Geospatial Visual Analytics:
Visual analysis of spatio-temporal data
Part 1. Spatial time series

Fraunhofer Institut
Intelligente Analyse- und
Informationssysteme

Gennady Andrienko & Natalia Andrienko
http://geoanalytics.net

Types of Temporal Variance

- Changes of thematic properties (values of attributes) associated with places
  - e.g. district population, data from stationary sensors
- Existential changes (appearance and disappearance)

  Events: objects with limited life time
  - e.g. earthquakes, traffic incidents, observations of rare plants or animals
- Changes of spatial properties: location, size, shape, orientation, altitude, etc.
  - e.g. movement of vehicles, growth of cities

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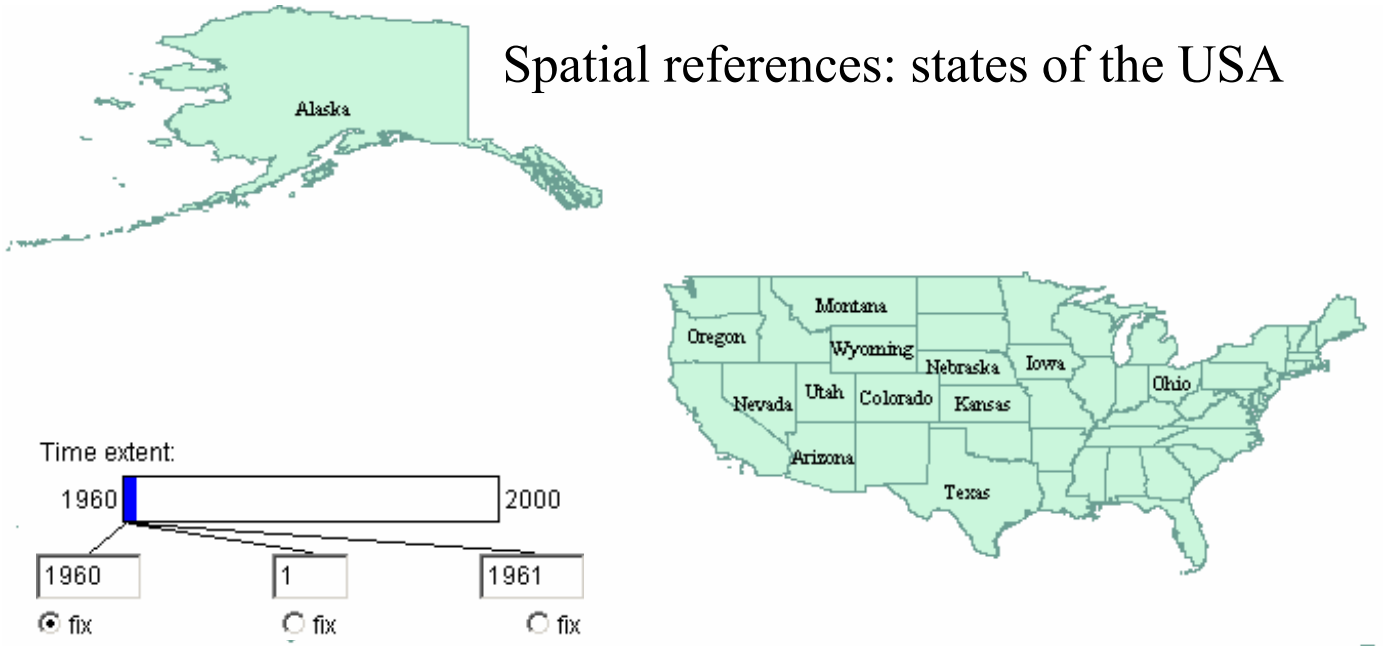
Example: crime rates in the states of the USA

year	id	State	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
1960	1	Alabama	3266740	1222	186.6	12.4	8.6	27.5	138.1	1035.4	355.9	592.1	87.3
1960	2	Alaska	226167	1649.2	104.3	10.2	20.8	28.3	45.1	1544.9	332.1	970.5	242.3
1960	4	Arizona	1302161	3013.7	207.7	6	16.1	54.2	131.4	2806	685.5	1782.2	338.4
1960	5	Arkansas	1786272	1034.1	107.7	8.5	8.9	24.8	65.5	926.4	302.2	573.8	50.3
1960	6	California	15717204	3474.3	239	3.9	18.2	97.3	119.6	3235.4	910.5	1984.8	340.1
1960	8	Colorado	1753947	2172.4	137.3	4.2	13.1	77.7	42.4	2035.1	569.9	1251.4	213.8
1960	9	Connecticu	2535234	1156.5	36.6	1.6	4.1	9.3	21.6	1119.9	333.4	656.9	129.7
1960	10	Delaware	446292	2160.5	84	7.4	9.2	35.2	32.3	2076.4	596.2	1314.6	165.6
1960	11	District of C	763956	2712.9	553.7	10.6	14.5	140.3	388.2	2159.2	600.4	1296.5	262.2
1960	12	Florida	4951560	2704.6	223.4	10.6	8.1	80.9	123.7	2481.2	807.1	1486.5	187.6
1960	13	Georgia	3943116	1407.9	158.8	11.9	7.5	24.7	114.8	1249.1	392.1	709.6	147.4
1960	15	Hawaii	632772	2298.3	21.8	2.4	3.3	10.9	5.2	2276.5	525.9	1480.6	269.9
1960	16	Idaho	667191	1771	38.2	2.4	7.2	13.8	14.8	1732.8	301.4	1331.4	100
...	...	...	...	...	...	...	...	...	...	...	...	...	...
1961	1	Alabama	3302000	1154	168.5	12.9	7.6	19.1	128.9	985.5	339.3	569.4	76.8
1961	2	Alaska	234000	1629.5	88.9	11.5	13.2	12.4	51.7	1540.6	380.8	950	209.8
1961	4	Arizona	1391000	3133.9	164.5	6	14.4	56.5	87.6	2969.4	737.7	1876.3	355.4
1961	5	Arkansas	1797000	1037.6	100.7	9.1	7.2	24.8	59.5	936.9	308.1	568.2	60.6
1961	6	California	16397000	3410.1	232.7	3.7	18.5	90.5	120	3177.5	894.2	1950.6	332.7
1961	8	Colorado	1781000	2404	149.3	4.7	12.9	91.7	40	2254.7	655.9	1322.3	276.5
1961	9	Connecticu	2614000	1244.7	33.6	1	2.4	9.1	21.1	1211.1	364.4	715.8	130.8
1961	10	Delaware	458000	2109.4	69.4	4.4	5.9	27.1	32.1	2040	591.9	1284.9	163.1
1961	11	District of C	763956	2825.3	587.9	11.5	13.1	176.4	386.8	2237.4	641.7	1273.9	321.9
1961	12	Florida	5222000	2461.1	217.8	9.1	7.6	71.7	129.4	2243.3	720.5	1353	169.7
1961	13	Georgia	3987000	1497.7	157.2	10	9.5	28.3	109.4	1340.5	437.4	746.1	157
1961	15	Hawaii	657000	2522.2	24.5	2.3	3.8	10.7	7.8	2497.7	595	1597.9	304.9
1961	16	Idaho	684000	1862.3	32.5	2	6.4	9.4	14.6	1829.8	322.1	1394.7	113
...	...	...	...	...	...	...	...	...	...	...	...	...	...

Data structure



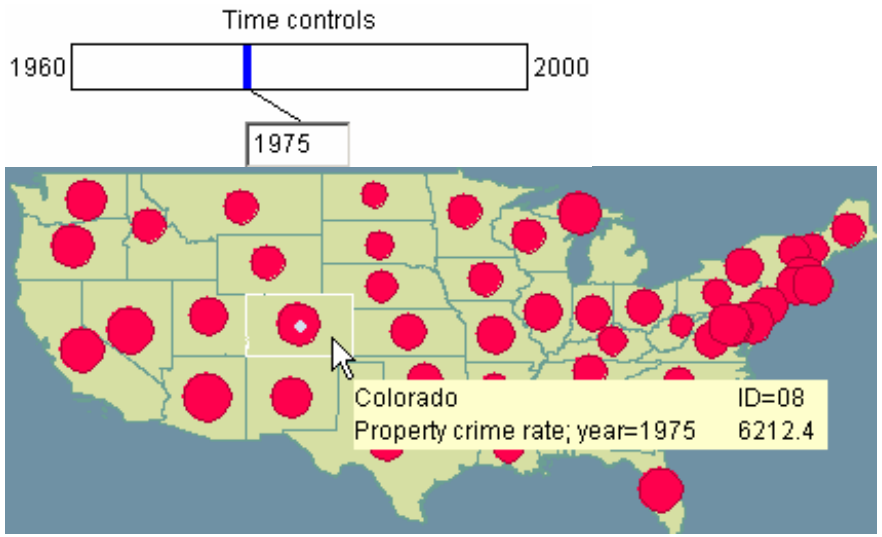
Spatial references: states of the USA

Temporal references: years from 1960 till 2000 (41)

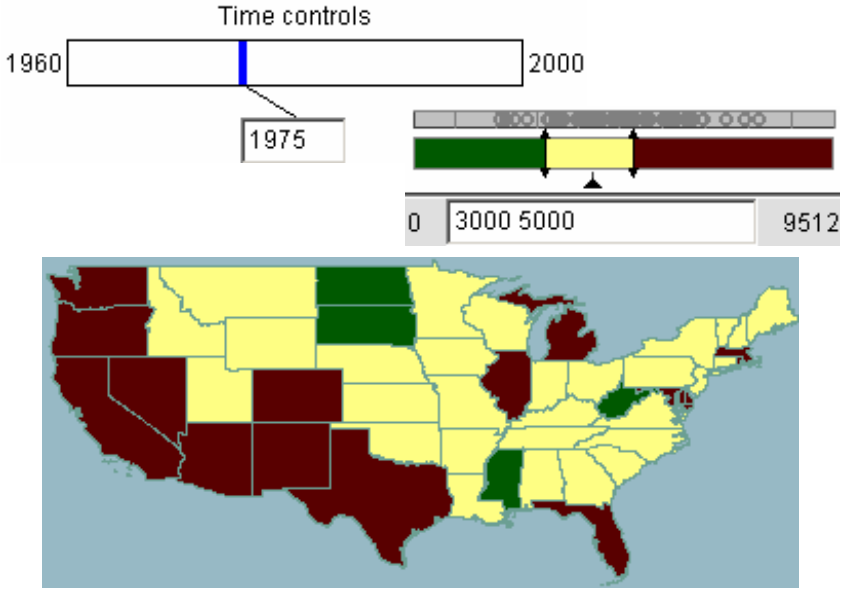
Attributes: population + various crime rates

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

Elementary (local) queries

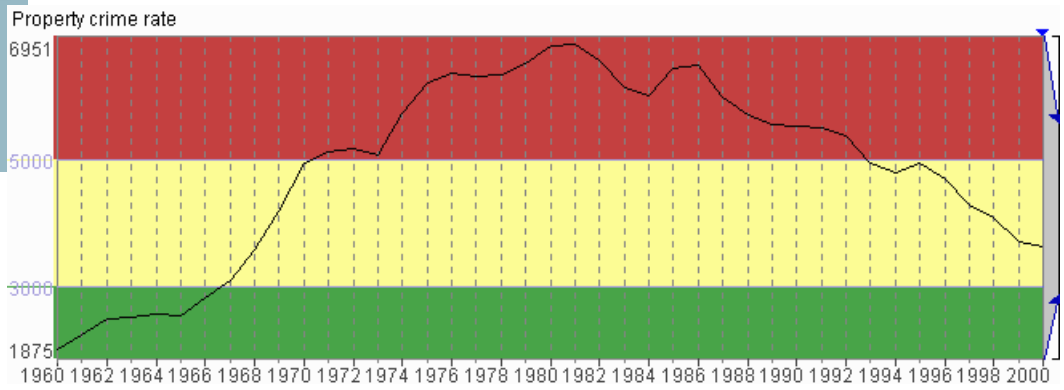


Where + when → what



What + when → where

What + where → when



Higher level analysis questions

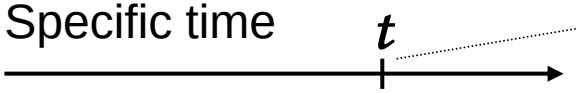
- How are attribute values distributed over the territory at a given time moment?
- How do the attribute values at a given place vary over time?
- How does the overall spatial pattern of value distribution evolve over time?
- How are different behaviour patterns distributed over the territory? Are there spatial clusters of similar behaviours?

Question 1

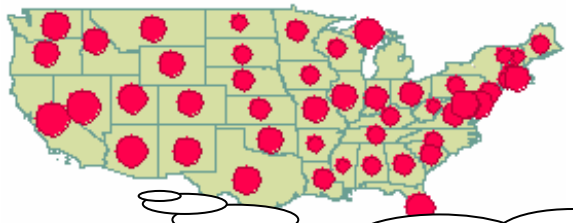
How are attribute values distributed over the territory at a given time moment?

Space as a whole

Specific time



Spatial distribution of attribute values *(spatial behaviour)* at time *t*



Synoptic (global) with regard to space but elementary (local) with regard to time

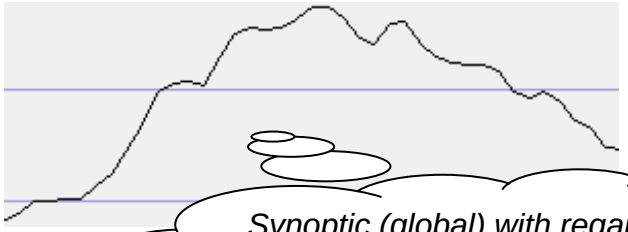
Question 2

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

Specific place

Time as a whole

Temporal variation of attribute values *(temporal behaviour)* in place *ℓ*



Synoptic (global) with regard to time but elementary (local) with regard to space

Spatio-temporal behaviour: two aspects

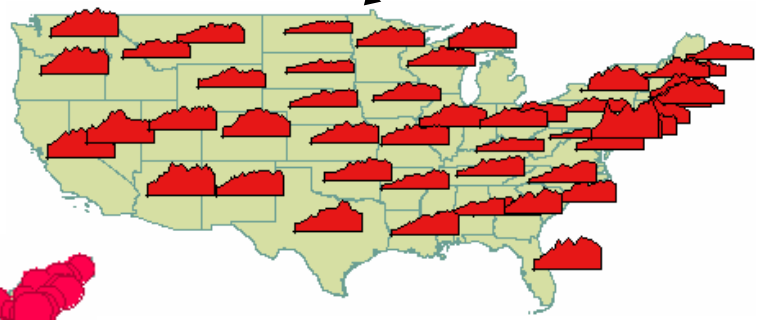
Space as a whole

Time as a whole

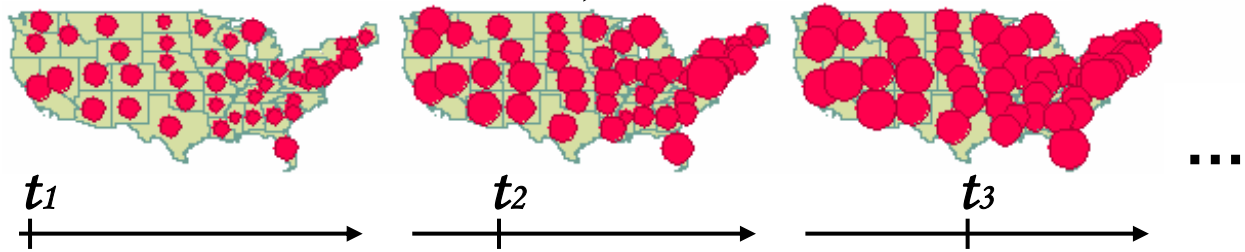
Spatio-temporal behaviour

Synoptic (global) with regard to both space and time

Aspect 2:
Spatial variation of the temporal behaviour



Aspect 1:
Temporal variation of the spatial behaviour



Question 3

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

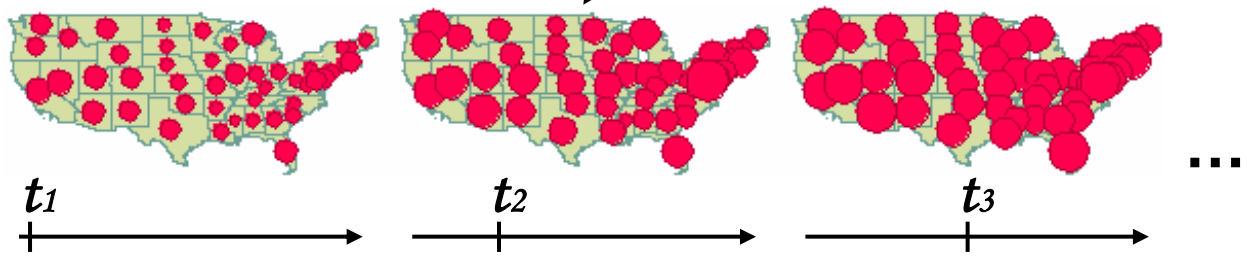
Space as a whole

Time as a whole

Spatio-temporal behaviour

Synoptic (global) with regard to both space and time

Aspect 1:
Temporal variation of the spatial behaviour



Question 4

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

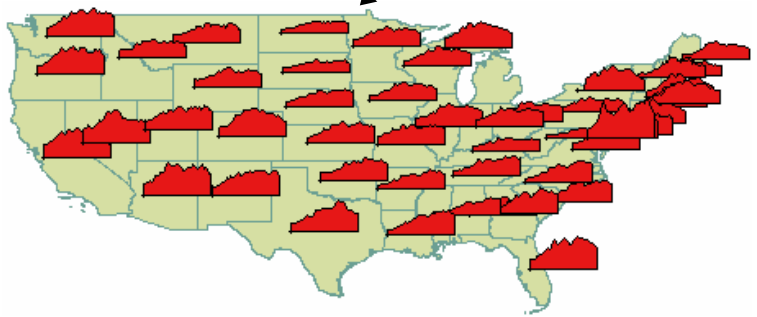
Space as a whole

Time as a whole

Spatio-temporal behaviour

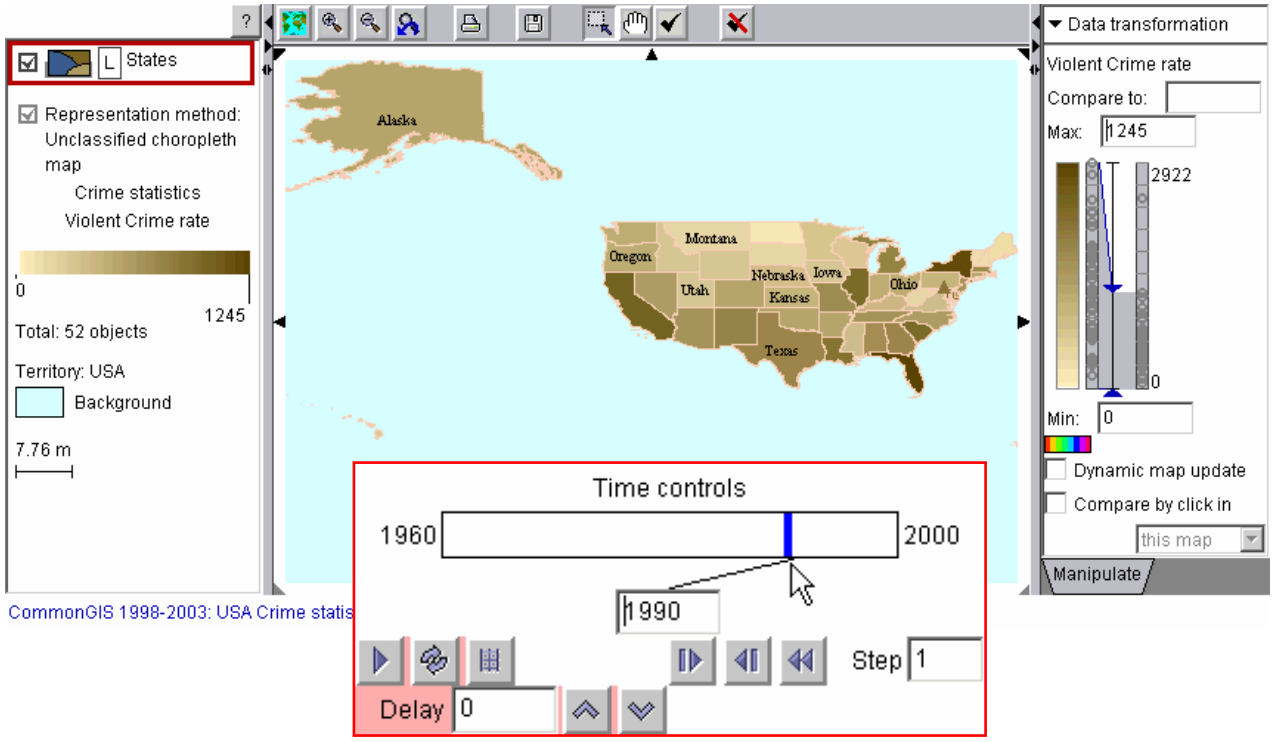
Synoptic (global) with regard to both space and time

<u>Aspect 2:</u>
Spatial variation of the temporal behaviour



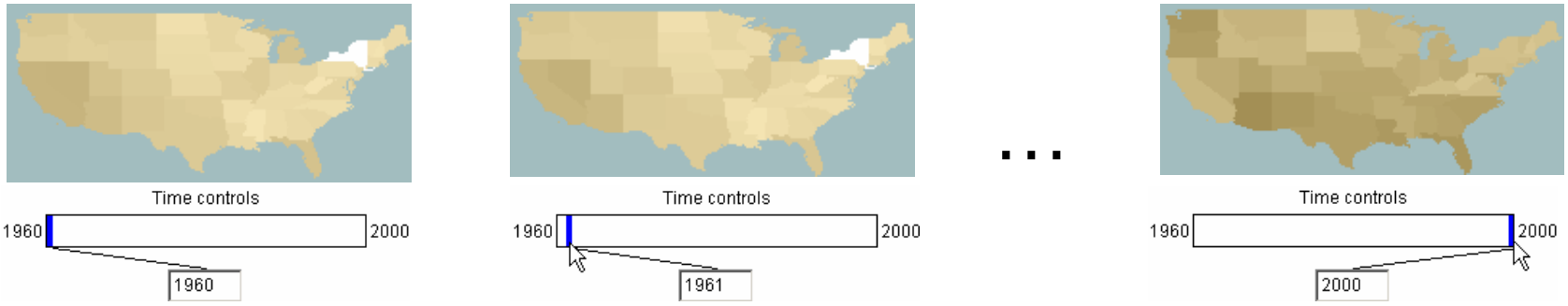
Time map

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



For a time map, one can use any representation method suitable for static data. Thus, a choropleth map is good for exploring spatial distribution patterns.

When time map is useful

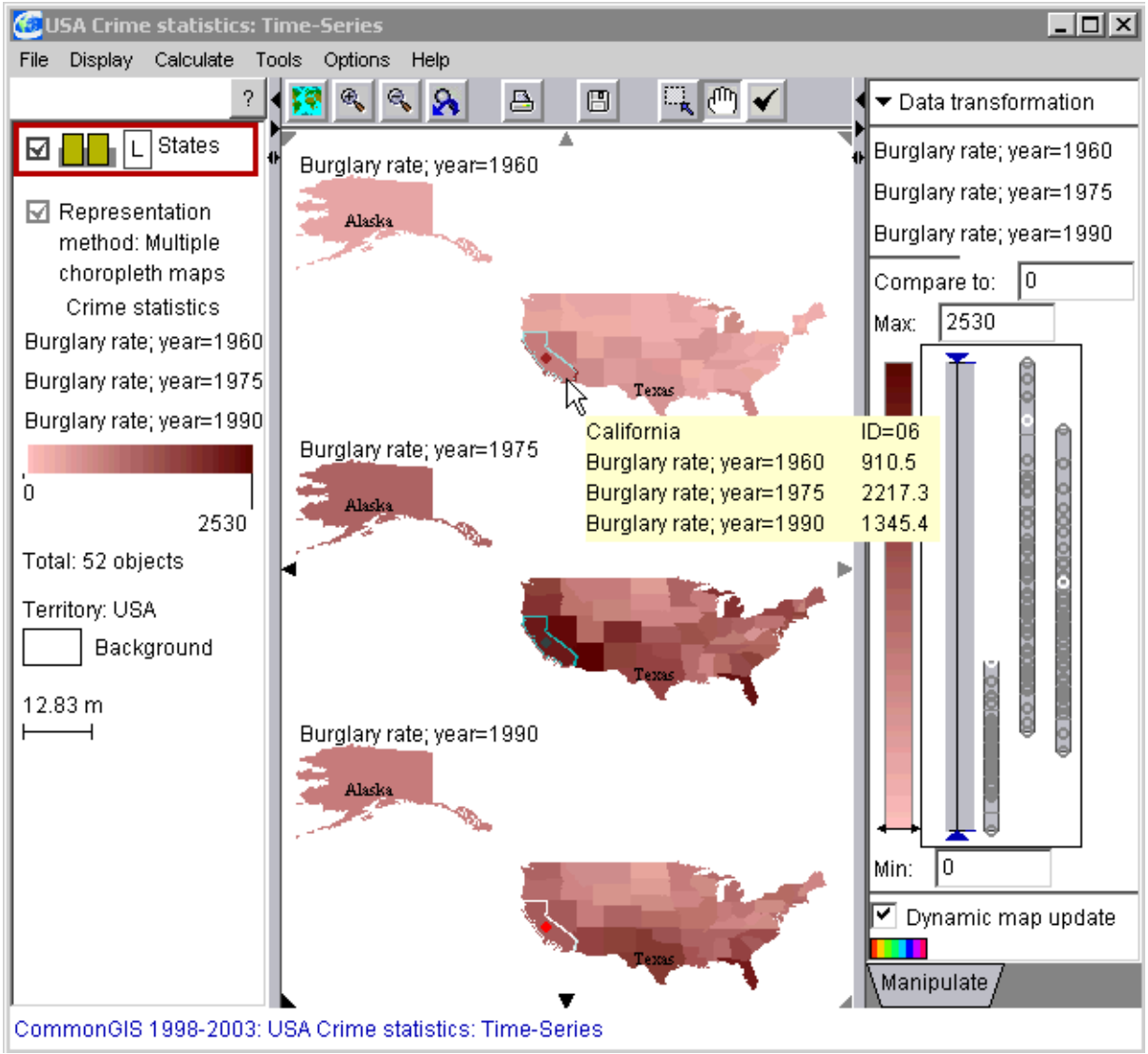


✓ How did the spatial distribution pattern develop over time?

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

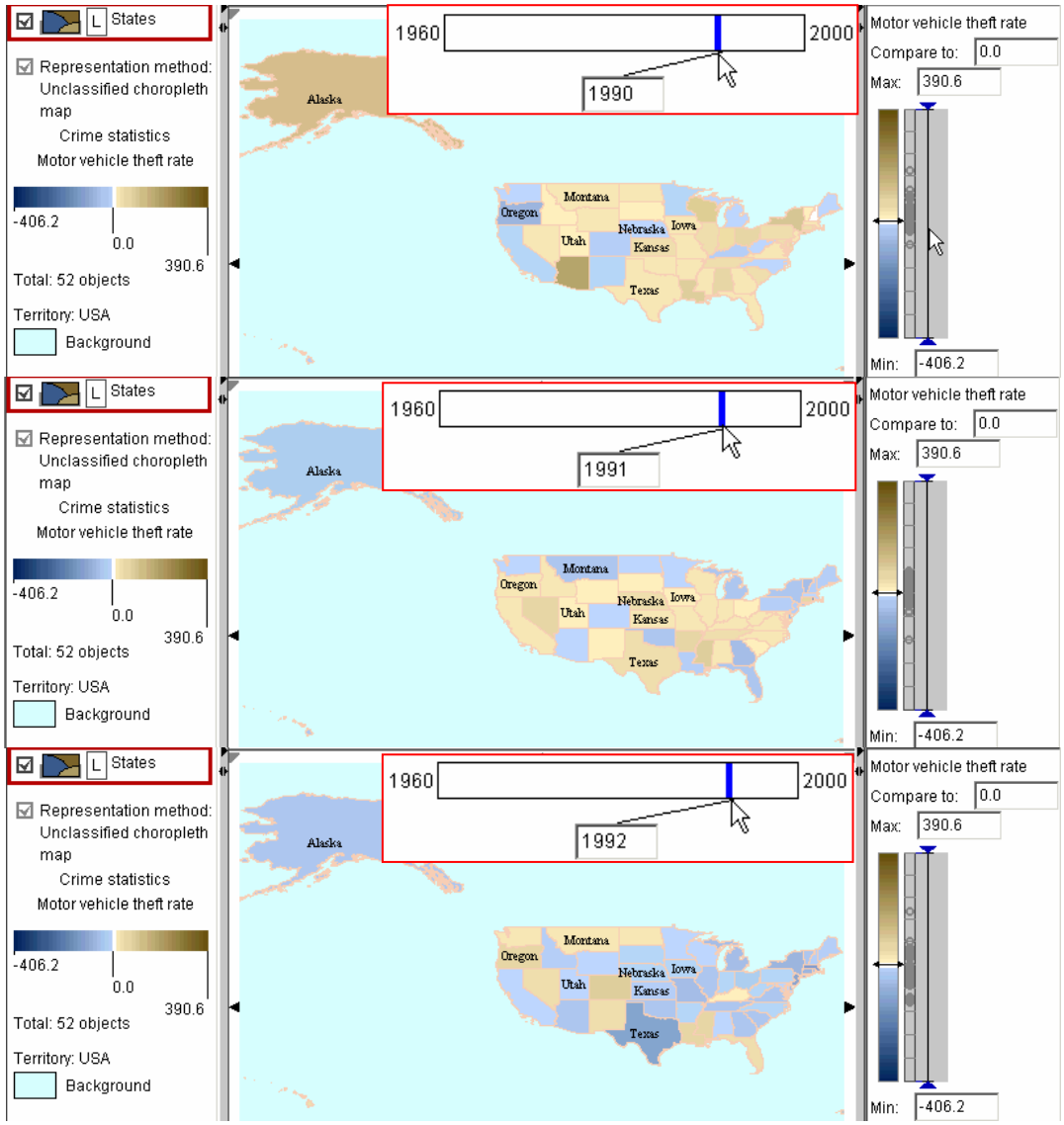
✓ At what time moment were the values distributed over the space in the given manner?

Map Series



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.

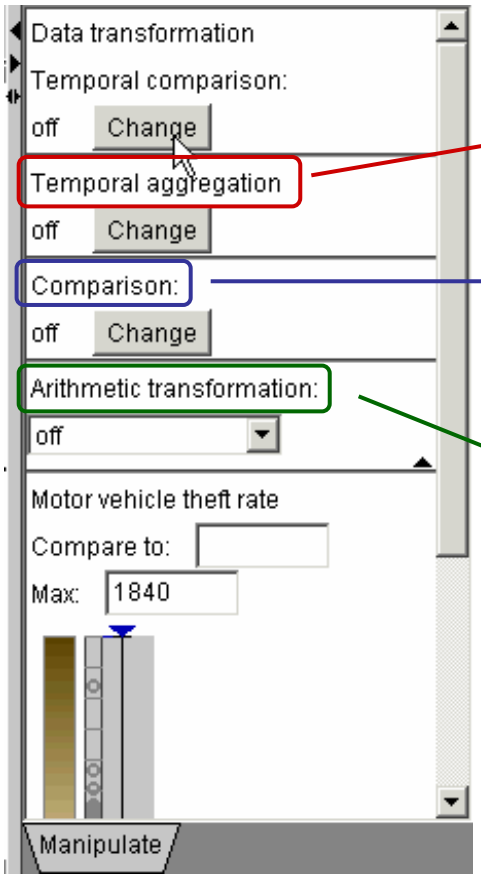
Exploring the Distribution of Changes



Instead of original attribute values, a time map or map series can represent changes, 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

Other Useful Data Transformations

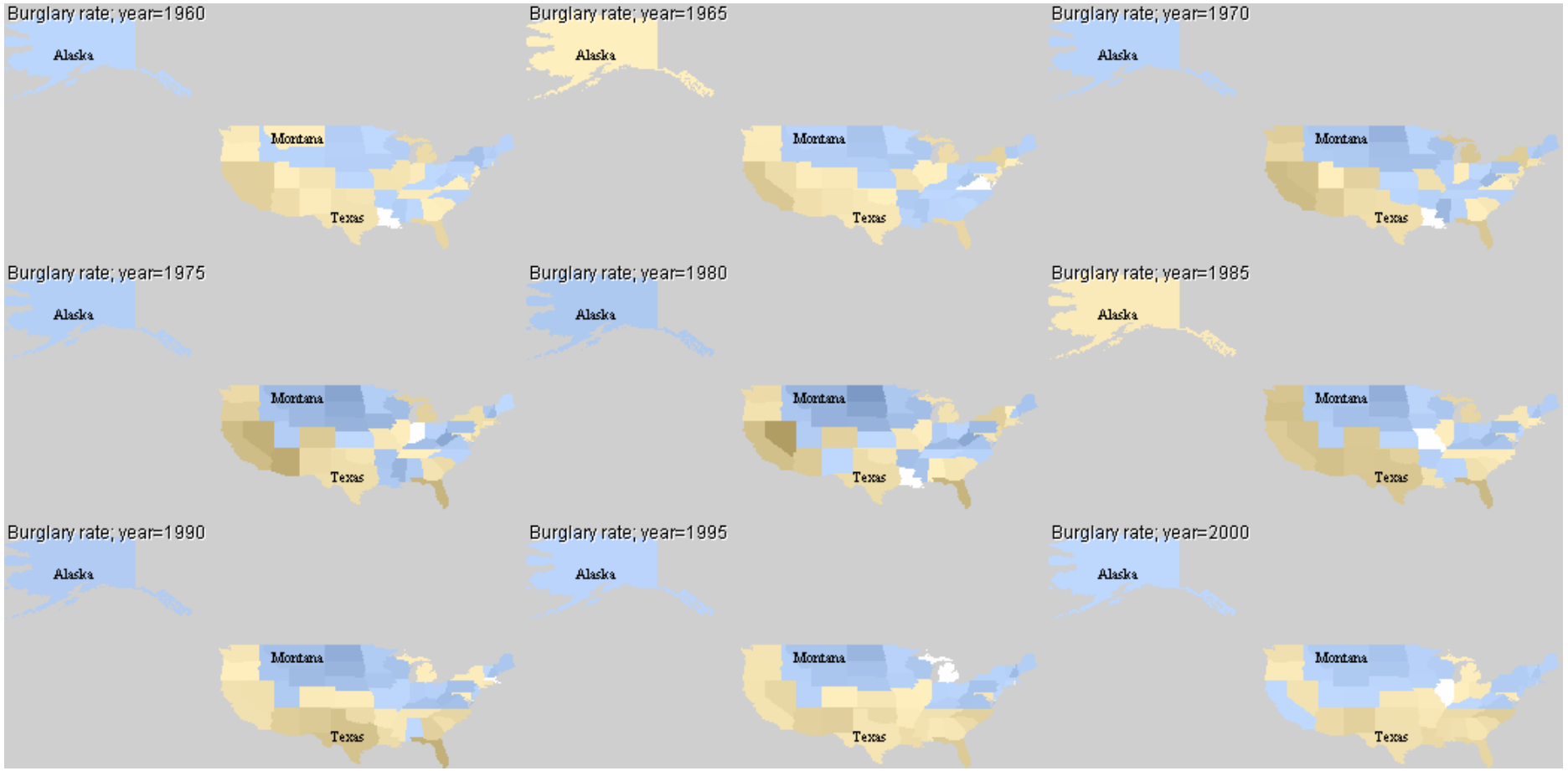


Temporal smoothing and computing of residuals

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

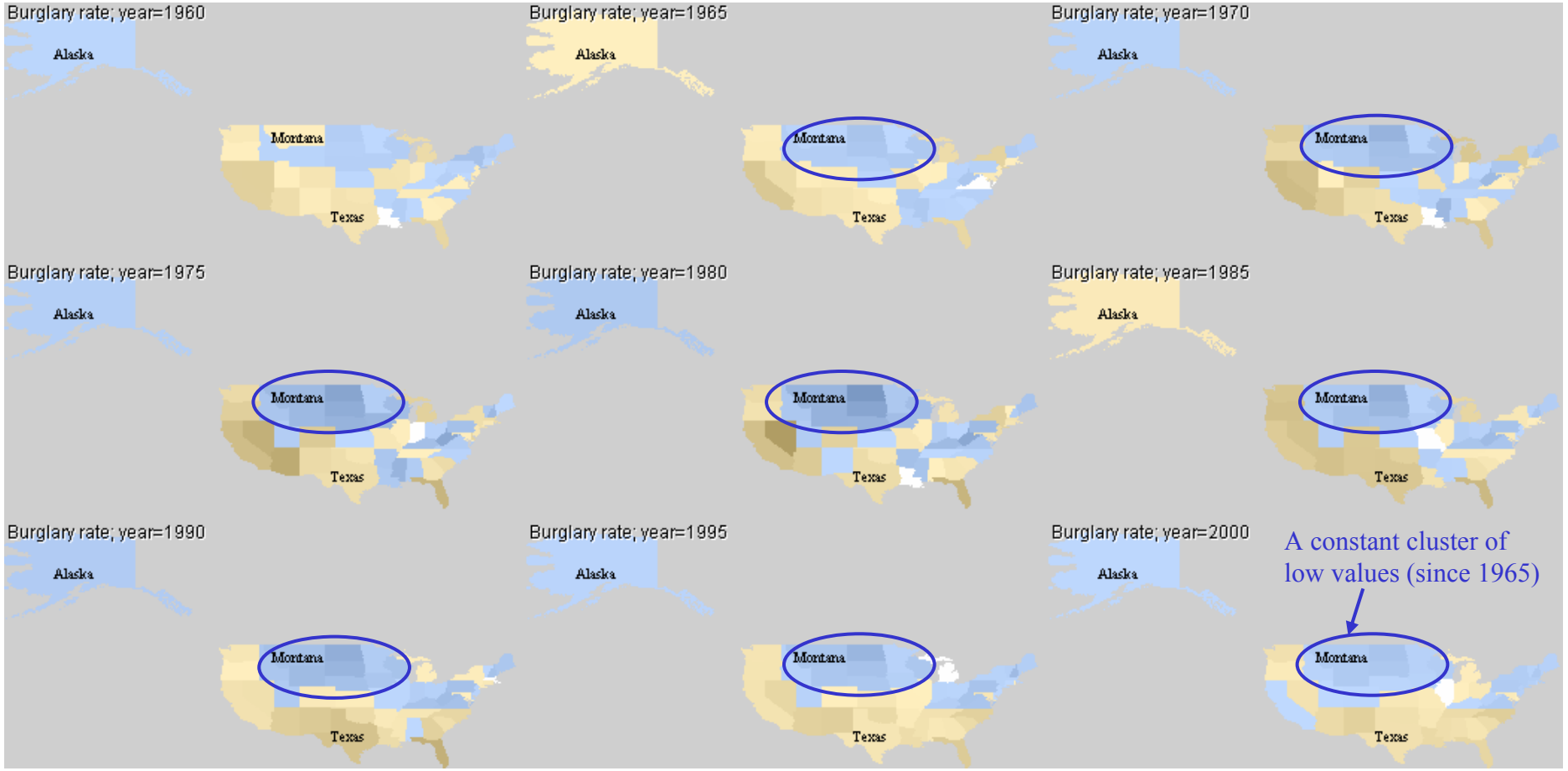
Value scale transformation, e.g. logarithmic

Comparison to country's median

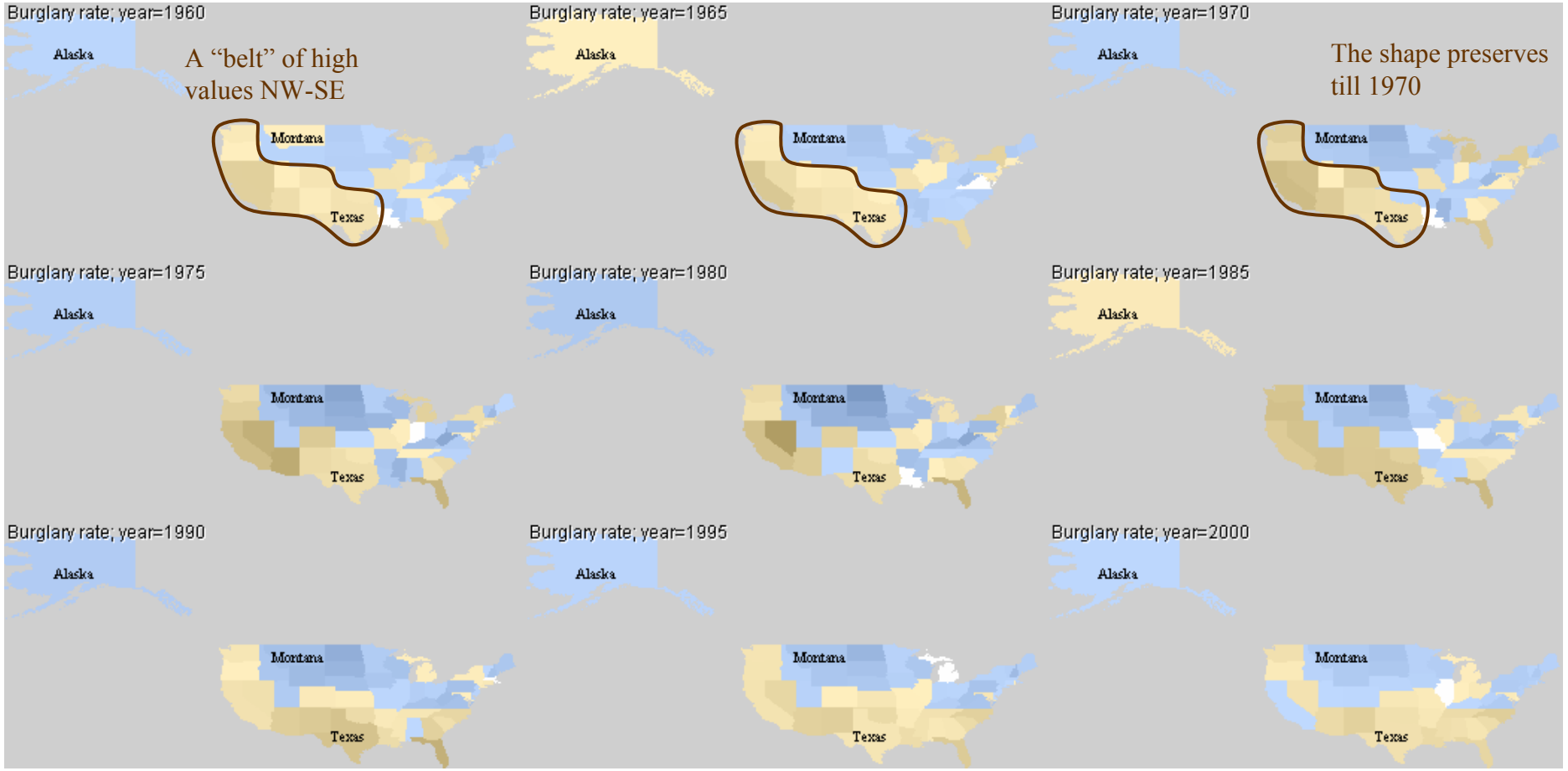


In this mode, the patterns of spatial distribution of attribute values may become more vivid and their evolution over time better seen.

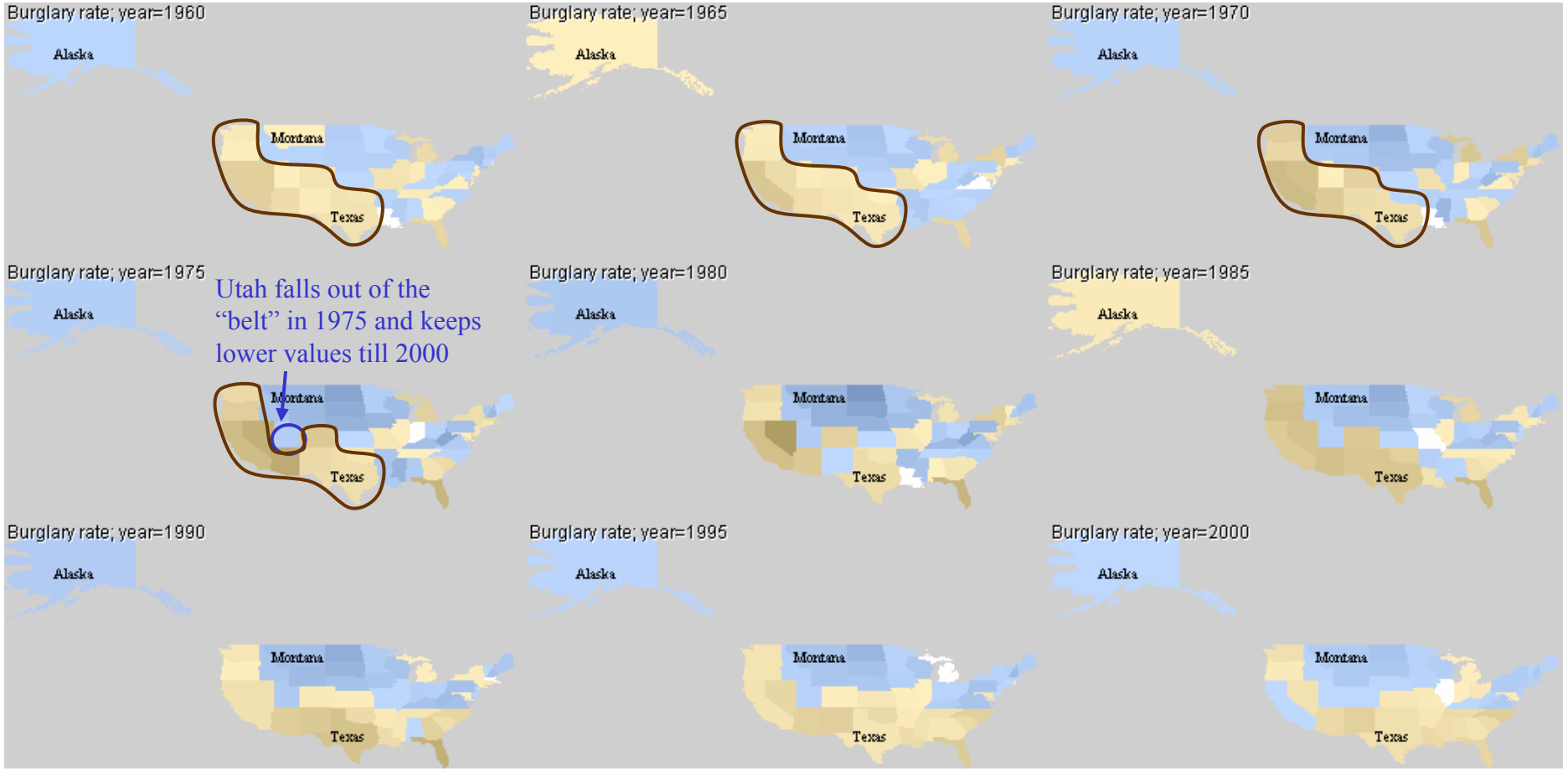
Comparison to country's median



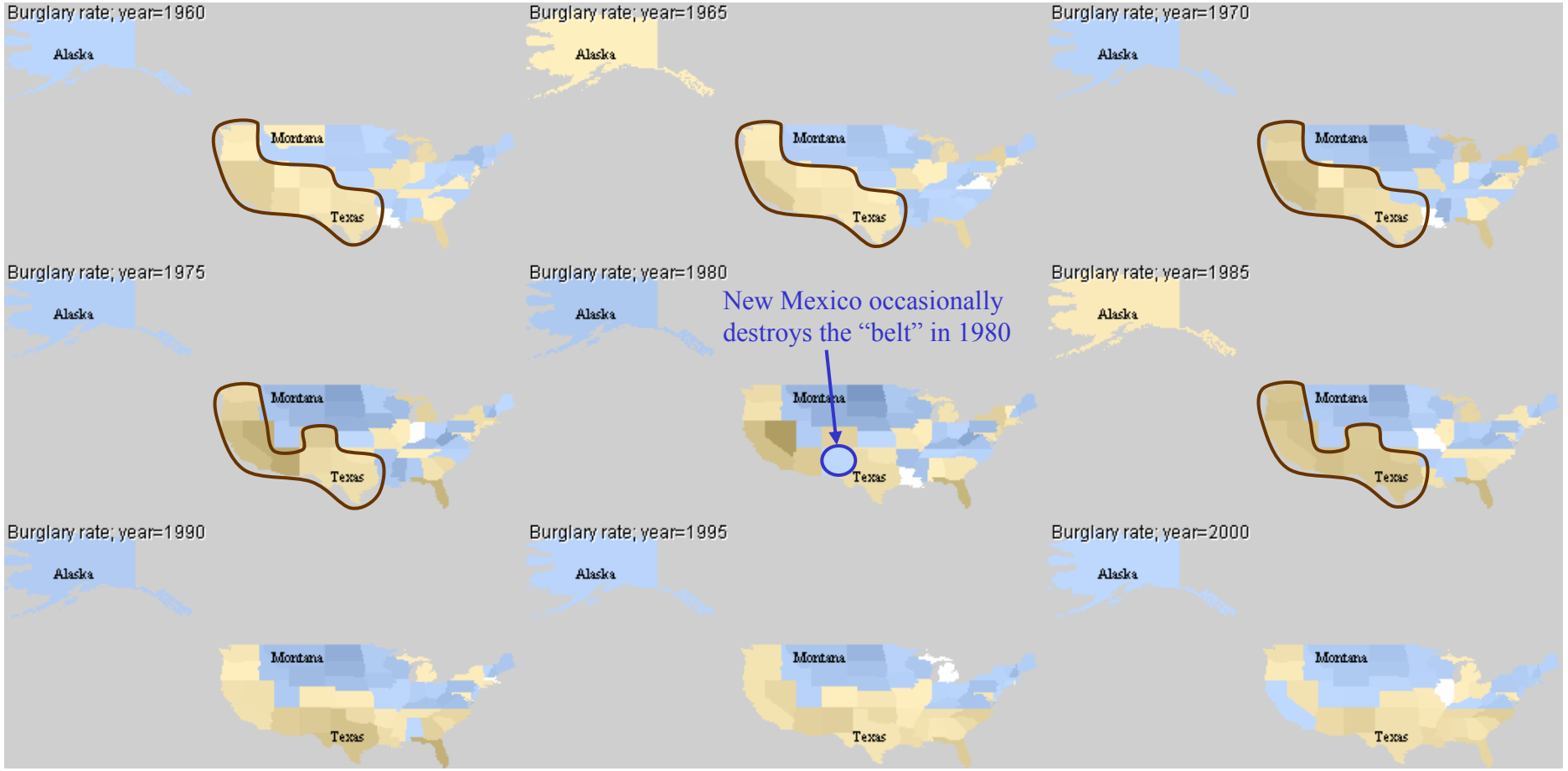
Comparison to country's median



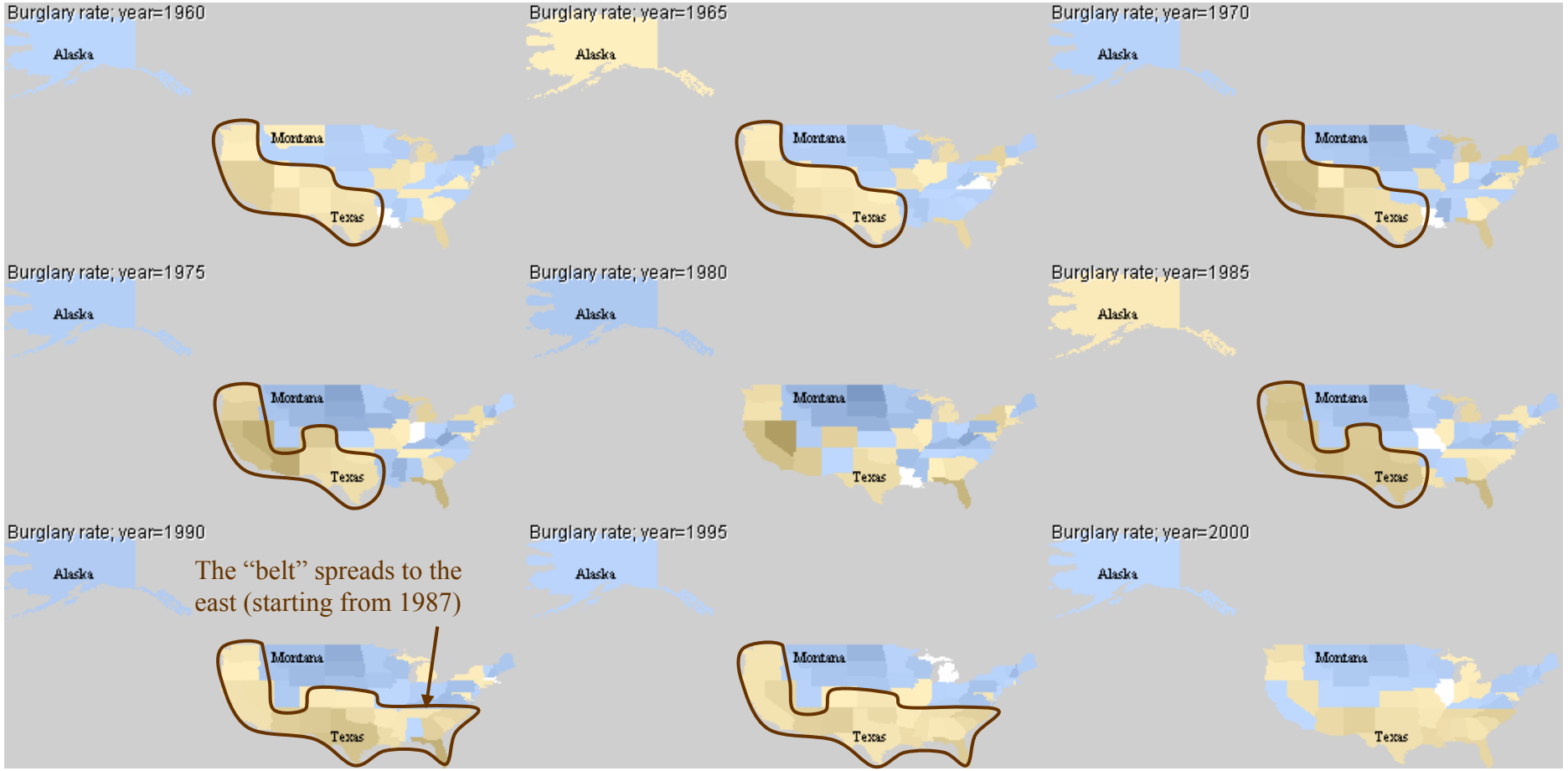
Comparison to country's median



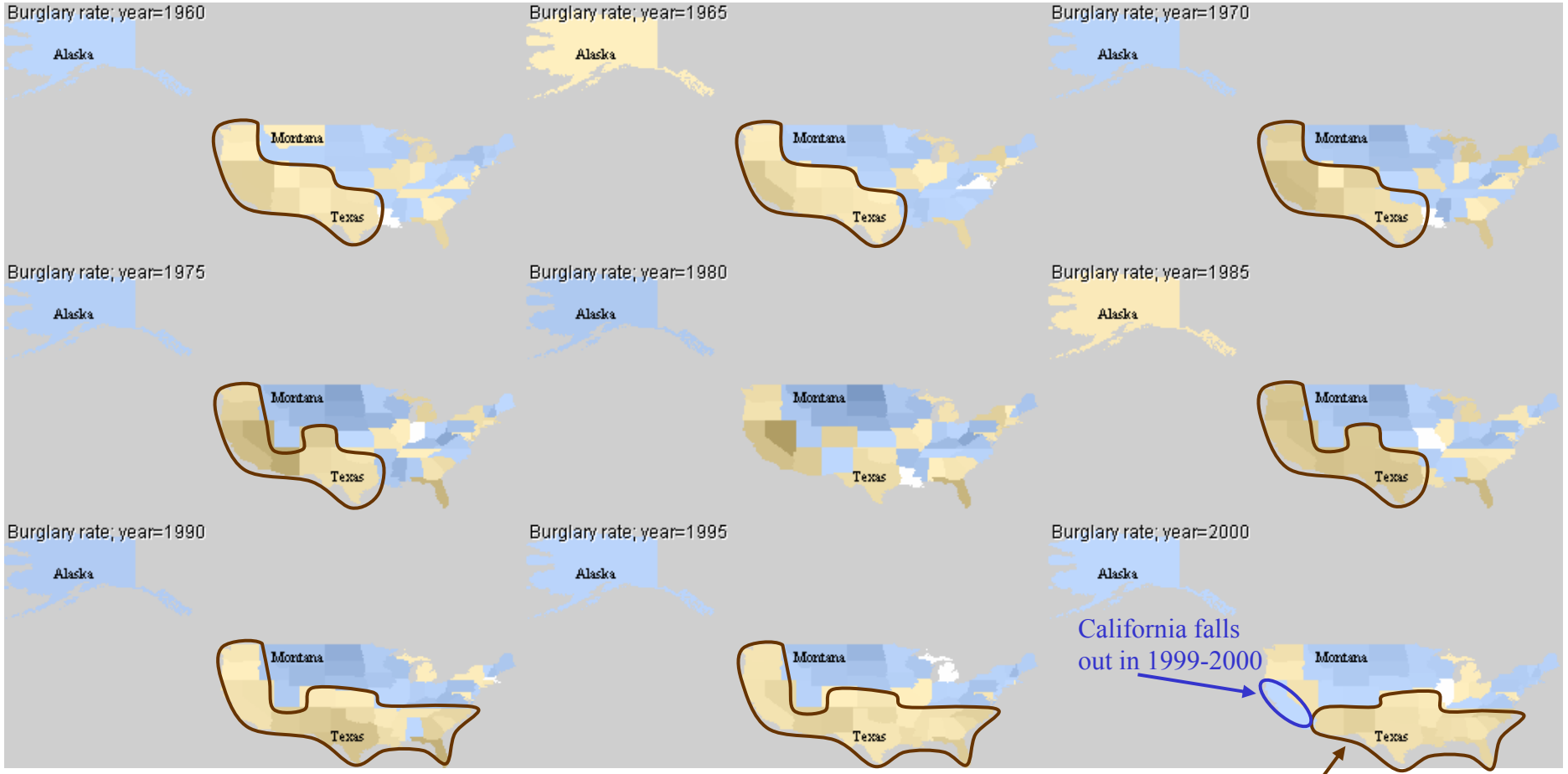
Comparison to country's median



Comparison to country's median

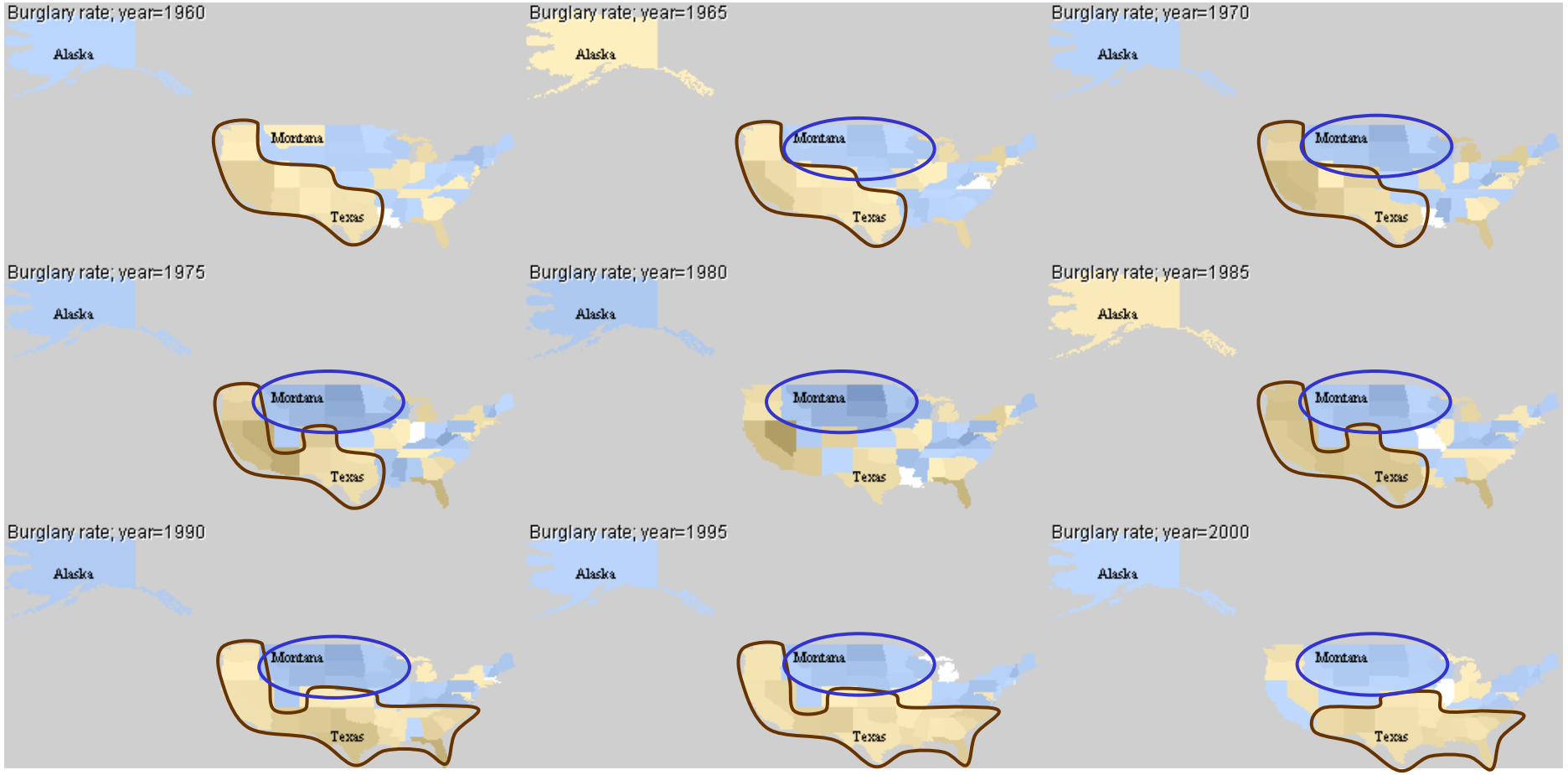


Comparison to country's median

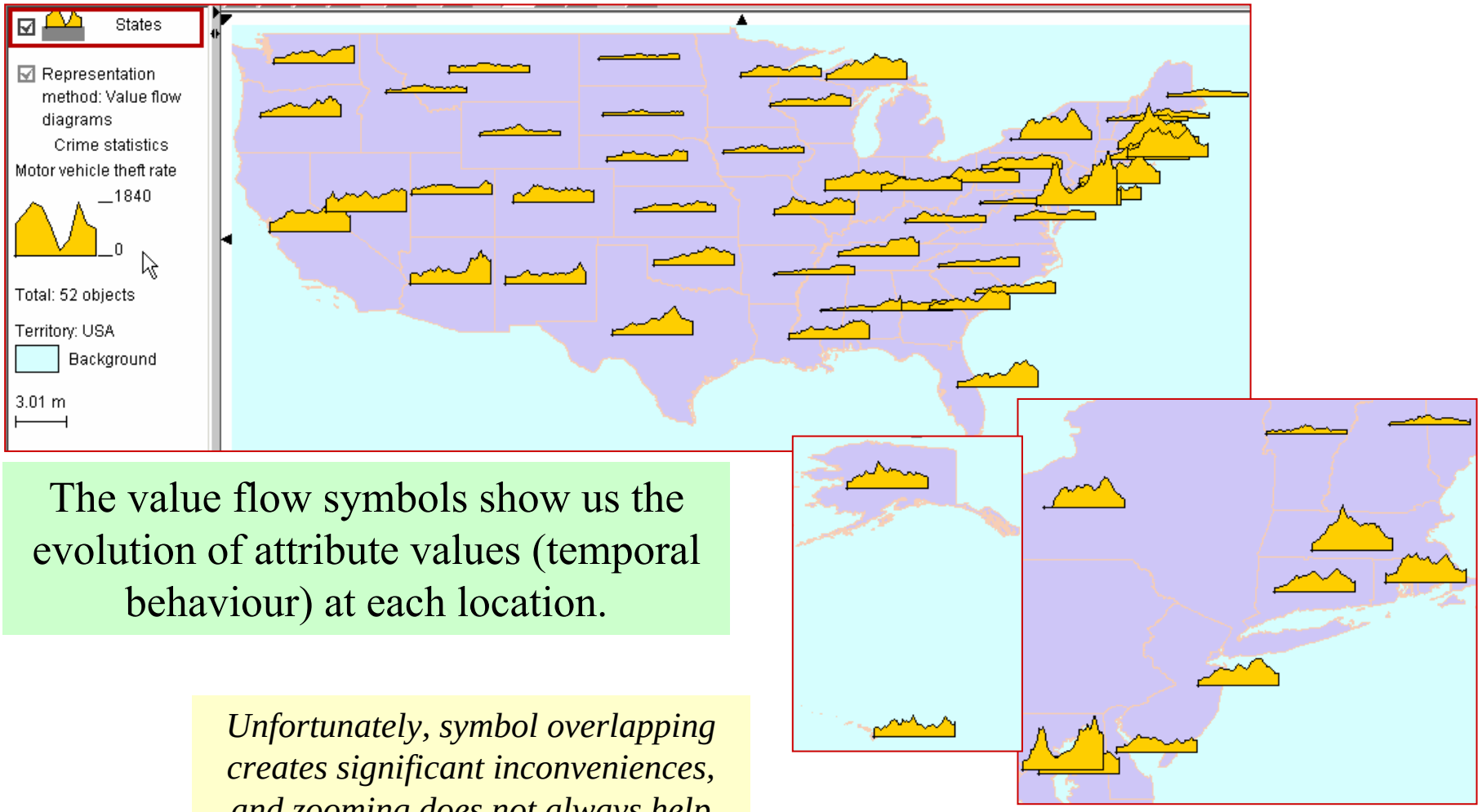


The original NW-SE "belt" transforms into a cluster of high values on the south

Comparison to country's median



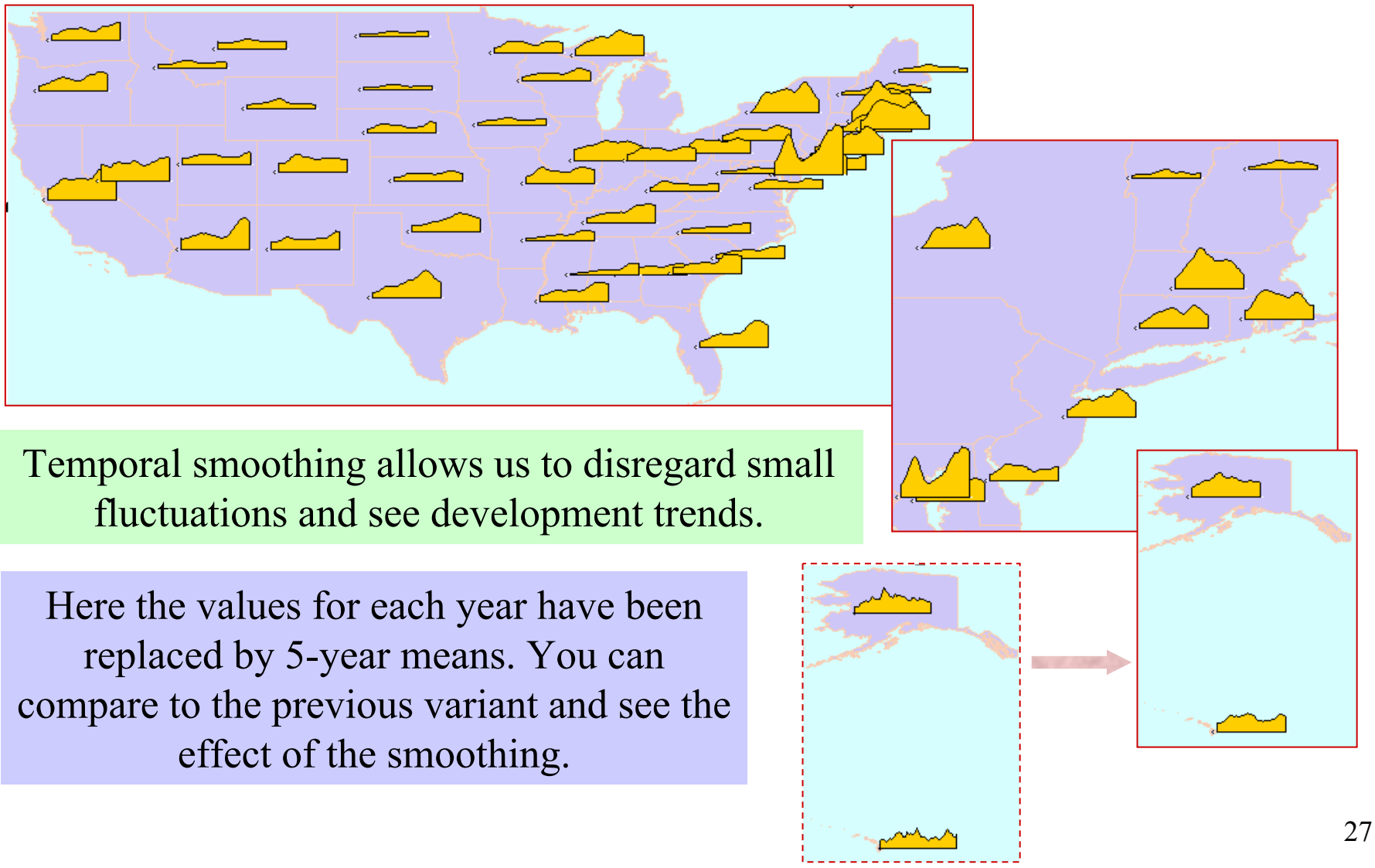
Value flow map



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

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

Value flow map (2)



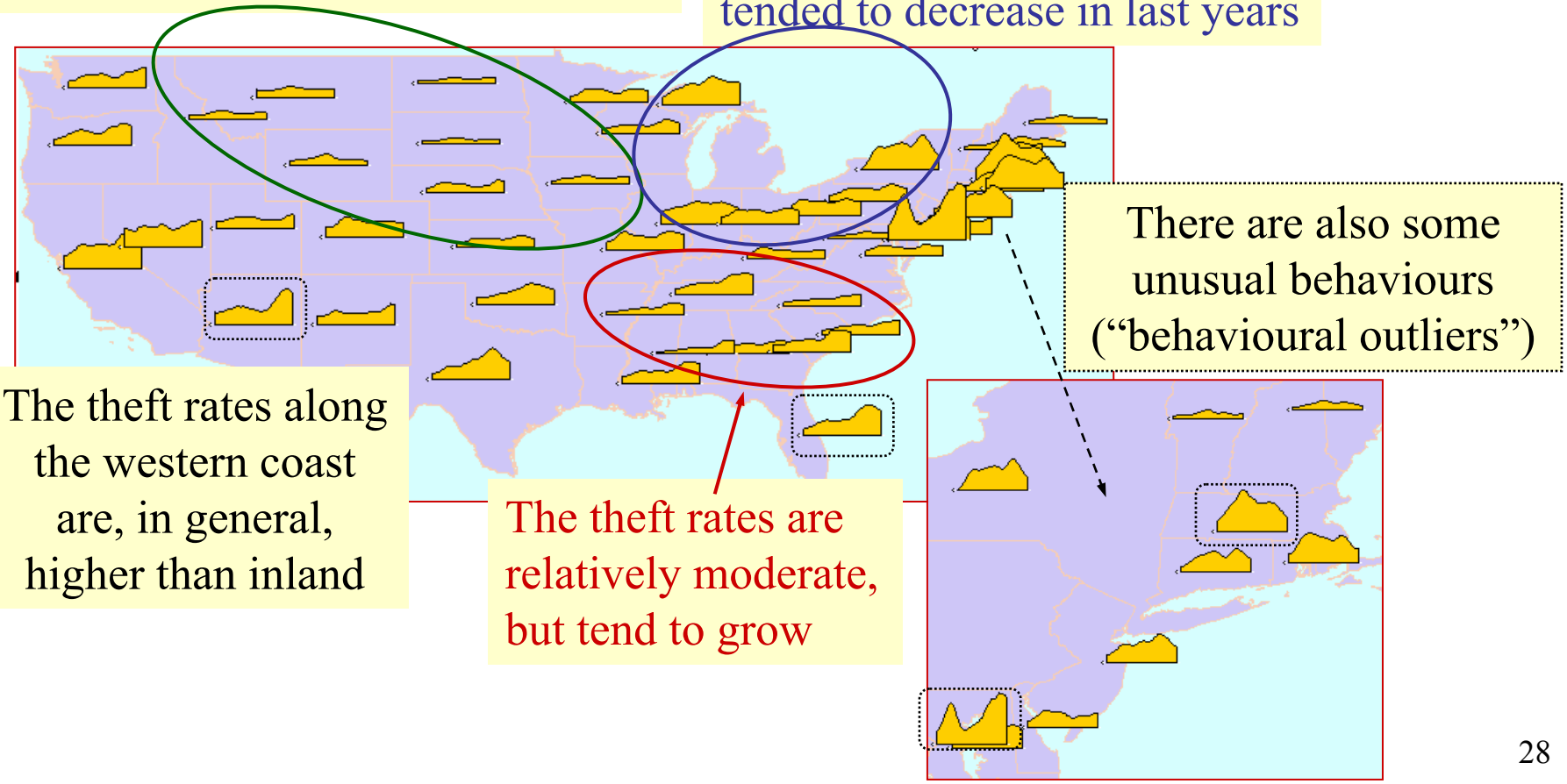
Temporal smoothing allows us to disregard small fluctuations and see development trends.

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.

Exploring the spatial distribution of the local temporal behaviours

This appears to be a spatial cluster of similar behaviours

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



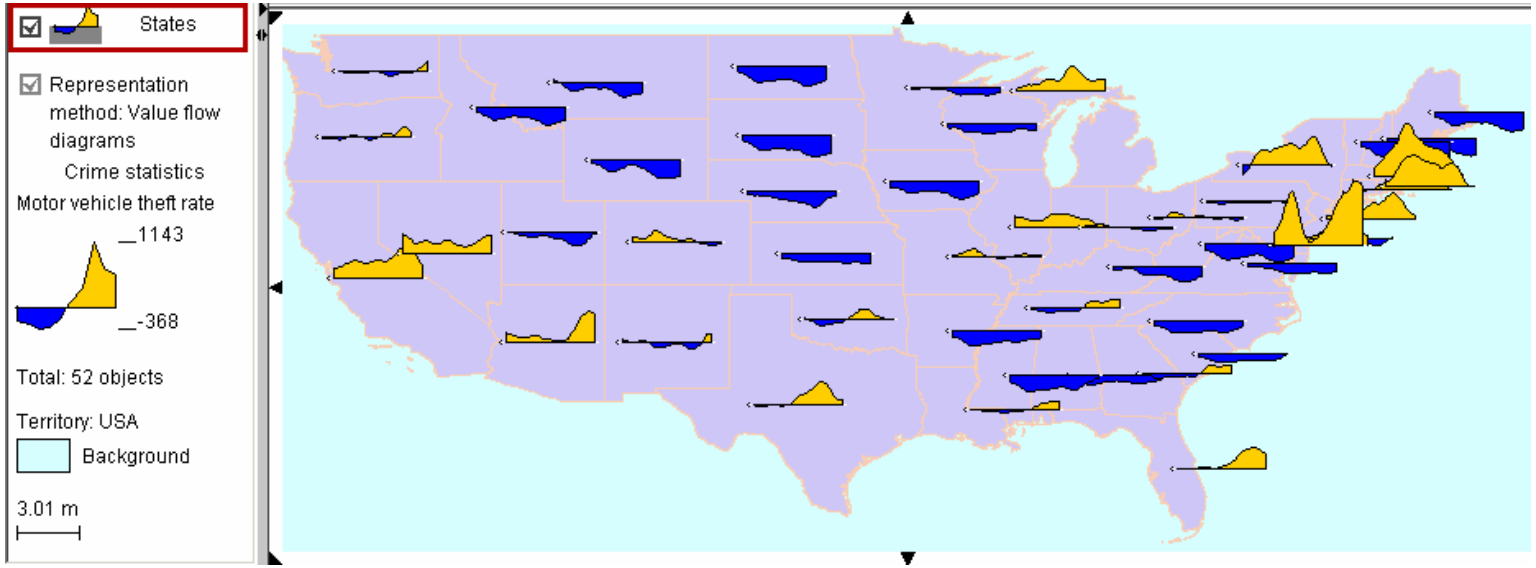
There are also some unusual behaviours ("behavioural outliers")

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

The theft rates are relatively moderate, but tend to grow

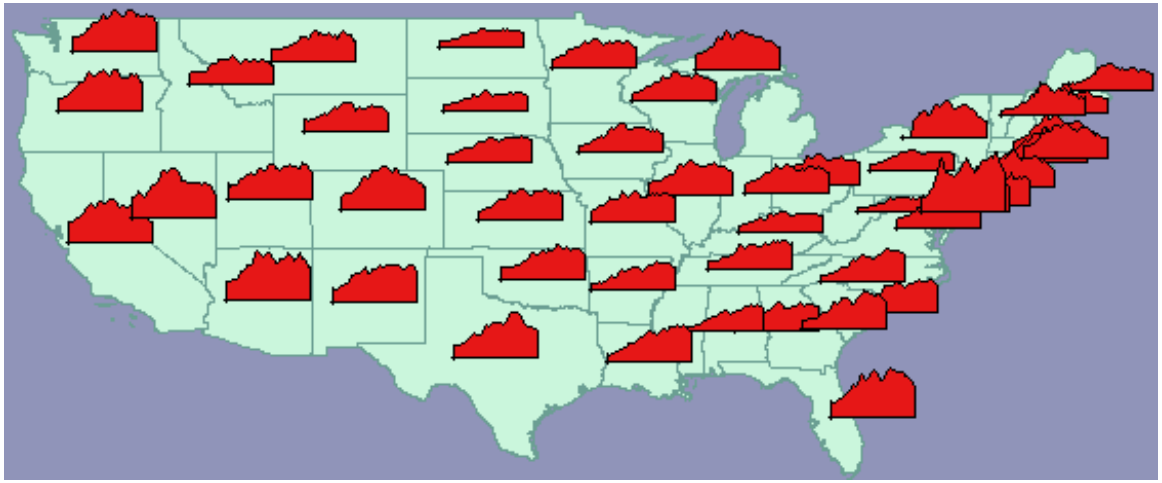
Data transformations for temporal behaviour exploration

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



Here we have applied the comparison to the country's mean: the values for each moment are replaced by their differences to the country's mean at the same moment. Yellow colour corresponds to positive differences, and blue – to negative. We have received a rather clear spatial pattern.

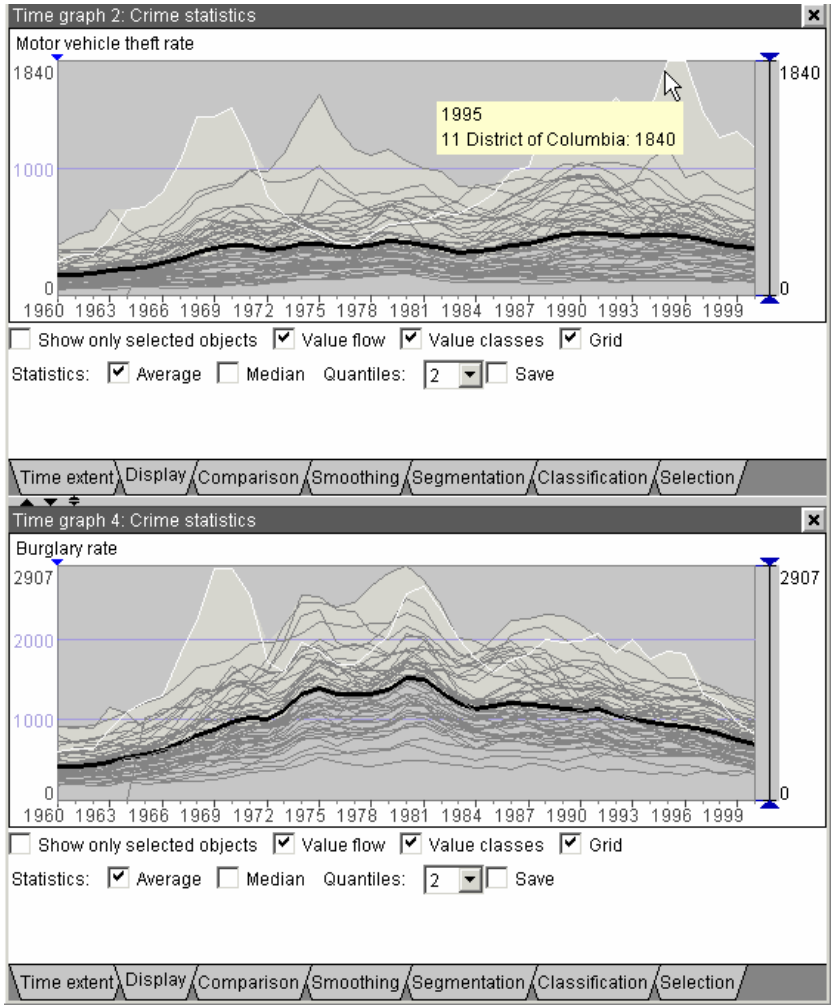
Flow map disadvantages



- 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

- ✓ seeing the temporal behaviours in the space context
- – seeing all behaviours at once
- – detecting behaviours with particular features
- – noticing what sorts of features exist in the data

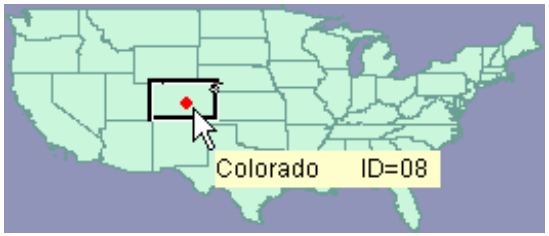
Time graph

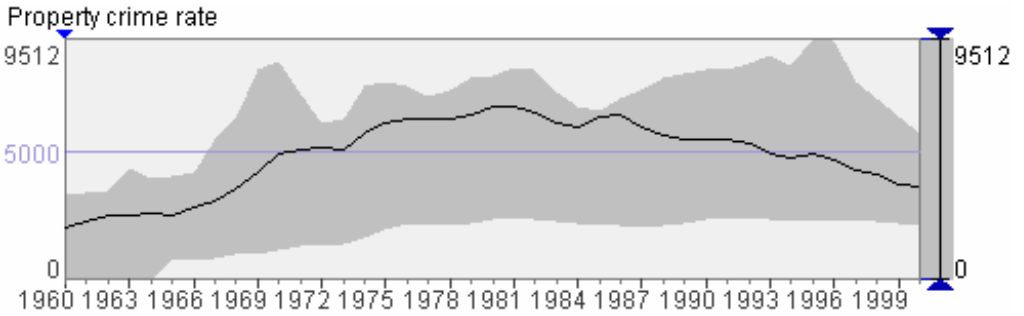


Putting all behaviours together, as in these time graphs, can make their comparison more convenient. When we point on any line, we may see the corresponding object's name and value.

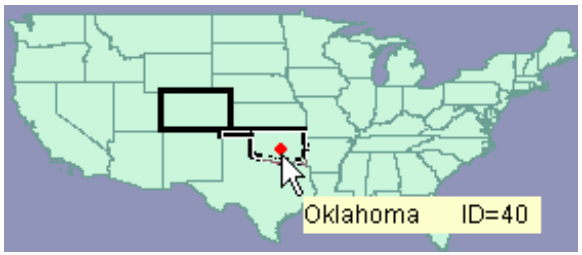
Besides lines for individual objects, a time graph can also show us the "mean behaviour" (the line obtained by connecting each year means) or the "median behaviour" (obtained from each year's medians). This helps us to understand the general development trends for the whole set of objects.

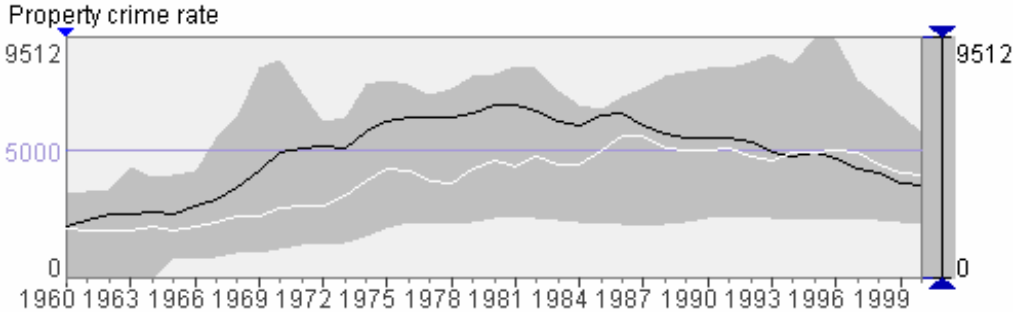
Map + time graph





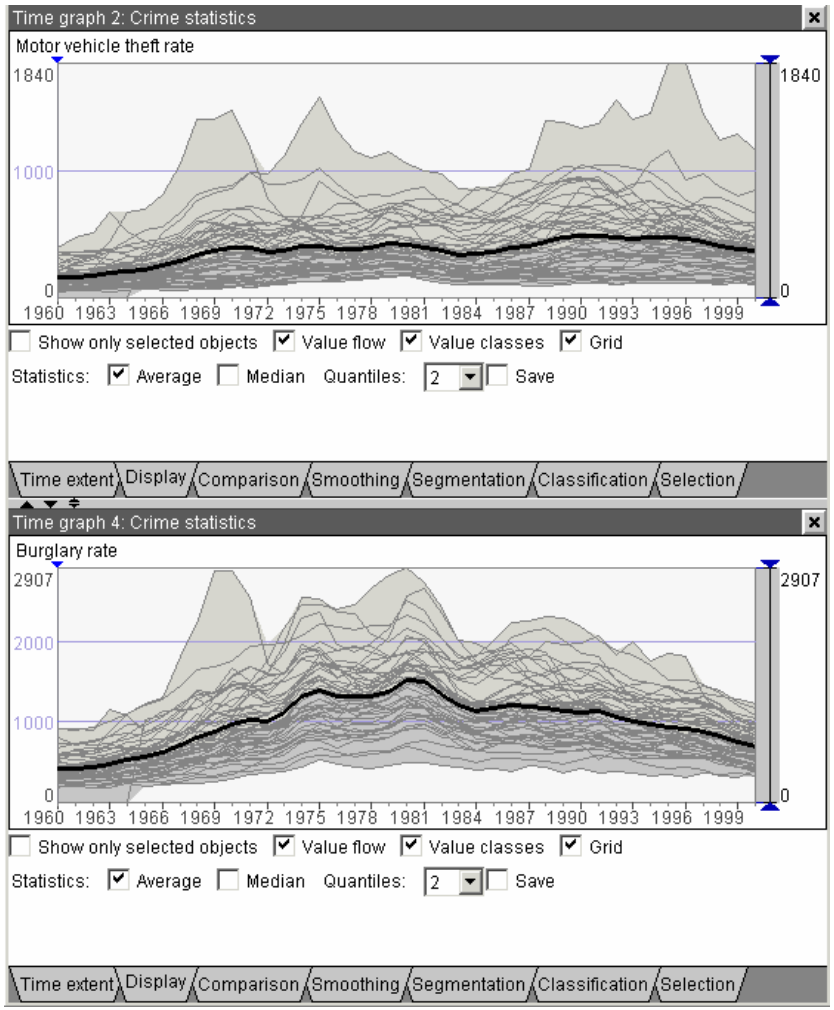
✓ At place ℓ, how did the values behave over the whole time?





✓ Compare the temporal behaviours at places ℓ_1 and ℓ_2

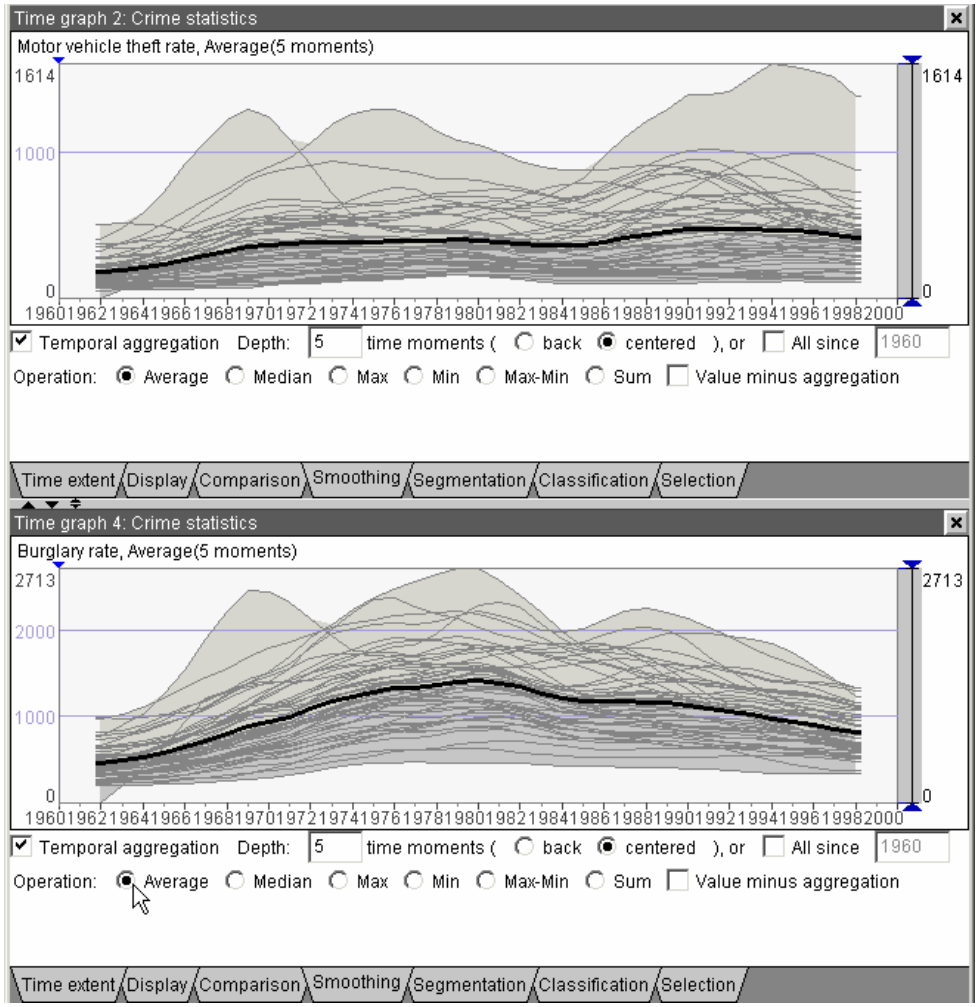
Comparing variations and trends of different attributes (1)



Time graphs are suitable for comparing temporal variations of two or more attributes.

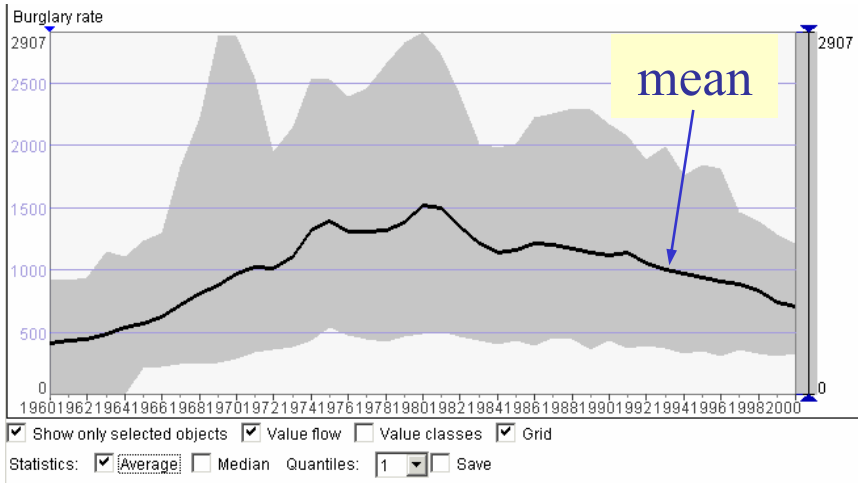
Here we observe that the attributes "Motor vehicle theft rate" and "Burglary rate" have quite different trends of general development.

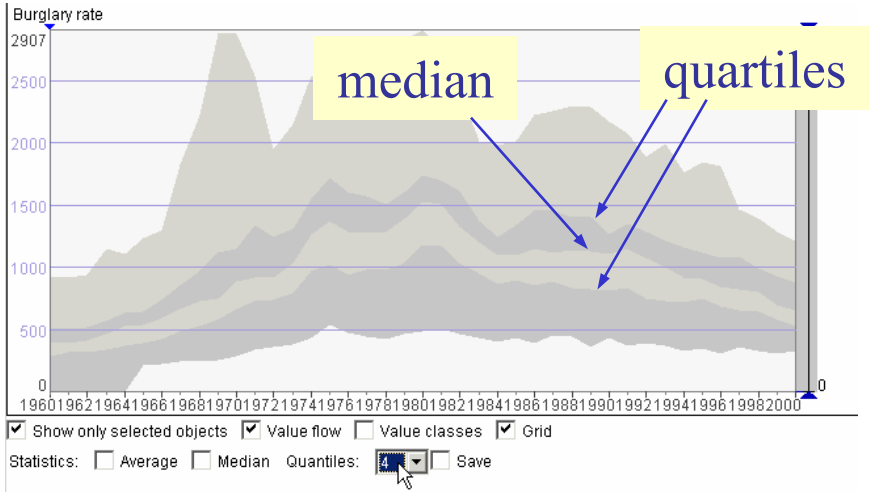
Comparing variations and trends of different attributes (2)

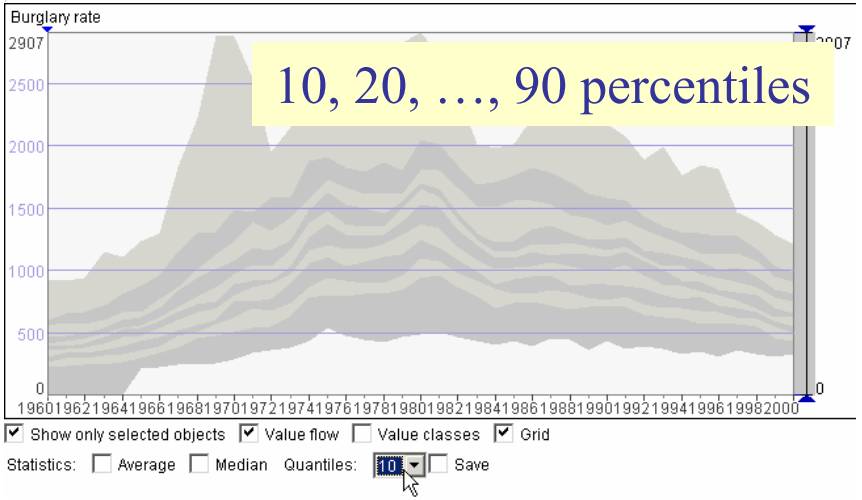


Smoothing (value averaging over intervals) mitigates small fluctuations and exposed the trends more clearly.

Varying level of detail in trend analysis

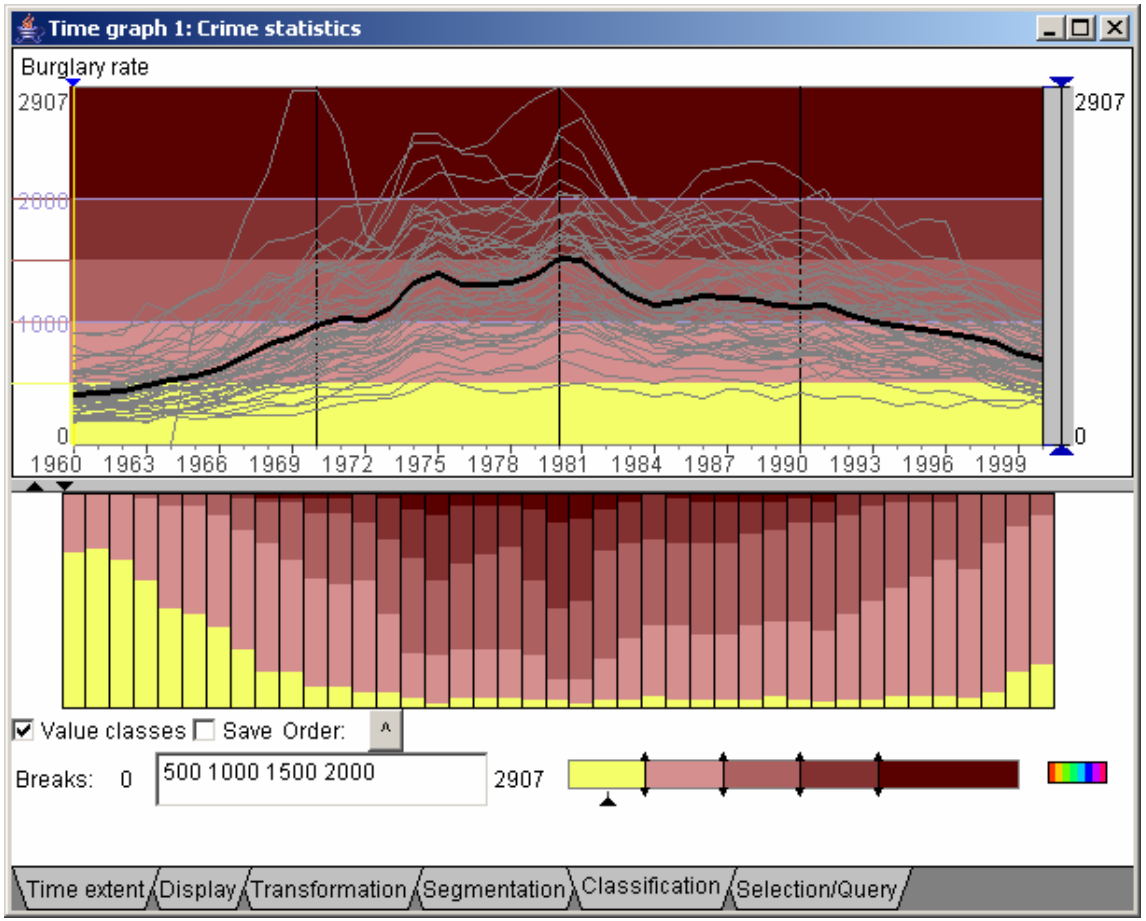






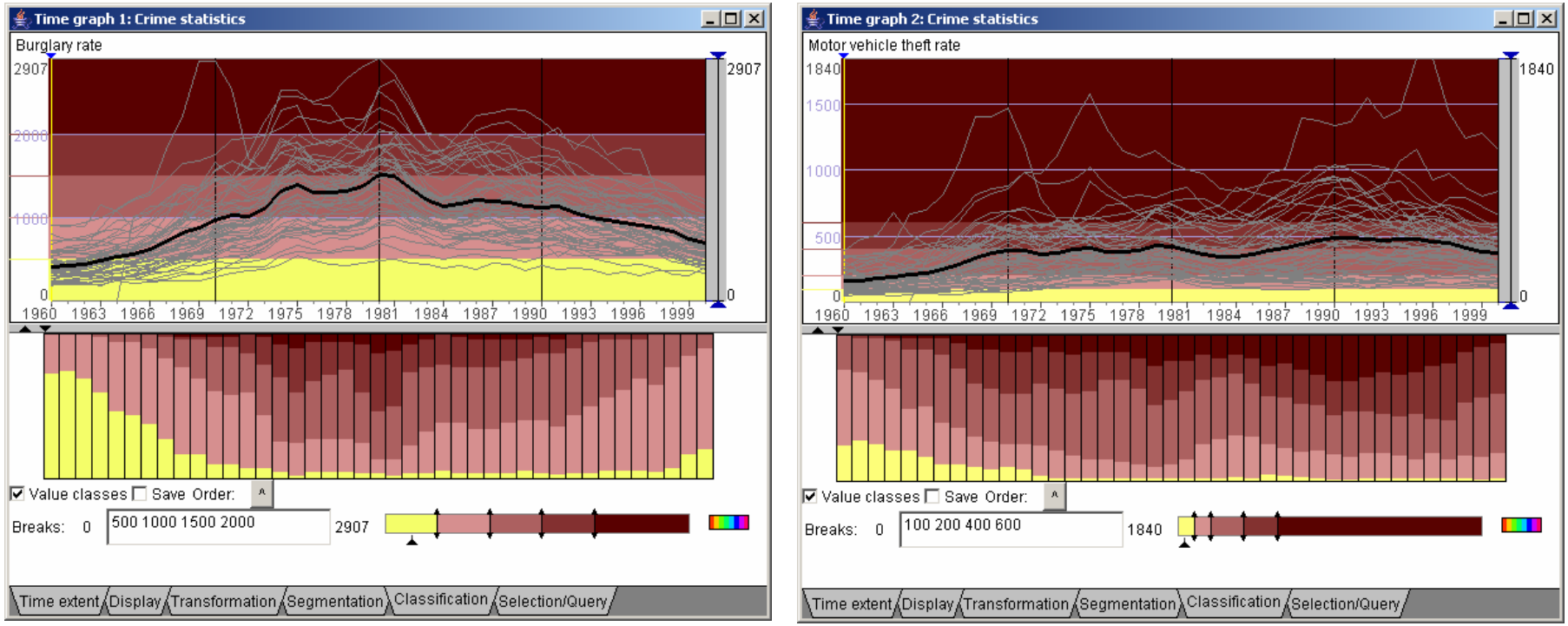
The mean or median line gives only a very coarse picture of the general properties of the value variation.
For a finer analysis, we may prefer to look also at the quartiles or even smaller percentiles.

Aggregation by value intervals (time histogram)



- We divide the value range of the attribute into intervals
- For each interval a specific colour or shade is chosen
- The time histogram below shows for each time moment (here a year) the relative frequencies of the values from each interval by the sizes of the coloured segments
- Here we see an increase of the crime rates over the country in 70ies and early 80ies (note 2 peaks in 1975 and 1981-82) and then gradual decrease

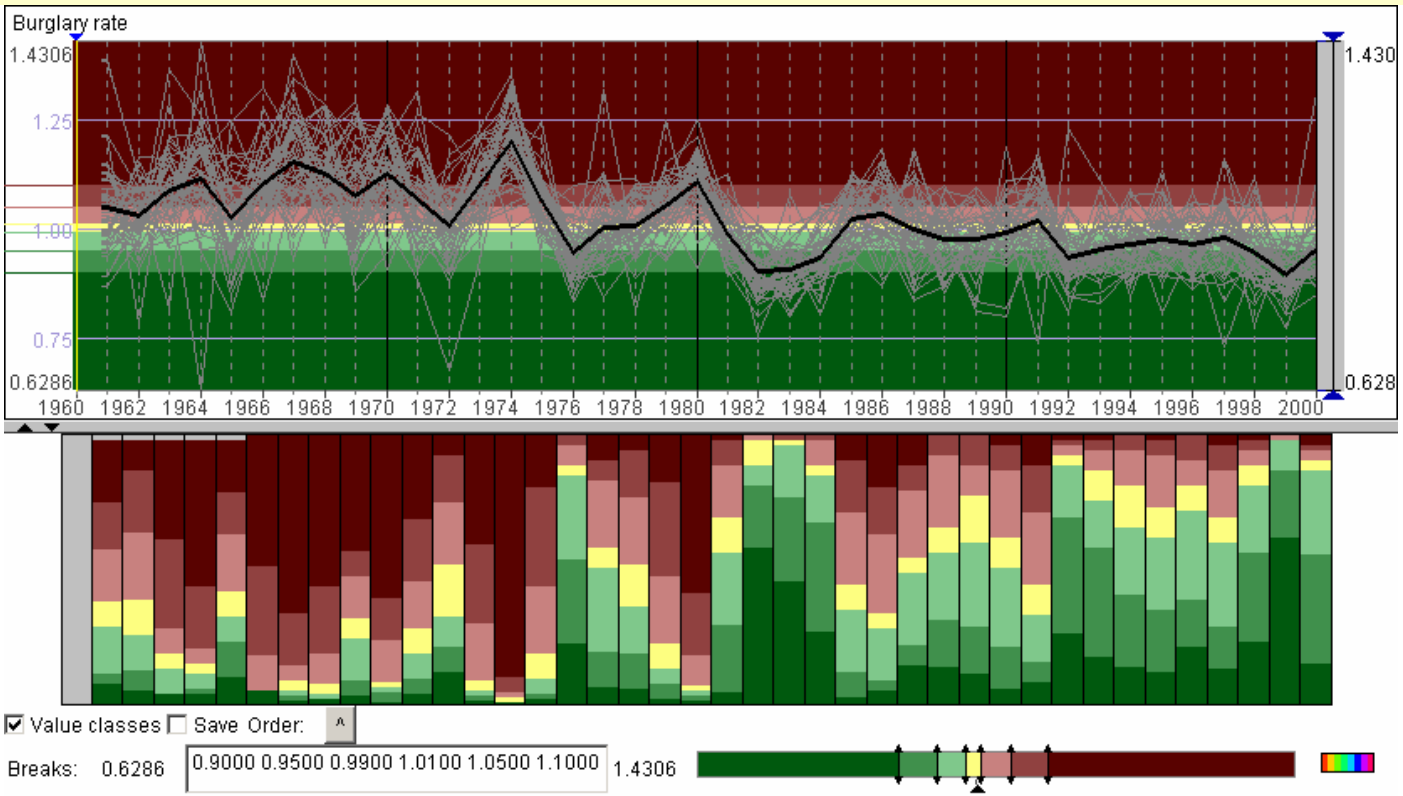
Comparison of 2 (or more) attributes



Despite different value ranges, we can compare the overall temporal trends of the attributes “Burglary rate” and “Motor vehicle theft rate”.
The second attribute also increased in 70ies, then slightly decreased (1980-1984), then increased again (1985-1990). A slight decreasing trend appeared in the last 3 years. The first attribute had a much longer and more vivid decreasing trend.

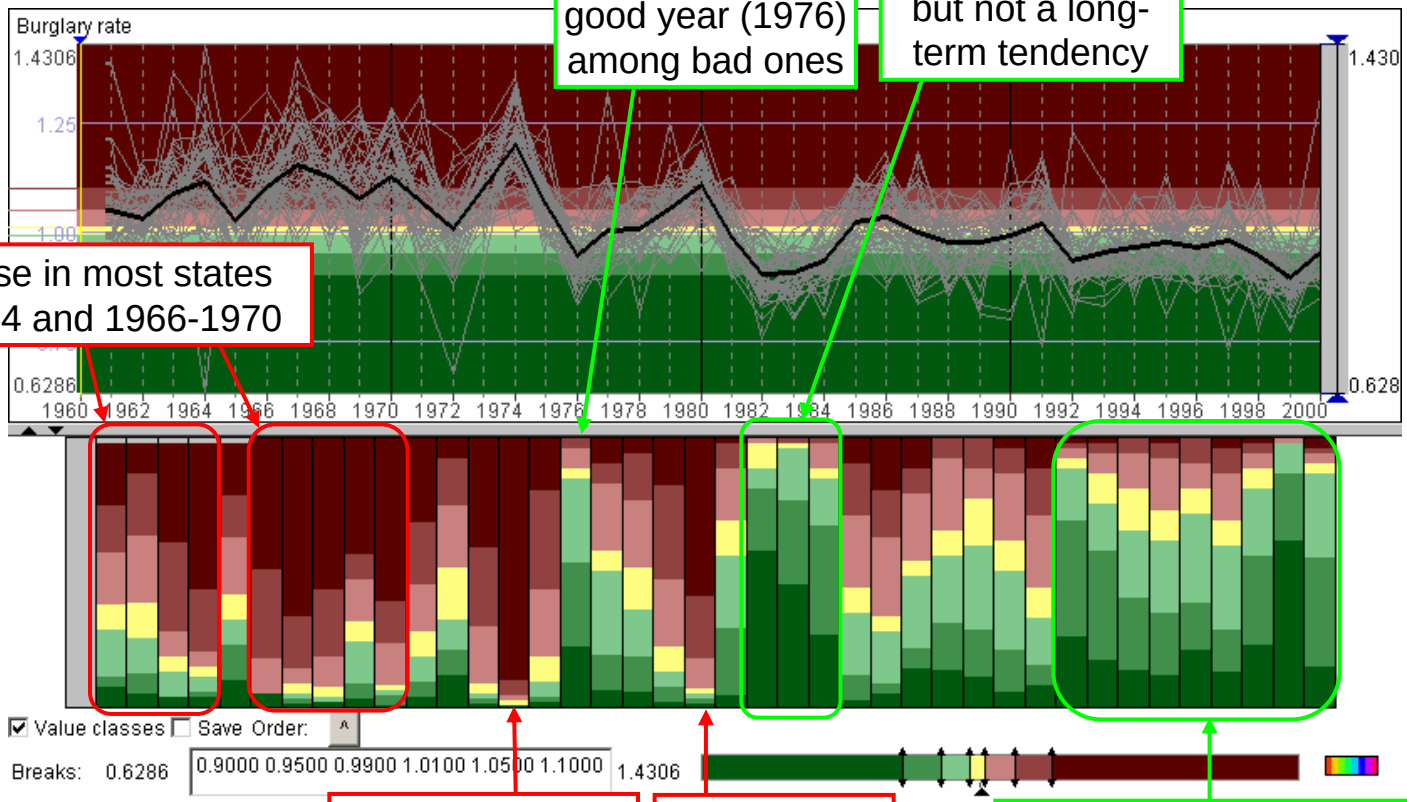
Time histogram of changes

The values of the attribute “Burglary rate” for each year have been transformed into relative differences (ratios) with regard to the values in the previous year.



The aggregation by value intervals has been applied to the transformed values.
The intervals and respective colours have been chosen so that yellow means practical absence of change (±1%), red means increase (up to 5%, from 5 to 10%, over 10%), and green means decrease (up to 5%, from 5 to 10%, over 10%).

Time histogram of changes



An occasional good year (1976) among bad ones

3 good years in a row (1982-1984) but not a long-term tendency

High increase in most states in 1961-1964 and 1966-1970

An extraordinarily bad year (1974): increase in all but one states, in 46 states over 10%

1980 was not much better than 1974

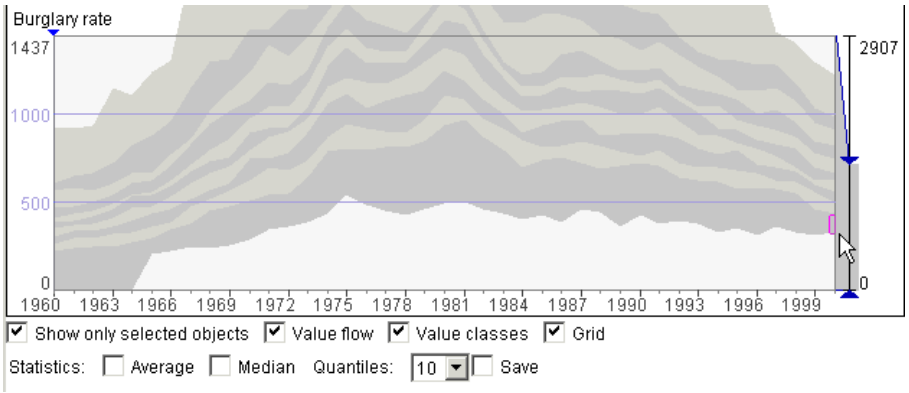
A good tendency (prevailing decrease of the burglary rates) since 1992

From generals to particulars

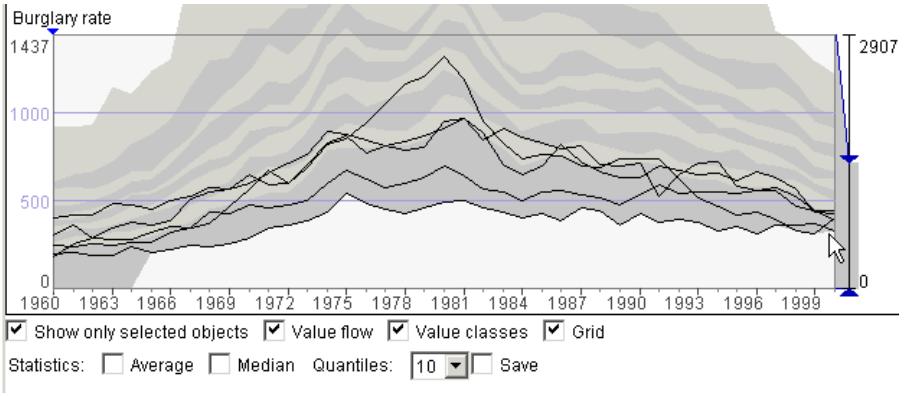
General principle of analysis:

1. See the whole
   In our case:
   - Evolution of the overall spatial distribution over time
   - Distribution of the temporal behaviours over the whole space
   - Evolution of the overall statistical distribution of attribute values over time
2. Attend to particulars: outliers, unusual behaviours, unexpected patterns, …
   In our case:
   - Particular time moments (e.g. years of extreme changes)
   - Particular places with uncommon behaviours

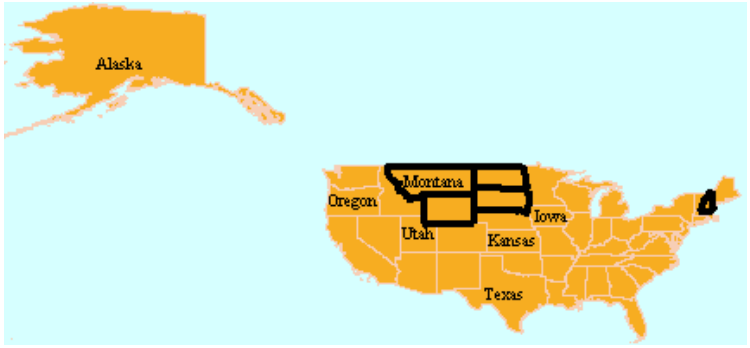
Combining generic and specific information display (example)



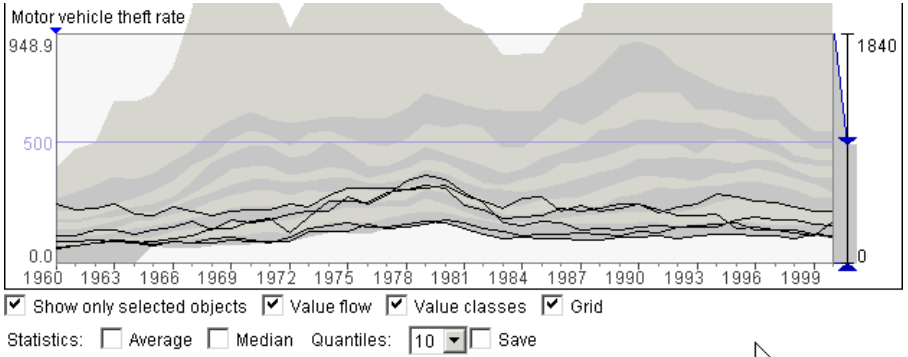
1) We select the counties with burglary rates in 2000 fitting in the bottom 10%…



2) …and look how these countries behaved over the whole time period 1960-2000

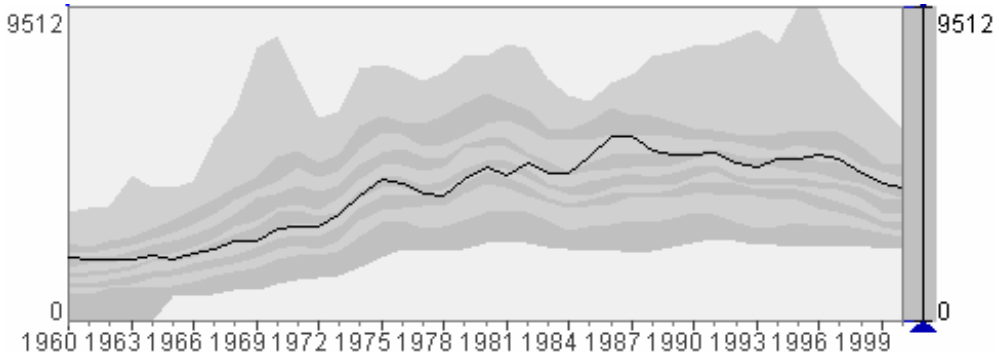


3) We also see where these counties are on the map…



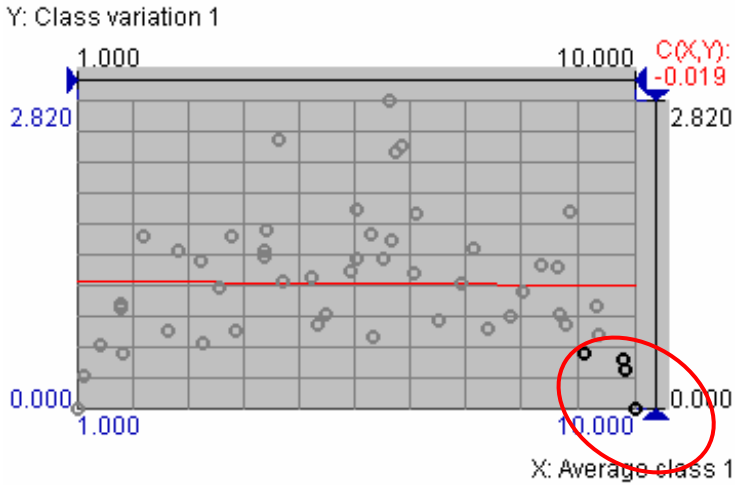
4) …and how motor vehicle theft rates progressed there

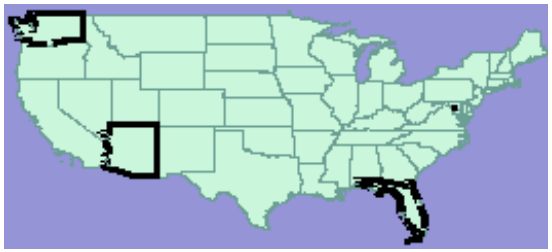
Detecting particular behaviours



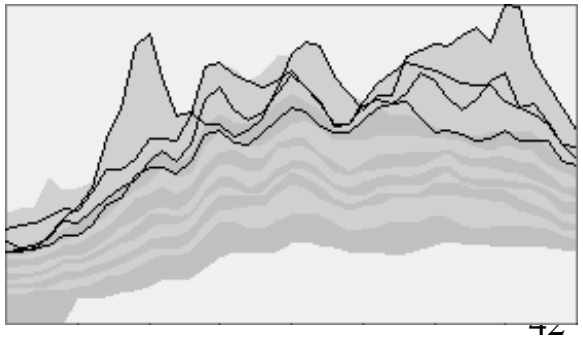
1. Obtain simple counts for every temporal behaviour:
- Number of times in each class (quantile)
- Average class, variance
- Number of "ups" and "downs"

2. Visualise the counts on an appropriate display linked to a map

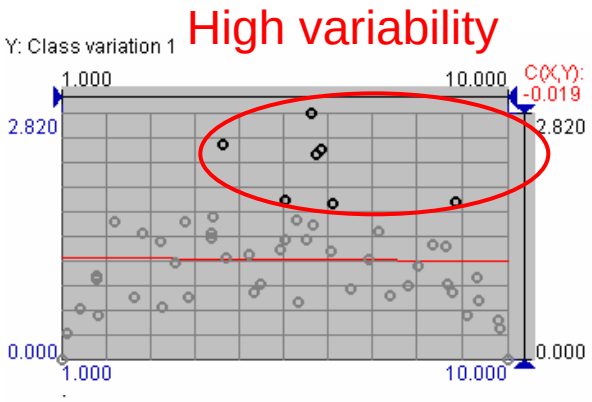


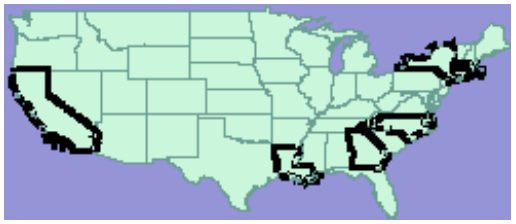


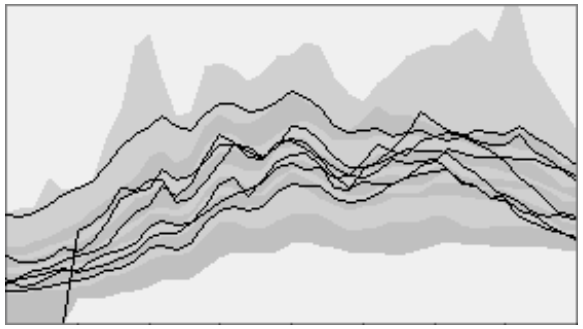
E.g. detect places & behaviours with the highest values and low class variance

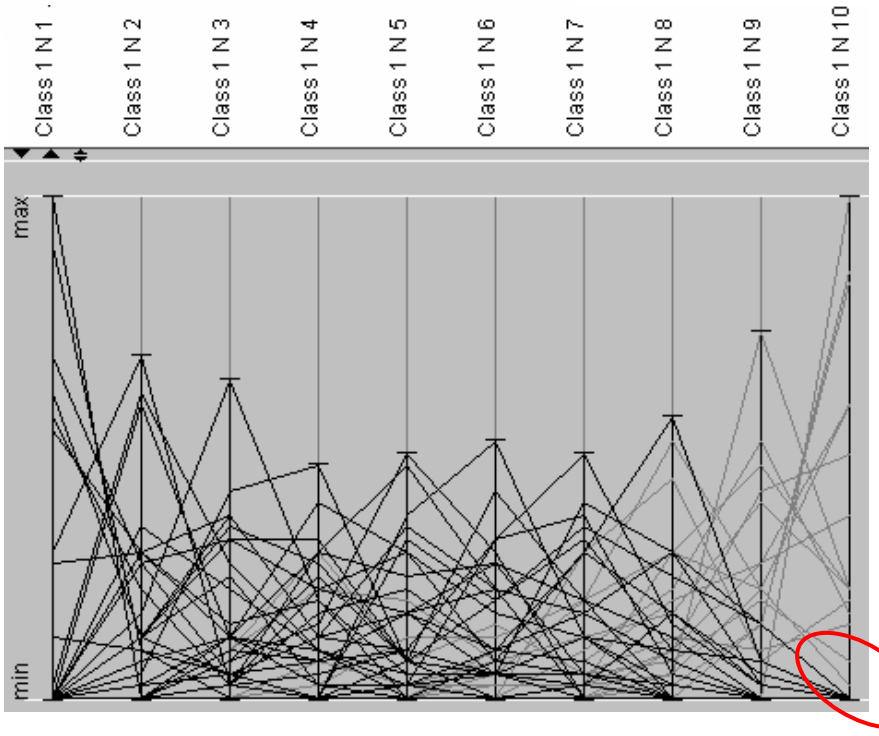


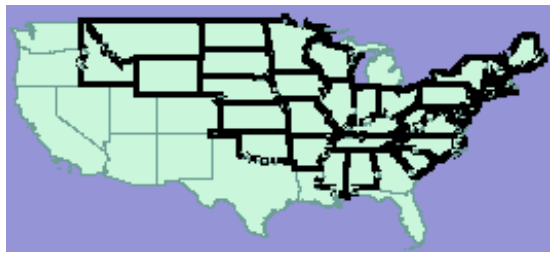
A few more examples…





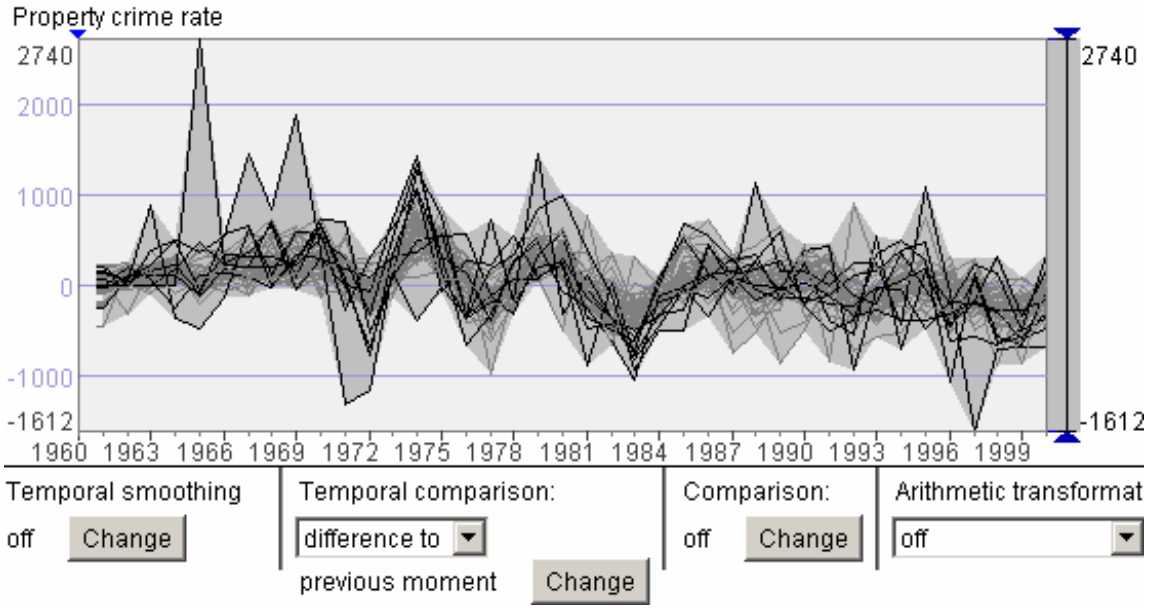


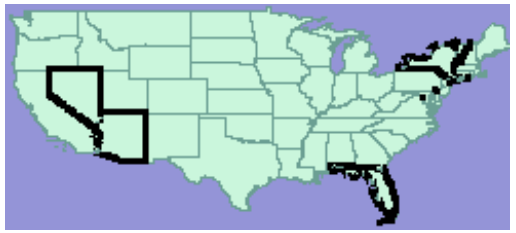




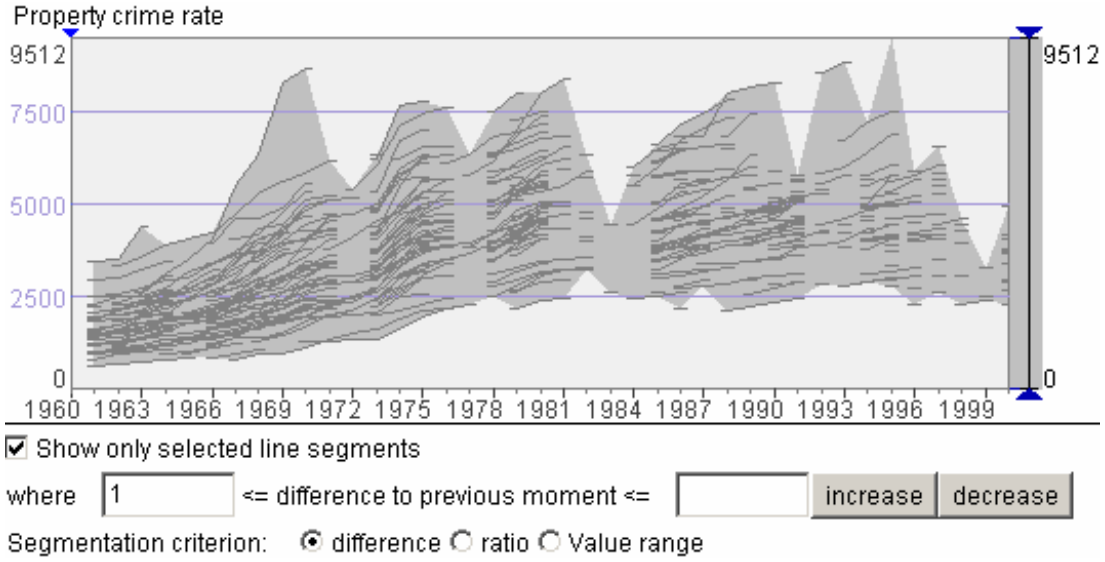
Never in class 10

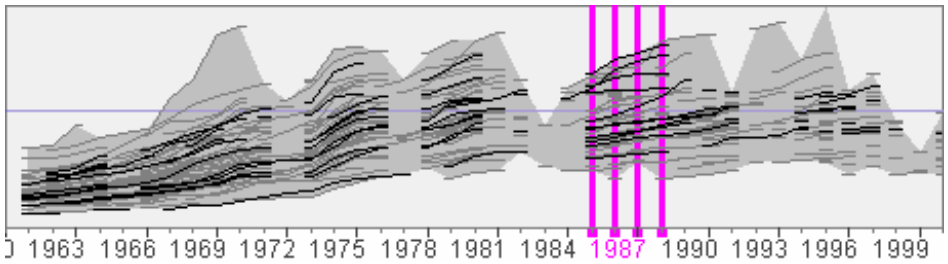
Detect behaviours with extreme rises or drops

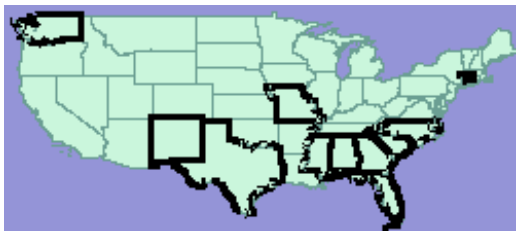




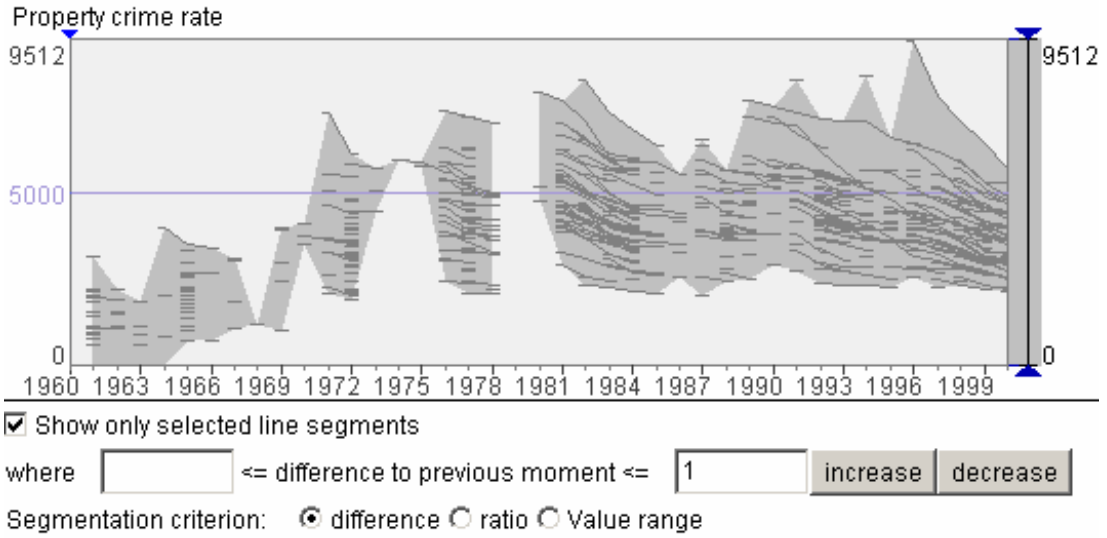
Detect behaviours with continuous increase

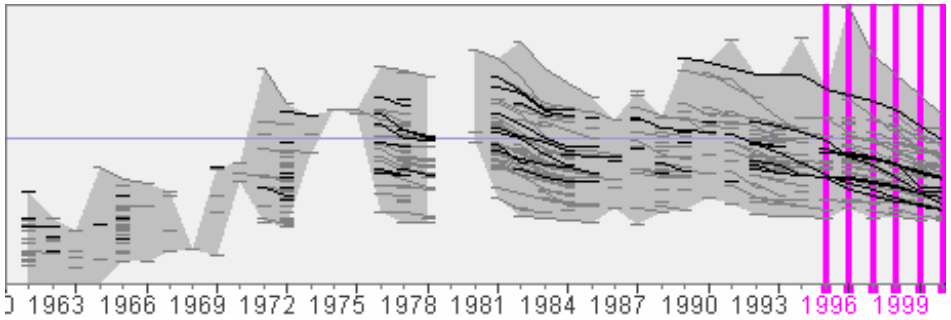


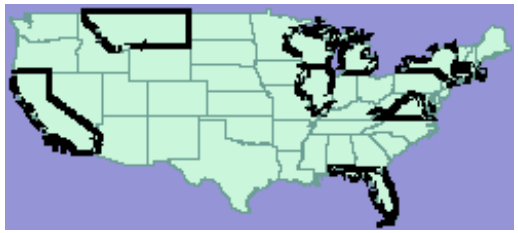




Detect behaviours with continuous decrease







Summary

- Different types of spatio-temporal variation:
  - thematic data (attribute values) referring to places or static spatial objects (spatial time series)
  - appearance and disappearance of objects (events)
  - change of spatial properties: position, size, shape
- Structure of spatial time series:
  - spatial references, temporal references, attribute values
- Two complementary views:
  - temporal variation of the spatial distribution (behaviour) of attribute values
  - spatial distribution of the local temporal behaviours of attribute values
- Visualisation techniques: time map, value flow map, time graph
- Value transformations: change computing, smoothing, comparison
- Statistics and aggregation: quantile variation, temporal histogram
- Specific interactive technique: change-based selection

See also

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

  Chapter 4