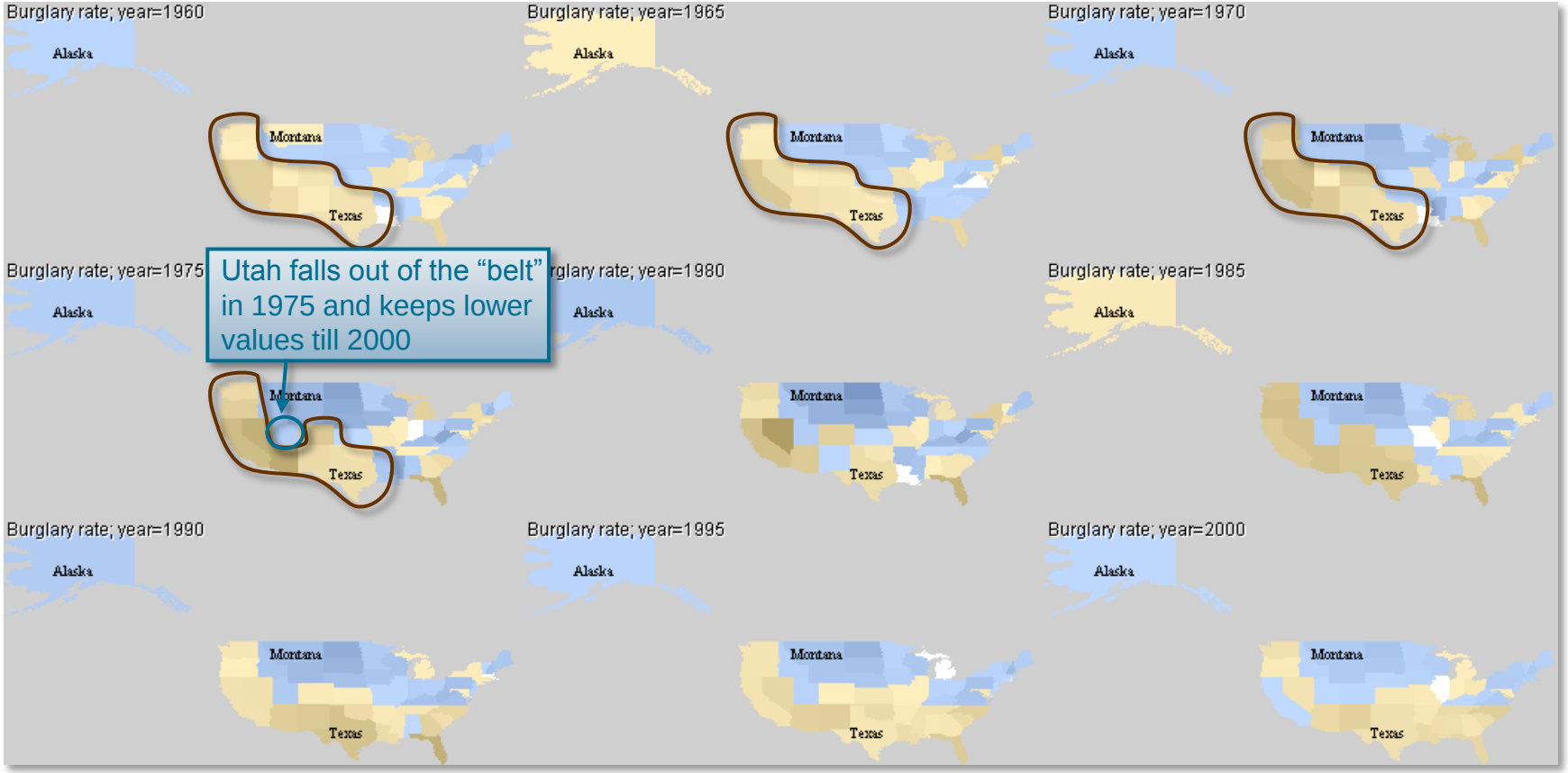
Comparison to country's median

Spatial Time Series: Data Transformations



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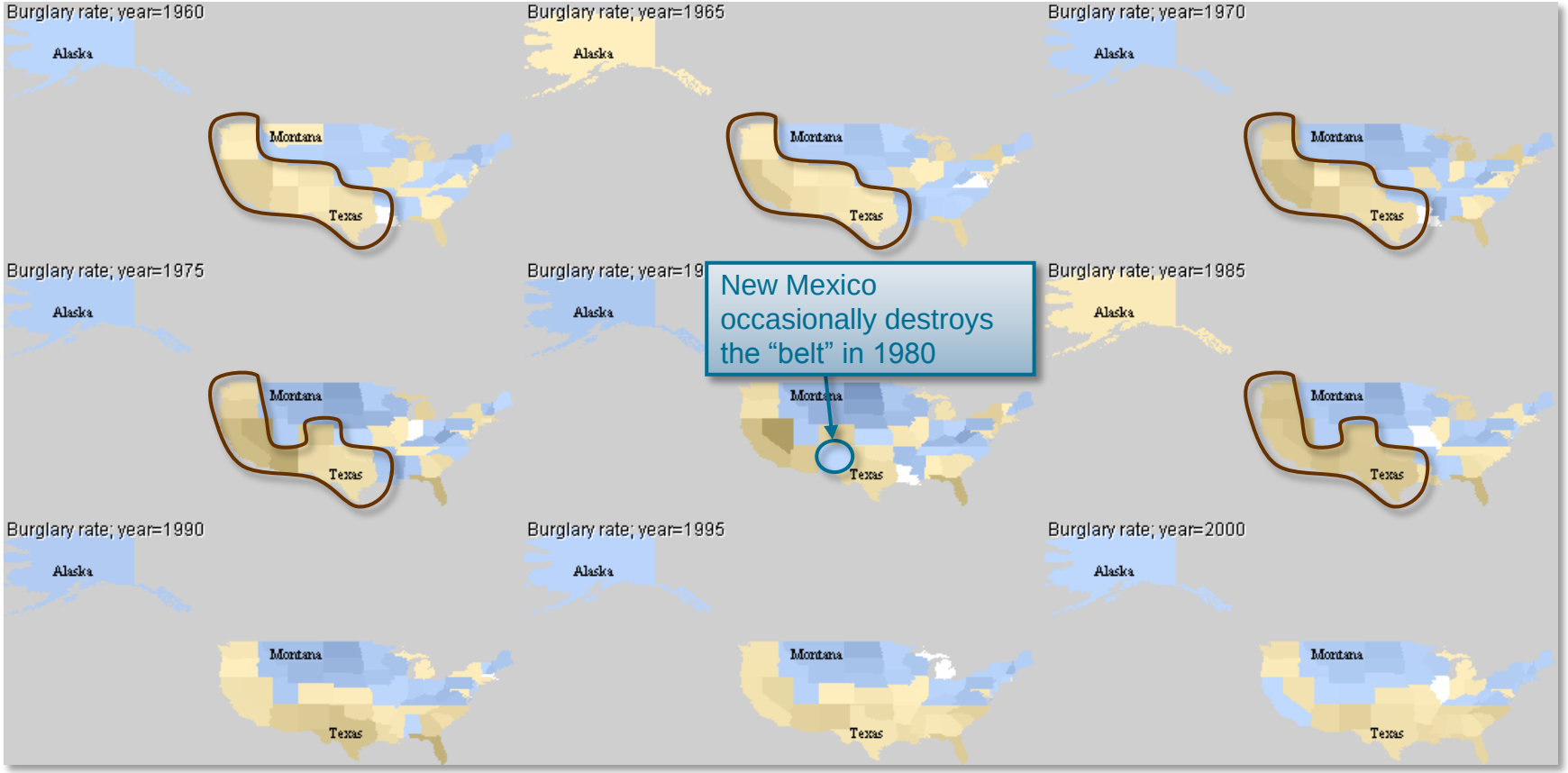
Comparison to country's median

Spatial Time Series: Data Transformations



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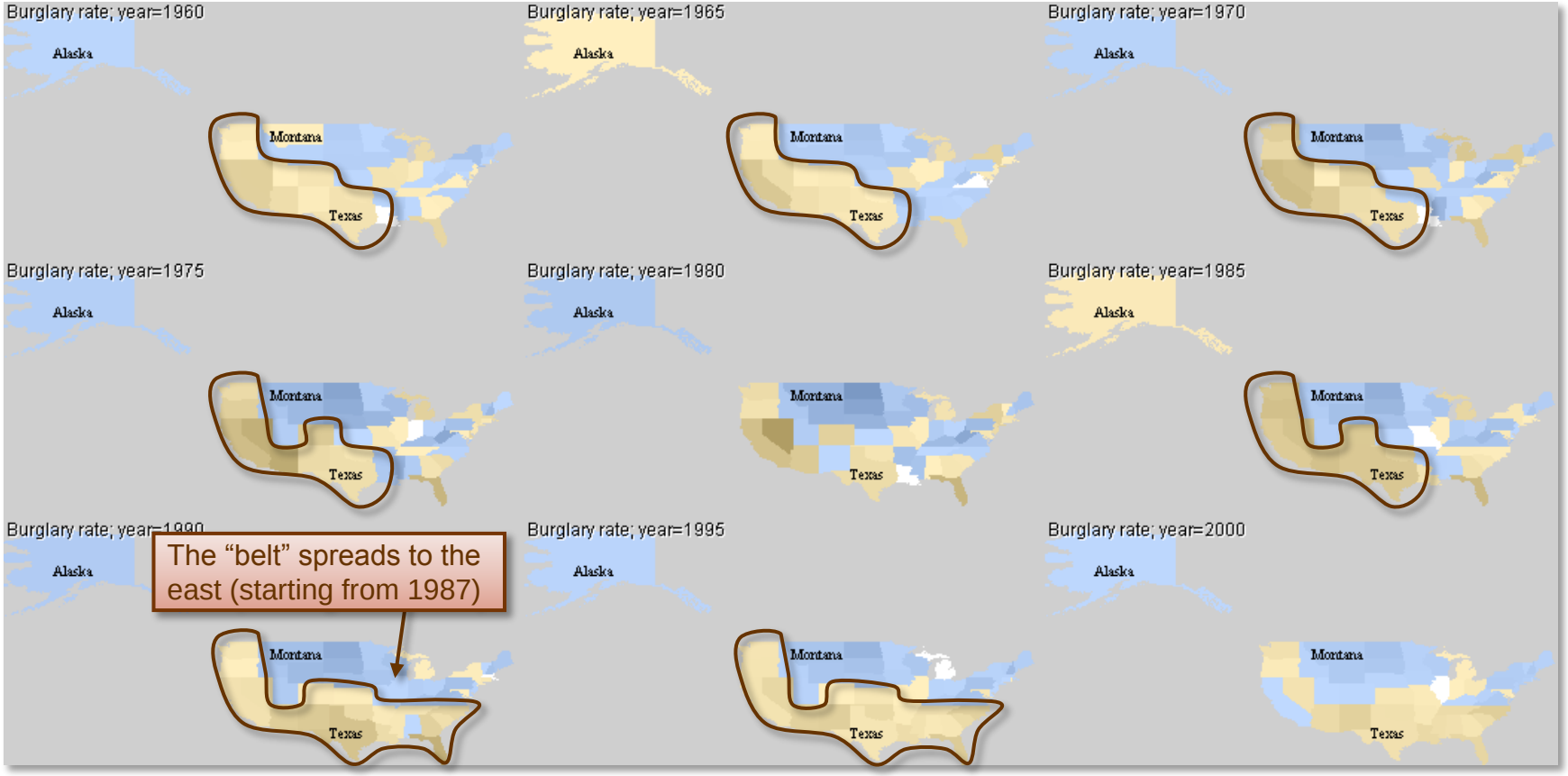
Comparison to country's median

Spatial Time Series: Data Transformations



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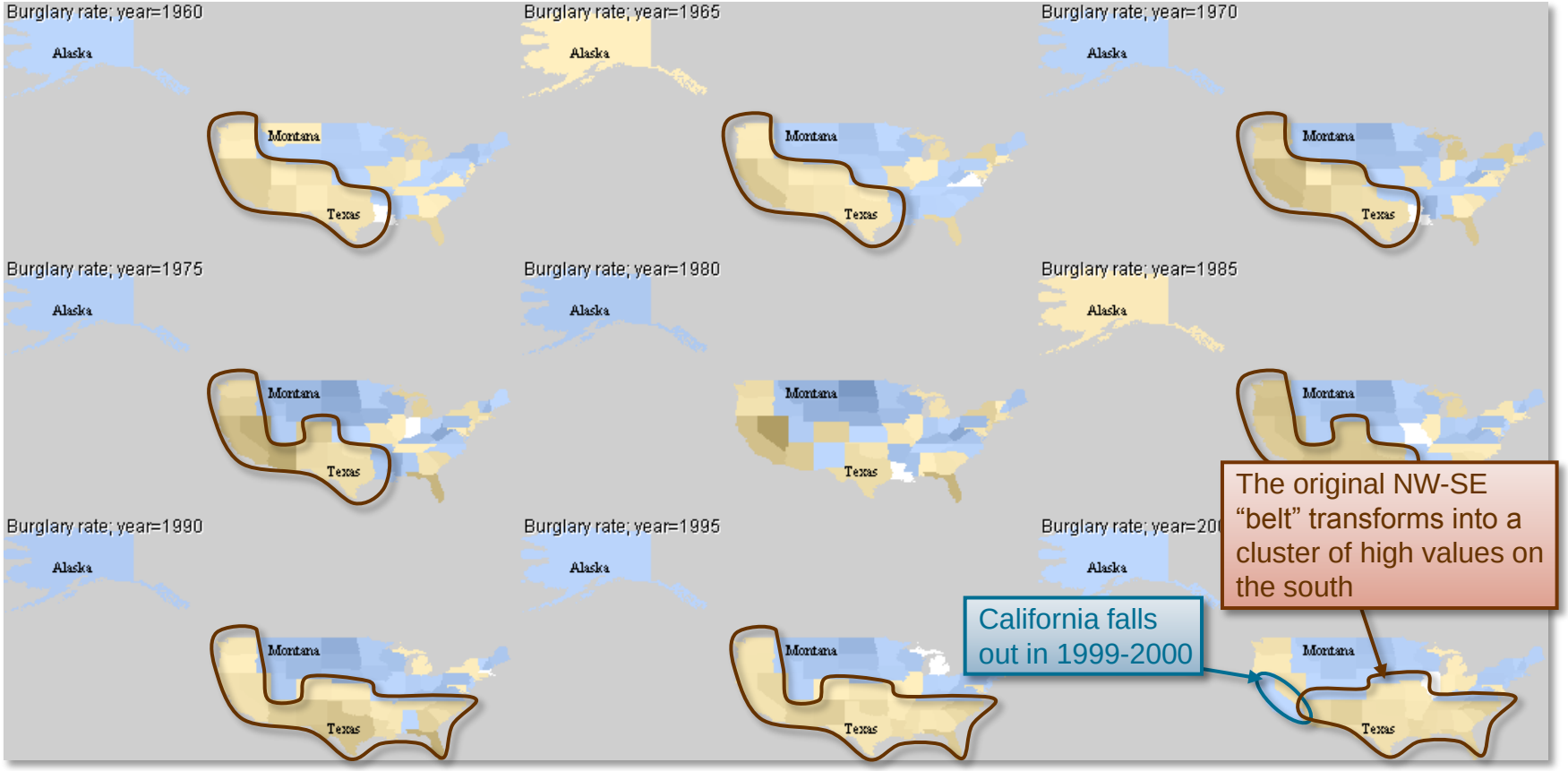
Comparison to country's median

Spatial Time Series: Data Transformations



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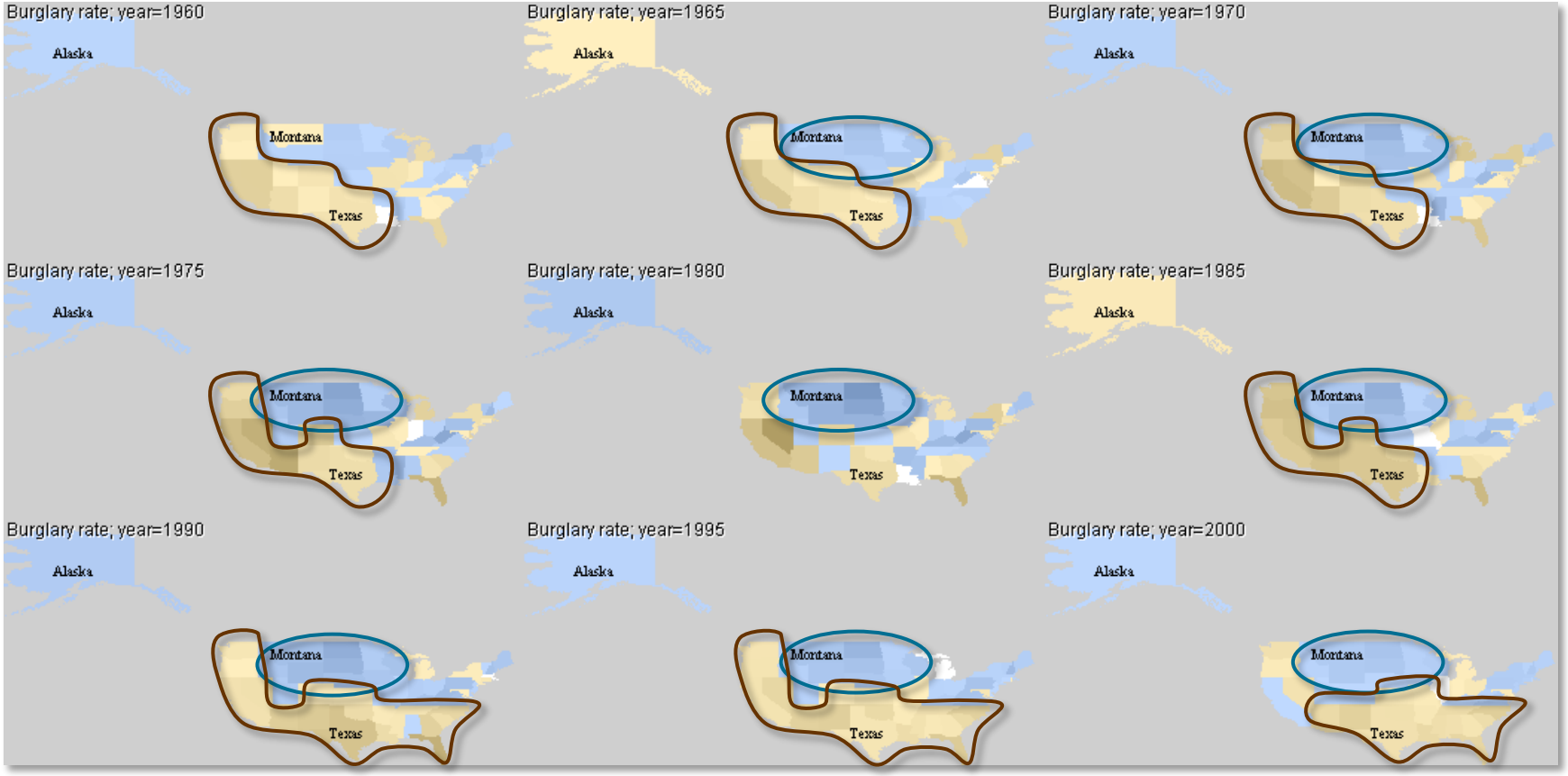
Comparison to country's median

Spatial Time Series: Data Transformations



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Spatial Time Series

Methods & Techniques for Different Spatio-Temporal Data I

Visualization methods

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Time Graph

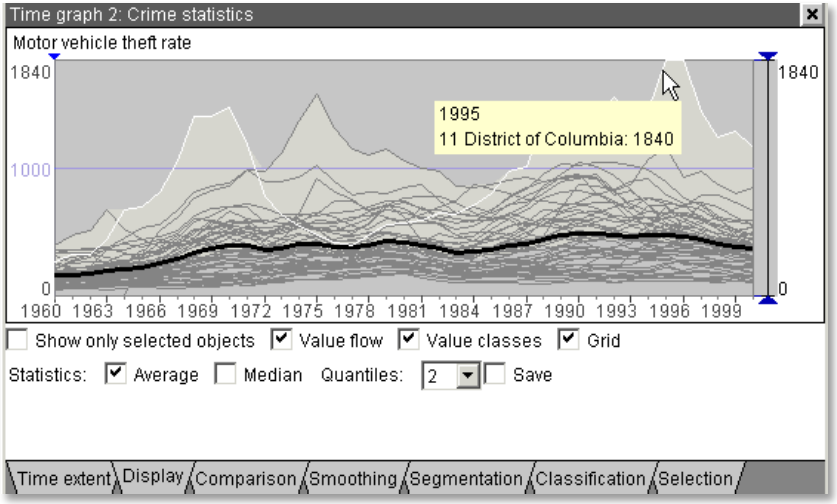
Spatial Time Series: Basic Visualization Methods III

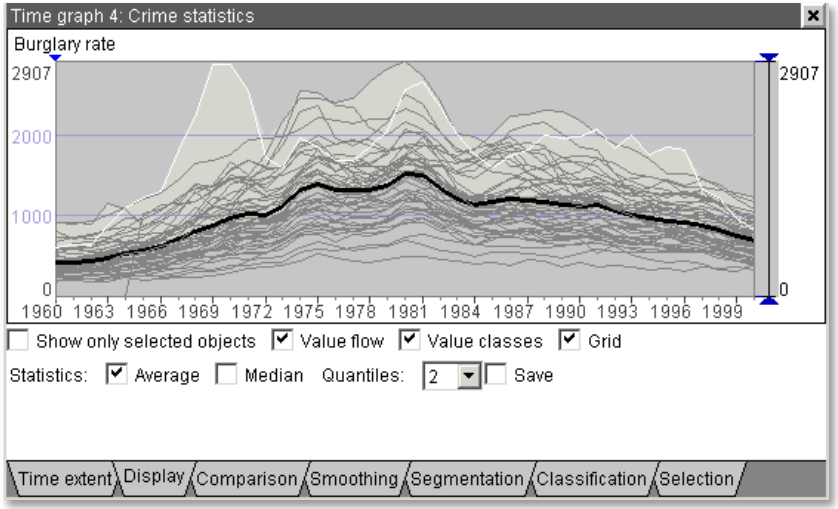
Putting all behaviors together makes their comparison more convenient

- Numeric details on-demand by pointing on an object's line

Plus, to better understand general development trends :

- "mean behavior line" connecting means of each year
- "median behavior" connecting the year medians





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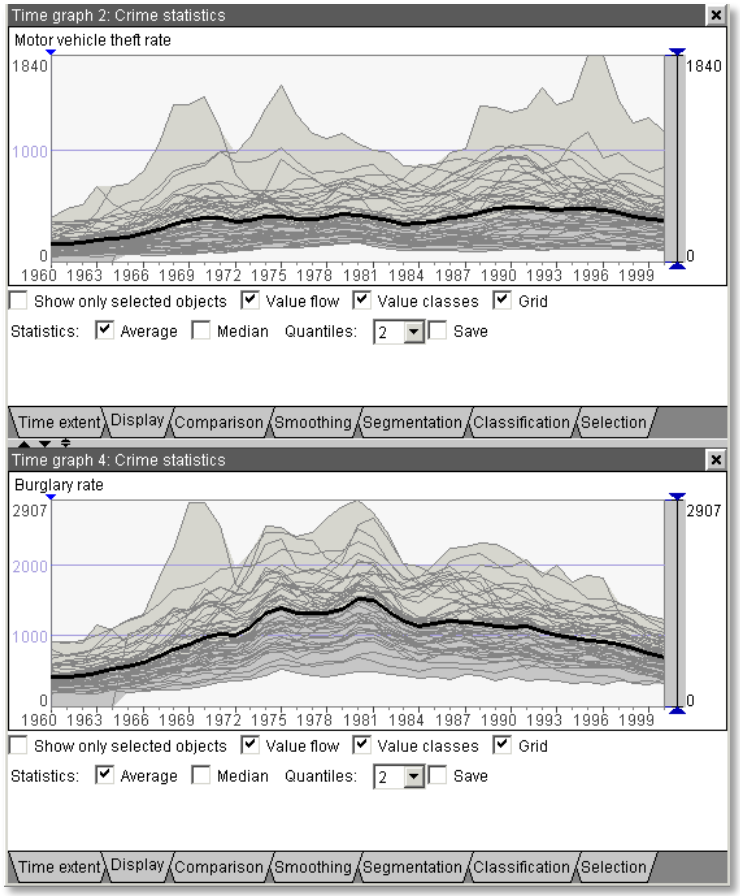
Time Graph: Multiple View Comparisons

Spatial Time Series: Basic Visualization Methods III



Juxtaposed time graphs are suitable for comparing trends and temporal variations of two or more attributes

This example shows that attributes “Motor vehicle theft rate” and “Burglary rate” have quite different trends of general development

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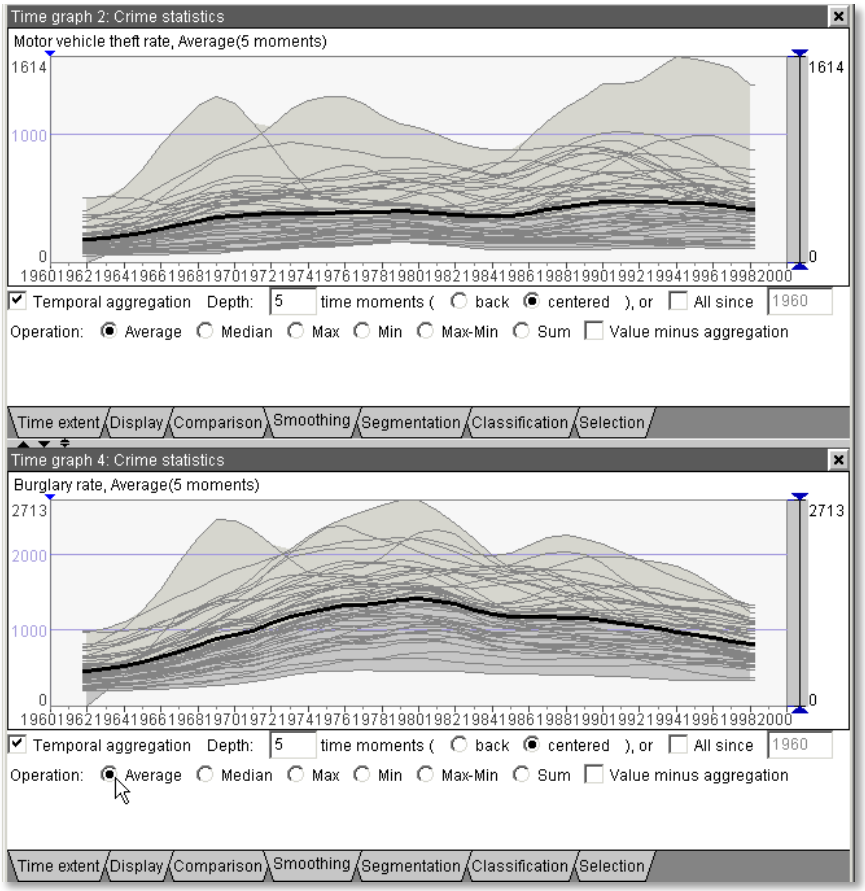
Time Graph: Multiple View Comparisons

Spatial Time Series: Basic Visualization Methods III



Additionally employ <u>smoothing</u> (value averaging over intervals)

Mitigates small fluctuations

Exposes trends more clearly

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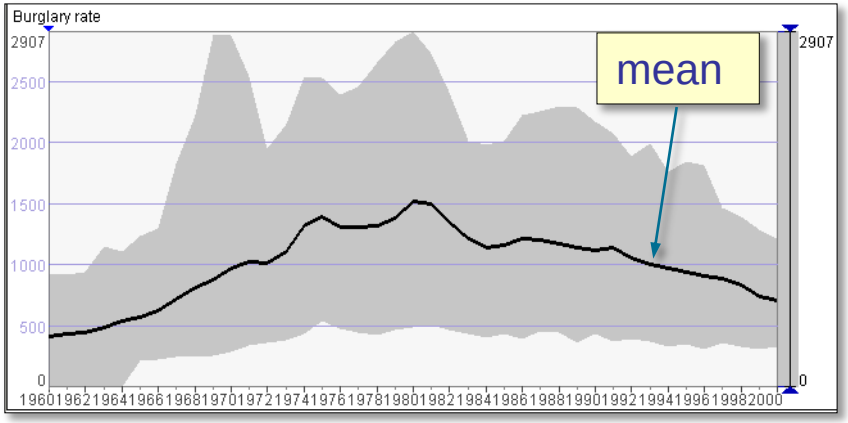
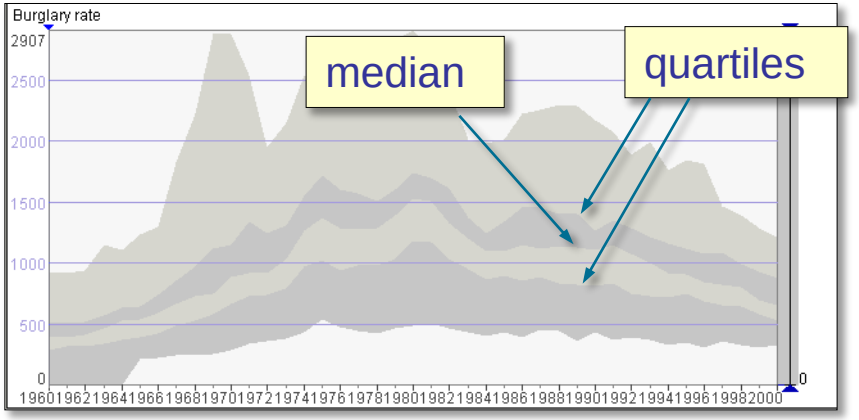
Time Graph: Level of Detail

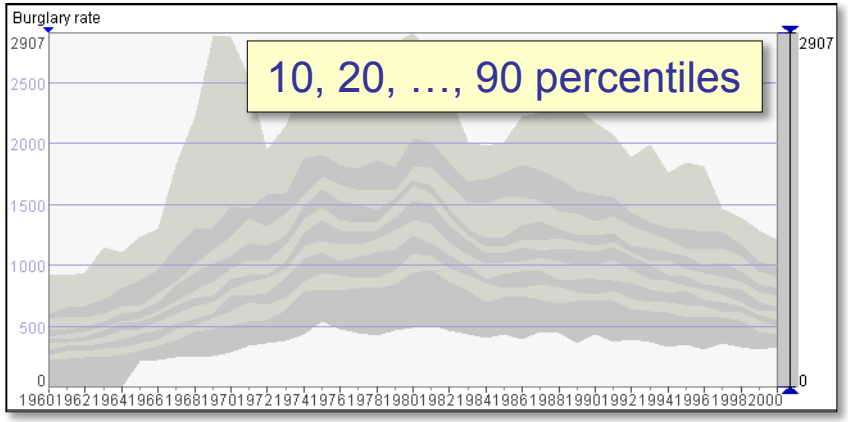
Spatial Time Series: Basic Visualization Methods III



Mean and median lines only give very coarse picture of the general value variation properties

For a finer analysis, may also look at the <u>quartiles</u> or even smaller <u>percentiles</u>.





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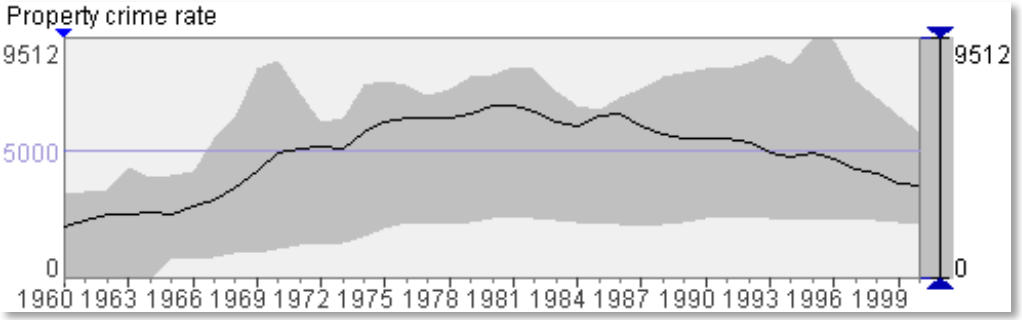
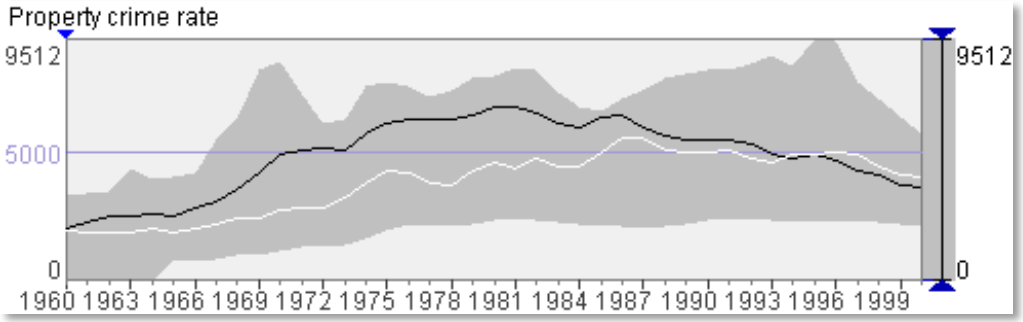
Linked Views: Map + Time Graph

Spatial Time Series: Basic Visualization Methods IV

At place L_1, how did the values behave over the entire time period?



Compare the temporal behavior at places L_1 and L_2



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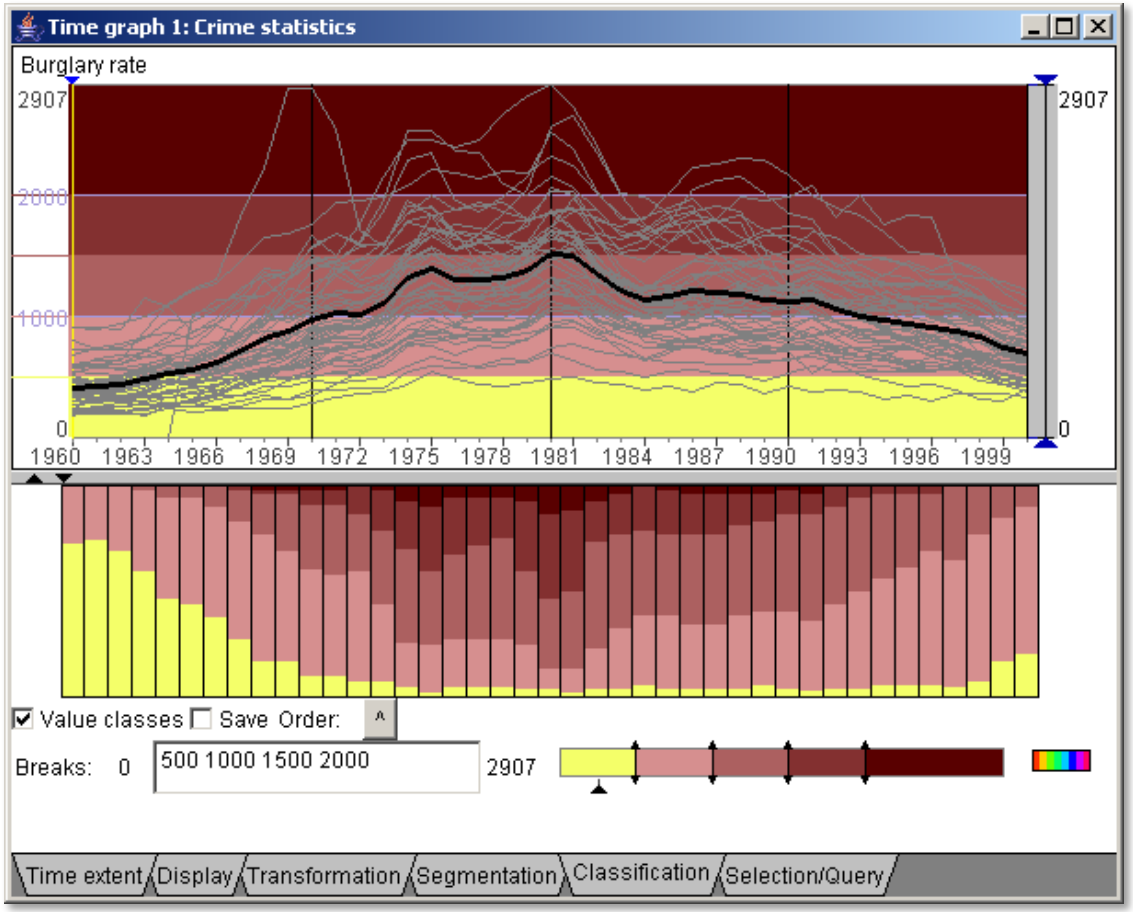
Time Graph++: Time Histogram

Spatial Time Series: Basic Visualization Methods V



Divide value range of the attribute into intervals

Choose specific color/ shade for each interval

Size of colored segments encodes relative frequencies of values from corresponding interval, for each time moment

This example:

- Each bar: one year
- Shows increase of the crime rates over the country in 70's & early 80's
- Note two peaks in 1975 and 1981-82, followed by gradual decrease

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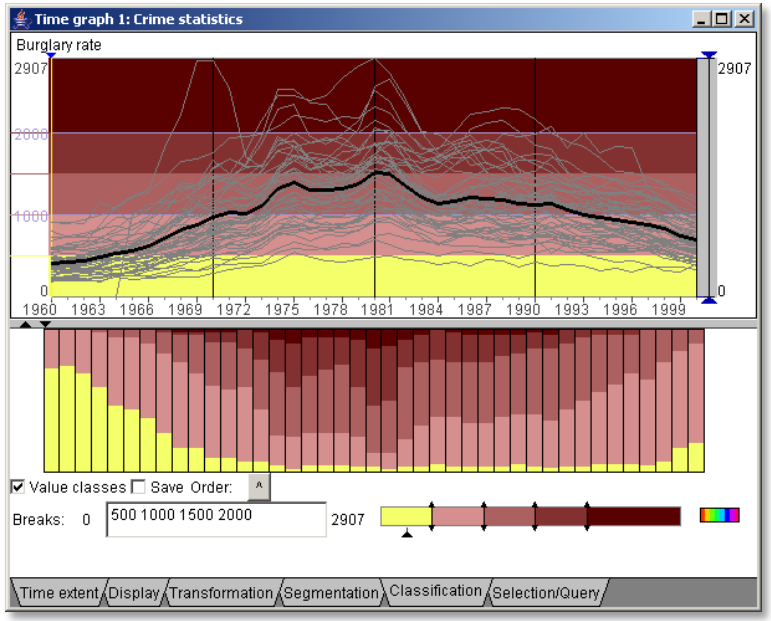
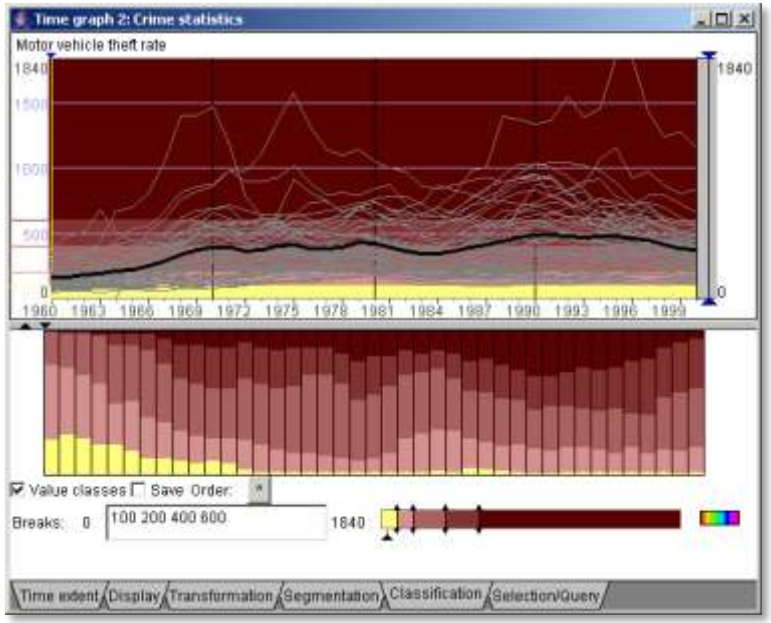
Time Graph++: Time Histogram

Spatial Time Series: Basic Visualization Methods V

Time histograms facilitate comparison of 2 (or more) attributes

- Compare temporal trends *despite differences in value ranges*





- Here: attributes “Burglary rate” and “Motor vehicle theft rate”

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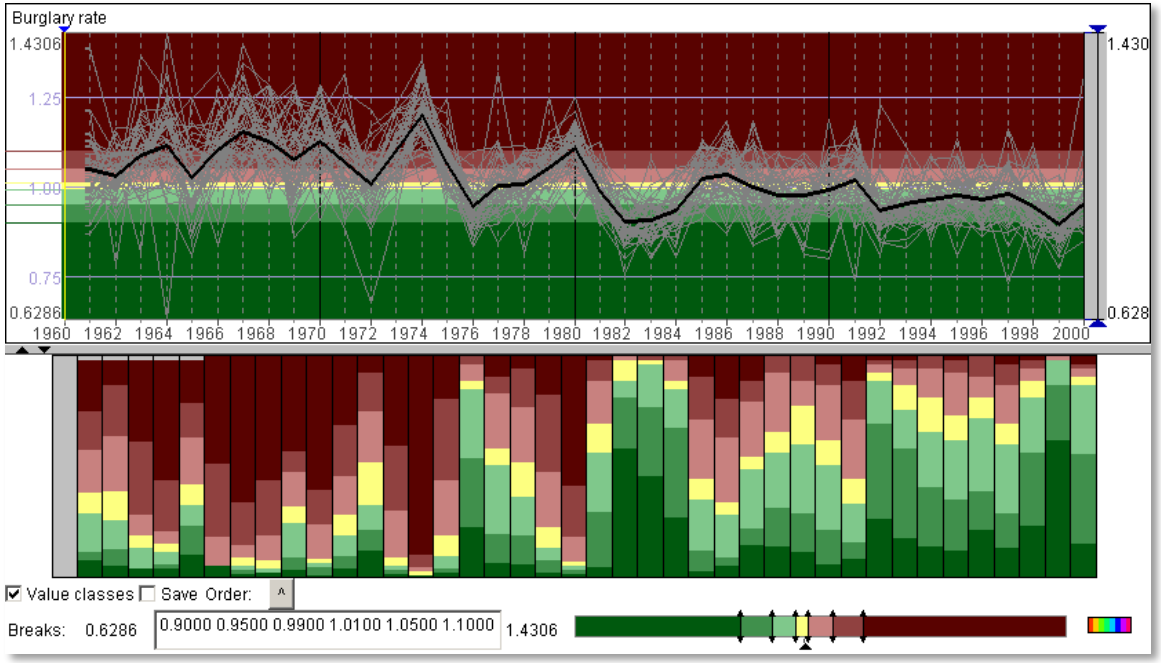
Time Histogram of Changes

Spatial Time Series: Basic Visualization Methods VI

Transform attribute values into relative differences

Apply aggregation by value intervals to the transformed values

Encode values using partitioned color scale



- "Burglary rate" values, transformed into relative difference to previous year
- Three color segments: red for increase (< +5%, +5-10%, > +10%), yellow for no change (±1%), green for decrease (< -5%, -5-10%, > -10%)

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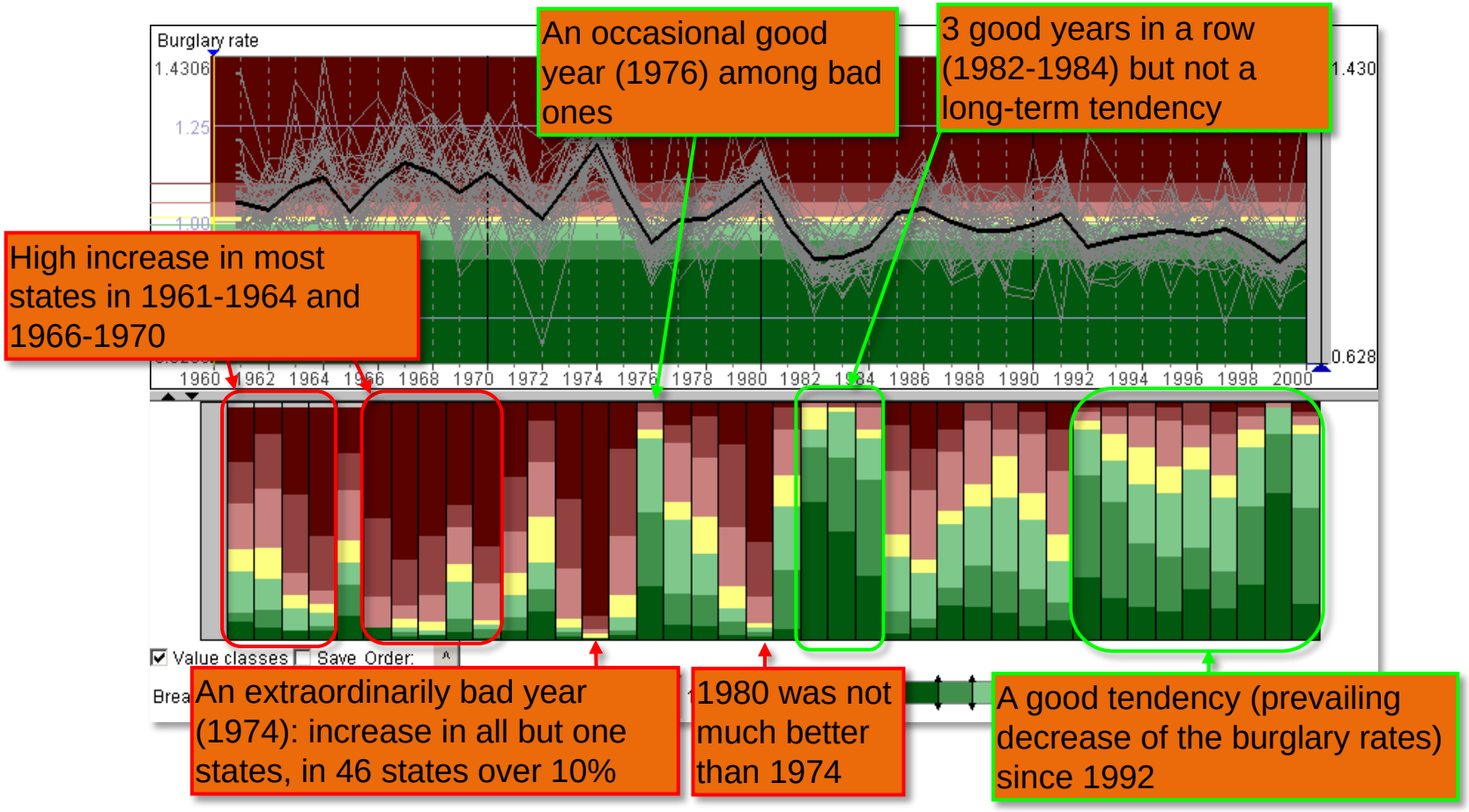
Time Histogram of Changes

Spatial Time Series: Basic Visualization Methods VI



See also

- Natalia and Gennady Andrienko
  Exploratory Analysis of Spatial and Temporal Data
  A Systematic Approach
  Springer-Verlag, December 2005

  Chapter 4