

# How to Measure Legislative District Compactness If You Only Know it When You See it<sup>1</sup>

Gary King<sup>2</sup>

Institute for Quantitative Social Science  
Harvard University

Department of Biomedical Informatics Harvard Medical School, 3/16/2021

---

<sup>1</sup>Based on joint work with Aaron Kaufman and Mayya Komisarchik

<sup>2</sup>GaryKing.org

# Redistricting Defines Democracy — & Needs Fixing

# Redistricting Defines Democracy — & Needs Fixing

- Fundamental to Democracy

# Redistricting Defines Democracy — & Needs Fixing

- Fundamental to Democracy
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation

# Redistricting Defines Democracy — & Needs Fixing

- Fundamental to Democracy
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game

# Redistricting Defines Democracy — & Needs Fixing

- Fundamental to Democracy
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time

# Redistricting Defines Democracy — & Needs Fixing

- Fundamental to Democracy
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**
  - Constrain redistricters via:

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**
  - Constrain redistricters via: Population equality,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**
  - Constrain redistricters via: Population equality, partisan fairness,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**
  - Constrain redistricters via: Population equality, partisan fairness, racial fairness,

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**
  - Constrain redistricters via: Population equality, partisan fairness, racial fairness, respect for municipal boundaries . . .

# Redistricting Defines Democracy — & Needs Fixing

- **Fundamental to Democracy**
  - Control redistricting  $\rightsquigarrow$  Define basic units of representation
  - \$100s of millions spent trying to influence the rules of the game
  - Litigation in almost every jurisdiction, every time
  - $\rightsquigarrow$  Get the ball, move the goalposts
- **Blamed for:**
  - unfair elections, excessive partisanship, policy gridlock, partisan bias, lack of electoral responsiveness, racial bias, . . .
- **How to fix this?**
  - Constrain redistricters via: Population equality, partisan fairness, racial fairness, respect for municipal boundaries . . . **compactness**

# The Political Science Discipline & Redistricting

# The Political Science Discipline & Redistricting

- Political science contributions to the real world



# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  
- Political science disconnect from the real world: **Compactness**

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  
- Political science disconnect from the real world: **Compactness**

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  
- Political science disconnect from the real world: **Compactness**

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
- Political science disconnect from the real world: **Compactness**

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution:

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington:

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington: “Each district shall be as compact as possible”

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington: “Each district shall be as compact as possible”
    - Iowa:

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington: “Each district shall be as compact as possible”
    - Iowa: “avoid drawing districts that are oddly shaped”

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington: “Each district shall be as compact as possible”
    - Iowa: “avoid drawing districts that are oddly shaped”
    - Supreme Court:

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington: “Each district shall be as compact as possible”
    - Iowa: “avoid drawing districts that are oddly shaped”
    - Supreme Court: “One need not use Justice Stewart’s classic definition of obscenity—‘I know it when I see it’—... to recognize that *dramatically irregular shapes* may have sufficient probative force to call for an explanation”

# The Political Science Discipline & Redistricting

- Political science contributions to the real world
  - **Partisan fairness**: Invented standard (partisan symmetry) & methods
  - **Racial fairness**: Invented methods of ecological inference (for VRA)
  - **Forecasting elections** in new districts, for all sides
  - **Public service**: as consultants, expert witnesses, special masters
  - **Measurable impact**: in numerous legal cases, state laws
- Political science disconnect from the real world: **Compactness**
  - **Researchers**: Assumed so **complicated**, numerous measures needed
  - **Law**: Assumed so **simple**, no definition needed!
    - Illinois Constitution: “Legislative Districts shall be compact”
    - Washington: “Each district shall be as compact as possible”
    - Iowa: “avoid drawing districts that are oddly shaped”
    - Supreme Court: “One need not use Justice Stewart’s classic definition of obscenity—‘I know it when I see it’—... to recognize that *dramatically irregular shapes* may have sufficient probative force to call for an explanation”
    - Required in many other jurisdictions

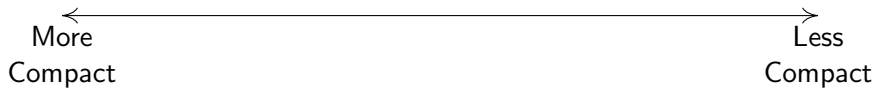
# Compactness According to the Law

# Compactness According to the Law

A simple single compactness dimension that you know when you see

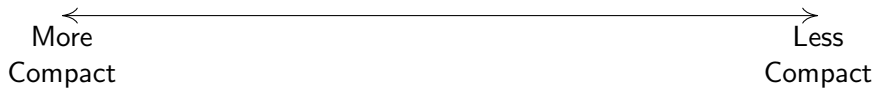
# Compactness According to the Law

A simple single compactness dimension that you know when you see



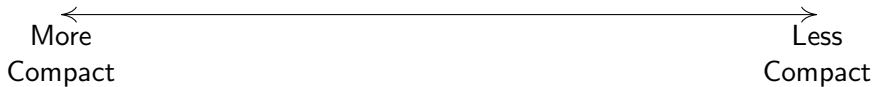
# Compactness According to the Law

A simple single compactness dimension that you know when you see



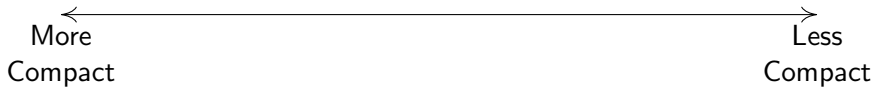
# Compactness According to the Law

A simple single compactness dimension that you know when you see



# Compactness According to the Law

A simple single compactness dimension that you know when you see



# Compactness According to the Law

A simple single compactness dimension that you know when you see



←  
More  
Compact

→  
Less  
Compact

# Compactness According to the Law

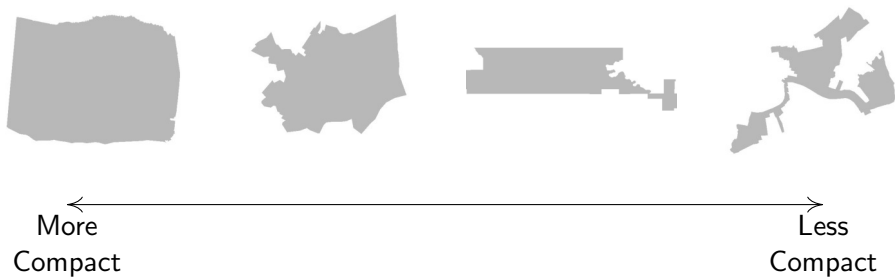
A simple single compactness dimension that you know when you see



- The dimension **is** intuitive

# Compactness According to the Law

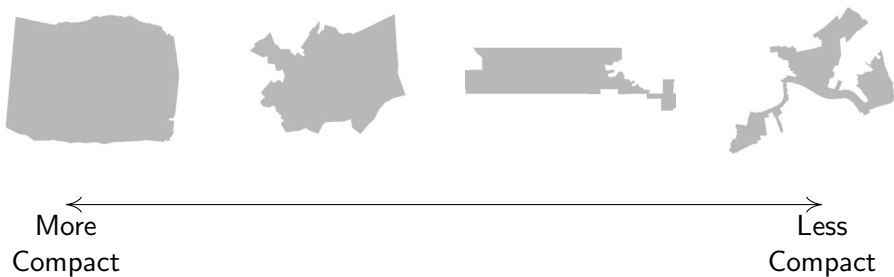
A simple single compactness dimension that you know when you see



- The dimension **is** intuitive
- How to **estimate** where a new district shape falls on this dimension?

# Compactness According to the Law

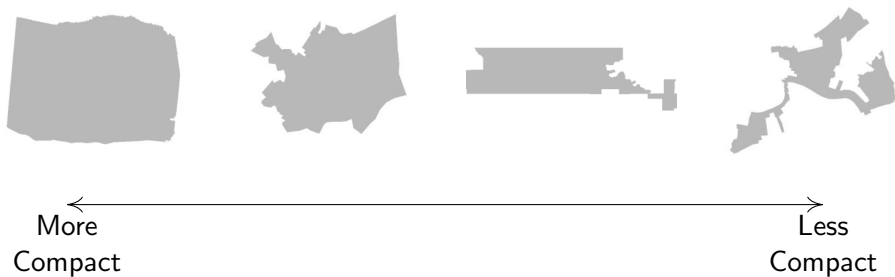
A simple single compactness dimension that you know when you see



- The dimension **is** intuitive
- How to **estimate** where a new district shape falls on this dimension?
- Only a **consensus measure** can constrain advocates

# Compactness According to the Law

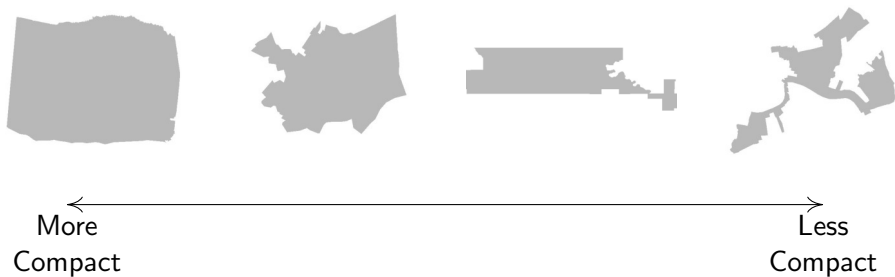
A simple single compactness dimension that you know when you see



- The dimension **is** intuitive
- How to **estimate** where a new district shape falls on this dimension?
- Only a **consensus measure** can constrain advocates
- Dimension **relative** to geography;

# Compactness According to the Law

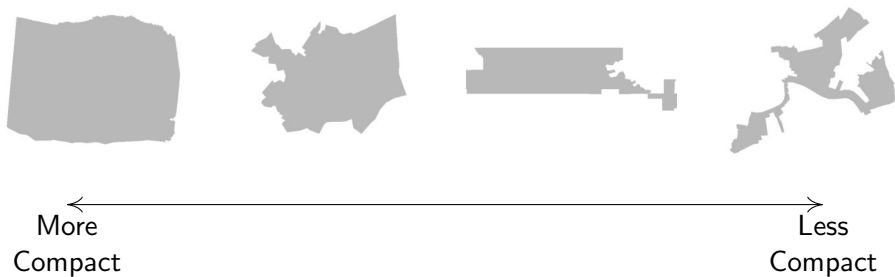
A simple single compactness dimension that you know when you see



- The dimension **is** intuitive
- How to **estimate** where a new district shape falls on this dimension?
- Only a **consensus measure** can constrain advocates
- Dimension **relative** to geography; could **generalize** (e.g., population)

# Compactness According to the Law

A simple single compactness dimension that you know when you see



- The dimension **is** intuitive
- How to **estimate** where a new district shape falls on this dimension?
- Only a **consensus measure** can constrain advocates
- Dimension **relative** to geography; could **generalize** (e.g., population)
- **↪ Let's start with existing measures by social scientists**

## Measure 1: Length/Width Ratio of Min Bounding Box

## Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones

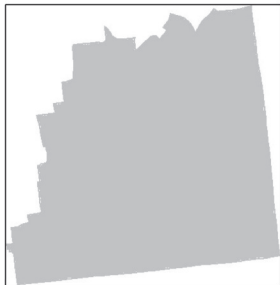
## Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones



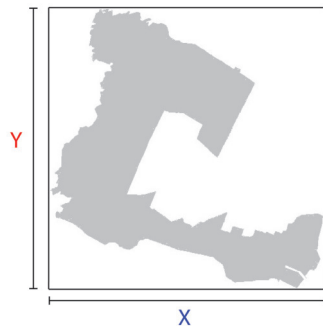
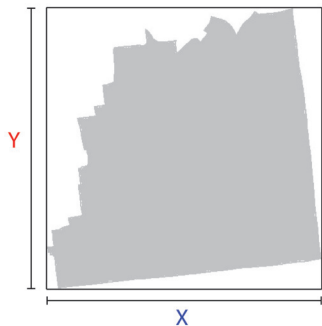
## Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones



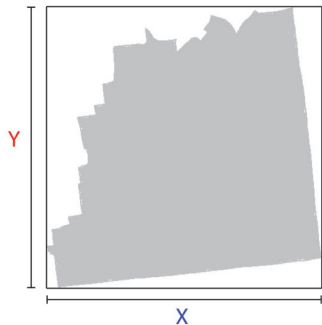
## Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones



## Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones



In both districts:  $X/Y \approx 1.30$

## Measure 2: Reock, District / Bounding Circle Areas

## Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact

## Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact



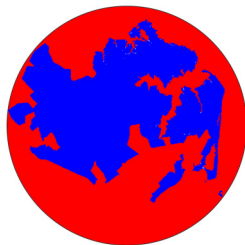
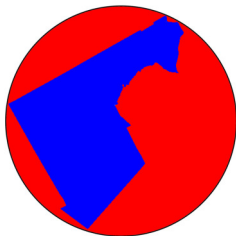
## Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact



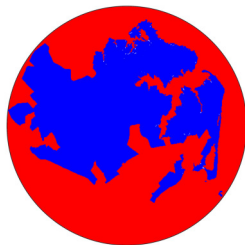
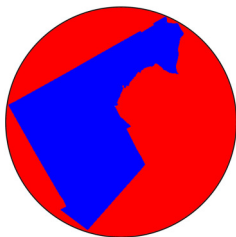
## Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact



## Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact



In both cases,  $X/(Y + X) \approx 0.37$

## Measure 3: Boyce-Clark, Variation in Centroid Deviations

## Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar

## Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar



## Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar



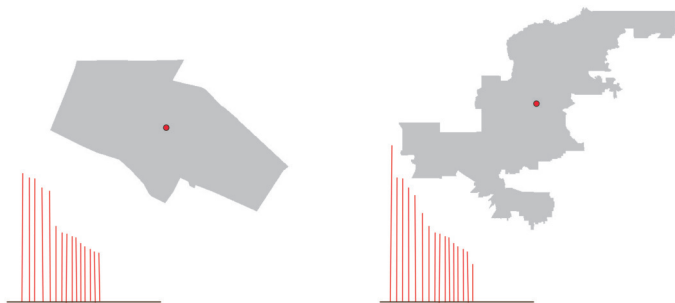
## Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar



## Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar



## Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar



In both cases,  $\text{MAD}(r)/\bar{r} \approx 0.31$

## A Brief Rotational Invariance Interlude:

A Brief Rotational Invariance Interlude:  
Can you Name this Celebrity?

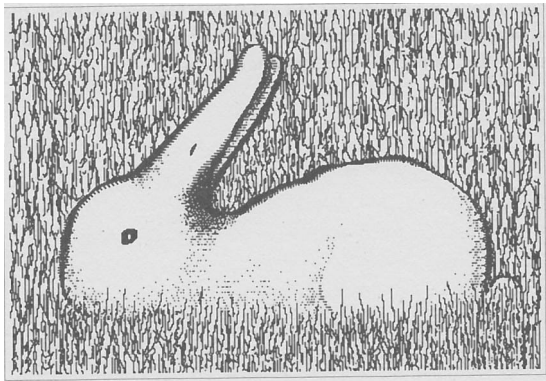
A Brief Rotational Invariance Interlude:  
Can you Name this Celebrity?



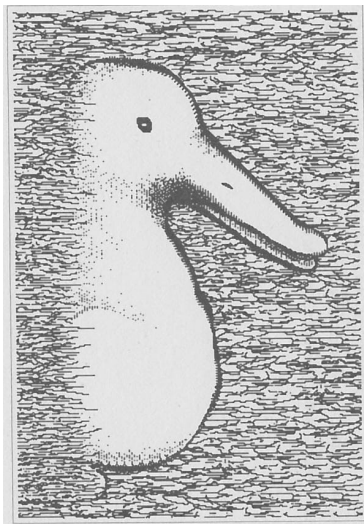
A Brief Rotational Invariance Interlude:  
Can you Name this Celebrity?



## A Brief Interlude on Perception: See the Rabbit?



## A Brief Interlude on Perception: See the Rabbit Duck?



## A Brief Interlude on Perception: See the Frog?



## A Brief Interlude on Perception: See the Frog Horse?



# Human Perception: Not Rotationally Invariant

# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:

# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:
  - Nearly 100 proposed

# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:
  - Nearly 100 proposed
  - Almost all are rotationally invariant

# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:
  - Nearly 100 proposed
  - Almost all are rotationally invariant
  - Blind to what humans perceive

# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:
  - Nearly 100 proposed
  - Almost all are rotationally invariant
  - Blind to what humans perceive
- Which is more compact?

# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:
  - Nearly 100 proposed
  - Almost all are rotationally invariant
  - Blind to what humans perceive
- Which is more compact?



# Human Perception: Not Rotationally Invariant

- Existing measures of compactness:
  - Nearly 100 proposed
  - Almost all are rotationally invariant
  - Blind to what humans perceive
- Which is more compact?



- $\rightsquigarrow$  Measuring “you know it when you see it”: No rotational invariance

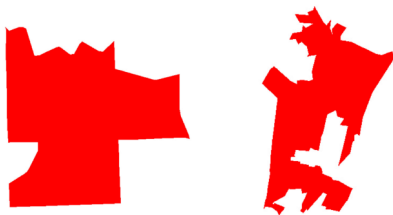
## New Measure: Y-Symmetry, area of symmetric reflection

# New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact

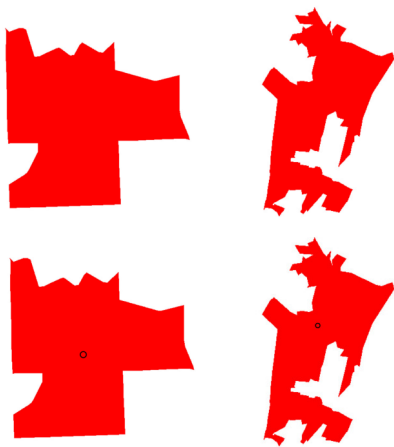
# New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact



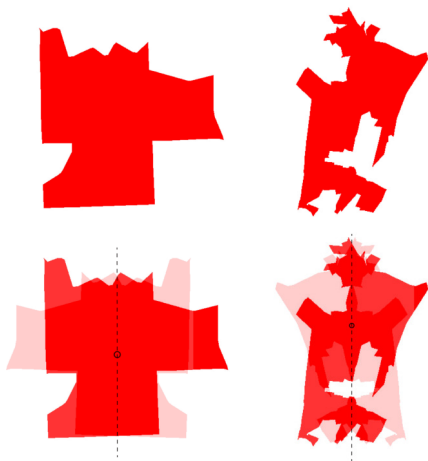
# New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact



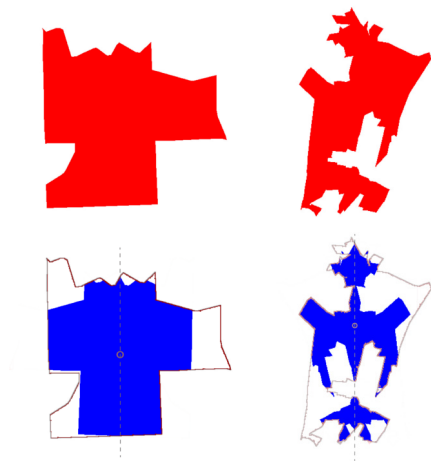
## New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact



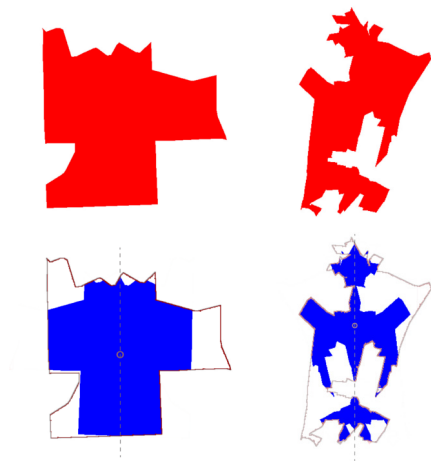
# New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact



## New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact



In both cases,  $\text{Overlap} / \text{Original Area} \approx 0.34$

## New Measure 2: Number of Visually Significant Corners

## New Measure 2: Number of Visually Significant Corners

Computer vision algorithm identifies “objects” in photos

## New Measure 2: Number of Visually Significant Corners

Computer vision algorithm identifies “objects” in photos

↪ Fewer corners is more compact

## New Measure 2: Number of Visually Significant Corners

Computer vision algorithm identifies "objects" in photos

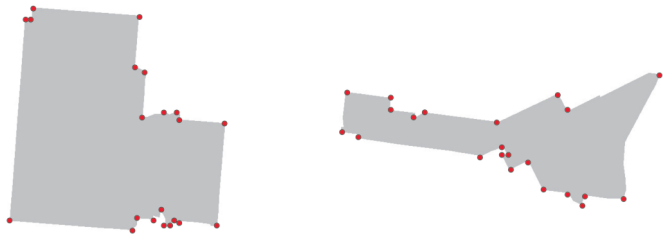
~> Fewer corners is more compact



## New Measure 2: Number of Visually Significant Corners

Computer vision algorithm identifies "objects" in photos

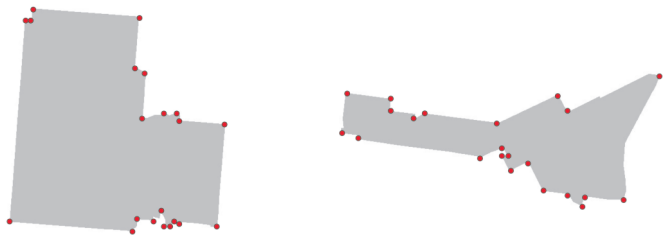
~> Fewer corners is more compact



## New Measure 2: Number of Visually Significant Corners

Computer vision algorithm identifies “objects” in photos

~> Fewer corners is more compact



Both districts have 21 significant corners

Which is more compact?



Which is more compact? Depends on the standard!



Which is more compact? Depends on the standard!



Convex Hull

4

3

2

1

## Which is more compact? Depends on the standard!



Convex Hull

4

3

2

1

Reock

1

2

3

4

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

- 7 measures;

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

- 7 measures; 7 unique rankings

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

- 7 measures; 7 unique rankings
- Unusual?

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

- 7 measures; 7 unique rankings
- **Unusual?** From 18,215 Congressional and State Legislative Districts,

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

- 7 measures; 7 unique rankings
- **Unusual?** From 18,215 Congressional and State Legislative Districts, we found 162 trillion others (about 0.15%)

## Which is more compact? Depends on the standard!



Convex Hull	4	3	2	1
Reock	1	2	3	4
Polsby-Popper	4	1	2	3
Boyce-Clark	2	3	1	4
Length/Width	3	2	1	4
X-Axis Symmetry	1	4	3	2
Significant Corners	4	1	3	2

- 7 measures; 7 unique rankings
- **Unusual?** From 18,215 Congressional and State Legislative Districts, we found 162 trillion others (about 0.15%)
- **Many more inconsistencies on individual districts**

# Spanning the Academic–Legal Divide

## Spanning the Academic–Legal Divide

- (Recall) The concept of compactness

## Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - **Researchers:** So **complicated**, numerous measures needed

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - **Researchers:** So **complicated**, numerous measures needed
  - **Law:** So **simple**, no definition needed

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - **Researchers:** So **complicated**, numerous measures needed
  - **Law:** So **simple**, no definition needed
- **Our Hypothesis:** both are right

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?
  - Public officials and many other types of people:

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?
  - Public officials and many other types of people:
    - Know it when they see it,

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?
  - Public officials and many other types of people:
    - Know it when they see it,
    - See the same dimension

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?
  - Public officials and many other types of people:
    - Know it when they see it,
    - See the same dimension
  - I.e., estimate the one dimension of legal interest; show it has:

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?
  - Public officials and many other types of people:
    - Know it when they see it,
    - See the same dimension
  - I.e., estimate the one dimension of legal interest; show it has:
    - high intercoder (and intracoder) reliability

# Spanning the Academic–Legal Divide

- (Recall) The concept of compactness
  - Researchers: So complicated, numerous measures needed
  - Law: So simple, no definition needed
- Our Hypothesis: both are right
  - The Theoretical Concept: multidimensional
  - The Legal Concept: one dimensional
  - Which dimension? The one we know when we see
- How do we know if we find it?
  - Public officials and many other types of people:
    - Know it when they see it,
    - See the same dimension
  - I.e., estimate the one dimension of legal interest; show it has:
    - high intercoder (and intracoder) reliability
    - high predictive accuracy

How to rank districts on the same dimension?

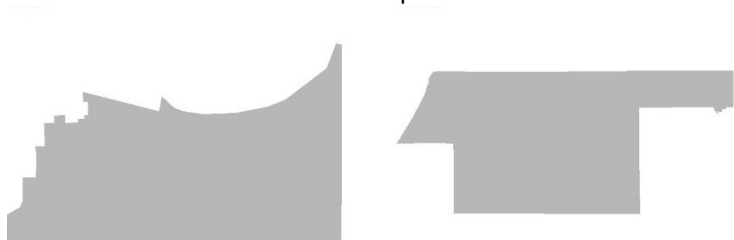
# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

## Paired Comparison



# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

## Paired Comparison



Utterly fails on inter- and intra-coder reliability

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

## Full Ranking

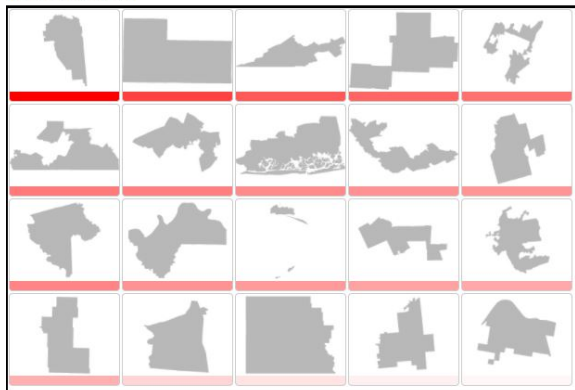


# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

## Full Ranking — on line

MOST Compact Here



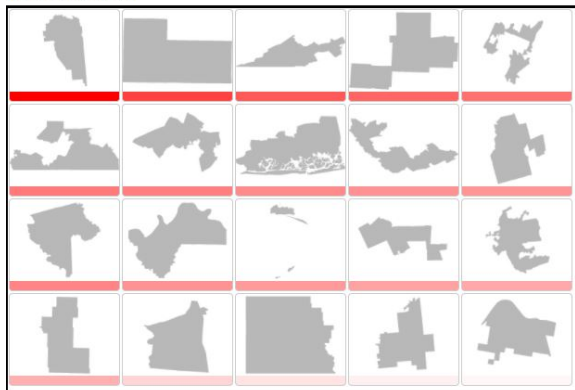
LEAST Compact Here

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

## Full Ranking — on line

MOST Compact Here



LEAST Compact Here

We show: very high reliability

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.  
Would it take you 2 quintillion seconds to rank 20 districts?

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.  
Would it take you 2 quintillion seconds to rank 20 districts?
  - 190 paired comparisons is tedious and boring;

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.  
Would it take you 2 quintillion seconds to rank 20 districts?
  - 190 paired comparisons is tedious and boring;  
Ranking is more intellectually engaging

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.  
Would it take you 2 quintillion seconds to rank 20 districts?
  - 190 paired comparisons is tedious and boring;  
Ranking is more intellectually engaging
  - Saves time: 1 task v 190 comparisons

# How to rank districts on the same dimension?

Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.  
Would it take you 2 quintillion seconds to rank 20 districts?
  - 190 paired comparisons is tedious and boring;  
Ranking is more intellectually engaging
  - Saves time: 1 task v 190 comparisons
  - Paired Comparisons can be answered on **different dimensions**

# How to rank districts on the same dimension?

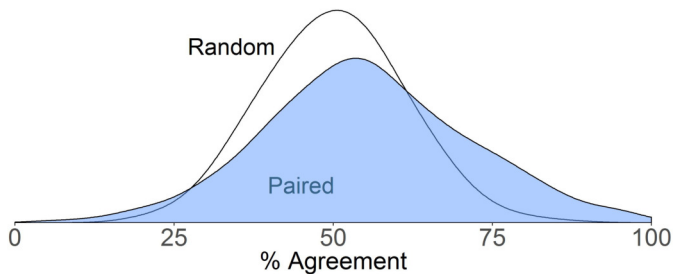
Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

- Why Paired Comparisons is supposedly better
  - Everyone does what they are good at:
    - Respondents answer simple, concrete questions
    - Researchers reconstruct the scale
  - Much easier:  $\binom{20}{2} = 190$  pairs v  $20! \approx 2$  quintillion ranks
- Why Ranking is actually better (at least in our application)
  - Humans use time-saving heuristics.  
Would it take you 2 quintillion seconds to rank 20 districts?
  - 190 paired comparisons is tedious and boring;  
Ranking is more intellectually engaging
  - Saves time: 1 task v 190 comparisons
  - Paired Comparisons can be answered on **different dimensions**  
Ranking: all evaluations on **one dimension** of user's choice

## Intercoder Reliability of Pairs

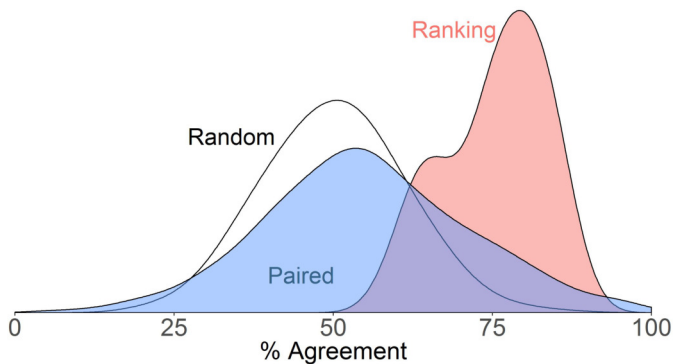
## Intercoder Reliability of Pairs

Paired Comparisons: only slightly better than chance;



## Intercoder Reliability of Pairs

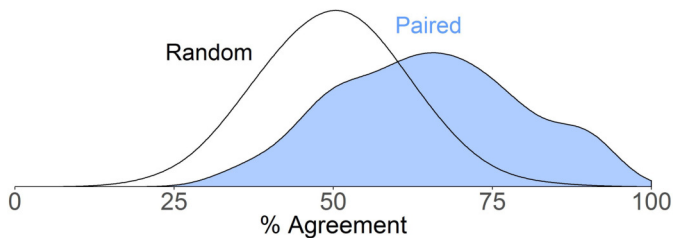
Paired Comparisons: only slightly better than chance; Pairs implied by ranks: better



## Intracoder Reliability of Pairs

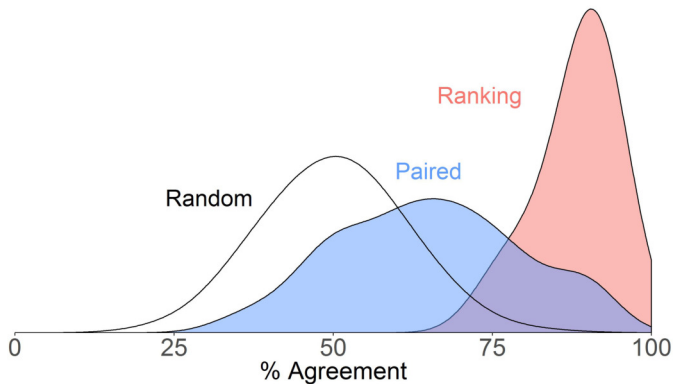
## Intracoder Reliability of Pairs

Paired Comparisons: better than chance;

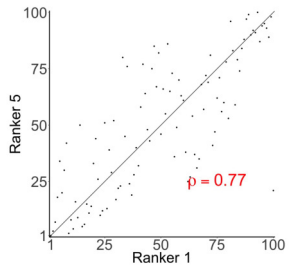


## Intracoder Reliability of Pairs

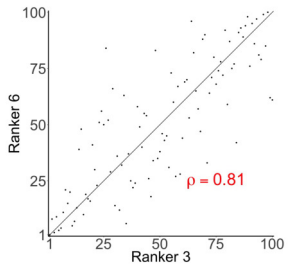
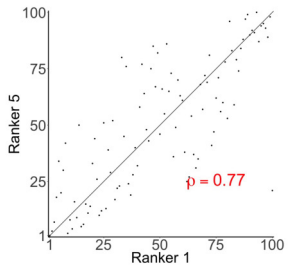
Paired Comparisons: better than chance; Pairs implied by ranks: much better



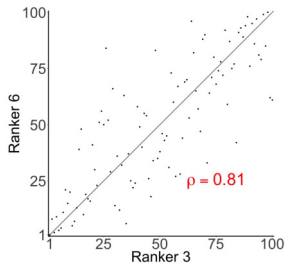
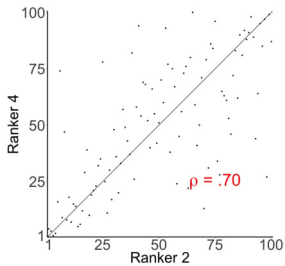
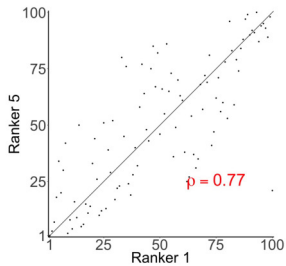
## Intercoder Reliability on Ranks



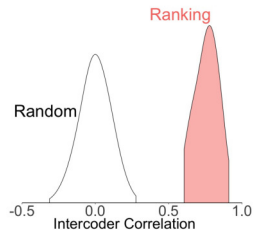
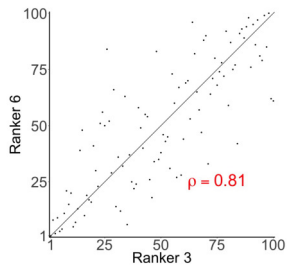
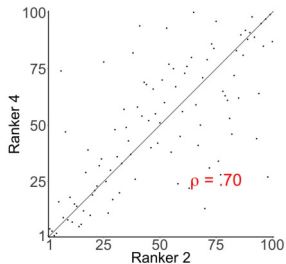
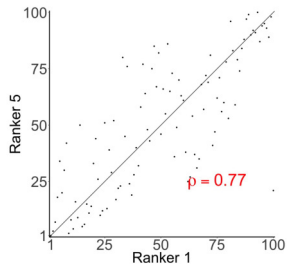
# Intercoder Reliability on Ranks



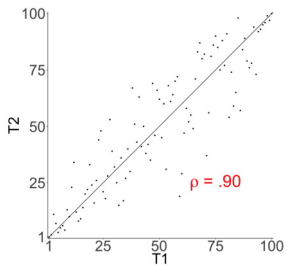
# Intercoder Reliability on Ranks



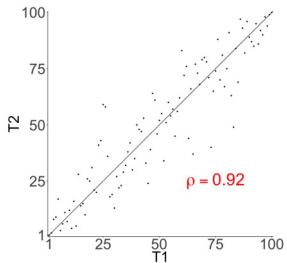
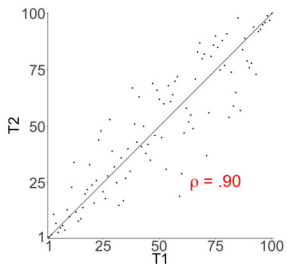
# Intercoder Reliability on Ranks



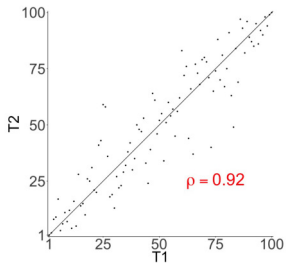
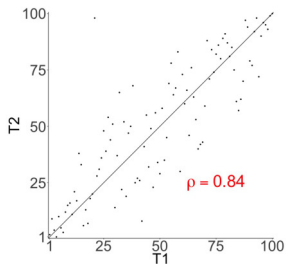
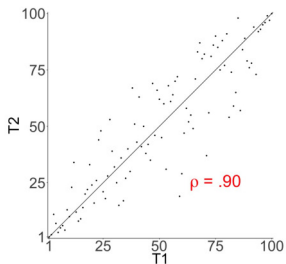
## Intracoder Reliability on Ranks



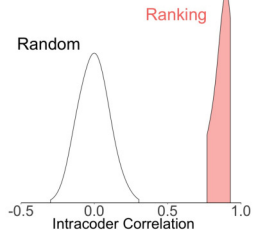
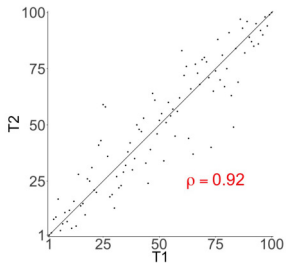
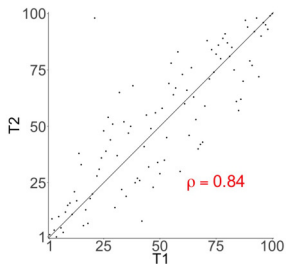
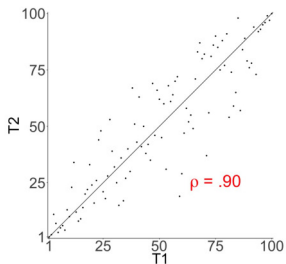
# Intracoder Reliability on Ranks



# Intracoder Reliability on Ranks



# Intracoder Reliability on Ranks



So we can measure it. Can we model it?

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

## So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- Training data: Outcome variable from human rankings

## So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)

## So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- Training data: Outcome variable from human rankings
- Outcome measure: A district's rank (in a set of 100)
- Covariates. Features of district shape

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark...

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark...
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance...

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark...
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance...
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners...

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .
- **Meaning of resulting measure:**

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .
- **Meaning of resulting measure:**
  - **Polanyi's Paradox:**

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .
- **Meaning of resulting measure:**
  - **Polanyi's Paradox:** we know more than we can tell

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .
- **Meaning of resulting measure:**
  - **Polanyi's Paradox:** we know more than we can tell
  - **Tell!**

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .
- **Meaning of resulting measure:**
  - **Polanyi's Paradox:** we know more than we can tell
  - **Tell!** squarish, with minimal arms, pockets, islands, or jagged edges

# So we can measure it. Can we model it?

Goal: Compactness score =  $f(\text{shape})$

- **Training data:** Outcome variable from human rankings
- **Outcome measure:** A district's rank (in a set of 100)
- **Covariates. Features of district shape**
  - **Existing:** Reock, Polsby-Popper, Convex Hull, Length/Width, Boyce-Clark. . .
  - **Geometric:** Perimeter, area, vertices, polygons, vertex variance, edge length variance. . .
  - **New:** X-axis symmetry, Y-axis symmetry, Significant Corners. . .
- **Ensemble of predictive methods:** least squares, AdaBoosted decision trees, SVM, random forests. . .
- **Meaning of resulting measure:**
  - **Polanyi's Paradox:** we know more than we can tell
  - **Tell!** squarish, with minimal arms, pockets, islands, or jagged edges
  - (Not a description of any one existing measure)

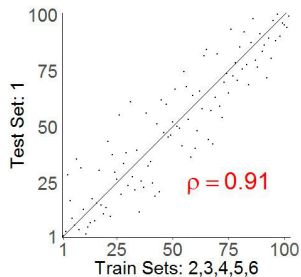
# Model Validation: 6-Fold Cross-validation

# Model Validation: 6-Fold Cross-validation

Predict Test Set from 5 Training Sets

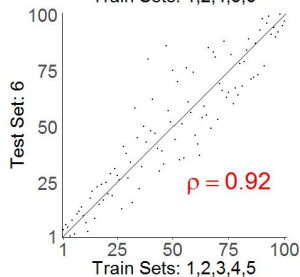
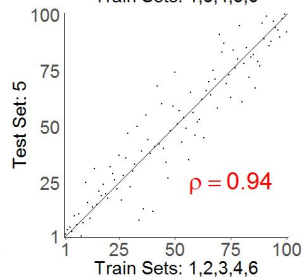
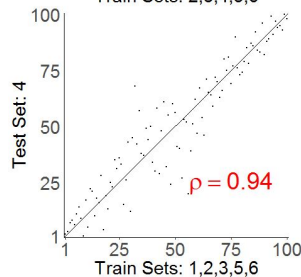
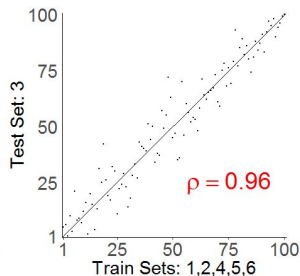
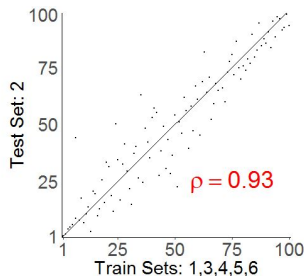
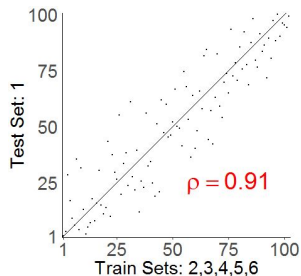
# Model Validation: 6-Fold Cross-validation

Predict Test Set from 5 Training Sets



# Model Validation: 6-Fold Cross-validation

Predict Test Set from 5 Training Sets



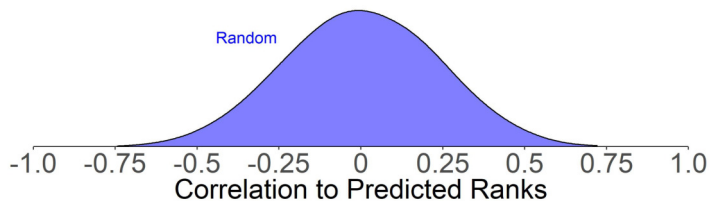
# Model Validation: Diverse Respondents

# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting

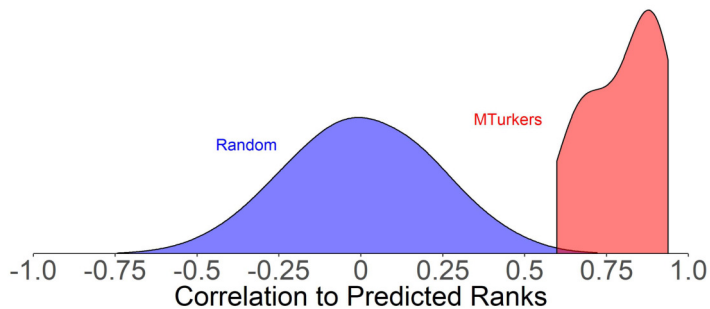
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



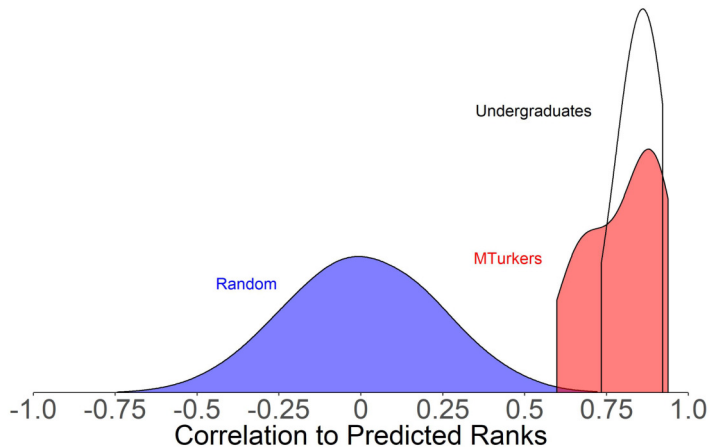
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



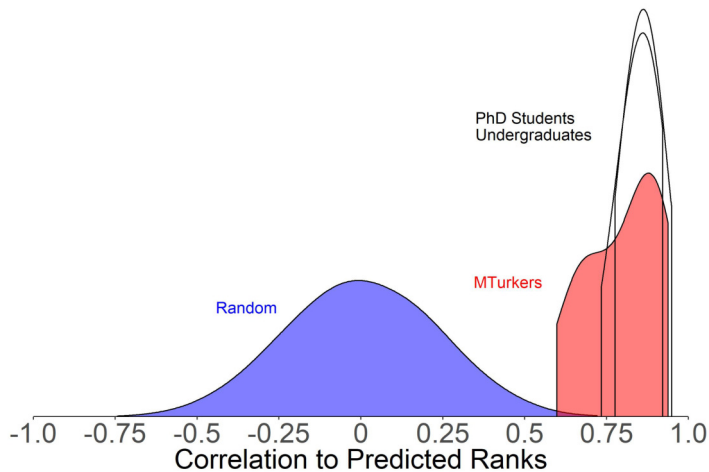
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



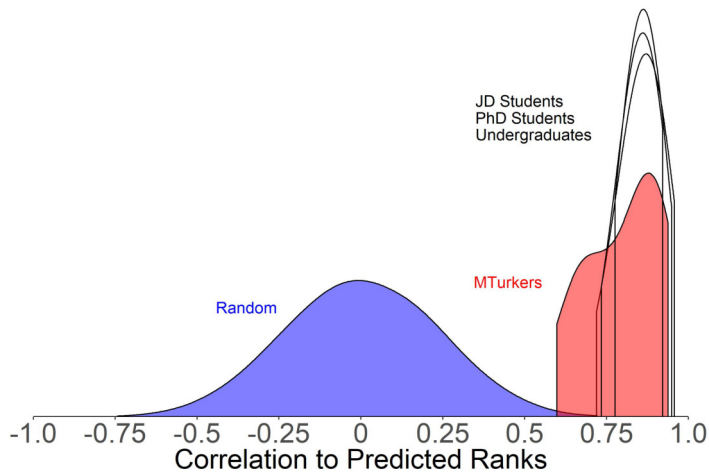
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



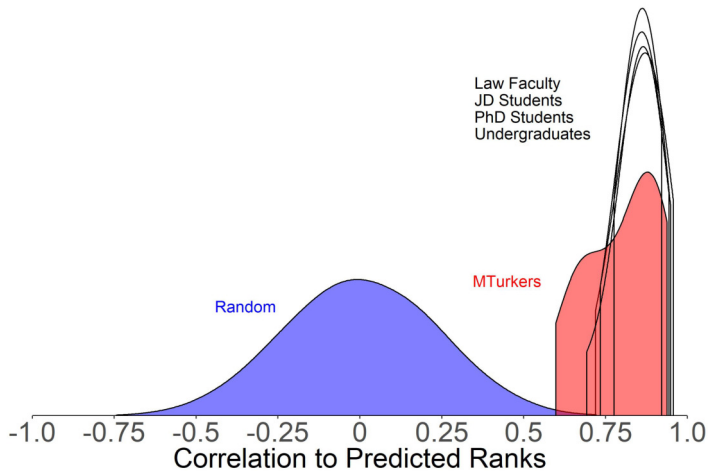
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



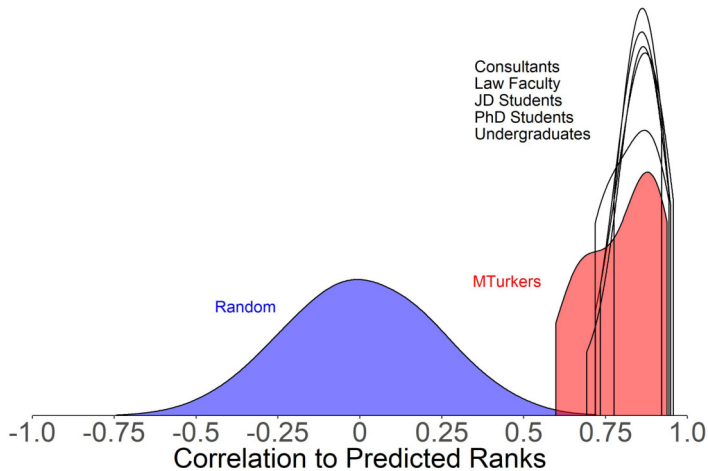
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



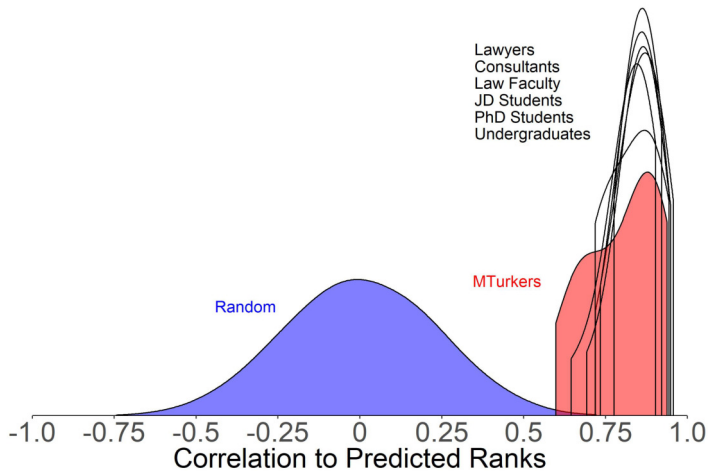
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



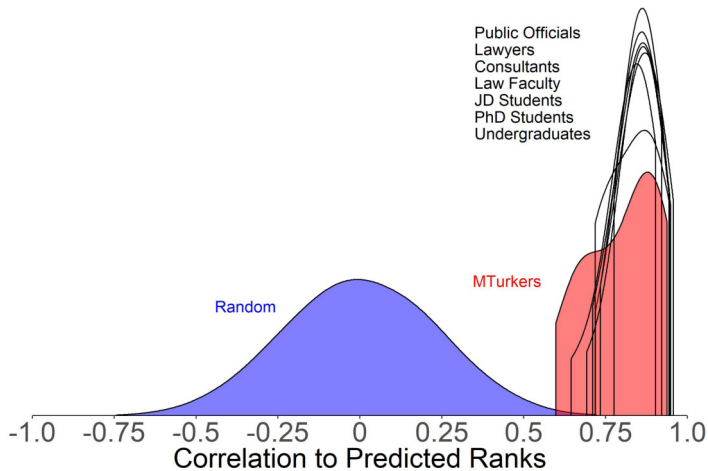
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



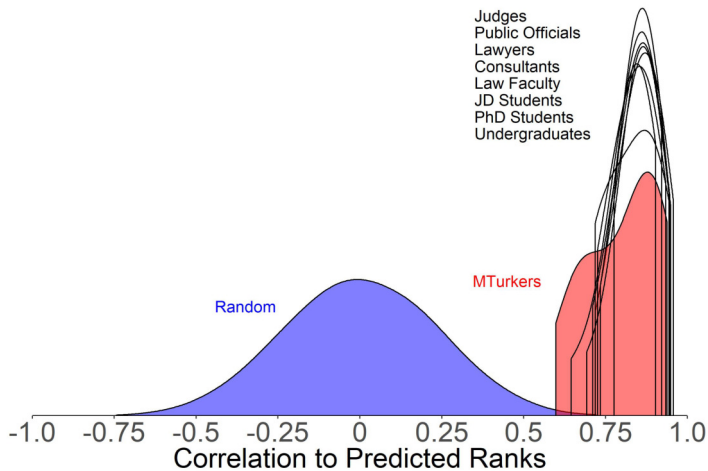
# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



# Model Validation: Diverse Respondents

Respondents ranging from ordinary citizens to those responsible for redistricting



What do you think?

## What do you think?

Our measure:	COMPACT	noncompact	noncompact	COMPACT
Existing measure:	COMPACT	noncompact	COMPACT	noncompact

# What do you think?

Our measure:

COMPACT

noncompact

noncompact

COMPACT

Existing measure:

COMPACT

noncompact

COMPACT

noncompact

Reock



# What do you think?

Our measure:

COMPACT

noncompact

noncompact

COMPACT

Existing measure:

COMPACT

noncompact

COMPACT

noncompact

Reock



Boyce-Clark



# What do you think?

Our measure:	COMPACT	noncompact	noncompact	COMPACT
Existing measure:	COMPACT	noncompact	COMPACT	noncompact

Reock



















Boyce-Clark



Length/Width



# What do you think?

Our measure:	COMPACT	noncompact	noncompact	COMPACT
Existing measure:	COMPACT	noncompact	COMPACT	noncompact
Reock				
Boyce-Clark				
Length/Width				
X-Symmetry				

# What do you think?

Our measure:	COMPACT	noncompact	noncompact	COMPACT
Existing measure:	COMPACT	noncompact	COMPACT	noncompact

Reock



Boyce-Clark



Length/Width



X-Symmetry



## Concluding Remarks

## Concluding Remarks

- **We address:** Disconnect between political science & the real world

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - ↷ Continue political science tradition of contributing to a fundamental part of representative democracy

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - $\rightsquigarrow$  Continue political science tradition of contributing to a fundamental part of representative democracy
- **Accompanying this paper:**

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - ↷ Continue political science tradition of contributing to a fundamental part of representative democracy
- **Accompanying this paper:**
  - Measures: for 18,215 Congressional & State Legislative districts

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - $\rightsquigarrow$  Continue political science tradition of contributing to a fundamental part of representative democracy
- **Accompanying this paper:**
  - Measures: for 18,215 Congressional & State Legislative districts
  - Software to calculate compactness from any district shape

## Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - $\rightsquigarrow$  Continue political science tradition of contributing to a fundamental part of representative democracy
- **Accompanying this paper:**
  - Measures: for 18,215 Congressional & State Legislative districts
  - Software to calculate compactness from any district shape
- **Along the way:**

# Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - $\rightsquigarrow$  Continue political science tradition of contributing to a fundamental part of representative democracy
- **Accompanying this paper:**
  - Measures: for 18,215 Congressional & State Legislative districts
  - Software to calculate compactness from any district shape
- **Along the way:**
  - New perspective on  $> 150$  year consensus of ranking v paired comparisons

# Concluding Remarks

- **We address:** Disconnect between political science & the real world
  - The Theoretical Concept: multidimensional and complex
  - The Legal Concept: one dimensional and simple
- **A proposed resolution:** measure the one dimension everyone sees
  - Calculated solely from district geometry
  - Very high intercoder & intracoder reliability
  - Very high predictive validity
  - Diverse people see it the same way
  - $\rightsquigarrow$  Continue political science tradition of contributing to a fundamental part of representative democracy
- **Accompanying this paper:**
  - Measures: for 18,215 Congressional & State Legislative districts
  - Software to calculate compactness from any district shape
- **Along the way:**
  - New perspective on  $> 150$  year consensus of ranking v paired comparisons
  - New directions for two venerable literatures

## For more information



[AaronRKaufman.com](http://AaronRKaufman.com)



[GaryKing.org](http://GaryKing.org)



[MayyaKomisarchik.com](http://MayyaKomisarchik.com)

Paper, data, software, slides: [j.mp/Compactness](https://j.mp/Compactness)