How to Measure Legislative District Compactness
If You Only Know it When You See it

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University of Pittsburgh, Center for Research Computing, 3/8/2019

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1 Based on joint work with Aaron Kaufman and Mayya Komisarchik
2 GaryKing.org
Redistricting Defines Democracy — & Needs Fixing

Fundamental to Democracy

- Control redistricting
- Define basic units of representation

$100$s of millions spent trying to influence the rules of the game

- Litigation in almost every jurisdiction, every time

⇝

- 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
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Computing Needs

Needs differ:

Computation: “Embarrassingly parallel”

More informative individual data points: Person v. molecule

Fewer cores: 100s v. 1,000s (5 v. 2,000 TeraFlops)

Larger individual cores: 20 GB - 1 TB v. 1-4 GB

⇝ Fewer, more data intensive, operations

Goals differ:

While figuring it out:

Run anything we dream up, fast

Need big, beefy, gigantic computers (dreams are inefficient)

Ultimate goal:

Using smaller computers

Supercomputers mean: insufficient exploration, model dependence checks, uncertainty estimation, or influence on others

Laptops beat supercomputers!
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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
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    - 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

More

Compact

Less

Compact

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

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The dimension is intuitive
- How to estimate where a new district shape falls on this dimension?
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⇒ Let’s start with existing measures by social scientists
Measure 1: Length/Width Ratio of Min Bounding Box

In both districts: \( \frac{X}{Y} \approx 1.30 \).
Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones

\[ \frac{6}{27} \approx 0.30 \]
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Measure 2: Reock, District / Bounding Circle Areas

In both cases, \( \frac{X}{Y + X} \approx 0.37 \frac{7}{27} \).
Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact
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In both cases, \( \frac{X}{Y + X} \approx 0.37 \)
Measure 3: Boyce-Clark, Variation in Centroid Deviations

In both cases, \( \text{MAD}(r)/\overline{r} \approx 0.318/27 \)
Measure 3: Boyce-Clark, Variation in Centroid Deviations

All travel distances from center should be similar
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In both cases, \( \text{MAD}(r) / \bar{r} \approx 0.31 \)
A Brief Rotational Invariance Interlude:
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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

Existing measures of compactness:

- Nearly 100 proposed
- Almost all are rotationally invariant
- Blind to what humans perceive

Which is more compact?

- Measuring "you know it when you see it": No rotational invariance
Human Perception: Not Rotationally Invariant

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~→ Measuring “you know it when you see it”: No rotational invariance
New Measure: Y-Symmetry, area of symmetric reflection
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New Measure: Y-Symmetry, area of symmetric reflection

Symmetric figures (circles, squares) are more compact

In both cases, Overlap/Original Area ≈ 0.34
New Measure 2: Number of Visually Significant Corners

Both districts have 21 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

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Which is more compact?

- Convex Hull
- Polsby-Popper
- Boyce-Clark
- Length/Width
- X-Axis Symmetry

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

Convex Hull

4  3  2  1
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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
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How to rank districts on the same dimension?

Why Paired Comparisons is supposedly better

Everyone does what they are good at:

Respondents answer simple, concrete questions

Researchers reconstruct the scale

Much easier:

\[
\binom{20}{2} = 190 \text{ pairs } \approx 2 \text{ quintillion ranks}
\]

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
How to rank districts on the same dimension?
Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

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Paired Comparison

Utterly fails on inter- and intra-coder reliability
How to rank districts on the same dimension?

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Full Ranking

[Image of a conference room with a table set up for ranking tasks]
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Full Ranking — on line

We show: very high reliability
How to rank districts on the same dimension?
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Intercoder Reliability of Pairs

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Intracoder Reliability of Pairs
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Paired Comparisons: better than chance;
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\[ \rho = 0.77 \]
Intercoder Reliability on Ranks

$\rho = 0.77$

$\rho = 0.81$
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\[ \rho = 0.70 \]

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

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

Training data: Outcome variable from human rankings

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)
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Predict Test Set from 5 Training Sets
Model Validation: 6-Fold Cross-validation

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$\rho = 0.91$
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Predict Test Set from 5 Training Sets

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Model Validation: Diverse Respondents
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Respondents ranging from ordinary citizens to those responsible for redistricting
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What do you think?
<table>
<thead>
<tr>
<th>What do you think?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Our measure:</strong></td>
</tr>
<tr>
<td><strong>Existing measure:</strong></td>
</tr>
</tbody>
</table>
What do you think?

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

Reock
What do you think?

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Reock

Boyce-Clark
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Reock

Boyce-Clark

Length/Width
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<thead>
<tr>
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- **Reock**
- **Boyce-Clark**
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- **X-Symmetry**
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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

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
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- Diverse people see it the same way
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Accompanying this paper:
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Along the way:
- New perspective on 150 year consensus of ranking v paired comparisons
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Concluding Remarks

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