

Surprise! Bayesian Weighting for De-Biasing Thematic Maps

Michael Correll

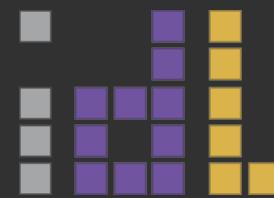
Jeffrey Heer

Surprise! Bayesian Weighting for De-Biasing Thematic Maps

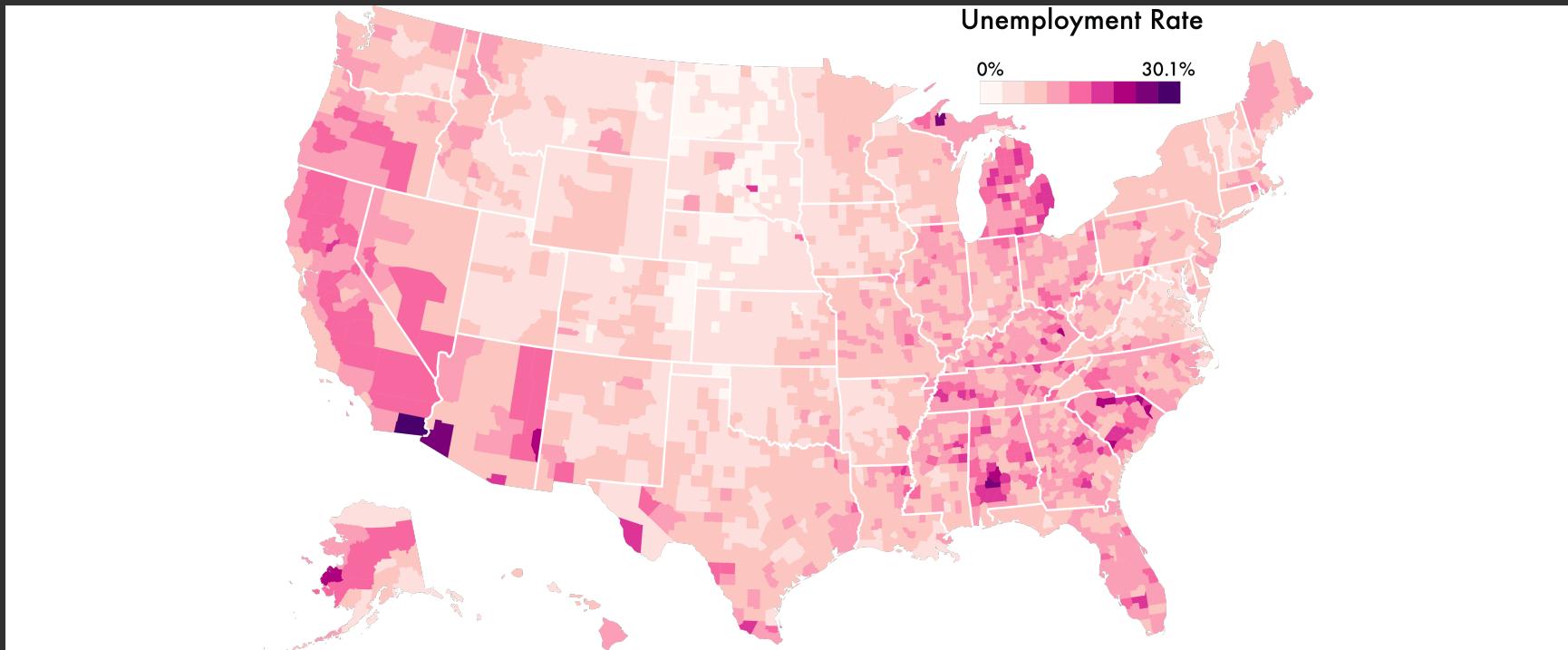


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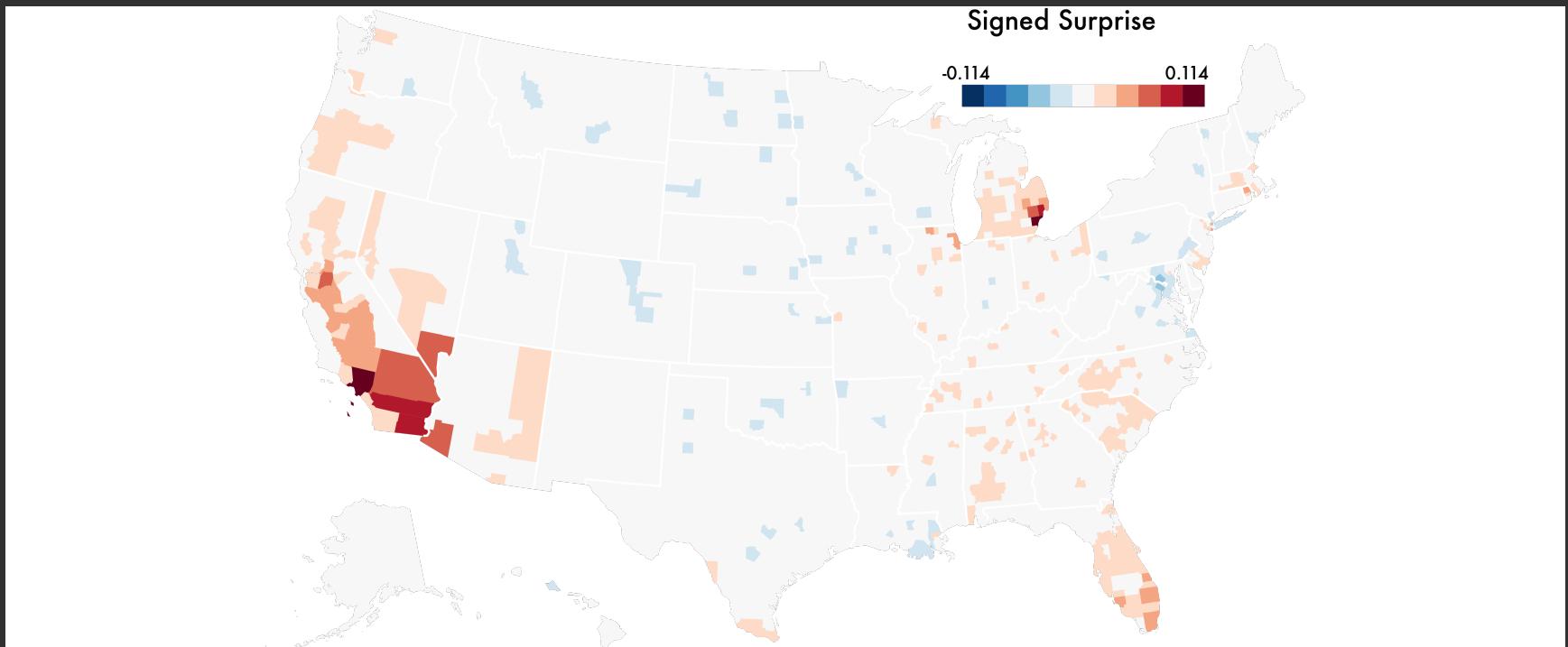
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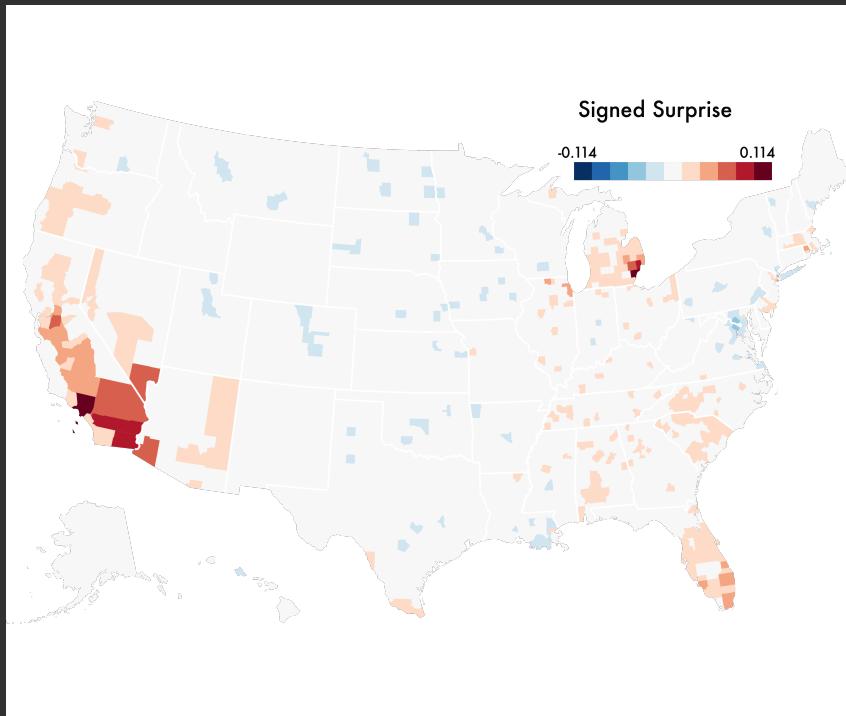
Thematic Map



Surprise Map!



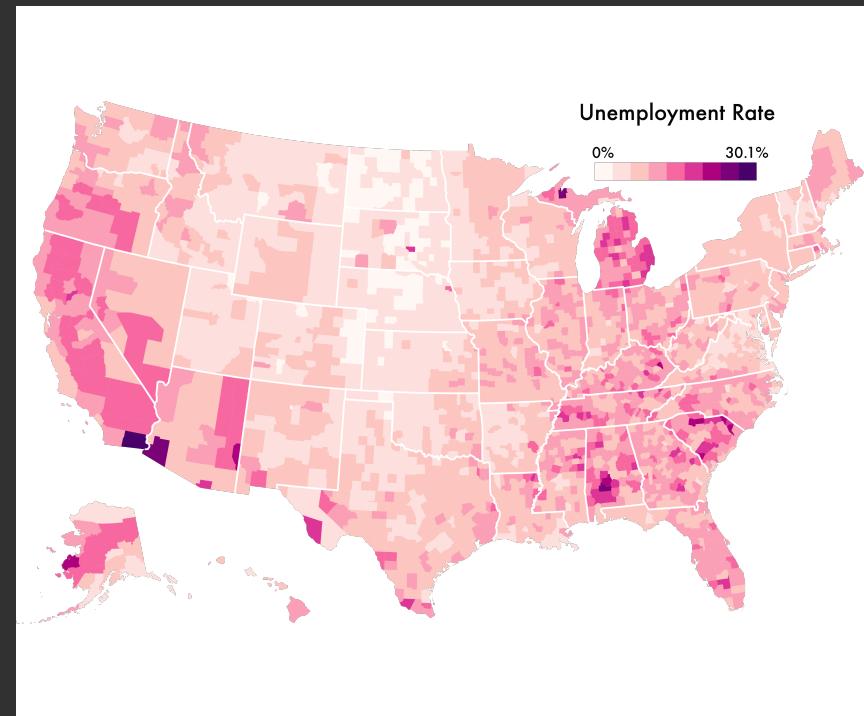
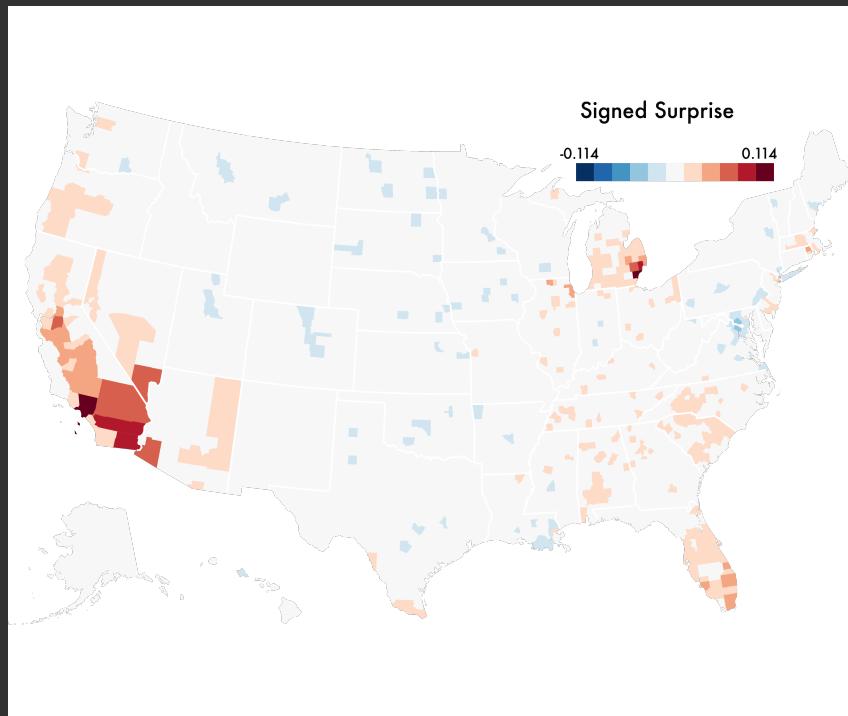
Surprise Map



Use models of **expectation** to highlight **surprising** data.

Visualize the **surprise**, not the value!

Surprise Map



Outline

What's Wrong With Heatmaps?

Bayesian Surprise

Surprise Maps

Outline

What's Wrong With Heatmaps?

Bayesian Surprise

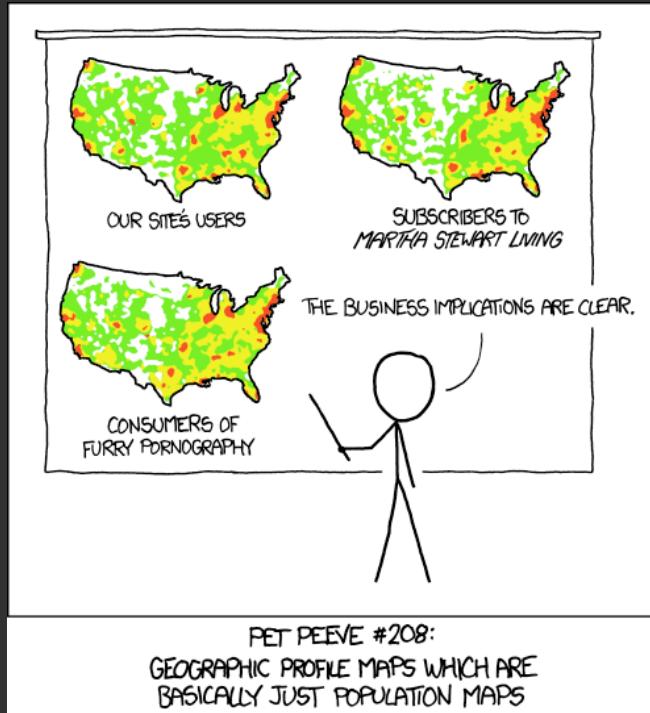
Surprise Maps

What's Wrong With Heatmaps?

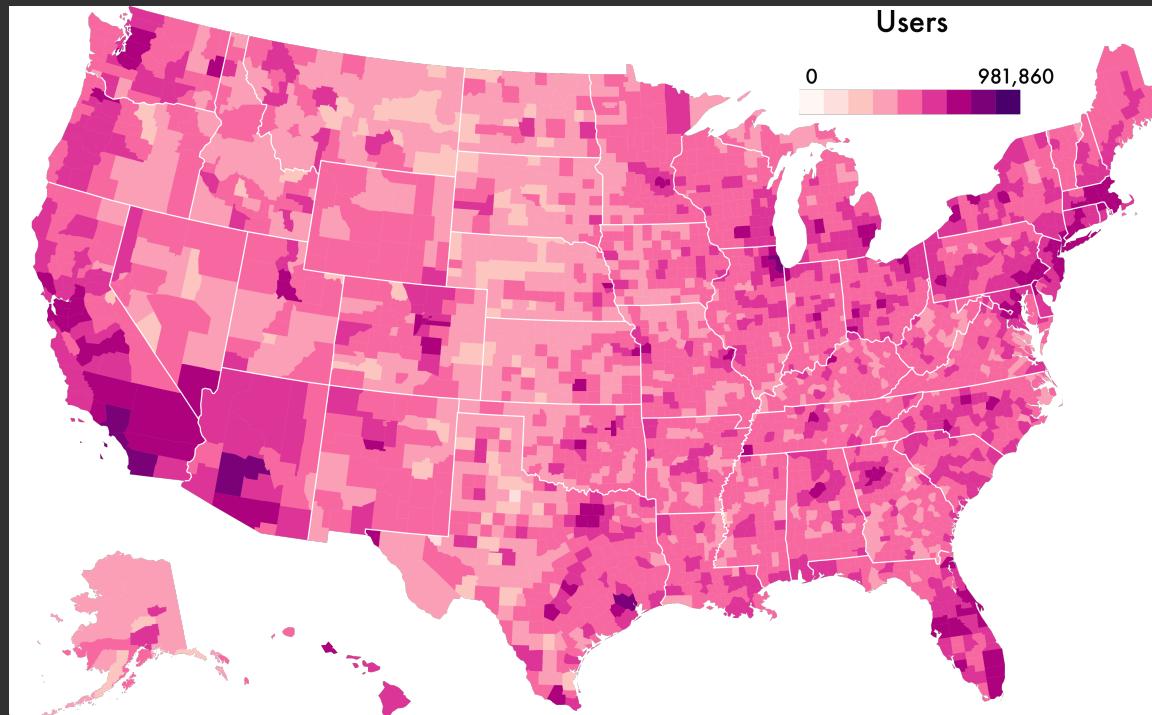
No accounting for **confounds**

No accounting for **variance**

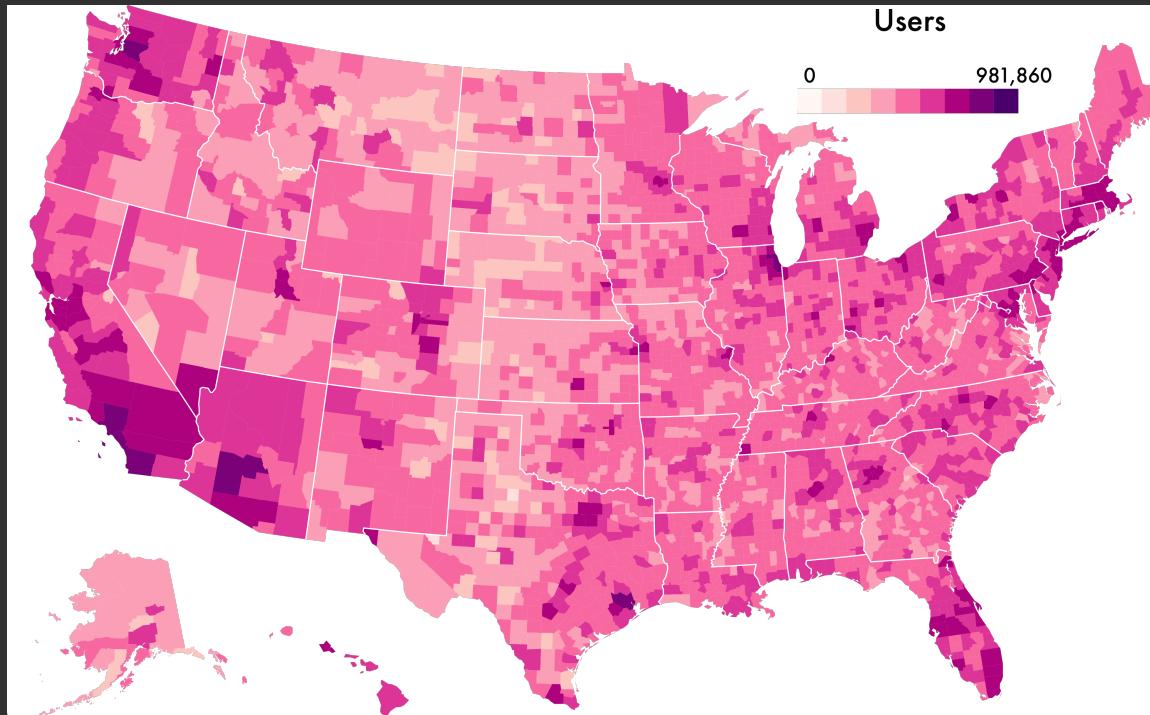
Confound



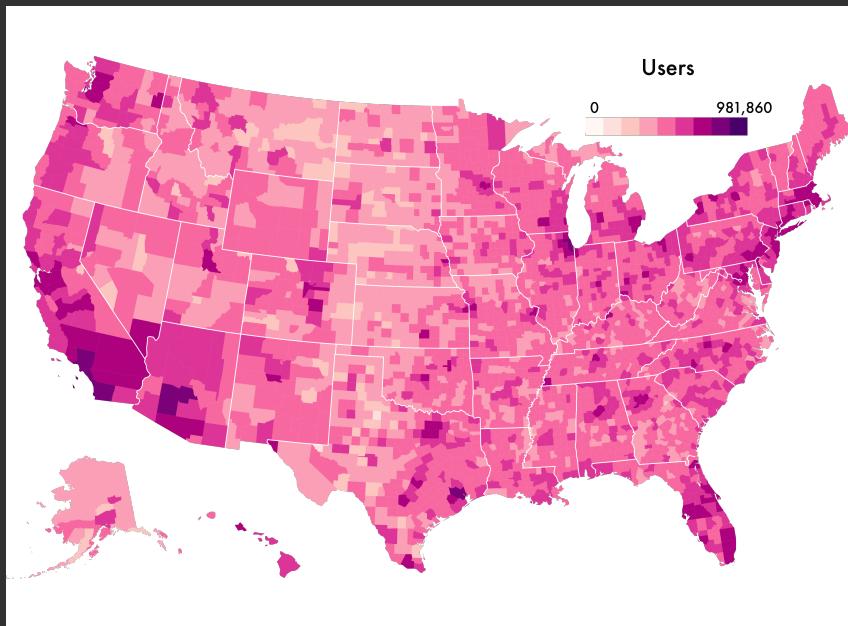
Where Do Our Users Live?



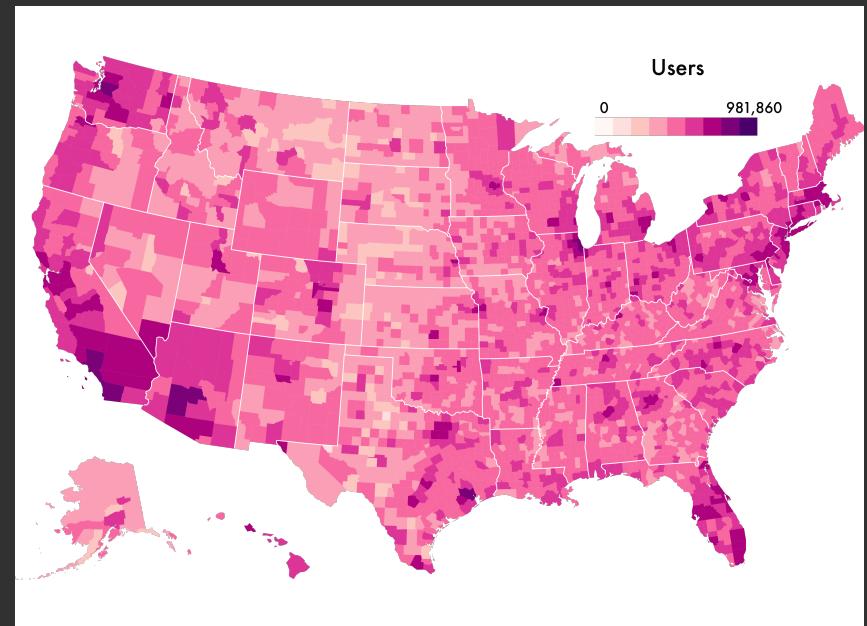
And Our Competitor's Users?



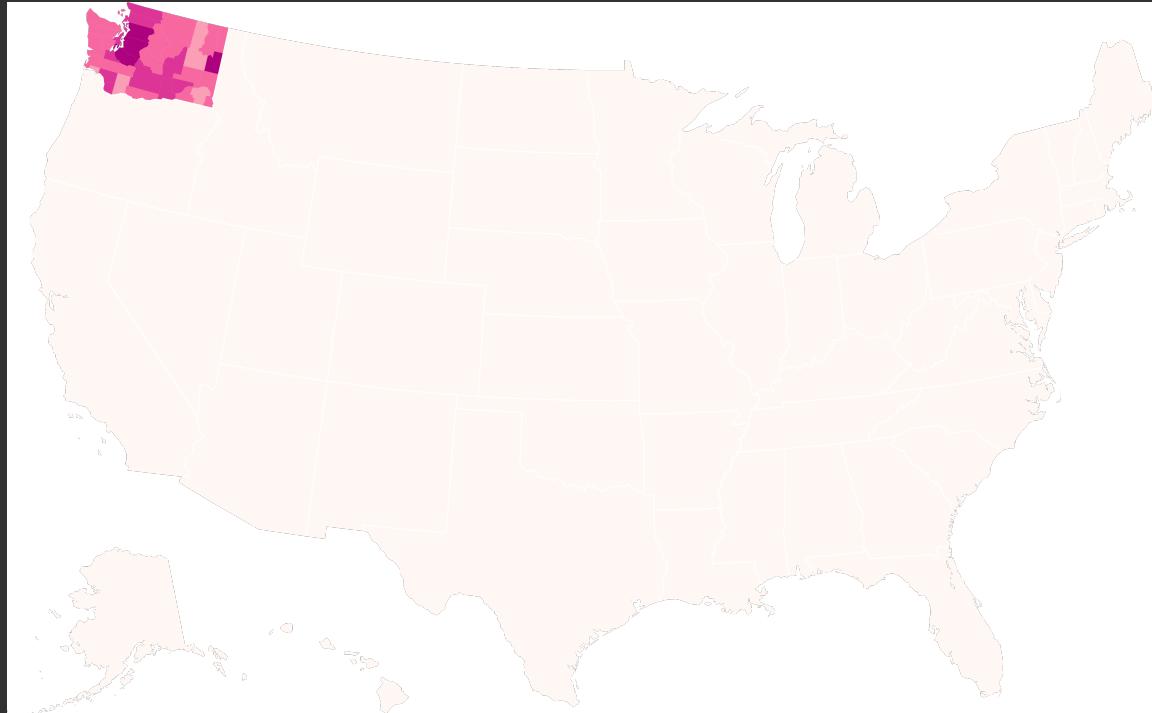
Users of Our App



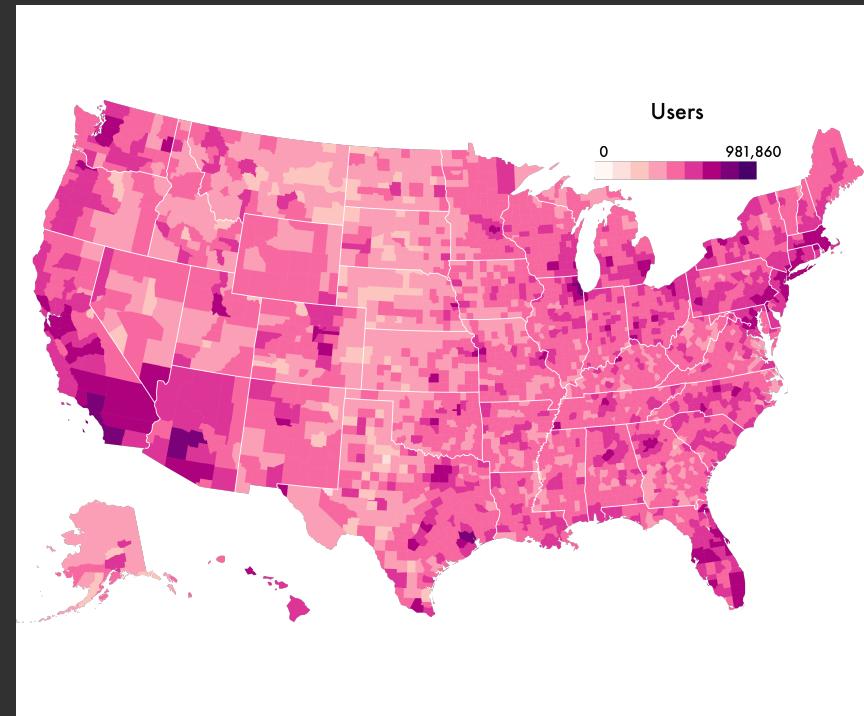
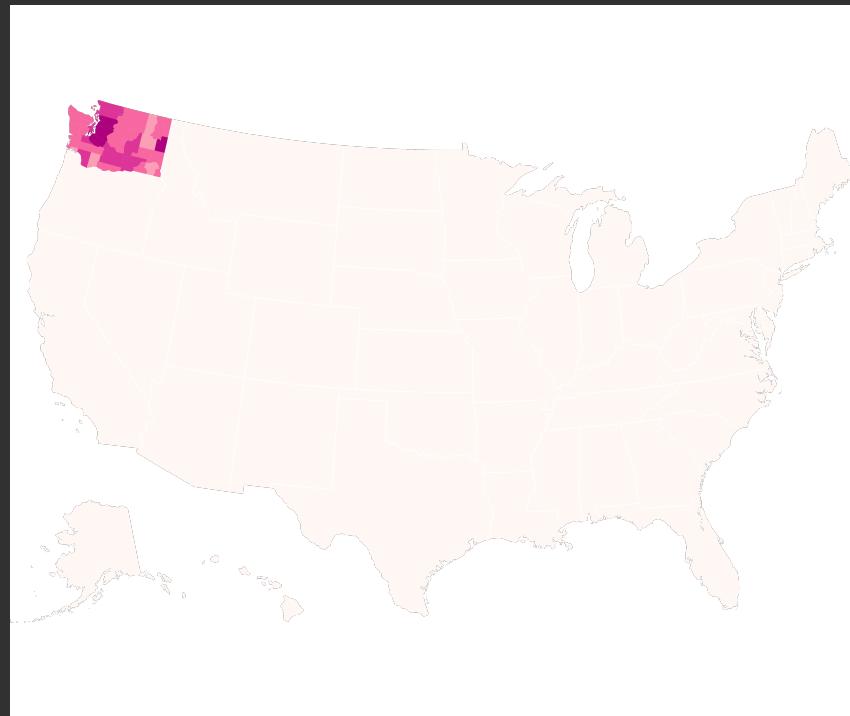
Users of Their App



Theirs-Ours



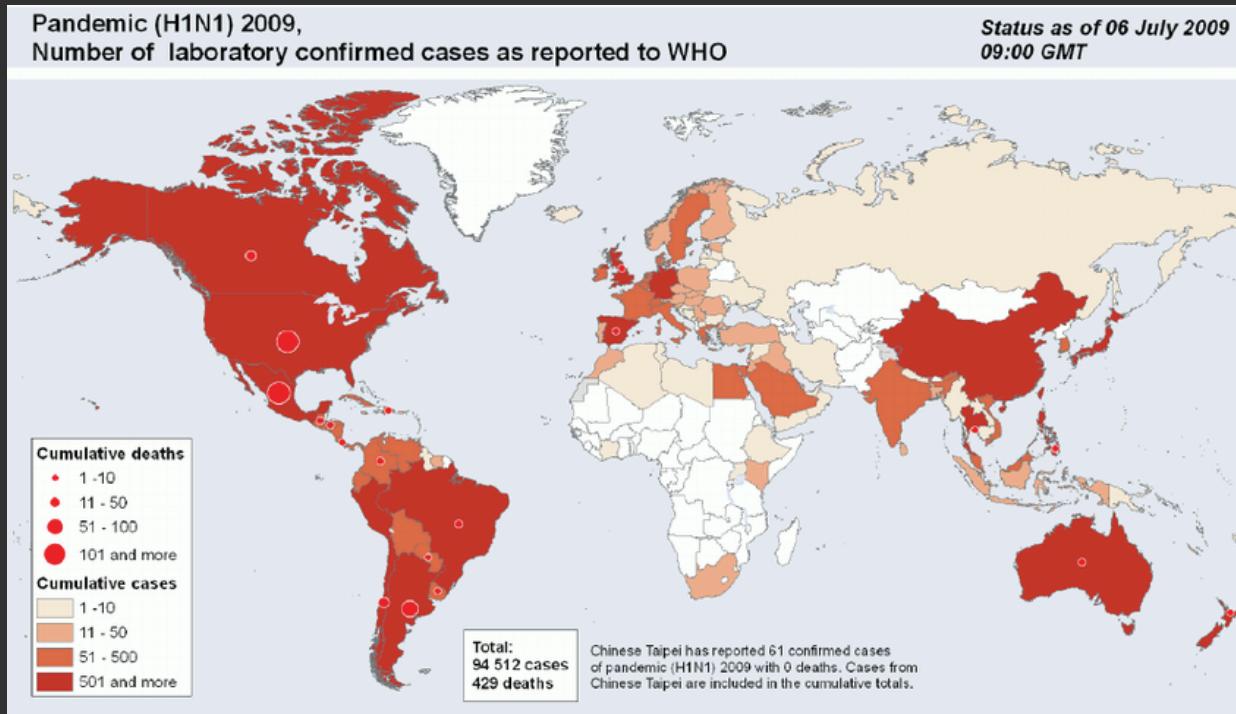
Theirs-Ours



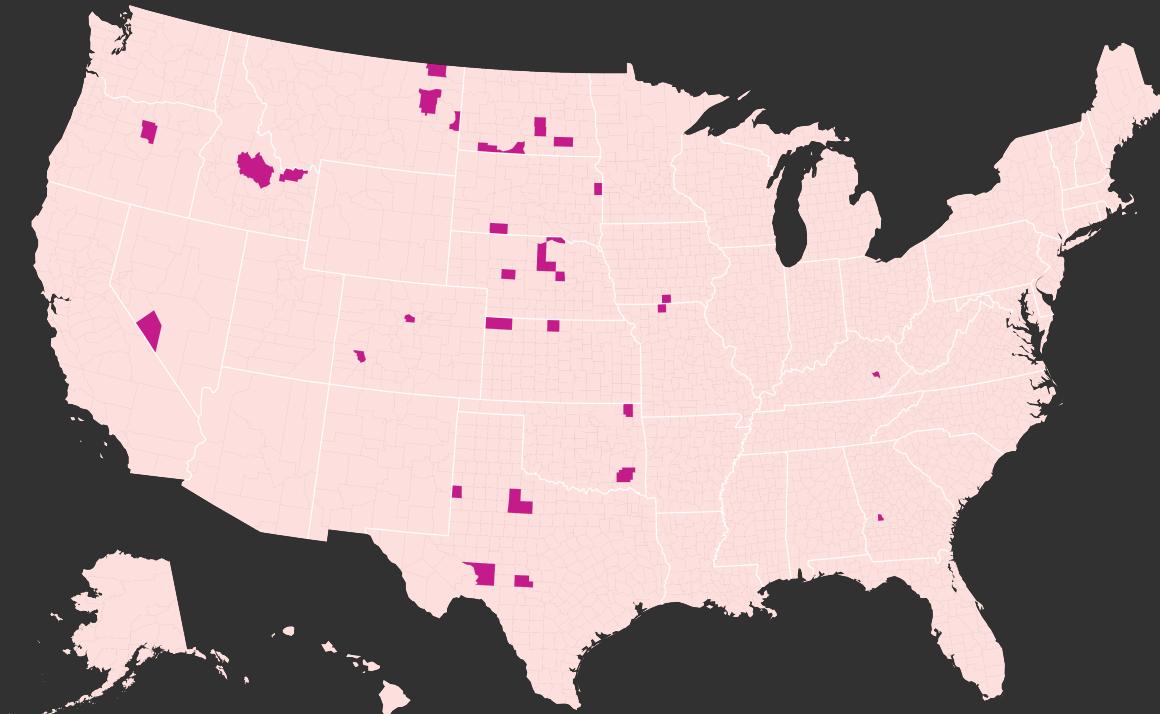




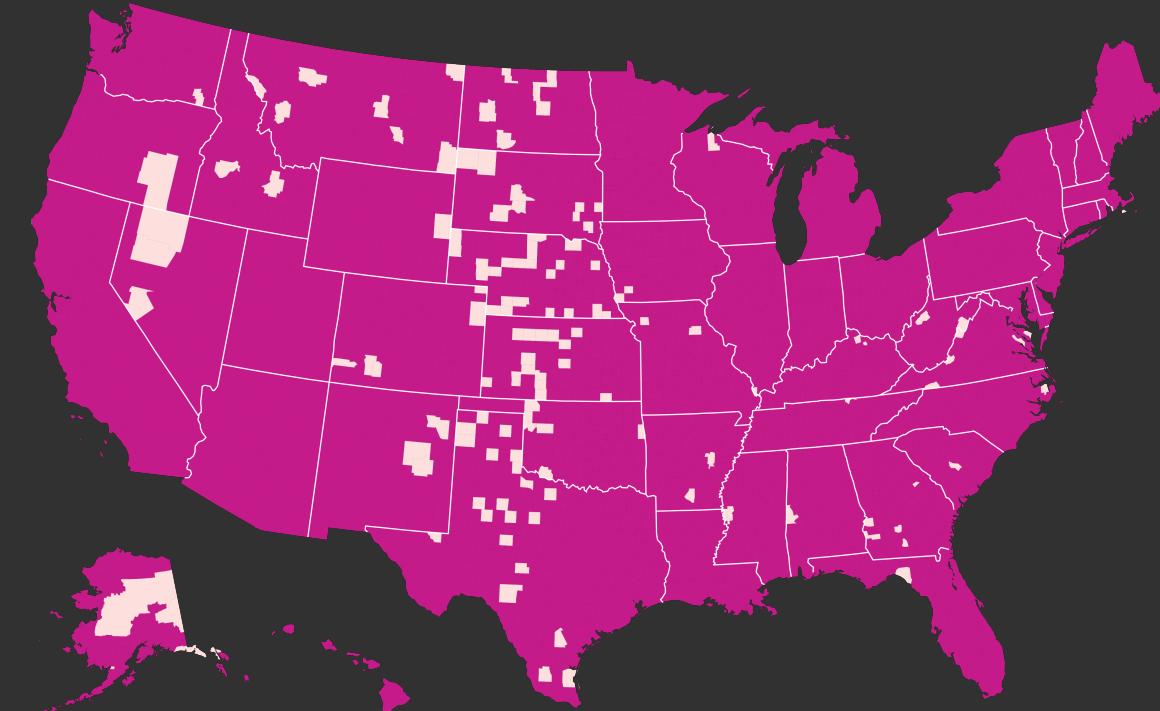
Variance



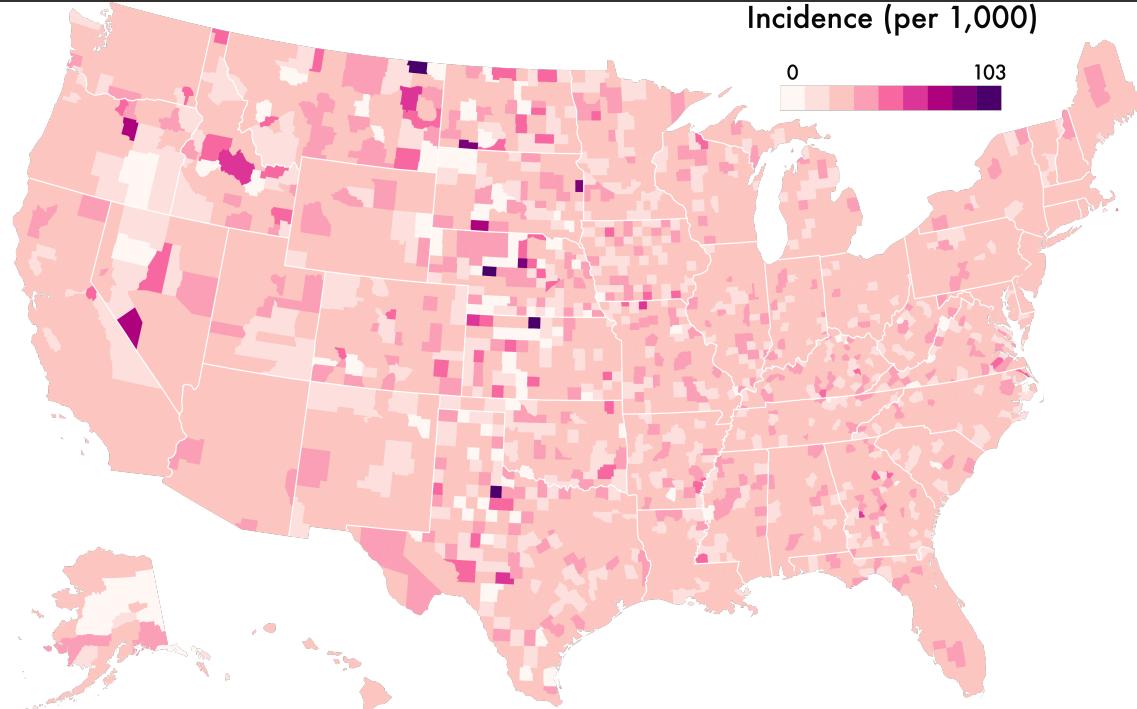
The dangerous counties?

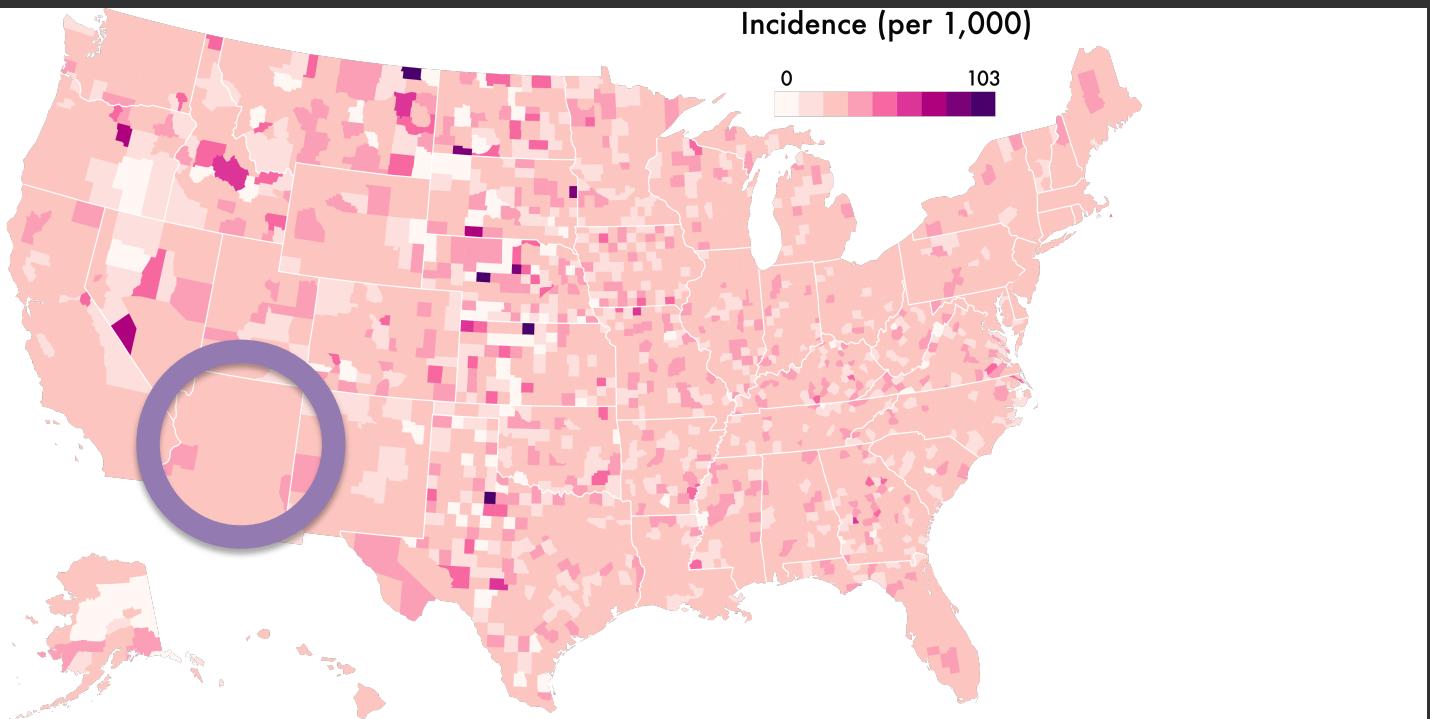


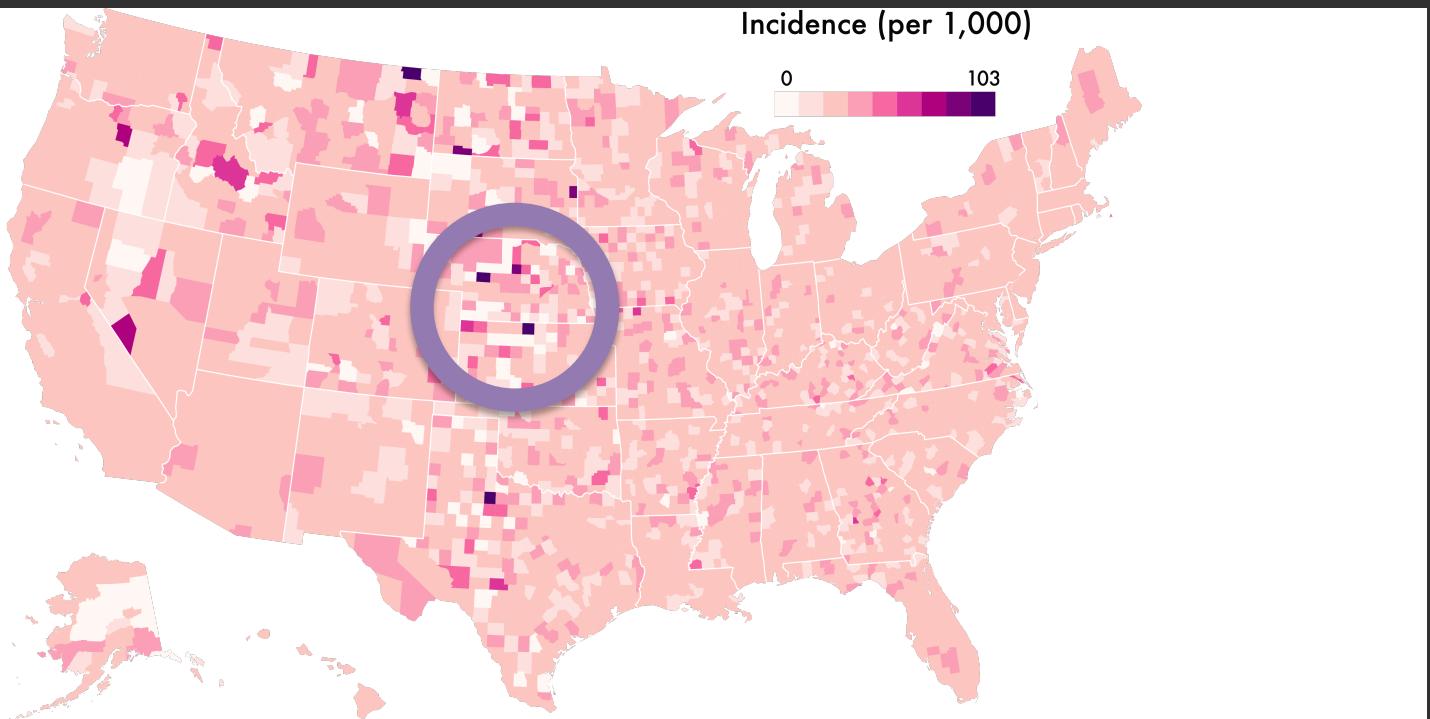
The safe counties?



Incidence (per 1,000)





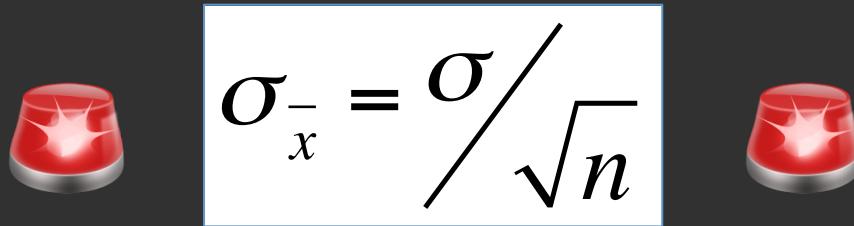


The Most Dangerous Equation

$$\sigma_x = \sigma / \sqrt{n}$$

The Most Dangerous Equation. Wainer, 2007.

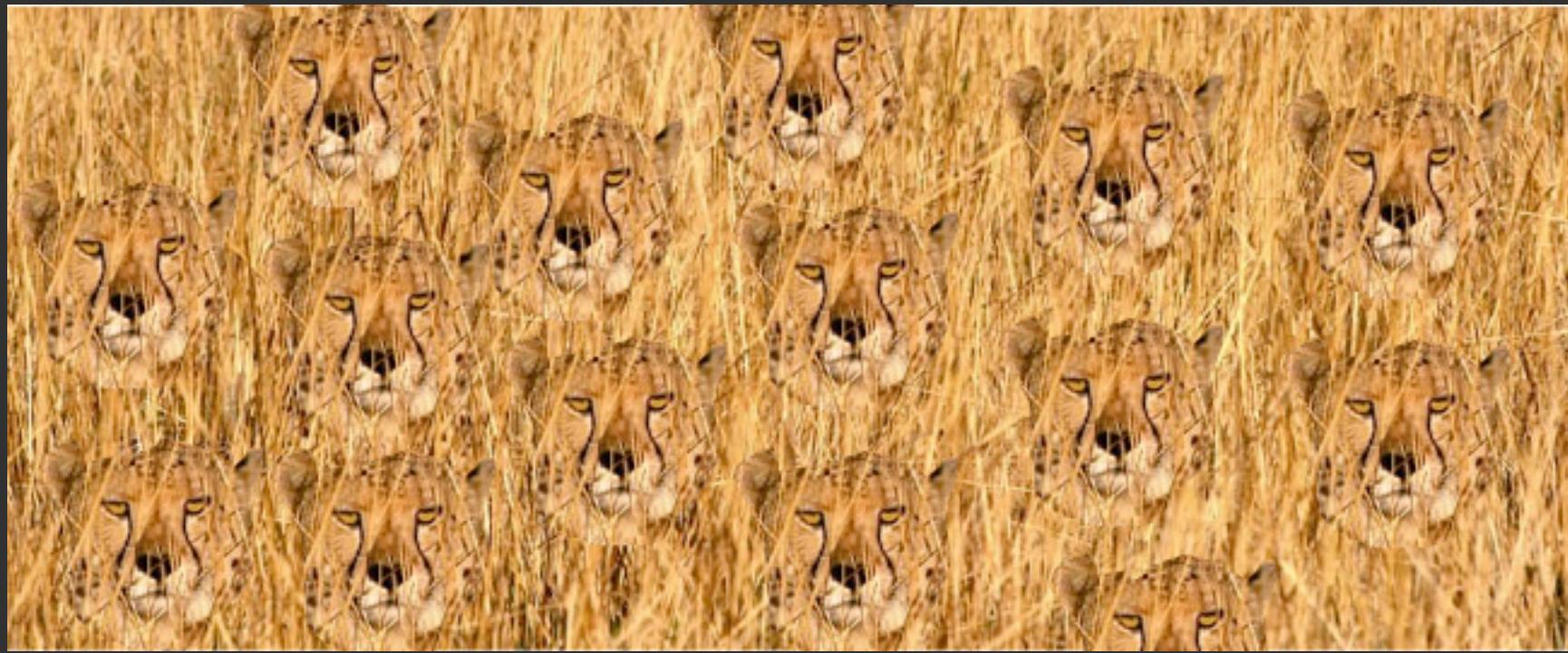
The Most Dangerous Equation


$$\sigma_{\bar{x}} = \sigma / \sqrt{n}$$

Population goes down

=

Variance goes up!





Problems

Task-irrelevant patterns can drown out important signals

Variation can create false signals.

Solutions

Task-irrelevant patterns can drown out important signals

- Highlight important data

Variation can create false signals.

- Downweight unimportant data

What's Important Data?

What's Important Data?

Deviation from expectation

What's Important Data?

Deviation from **expectation**



MODELS

What's Important Data?

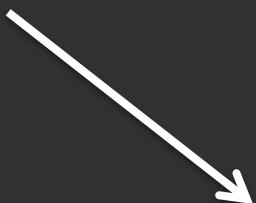
Deviation from **expectation**



What's Important Data?

Deviation from expectation

EVIDENCE



MODELS



Bayesian Approach

Outline

What's Wrong With Heatmaps?

Bayesian Surprise

Surprise Maps

Bayes' Rule

$$P(A|B) \sim P(B|A)P(A)$$

Prior

$$P(A|B) \sim P(B|A)P(A)$$

Likelihood/Evidence

$$P(A|B) \sim P(B|A)P(A)$$

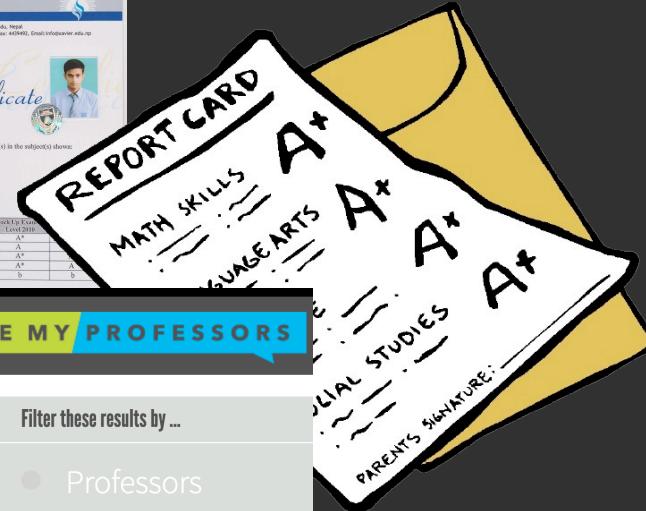
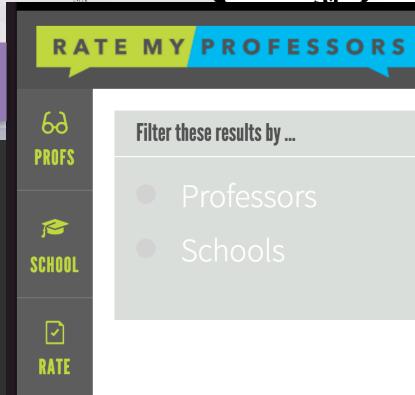
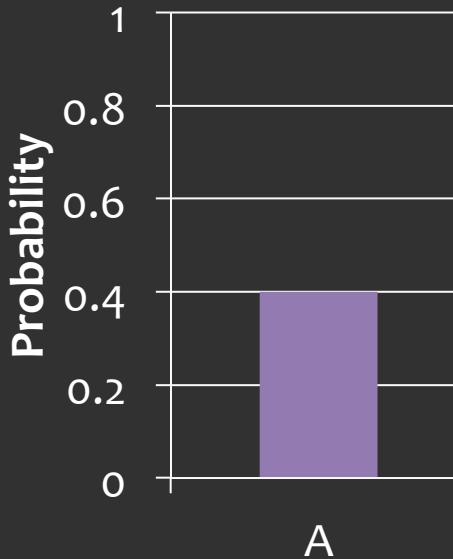
Posterior

$$P(A|B) \sim P(B|A)P(A)$$

An Example

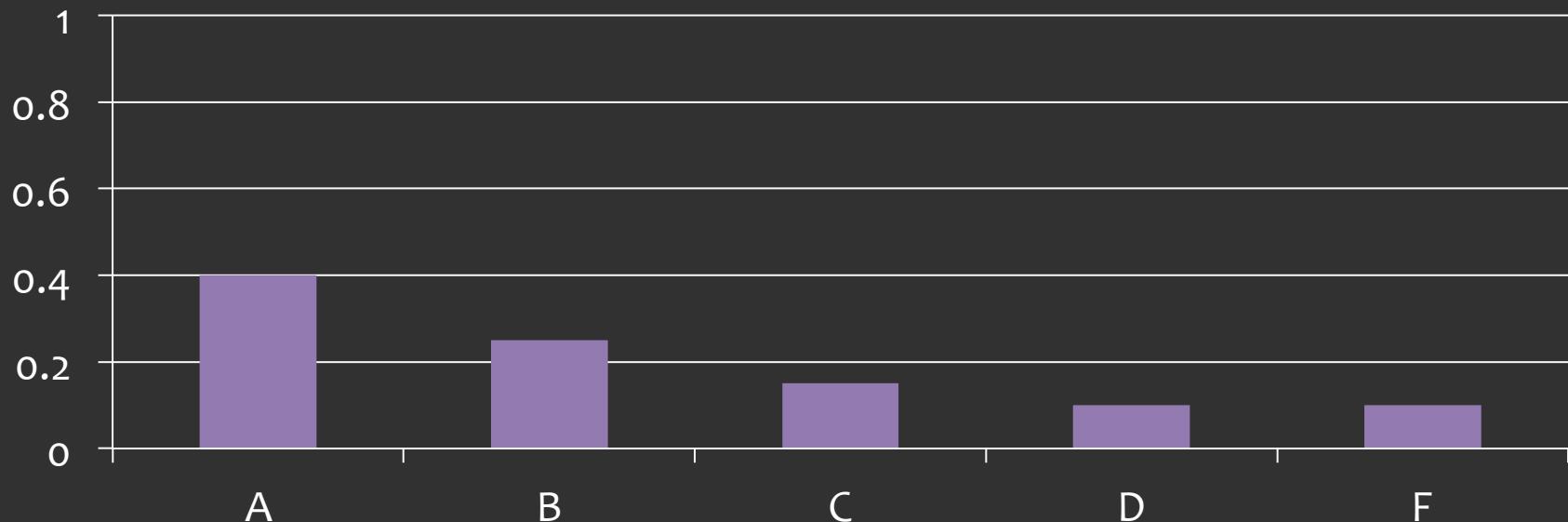


Will I Earn An A?



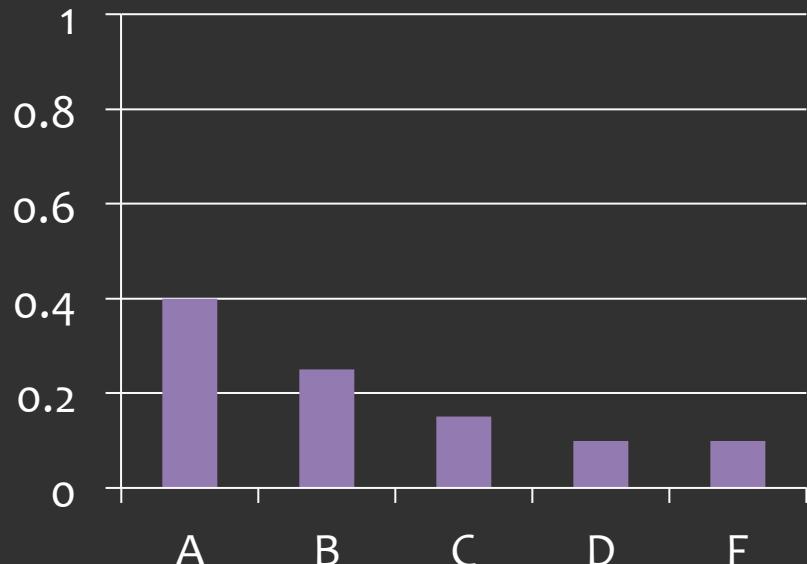
Prior

Likely Final Grade

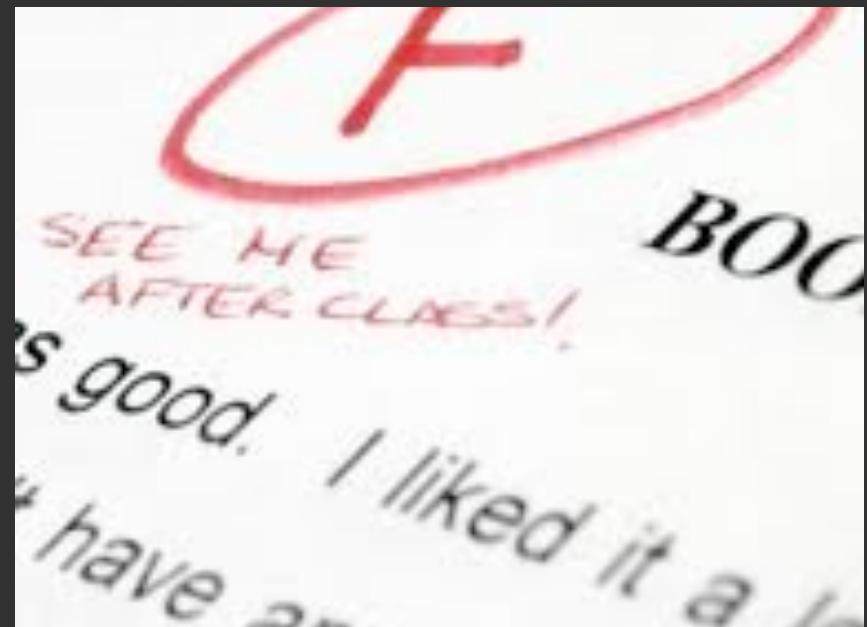


Bayesian Surprise

Prior

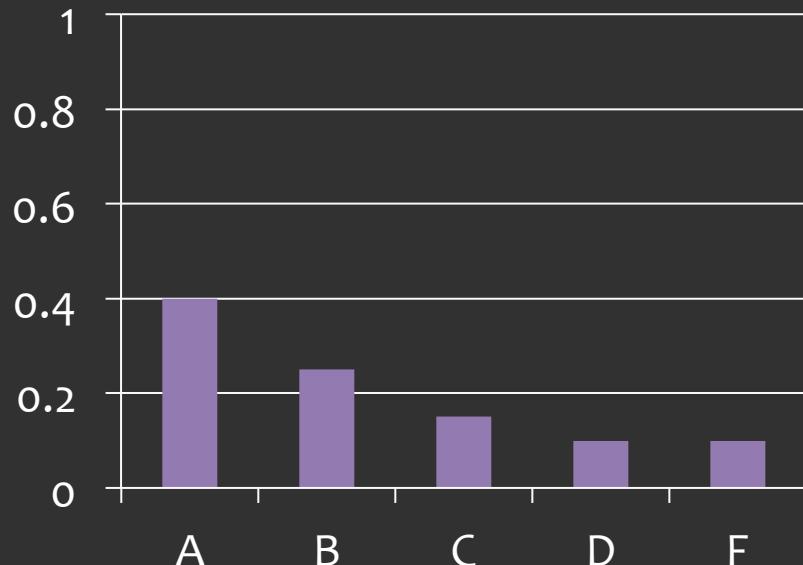


Evidence

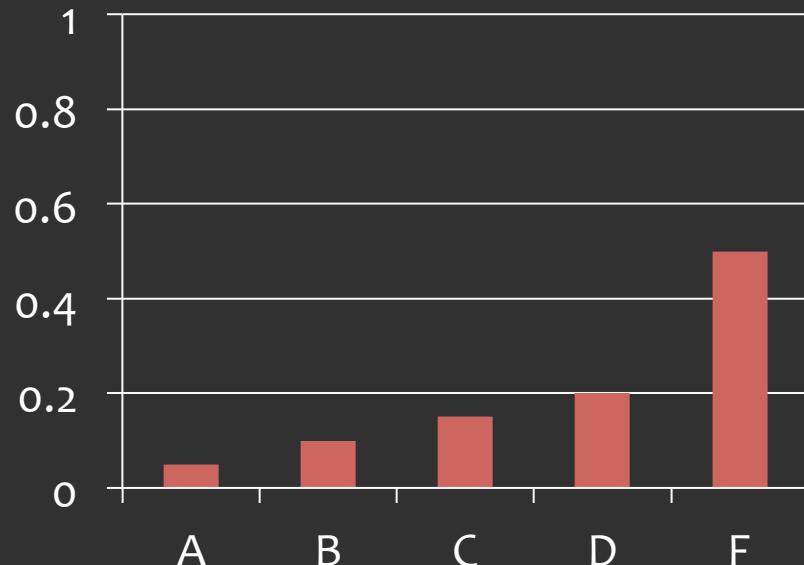


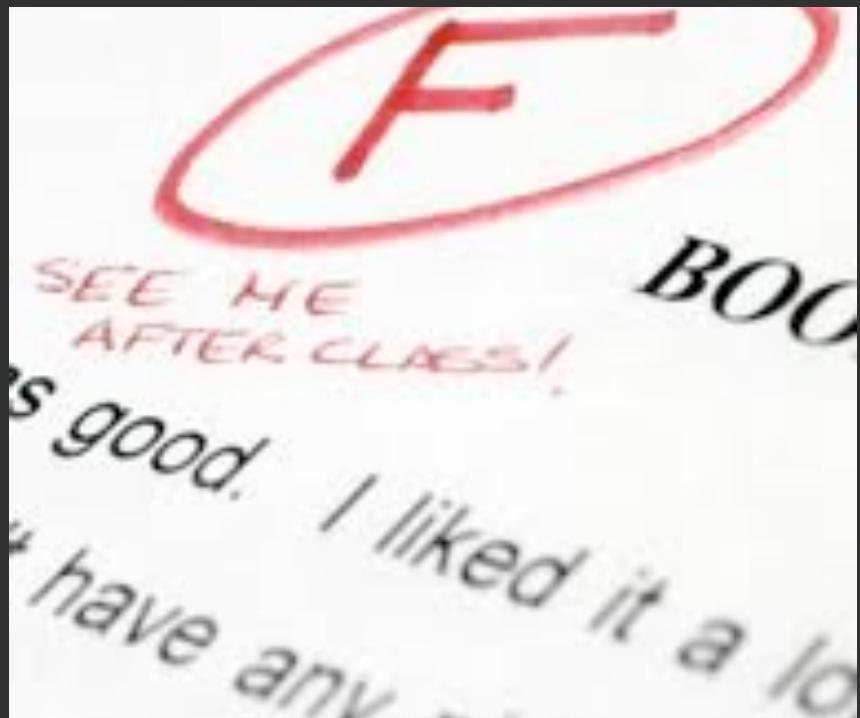
Bayesian Surprise

Prior

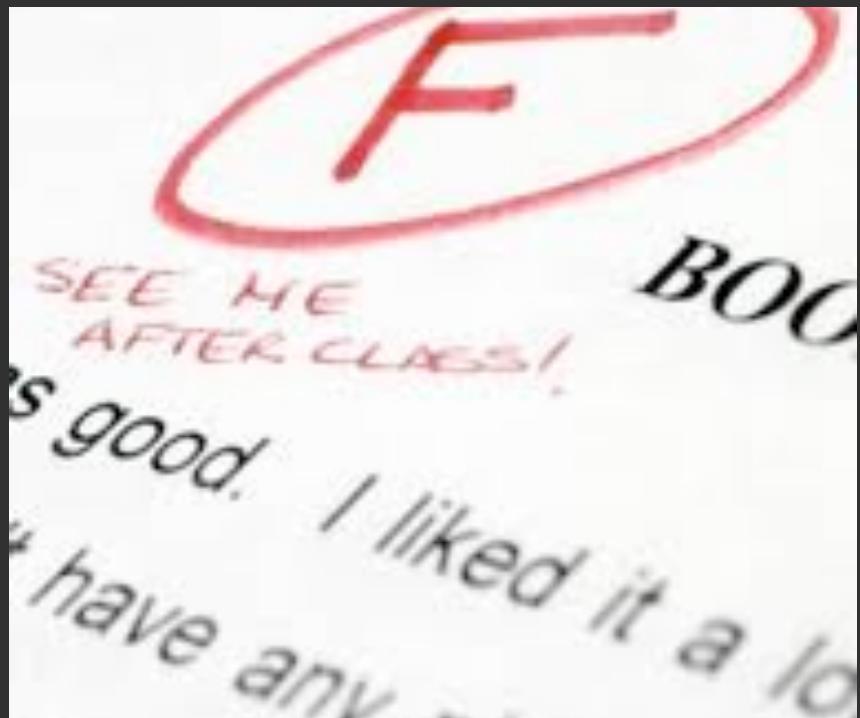
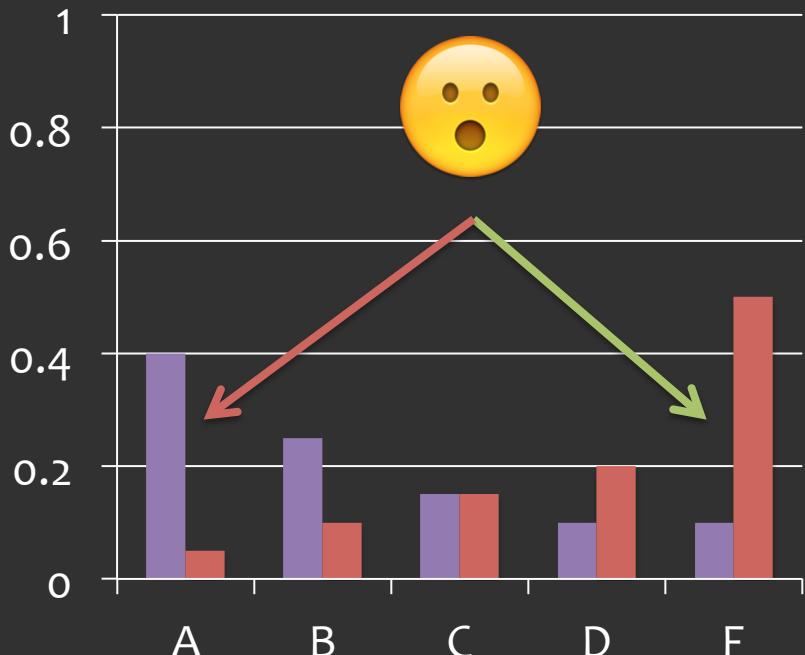


Posterior

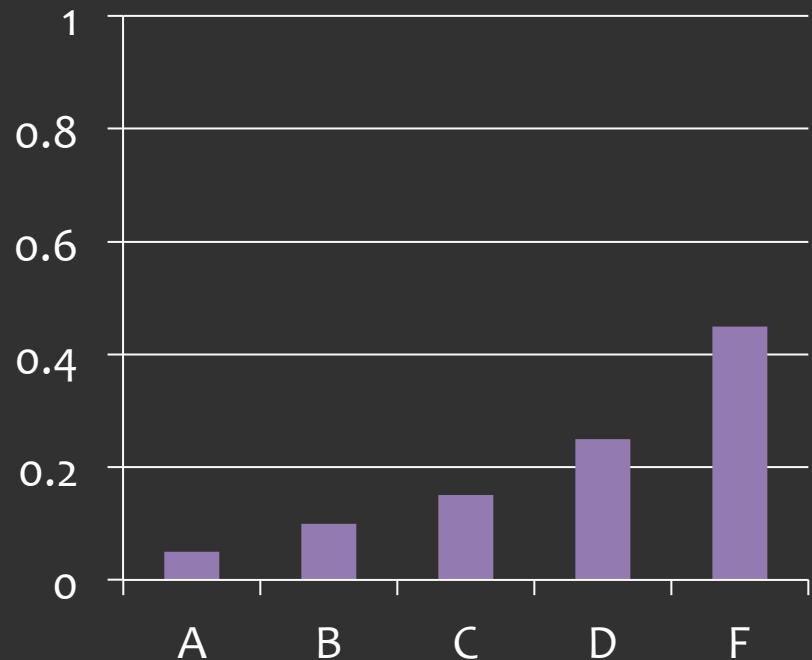


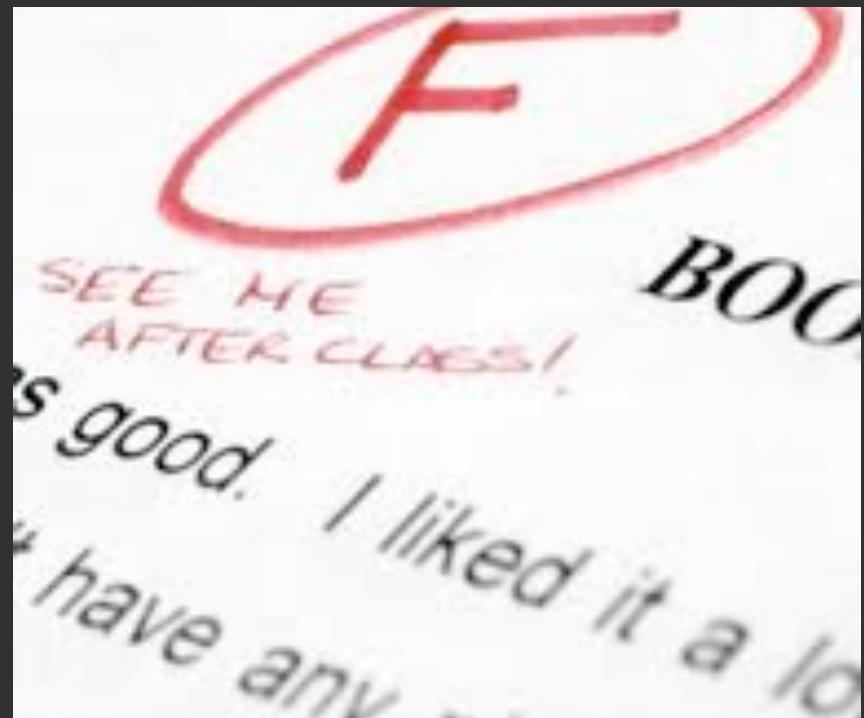


Wow!

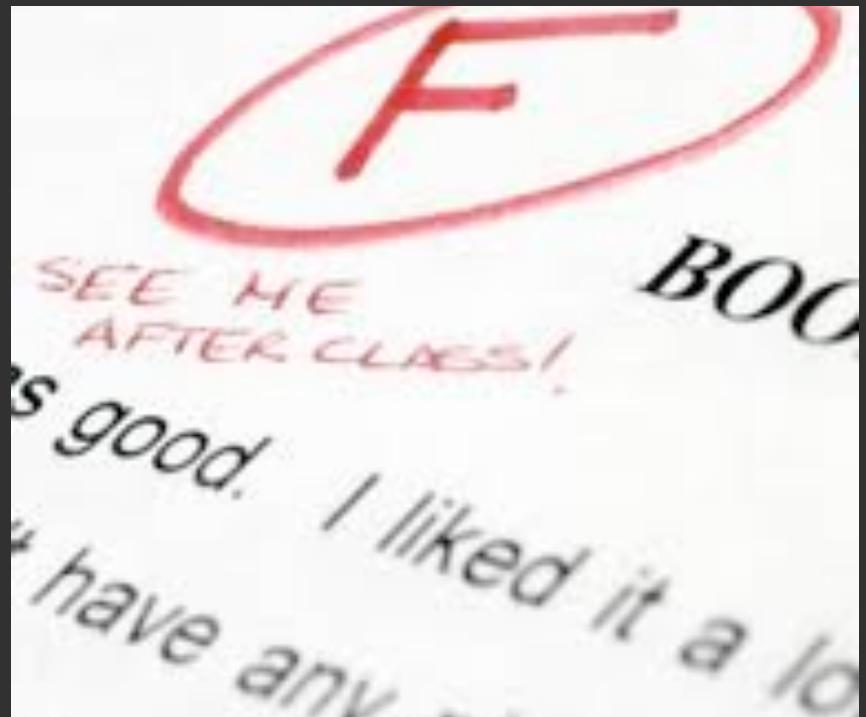
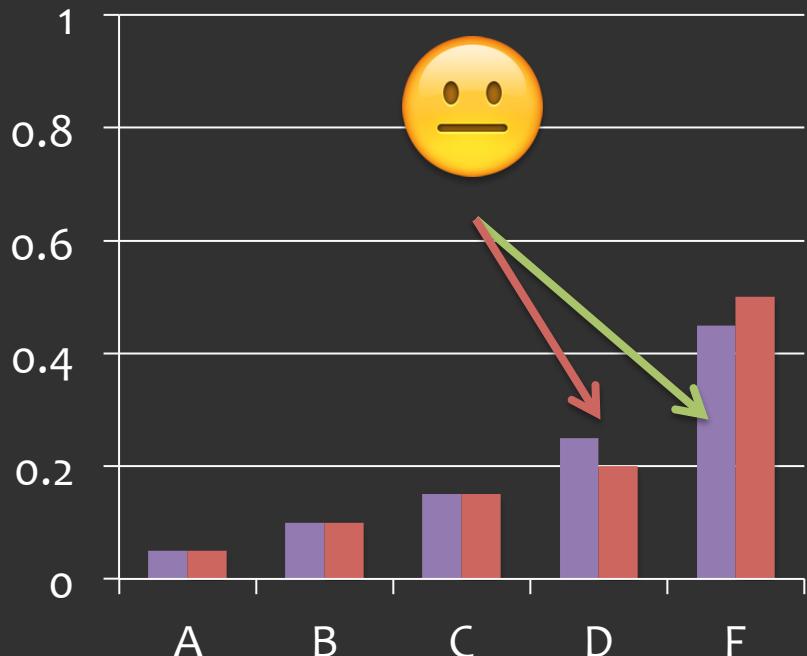


A Different Prior

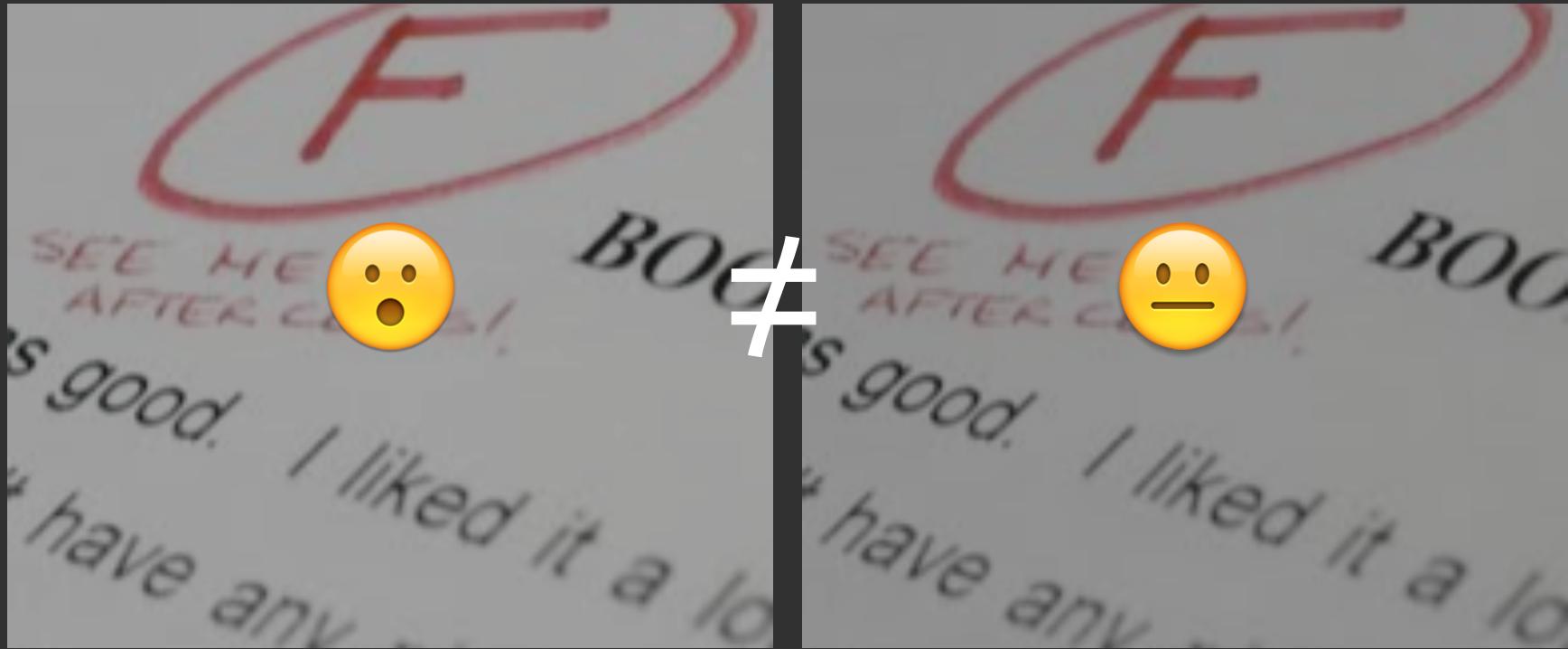




Meh.



Bayesian Surprise



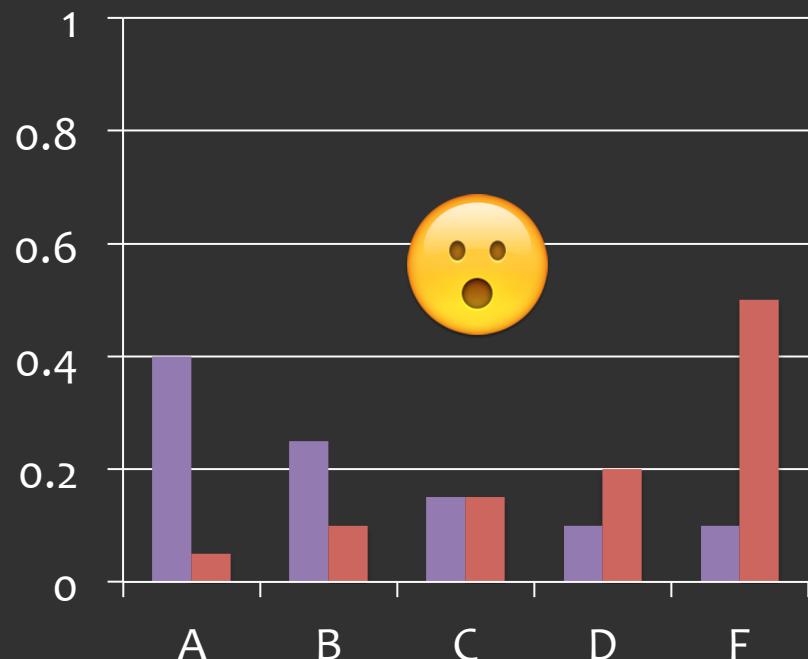
Bayesian Surprise

M = Model (prior)

O = Observation
(posterior)

$$\text{Surprise} = D_{\text{KL}}(O \parallel M)$$

Big Changes = Lots of Surprise



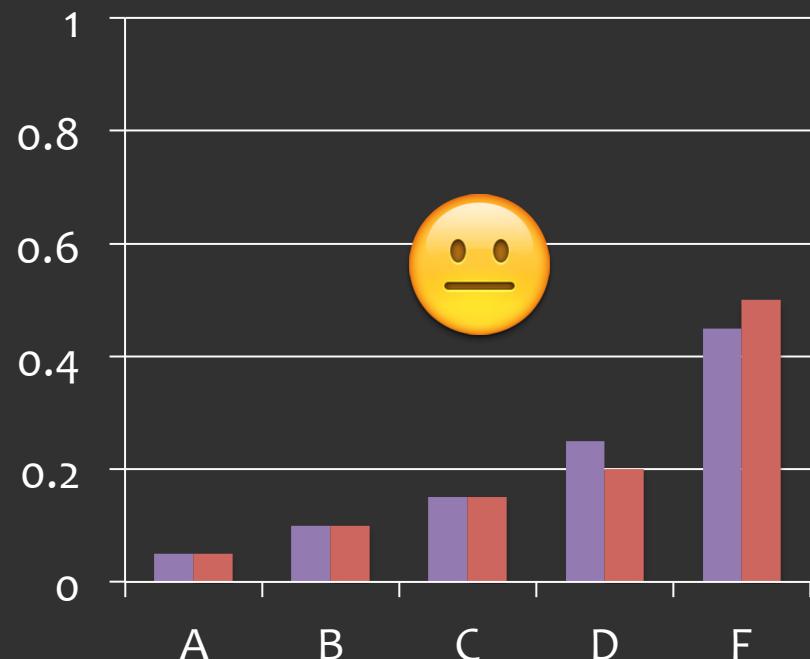
Bayesian Surprise

M = Model (prior)

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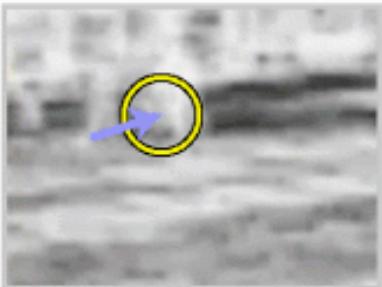
Small Changes = Little Surprise



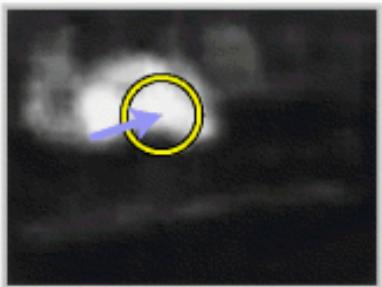
Input



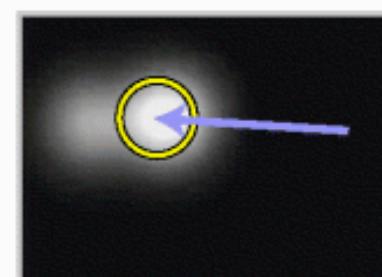
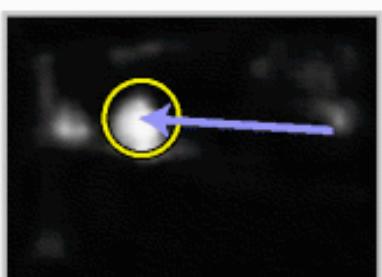
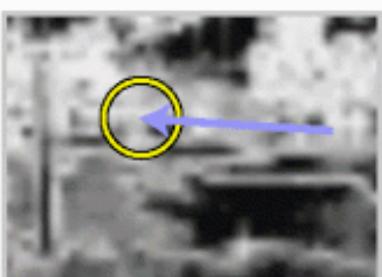
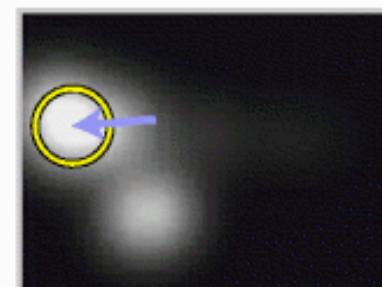
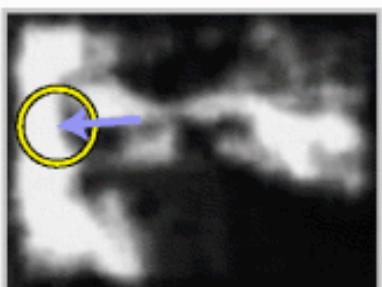
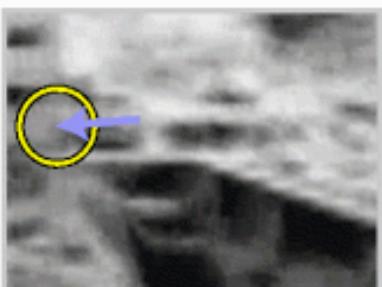
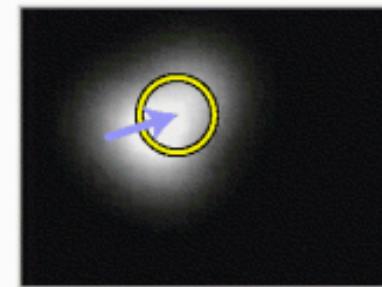
Entropy



Surprise



Humans



Outline

What's Wrong With Heatmaps?

Bayesian Surprise

Surprise Maps

How To Make A Surprise Map?

Select Models of Expectation

Collect Data

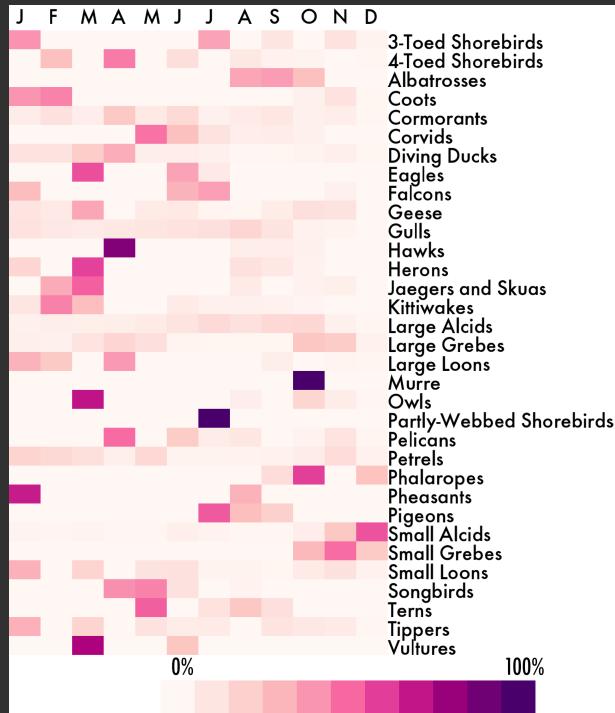
Calculate Bayesian Surprise

COASST

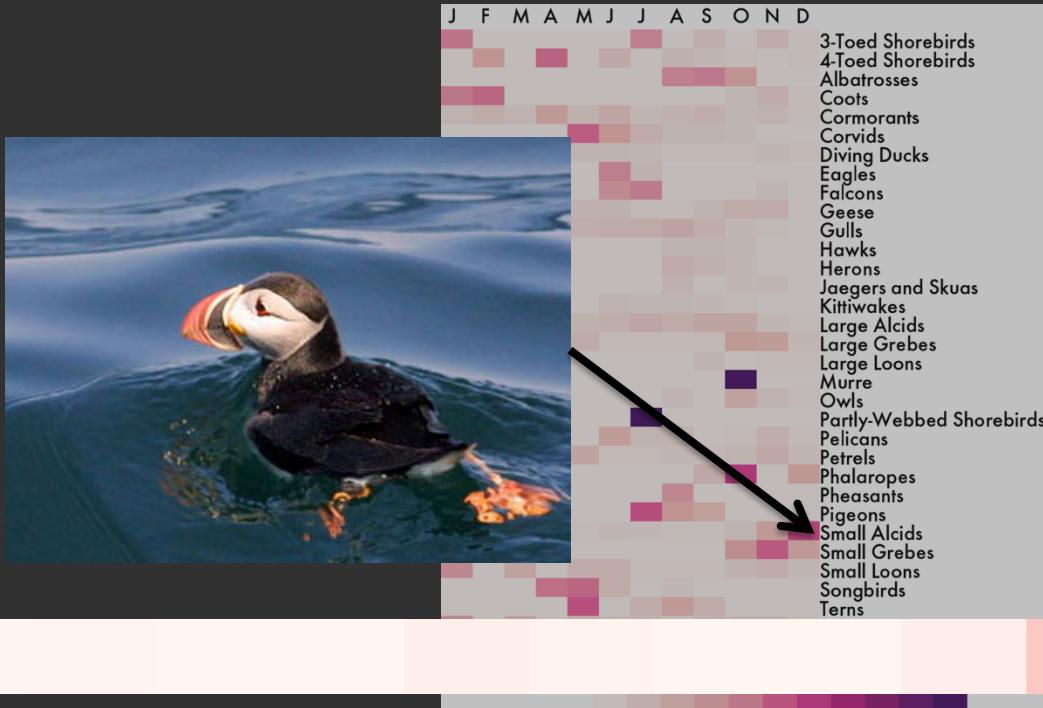


<https://deps.washington.edu/coasst/>

2015 Observed Bird Deaths



2015 Observed Bird Deaths



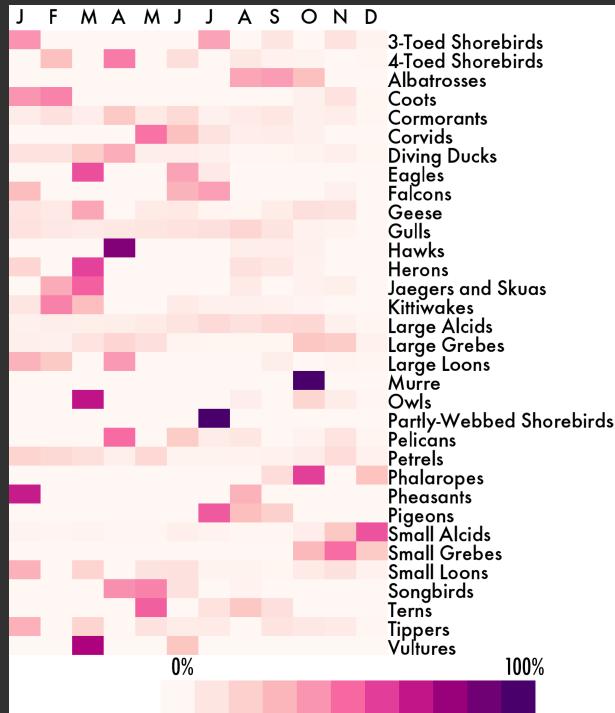
Small Alcids

2015 Observed Bird Deaths



Gulls

2015 Observed Bird Deaths



How To Make A Surprise Map?

Select Models of Expectation

Collect Data

Calculate Bayesian Surprise

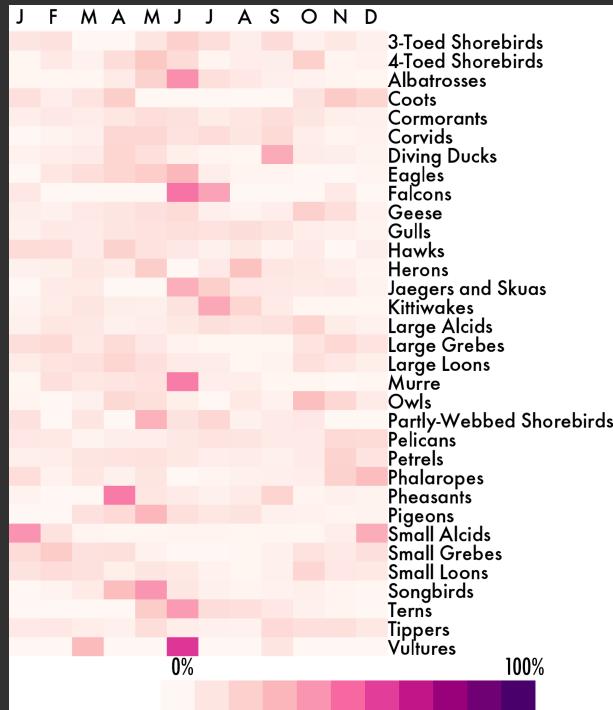
Seasonal Model



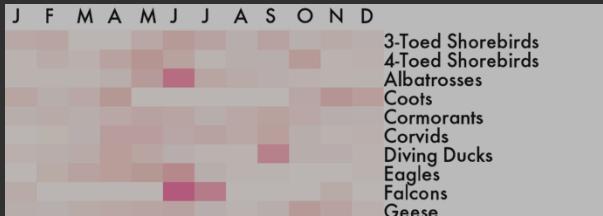
Seasonal Model



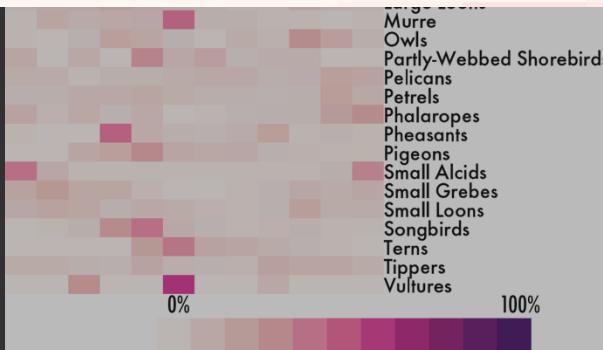
2009-2014



2009-2014



Pigeons
Small Alcids



Our Models

Seasonal



Past5



What Are Good Models?

Simple

Explainable

Divergence is Meaningful

What Are Good Models?

If you have the “correct” model, then you probably don’t need a surprise map, just a residual plot.

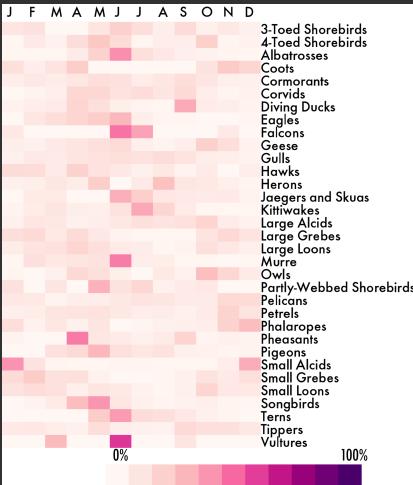
How To Make A Surprise Map?

Select Models of Expectation

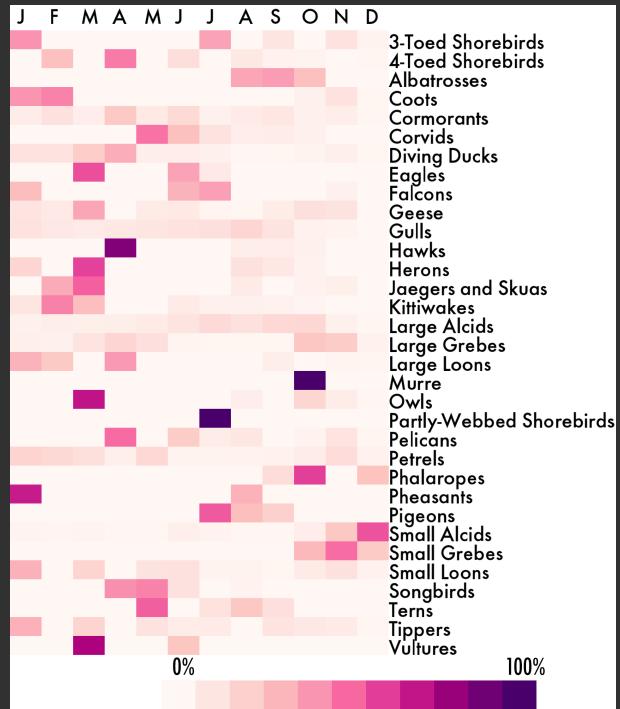
Collect Data

Calculate Bayesian Surprise

Expected



Actual



How To Make A Surprise Map?

Select Models of Expectation

Collect Data

Calculate Bayesian Surprise

Seasonal Model

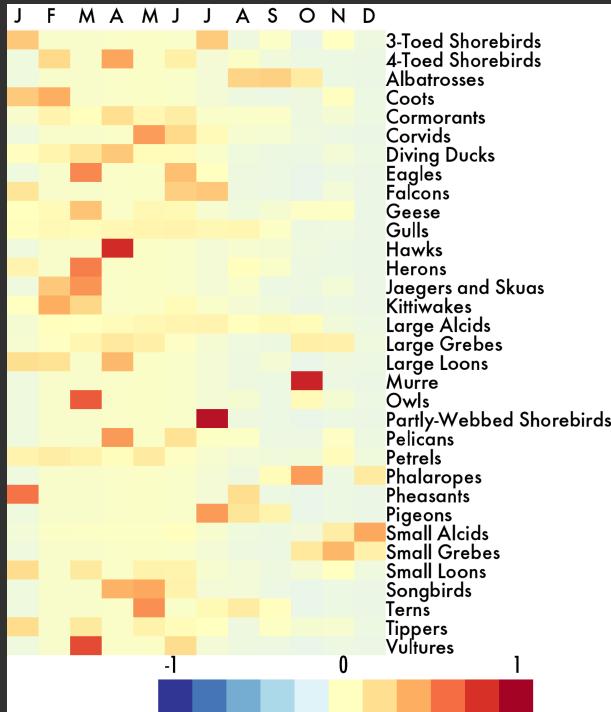
Expected



Observed



Observed-Expected



Calculating Surprise

$$P(O | M_{\text{seasonal}}) \approx 1 - |O - E|$$

$$P(M_s | O) \sim P(M_s)P(O|M_s)$$

$$\text{Surprise} = D_{KL}(P(M|O) || P(M))$$

Calculating Surprise

$$P(O | M_{\text{seasonal}}) \approx 1 - |O - E|$$

$$P(M_s | O) \sim P(M_s)P(O|M_s)$$

$$\text{Surprise} = D_{KL}(P(M|O) || P(M))$$

Calculating Surprise

$$P(O | M_{\text{seasonal}}) \approx 1 - |O - E| = 0$$



$$P(M_s | O) \sim P(M_s)P(O|M_s)$$

$$\text{Surprise} = D_{KL}(P(M|O) || P(M))$$

Calculating Surprise

$$P(O | M_{\text{seasonal}}) \approx 1 - |O - E| = 1$$

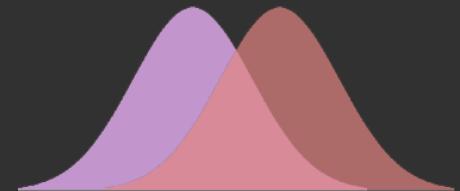


$$P(M_s | O) \sim P(M_s)P(O|M_s)$$

$$\text{Surprise} = D_{KL}(P(M|O) || P(M))$$

Calculating Surprise

$$P(O | M_{\text{seasonal}}) \approx 1 - |O - E| = 0.5$$



$$P(M_s | O) \sim P(M_s)P(O|M_s)$$

$$\text{Surprise} = D_{KL}(P(M|O) || P(M))$$

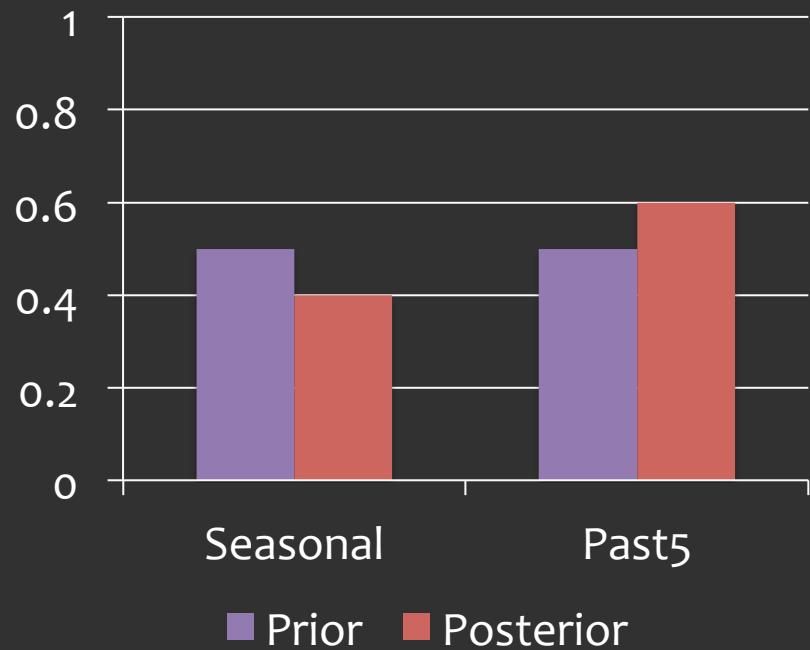
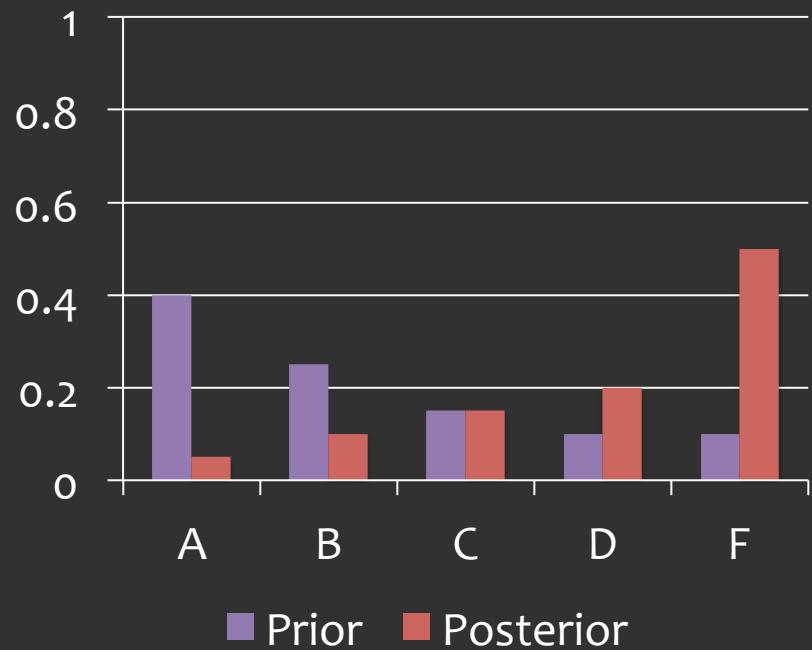
Calculating Surprise

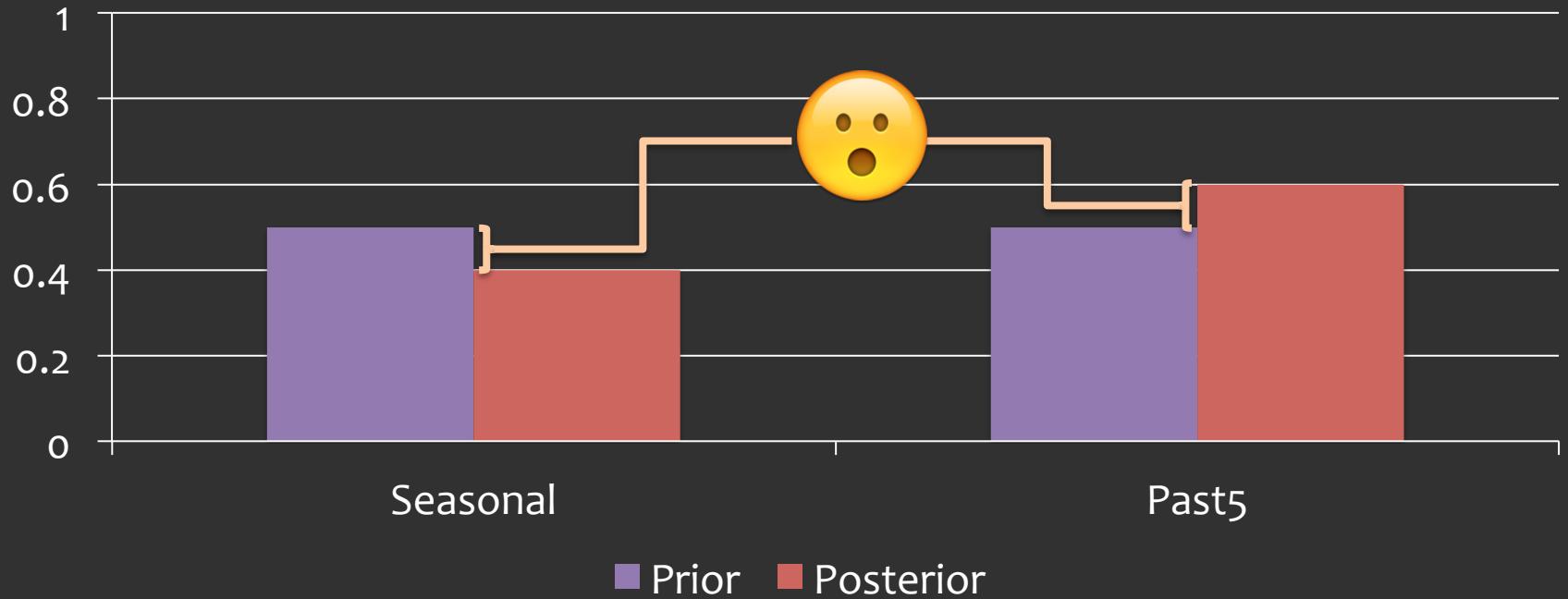
$$P(O | M_s) \approx 1 - |O-E|$$

$$P(M_s | O) \sim P(M_s)P(O|M_s)$$

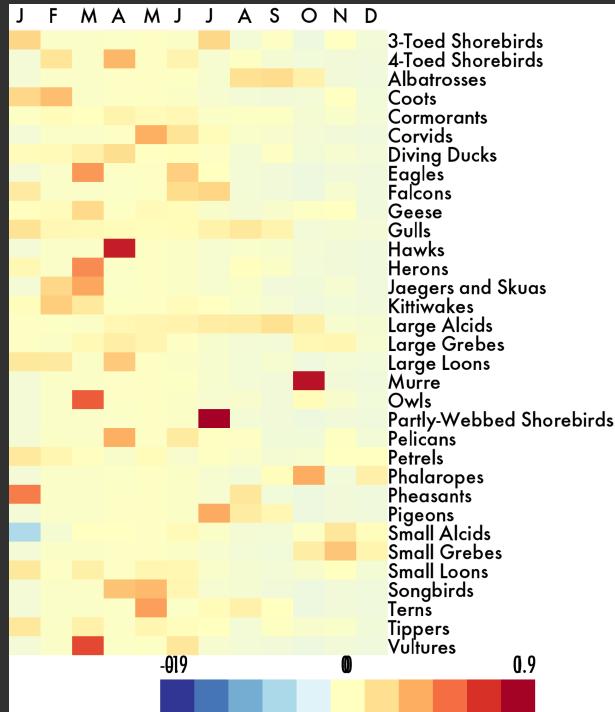
$$\text{Surprise} = D_{KL}(P(M|O) || P(M))$$

$$\text{Signed Surprise} = \text{Surprise} \times \text{Sign}(O-E)$$

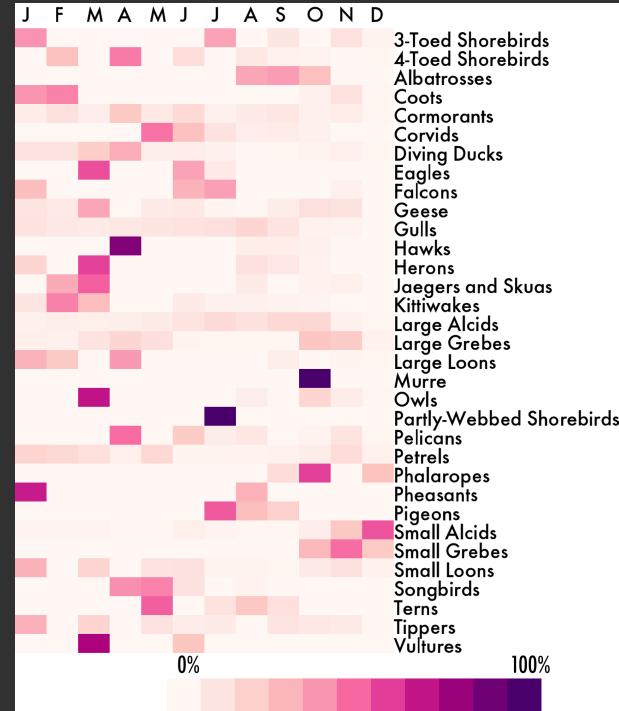
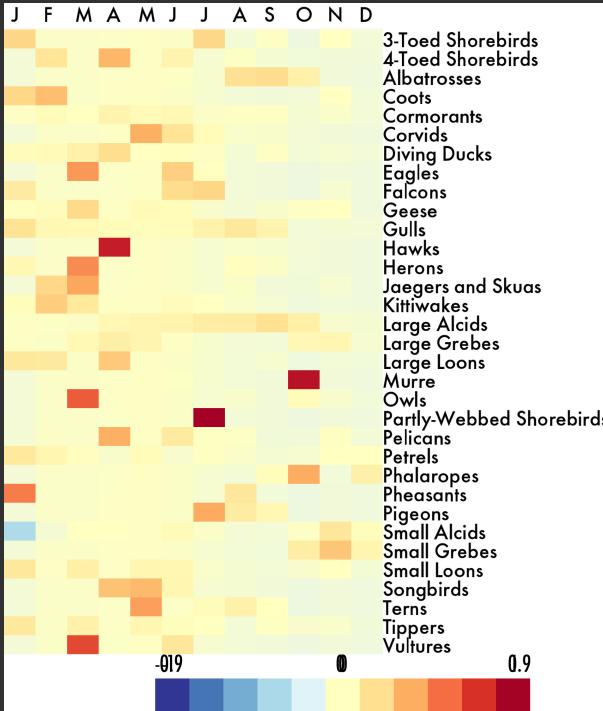




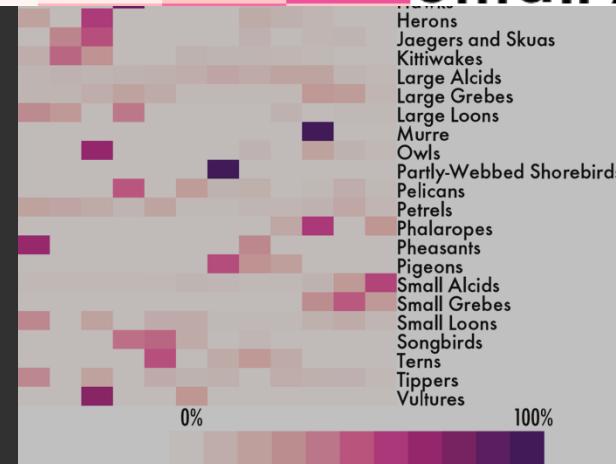
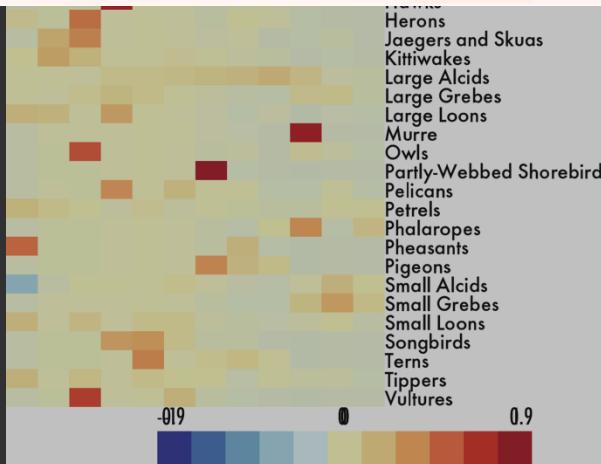
Final Map



Final Map



Where Are The Puffins?

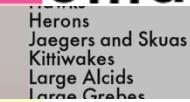


Small Alcids

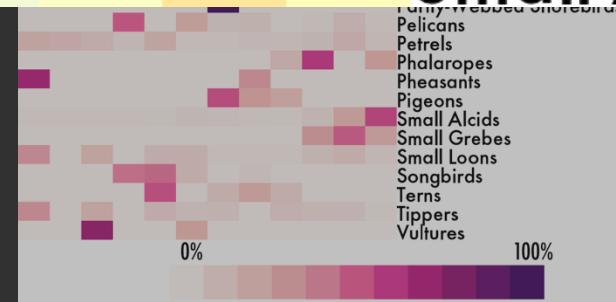
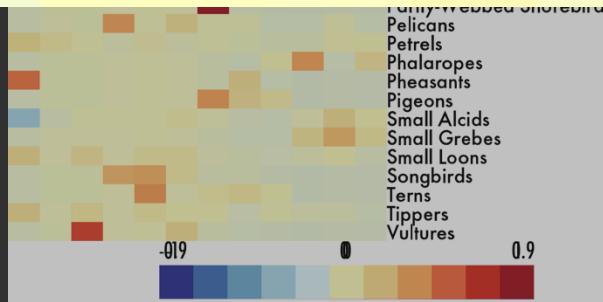
Where Are The Puffins?



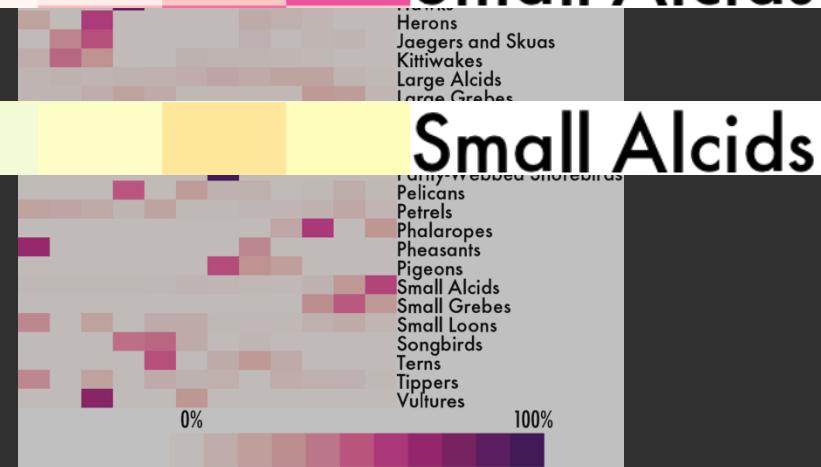
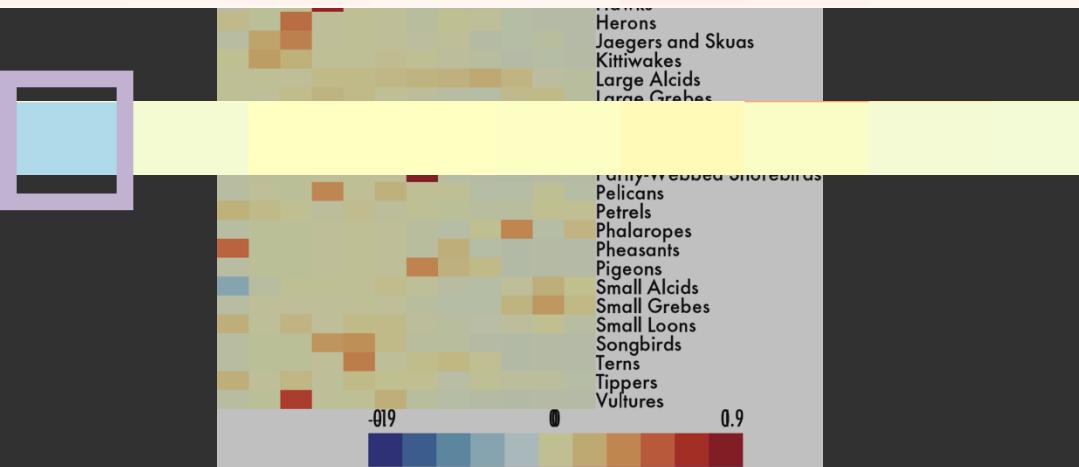
Small Alcids



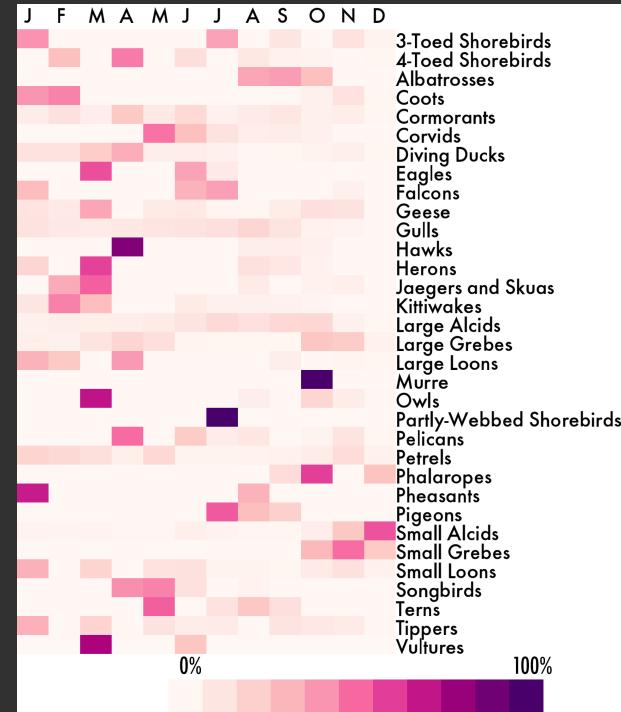
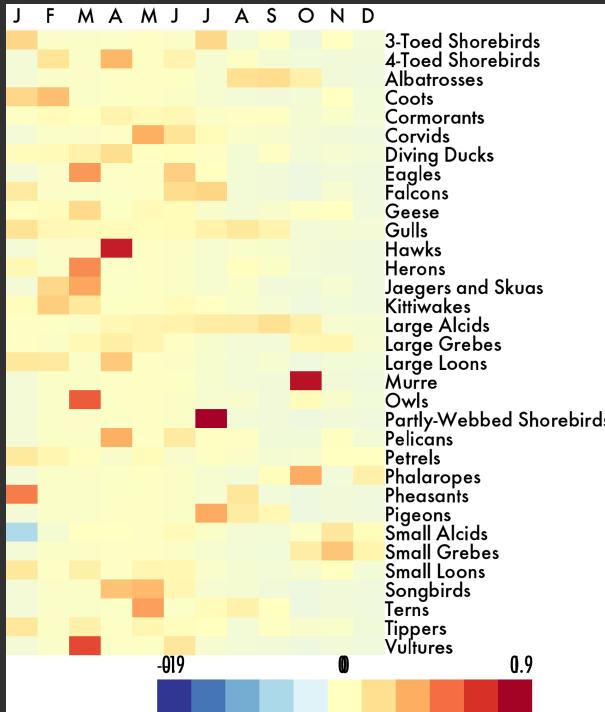
Small Alcids



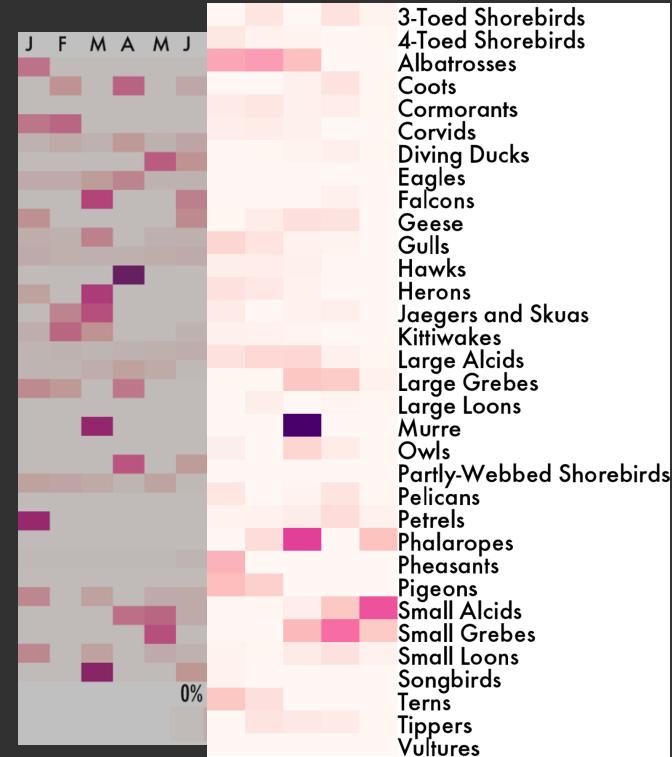
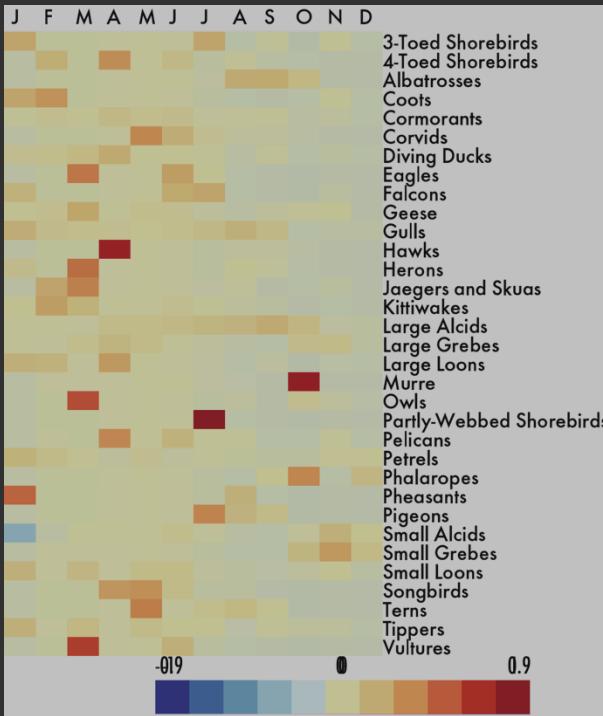
Where Are The Puffins?



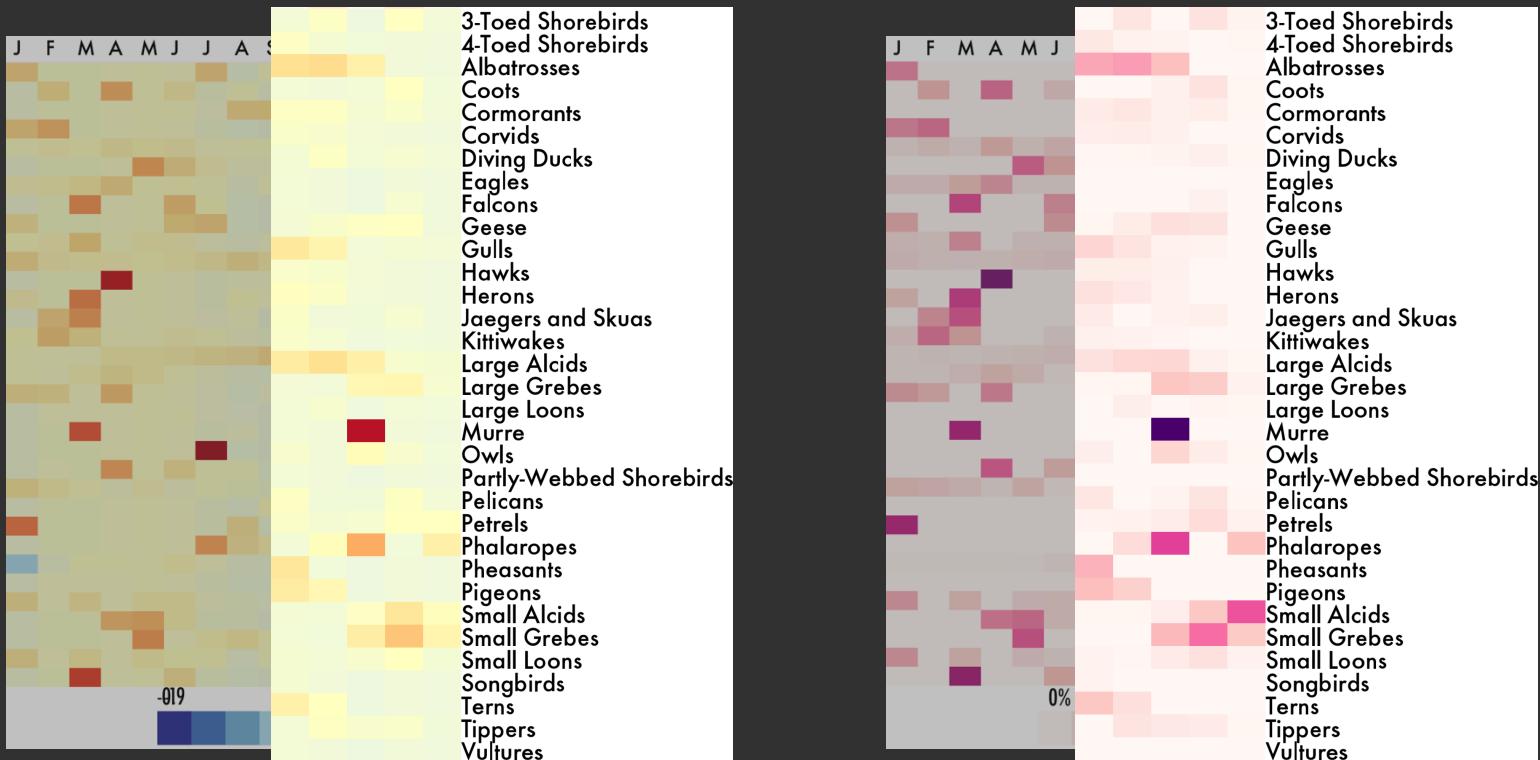
Old Man Winter



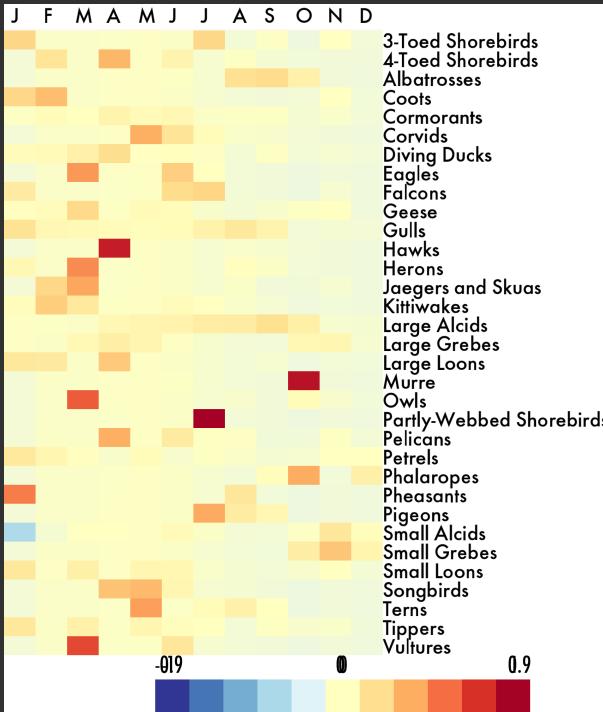
Old Man Winter

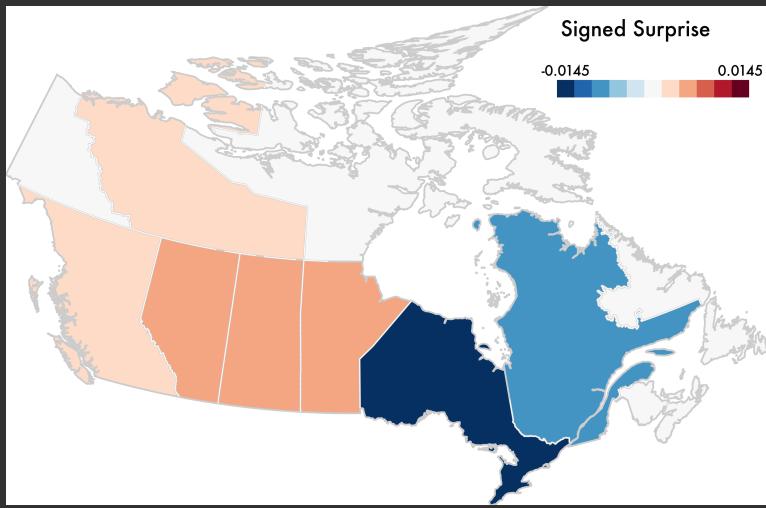


Old Man Winter

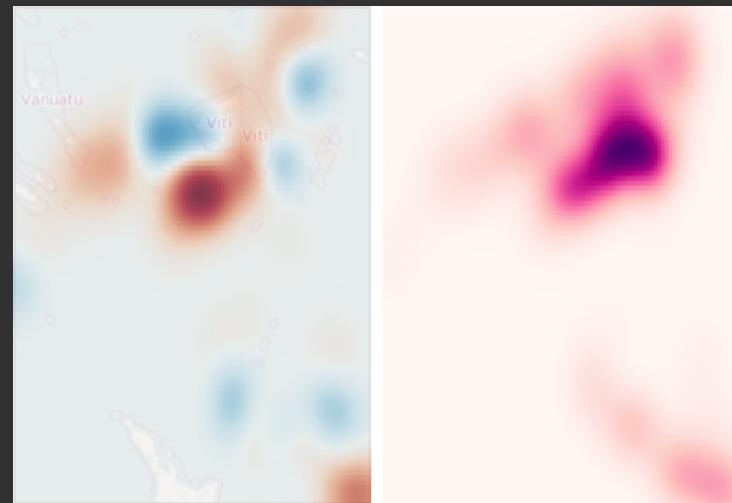
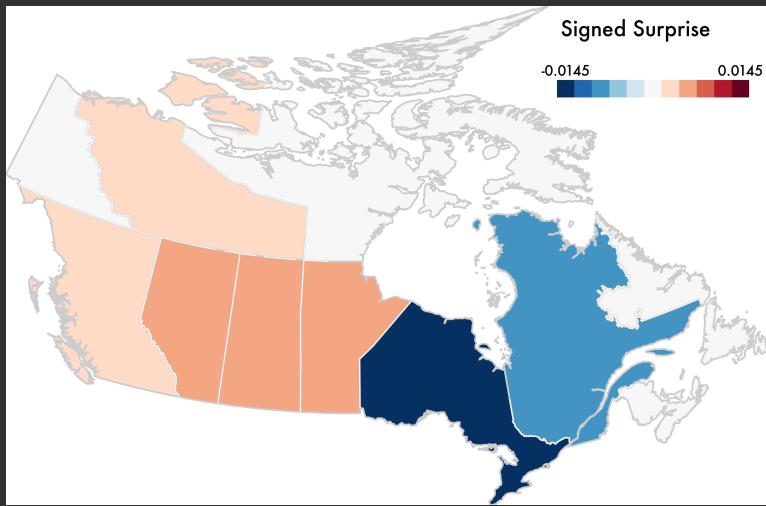


Final Map

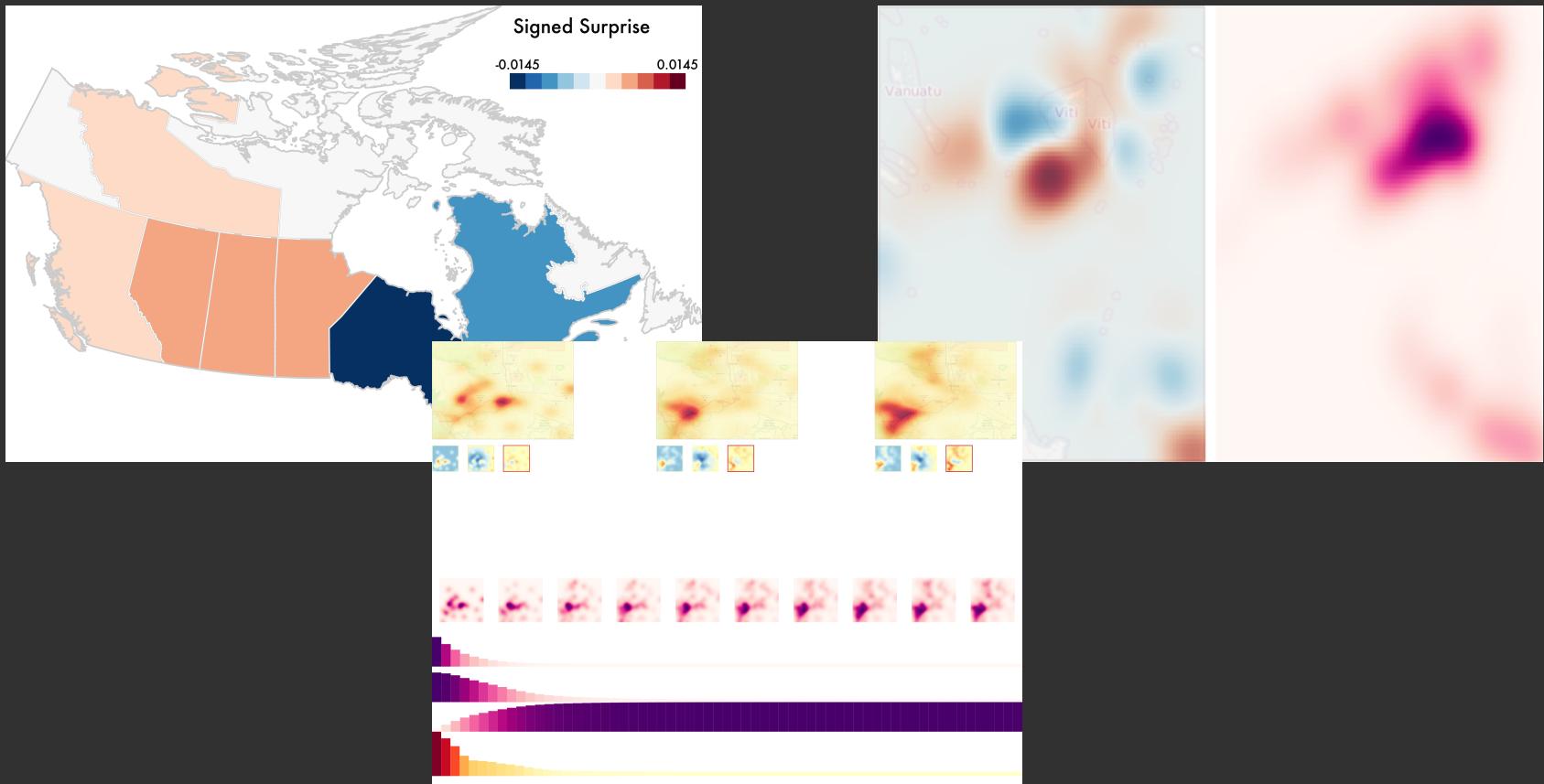




Choropleth Maps



Heat Maps



Spatio-temporal Data

Caveats

Surprise != Value

Caveats

Surprise != Value

Surprise != Value

Surprise != Value

Caveats

Nonsense Models = Nonsense Map



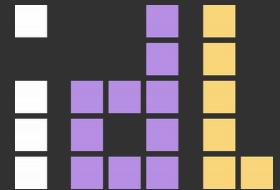
Thanks!

This work was supported by a Moore Foundation
Data-Driven Discovery Investigator award.

Materials and demo available at:

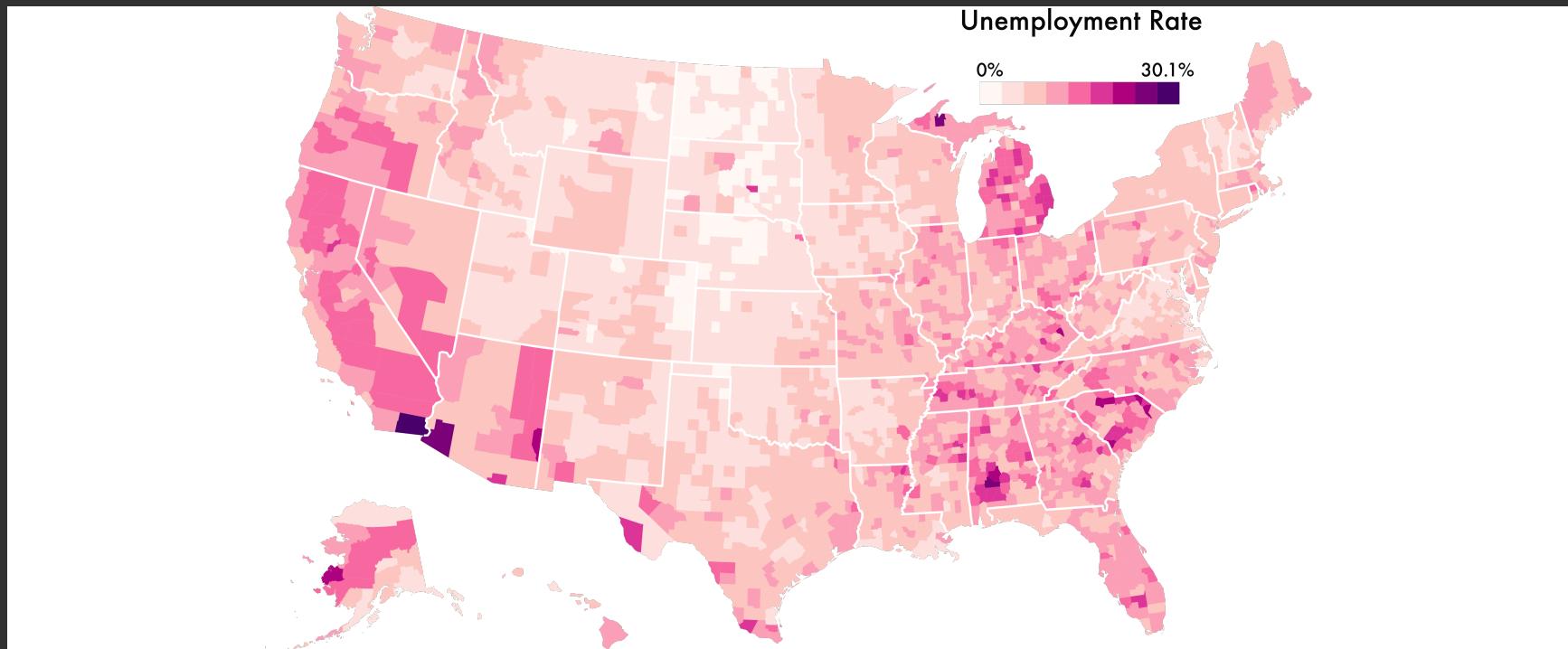
<https://github.com/uwdata/bayesian-surprise>

W.

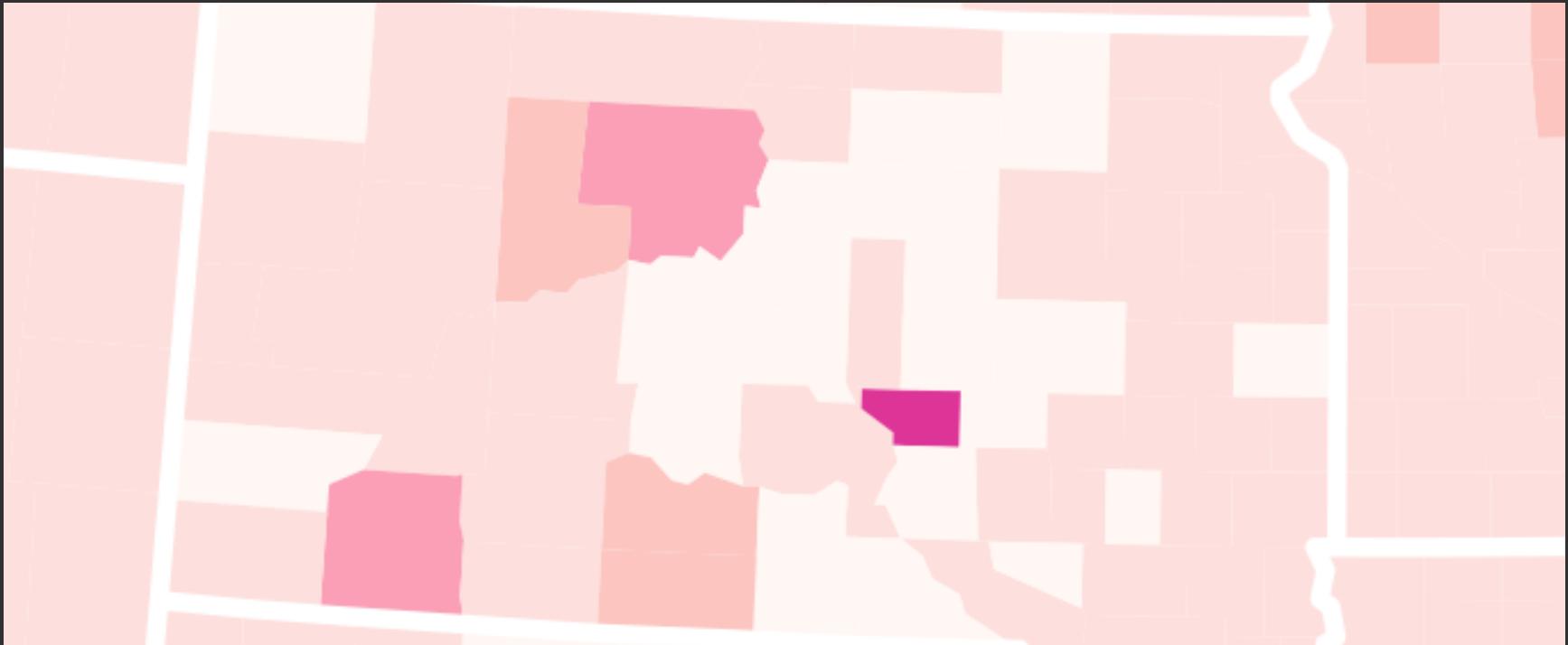


Extra Slides

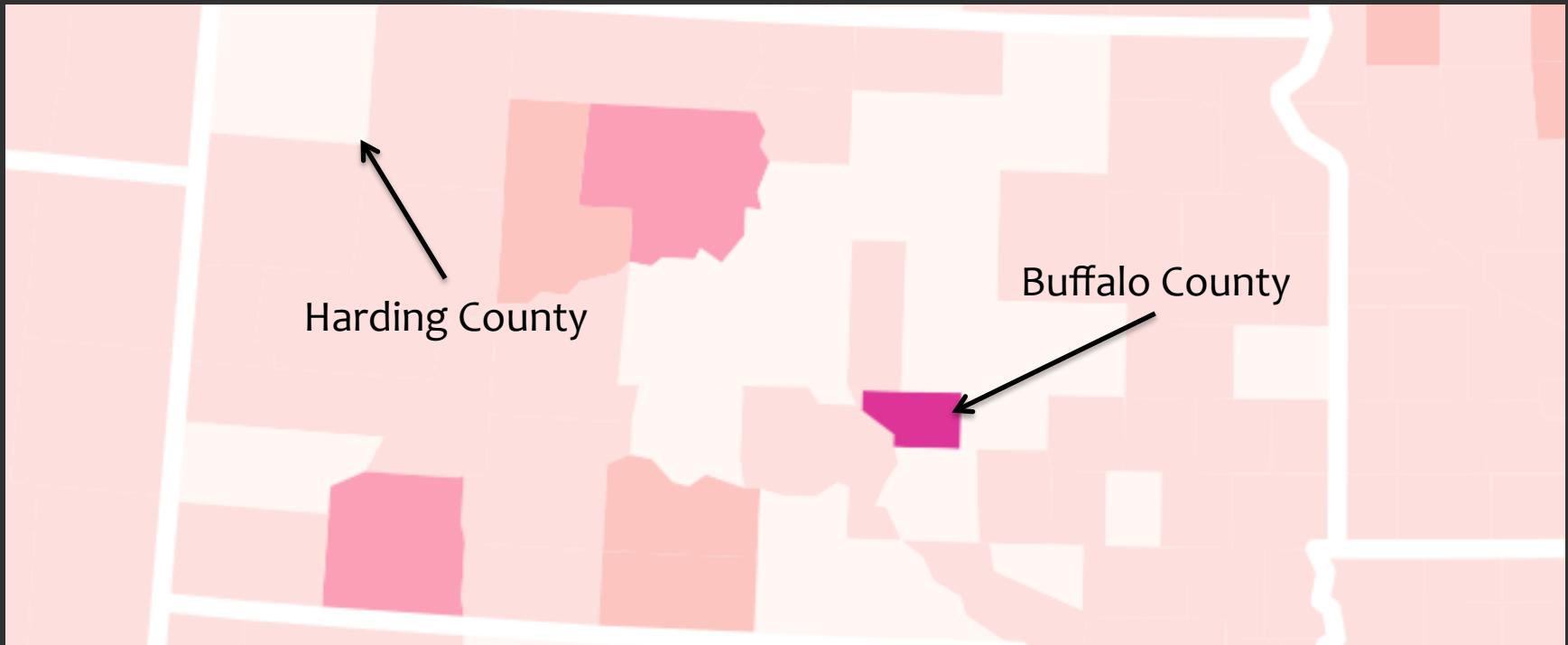
Thematic Maps



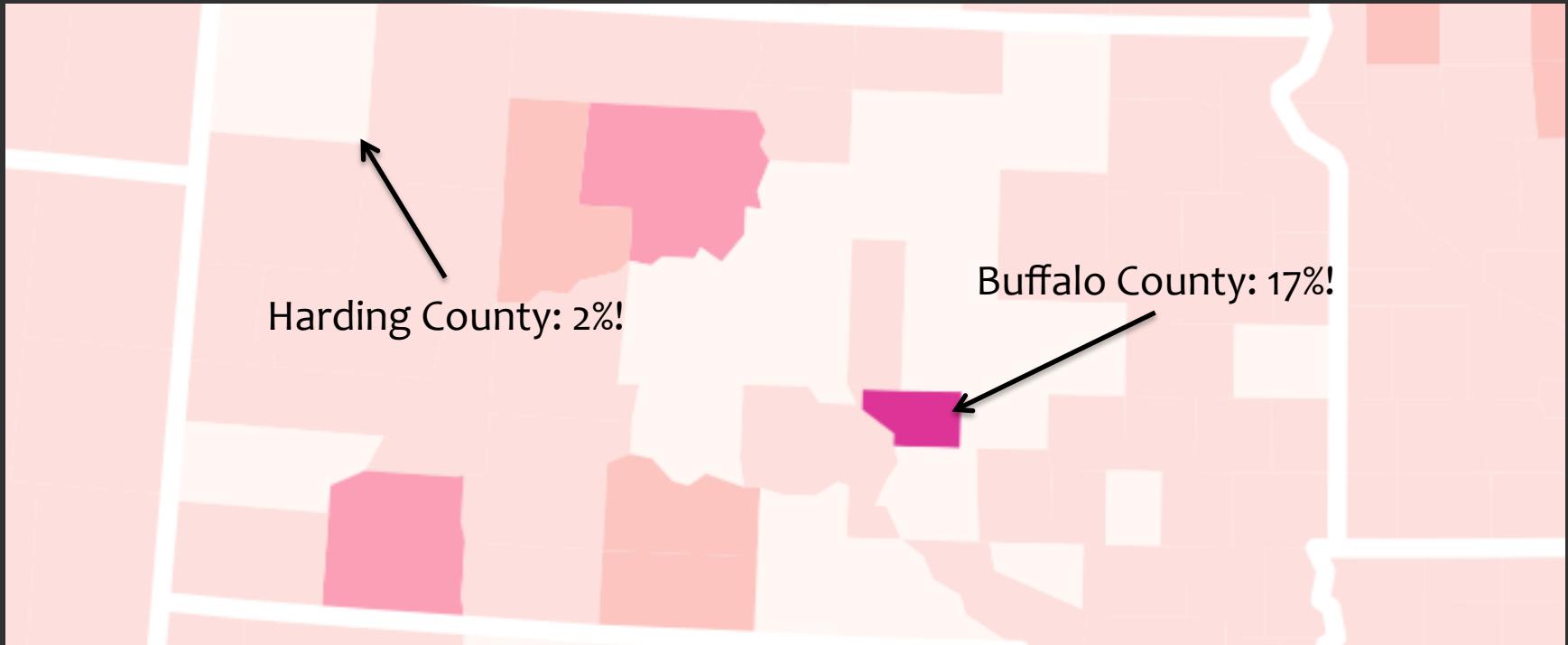
South Dakota



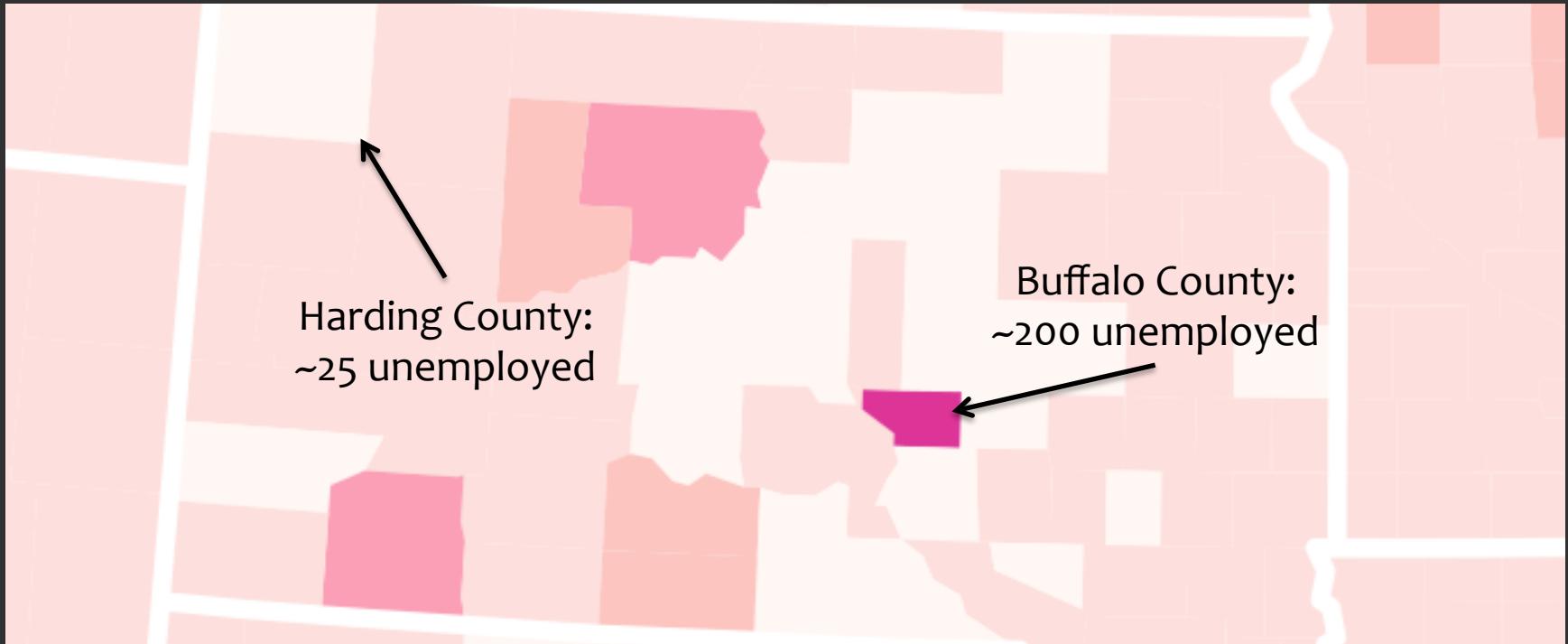
South Dakota

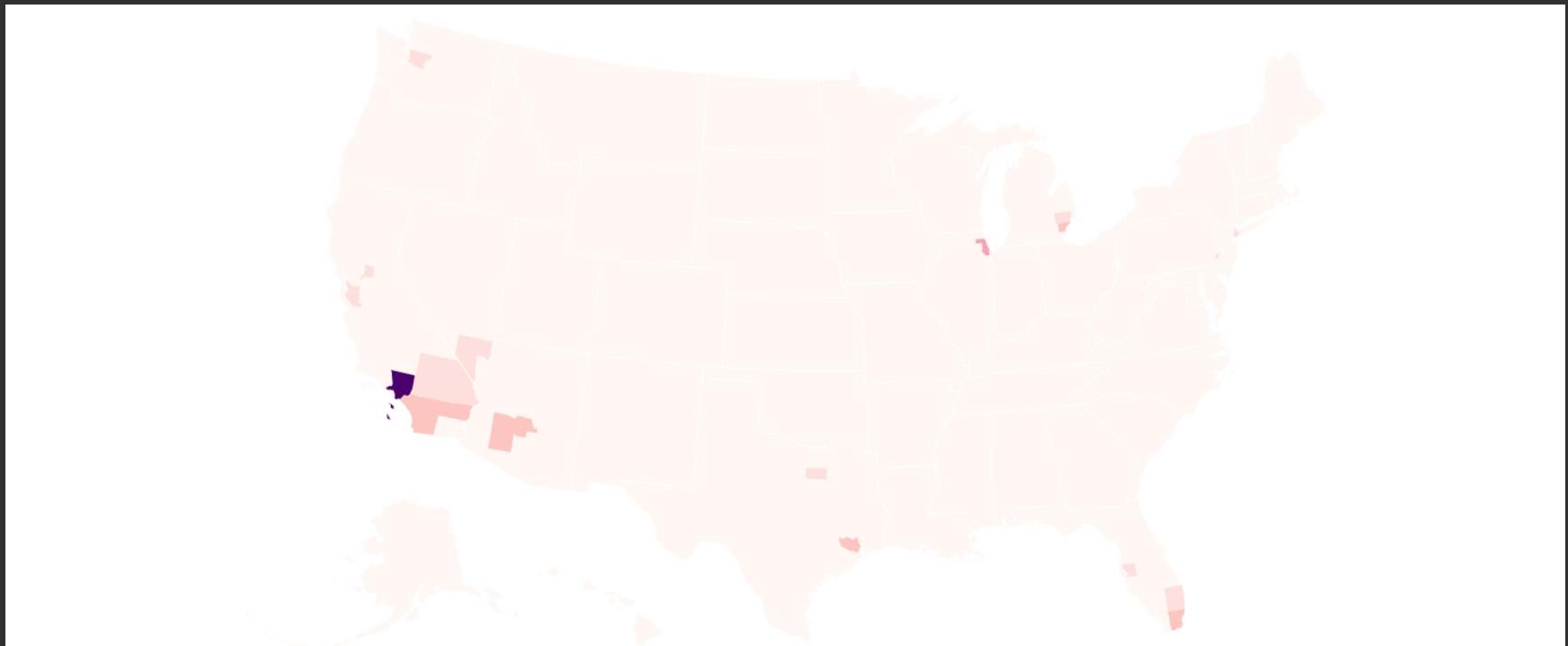


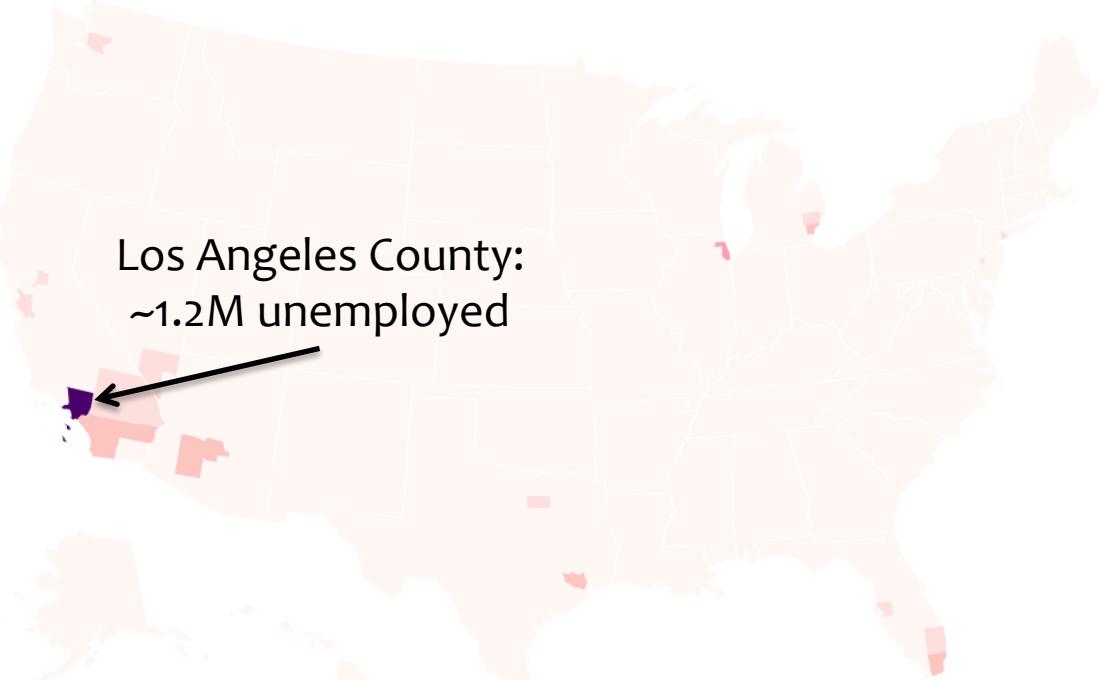
South Dakota



South Dakota

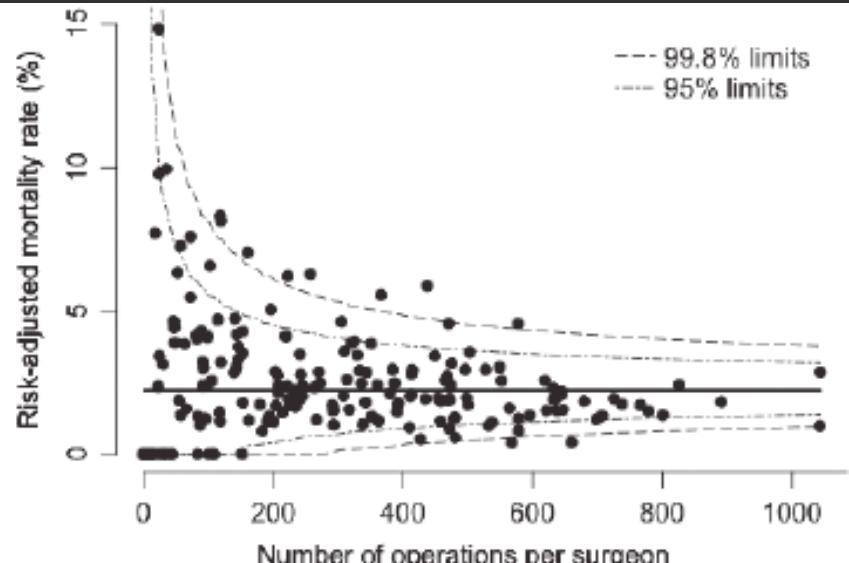
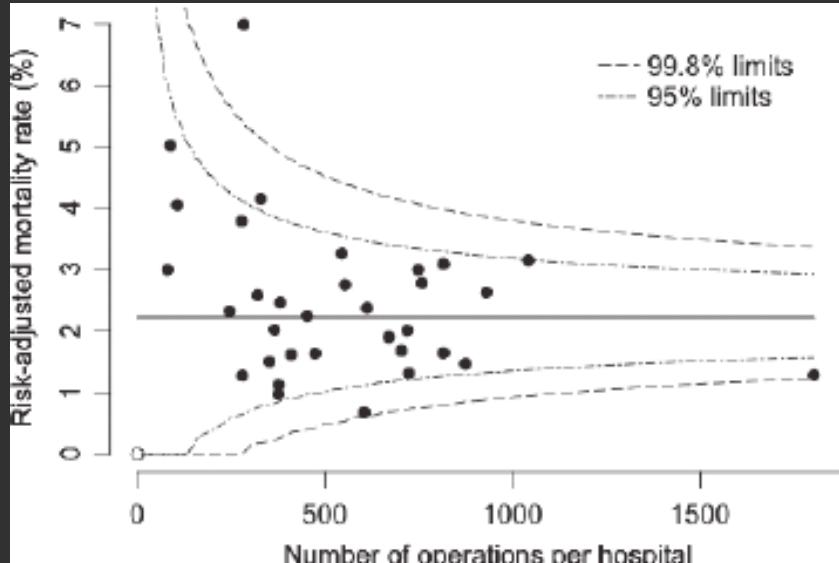






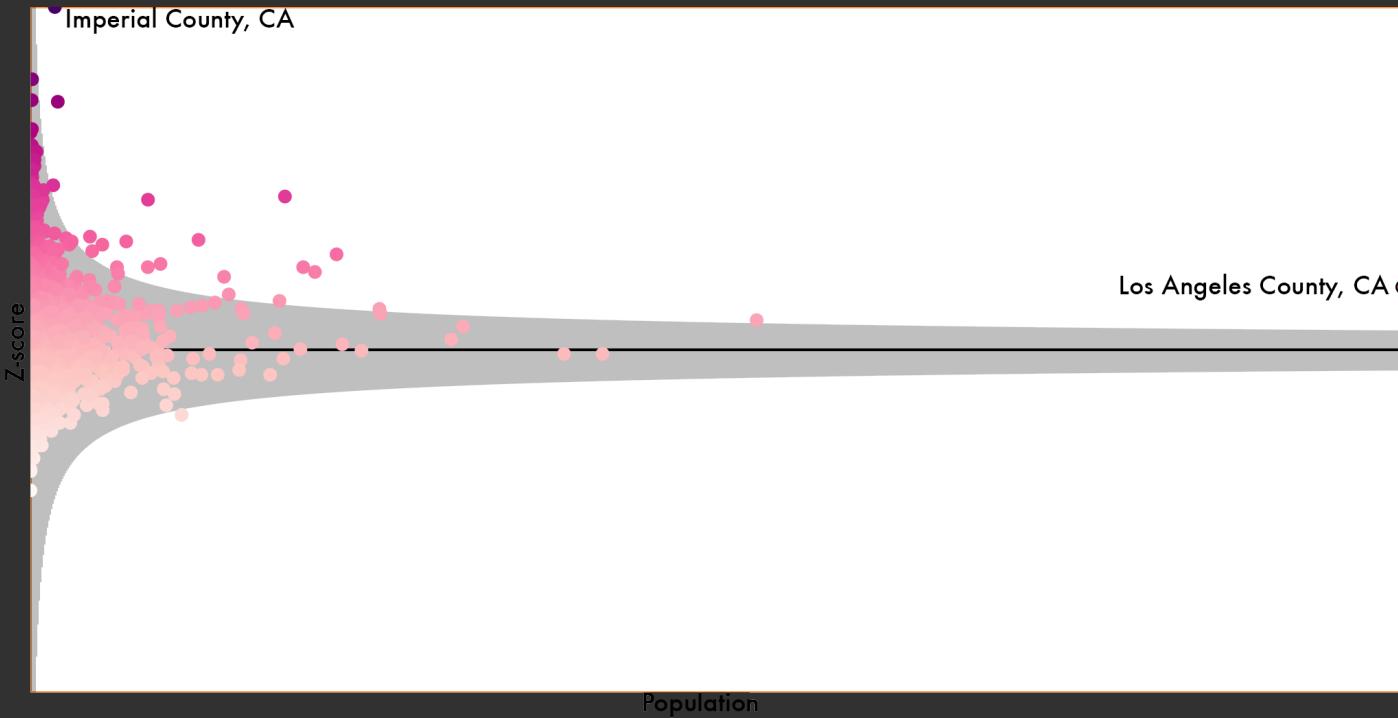
Los Angeles County:
~1.2M unemployed

Funnel Plots



The pros and cons of funnel plots as a risk communication aid for individual decisions about medical treatment. Rakow et al., 2014.

Unemployment Funnel



Unemployment Funnel



Unemployment Funnel

