

# Computing Stable Demers Cartograms

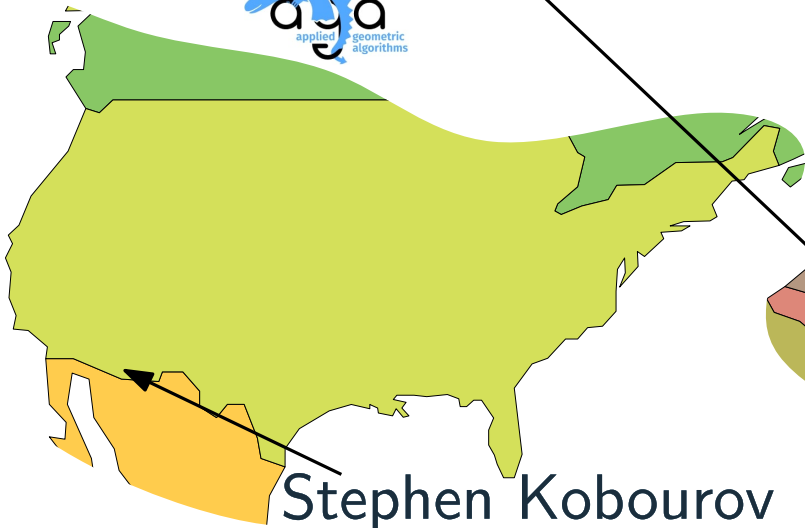
GD 2019 · September 17, 2019

Jaakko Peltonen  
Tampere University

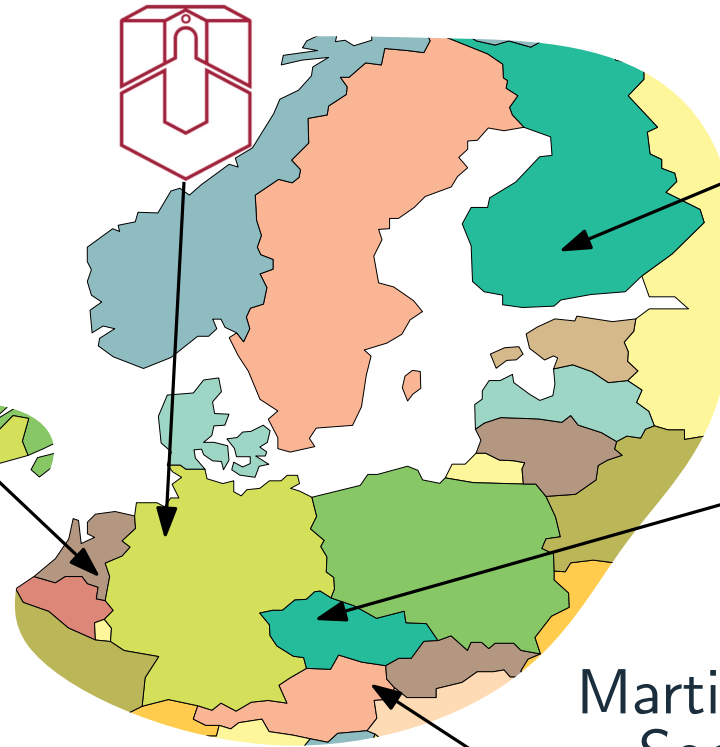
Markus Chimani  
Osnabrück University

Wouter Meulemans  
Max Sondag  
TU Eindhoven

**TU/e**



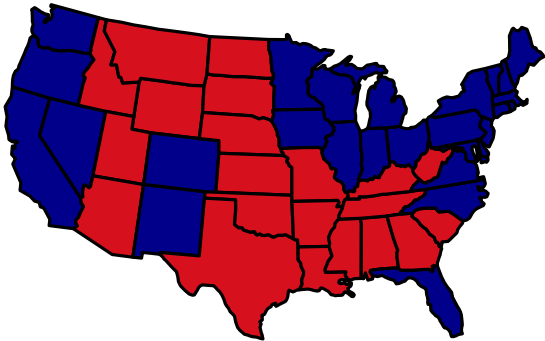
Stephen Kobourov  
University of Arizona



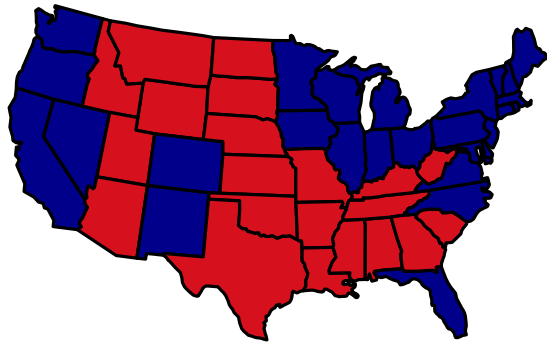
Martin Nöllenburg  
Soeren Nickel  
TU Vienna



# Cartograms



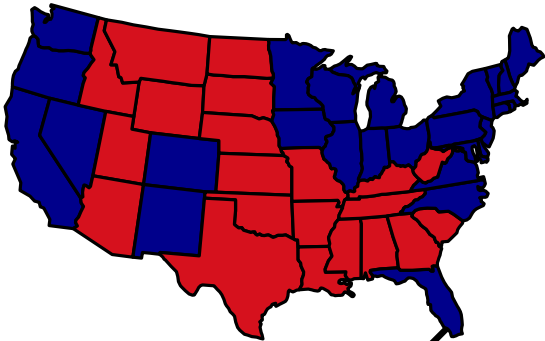
# Cartograms



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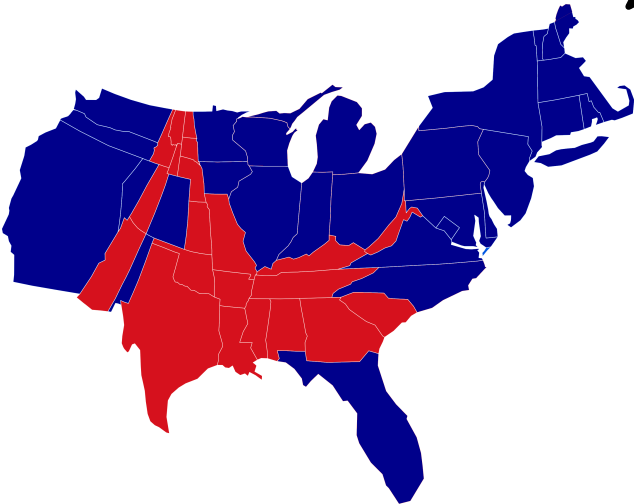
State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	10169
California	1955856	1990678.2	1920061.8	1974614.5
Colorado	246043.5	255566.8	248593.6	255140.8
Connecticut	237542.7	240910.9	236393.2	237653
Delaware	56278.5	This is	real data!	57447
Florida	768661	750501.6	724582.2	737791
Georgia	415131.9	412911.9	No	seriously!
Idaho	53852.1	55546	53775	55170.7
Illinois	647862.1	646366.6	644690.1	662637
Indiana	269053.6	272845.6	261238.3	280120
Iowa	136977	136553.6	136251.2	14148
Kansas	122453.3		124346	127

# Cartograms

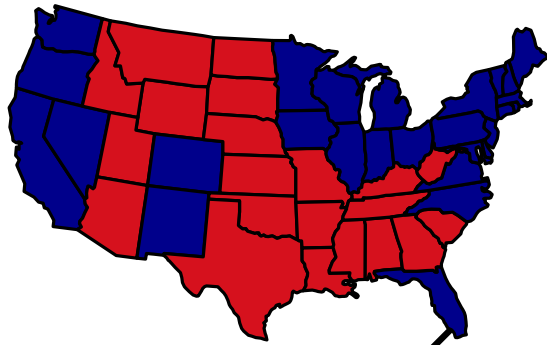


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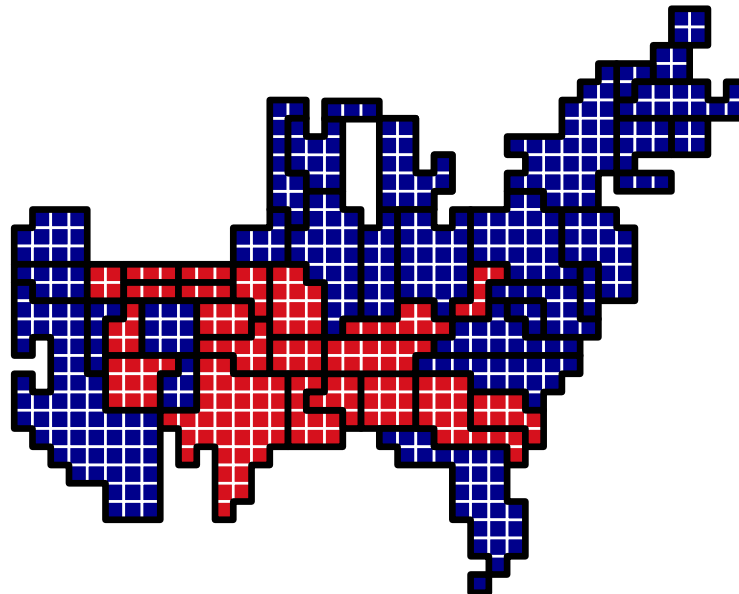
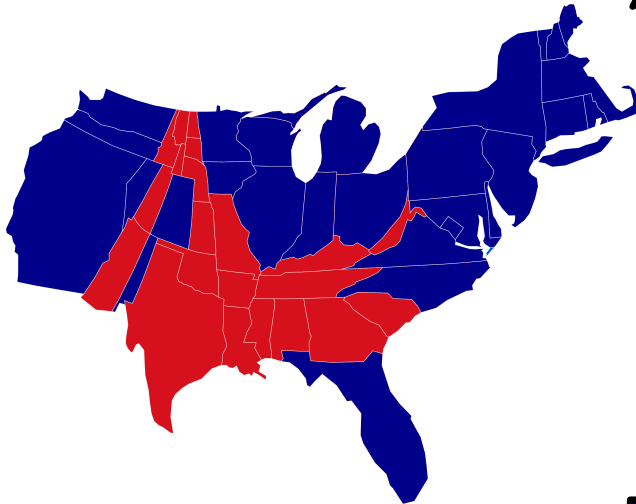


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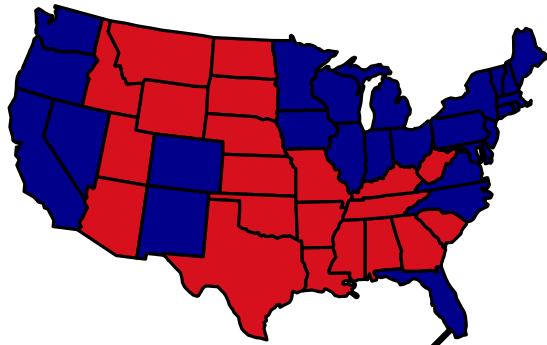


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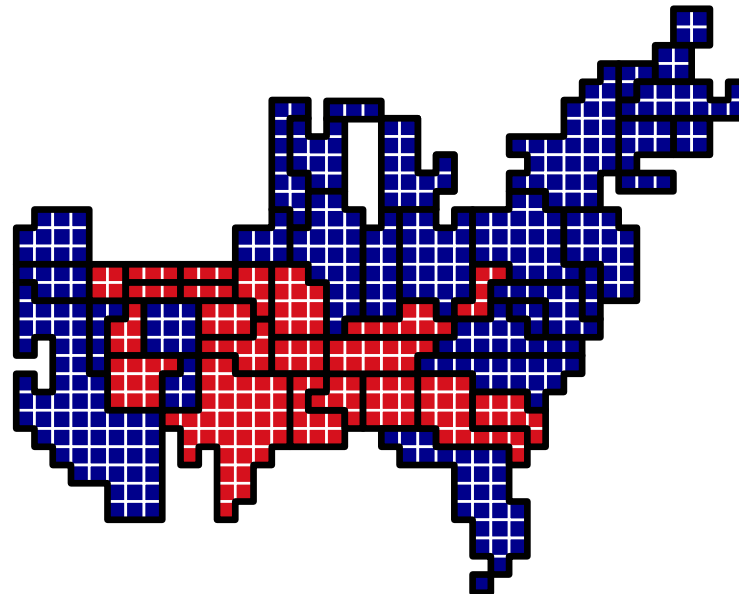
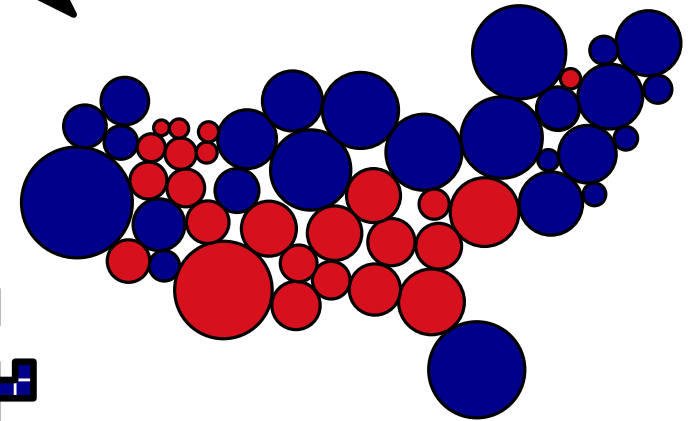
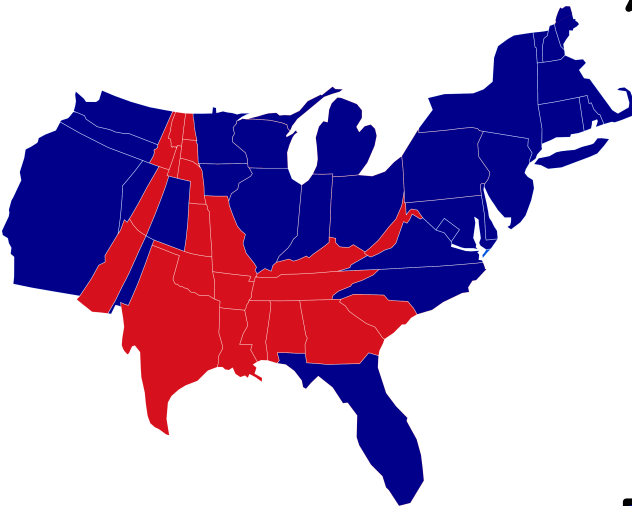


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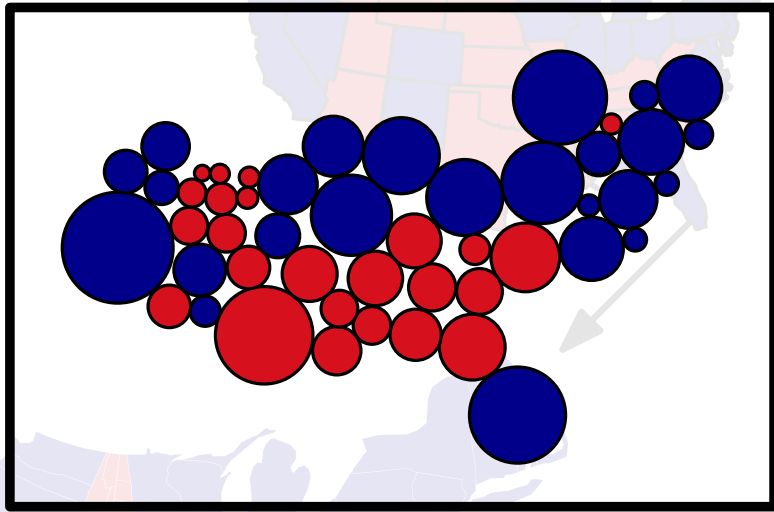
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Kansas	122453.3		124346	127

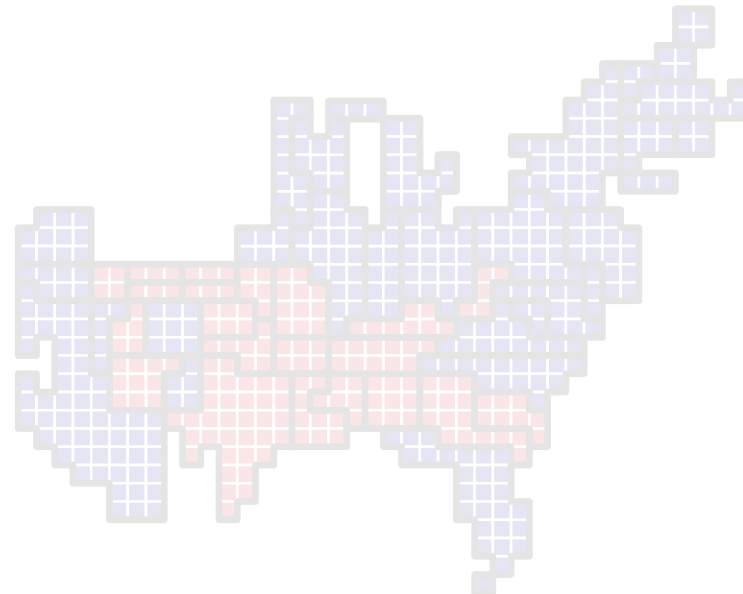
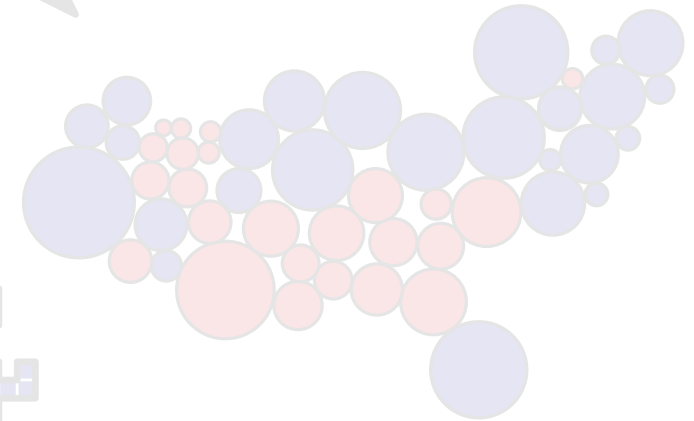


# Cartograms

Dorling Cartogram [Dorling, 1996]

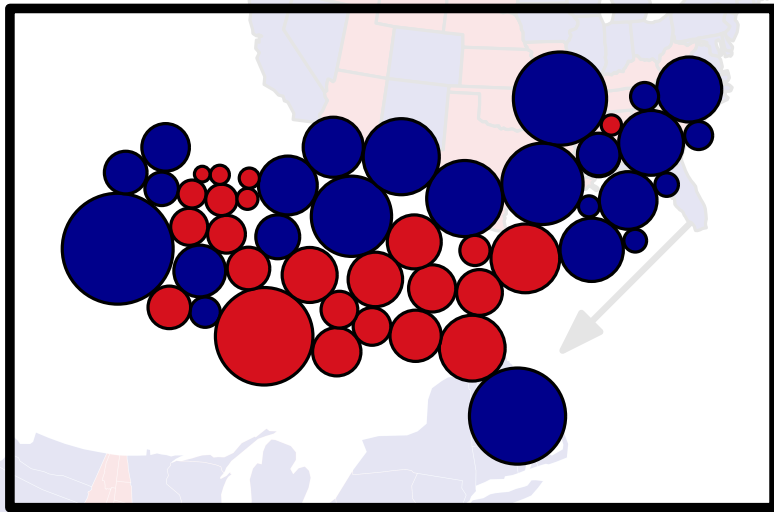


State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	10169
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Colorado	246043.5	255566.8	248593.6	255140.
Connecticut	237542.7	240910.9	236393.2	237653
Delaware	56278.5	This is	real data!	57447
Florida	768661	750501.6	724582.2	737791.
Georgia	415131.9	412911.9	No	seriously!
Idaho	53852.1	55546	53775	55170.7
Illinois	647862.1	646366.6	644690.1	662637.
Indiana	269053.5	272845.6	261238.3	280120.
Iowa	136977	136553.6	136251.2	14148
Kansas	122453.3		124346	127



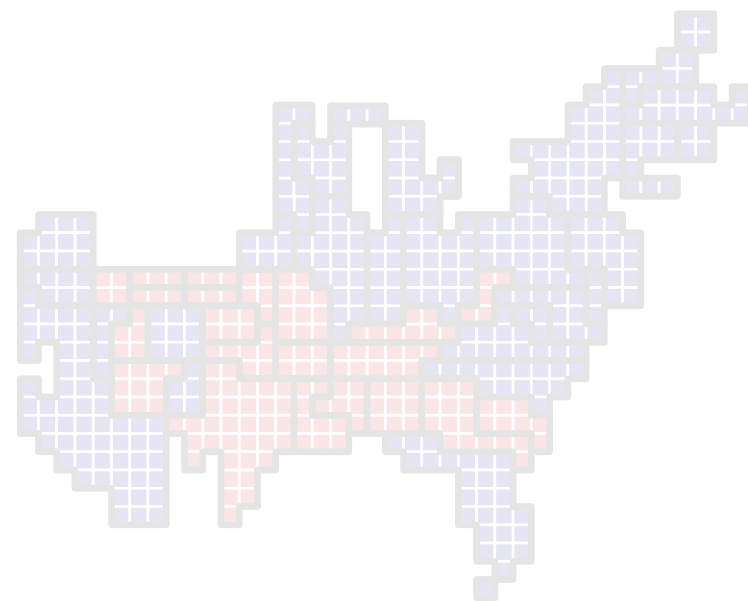
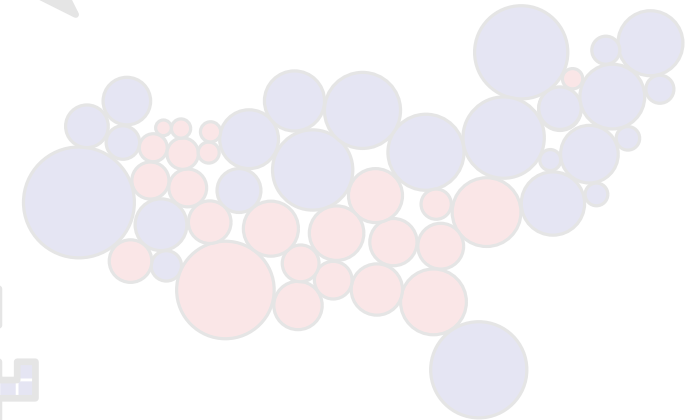
# Cartograms

Dorling Cartogram [Dorling, 1996]



Regions: non-overlapping circles

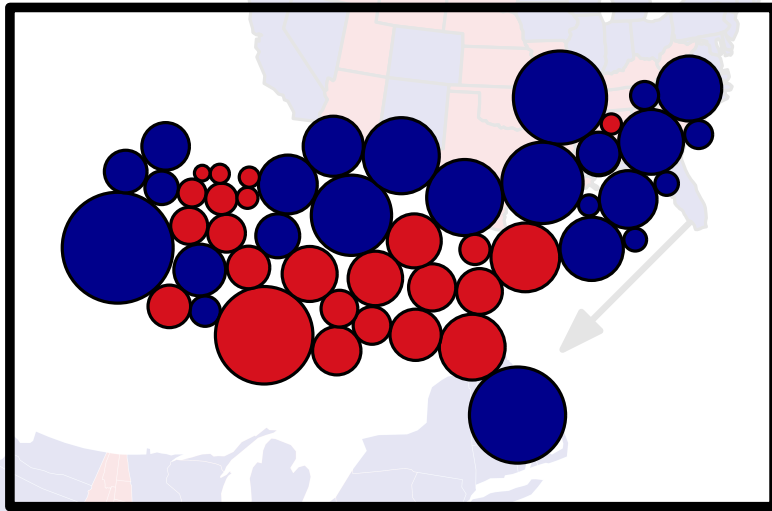
State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	10169
California	1955856	1990678.2	1920061.8	1974614.5
Colorado	246043.5	255566.8	248593	255140
Connecticut	2375	This is	year data	747
Delaware	56278.5			
Florida	768661	750501.6	724582.2	737791
Georgia	415131.9	412911.9	No	seriously
Idaho	53852.1	55546	53775	55170.7
Illinois	647862.1	646366.6	644690.1	662637
Indiana	269053.5	272845.6	261238.3	280120
Iowa	136977	136553.6	136251.2	14148
Kansas	122453.3		124340	125





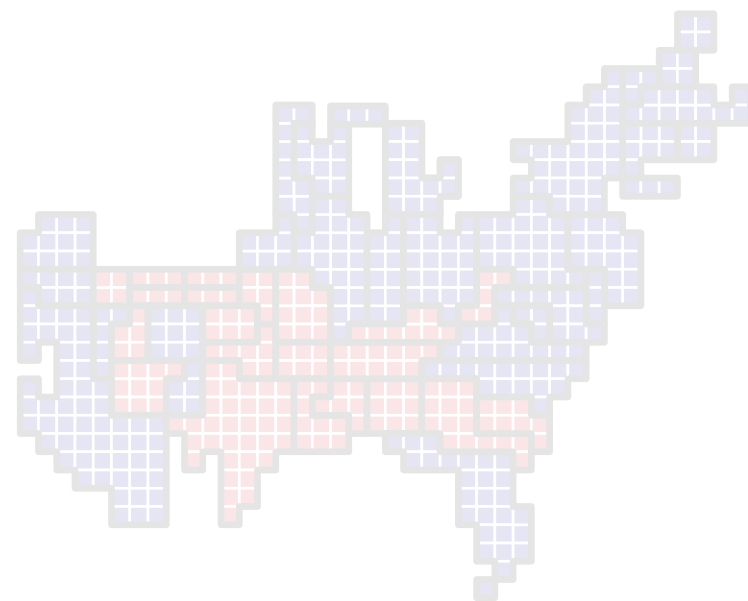
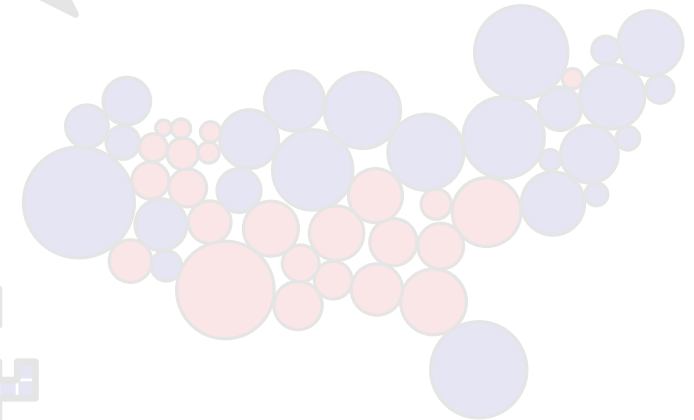
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Dorling Cartogram [Dorling, 1996]



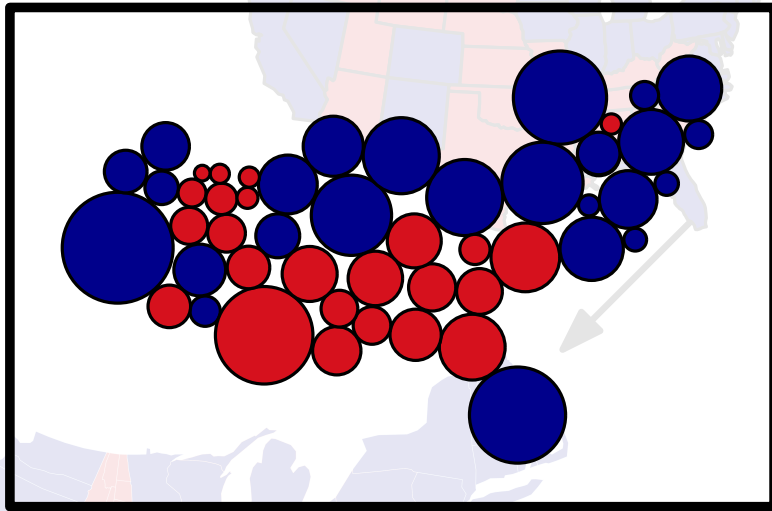
- Regions: non-overlapping circles
- Size proportional to data

State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	10169
California	1955856	1990678.2	1920061.8	1974614.5
Colorado	246043.5	255566.8	248593	255140
Connecticut	2375	2375	This is year data!	1747
Delaware	56278.5			
Florida	768661	750501.6	724582.2	737791
Georgia	415131.9	412911.9	No seriously!	
Hawaii	58953.1	55546	53175	55120
Idaho	100000	100000	100000	100000
Illinois	1200000	1200000	1200000	1200000
Indiana	269053.5	272845.6	261238.3	280120
Iowa	136977	136553.6	136251.2	14148
Kansas	122453.3		124340	122



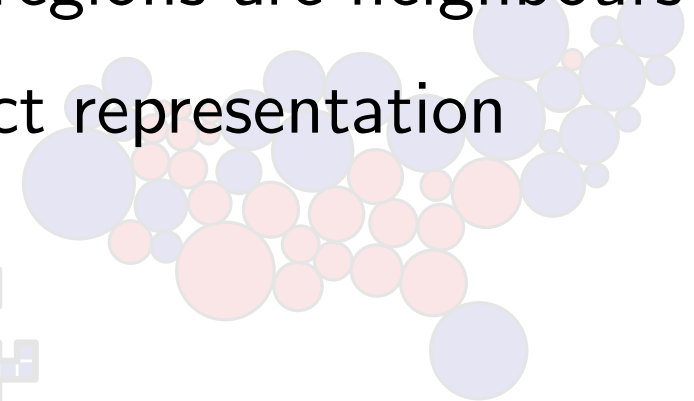
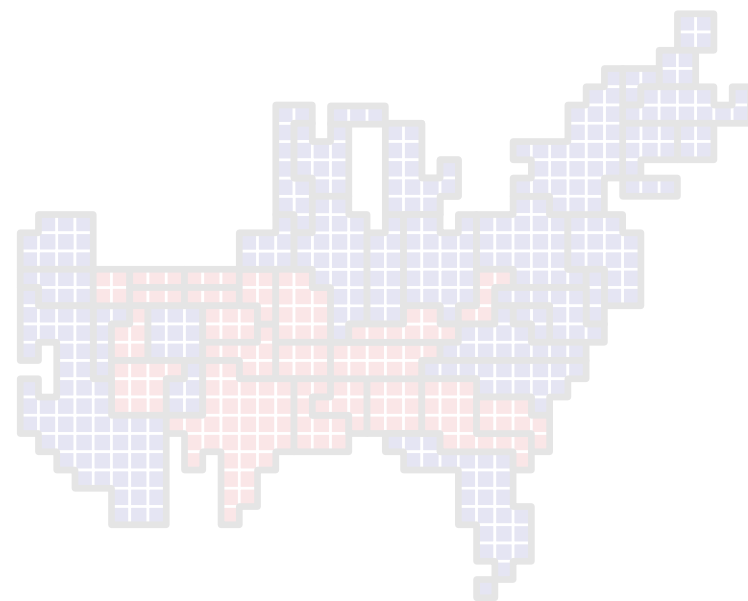
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Dorling Cartogram [Dorling, 1996]



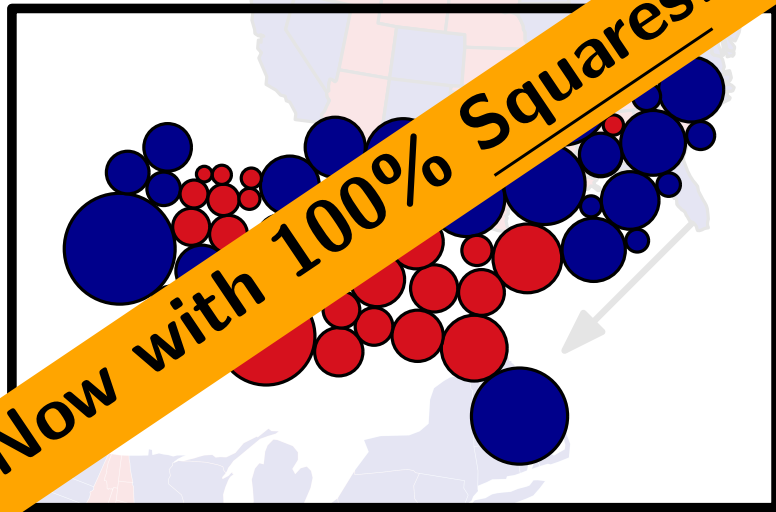
- Regions: non-overlapping circles
- Size proportional to data
- Contact if regions are neighbours
- Disk contact representation

State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	10169
California	1955856	1990678.2	1920061.8	1974614.5
Colorado	246043.5	255566.8	248593	255140
Connecticut	3375	3414	3414	3414
Delaware	56278.5	This is	year data	1747
Florida	768661	750501.6	724582.2	737791
Georgia	415131.9	412911.9	No	seriously
Idaho	58953.1	55546	5315	5510
Illinois	3080000	3080000	3080000	3080000
Indiana	269053.5	272845.6	261238.3	280120
Iowa	136977	136553.6	136251.2	14148
Kansas	127153	127153	124346	127153



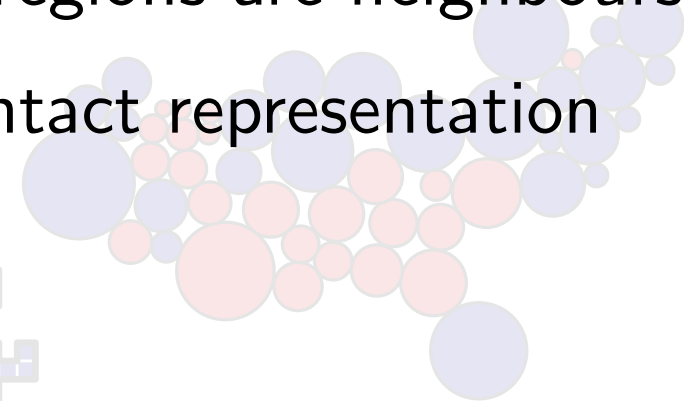
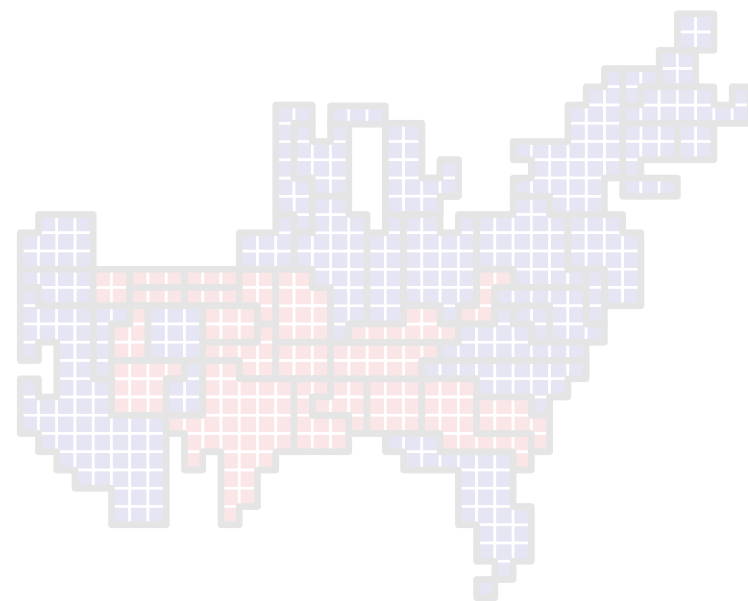
# Cartograms

Dorling Cartogram [Dorling 1996]



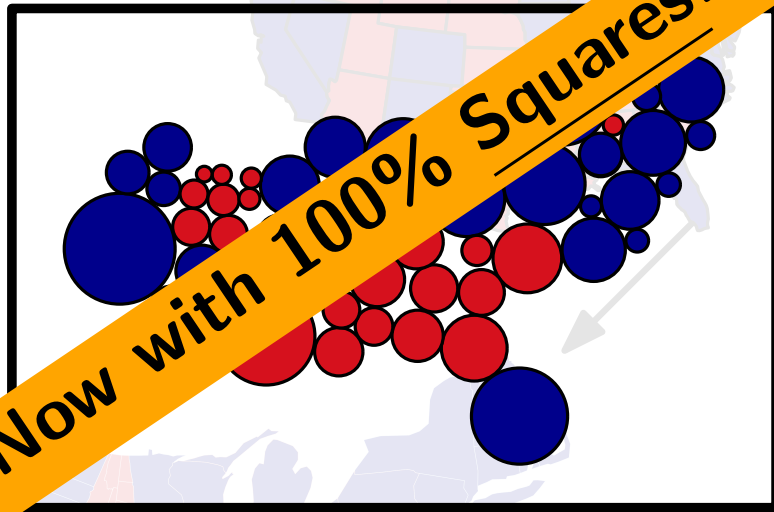
- Regions: non-overlapping squares
- Size proportional to data
- Contact if regions are neighbours
- **Square** contact representation

State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	10169
California	1955856	1990678.2	1920061.8	1974614.5
Colorado	246043.5	255566.8	248593	255140
Connecticut	3375	3414	3375	3414
Delaware	56278.5	56278.5	56278.5	56278.5
Florida	768661	750501.6	724582.2	737791
Georgia	415131.9	412911.9	No seriously!	5513
Idaho	58953.1	57546	57546	5513
Illinois	121153	121153	121153	121153
Indiana	269053.5	272845.6	261238.3	280120
Iowa	136977	136553.6	136251.2	14148
Kansas	121153	121153	124346	124346

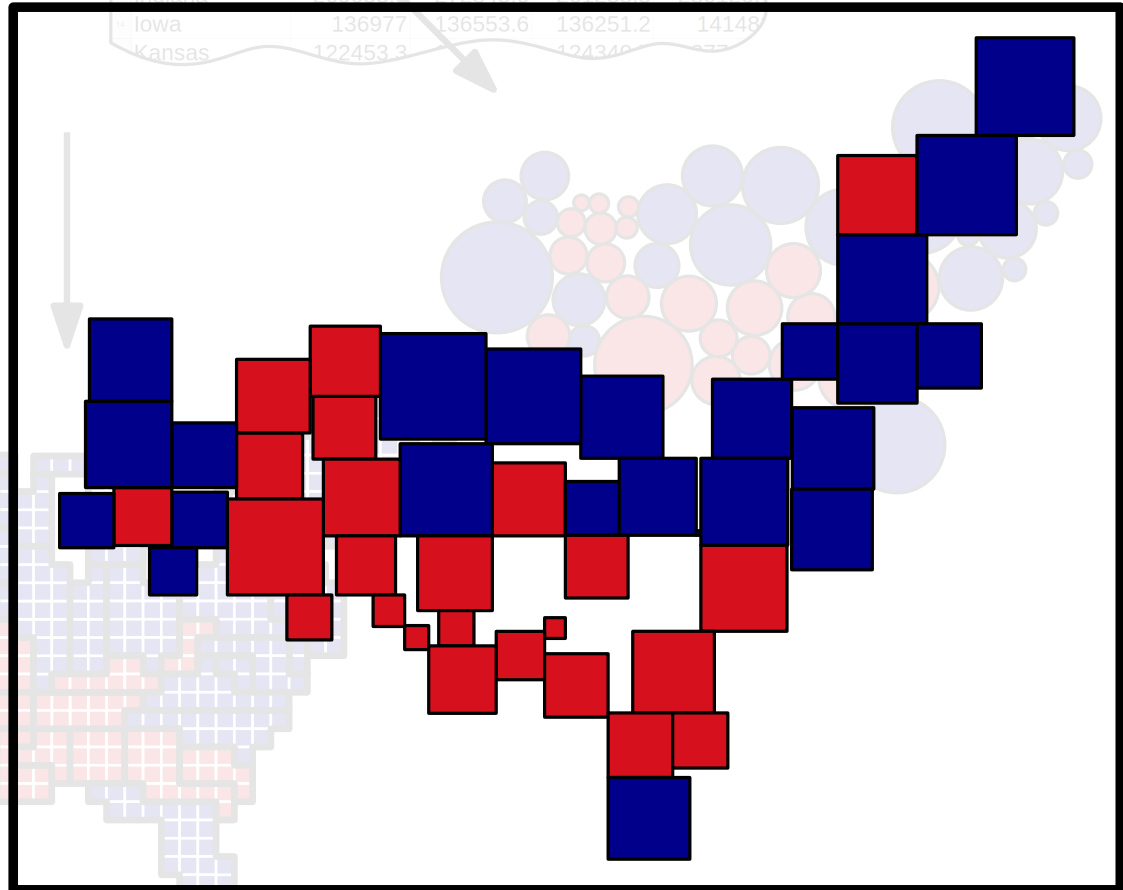


# Cartograms

Dorling Cartogram [Dorling et al., 1996]

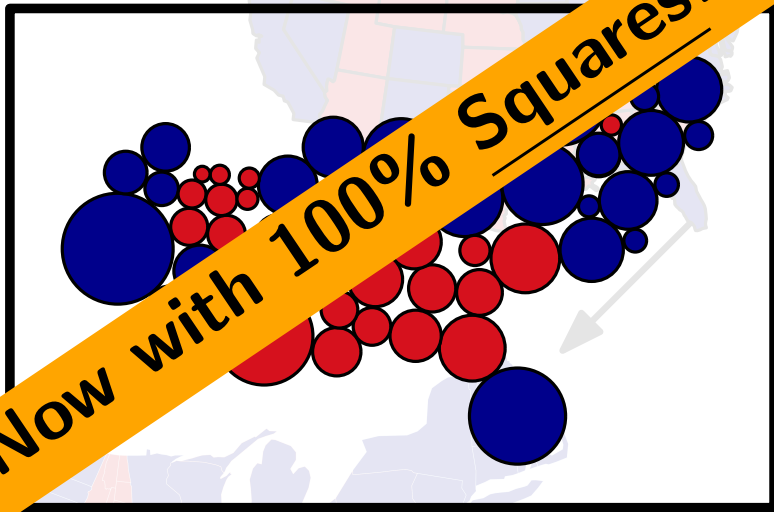


Demers Cartograms [Demers et al., 2002]



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Colorado	246043.5	255566.8	248593.6	255140.
Connecticut	237542.7	240910.9	236393.2	237653
Delaware	56278.5	This is	real data!	57447
Florida	768661	750501.6	724582.2	737791.
Georgia	415131.9	412911.9	No	seriously!
Illinois	64786	646300.8	644090.1	602637.
Indiana	269053.5	272845.6	261238.3	280120
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Kansas	122453.3		124340	137

Dorling Cartogram [Dorling et al., 1996]

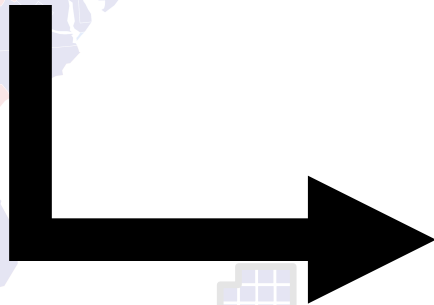
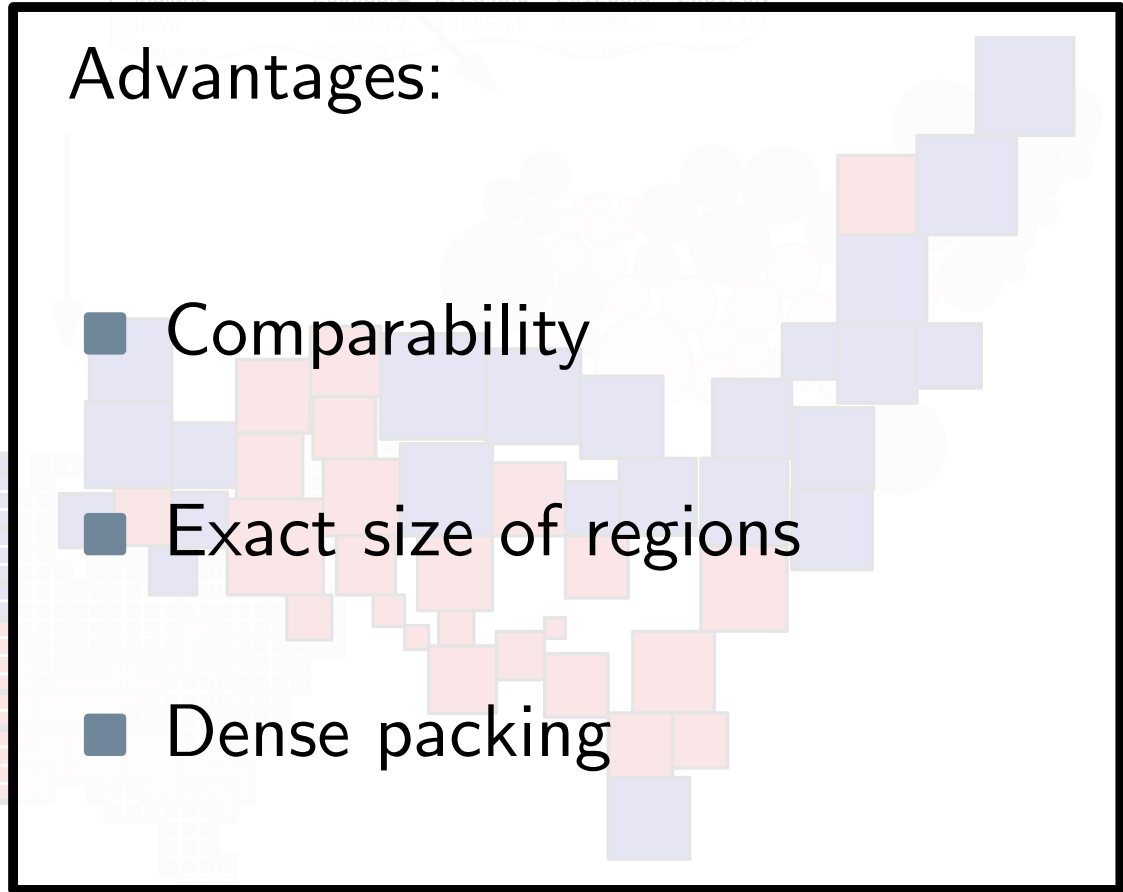


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Georgia	415131.9	412911.9	No	seriously!
Illinois	64786	646300.8	644090.1	662657.
Indiana	269053	272845.6	261238.3	280120

Demers Cartograms [Demers et al., 2002]

## Advantages:

- Comparability
- Exact size of regions
- Dense packing



What is important for a “good cartogram”?

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1. Cartographic accuracy:


Relative region sizes should be close to the data values

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1. Cartographic accuracy:  Relative region sizes should be close to the data values



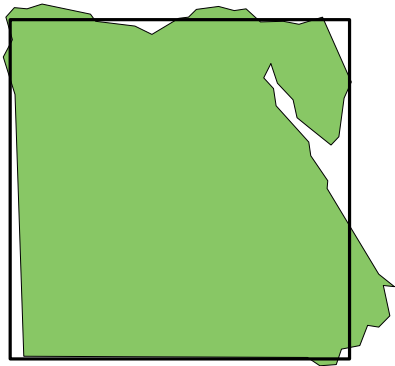
What is important for a “good cartogram”?

1. Cartographic accuracy:   
Relative region sizes should be close to the data values
2. Shape deformation:  
Each region should resemble its geographic shape

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## Egypt

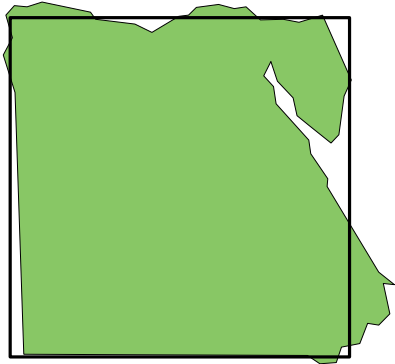


Source: [pappubahry.com/misc/rectangles/](http://pappubahry.com/misc/rectangles/)

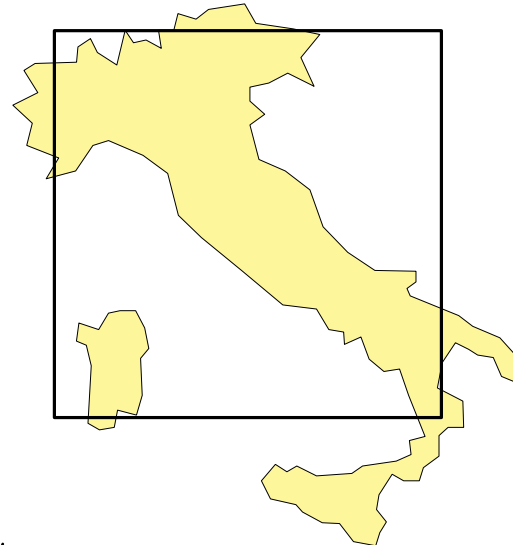
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## Egypt





## Italy





Source: [pappubahry.com/misc/rectangles/](http://pappubahry.com/misc/rectangles/)



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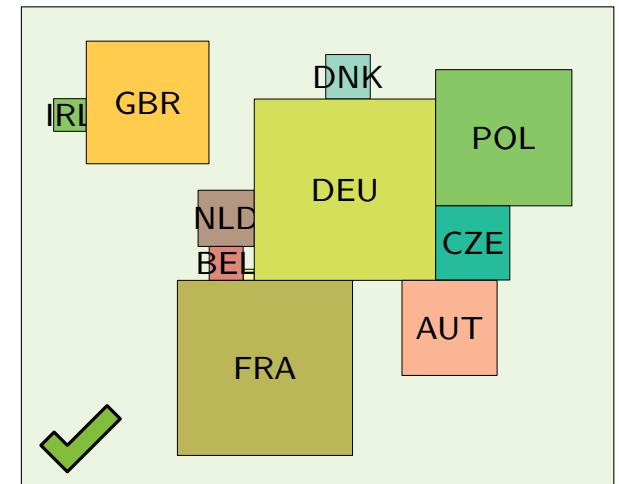
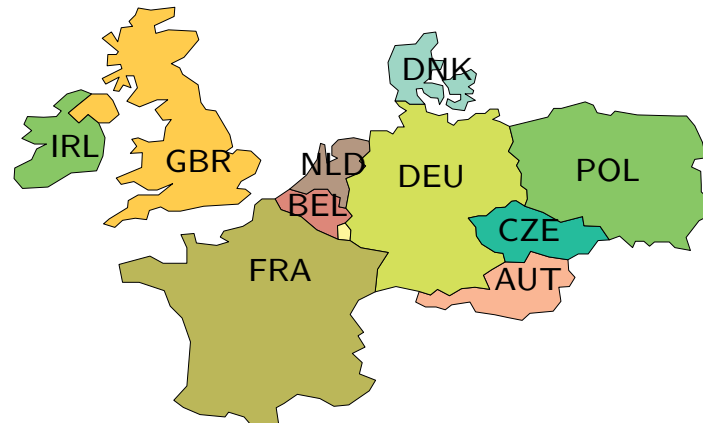
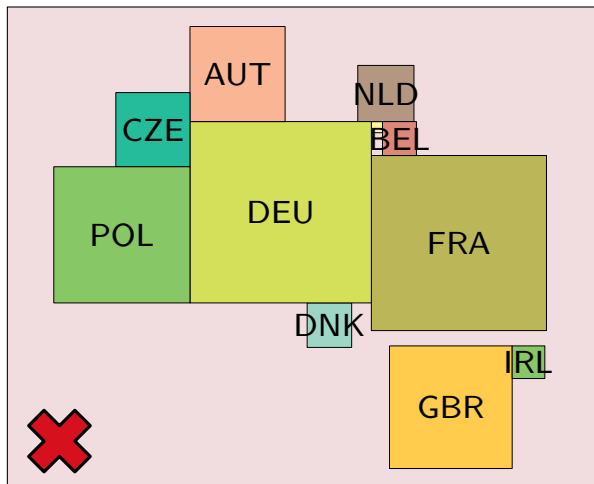
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What is important for a “good cartogram”?

1. Cartographic accuracy:   
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2. Shape deformation:   
Each region should resemble its geographic shape
3. Preservation of relative directions:  
Spatial relations (north-south/east-west) should be maintained

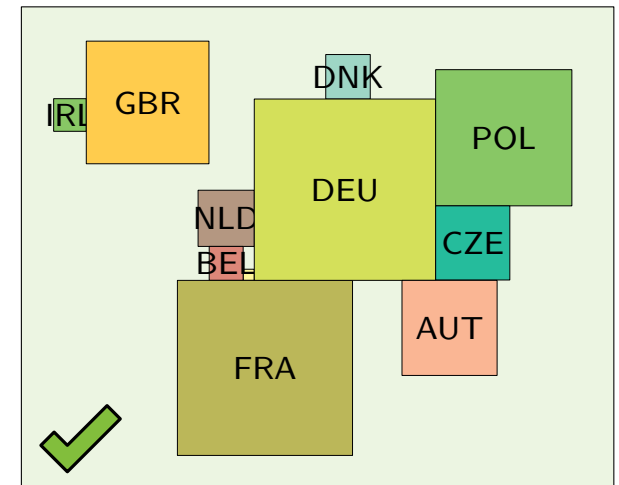
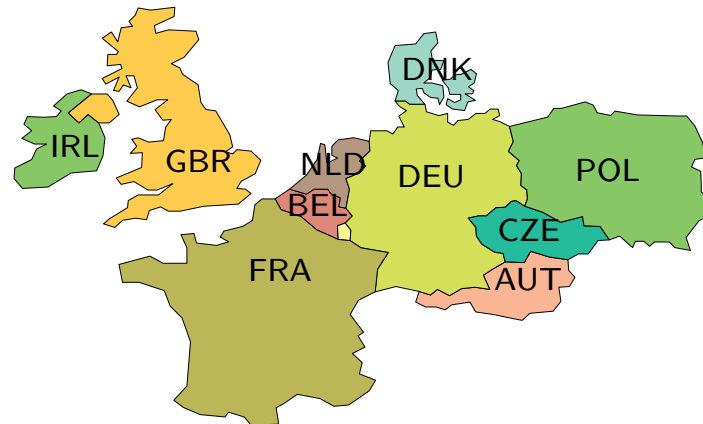
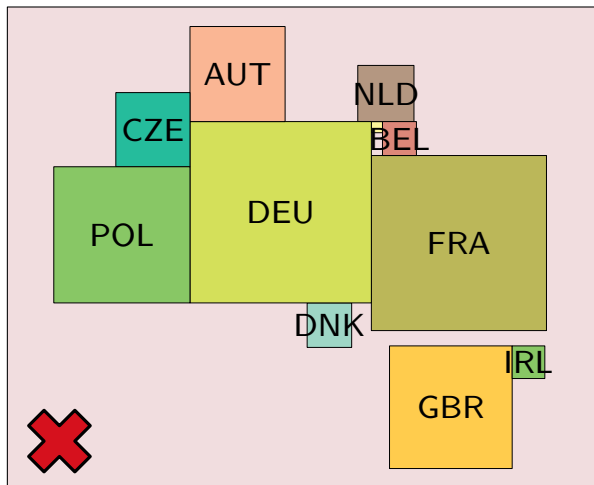
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What is important for a “good cartogram”?

1. Cartographic accuracy: Relative region sizes should be close to the data values
2. Shape deformation: Each region should resemble its geographic shape
3. Preservation of relative directions: **separation constraints**  
Spatial relations (north-south/east-west) should be maintained



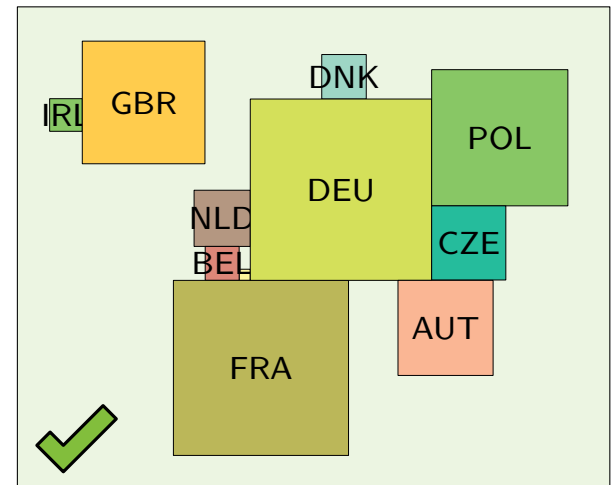
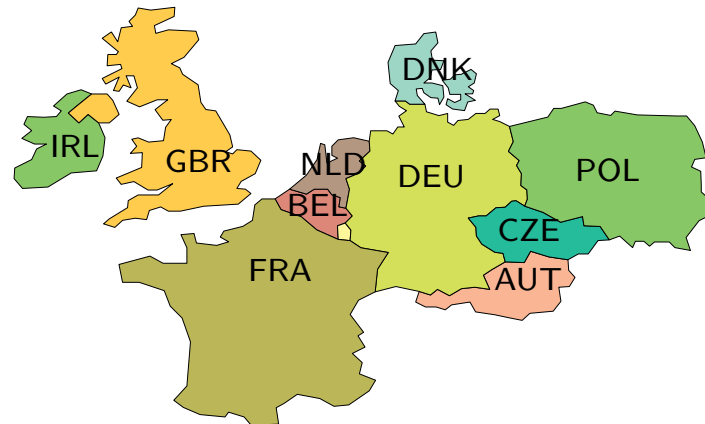
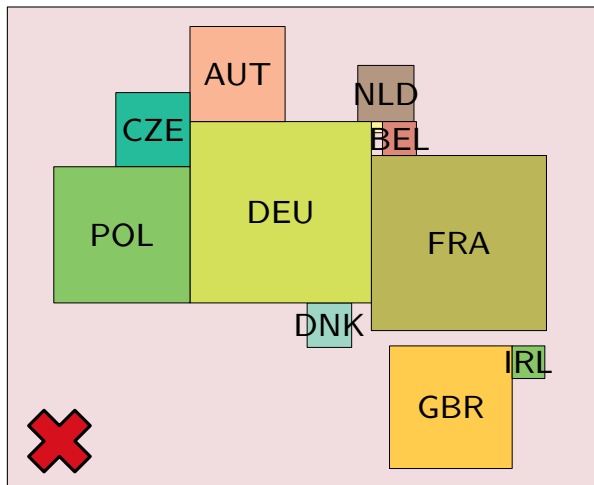
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3. Preservation of relative directions: **separation constraints**  
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 Next slide





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2. Shape deformation:   
Each region should resemble its geographic shape


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Spatial relations (north-south/east-west) should be maintained

4. Topological accuracy:  
Geographically adjacent regions should be adjacent in the cartogram,  
and vice versa

 Next slide

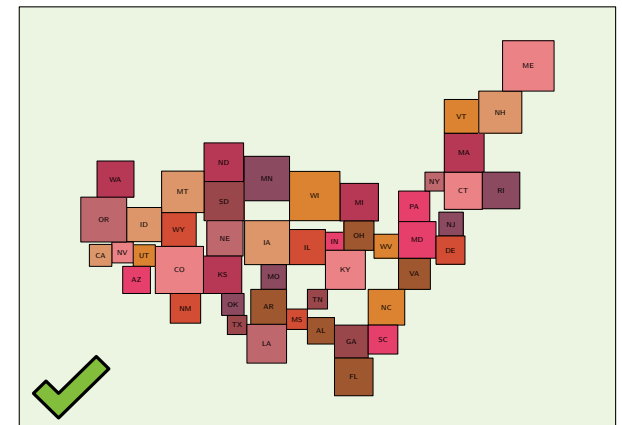
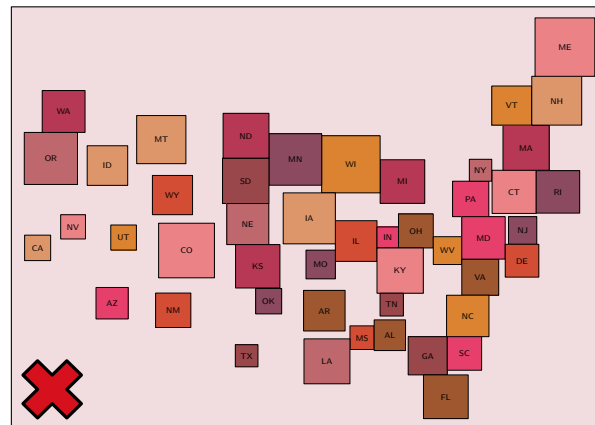
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Next slide

**separation constraints**



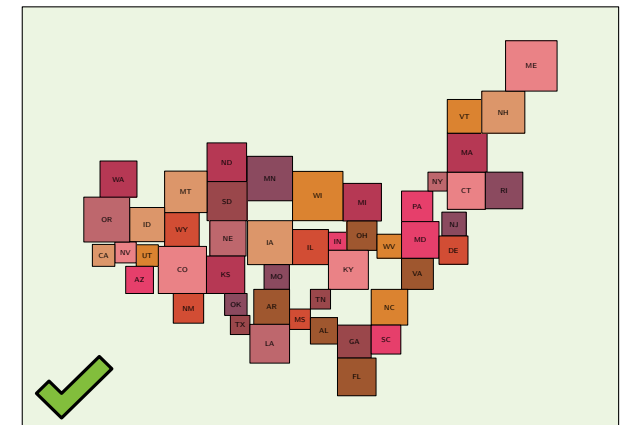
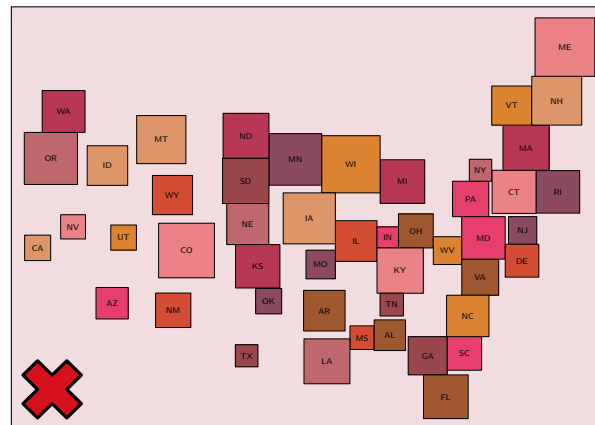
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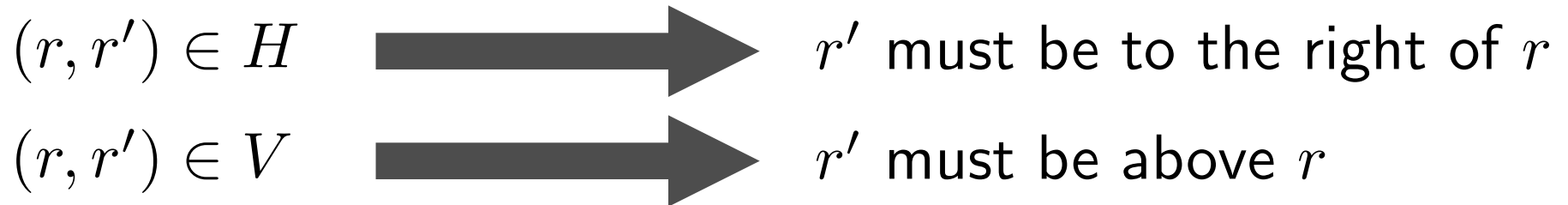
4. Topological accuracy: **main optimization goal!**  
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5. Spatial deformation: **alternative optimization goal!**  
Regions should be placed close to their geographic location

 Next slide



**Given:** a set of regions  $\mathcal{R}$  with their adjacencies and the centroids, the size of every region  $r \in \mathcal{R}$  and two sets  $H, V$  of ordered region pairs (**separation constraints**)

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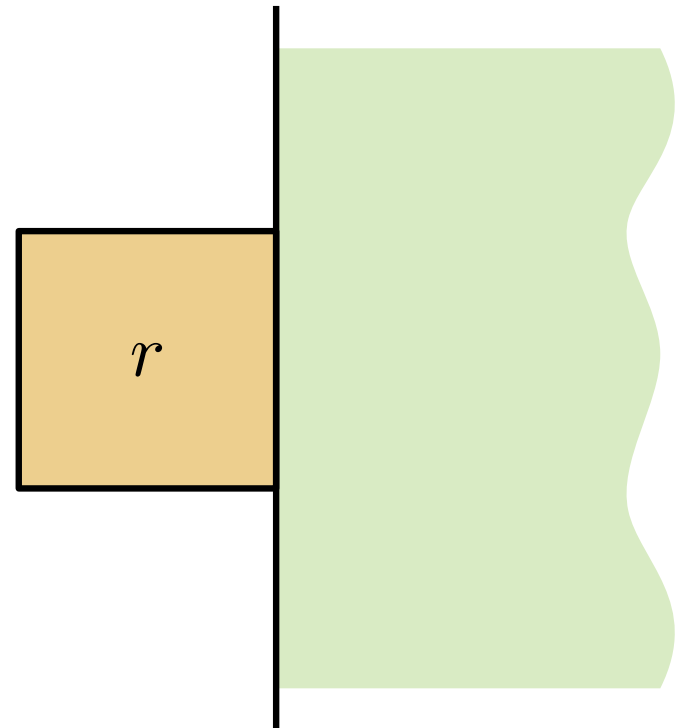


# Formal Setting

**Given:** a set of regions  $\mathcal{R}$  with their adjacencies and the centroids, the size of every region  $r \in \mathcal{R}$  and two sets  $H, V$  of ordered region pairs (**separation constraints**)

$(r, r') \in H$          $r'$  must be to the right of  $r$   
 $(r, r') \in V$          $r'$  must be above  $r$

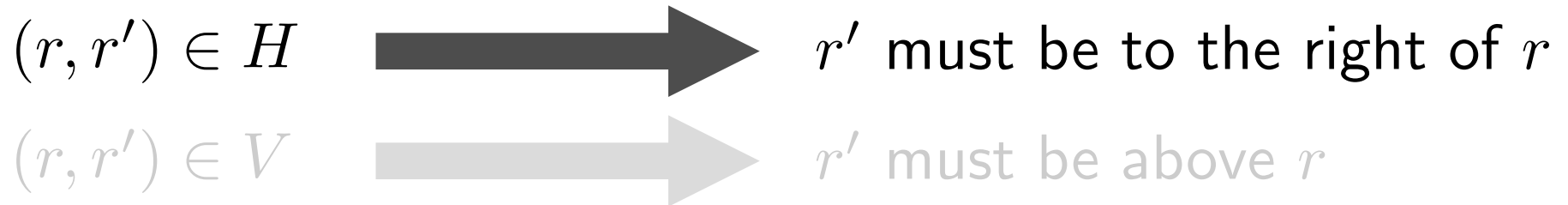
Place regions according to constraints





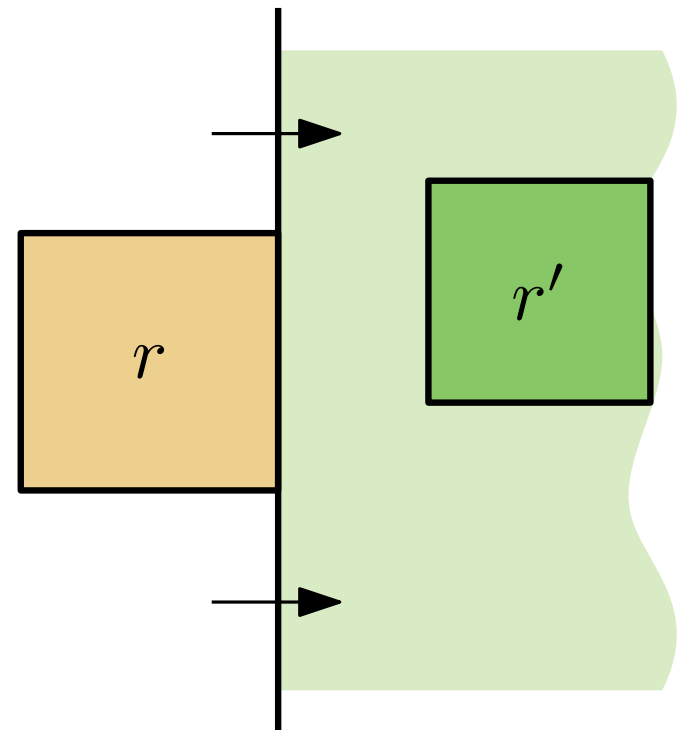
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Place regions according to constraints

$r'$  **must** be placed right of  $r$



# Formal Setting

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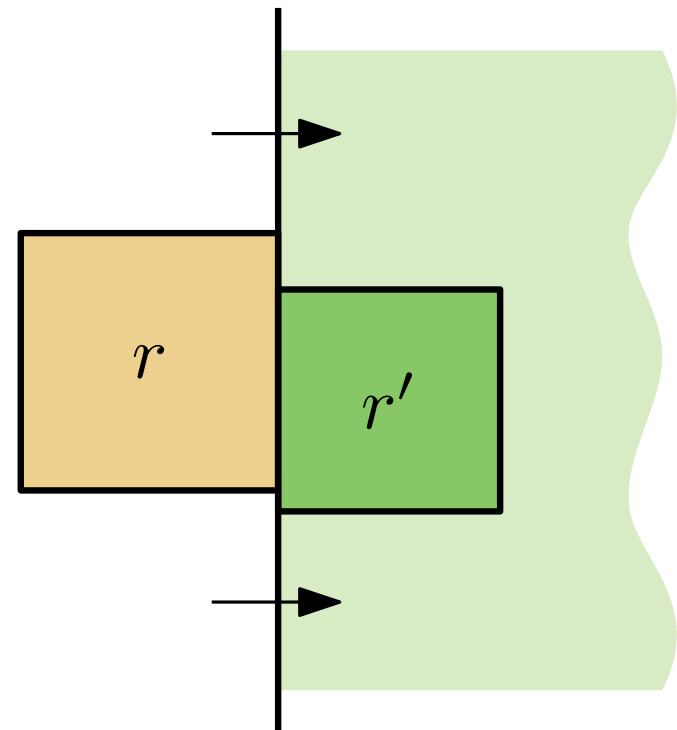
$(r, r') \in H$    $r'$  must be to the right of  $r$   
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Place regions according to constraints

$r'$  **must** be placed right of  $r$

Adjacent regions **should** touch.

This might have to be violated.



# Approach to Compute Cartograms

We use a linear program to create optimized cartograms

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- Formulation of desired qualities and required properties as linear (in-)equalities

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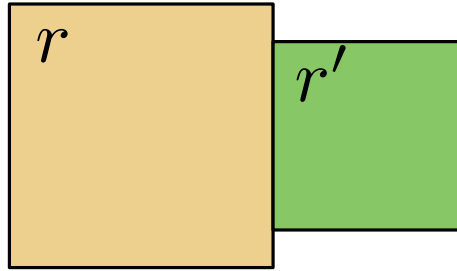
Why use an LP?

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What should the LP do?

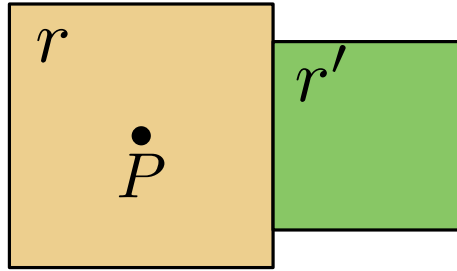
- Encode placement of regions
- Fulfill separation constraints
- Minimize objective function (topological error or spatial deformation)

# Approach to Compute Cartograms



- Introduce centroid position variables:

# Approach to Compute Cartograms

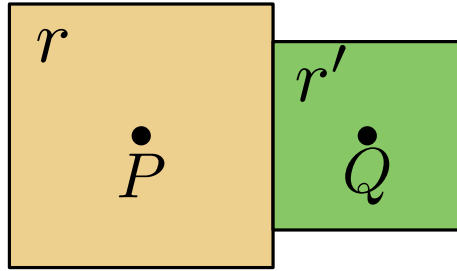


- Introduce centroid position variables:

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# Approach to Compute Cartograms

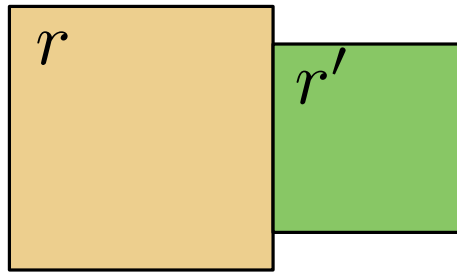
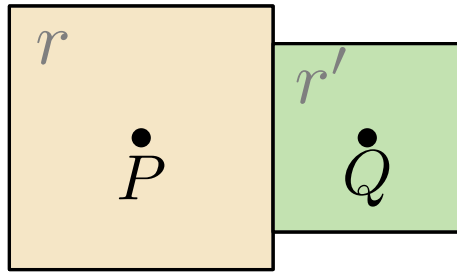


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# Approach to Compute Cartograms



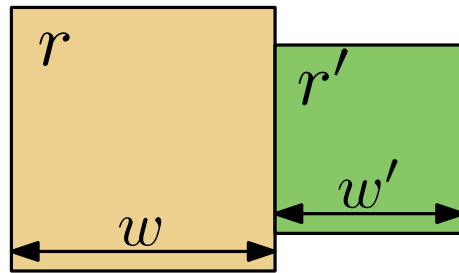
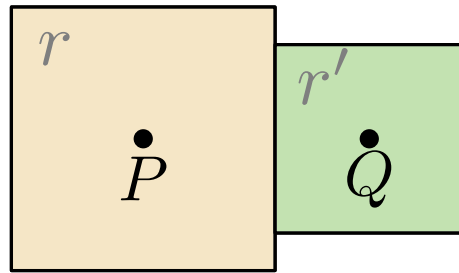
- Introduce centroid position variables:

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- Guarantee non-overlap:

# Approach to Compute Cartograms



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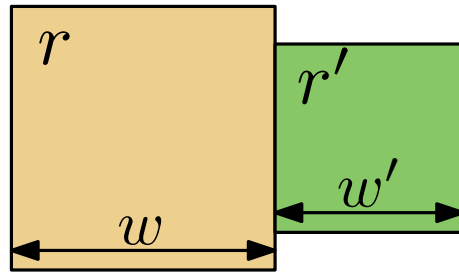
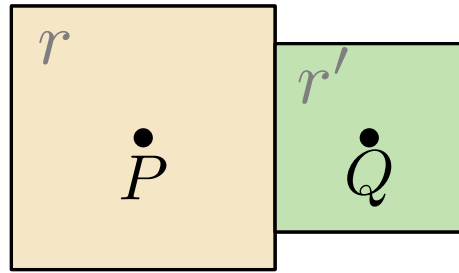
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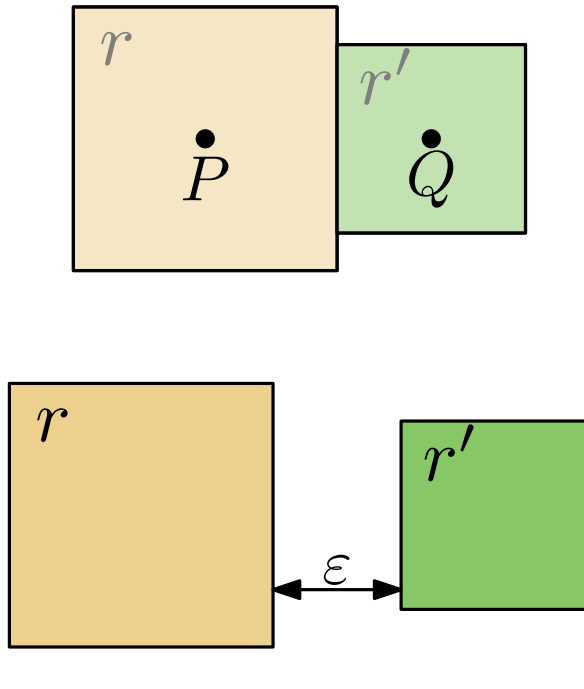
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$$y_{r'} - y_r \geq \frac{w+w'}{2}$$

Choice dependent on separation constraint

# Approach to Compute Cartograms



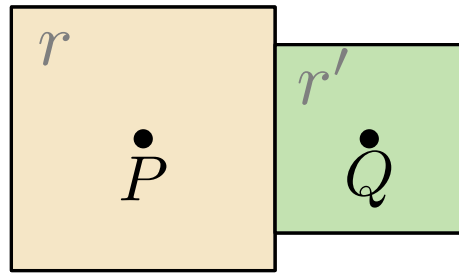
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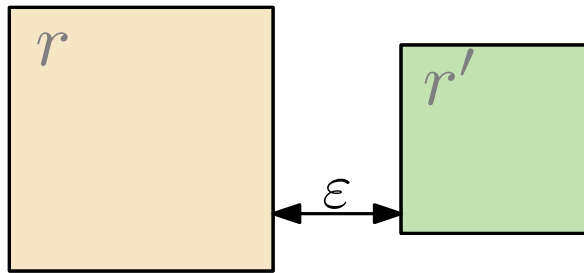
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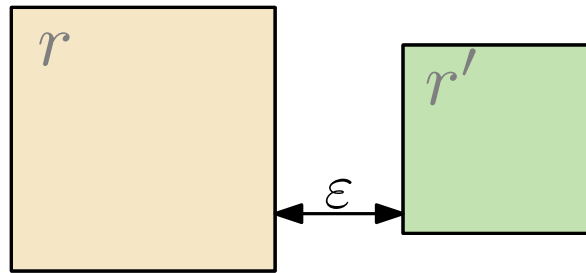
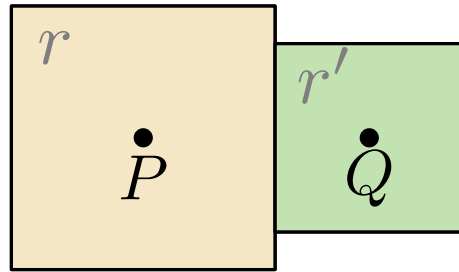
$$x_{r'} - x_r \geq \frac{w+w'}{2} + \varepsilon$$



- Minimize  $L_1$ -distance between adjacent regions:

## 4. Topological accuracy: **main optimization goal!**

Geographically adjacent regions should be adjacent in the cartogram



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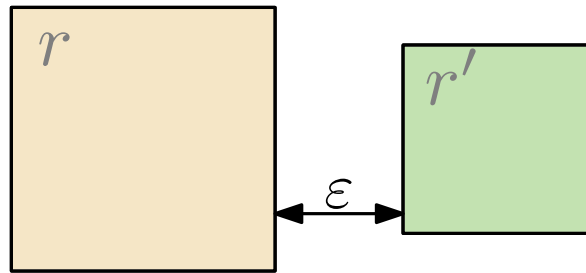
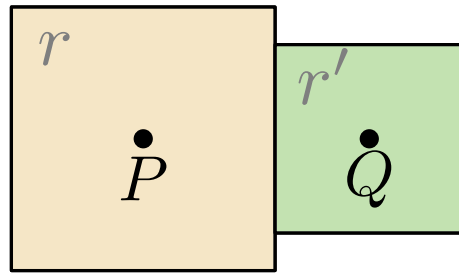
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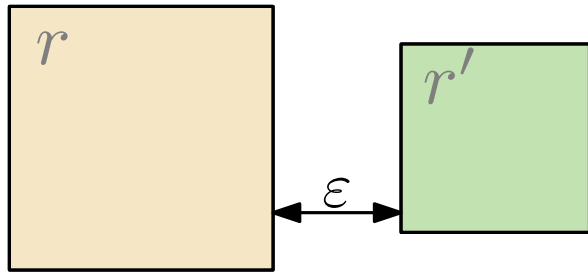
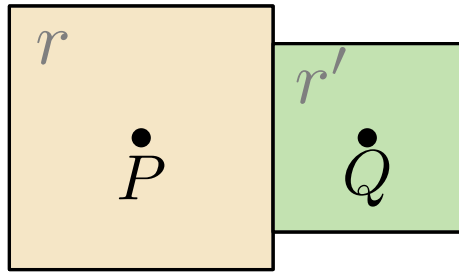
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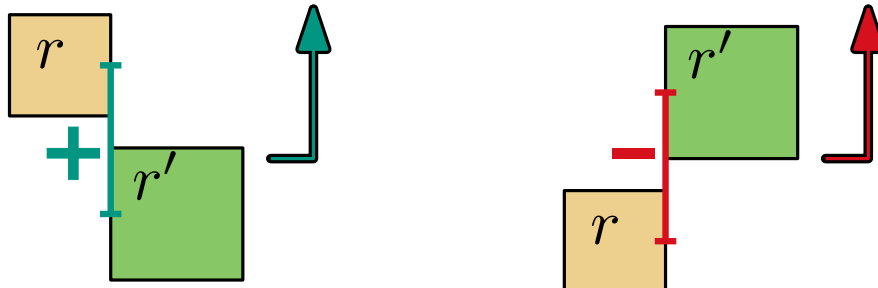
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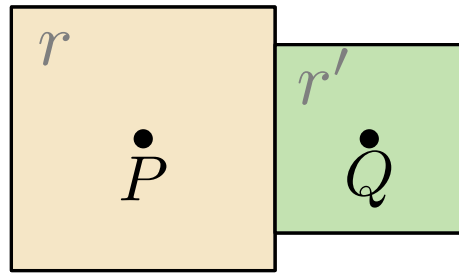
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$$v_{r,r'} \geq \max\left\{ (y_r - y_{r'}) - \frac{w+w'}{2}, (y_{r'} - y_r) - \frac{w+w'}{2} \right\}$$



$$\min \sum_{\{r,r'\} \in \mathcal{E}} h_{r,r'} + v_{r,r'}$$



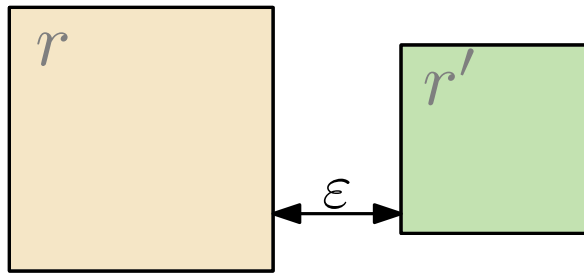
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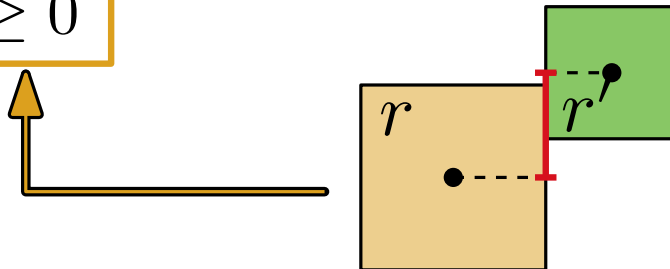


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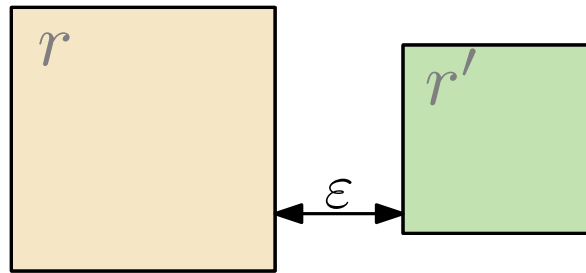
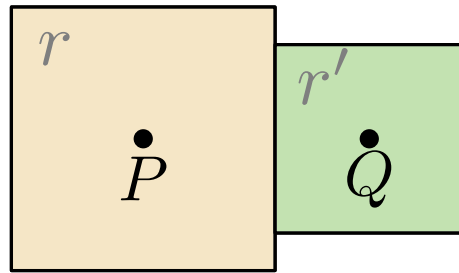
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$$v_{r,r'}, h_{r,r'} \geq 0$$



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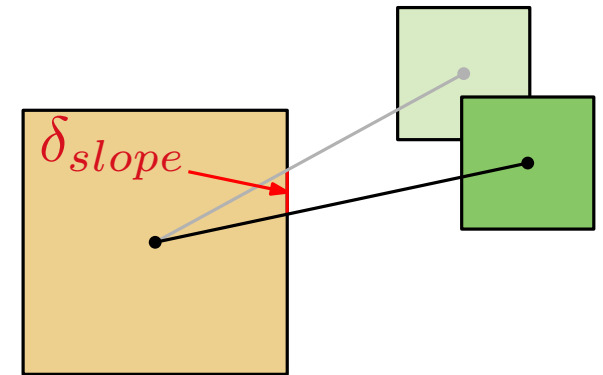
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If  $r, r'$  are touching then  $h_{r,r'} + v_{r,r'} = 0$

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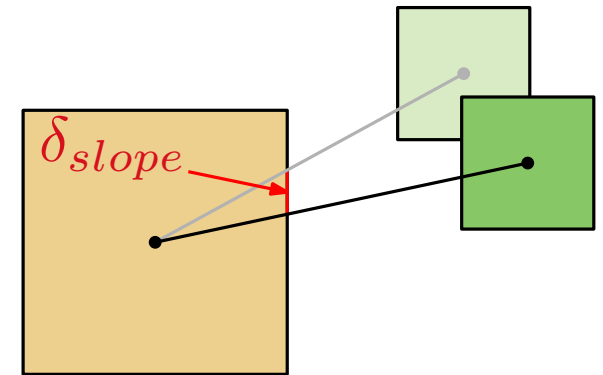
## 3. Preservation of relative directions

- Keep the slope between regions



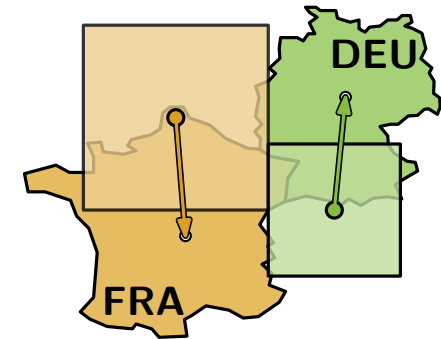
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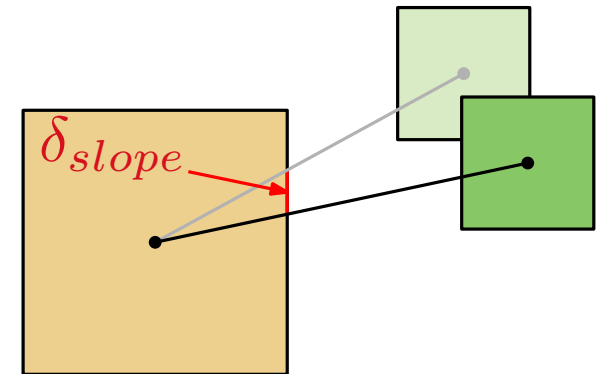
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- Minimize distance to input position



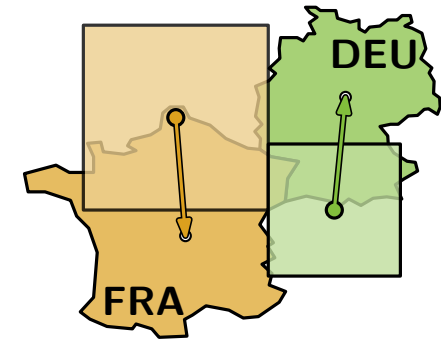
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An **ILP** is able minimize the actual number of lost adjacencies  
significantly higher runtimes / **ILP** is NP-hard

# Computing Cartogram Sequences

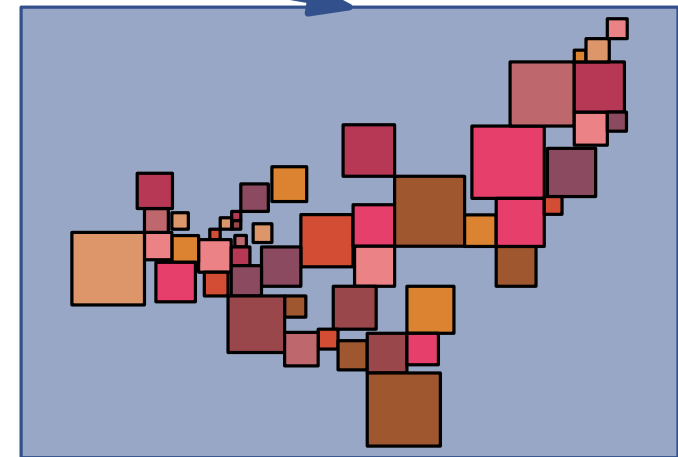
Data over time / different data on the same map

State	2007	2008	2009	2010
Alabama	169678.4	172686.8	168348	17475
Arizona	262322	259366.7	243929.4	24821
Arkansas	96948.2	98955.3	97058.9	101690
California	1955856	1990678.2	1920061.8	1974614.5
Colorado	246043.5	255566.8	248593.6	255140.5
Connecticut	237542.7	240910.9	236393.2	237653
Delaware	56278.5	54787.5	56871.2	57447
Florida	768661	750501.6	724582.2	737791
Georgia	415131.9	412911.9	407024.5	416883.8
Idaho	53852.1	55546	53775	55170.7
Illinois	647862.1	646366.6	644690.1	662637
Indiana	269053.6	272845.6	261238.3	280120
Iowa	136977	136553.6	136251.2	14148
Kansas	122453.3		124340	124340

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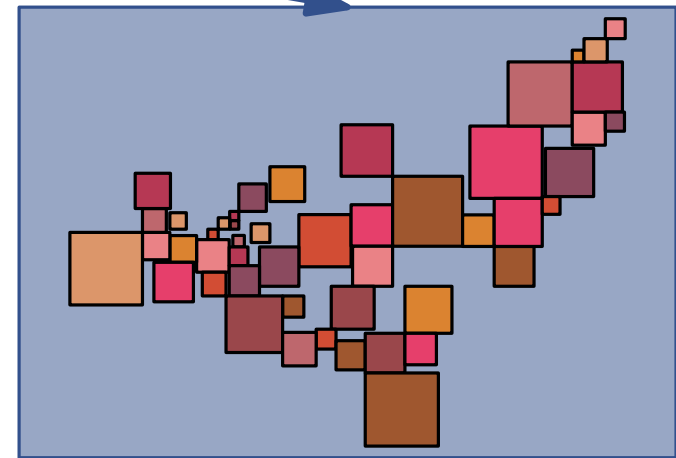
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Small changes in the data



Small changes in the cartogram



## Stability

Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

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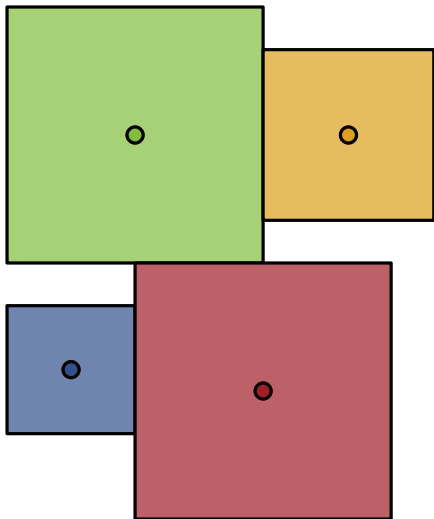
How do we achieve stability?

## Stability

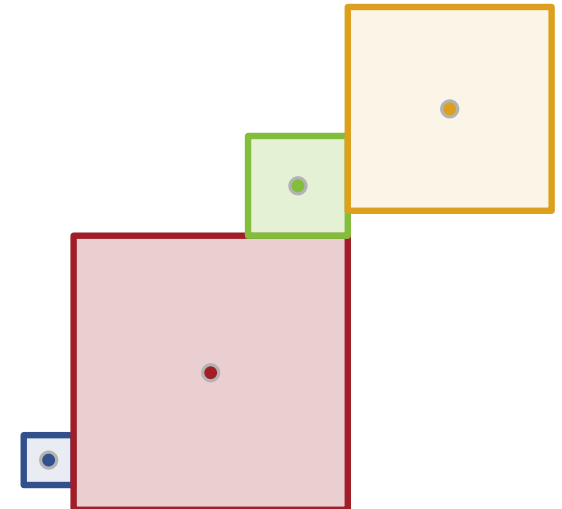
Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

How do we achieve stability?

Cartogram  $\mathcal{A}$



Cartogram  $\mathcal{B}$

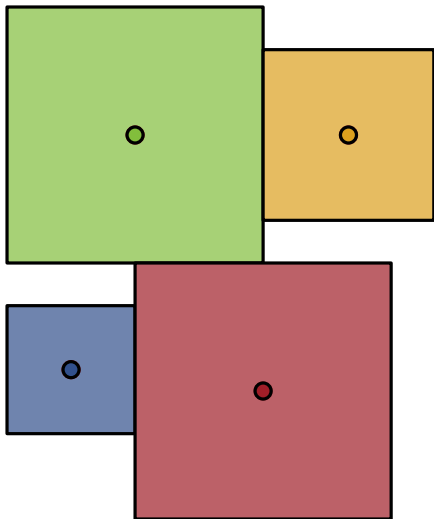


## Stability

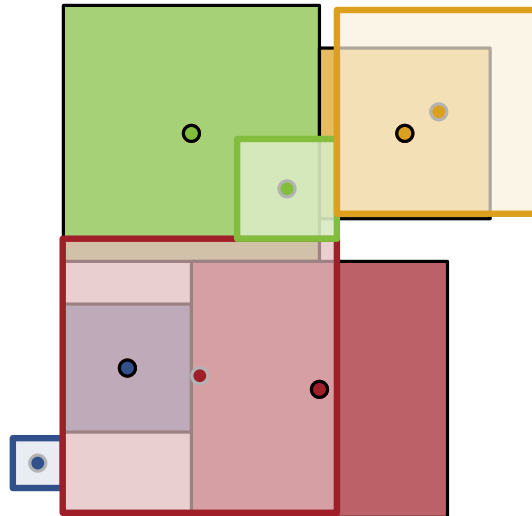
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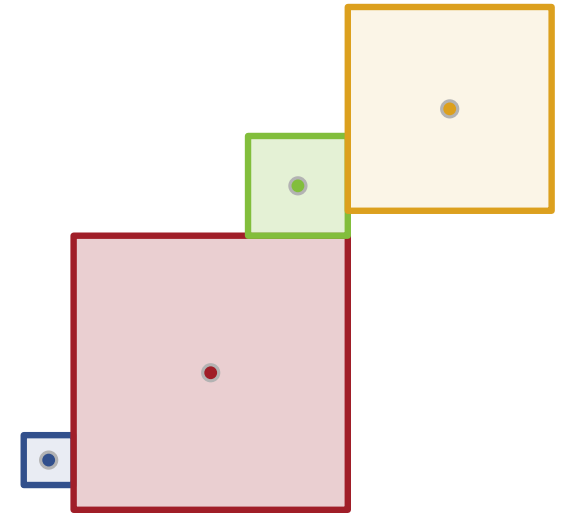
Cartogram  $A$



Overlay  $A \& B$



Cartogram  $B$

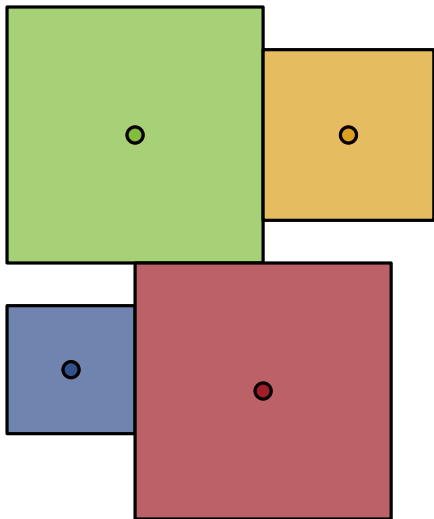


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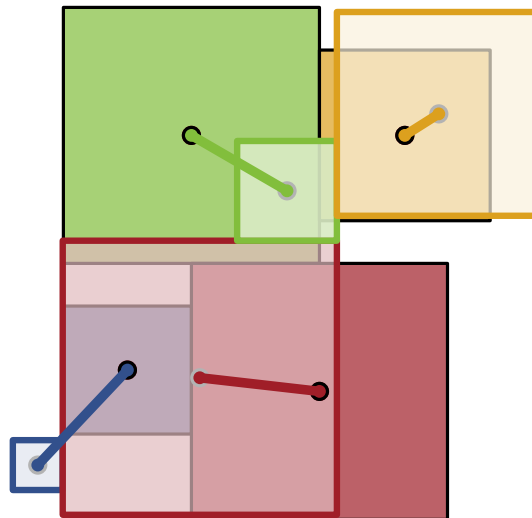
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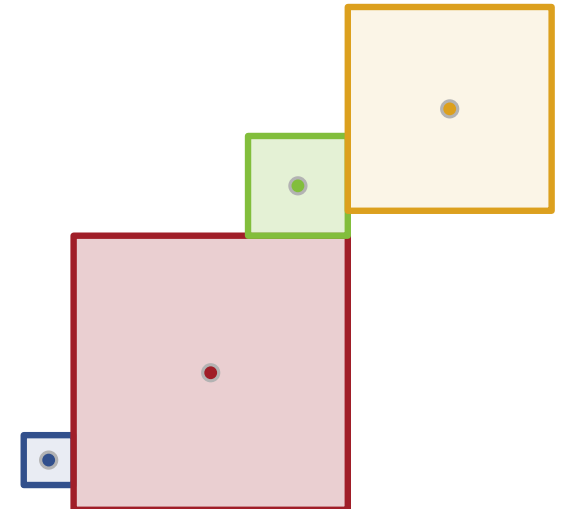
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Overlay  $A \& B$



Cartogram  $B$

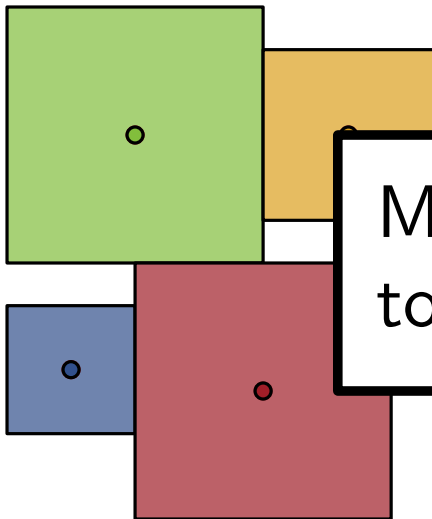


## Stability

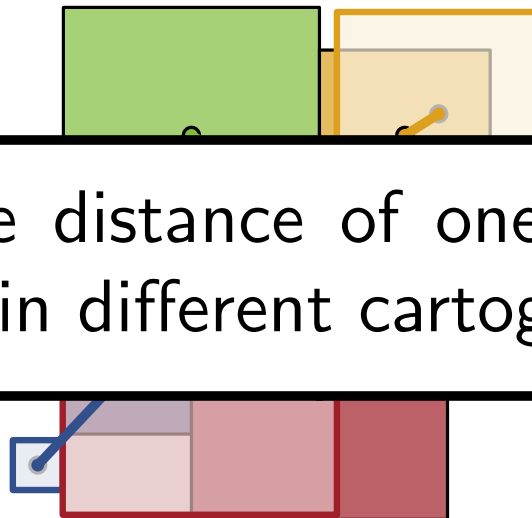
Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

How do we achieve stability?

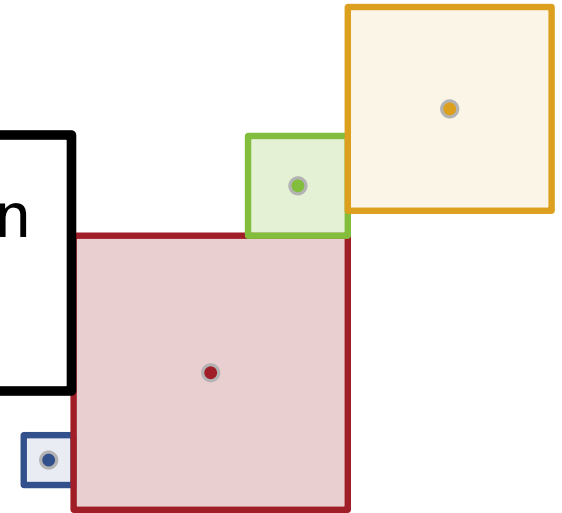
Cartogram  $A$



Overlay  $A \& B$



Cartogram  $B$



Minimize distance of one region to itself in different cartograms

## Stability

Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

How do we achieve stability?  
Minimize distance of one region  
to itself in different cartograms

## Stability Models

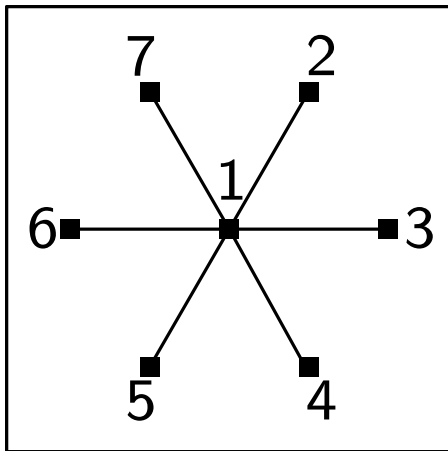


## Stability

Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

How do we achieve stability?  
Minimize distance of one region to itself in different cartograms

## Stability Models



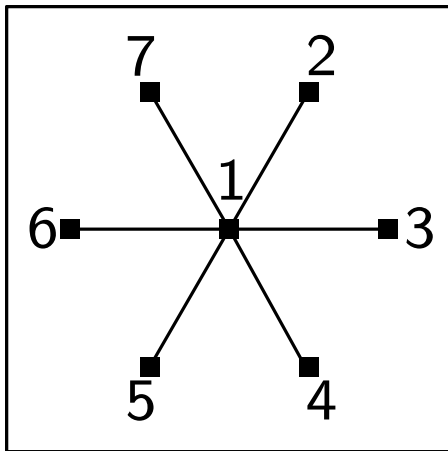
Star

## Stability

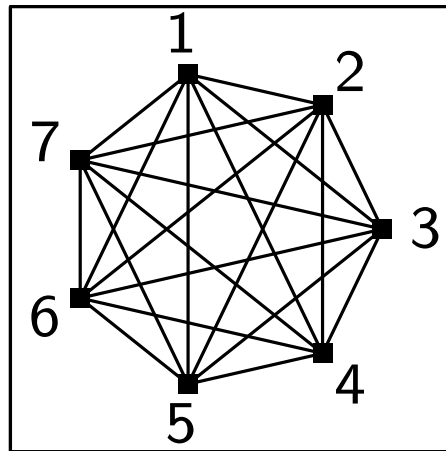
Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

How do we achieve stability?  
Minimize distance of one region to itself in different cartograms

## Stability Models



Star



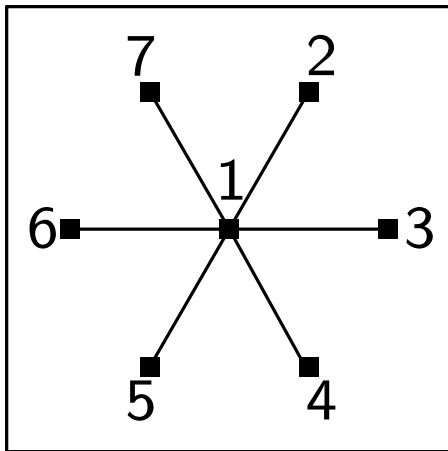
Complete

## Stability

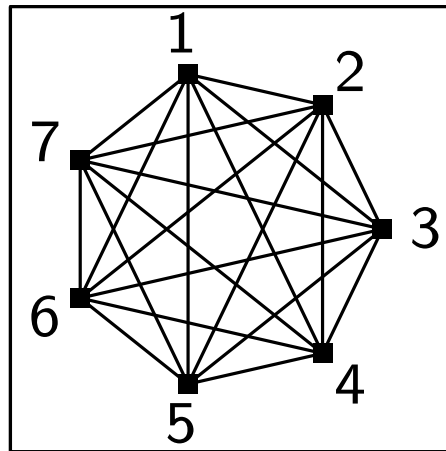
Small changes in the data  $\longleftrightarrow$  Small changes in the cartogram

How do we achieve stability?  
Minimize distance of one region to itself in different cartograms

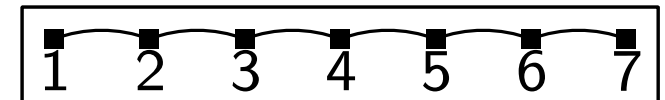
## Stability Models



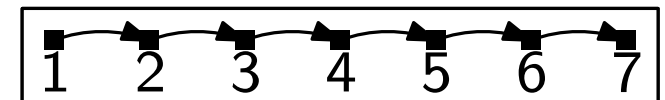
Star



Complete

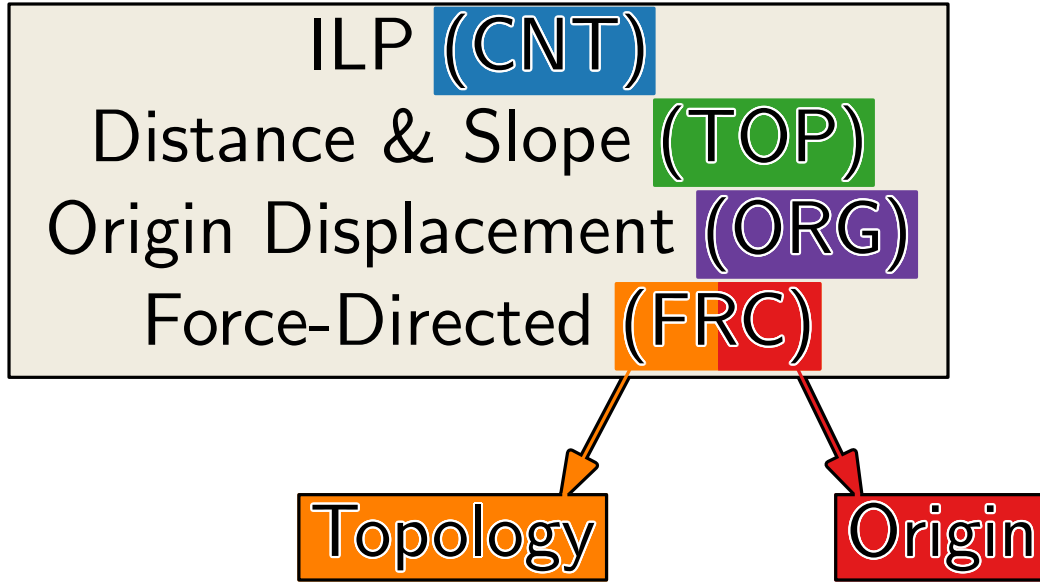


Successive

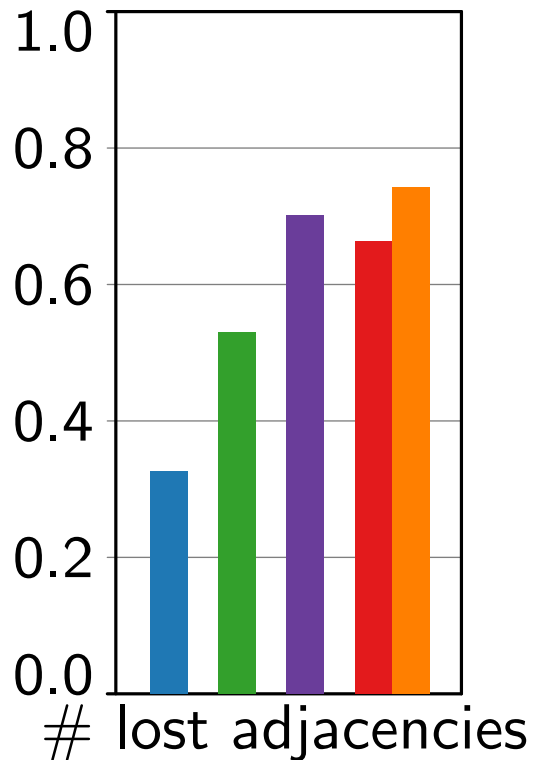
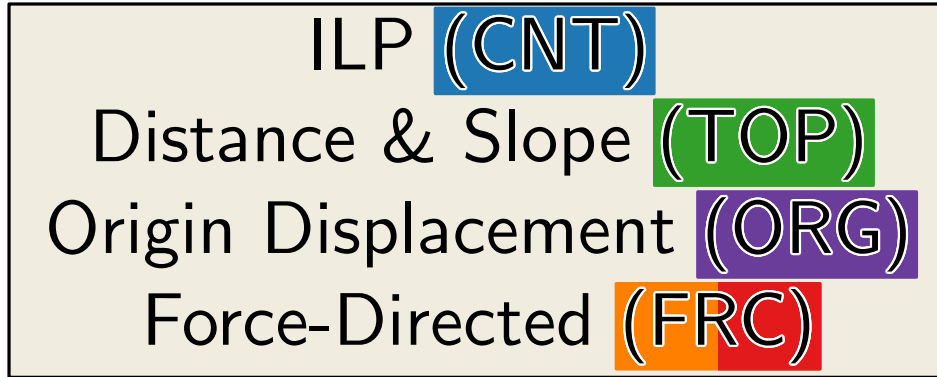


Iterative

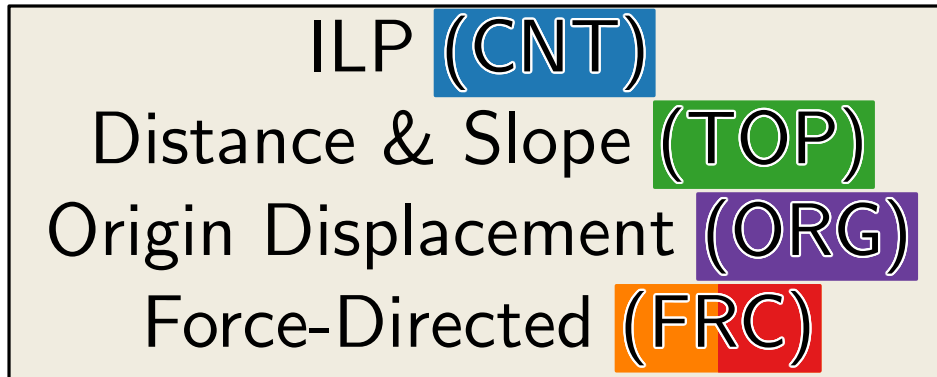
## Optimization Constraints



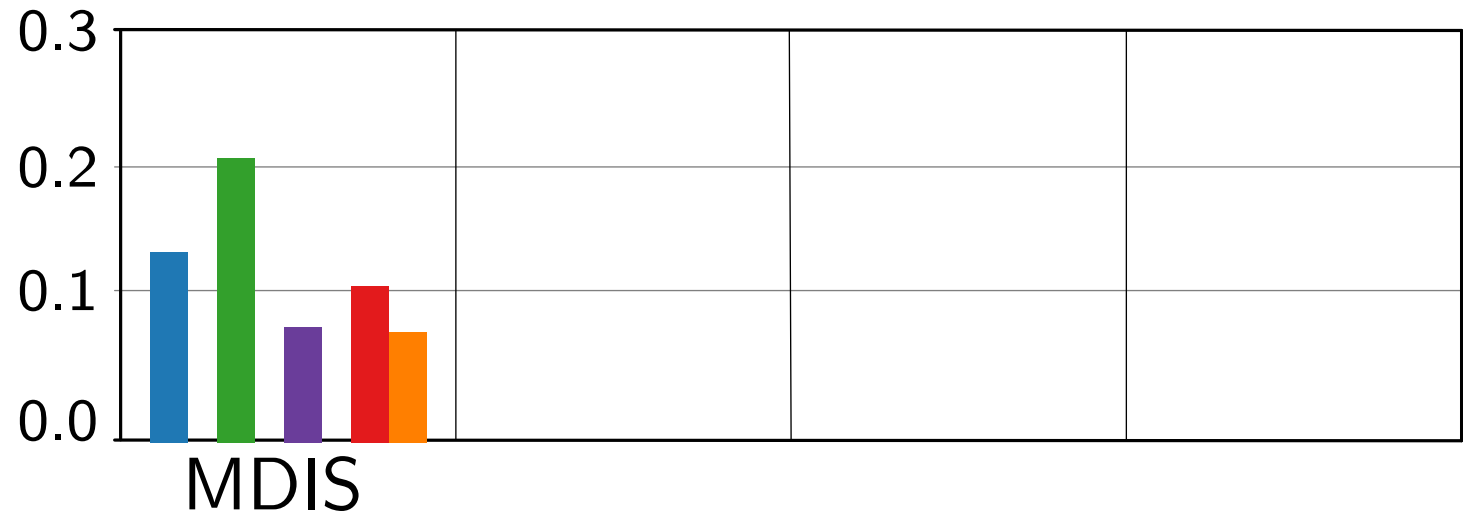
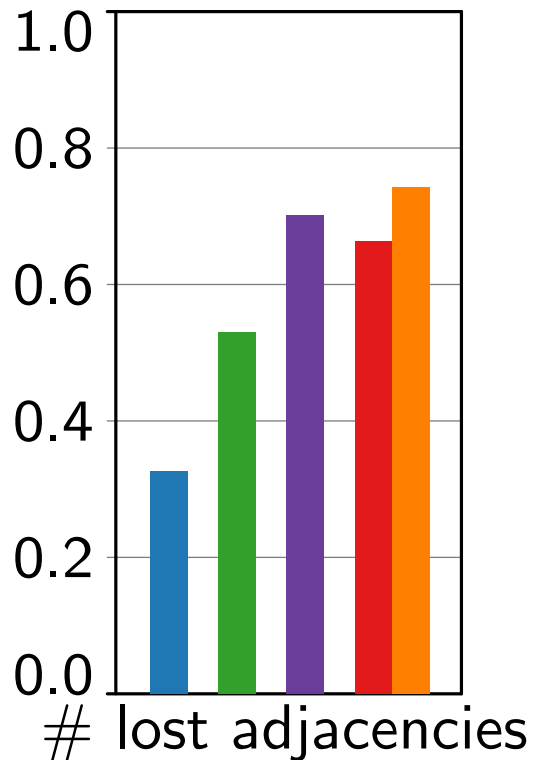
## Optimization Constraints



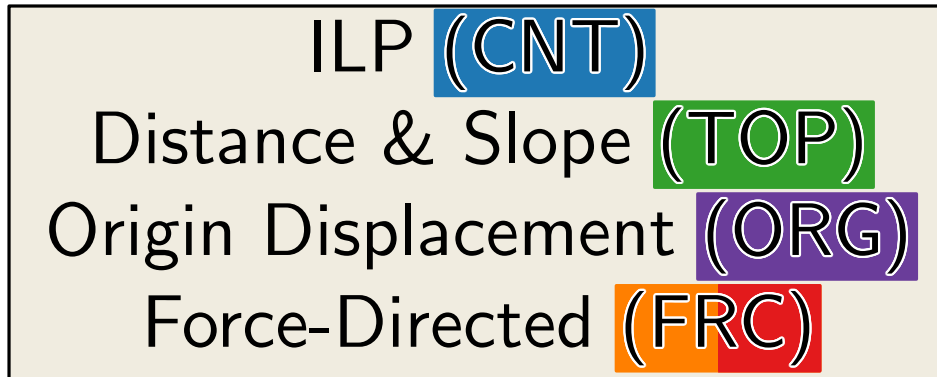
## Optimization Constraints



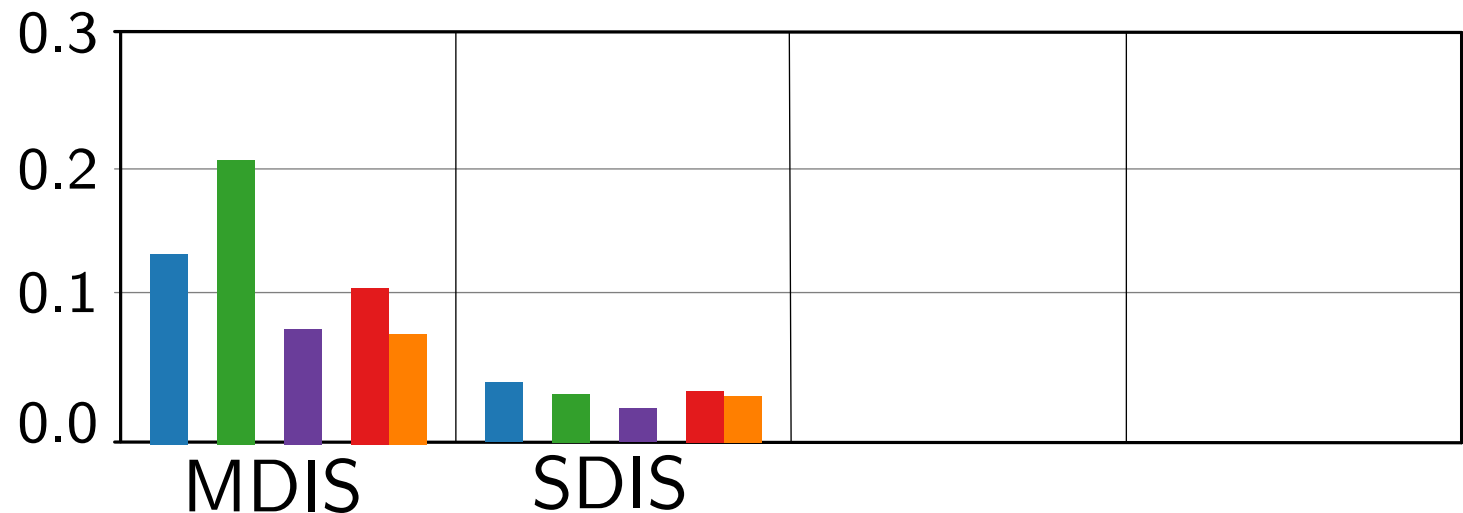
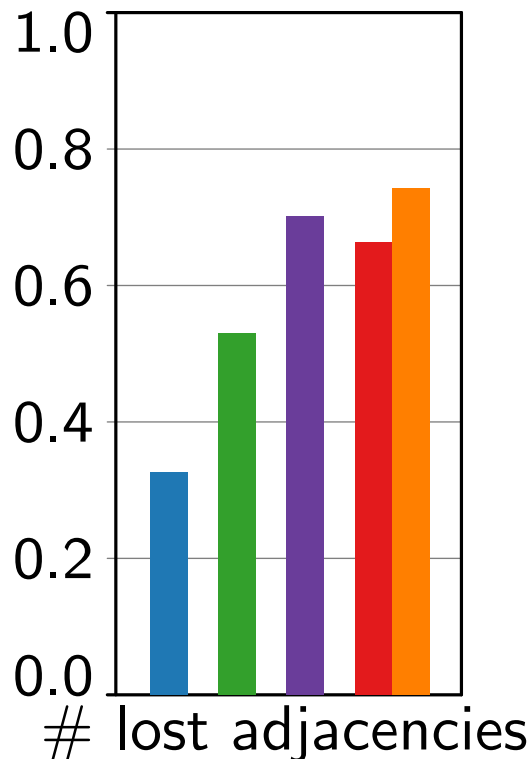
MDIS  $\hat{=}$  distance to original location



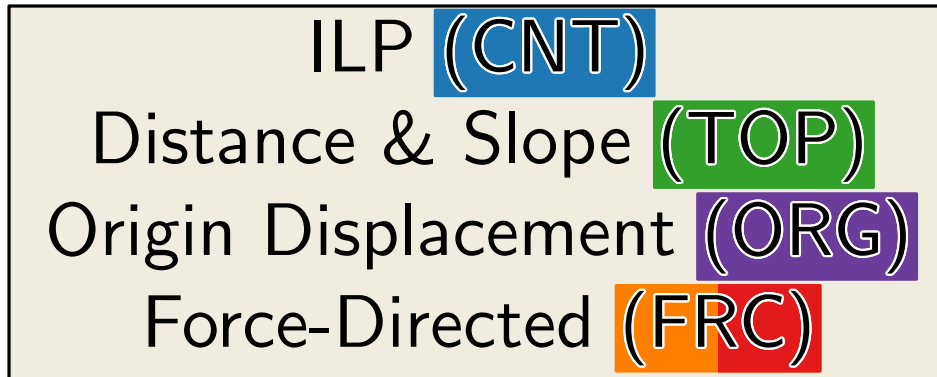
## Optimization Constraints



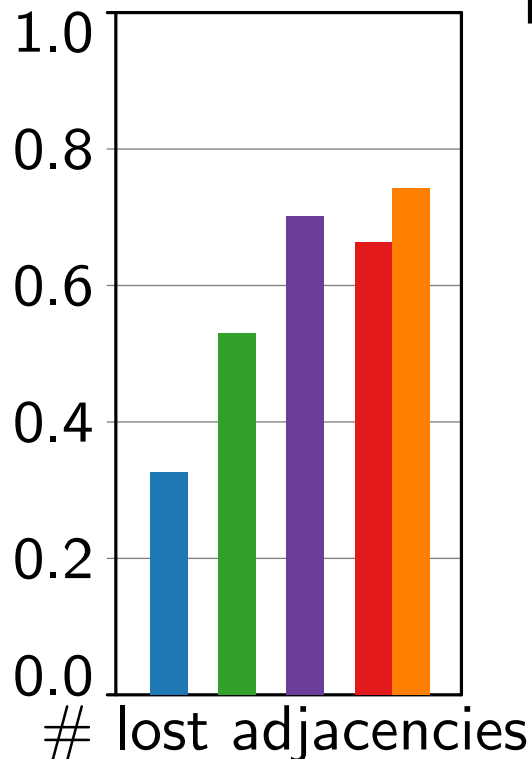
MDIS  $\hat{=}$  distance to original location  
SDIS  $\hat{=}$  distance to position of same region in different Cartograms



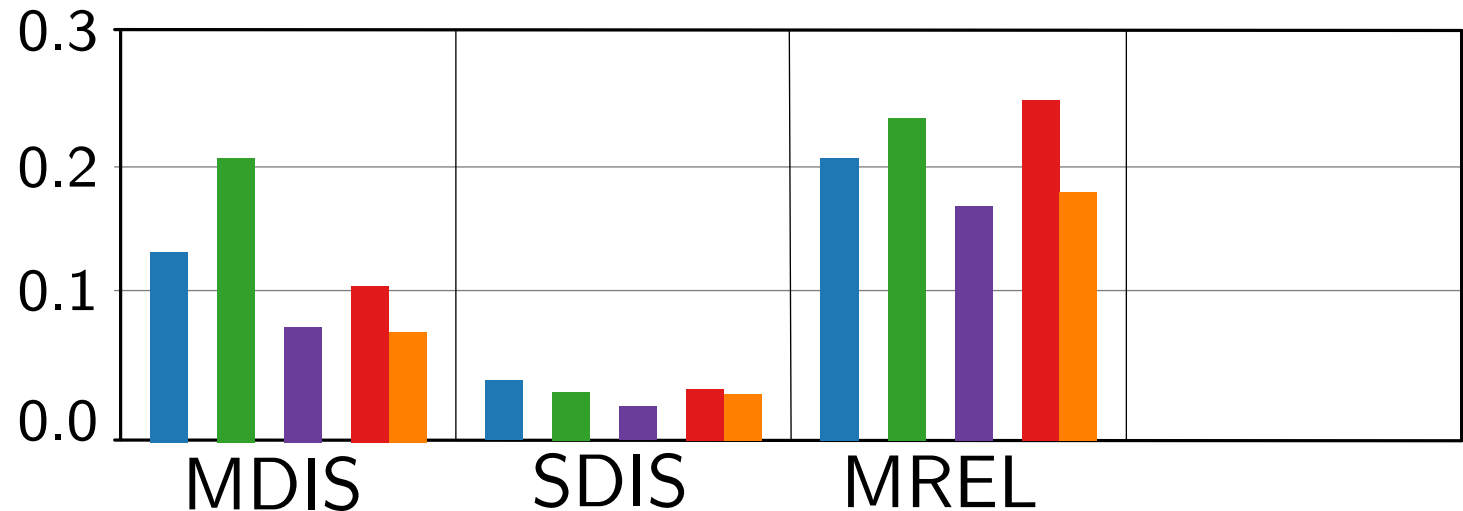
## Optimization Constraints



MDIS  $\hat{=}$  distance to original location  
SDIS  $\hat{=}$  distance to position of same region in different Cartograms

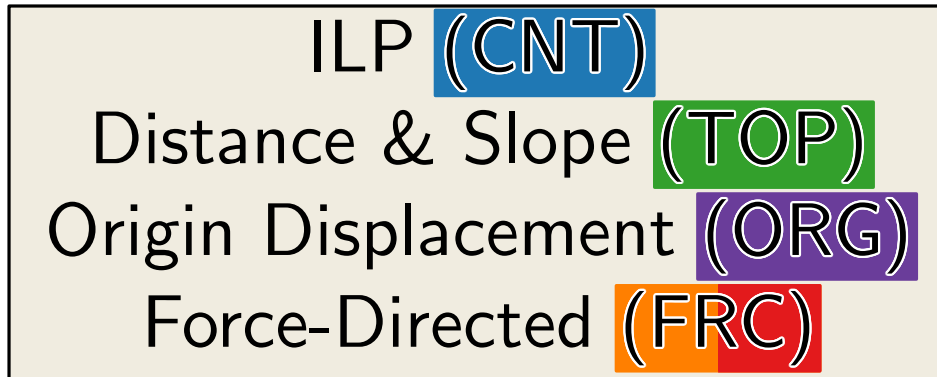


MREL  $\hat{=}$  position of regions relative to input





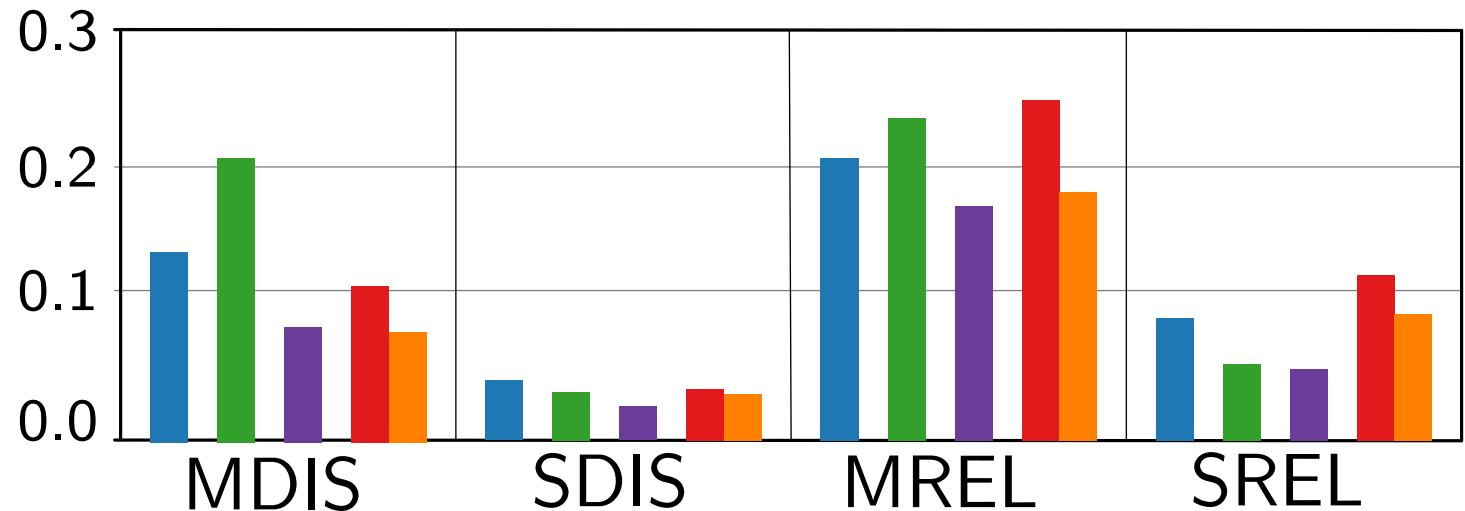
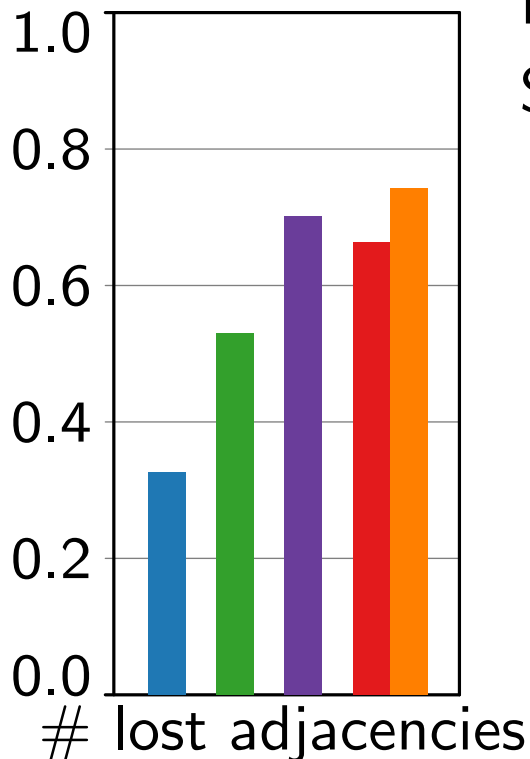
## Optimization Constraints



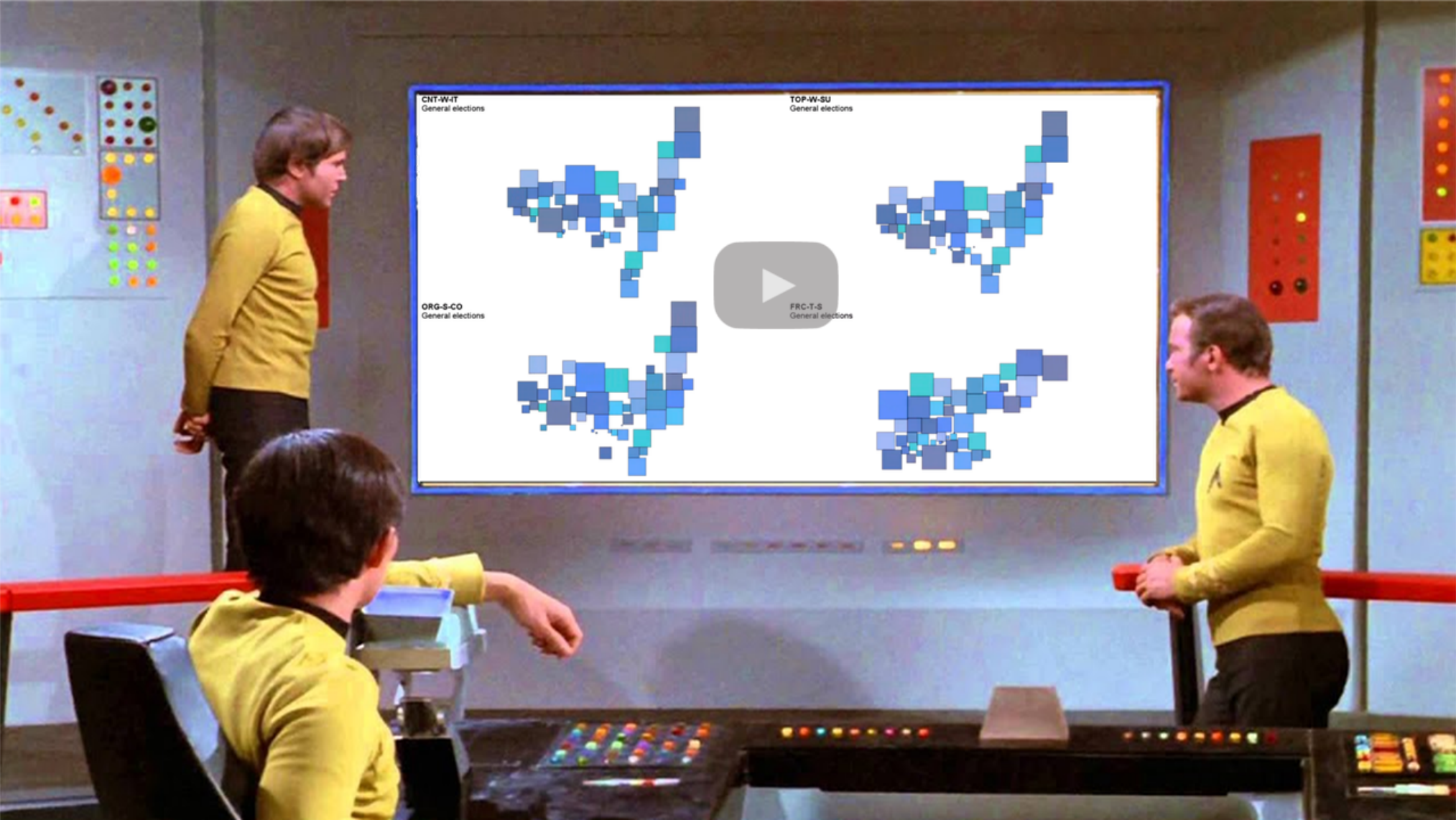
MDIS  $\hat{=}$  distance to original location  
SDIS  $\hat{=}$  distance to position of same region in different Cartograms

MREL  $\hat{=}$  position of regions relative to input

SREL  $\hat{=}$  position of regions relative to other cartograms

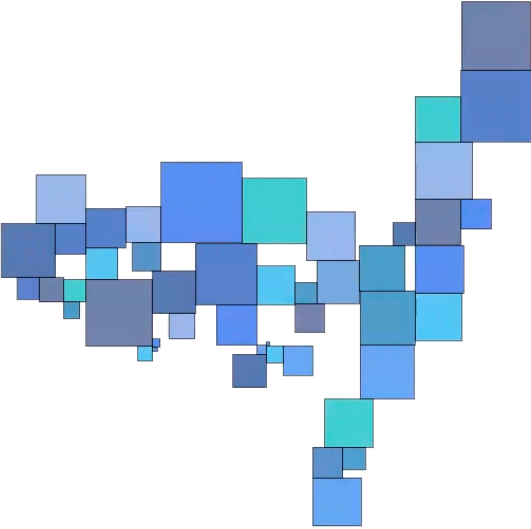


# Incoming Example

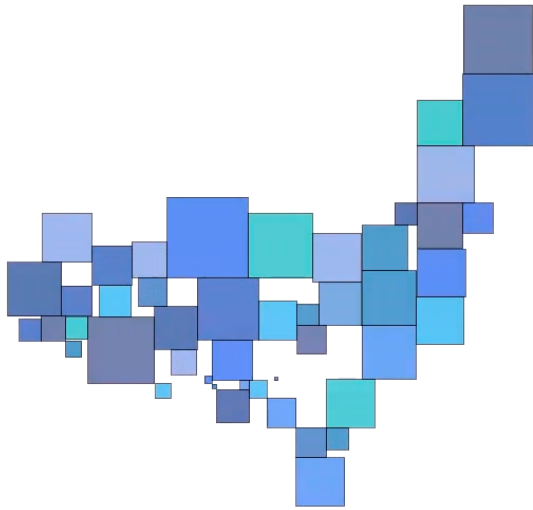


## In case of emergency

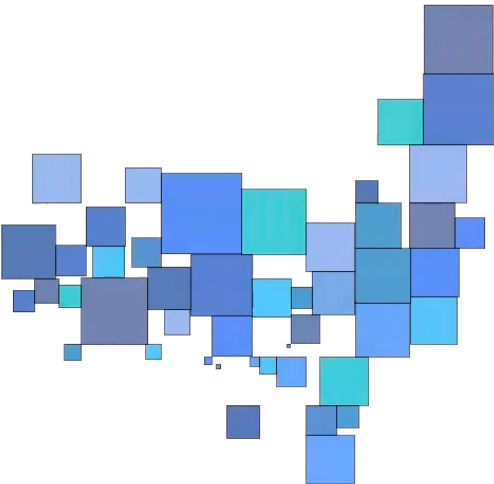
**CNT-W-IT**  
General elections



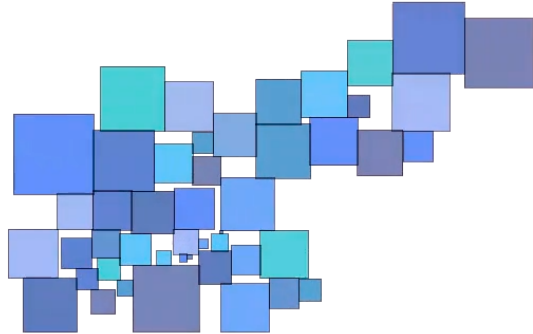
**TOP-W-SU**  
General elections



**ORG-S-CO**  
General elections



**FRC-T-S**  
General elections



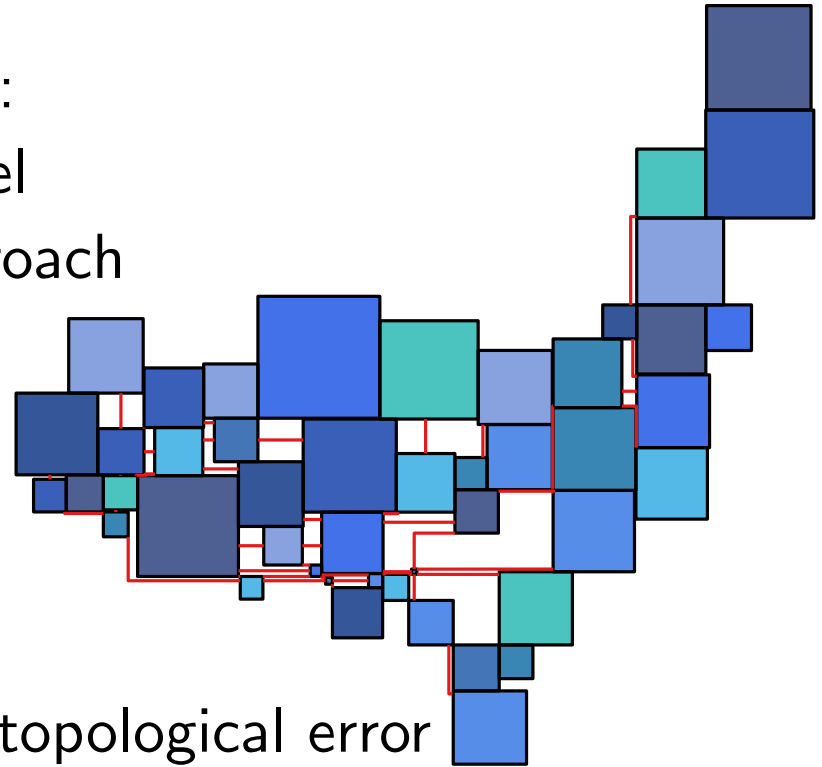
# Conclusion

Ensuring orthogonal separation constraints:

- helps maintain the spatial mental model
- outperforms a basic force-directed approach

General trade-off between the topological error and other metrics:

- ILP minimizes the topological error
- ORG scores high on all metrics except topological error
- TOP strikes a sensible balance



Added complexity of the complete stability model does not seem to pay off compared to the successive model

Lost adjacencies can be visualized by low complexity orthogonal line