Geospatial analysis

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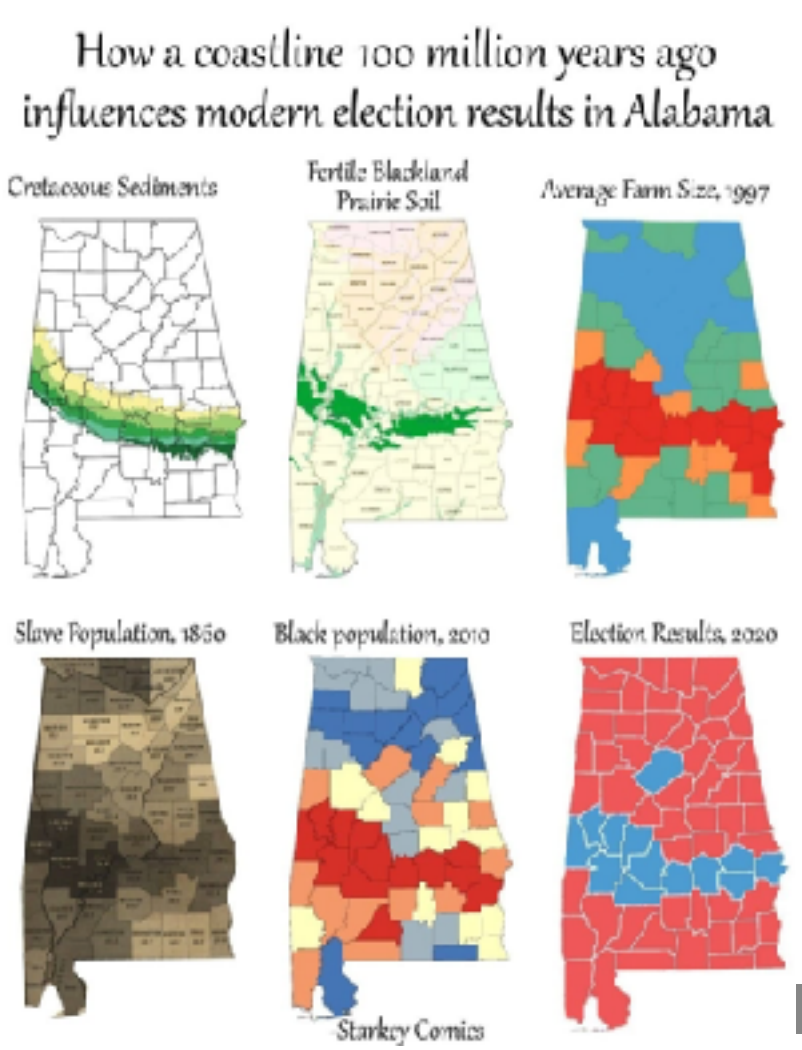
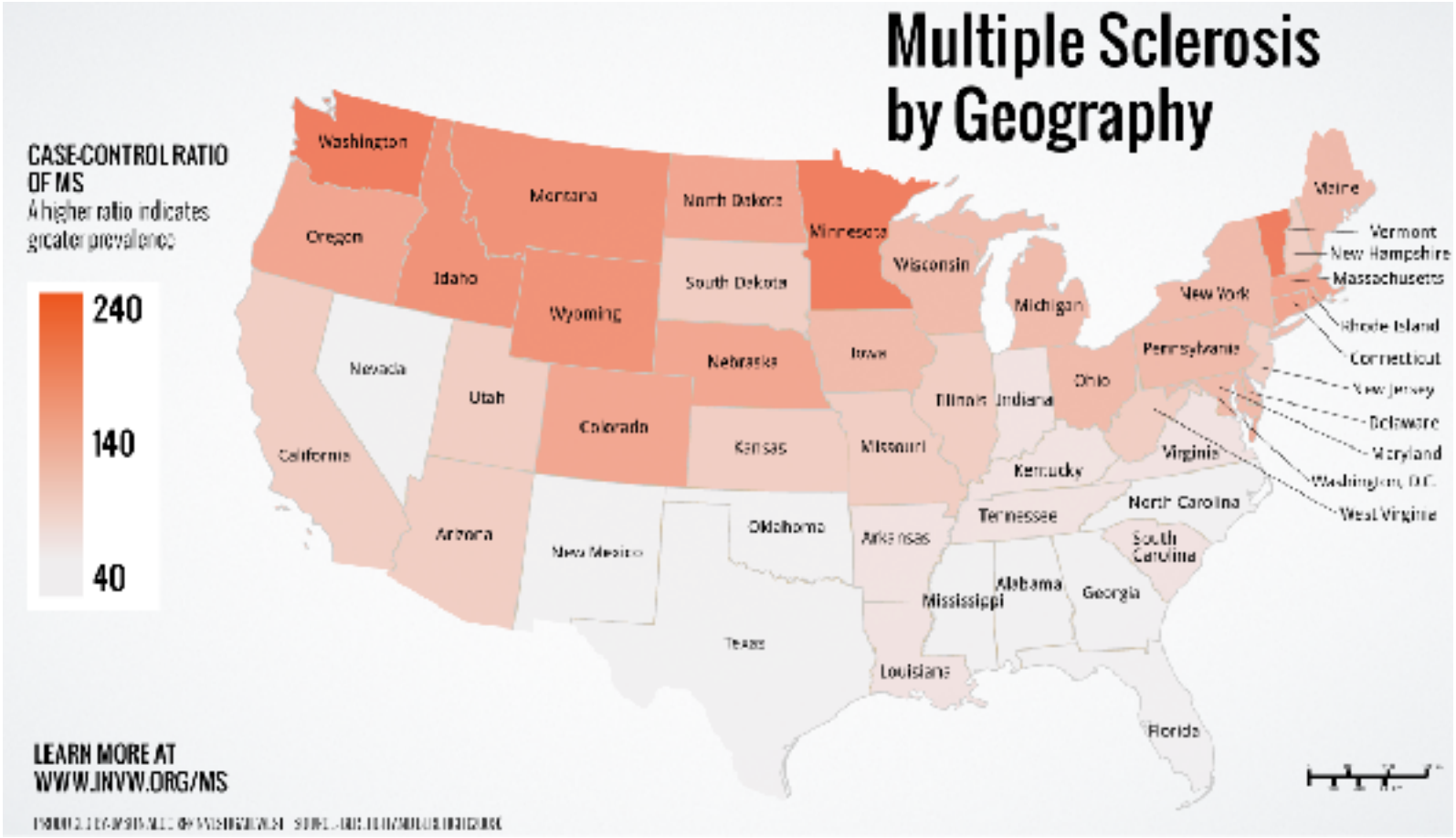


Why Geospatial Analysis?

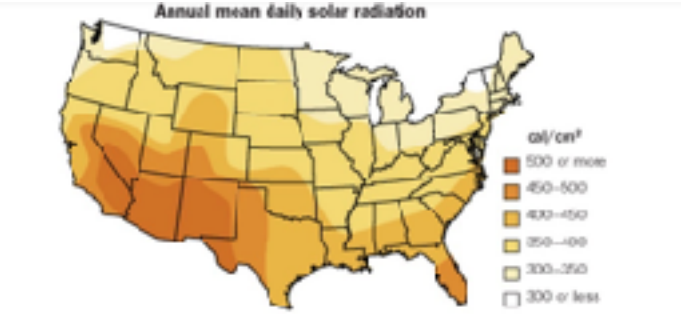
‘Everything is related to everything else, but near things are more related than distant things.” -Tobler 1979

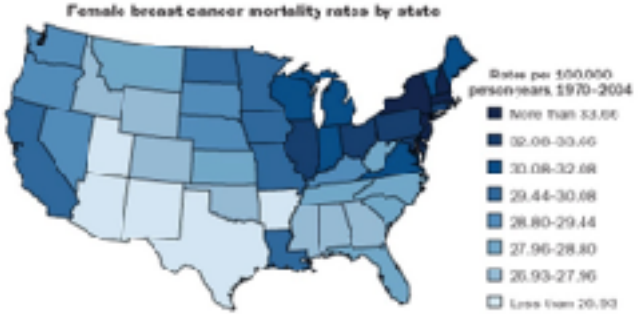
“...the purpose of geographic inquiry is to examine relationships between geographic features collectively and to use the relationships to describe the real-world phenomena that map features represent” -Clarke 2001



adapted from Brad Voytek

Clearly visualizes important differences in disease distribution



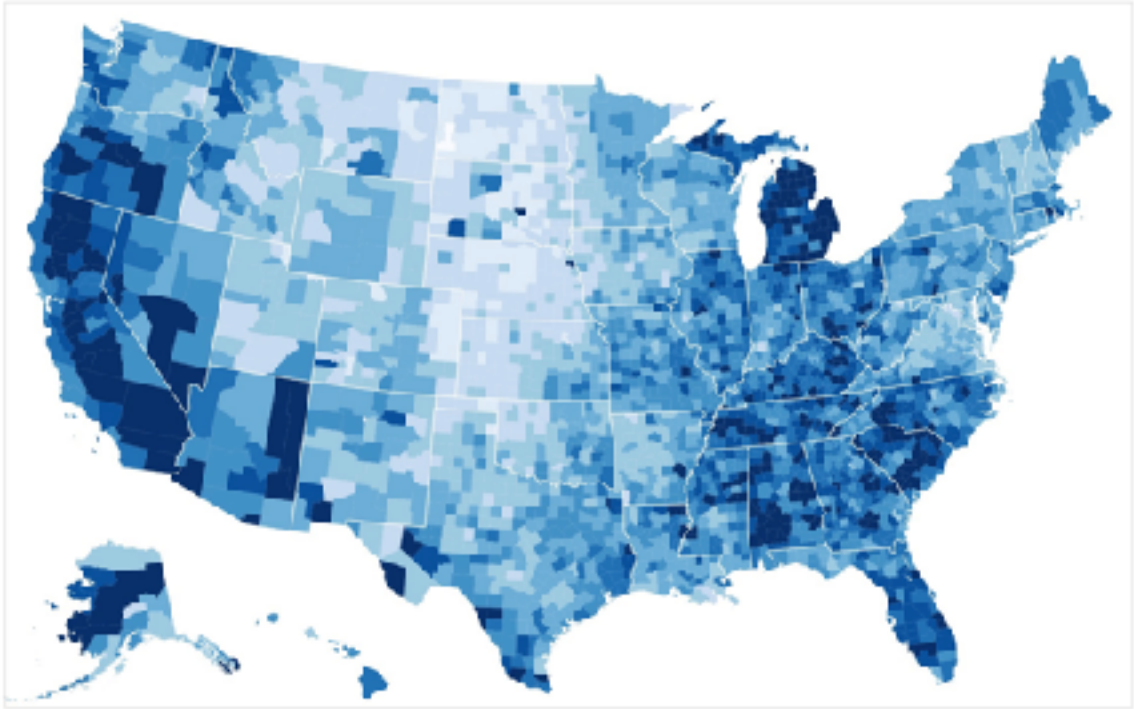


ON THE MAP Scientists who study vitamin D can't help but notice that a host of diseases seem to vary with latitude. Type 1 diabetes, multiple sclerosis and even some cancers appear to be more common in areas that get less sun -- meaning less opportunity for the body to produce vitamin D. The maps above illustrate the apparent link between solar radiation and breast cancer mortality rates.

SOURCE: FROM TOP: D. M. HARRIS AND V.L.W. GO / J. OF NUTRITION 2004; NATIONAL CANCER INSTITUTE

Visualizing Geospatial Data

Unemployment rate by county (August 2016)



This choropleth encodes unemployment rates from 2008 with a quantize scale ranging from 0 to 15%. A threshold scale is a useful alternative for coloring arbitrary ranges.

Open in a new window.

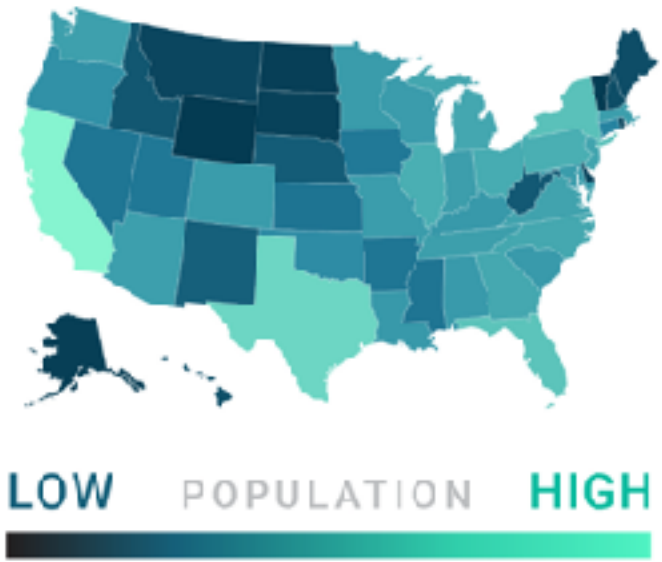
Choropleth maps are useful for visualizing *clear regional patterns* in the data

Source: http://bl.ocks.org/mbostock/4060606

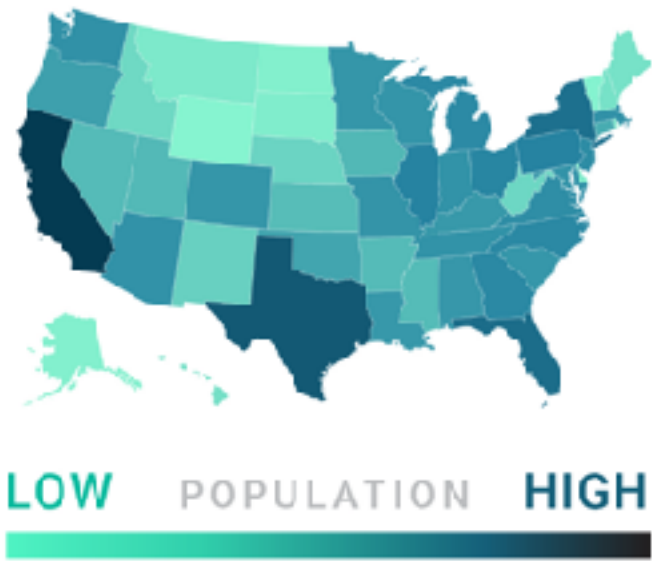
adapted from Brad Voytek

Use light colors for low values. Dark colors for high values.

NOT IDEAL



BETTER

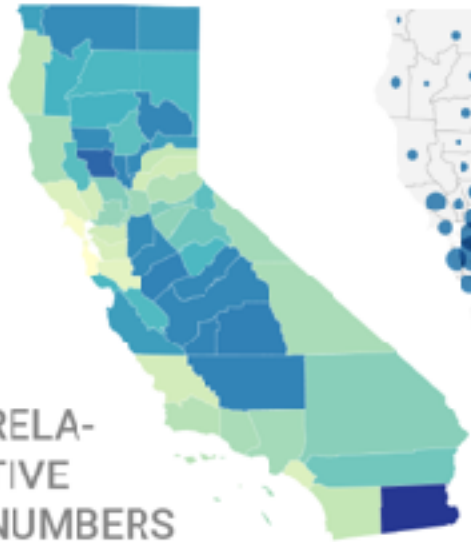


https://blog.datawrapper.de/colors/

Choropleth should display relative differences, *not* absolute numbers

NOT IDEAL

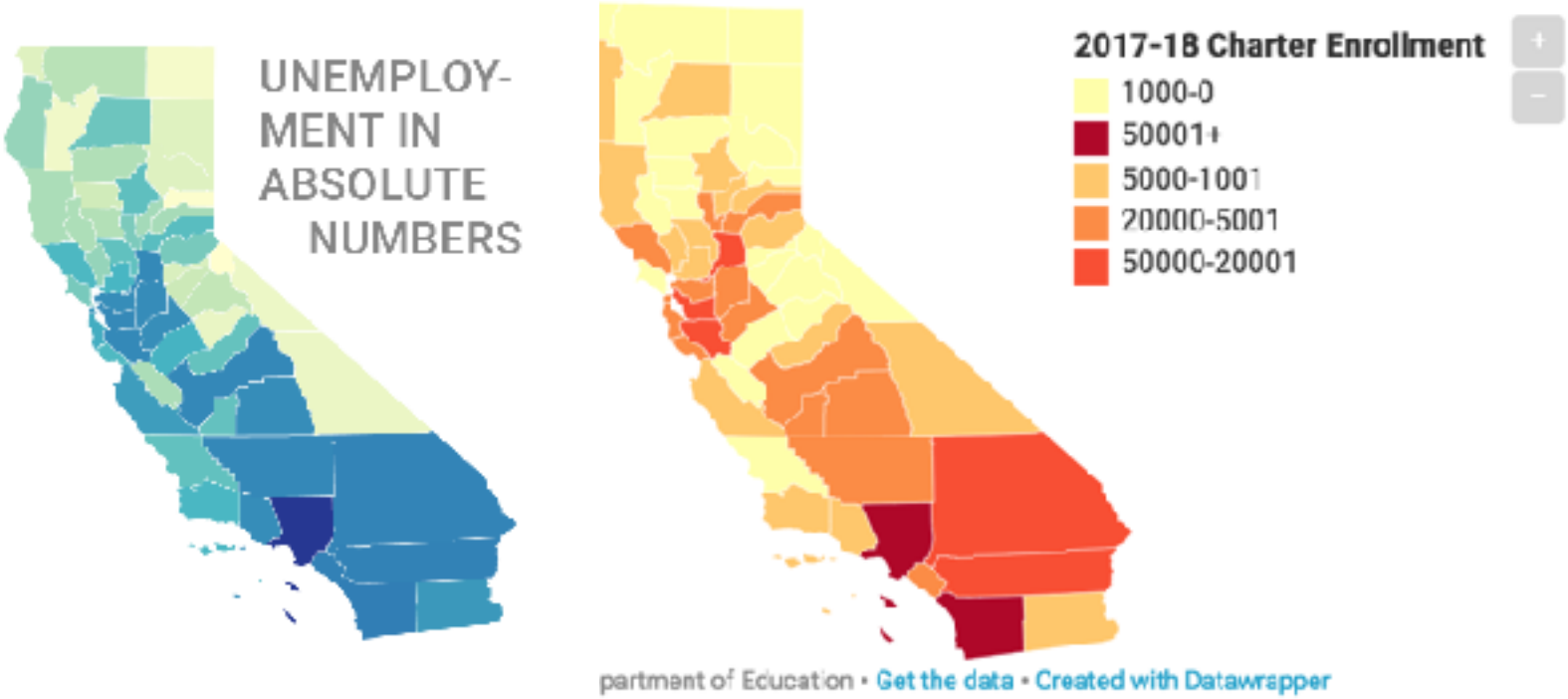
BETTER



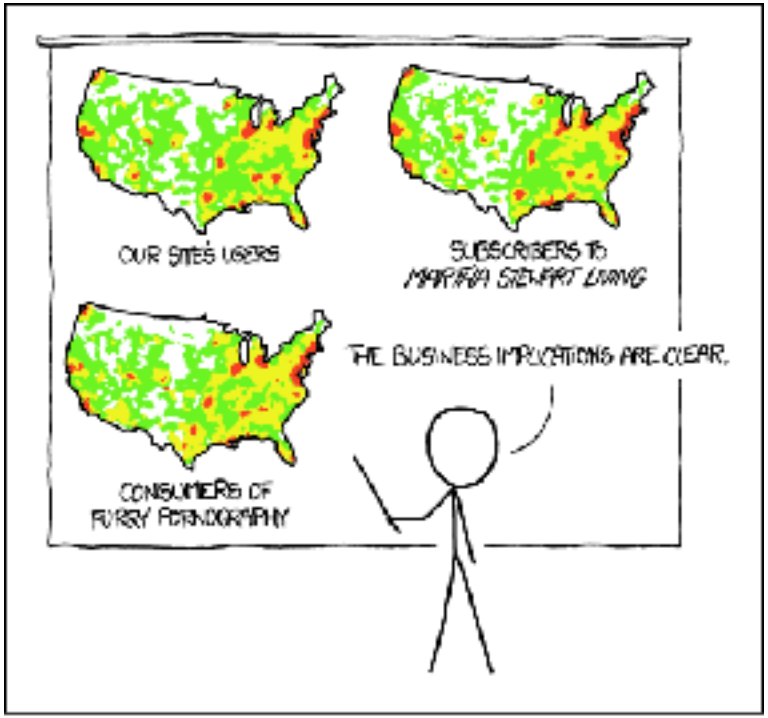
https://blog.datawrapper.de/choroplethmaps/

Map: Where Are Students Attending Charter Schools?

The majority of California's charter school student population is concentrated in Los Angeles, San Diego and Bay Area counties. Hover through the counties on each map for more information on their



https://calmatters.org/articles/california-charter-school-data-enrollment-cost-teachers-unions/



PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE
BASICALLY JUST POPULATION MAPS

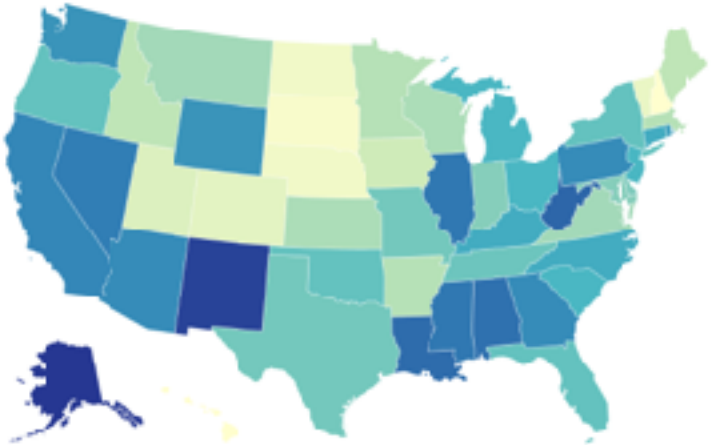
Choropleth maps can be misleading

https://xkcd.com/1138/

Consider using the smallest unit possible

(but there are exceptions!)

NOT IDEAL



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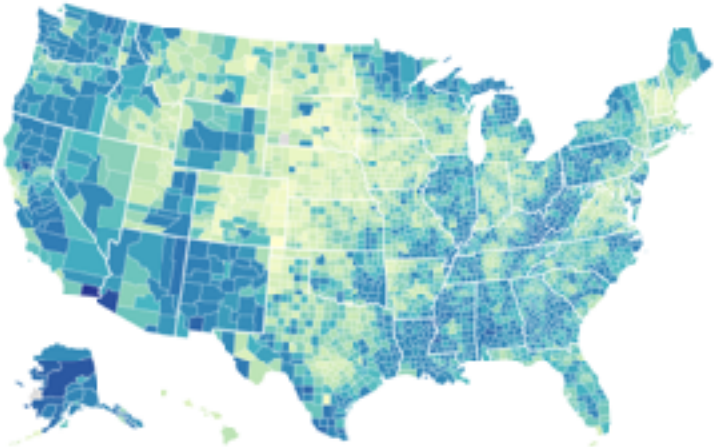
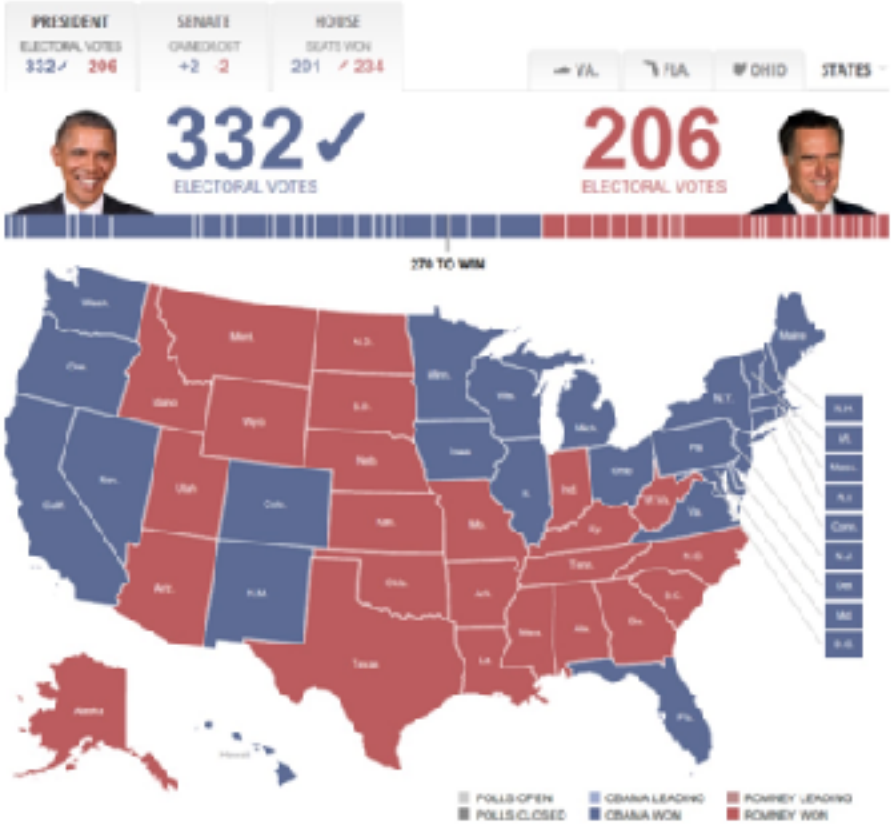
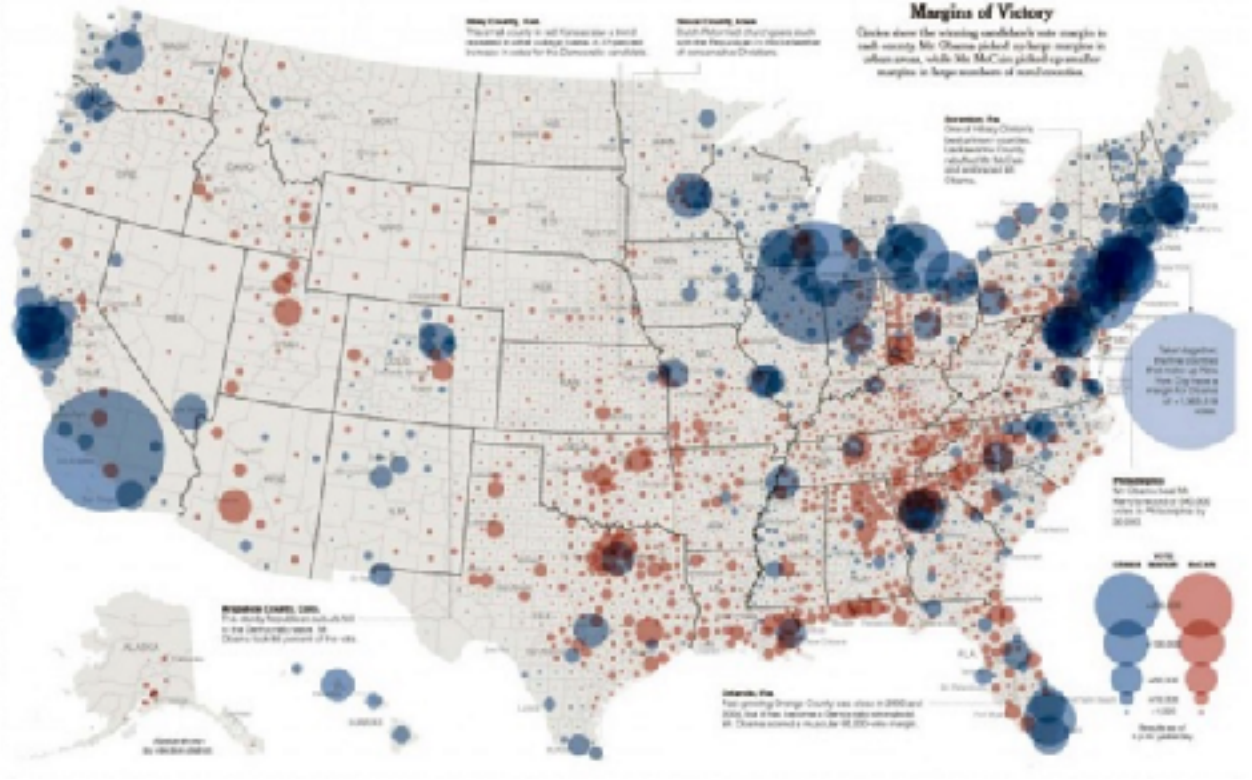


https://blog.datawrapper.de/choroplethmaps/



Sometimes summarizing at the state level is ok...

Source: *Huffington Post*, http://elections.huffingtonpost.com/2012/results adapted from Brad Voytek



This **bubble graph** more accurately tells the full story, since the size of the bubbles is reflective of the population

...but same data *can* be displayed more effectively and informatively.

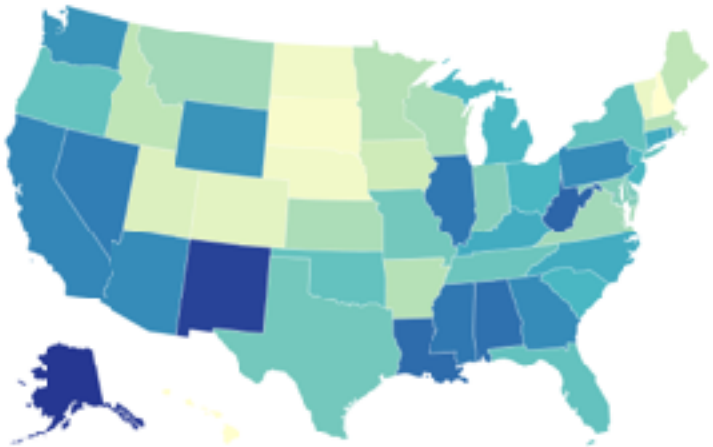
Source: http://www.thefunctionalart.com/2012/11/when-choropleth-maps-deceive.html

adapted from Brad Voytek

Visualization Choices

Cartograms should be considered when displaying how many people were affected

NOT IDEAL

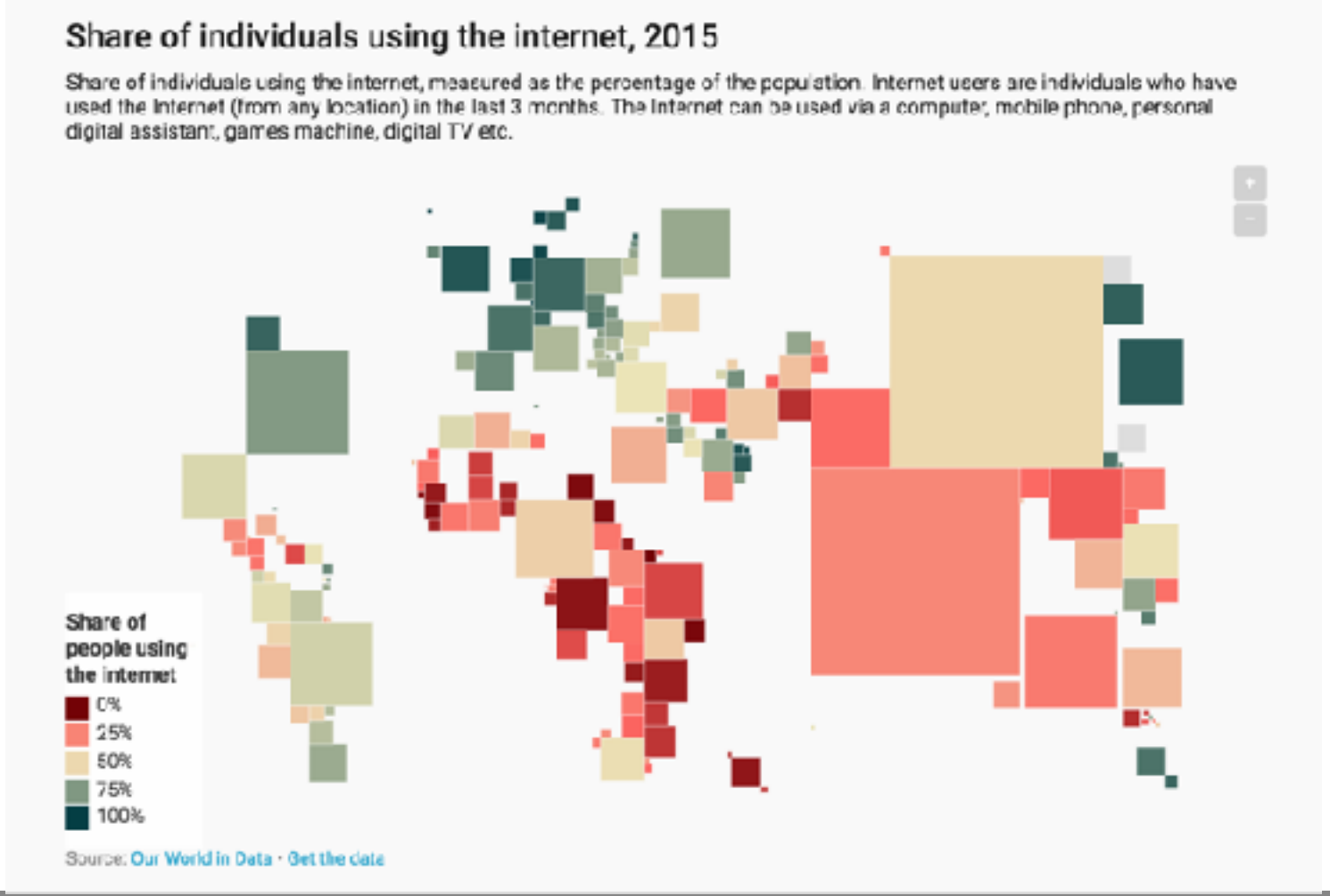


Choropleths answer “How much area was affected?”

BETTER

Cartograms answer “How many people were affected?”

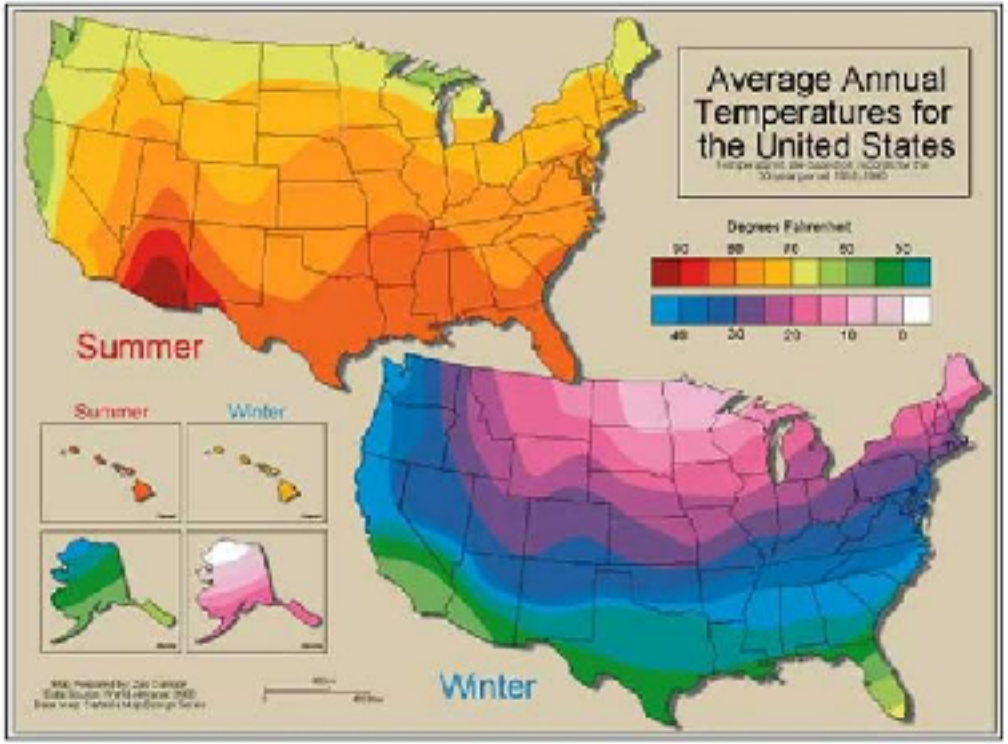
https://blog.datawrapper.de/choroplethmaps/



https://blog.datawrapper.de/cartograms/

Isarithmic maps demonstrate smooth, continuous phenomena

(temperature, elevation, rainfall, etc.)

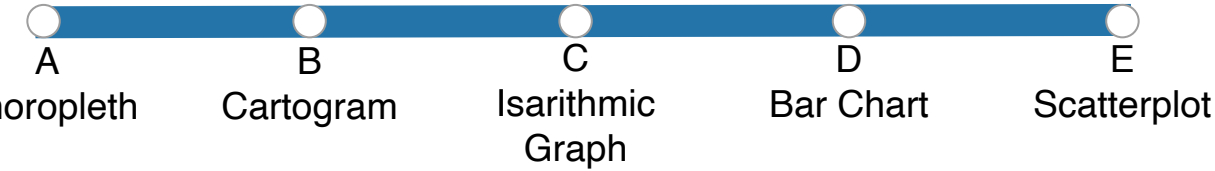


http://enb105-2012s-dem.blogspot.com/2012/03/isarithmic-map.html

Visualizing Geospatial Data

You want to visualize how many people have been affected by COVID19 worldwide.

Best approach to visualize these data?



Spatial Statistics : The Why

Spatial Statistics

The statistical techniques we've discussed so far don't work well when considering spatial distributions…

Spatial Statistics

The statistical techniques we've discussed so far don't work well when considering spatial distributions…

...which means we have a chance to take a look at data and the relationship between the data in new and interesting ways (distance, adjacency, interaction, and neighbor)

Spatial data violate conventional statistics:

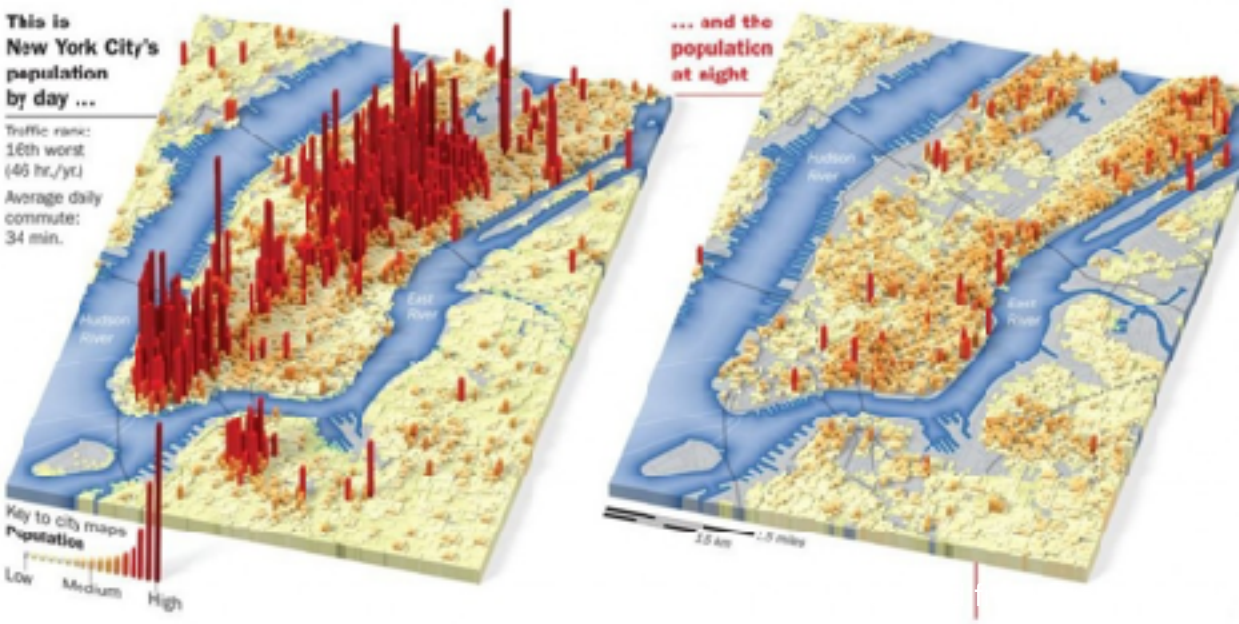
Violations of conventional statistics:

- Spatial autocorrelation
- Modifiable areal unit problem (MAUP)
- Edge effects (Boundary problem)
- Ecology fallacy
- Nonuniformity of space

Spatial Autocorrelation

Data from locations near one another in space are more likely to be similar than data from locations remote from one another:

- Housing market
- Elevation change
- Temperature

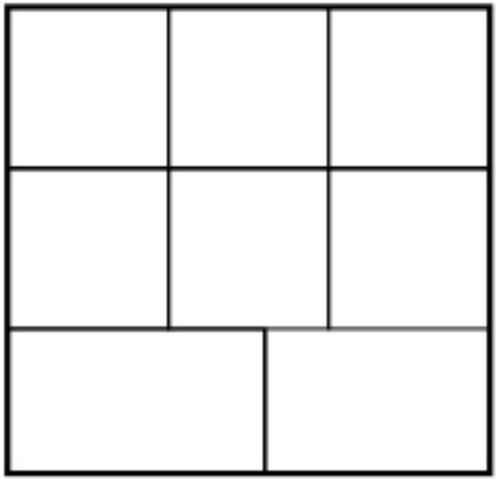


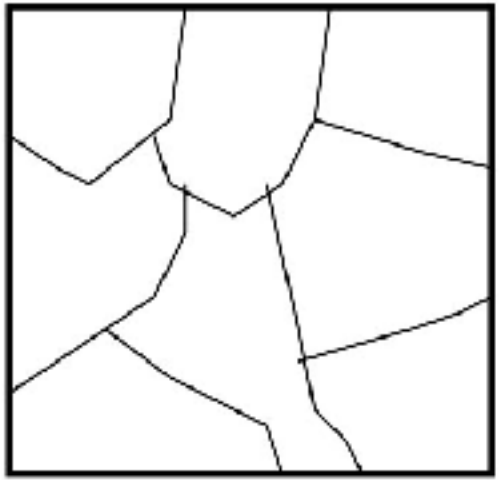
Modifiable Areal Unit Problem (MAUP)

The aggregation units used are arbitrary with respect to the phenomena under investigation, yet the aggregation units used will affect statistics determined on the basis of data reported in this way.

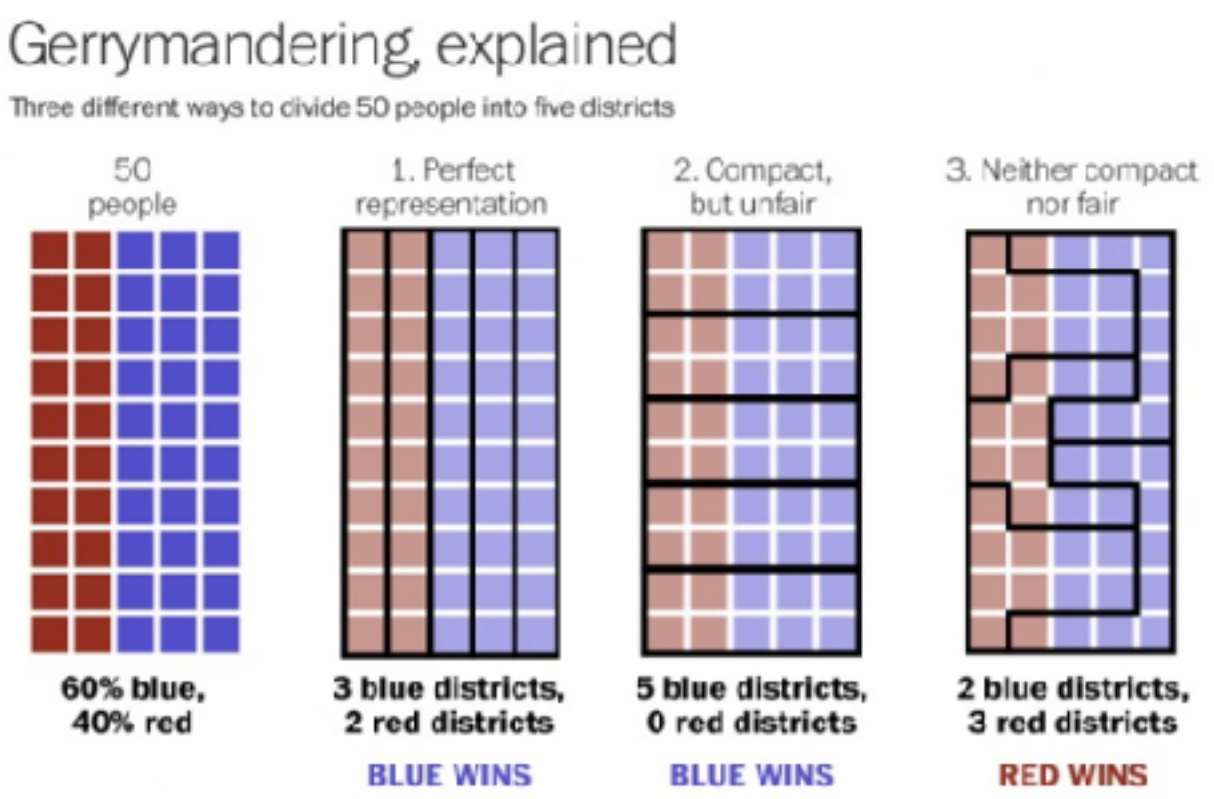
If the spatial units in a particular study were specified differently, we might observe very different patterns and relationships.

modifiable area: Units are arbitrary defined and different organization of the units may create different analytical results.





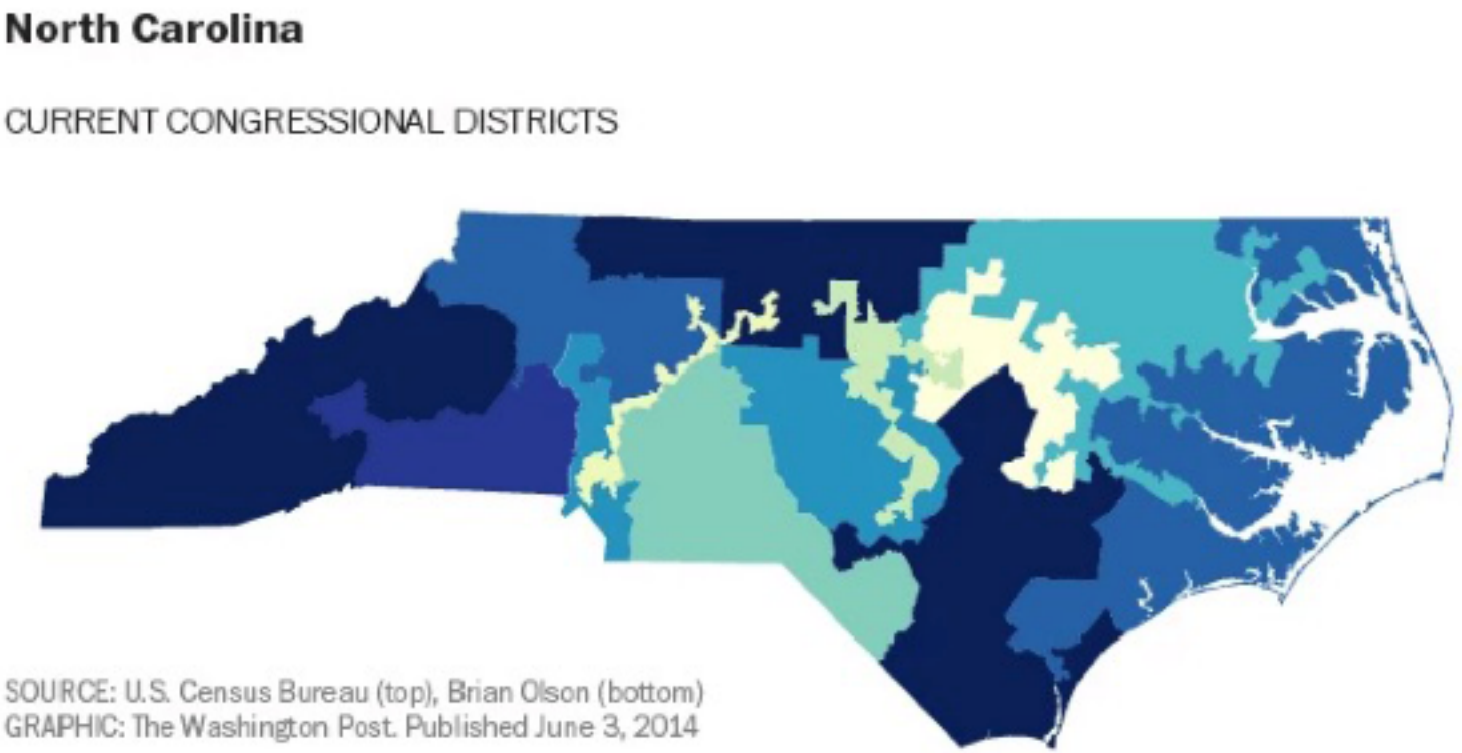
For example...gerrymandering



https://www.washingtonpost.com/news/wonk/wp/2015/03/01/this-is-the-best-explanation-of-gerrymandering-you-will-ever-see/

adapted from Brad Voytek

For example...gerrymandering



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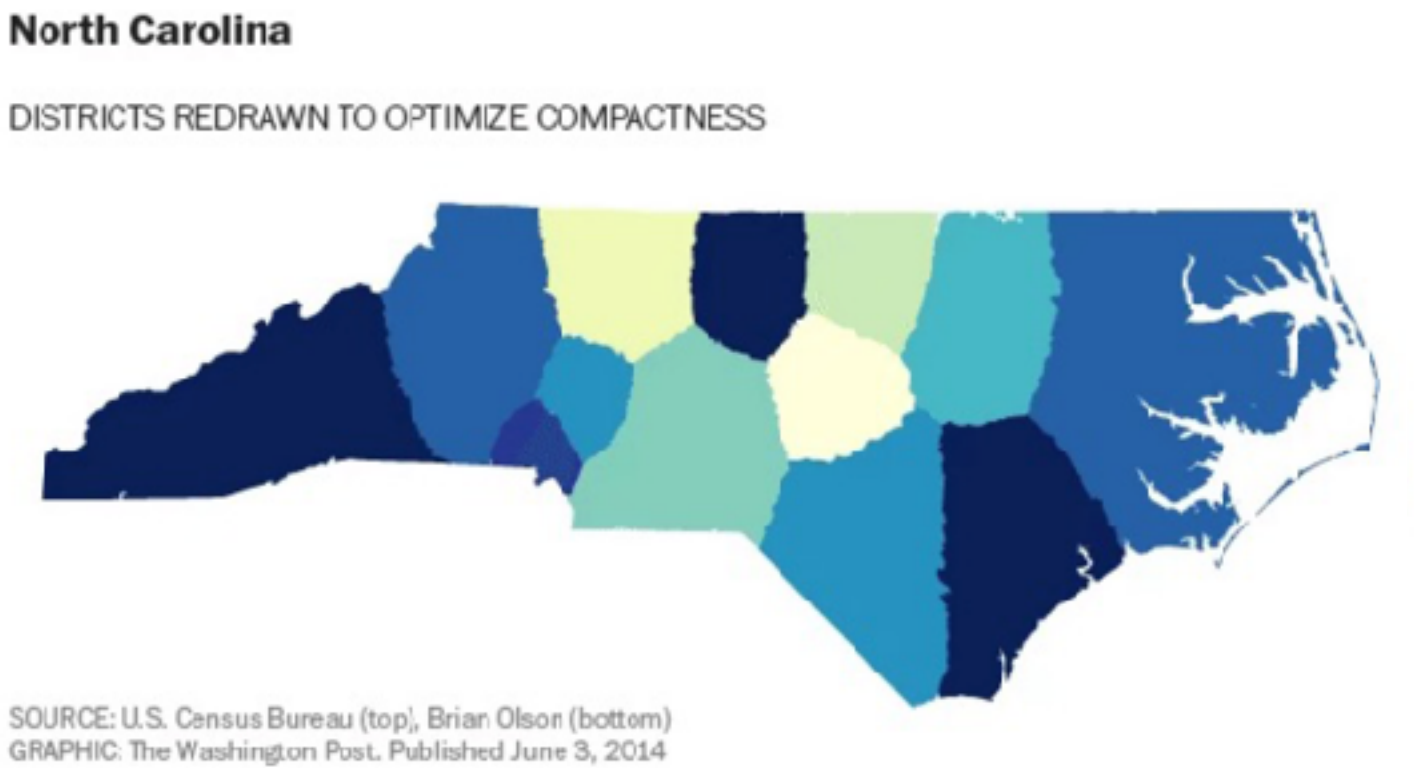


https://www.nytimes.com/interactive/2022/01/27/us/politics/congressional-gerrymandering-redistricting-game-2022.html

Modifiable Areal Unit Problem (MAUP)

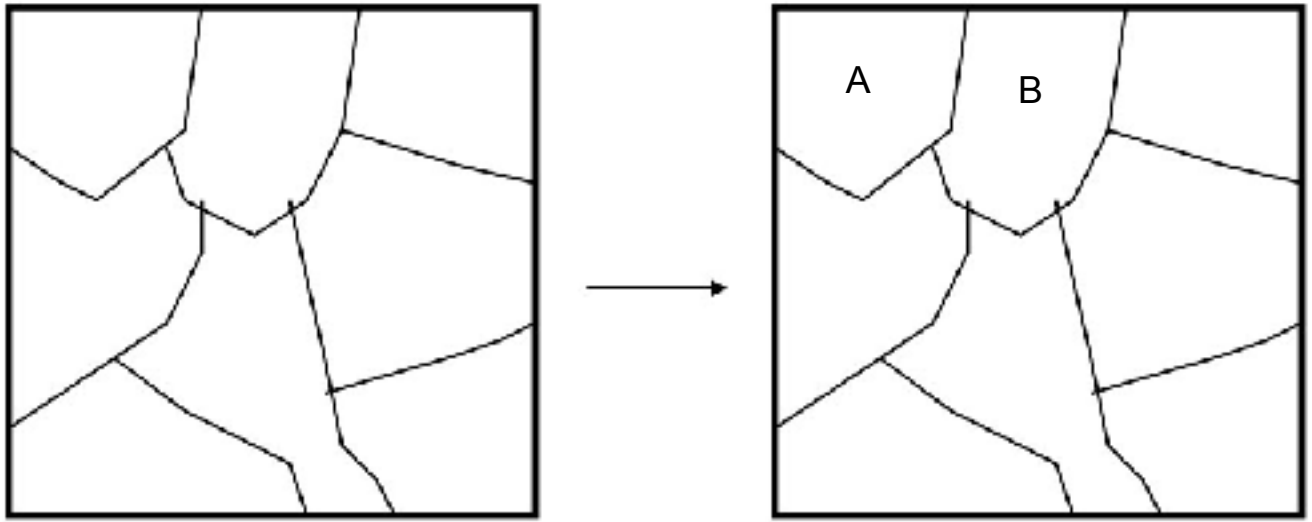
Potential problems in almost every field that utilizes spatial data.

In the 2016 U.S. presidential election, Hillary Clinton, with more of the population vote than Donald Trump, but failed to become president. (also true in Gore/Bush 2000)

A different aggregation of U.S. counties into states could have produced a different outcome.

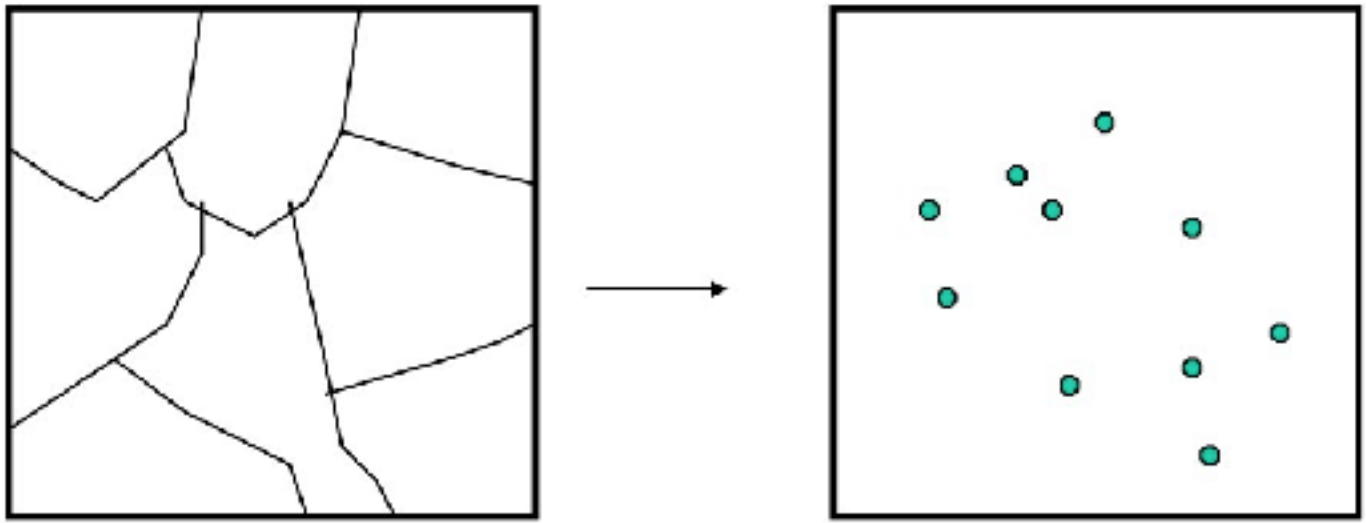
Edge Effects (The Boundary Problem)

Analyzing A vs B ignores similarities between the two based on their shared boundary



Ecological Fallacy

The Ecological Fallacy is a situation that can occur when a researcher or analyst makes an inference about an individual based on aggregate data for a group.



Ecological Fallacy

Example: we might observe a *strong relationship between income and crime at the county level*, with lower-income areas being associated with higher crime rate.

Conclusion:

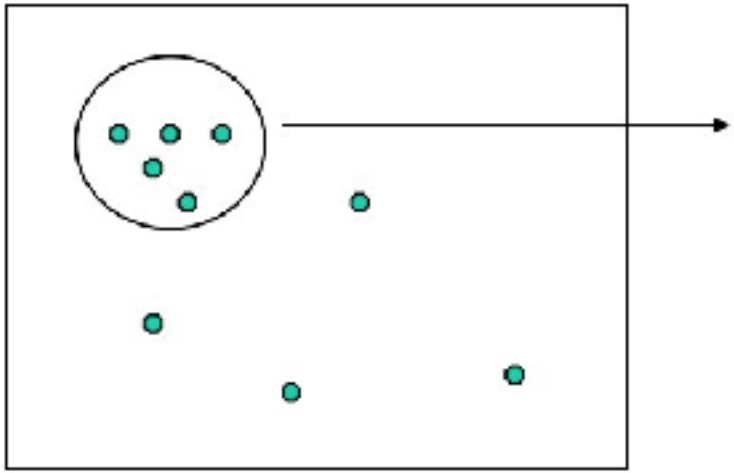
- Lower-income persons are more likely to commit crime
- Lower-income areas are associated with higher crime rates
- Lower-income counties tend to experience higher crime rates

Ecological Fallacy

Issues:
Inferences drawn about associations between the characteristics of an aggregate population and the characteristics of sub-units within the population are wrong. That is: *results from aggregated data (e.g. counties) cannot be applied to individual people*

What should we do?
Be aware of the process of aggregating or disaggregating data may conceal the variations that are not visible at the larger aggregate level

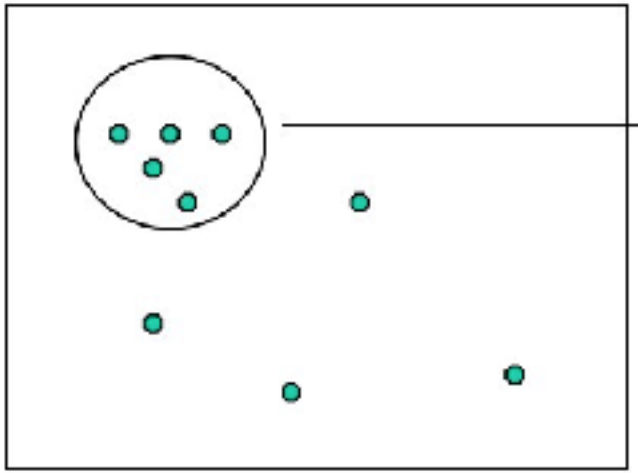
Nonuniformity



Area with high crime rates?

Crime locations

Nonuniformity

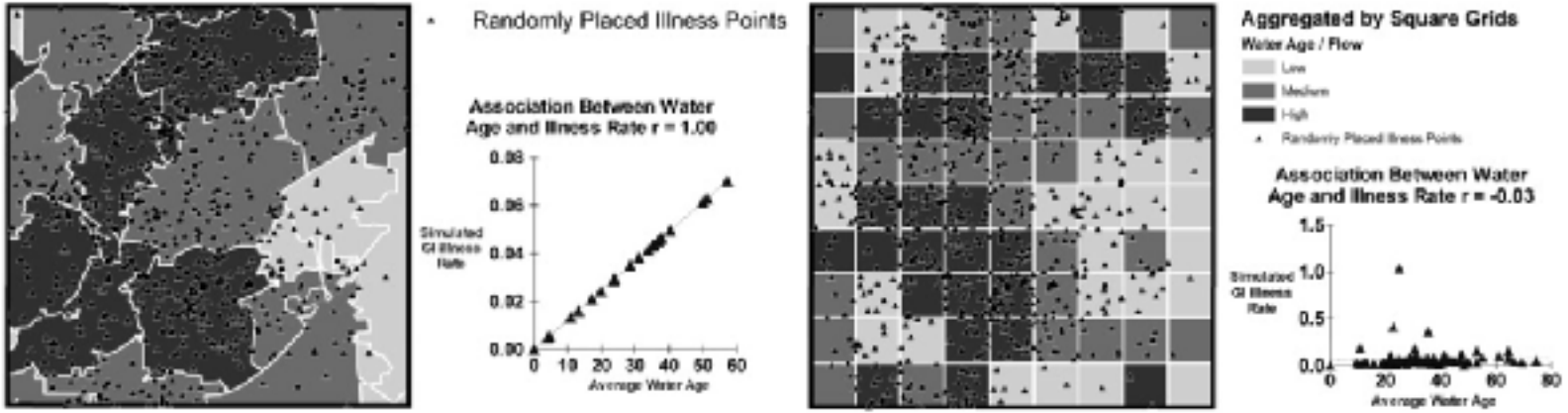


Crime locations

Area with high crime rates?

Conclusion: Bank robberies are clustered
….but only because banks are clustered!

Spatial Statistics



What explains what's going on here?

A
Spatial Autocorrelation

B
MAUP

C
Edge Effects

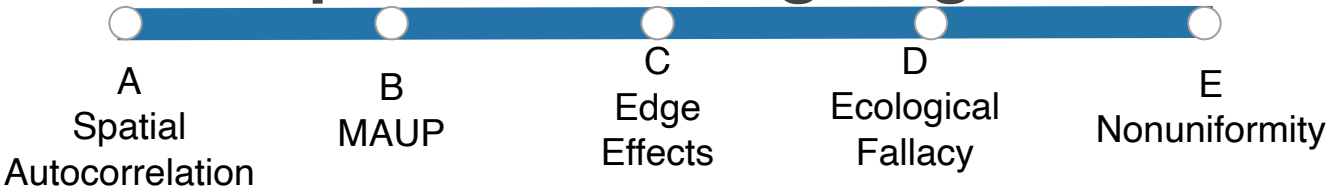
D
Ecological Fallacy

E
Nonuniformity

Spatial Statistics

In Baltimore City, police spend more time in a few neighborhoods. Crime rates are higher in those neighborhoods.

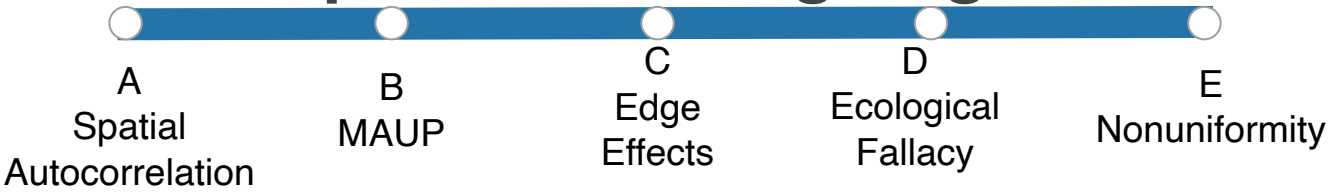
What explains what's going on here?



Spatial Statistics

A Trader Joe's just opened in a new neighborhood. Nearby homes are now worth more money.

What explains what's going on here?



Spatial Statistics : The Basics

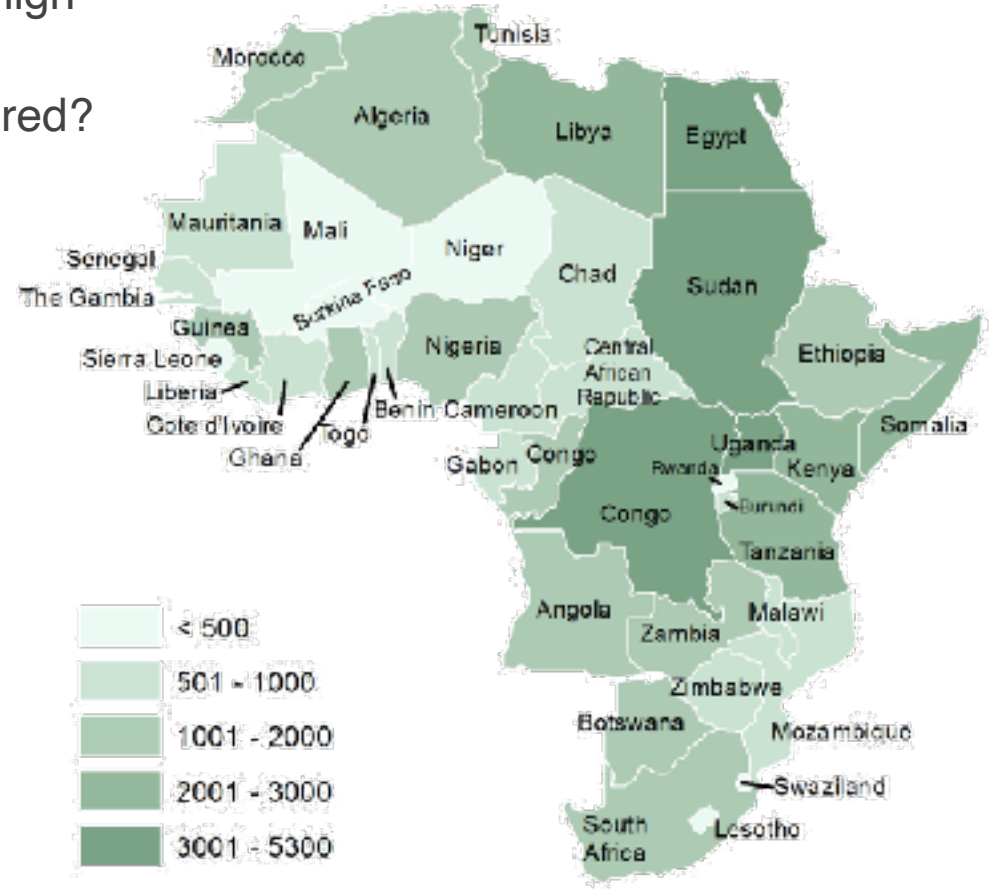
Are countries with a high conflict index score geographically clustered?

Table 1.1: Index of total African conflict for the 1956-78 period (Anselin and O'Loughlin 1992).

Country	Conflicts	Country	Conflicts
EGYPT	5246	LIBERIA	880
SUDAN	4751	SENEGAL	833
UGANDA	3134	CHAD	895
ZAIRE	3087	TOGO	848
TANZANIA	2881	GABON	824
LIBYA	2355	MAURITANIA	811
KENYA	2273	ZIMBABWE	795
SOMALIA	2122	MOZAMBIQUE	792
ETHIOPIA	1878	IVORY COAST	758
SOUTH AFRICA	1875	MALAWI	629
MOROCCO	1861	CENTRAL AFRICAN REPUBLIC	618
ZAMBIA	1554	CAMEROON	604

Data source: Anselin, L. and John O'Loughlin. 1992. Geography of international conflict and cooperation: spatial dependence and regional context in Africa. In The New Geopolitics, ed. M. Ward, pp. 39-75.

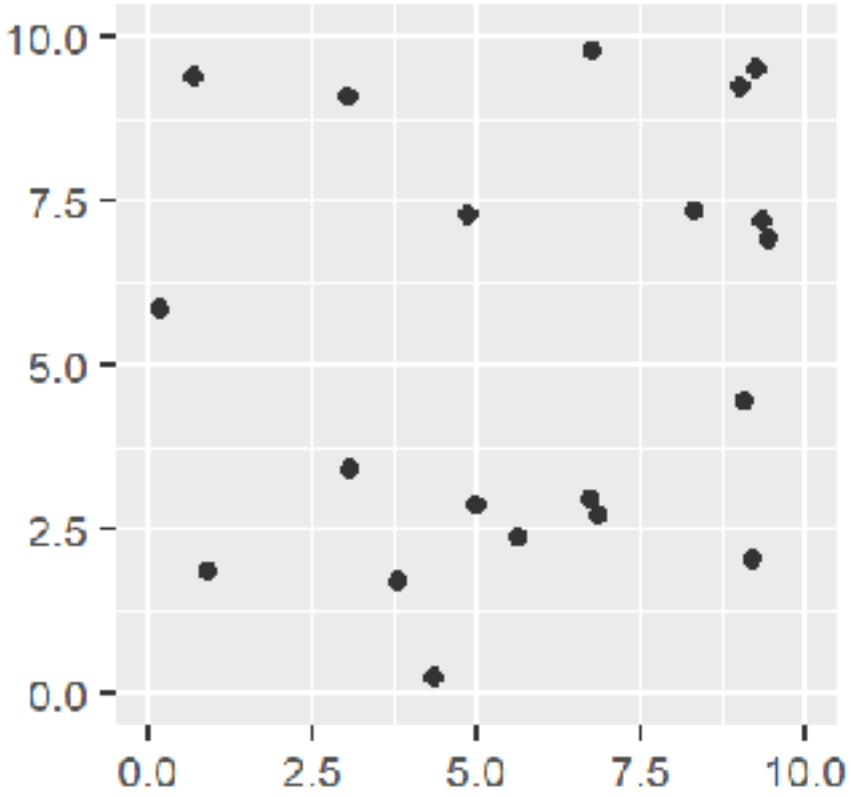
Are countries with a high conflict index score geographically clustered?



https://mgimond.github.io/Spatial/introGIS.html

Global Point Density

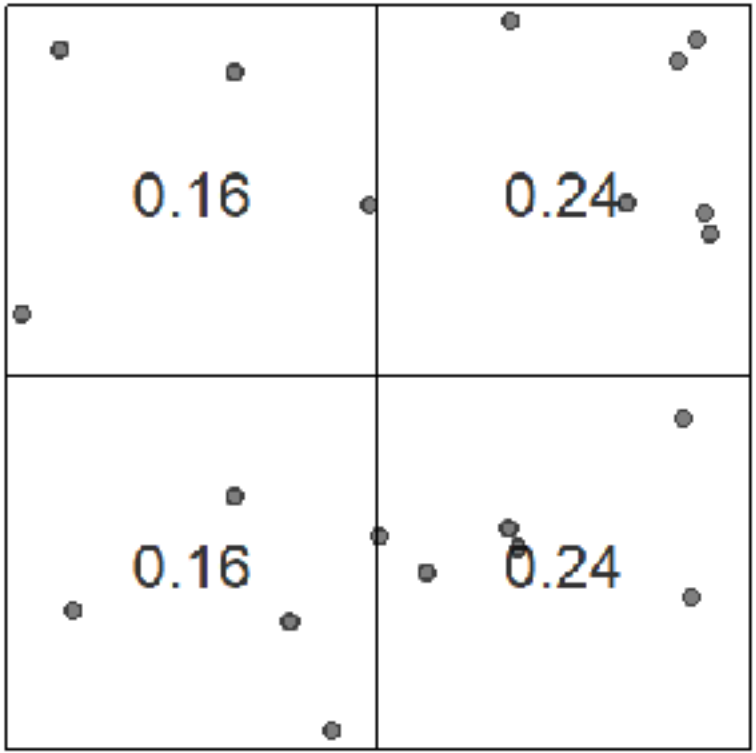
the ratio of observed number of points to the study region's surface area



Quadrat Density (local)

Surface is divided and then point density is calculated within quadrat

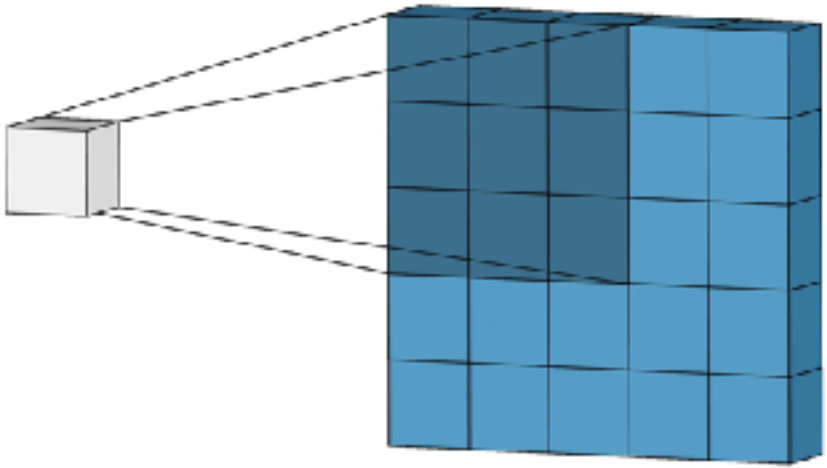
Note: quadrat number and shape will affect measurement estimate. Suffers from MAUP.



Kernel Density (local)

Point density is calculated within sliding windows (window size = kernel)

Note: kernel will affect measurement estimate, but this is less susceptible to MAUP.



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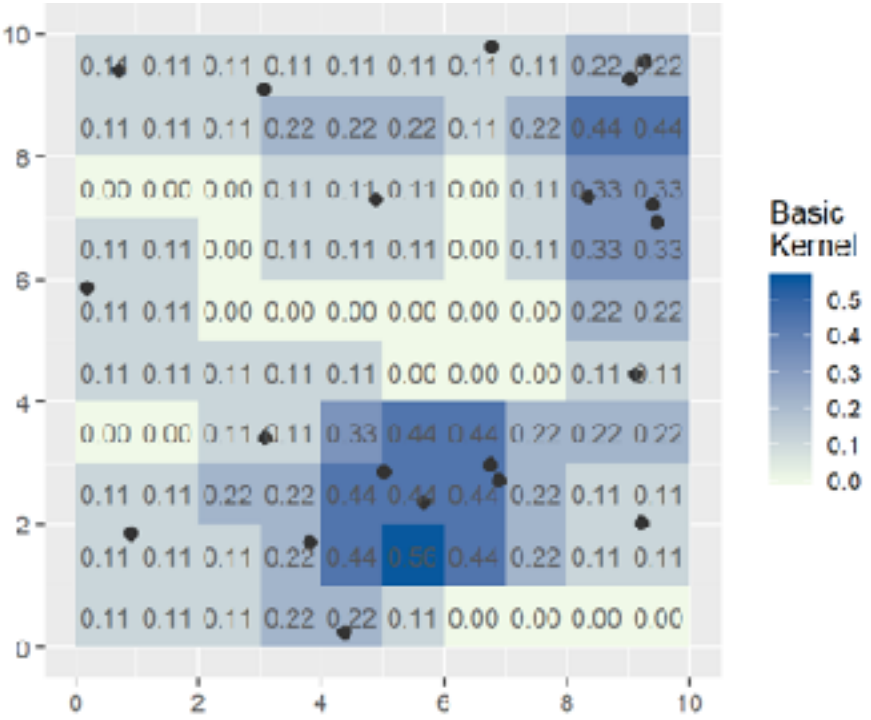


Modeling these data: Poisson Point Process

(Density-based Methods - - how the points are distributed relative to the study space)

$$\lambda(i) = e^{\alpha+\beta Z(i)}$$

λ(i) is the modeled intensity at location *i*

e^{α} is the base intensity when the covariate is *zero*

e^{β} is the multiplier by which the intensity increases (or decreases) for each 1 unit increase in the covariate

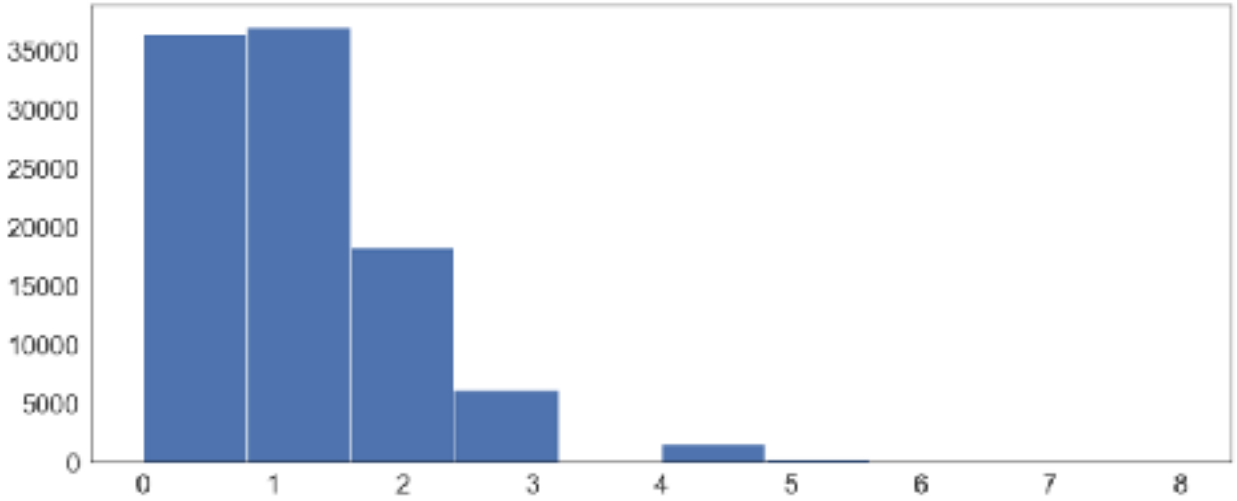
Poisson Distribution

The Poisson Distribution models events in fixed intervals of time, given a known average rate (and independent occurences).

In [55]:

Slide Type: Fragment

```
dat = poisson.rvs(mu=1, size=100000)
plt.hist(dat);
```

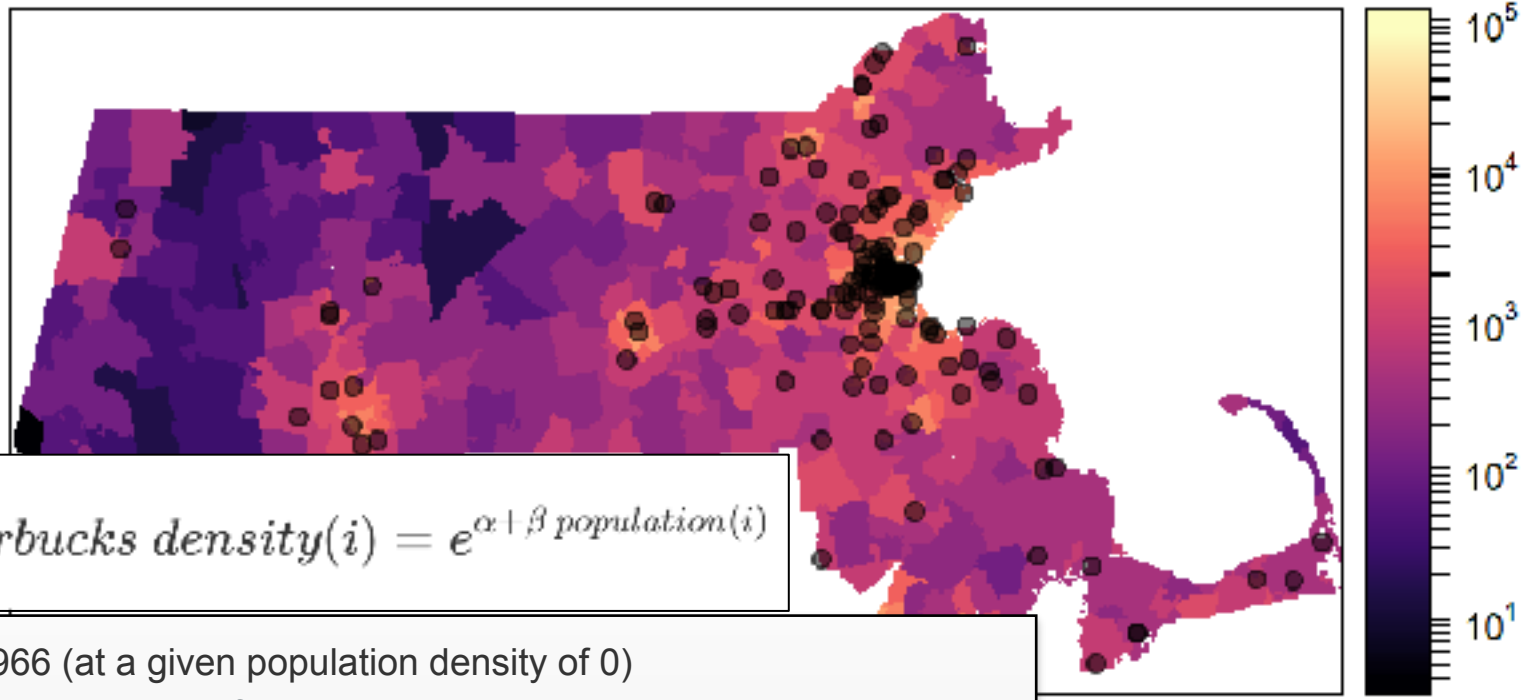


Slide Type: Fragment

The **number of visitors a fast food drive-through gets each minute** follows a Poisson distribution. In this case, maybe the average is 3, but there's some variability around that number.

A Poisson distribution can help calculate the probability of various events related to customers going through the drive-through at a restaurant. It will predict lulls (0 customers) and flurry of activity (5+ customers), allowing staff to plan and schedule more precisely.

Location of Starbucks relative to population density in MA



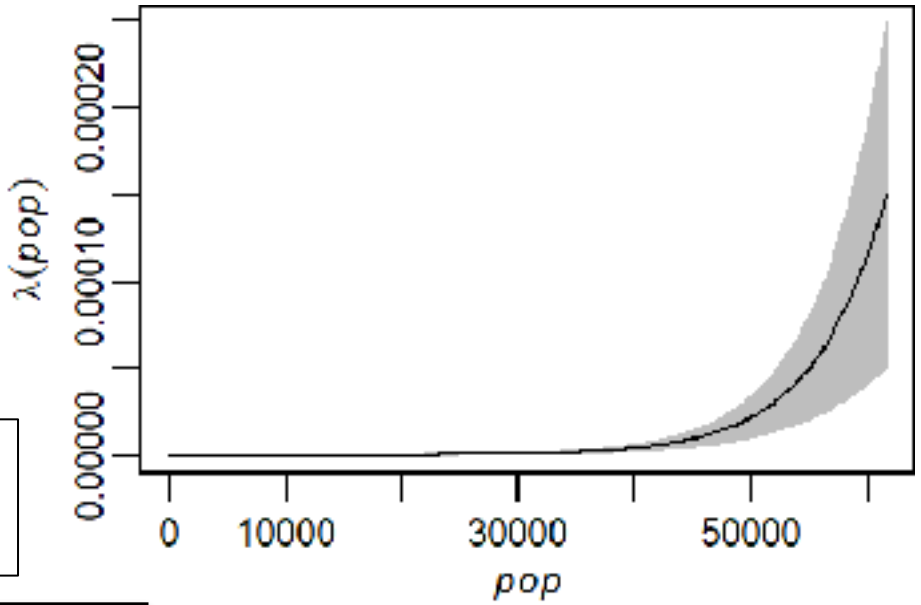
$$Starbucks\ density(i) = e^{\alpha + \beta\ population(i)}$$

α = -18.966 (at a given population density of 0)

$e^{-18.966}$ = 5.80 x 10^{-9} cafes per square meter

β = 0.00017; $e^{0.00017}$ or 1.00017

Location of Starbucks relative to population density in MA



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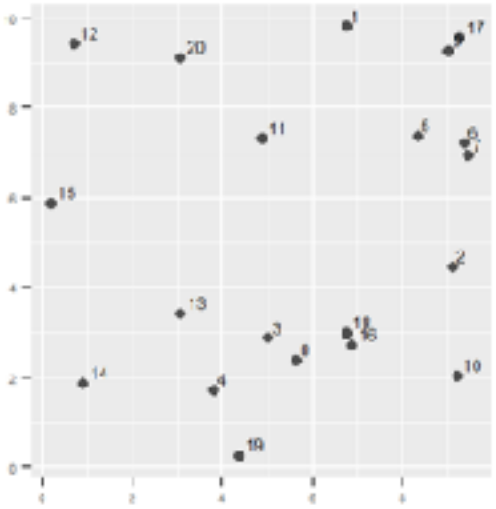
Modeling these data: Average Nearest Neighbor

(Distance-based Methods - how the points are distributed relative to one another)



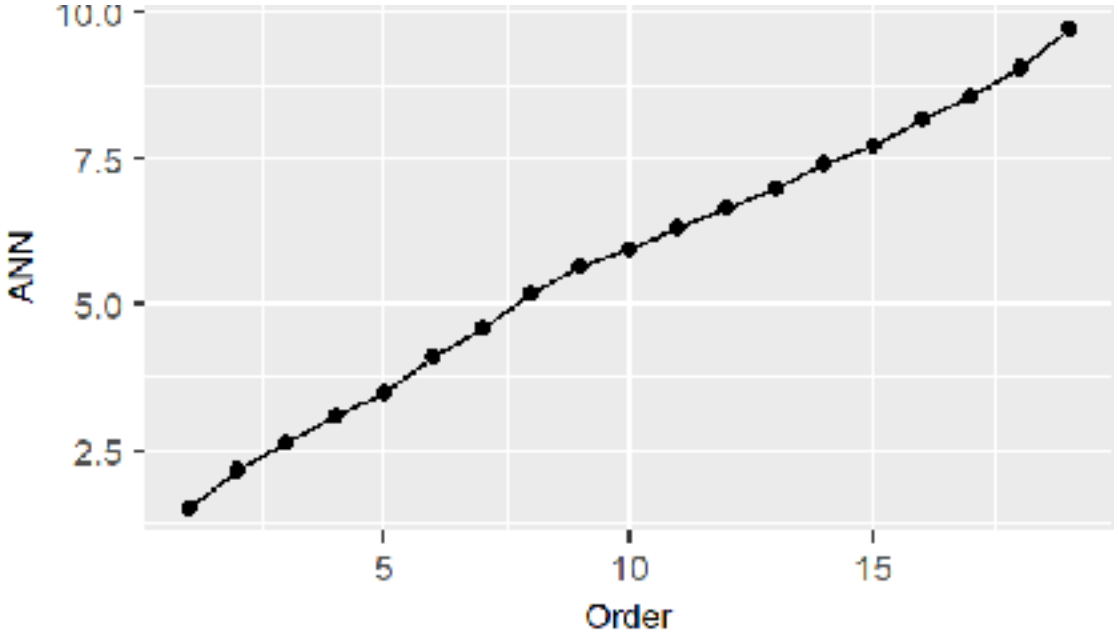
From	To	Distance	From	To	Distance
1	9	2.32	11	20	2.55
2	10	2.43	12	20	2.39
3	8	0.81	13	4	1.85
4	19	1.56	14	13	2.67
5	6	1.05	15	12	3.58
6	7	0.3	16	18	0.29
7	6	0.3	17	9	0.37
8	3	0.81	18	16	0.29
9	17	0.37	19	4	1.56
10	2	2.43	20	12	2.39

ANN = 1.52 units

Modeling these data: Average Nearest Neighbor

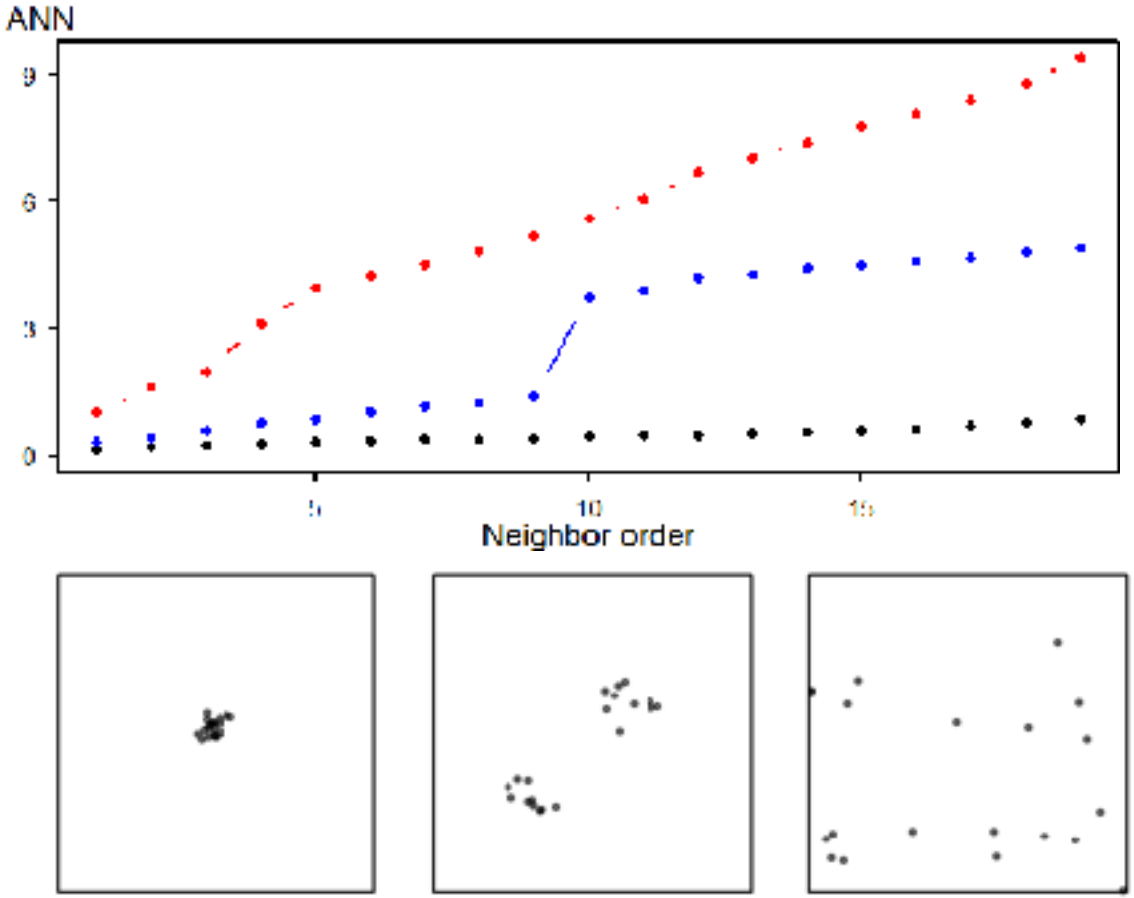
(Distance-based Methods - how the points are distributed relative to one another)

plot the ANN values for different order neighbors, that is for the first closest point, then the second closest point, and so forth.

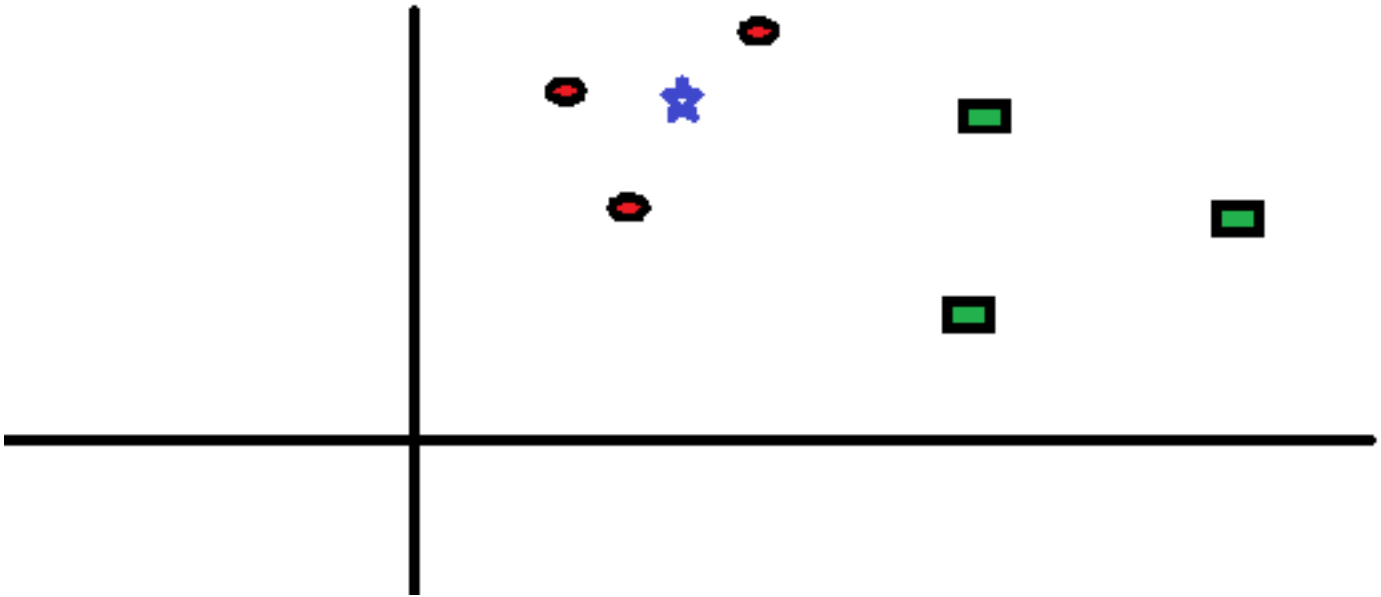


ANN vs neighbor order offers insight into underlying spatial relationship

Note: study space definition affects this measure

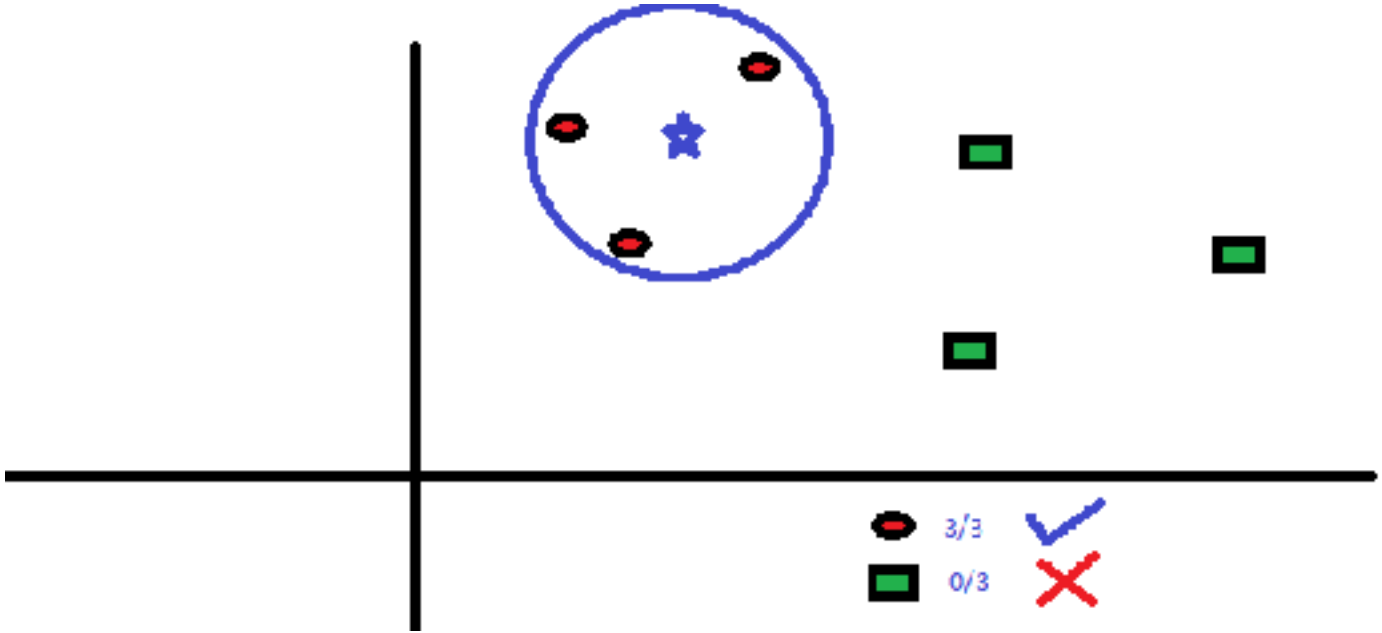


KNN: K Nearest Neighbor for Classification



https://www.analyticsvidhya.com/blog/2018/03/introduction-k-neighbours-algorithm-clustering/

KNN: To which class does the blue star belong?

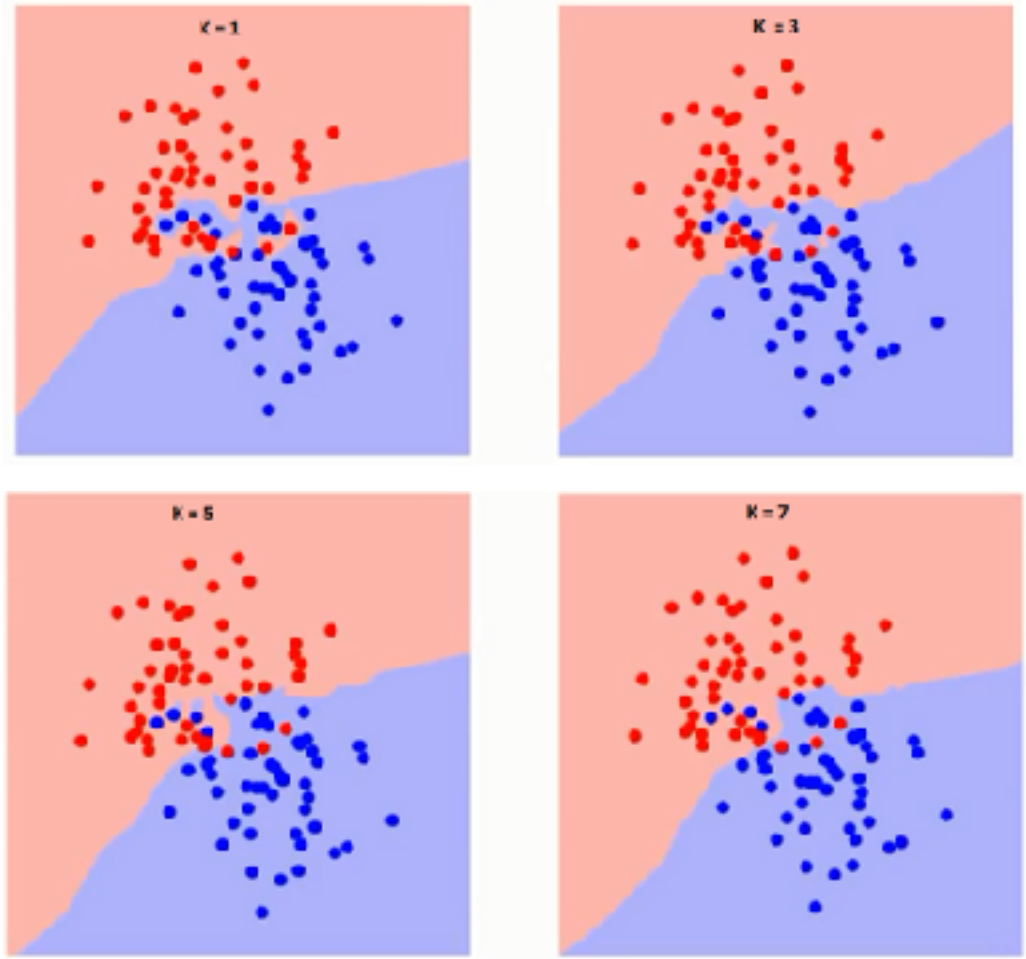


https://www.analyticsvidhya.com/blog/2018/03/introduction-k-neighbours-algorithm-clustering/

KNN: Choosing K

K specifies how many neighbors to consider.

Note that as more neighbors are considered, the boundary smooths out.



https://www.analyticsvidhya.com/blog/2018/03/introduction-k-neighbours-algorithm-clustering/

KNN: Pros & Cons

Pros:

- No assumptions about data (good for nonlinear)
- Simple and interpretable
- Relatively high accuracy
- Versatile (classification & regression)

Cons:

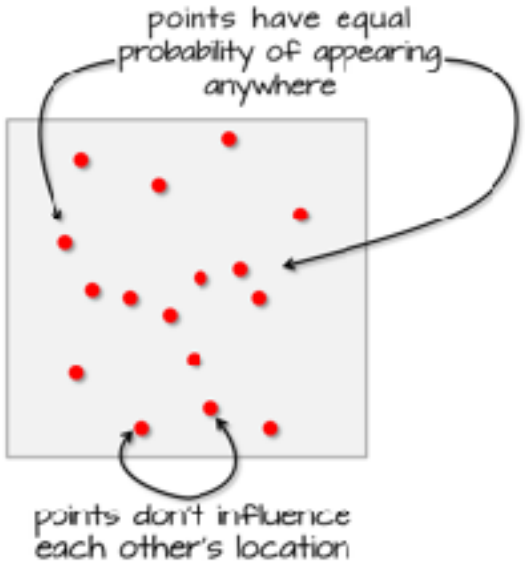
- Computationally intensive
- High Memory requirements
- Stores all (or most) of training data
- Prediction slow with large N
- Sensitive to outliers/irrelevant features

https://blog.usejournal.com/a-quick-introduction-to-k-nearest-neighbors-algorithm-62214cea29c7

Hypothesis Testing: CSR/IPR

(Distance-based Methods - how the points are distributed relative to one another)

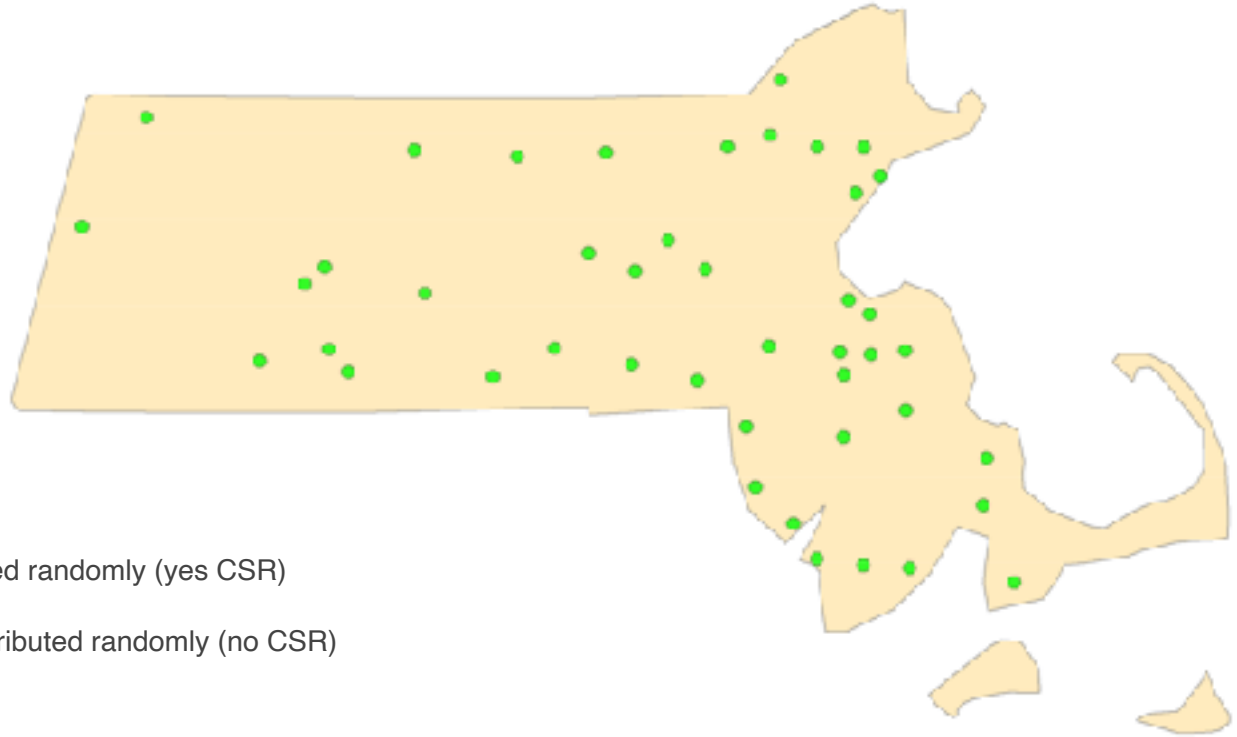
Compare observed point patterns to ones generated by an independent random process (IRP), aka complete spatial randomness (CSR).



CSR/IRP satisfy two conditions:

1. Any event has equal probability of being in any location, a 1st order effect.
2. The location of one event is independent of the location of another event, a 2nd order effect

Is this distribution of Walmarts in MA the result of CSR?



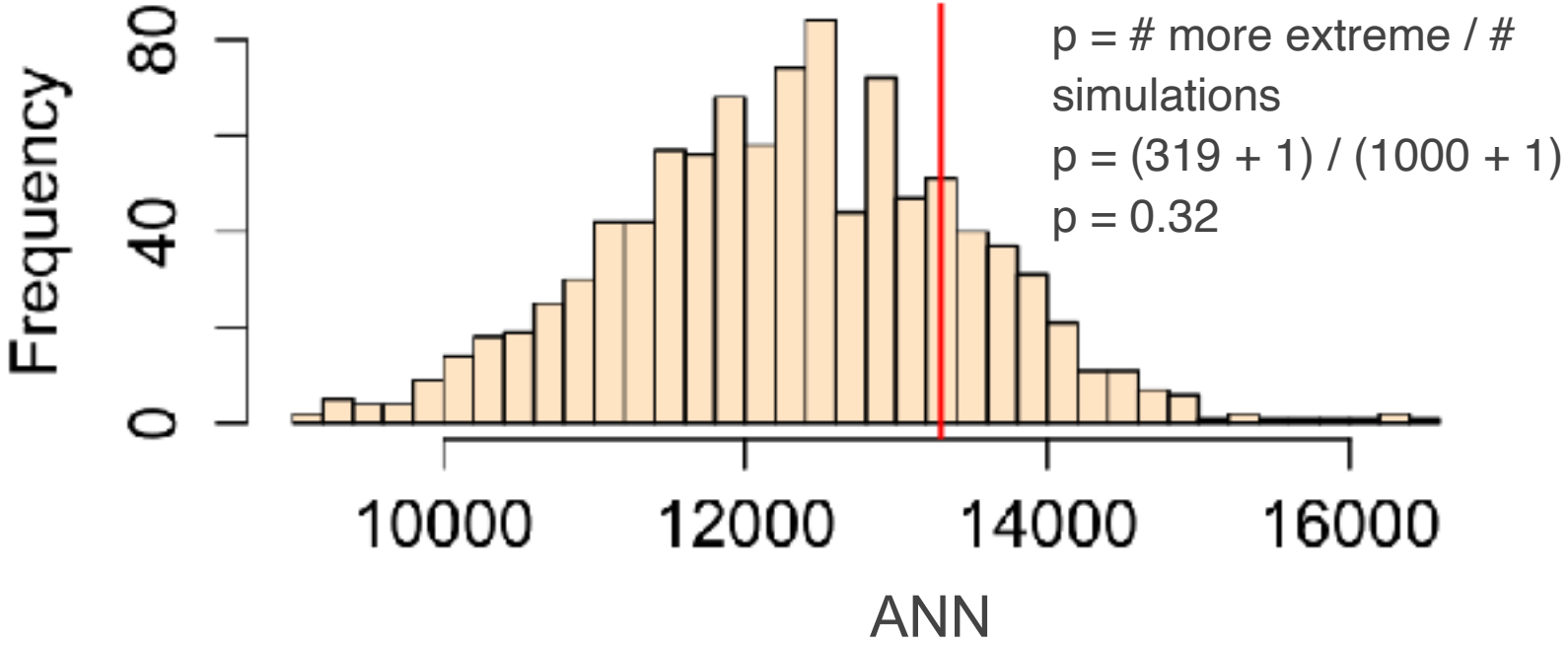
H_o: Distributed randomly (yes CSR)

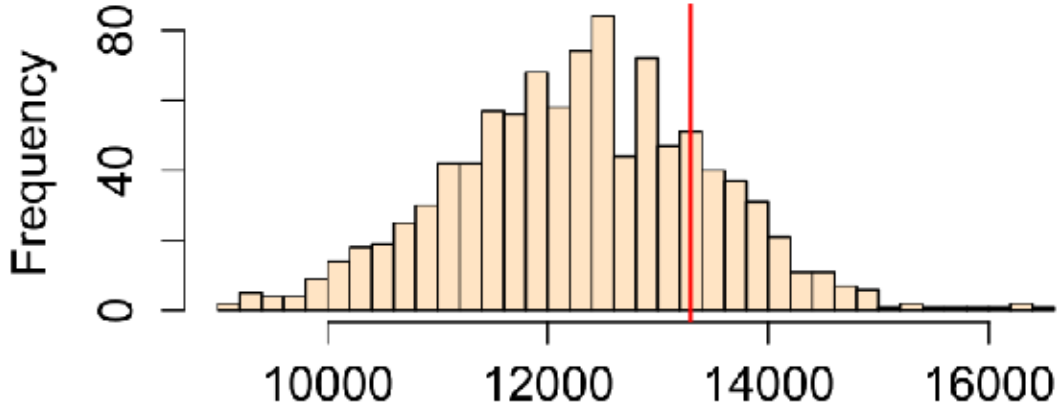
H_a: NOT distributed randomly (no CSR)

1. First, we postulate a process–our null hypothesis, H_o.

   For example, we hypothesize that the distribution of Walmart stores is consistent with a completely random process (CSR).
2. Next, we simulate many realizations of our postulated process and compute a statistic (e.g. ANN) for each realization.
3. Finally, we compare our observed data to the patterns generated by our simulated processes and assess (via a measure of probability) if our pattern is a likely realization of the hypothesized process.

This is an example of bootstrapping!


Frequency
0
40
80
10000
12000
14000
16000
ANN
p = # more extreme / # simulations
p = (319 + 1) / (1000 + 1)
p = 0.32



What does the histogram represent in this image?

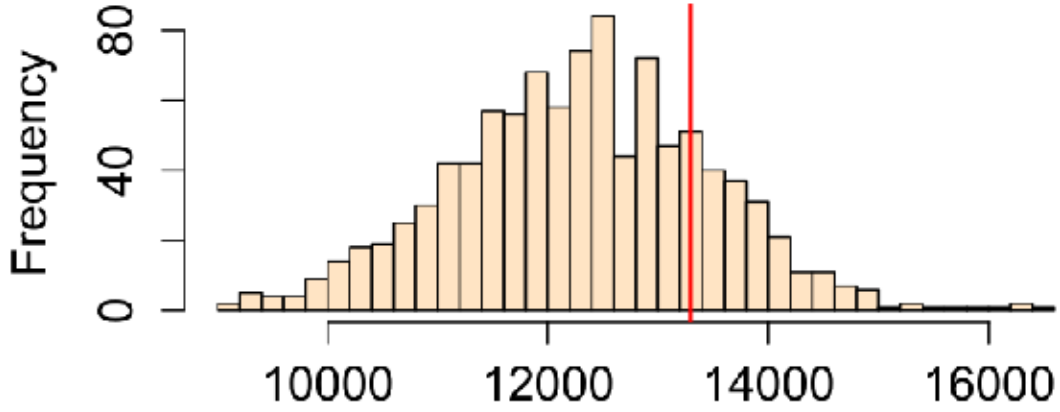
A
Alternative Hypothesis

B
Null Hypothesis

C
Distribution of ANN generated under the null

D
Distribution of ANN generated under the alternative

E
I'm lost



What does the red line represent?

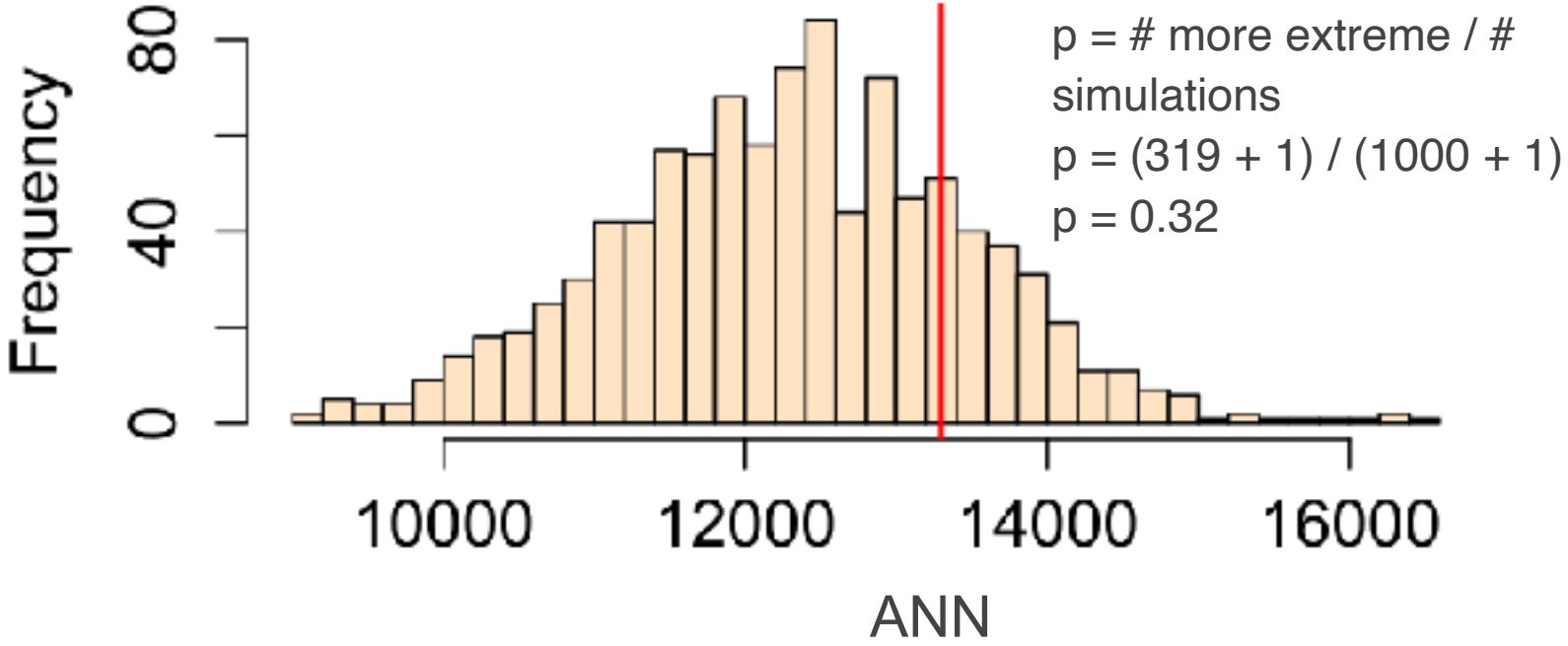
A
The observed data

B
The hypothetical data

C
The null distribution

D
The alternative distribution

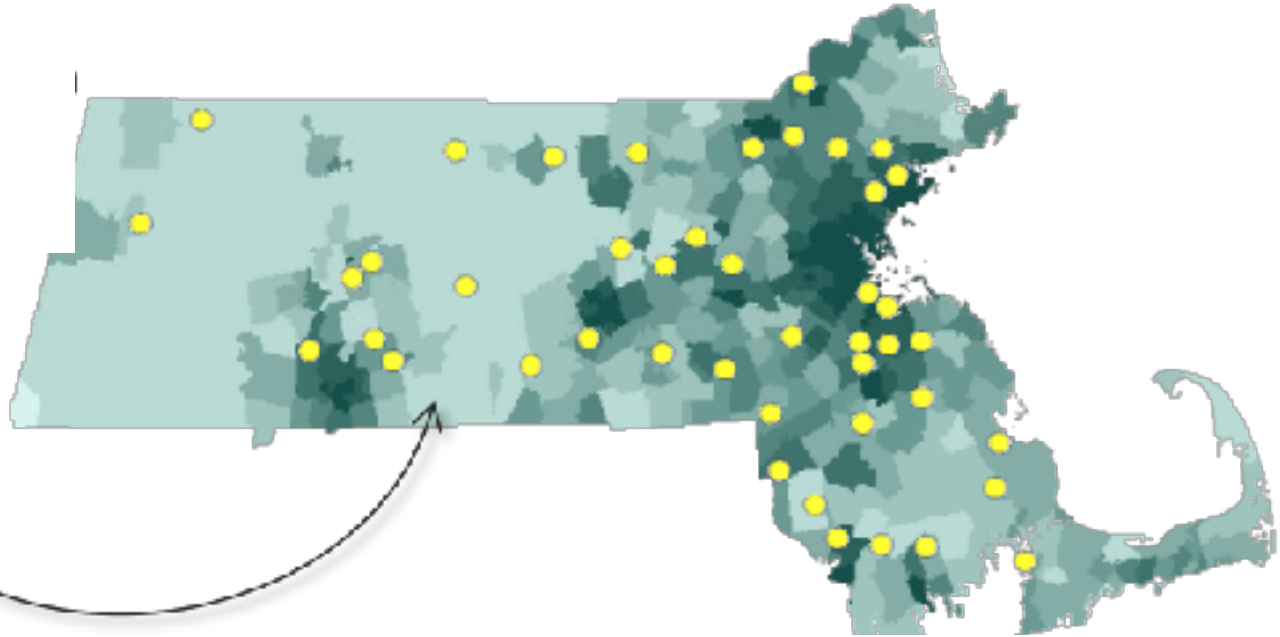
E
I'm lost



Fail to reject the null

Suggests that our results come from a CSR

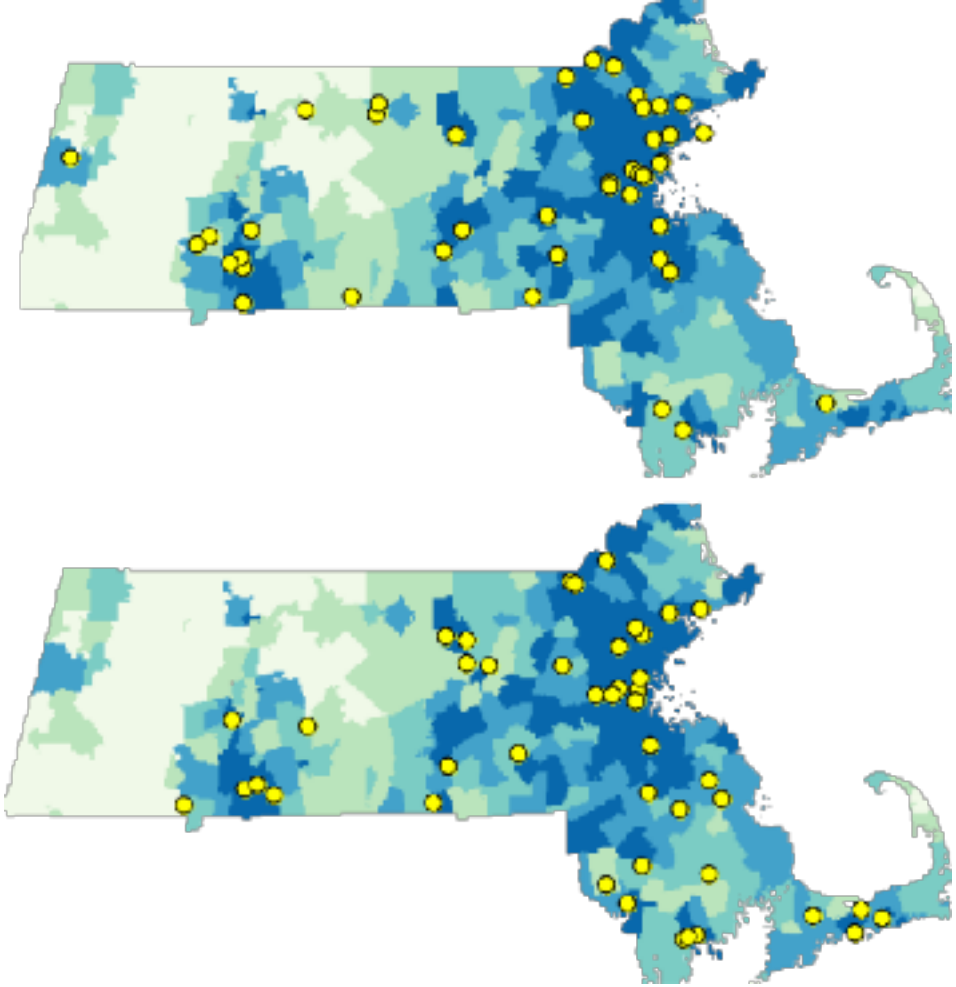
When controlling for population density, are Walmarts randomly distributed?



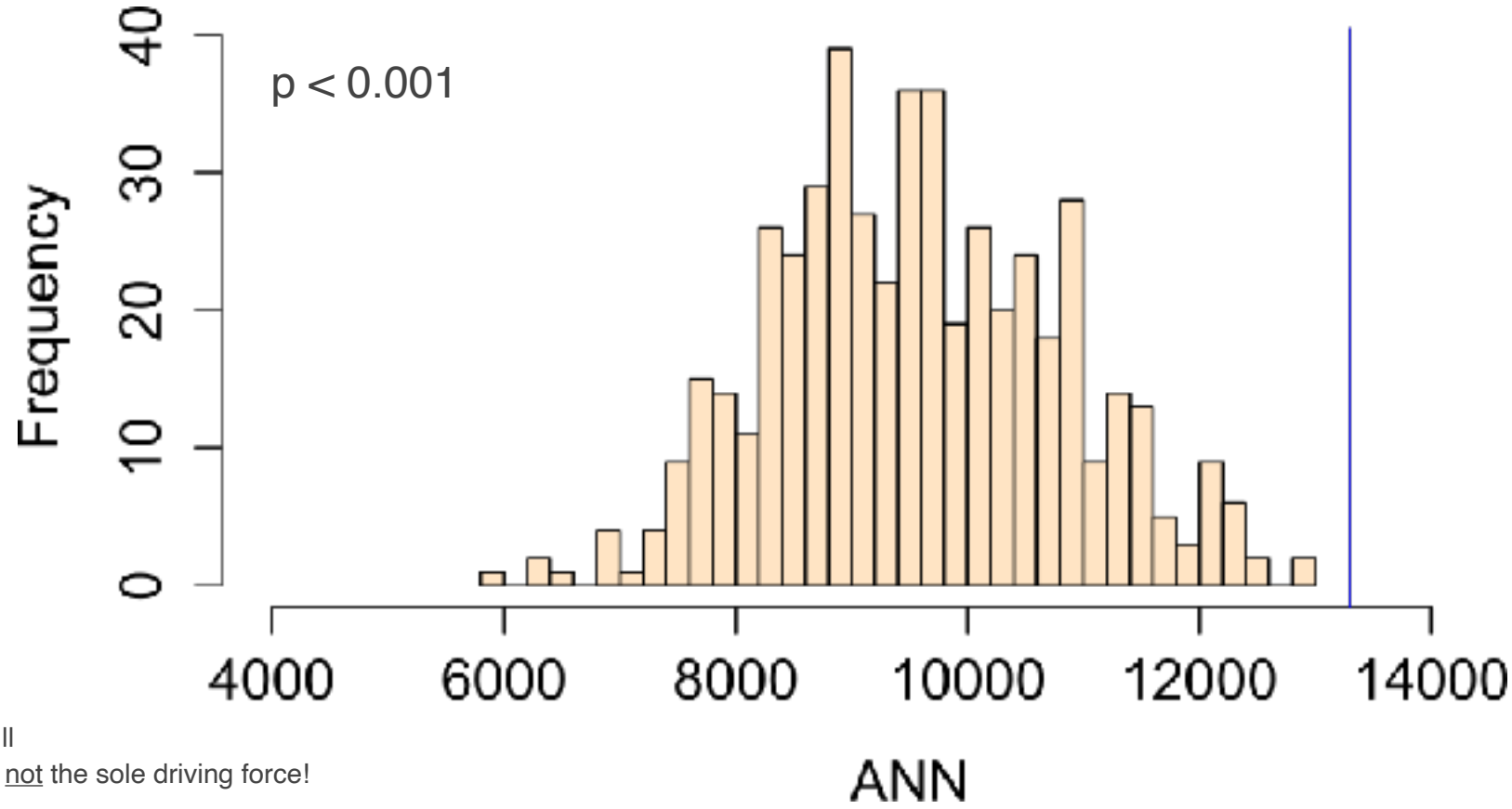
H_o: Walmarts are distributed according to population density alone

H_a: Walmarts are *not* distributed based on population density alone

two randomly generated point patterns using population density as the underlying process



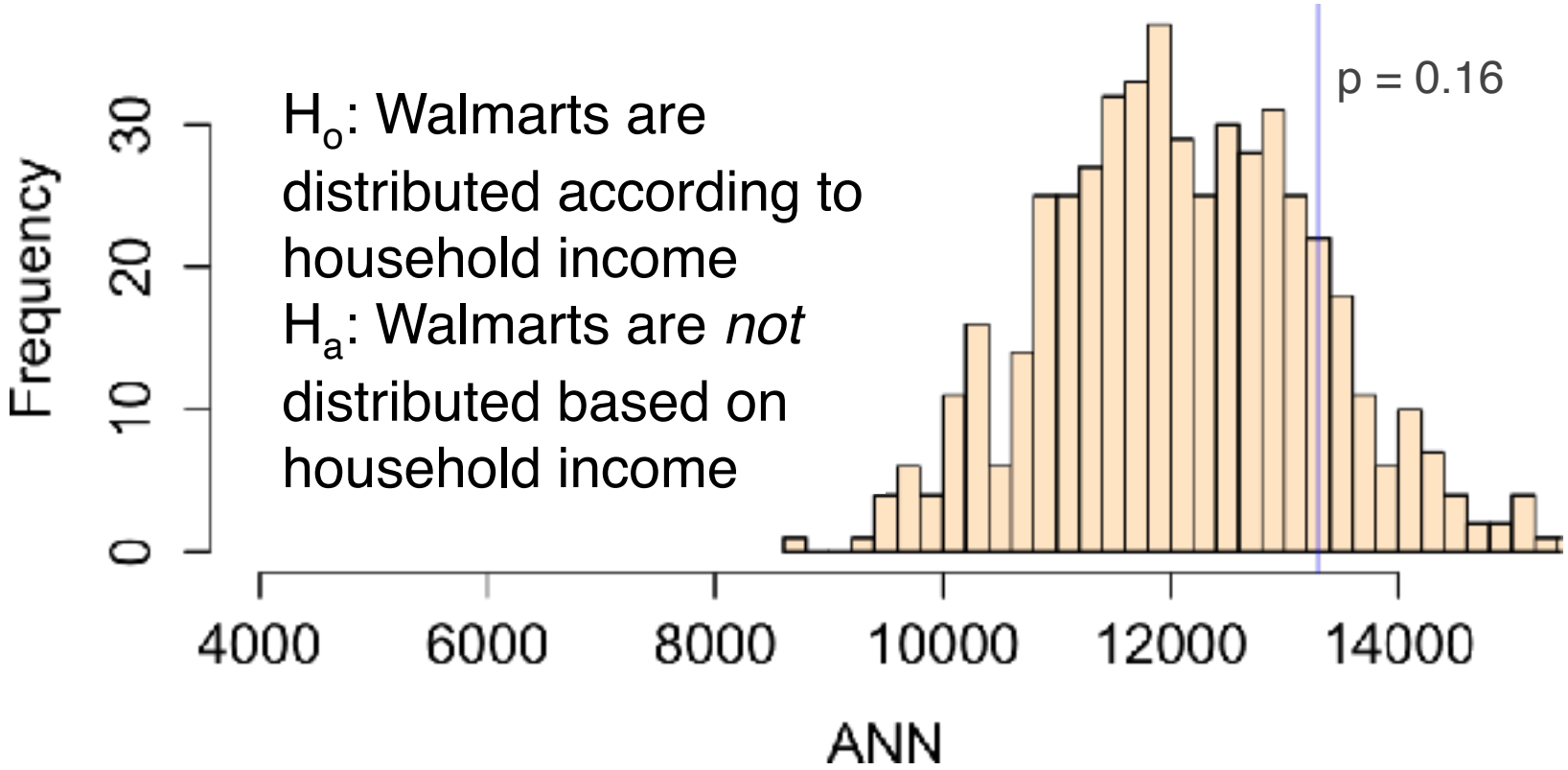
https://mgimond.github.io/Spatial/introGIS.html



Reject the null

Population is not the sole driving force!

Maybe median household income is the driving force…?



...Is it CSR or median household income?

hints at plausible scenarios, but doesn’t tell us which one it is definitively.

Basic Geospatial Analysis: Summary

1. Considerations when visualizing spatial data important to conclusions drawn
    a. values to plot?
    b. map type?
    c. color scale?
2. Traditional statistics fail with geospatial data:
    a. Spatial autocorrelation
    b. MAUP
    c. Edge effects
    d. Ecological fallacy
    e. Nonuniformity of space
3. Analysis still possible
    a. Global Point Density, Quadrat Density, Kernel Density
    b. Poisson Point Process
    c. K-Nearest Neighbor (KNN)
    d. Comparison to a CRP (using simulation)