PLACE & SPACE IN MULTILEVEL MODELS

TOWARDS MORE USEFUL GEOGRAPHY IN MULTILEVEL MODELS

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THE GEOGRAPHIC DICHOTOMY

DEFINING A CLASSIC MODEL

IS PLACE JUST ABOUT GROUP?

DOES IT REALLY MATTER?

THE GEOGRAPHIC DICHOTOMY

a core tension in geographic analysis

DEFINING A CLASSIC MODEL

IS PLACE JUST ABOUT GROUP?

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SPACE

PLACE

SPACE PLACE

Understanding the New Human Dynamics in Smart Spaces and Places: Toward a Splatial Framework

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†Department of Geosciences, University of Arkansas

SPACE

PLACE

SPACE

The geographic system over which objects of study are related.

- Earth Surface
- Road Systems
- Social Networks
- Economic Relations

PLACE

Geographic entities that are constructed by distinctiveness.

- Regions
- Neighborhoods
- Home/Staying locales
- Functional classifications

SPACE

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- Earth Surface
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PLACE

Geographic entities that are constructed by distinctiveness.

How or why do they emerge?
What are their properties?
What are their purpose?
Do they have effects on things we care about?

SPACE

The geographic system over which objects of study are related.

How do things interact?
Over what spatial systems?
In what manner?
What impact do entities have on others nearby?

PLACE

Geographic entities that are constructed by distinctiveness.

How or why do they emerge?
What are their properties?
What are their purpose?
Do they have effects on things we care about?

SPACE

The geographic system over which objects of study are related.

Dependence:

Nearby things are more related than distant things

PLACE

Geographic entities that are constructed by distinctiveness.

Dependence:

Things in the same place are more related than things in different places

THE GEOGRAPHIC DICHOTOMY

space & place are core to geography

DEFINING A CLASSIC MODEL

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THE GEOGRAPHIC DICHOTOMY

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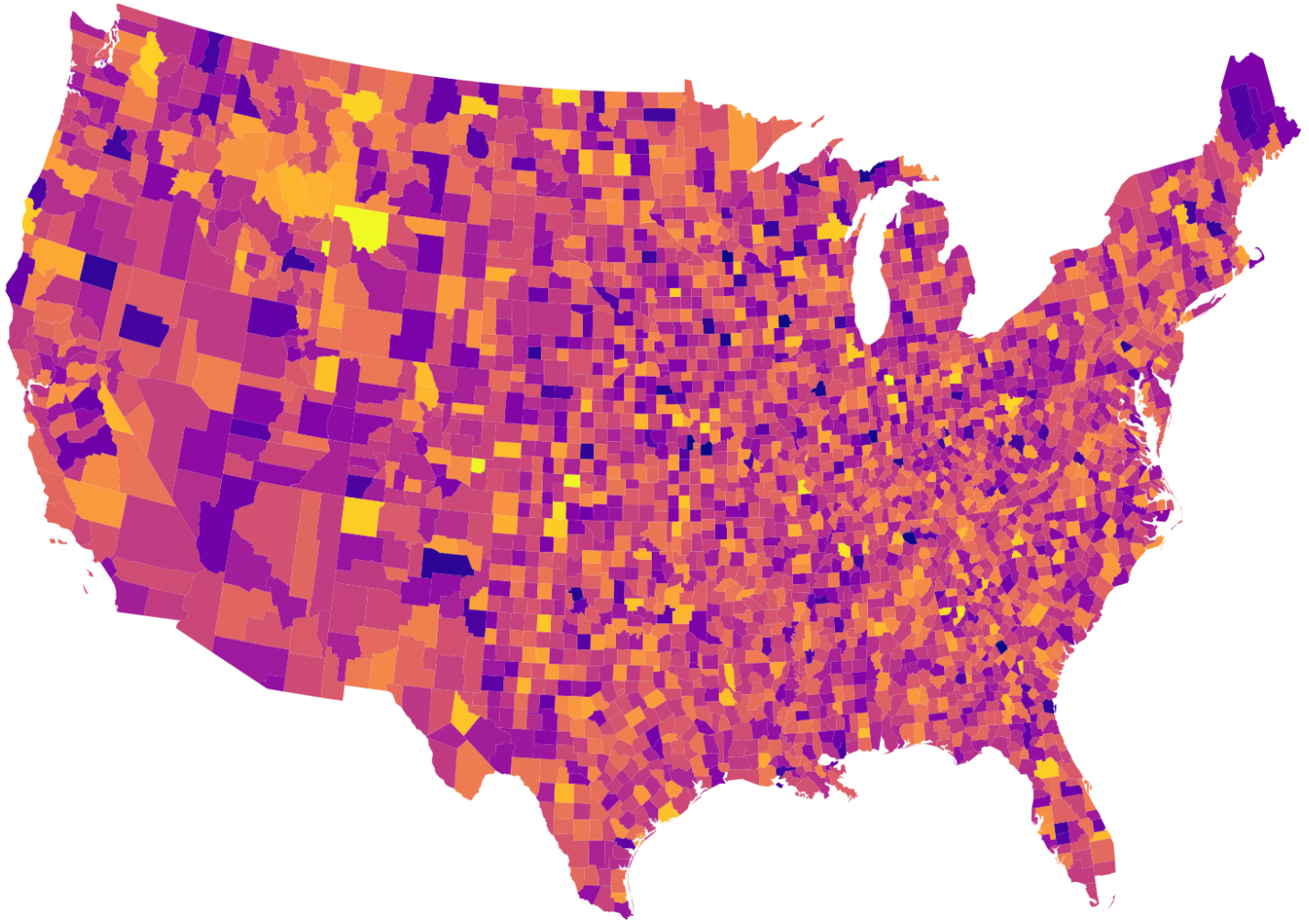
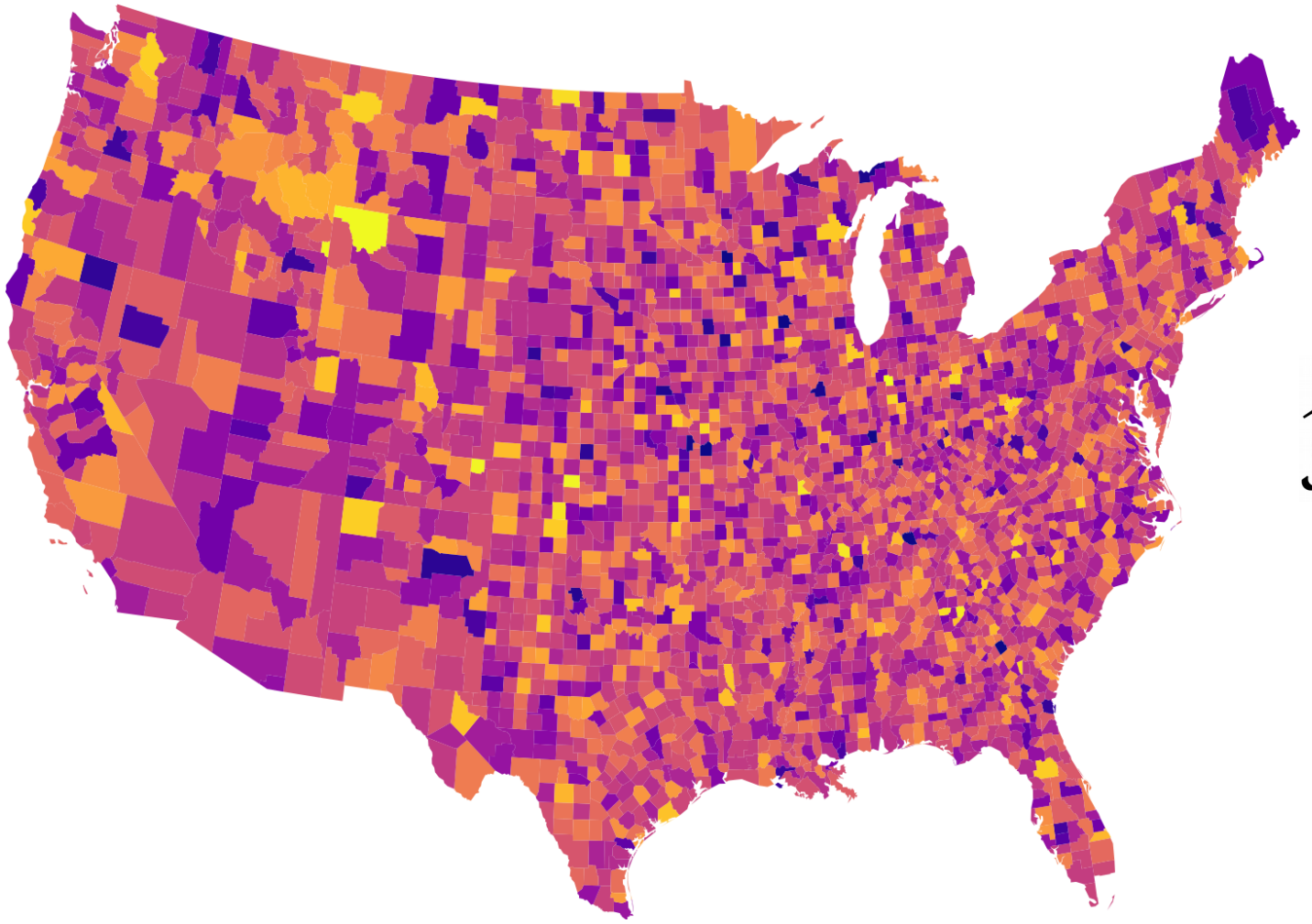
DEFINING A CLASSIC MODEL

actually, we'll need a few

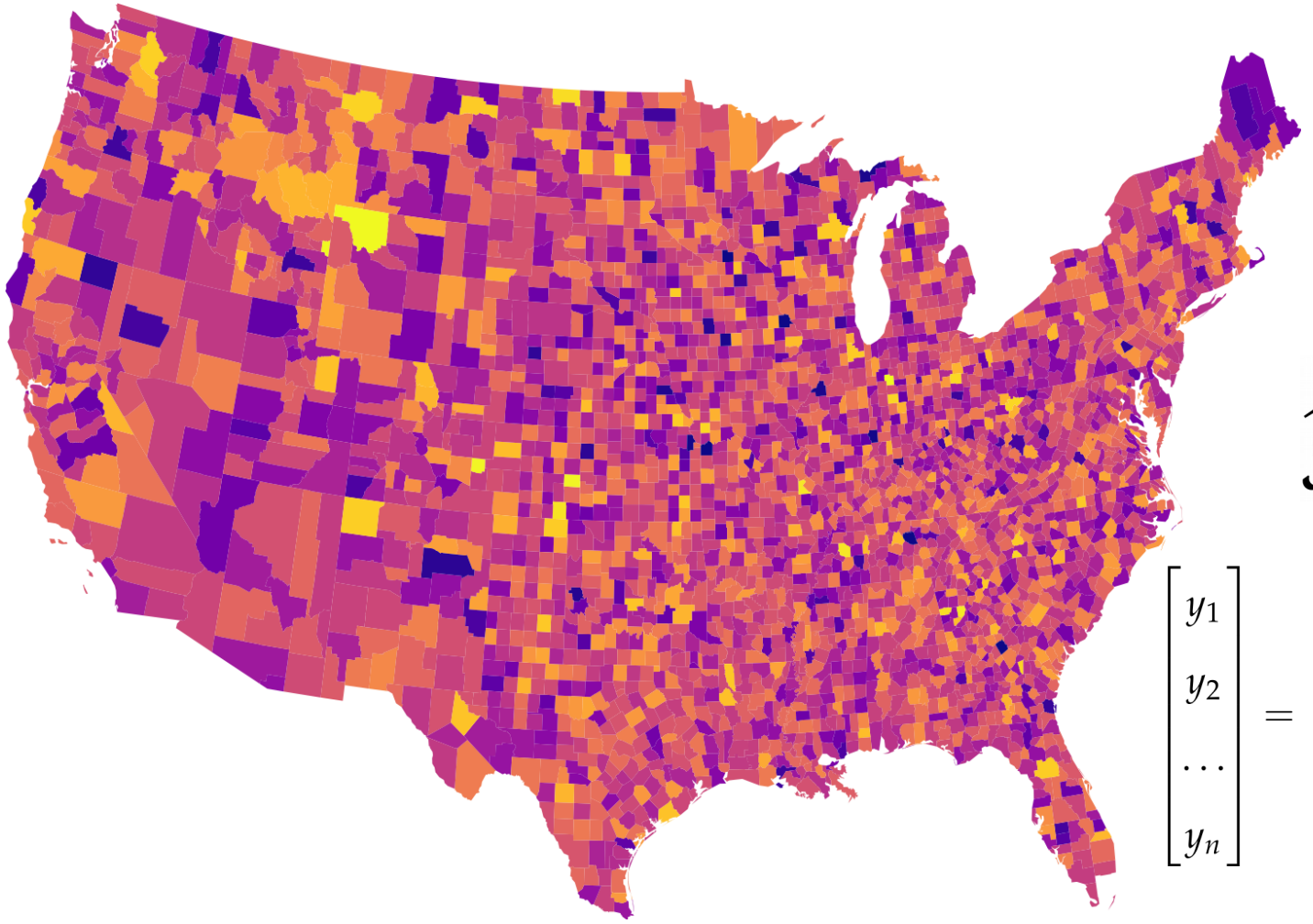
IS PLACE JUST ABOUT GROUP?

DOES IT REALLY MATTER?



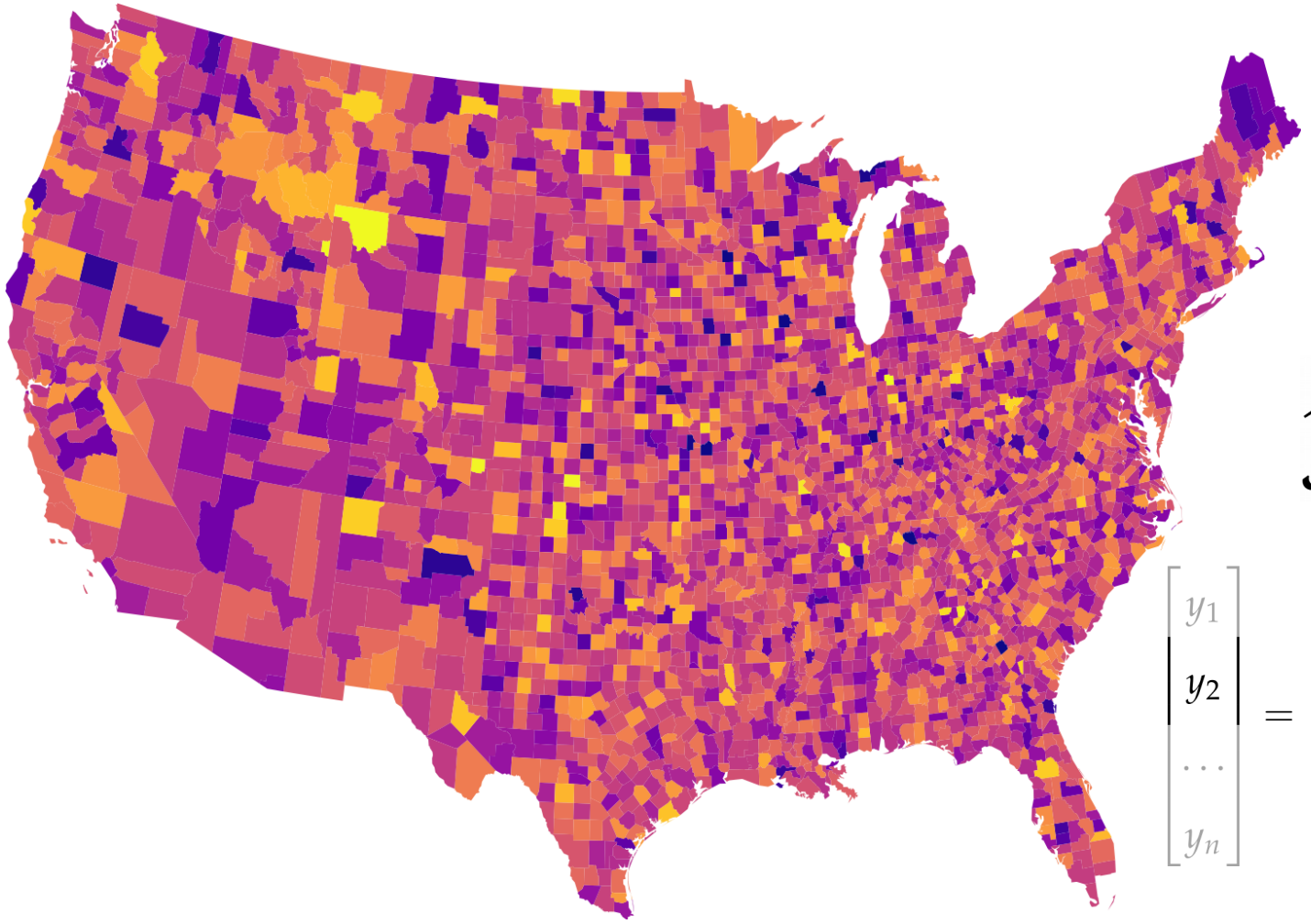


$$y = \mathbf{X}\beta + \epsilon$$



$$y = \mathbf{X}\beta + \epsilon$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_n \end{bmatrix} = \begin{bmatrix} x_{1,1} & x_{1,2} & \dots & x_{1,P} \\ x_{2,1} & x_{2,2} & \dots & x_{2,P} \\ \vdots & & \ddots & \vdots \\ x_{N,1} & x_{N,2} & \dots & x_{N,P} \end{bmatrix} \beta + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_N \end{bmatrix}$$



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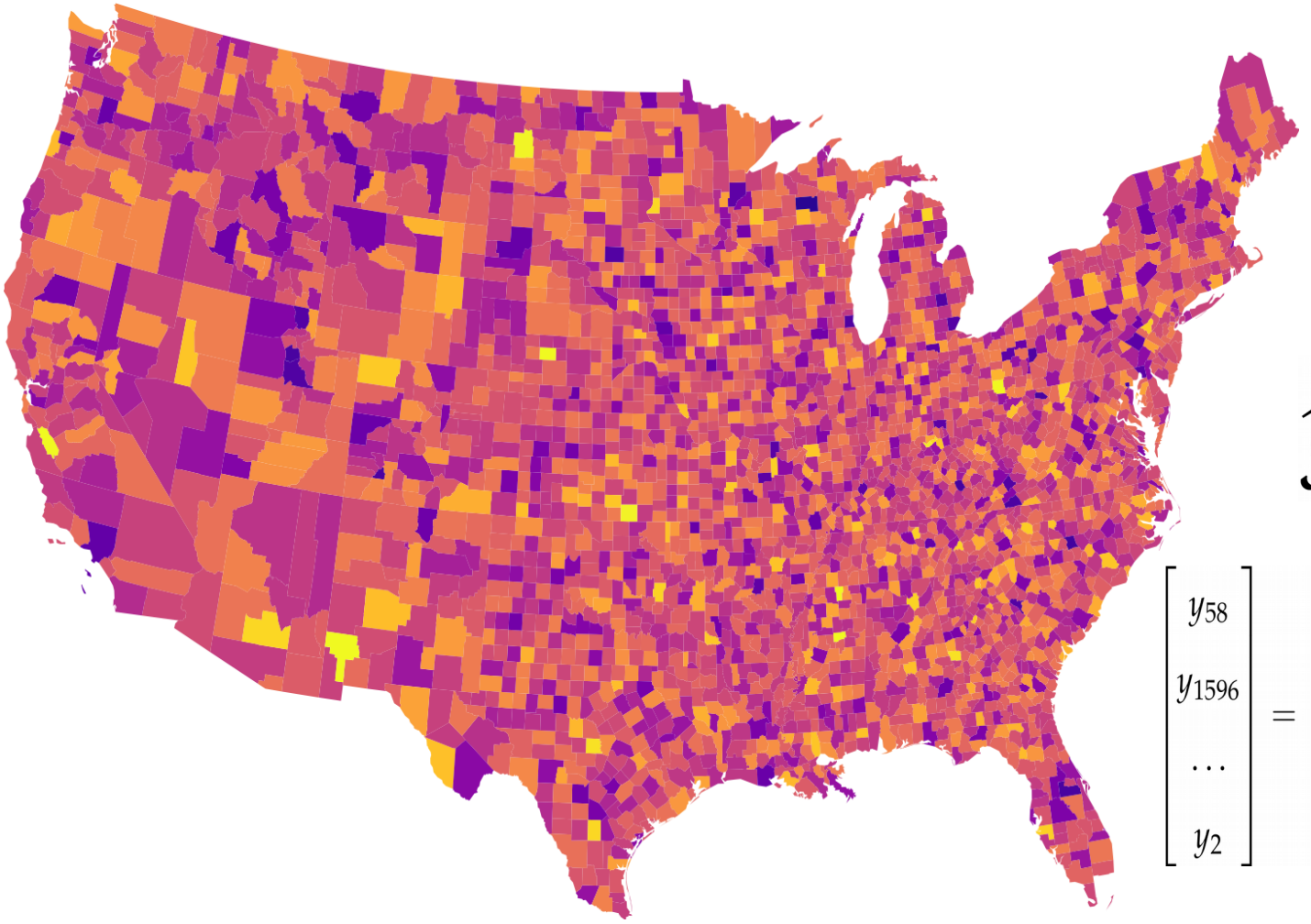
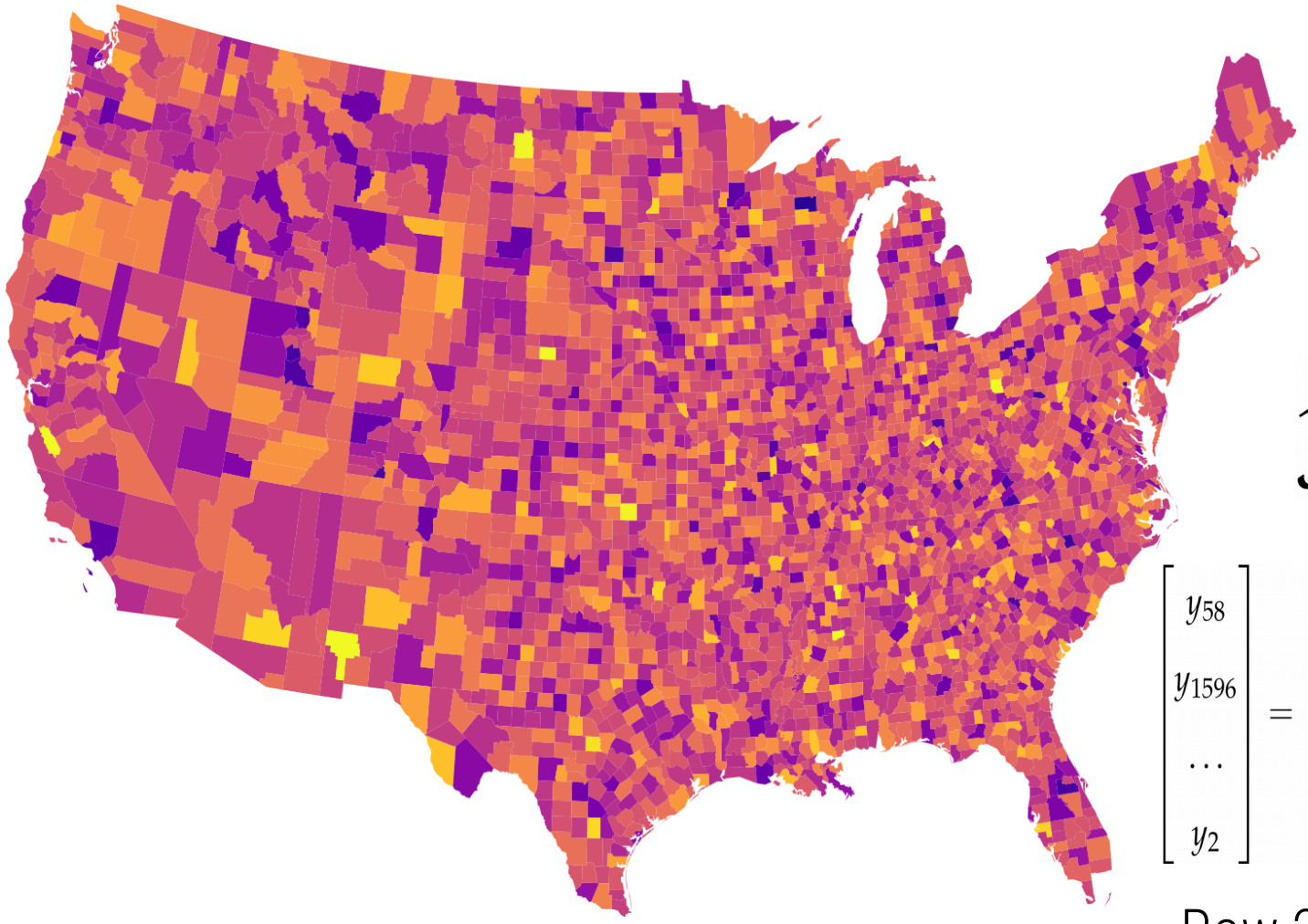
Outcome at site 2 is a function of our measurements at site 2, plus a random error term



$$y = \mathbf{X}\beta + \epsilon$$

$$\begin{bmatrix} y_{58} \\ y_{1596} \\ \dots \\ y_2 \end{bmatrix} = \begin{bmatrix} x_{58,1} & x_{58,2} & \dots & x_{58,P} \\ x_{1596,1} & x_{1596,2} & \dots & x_{1596,P} \\ \vdots & & \ddots & \vdots \\ x_{2,1} & x_{2,2} & \dots & x_{2,P} \end{bmatrix} \beta + \begin{bmatrix} \epsilon_{58} \\ \epsilon_{1596} \\ \vdots \\ \epsilon_2 \end{bmatrix}$$



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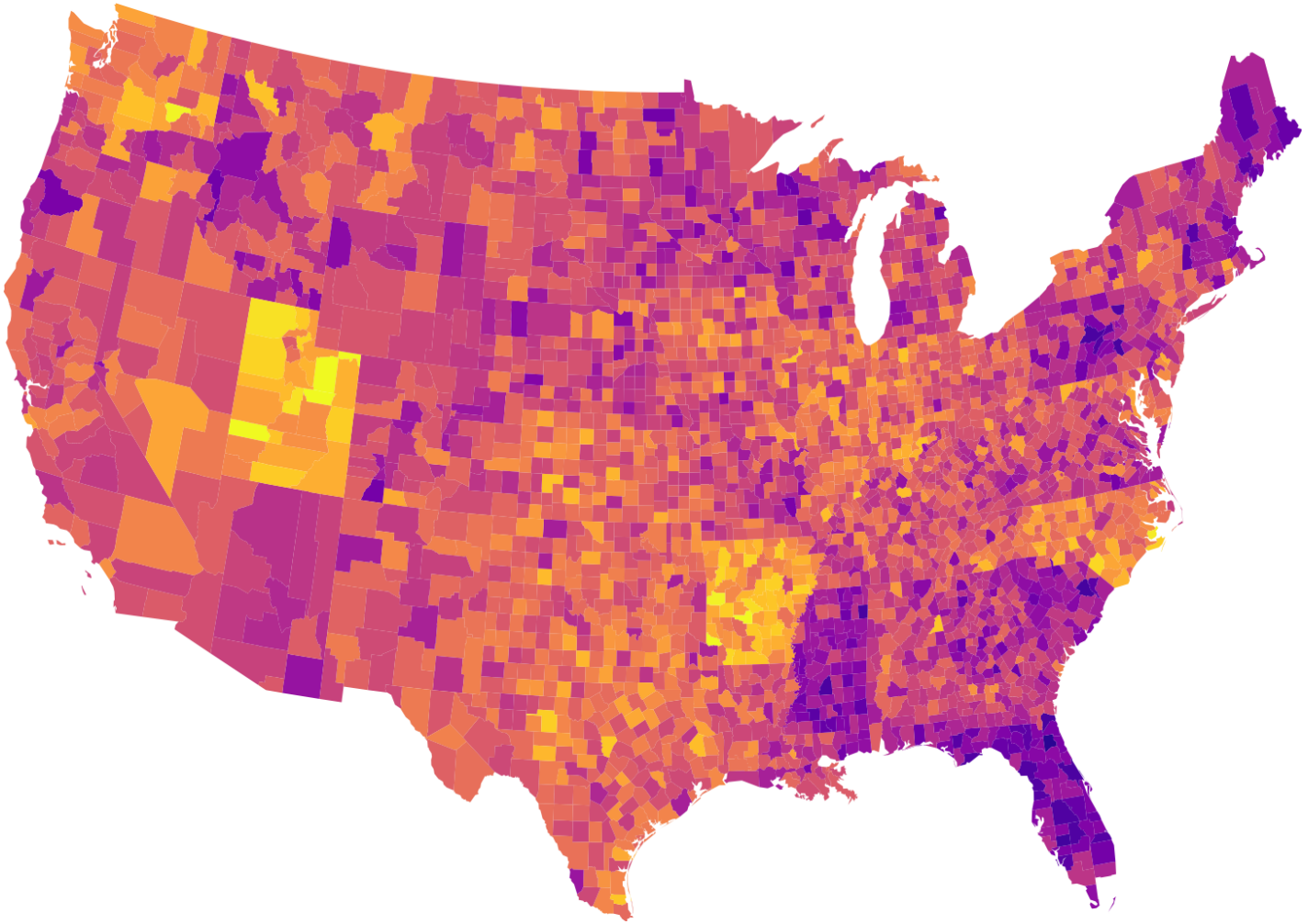
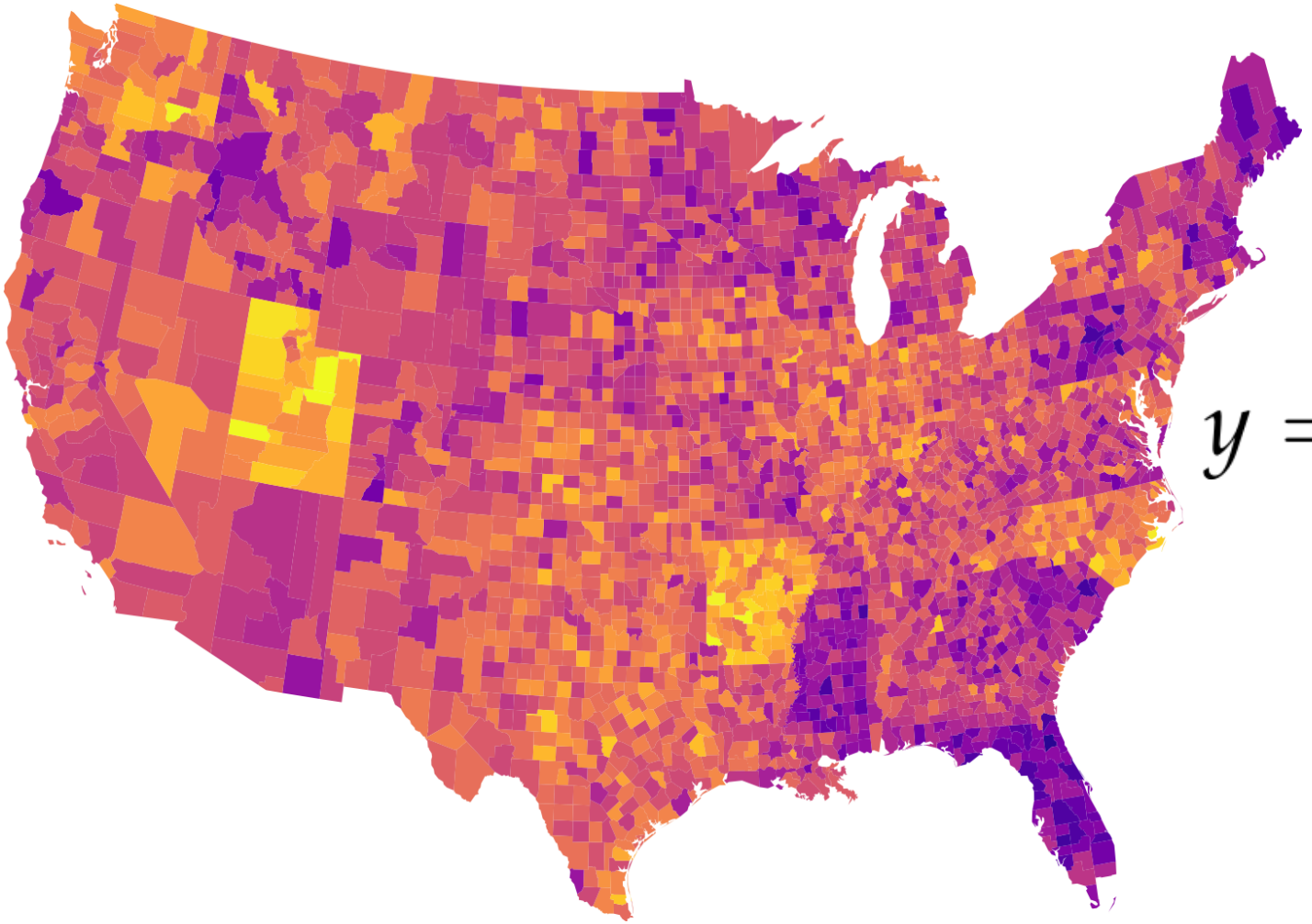
Row 2 is no longer site 2!

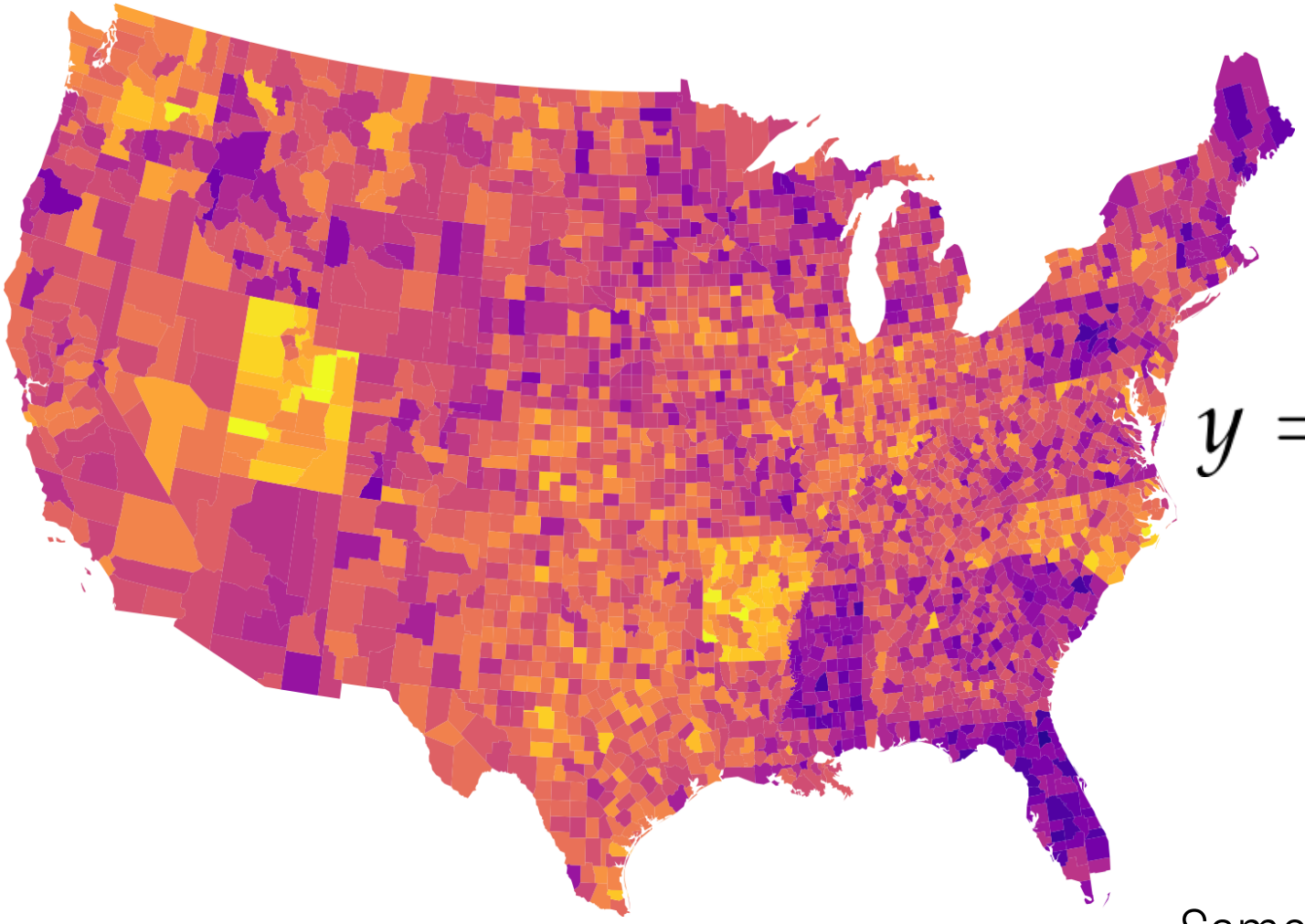
The geography has changed!

The model can't "see" this!



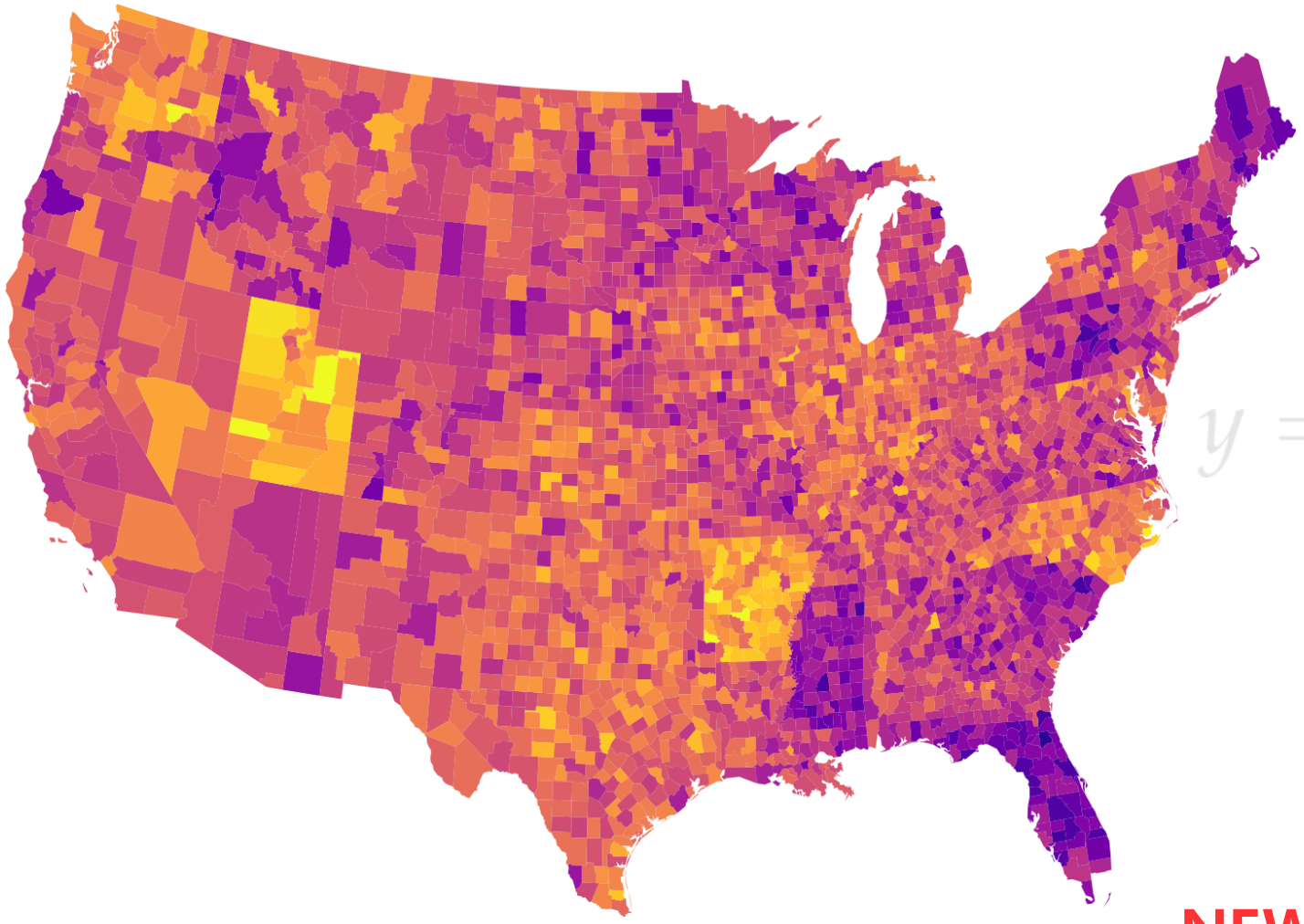


$$y = \mathbf{X}\beta + \mathbf{\Delta}u + \epsilon$$



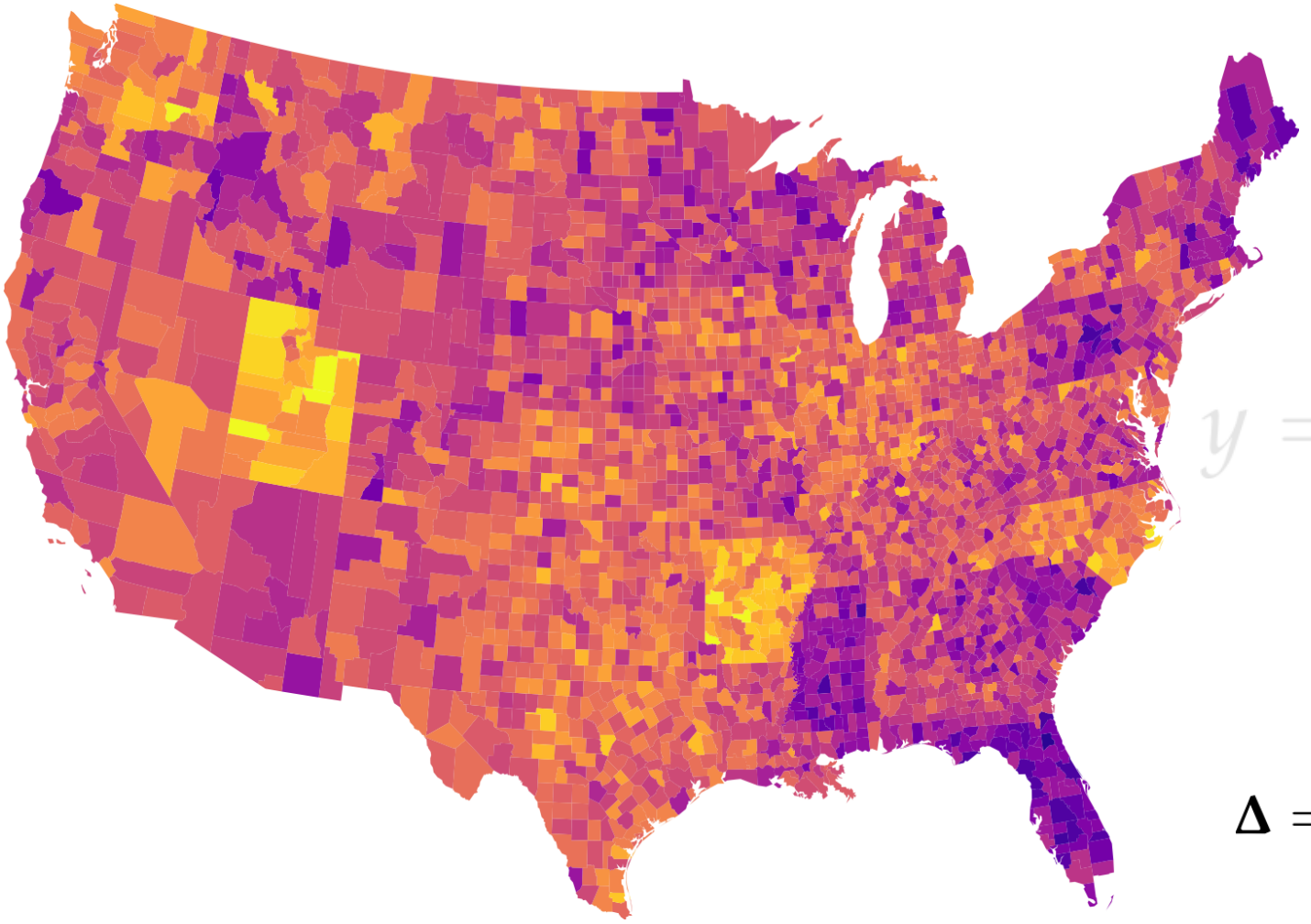
$$y = \mathbf{X}\beta + \Delta u + \epsilon$$

Same individual level factors we saw before



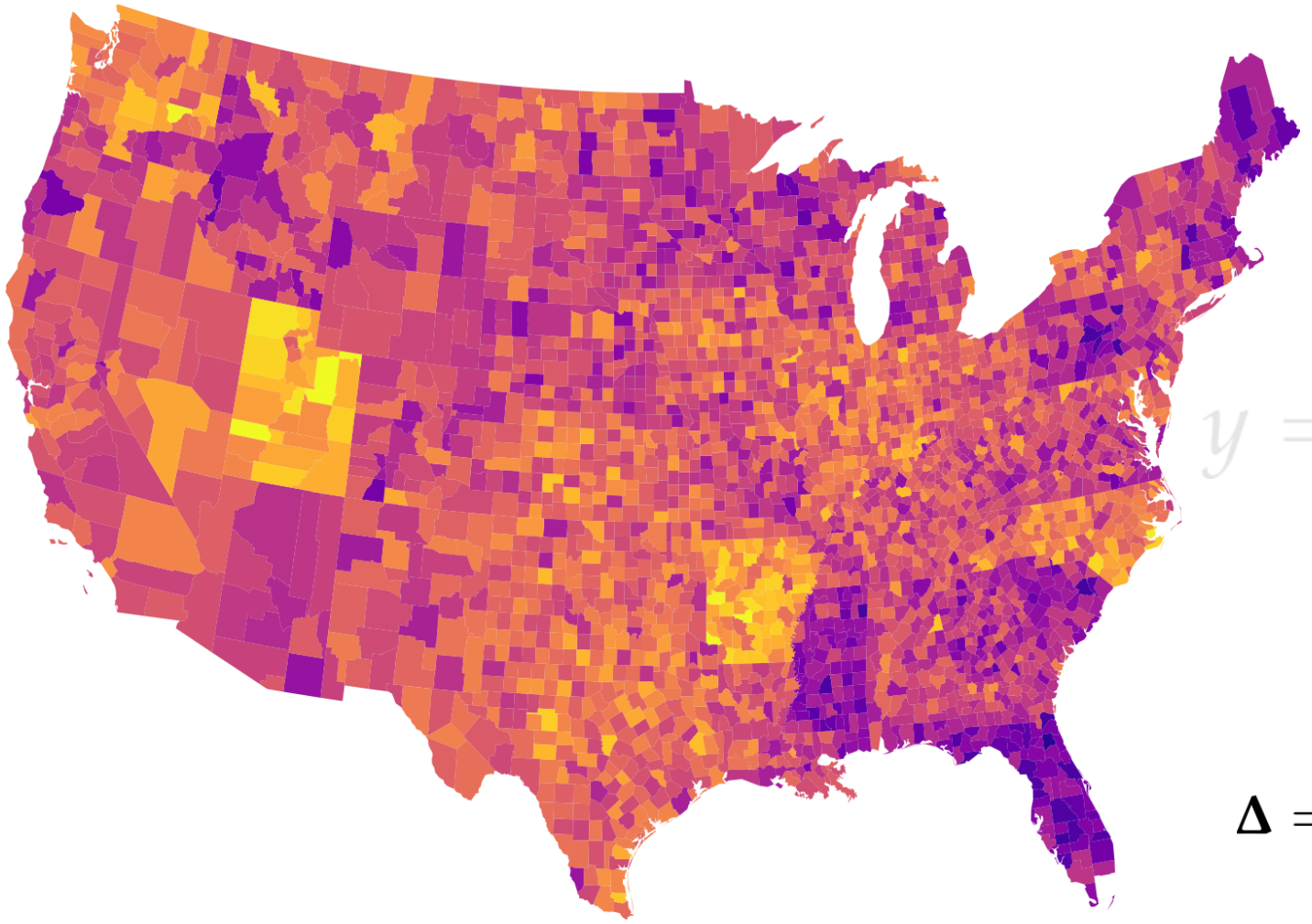
$$y = X\beta + \Delta u + \epsilon$$

NEW group-level factors
that pertain to each “group”



$$y = X\beta + \Delta u + \epsilon$$

$$\Delta = \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ 1 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & \dots & 0 \\ \vdots & & & \ddots & \vdots \end{bmatrix}$$



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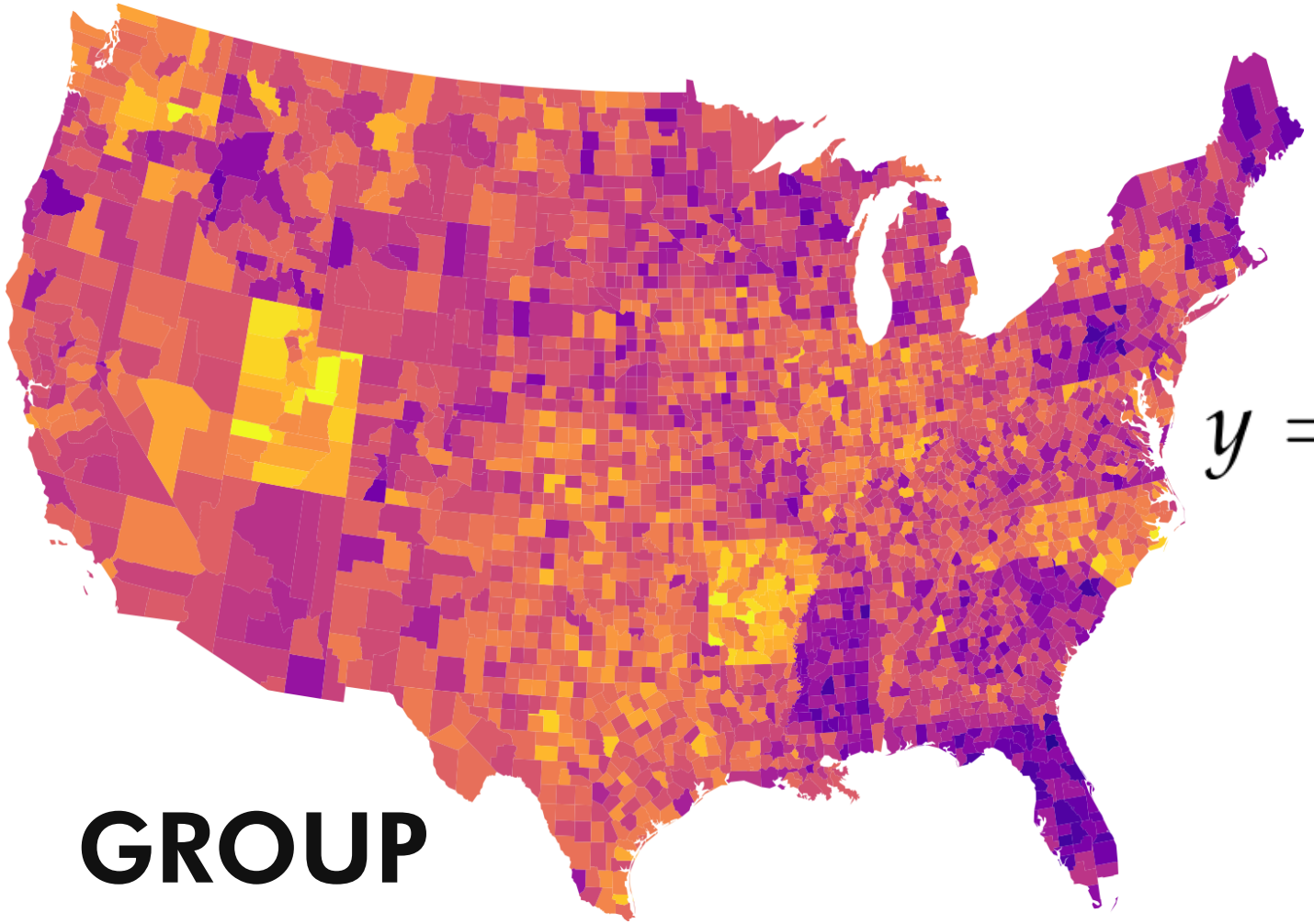

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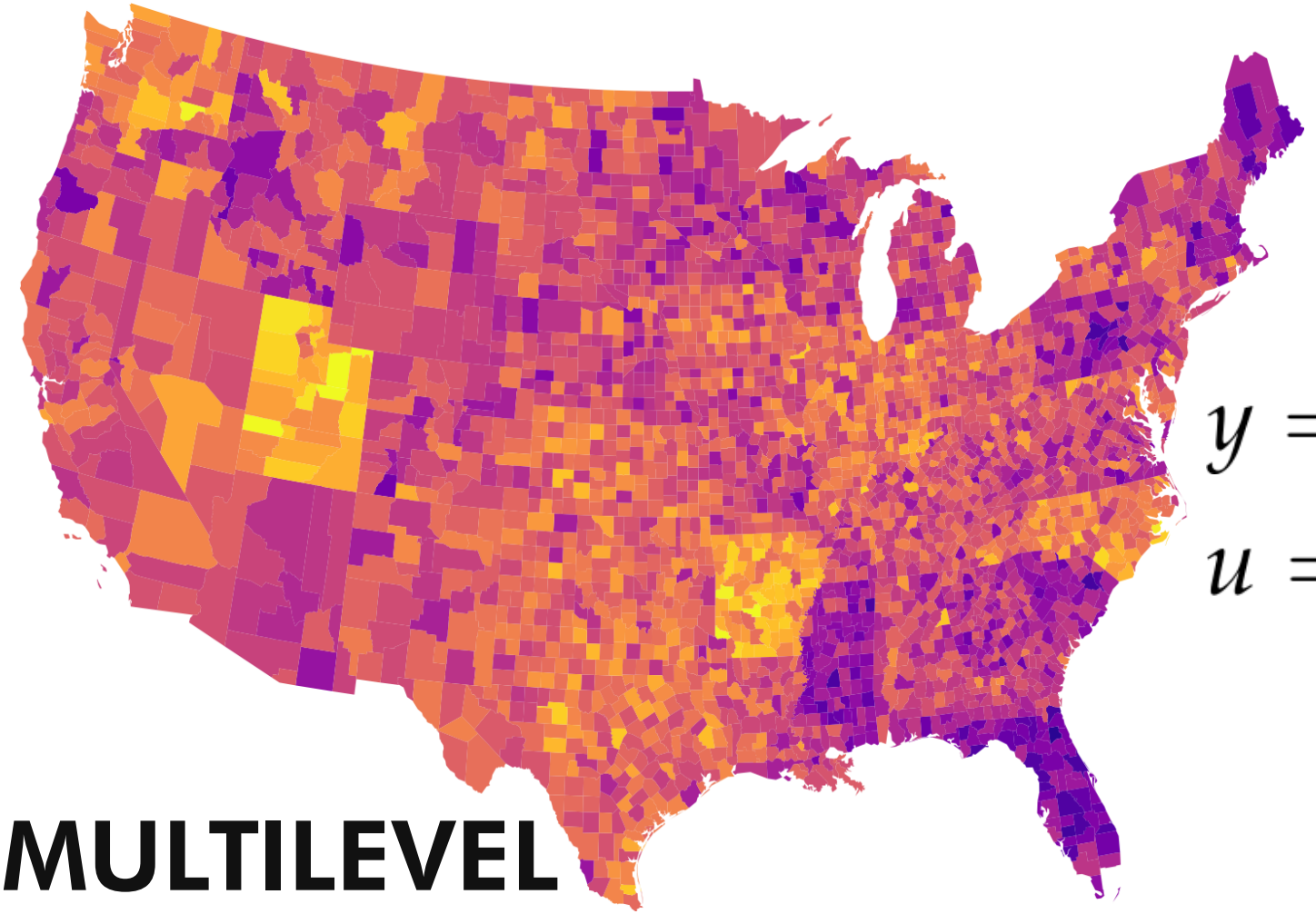
GROUP FIXED EFFECTS

Give groups separate intercepts.

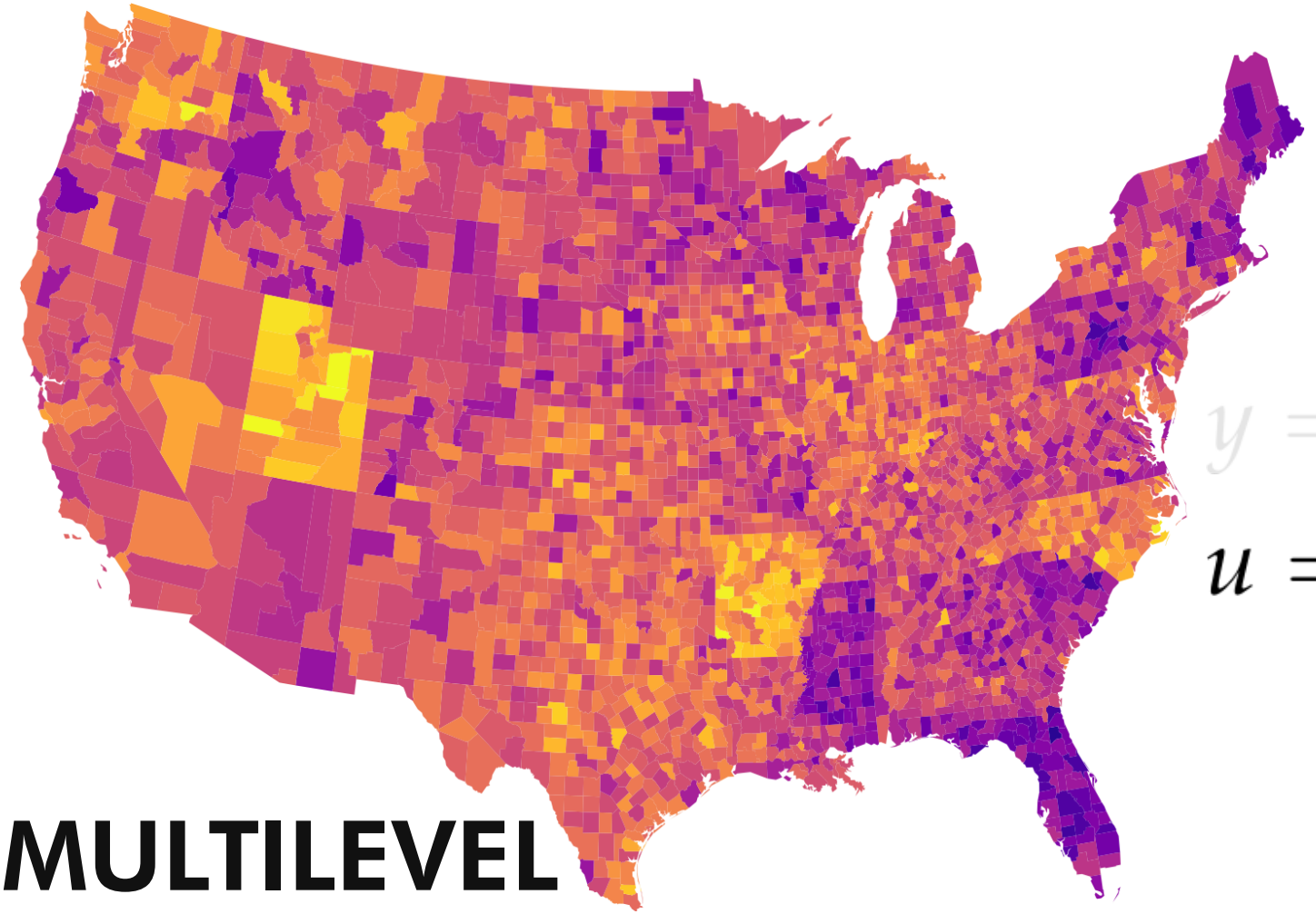


$$y = \mathbf{X}\beta + \mathbf{\Delta}u + \epsilon$$

$$u = a + \mathbf{Z}\gamma + \zeta$$

MULTILEVEL VARYING INTERCEPTS

Give groups separate intercepts.
Have a theory as to why/how they're different.



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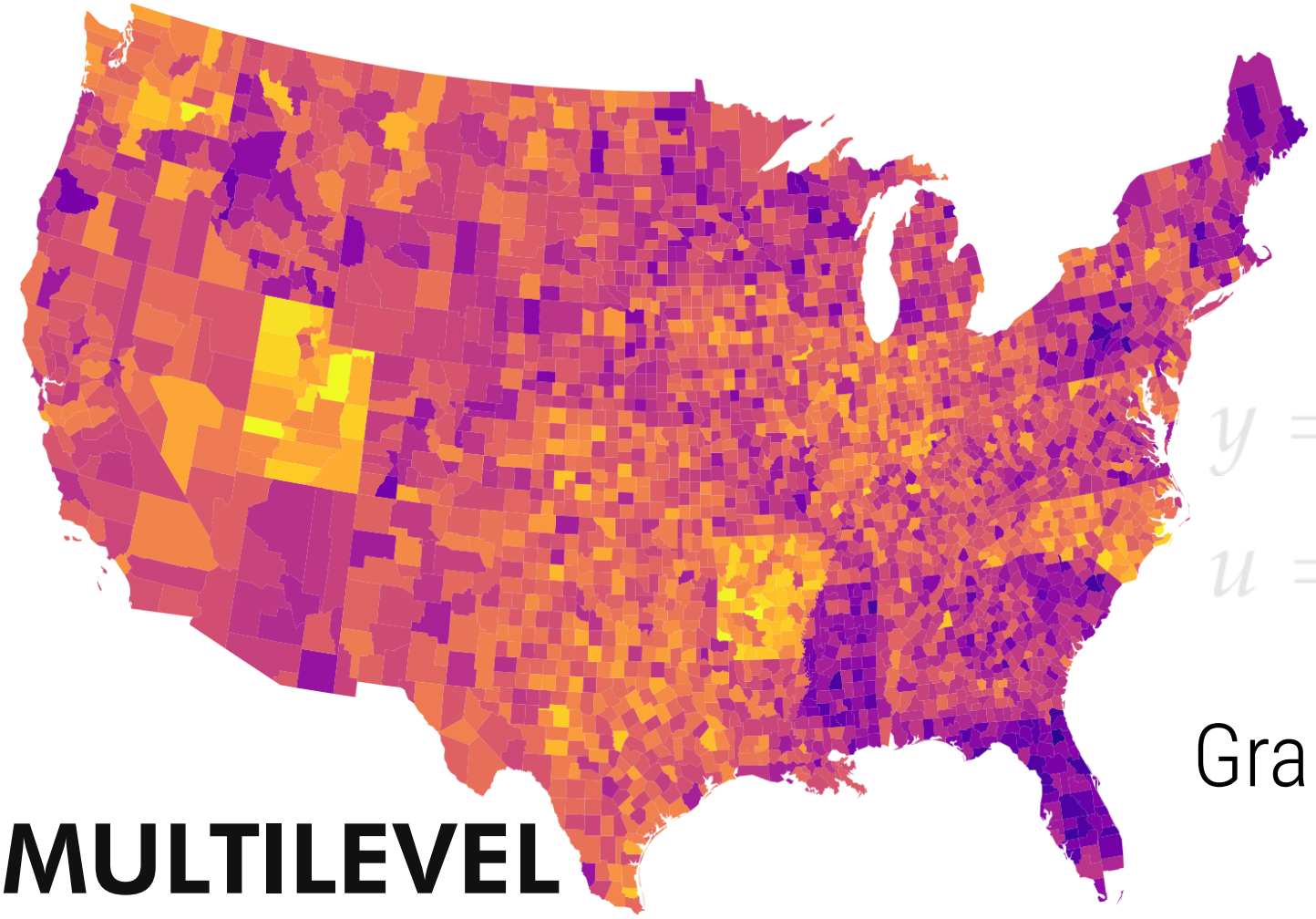

$$y = \mathbf{X}\beta + \Delta u + \epsilon$$

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Grand mean

MULTILEVEL VARYING INTERCEPTS

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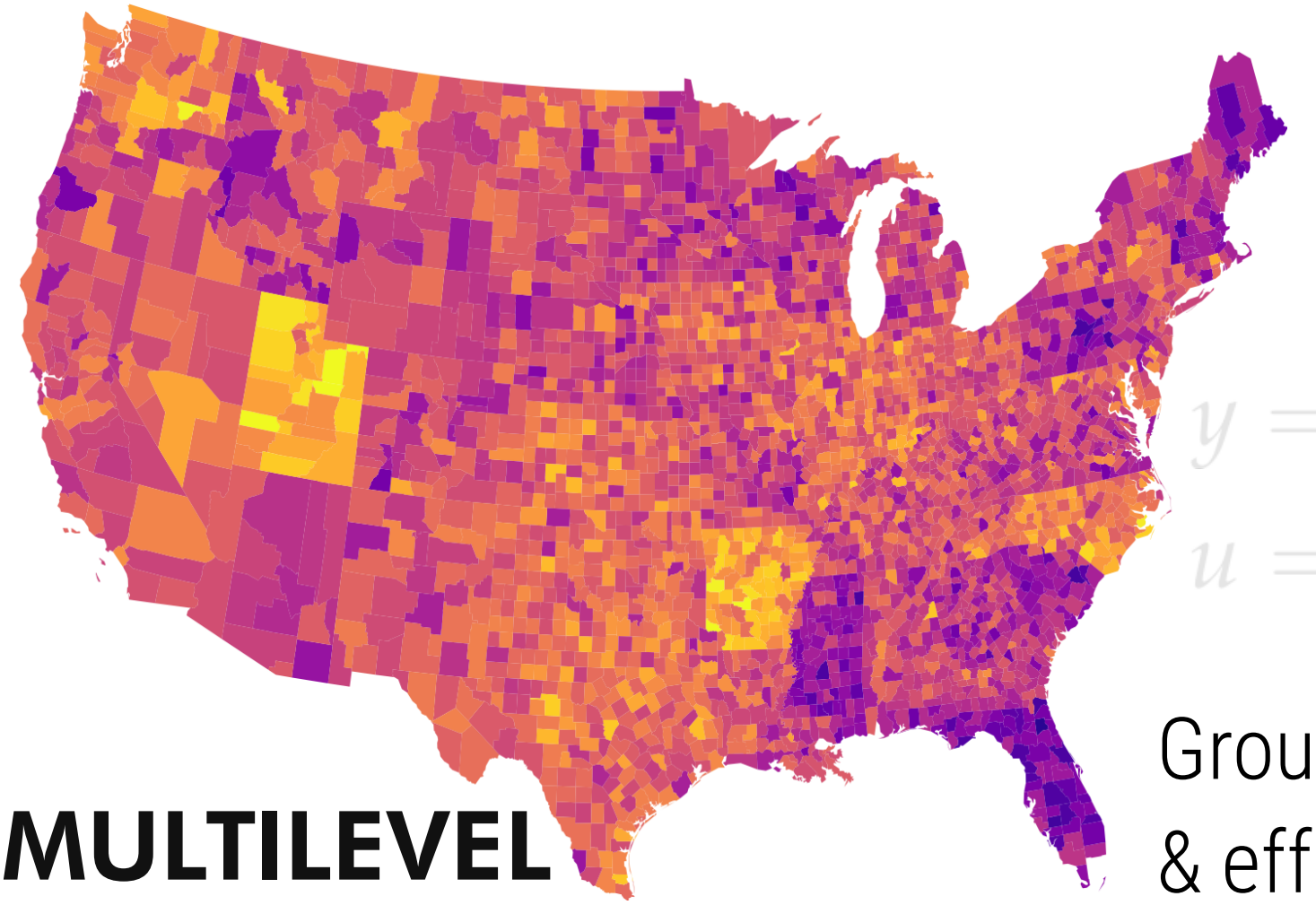


MULTILEVEL VARYING INTERCEPTS

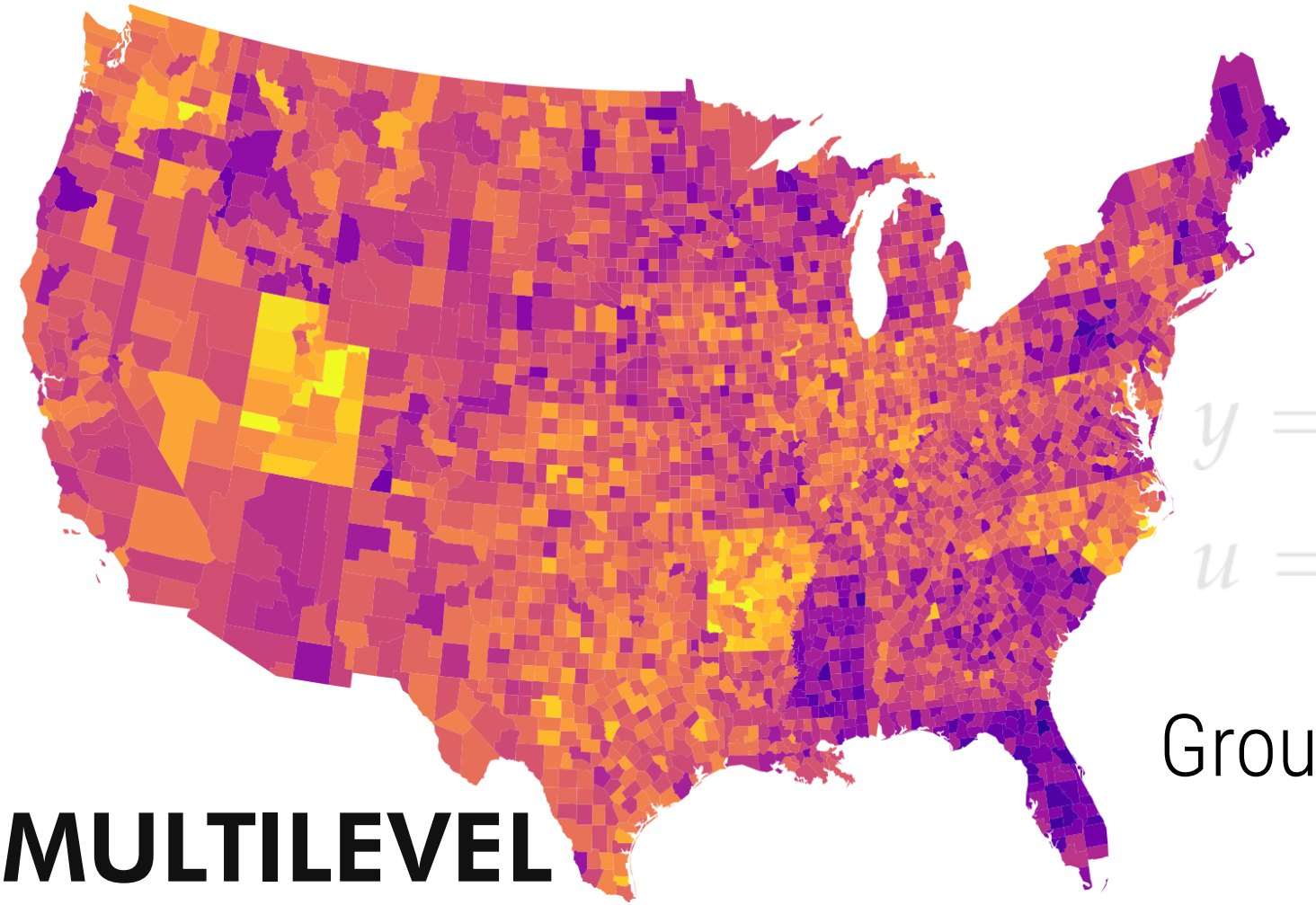
$$y = \mathbf{X}\beta + \Delta u + \epsilon$$

$$u = a + \mathbf{Z}\gamma + \zeta$$

Group-level data ($\mathbf{Z}$) & effects (γ)

Give groups separate intercepts.

Have a theory as to why/how they're different.



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Group-level error

MULTILEVEL VARYING INTERCEPTS

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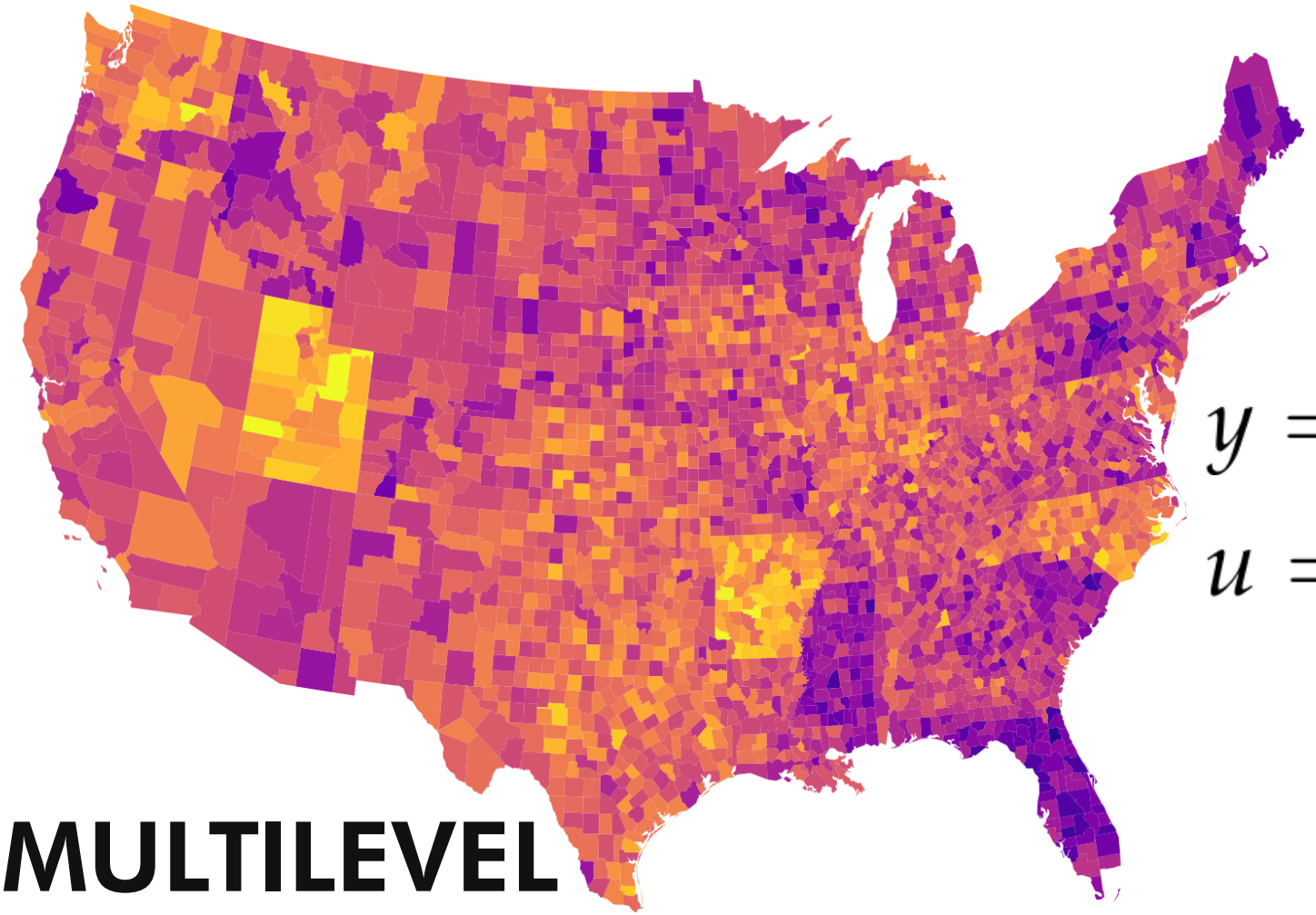


$$y = \Delta u + \epsilon$$

$$u = a + \zeta$$

MULTILEVEL VARYING INTERCEPTS

Even without $\mathbf{Z}$,$\mathbf{X}$, these give more precise but biased estimates (Gelman & Hill, 2006)

$$\hat{u}_{j,ols} = \frac{\sum_{i \in j} y_i}{n_j}$$

FIXED EFFECT ESTIMATES

The group intercept is the average of observations within the group.

(Gelman & Hill, 2006)

$$\hat{u}_{j,mlm} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\sigma_e^2}{n_j}} \hat{u}_{j,ols}$$

MULTILEVEL INTERCEPT ESTIMATES

The group intercept is the average of observations within the group,

biased towards zero!

(Gelman & Hill, 2006)

$$\hat{u}_{j,mlm} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\sigma_e^2}{n_j}} \hat{u}_{j,ols}$$

SHRINKAGE FACTOR

n_j : Group size

σ_e^2 : w/in group variation

σ_u^2 : between group variation

(Gelman & Hill, 2006)

$$\hat{u}_{j,mlm} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\sigma_e^2}{n_j}} \hat{u}_{j,ols}$$

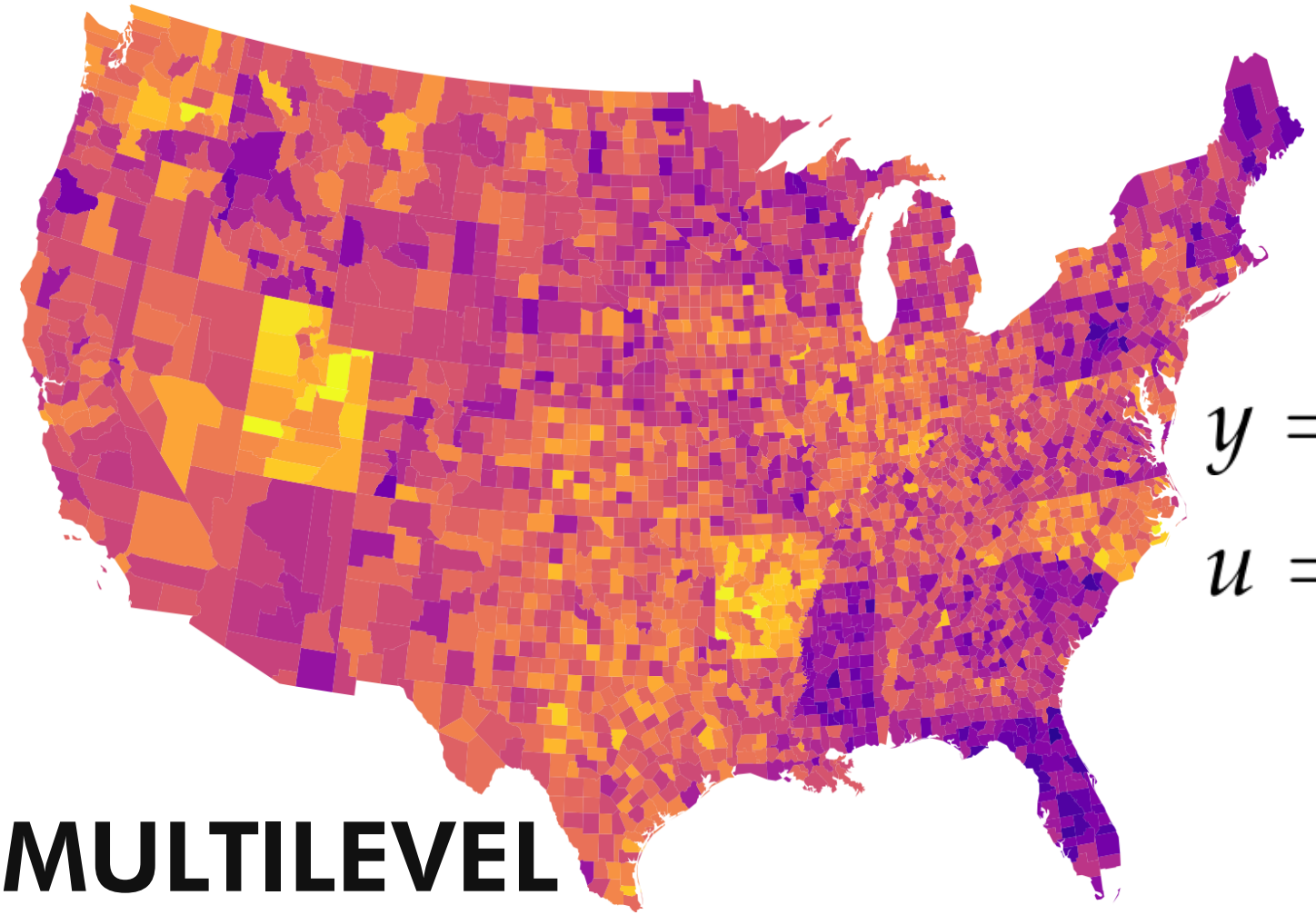
SHRINKAGE FACTOR

Small groups shrink more than big groups

Problems with noisy groups shrink more

Problems with similar groups shrink more

(Gelman & Hill, 2006)



$$y = \Delta u + \epsilon$$

$$u = a + \zeta$$

MULTILEVEL VARYING INTERCEPTS

Observations within my group
are likely more similar to me than others.

THE GEOGRAPHIC DICHOTOMY

space & place are core to geography

DEFINING A CLASSIC MODEL

multilevel models use place to estimate better

IS PLACE JUST ABOUT GROUP?

accidentally geographic models

DOES IT REALLY MATTER?

$$y = \Delta u + \epsilon$$

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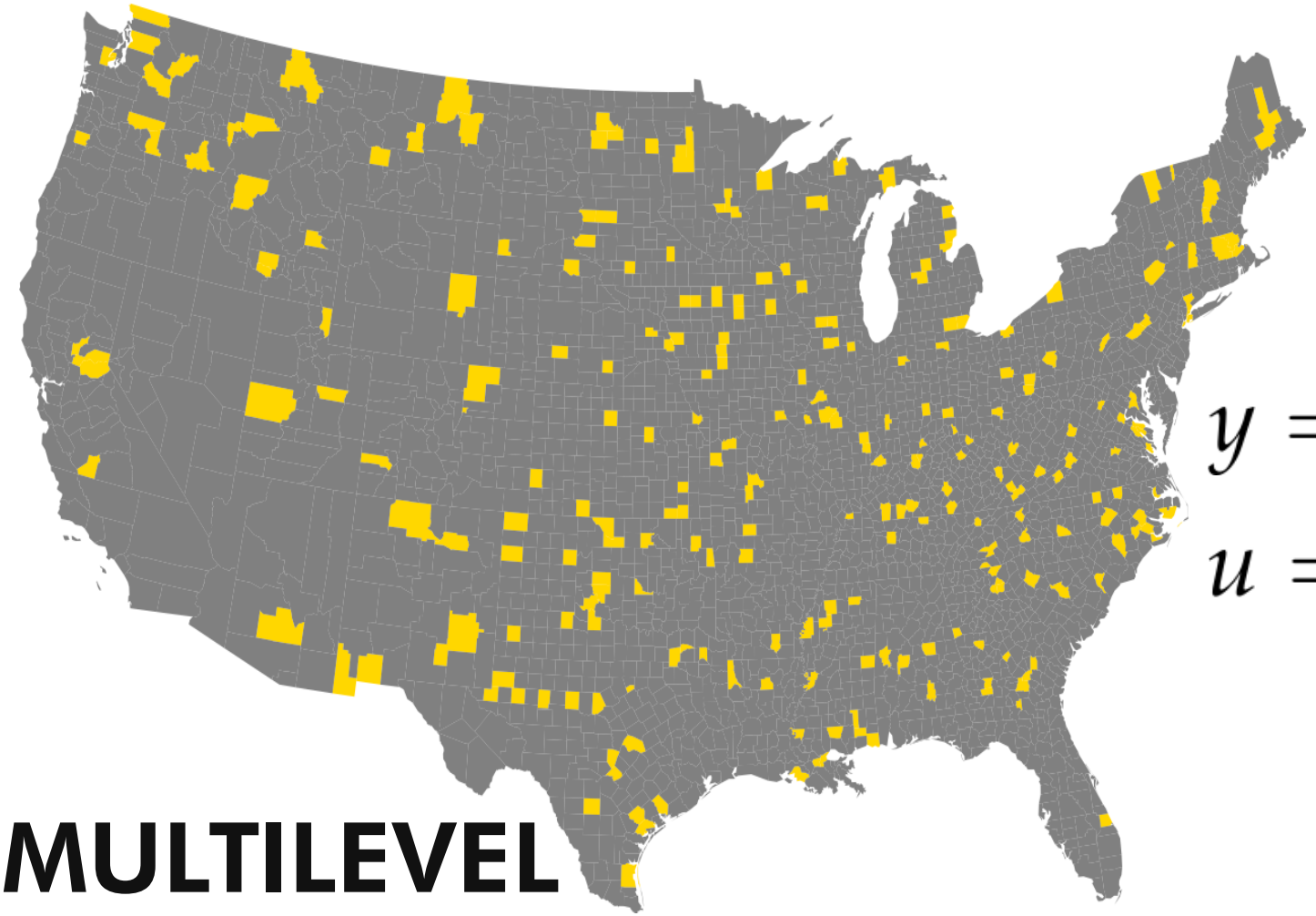
MULTILEVEL VARYING INTERCEPTS

Give **groups** separate intercepts.
Have a theory as to why/how they're different.



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MULTILEVEL VARYING INTERCEPTS

Give **groups** separate intercepts.

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MLMS ARE GEOGRAPHIC ONLY IF THEIR GROUPS ARE

$$y = \Delta u + \epsilon$$

$$u = a + \zeta$$

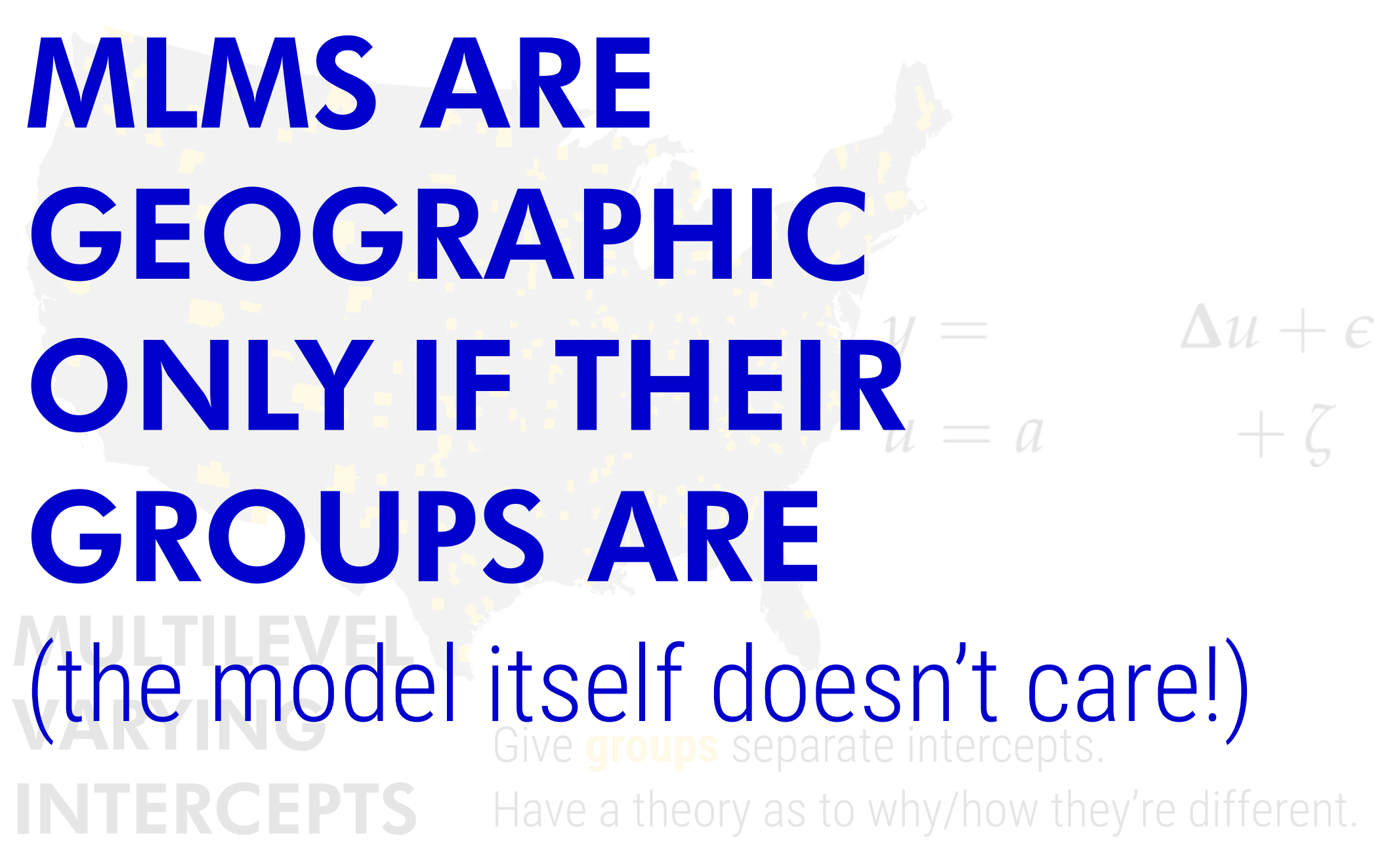
MULTILEVEL VARYING INTERCEPTS

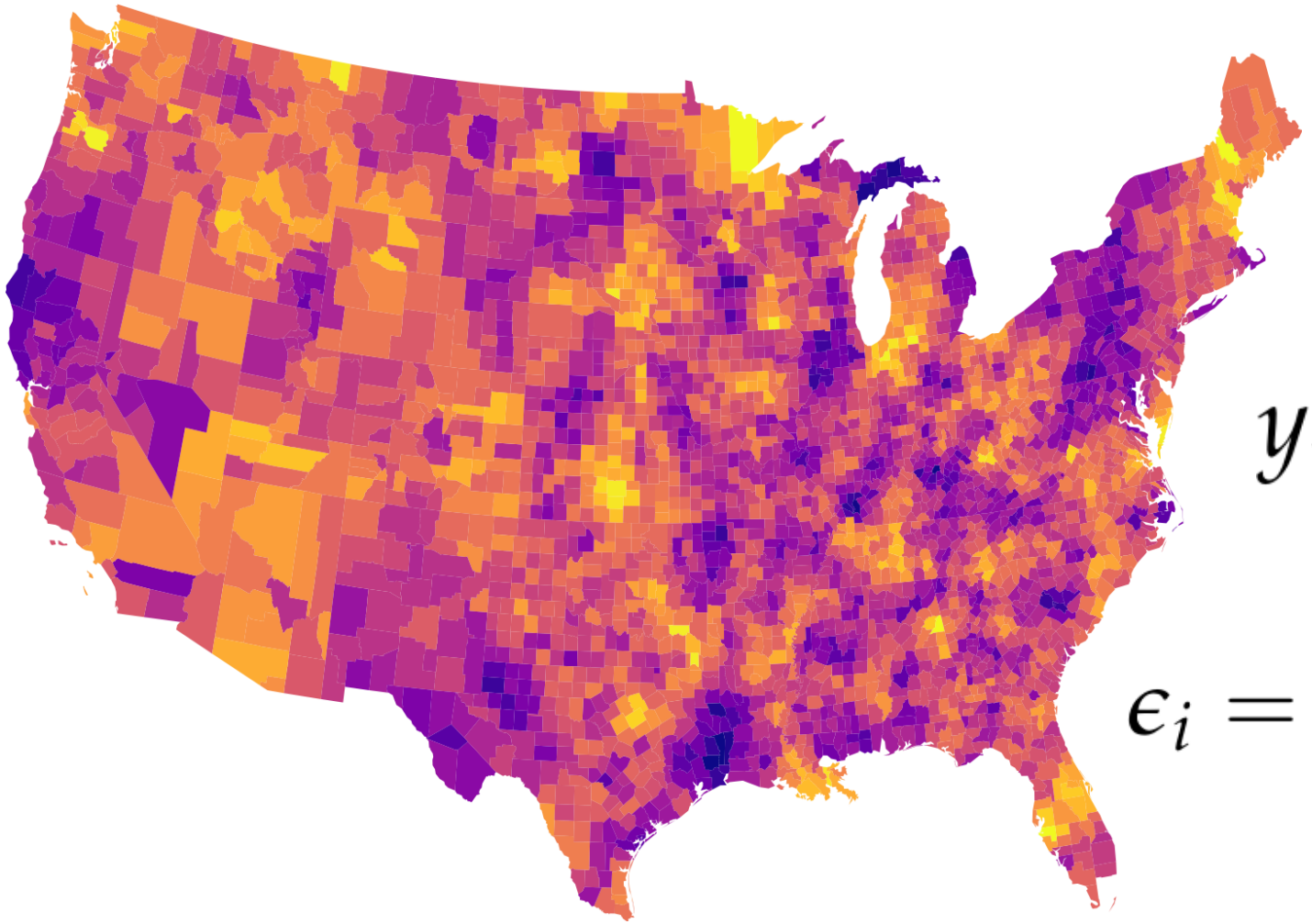
Give **groups** separate intercepts.

Have a theory as to why/how they're different.

MLMS ARE GEOGRAPHIC ONLY IF THEIR GROUPS ARE

(the model itself doesn't care!)

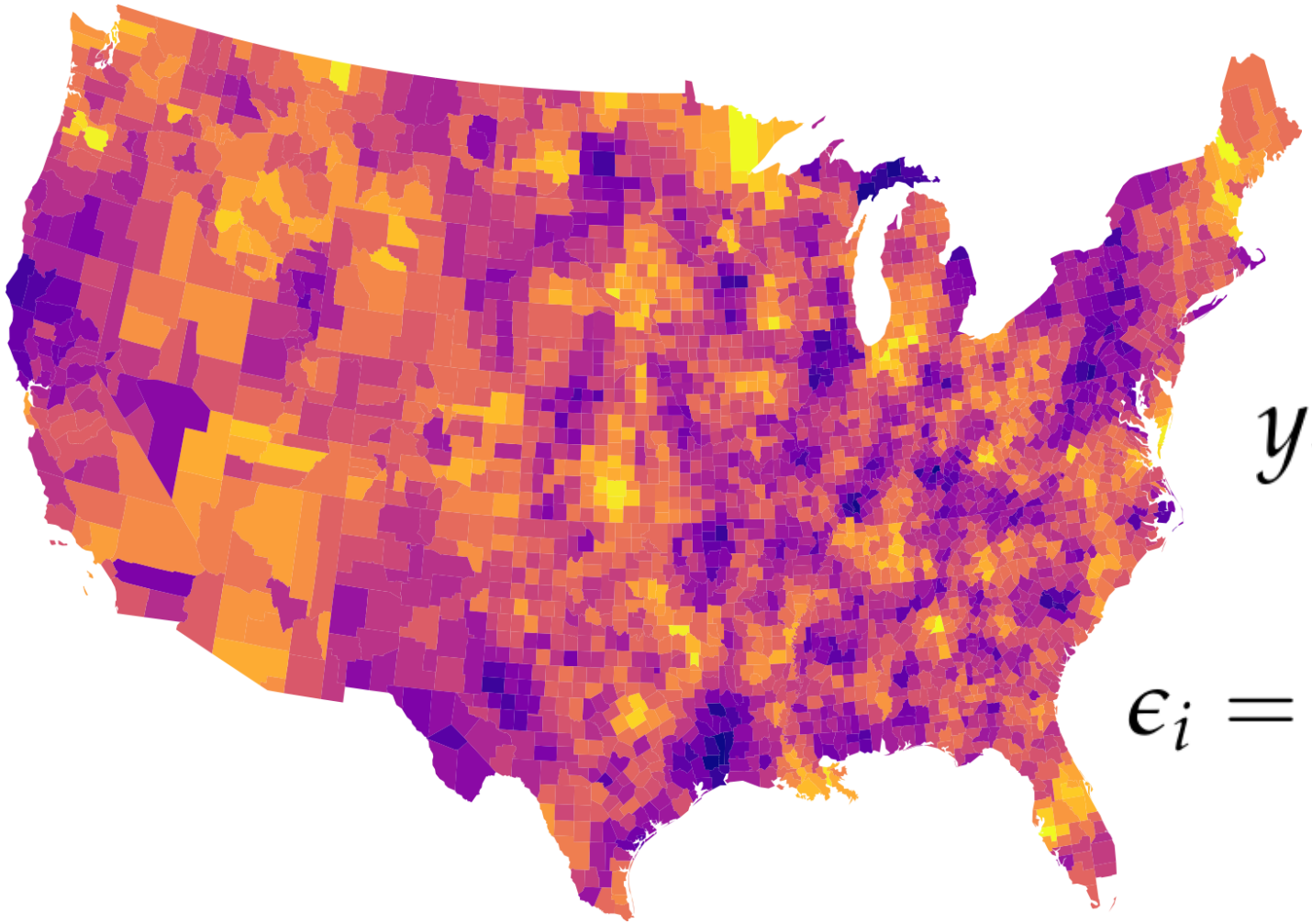




$$y_i = u_{j[i]} + \epsilon_i$$

$$\epsilon_i = \lambda \sum_{i}^{N} w_{ij}\epsilon_j + e_i$$

SIMULTANEOUS AUTOREGRESSIVE



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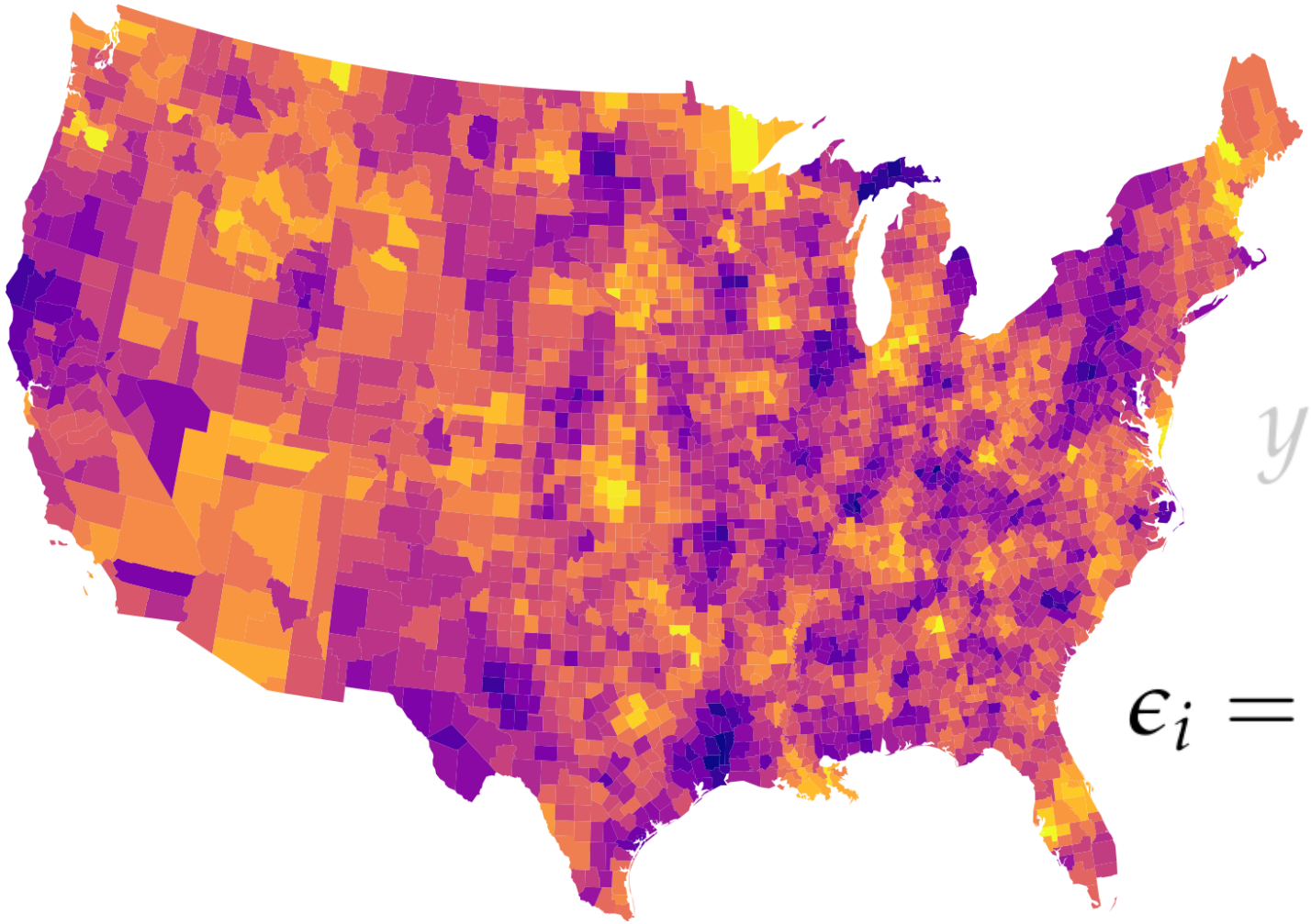
SIMULTANEOUS
AUTO**R**EGRESSIVE



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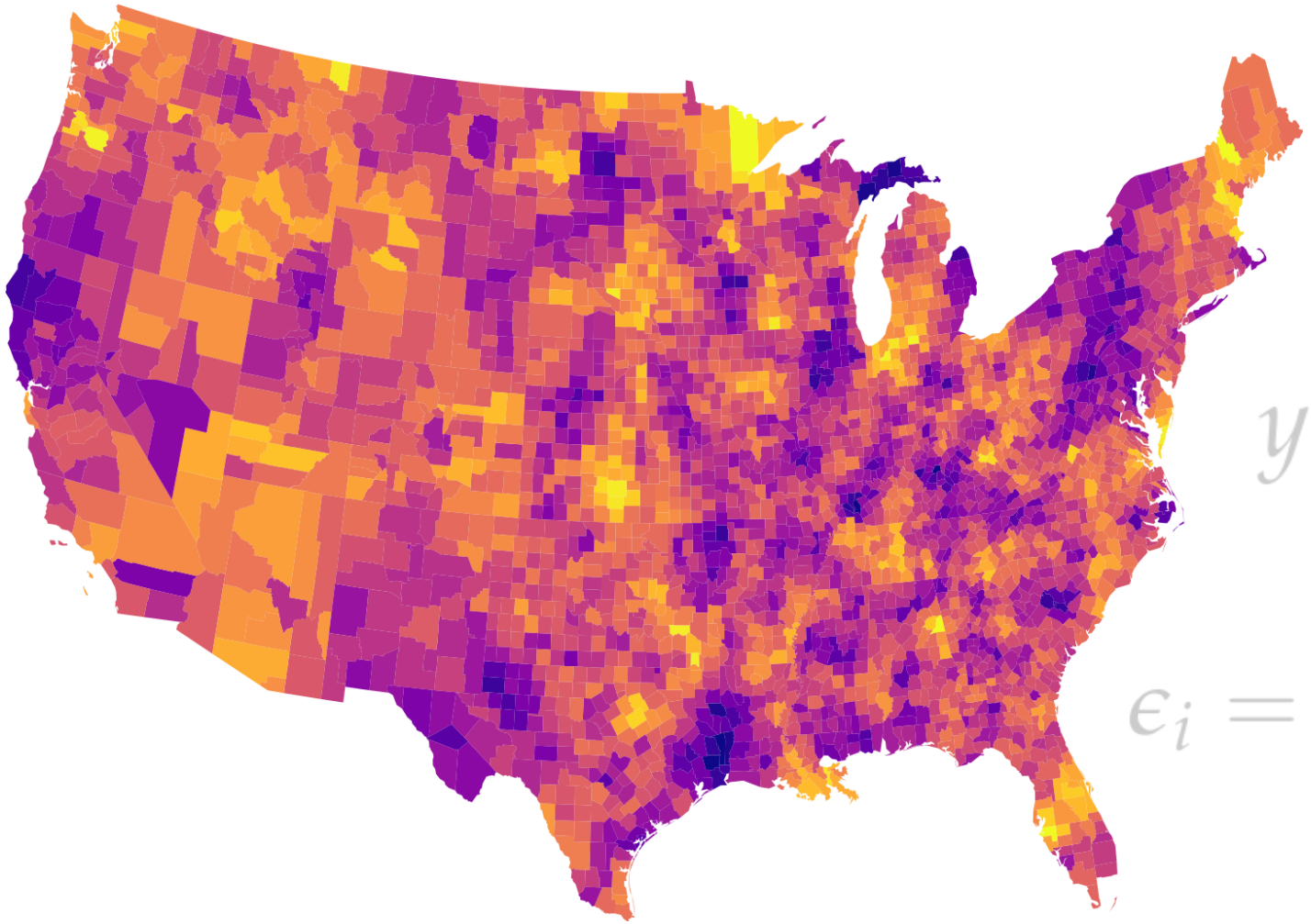
SAR MODELS

Error at site i is an average of surrounding errors, plus intrinsic error at site i



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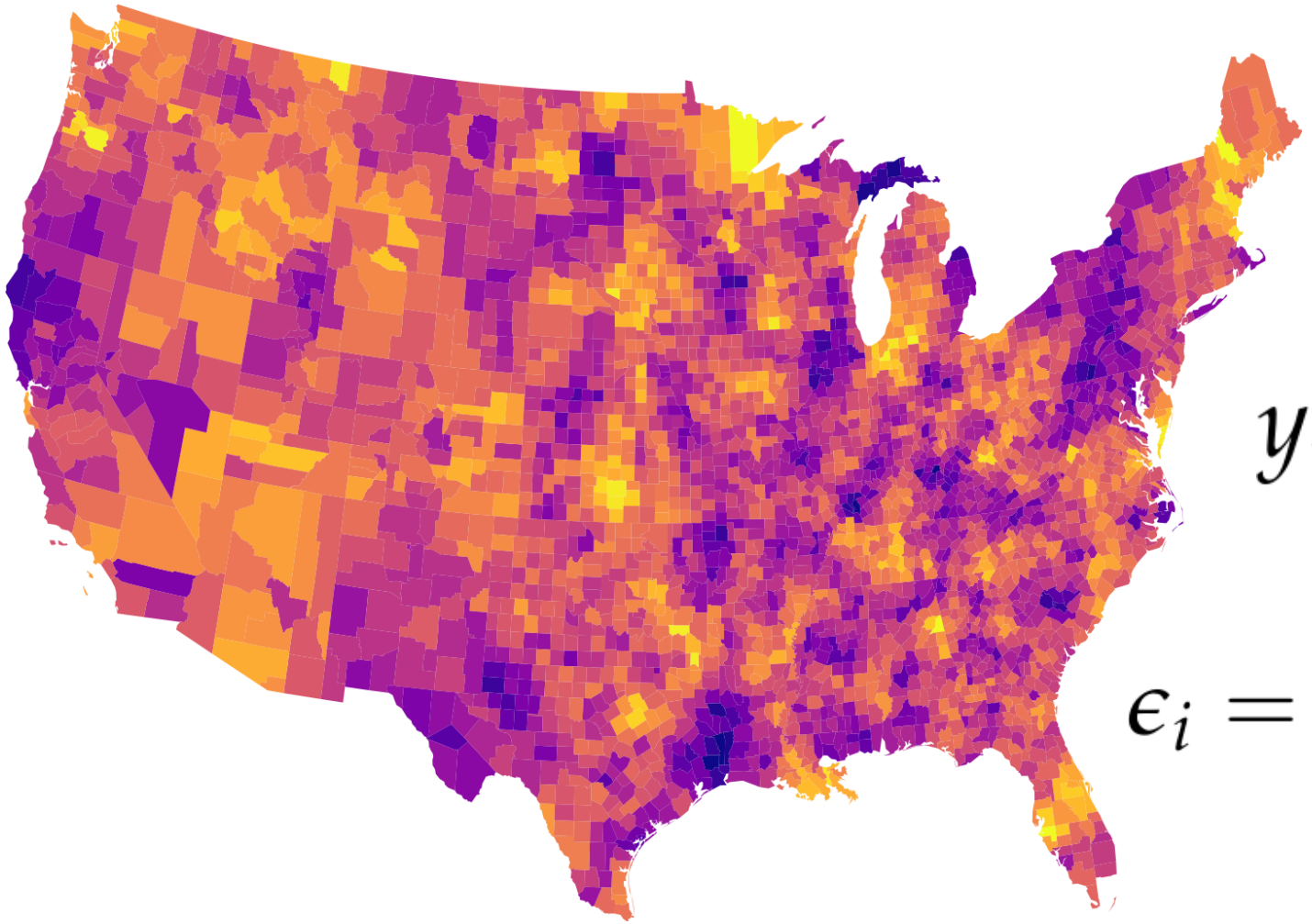
SAR MODELS

Still can have group-level model

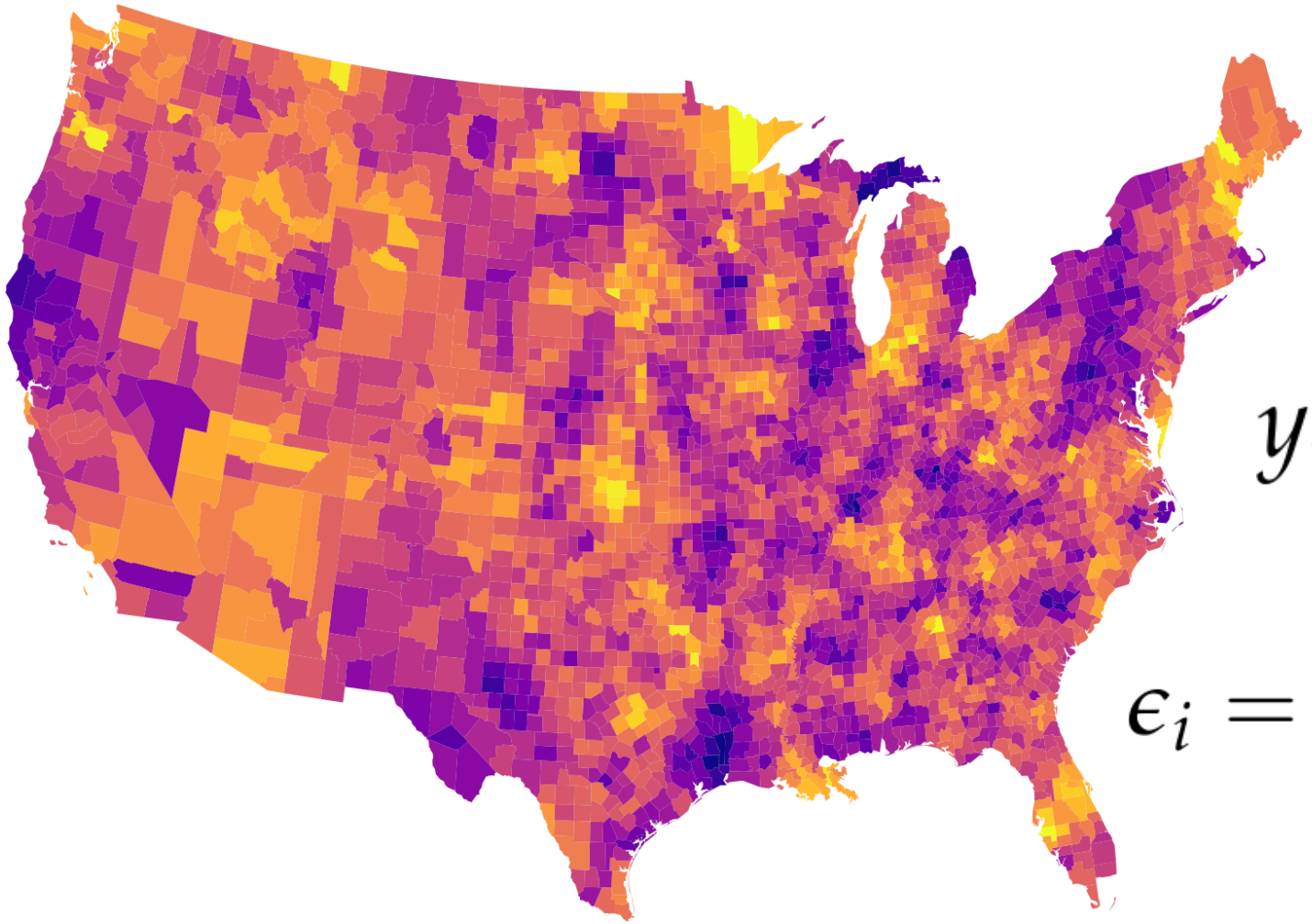


$$y_i = u_{j[i]} + \epsilon_i$$

$$\epsilon_i = \lambda \sum_{i}^{N} w_{ij}\epsilon_j + e_i$$

SAR MODELS

Your surroundings matter. (Anselin 1988)



$$y_i = u_{j[i]} + \epsilon_i$$

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SAR MODELS

This results in no change in estimates, but corrects overconfidence. **Estimates become less certain!**

$$y_i = u_{j[i]} + \epsilon_i$$

Responses center on group means

$$\epsilon_i = \lambda \sum_{i}^{N} w_{ij}\epsilon_j + e_i$$

Response-level error is spatially smoothed

$$u_j = a + \zeta_j$$

Groups center on grand mean

$$\zeta_j = \theta \sum_{k}^{J} m_{jk}\zeta_k + v_i$$

Region-level error is spatially smoothed

SPATIAL MULTILEVEL

$$y_i = u_{j[i]} + \epsilon_i$$

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$$u_j = a + \zeta_j$$

$$\zeta_j = \theta \sum_{k}^{J} m_{jk}\zeta_k + v_i$$

SPATIAL MULTILEVEL

DEPENDENCE THREE WAYS

RESPONSE SPATIAL

Nearby observations depend on one another, regardless of their group.

PLATIAL

Observations within groups depend on one another.

GROUP SPATIAL

Nearby groups depend on one another.

THE GEOGRAPHIC DICHOTOMY

space & place are core to geography

DEFINING A CLASSIC MODEL

multilevel models use place to estimate better

IS PLACE JUST ABOUT GROUP?

space is ignored, and that's important

DOES IT REALLY MATTER?

one bad nut can spoil the baklava

SAR ERRORS

Used because they:

1. capture geographic similarity
2. correct artificially precise estimates
3. leave estimates values alone (in expectation)

MULTILEVEL

Used because they:

1. capture w/in group similarity between observations
2. make group-level estimates more certain
3. shrink estimates for small groups with little info

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INTRINSICALLY OPPOSED!

On Spatial and Platial Dependence: Examining Shrinkage in Spatially-Dependent Multilevel Models*

Levi John Wolf[1,2], Luc Anselin[2], Daniel Arribas-Bel[2,3], and Lee Mobley[4]

Final Review,
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osf.io/ks6t3

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"Classic multilevel models may understate the uncertainty of the region-level parameter estimates and overstate their magnitude when spatial dependence exists at either level of the model."

"Intuition from simpler models must be updated for more complex models … 'nuisance' dependence in region-level variance components will show up as 'substantive' dependence."

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$$\hat{u}_{j,mlm} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\sigma_e^2}{n_j}} \hat{u}_{j,ols}$$

$$\hat{u}_{spmlm} = \left[\left(\mathbf{I}\sigma_u^2 + (\Delta' \mathbf{F}' \mathbf{F} \Delta)^{-1} \mathbf{G}' \mathbf{G} \sigma_e^2 \right)^{-1} \sigma_u^2 \right] \hat{u}_{mlerr}$$

"Intuition from simpler models must be updated for more complex models … 'nuisance' dependence in region-level variance components will show up as 'substantive' dependence."

osf.io/ks6t3

$$\hat{u}_{j,mlm} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\sigma_e^2}{n_j}} \hat{u}_{j,ols}$$

$$\hat{u}_{spmlm} = \left[\left(\underset{\text{platial}}{\mathbf{I}\sigma_u^2} + \underset{\text{spatial}}{(\Delta'\mathbf{F}'\mathbf{F}\Delta)^{-1}} \underset{\text{spatial}}{\mathbf{G}'\mathbf{G}\sigma_e^2} \right)^{-1} \underset{\text{platial}}{\sigma_u^2} \right] \hat{u}_{mlerr}$$

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$$\hat{u}_{j,mlm} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\sigma_e^2}{n_j}} \hat{u}_{j,ols}$$

$$\hat{u}_{spmlm} = \left[\left(\underset{\text{region}}{\mathbf{I}\sigma_u^2} + \underset{\text{response}}{(\Delta'\mathbf{F}'\mathbf{F}\Delta)^{-1}} \underset{\text{region}}{\mathbf{G}'\mathbf{G}\sigma_e^2} \right)^{-1} \underset{\text{region}}{\sigma_u^2} \right] \hat{u}_{mlerr}$$

platial spatial spatial platial

Because shrinkage is about variation, all of the (co)variation shows up!
Also can't separate out a single site anymore!

"Intuition from simpler models must be updated for more complex models … 'nuisance' dependence in region-level variance components will show up as 'substantive' dependence."

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$$y_i = u_{j[i]} + \epsilon_i$$

Responses center on group means

$$\epsilon_i = \lambda \sum_{i}^{N} w_{ij}\epsilon_j + e_i$$

Response-level error is spatially smoothed

$$u_j = a + \zeta_j$$

Groups center on grand mean

$$\zeta_j = \theta \sum_{k}^{J} m_{jk}\zeta_k + v_i$$

Region-level error is spatially smoothed

SPATIAL MULTILEVEL

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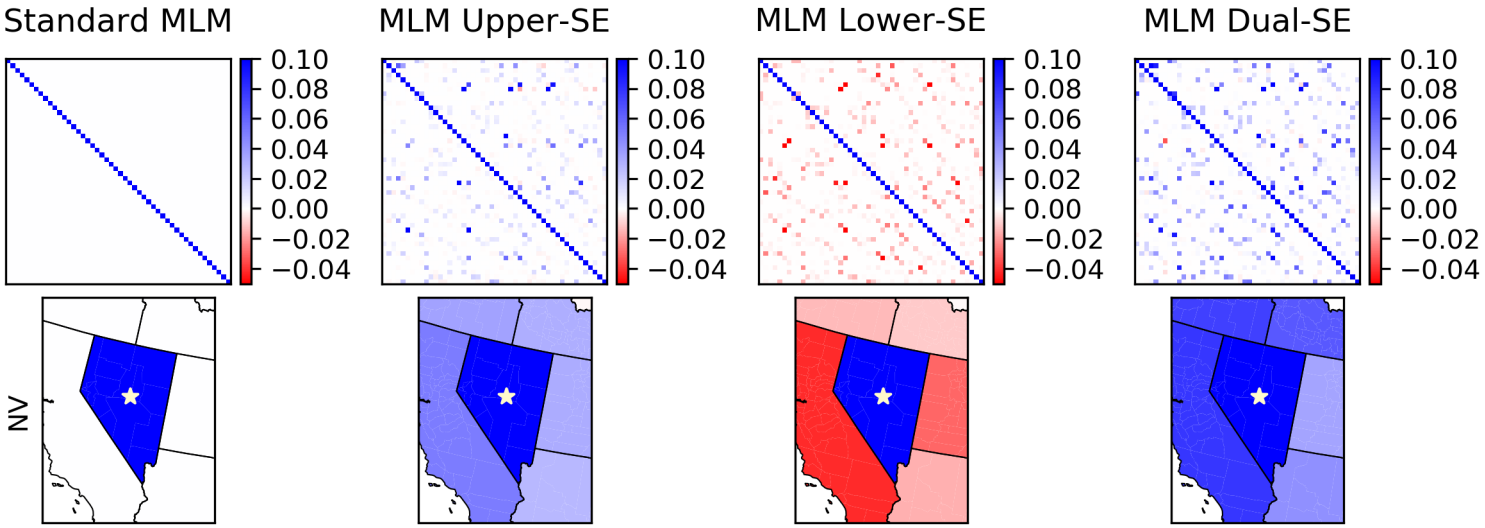
Region-level error is spatially smoothed

SPATIAL MULTILEVEL

"Turn off" each process & see what happens.
6 models in total. 2 single-level & 4 multilevel with varying configurations of regional & response-level spatial & platial dependence.



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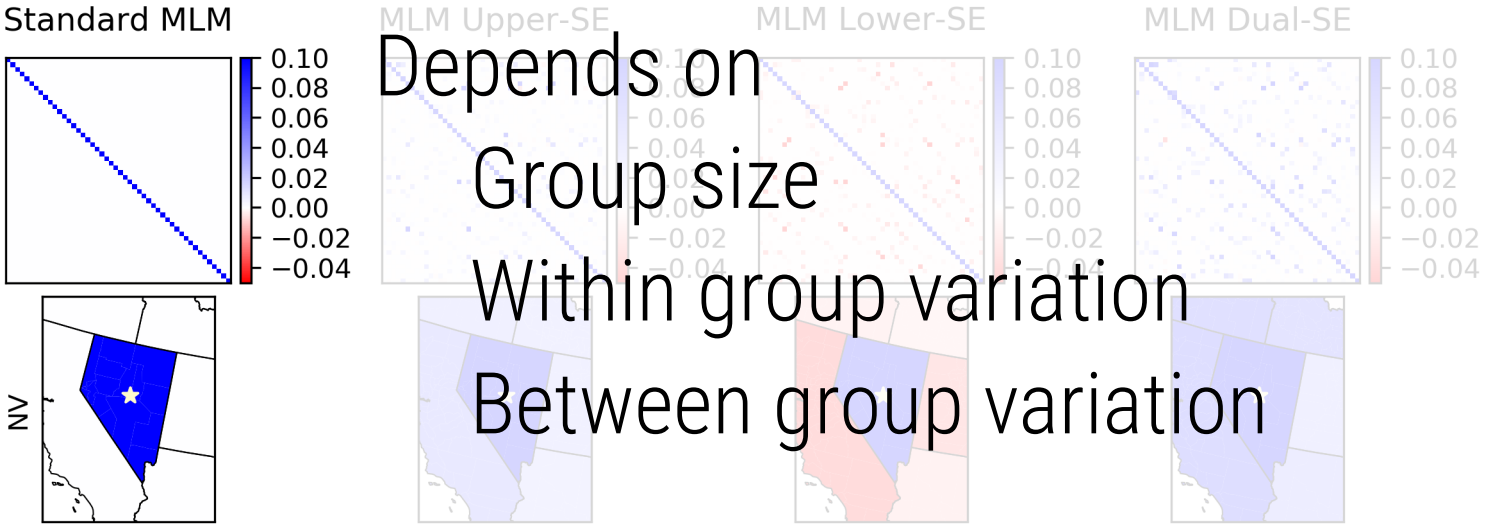

Depends on

Group size

Within group variation

Between group variation

Because shrinkage is about variation, all of the (co)variation shows up!
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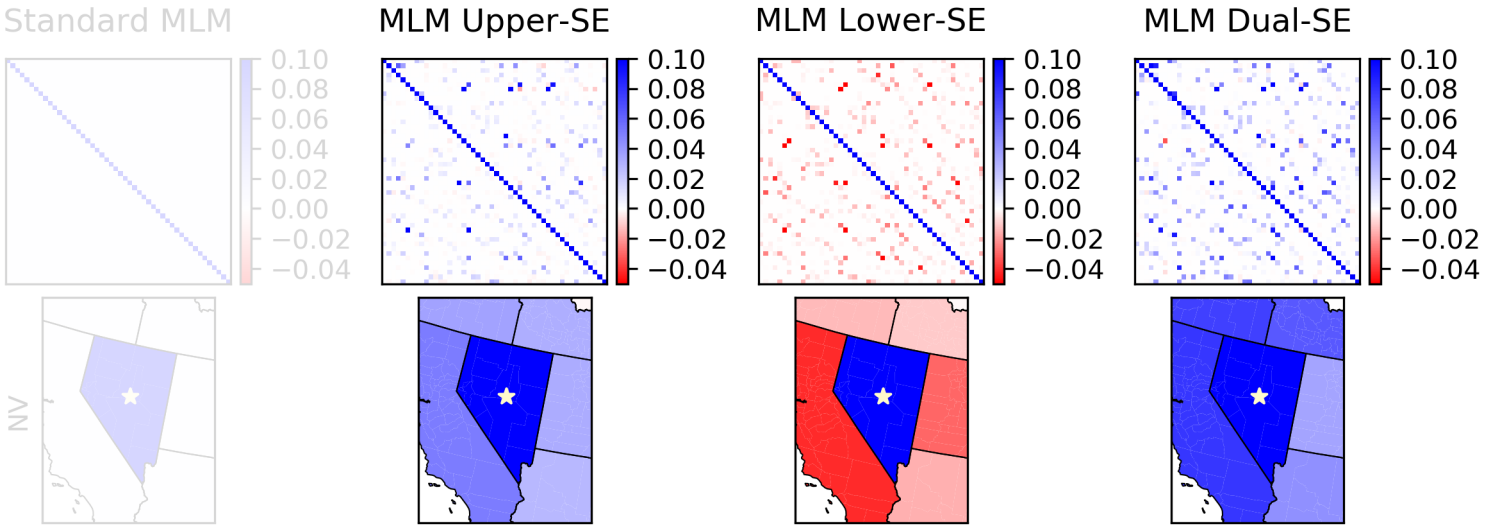

Cross state dependence at both levels can matter!

Because shrinkage is about variation, all of the (co)variation shows up!
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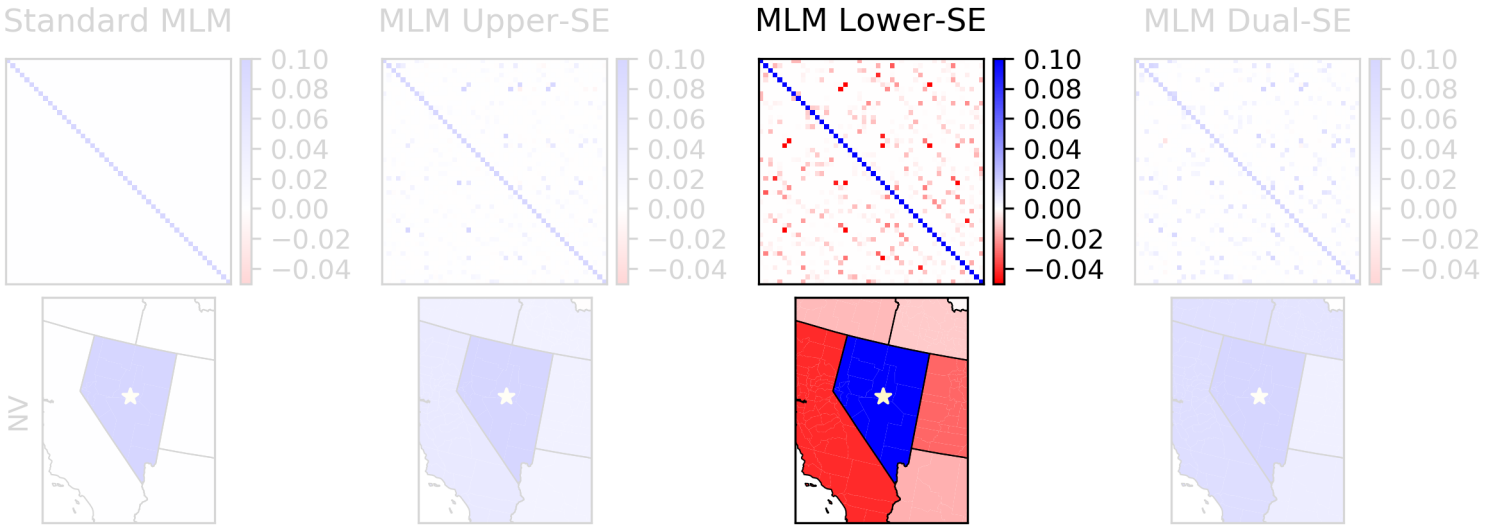

Even without group spatial dependence, information leaks between adjacent responses!

Because shrinkage is about variation, all of the (co)variation shows up!
Also can't separate out a single site anymore!

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osf.io/ks6t3

On Spatial and Platial Dependence: Examining Shrinkage in Spatially-Dependent Multilevel Models*

Levi John Wolf[1,2], Luc Anselin[2], Daniel Arribas-Bel[2,3], and Lee Mobley[4]

Final Review,
Annals of Am. Assoc. Geog.

osf.io/ks6t3

"Classic multilevel models may understate the uncertainty of the region-level parameter estimates and overstate their magnitude when spatial dependence exists at either level of the model."

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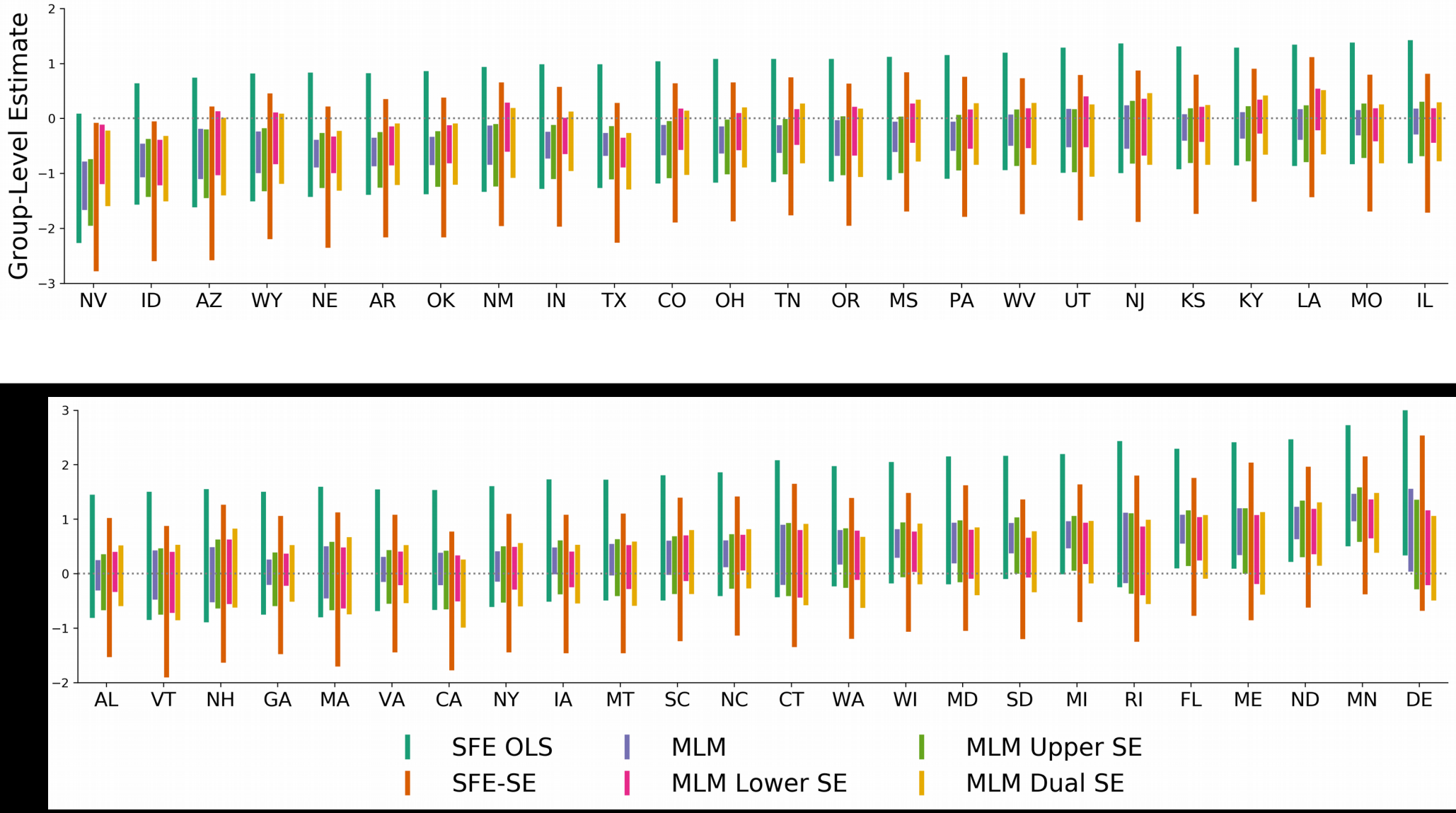
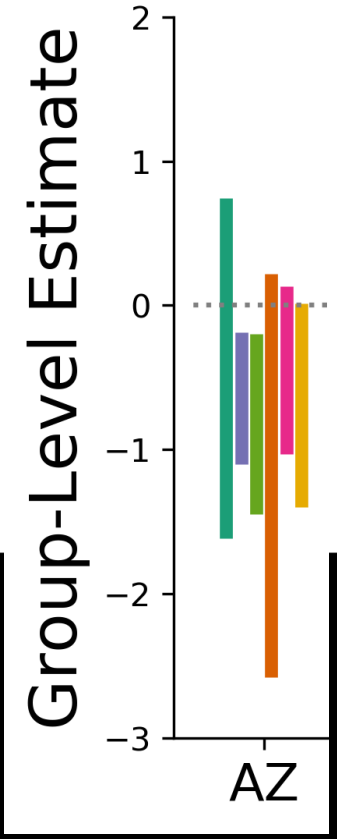

Group-Level Estimate
2
1
0
−1
−2
−3
NV ID AZ WY NE AR OK NM IN TX CO OH TN OR MS PA WV UT NJ KS KY LA MO IL
3
2
1
0
−1
−2
AL VT NH GA MA VA CA NY IA MT SC NC CT WA WI MD SD MI RI FL ME ND MN DE
SFE OLS
SFE-SE
MLM
MLM Lower SE
MLM Upper SE
MLM Dual SE

osf.io/ks6t3



95% posterior density intervals for Arizona's intercept in a model predicting colorectal cancer uptake among medicare recipients after introduction of Medicare Fee-For-Service

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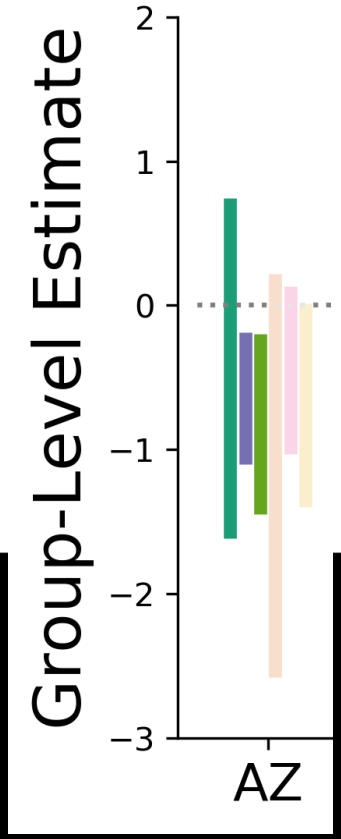
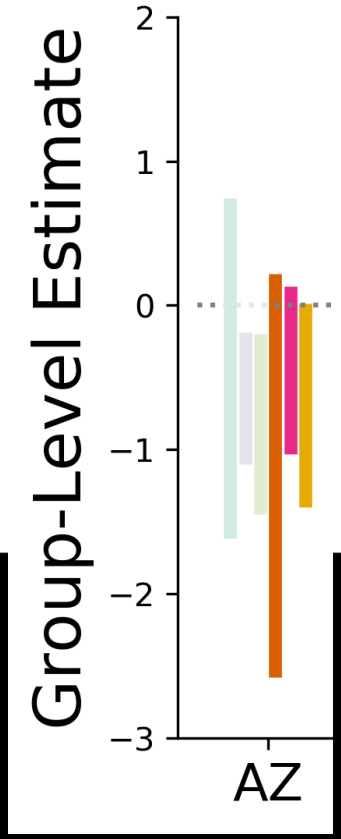


Cool Tone Colors

no response spatial dependence

"Classic multilevel models may understate the uncertainty of the region-level parameter estimates and overstate their magnitude when spatial dependence exists at either level of the model."

osf.io/ks6t3



Warm Tone Colors

response spatial dependence (possibly in addition to region)

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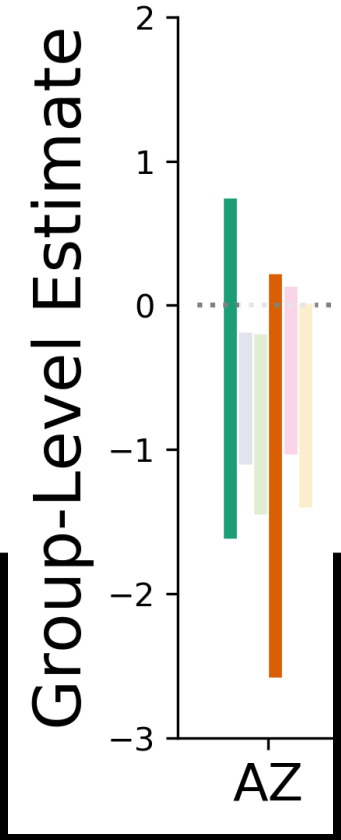
osf.io/ks6t3



Long Bars

Fixed effect estimates using maximum likelihood

"Classic multilevel models may understate the uncertainty of the region-level parameter estimates and overstate their magnitude when spatial dependence exists at either level of the model."

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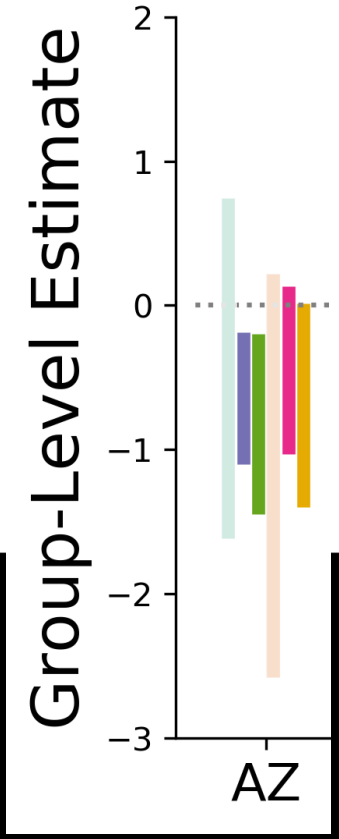

Short Bars

Multilevel estimates using Bayesian Gibbs Sampling

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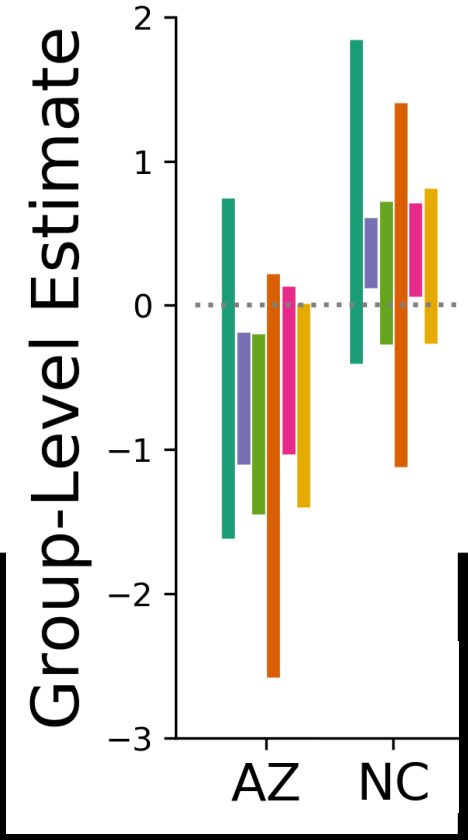

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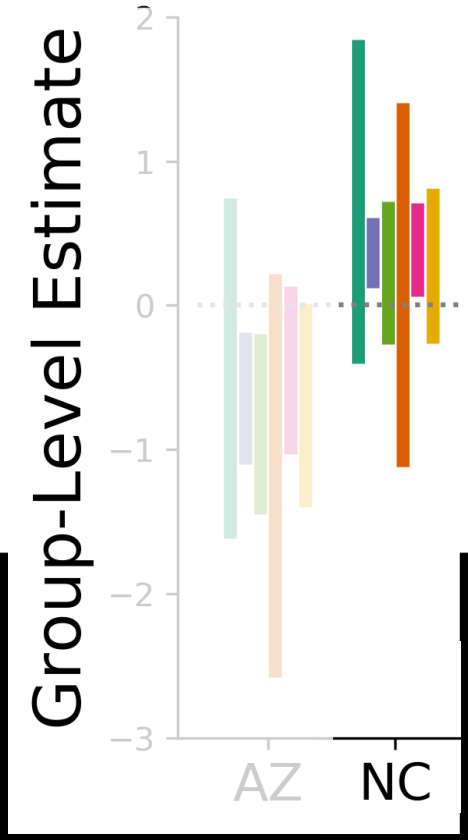

All multilevel models improve in certainty.

But, models with regional spatial dependence have weaker improvements!

The classic multilevel model is overconfident!

"Classic multilevel models may **understate the uncertainty** of the region-level parameter estimates and overstate their magnitude when spatial dependence exists at either level of the model."

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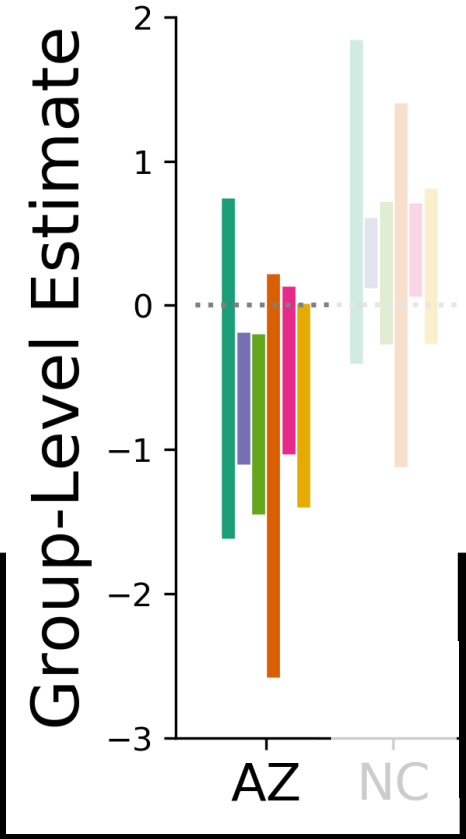

All multilevel model estimates shrink.

But ones that allow for response-level spatial dependence do so dramatically more!

The classic multilevel model is exaggerated!

"Classic multilevel models may understate the uncertainty of the region-level parameter estimates and **overstate their magnitude** when spatial dependence exists at either level of the model."

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THE GEOGRAPHIC DICHOTOMY

DEFINING A CLASSIC MODEL

IS PLACE JUST ABOUT GROUP?

DOES IT REALLY MATTER?

THE GEOGRAPHIC DICHOTOMY

space & place are core to geography

DEFINING A CLASSIC MODEL

multilevel models use place to estimate better

IS PLACE JUST ABOUT GROUP?

they ignore space, and that's important

DOES IT REALLY MATTER?

they can be overconfident and exaggerated

PLACE & SPACE IN MULTILEVEL MODELS

TOWARDS MORE USEFUL GEOGRAPHY IN MULTILEVEL MODELS

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LEE RIVERS MOBLEY

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