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

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

Control redistricting → Define basic units of representation

$100s 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
Redistricting Defines Democracy — & Needs Fixing

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How to fix this?
- Constrain redistricters via: Population equality, partisan fairness, racial fairness, respect for municipal boundaries … 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
- 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"
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Compactness According to the Law

More

Compact

Less

Compactness

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
Compactness According to the Law

A simple single compactness dimension that you know when you see
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Measure 1: Length/Width Ratio of Min Bounding Box

In both districts: \( \frac{X}{Y} \approx 1.30 \)
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Squarish districts more compact than long thin ones
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In both districts: $X/Y \approx 1.30$
Measure 2: Reock, District / Bounding Circle Areas

\[
\frac{X}{Y + X} \approx 0.37
\]
Measure 2: Reock, District / Bounding Circle Areas

Circular districts are most compact
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Circular districts are most compact

In both cases, $\frac{X}{Y + X} \approx 0.37$
Measure 3: Boyce-Clark, Variation in Centroid Deviations

$$\text{MAD}(r) / \bar{r} \approx 0.31$$
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All travel distances from center should be similar
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A Brief Rotational Invariance Interlude:
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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
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- Measuring “you know it when you see it”: No rotational invariance
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Symmetric figures (circles, squares) are more compact
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Symmetric figures (circles, squares) are more compact

In both cases, Overlap/Original Area \( \approx 0.34 \)
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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Both districts have 21 significant corners
Which is more compact?

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

7 measures; 7 unique rankings

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!

Convex Hull

Reock 1 2 3 4

Polsby-Popper

Boyce-Clark 2 3 1 4

Length/Width

X-Axis Symmetry 1 4 3 2

Significant Corners

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Unusual?

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| Convex Hull | 4 | 3 | 2 | 1 |
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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.
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Why Paired Comparisons is supposedly better

Everyone does what they are good at:

- Respondents answer simple, concrete questions
- Researchers reconstruct the scale

Much easier:

\[ \begin{align*}
190 \text{ pairs} & \approx 2 \text{ quintillion ranks} \\
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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:
  \[ 1 \text{ task} v 190 \text{ comparisons} \]
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Full Ranking
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Full Ranking — on line

Most Compact Here

Least Compact Here
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    Ranking: all evaluations on one dimension of user’s choice
Intercoder Reliability of Pairs
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Paired Comparisons: only slightly better than chance;
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\[ \rho = 0.77 \]
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\[ \rho = 0.81 \]
Intercoder Reliability on Ranks

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\[ \rho = 0.70 \]

\[ \rho = 0.81 \]
Intercoder Reliability on Ranks

- Ranker 1 vs. Ranker 5: $\rho = 0.77$
- Ranker 2 vs. Ranker 4: $\rho = 0.70$
- Ranker 3 vs. Ranker 6: $\rho = 0.81$

The plots show a strong correlation between rankers, with the correlation coefficients indicating a high degree of agreement.
Intracoder Reliability on Ranks

\[ \rho = .90 \]
Intracoder Reliability on Ranks

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\[ \rho = 0.92 \]
Intracoder Reliability on Ranks

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So we can measure it. Can we model it?

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. . .


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

Goal: Compactness score = $f(\text{shape})$
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Predict Test Set from 5 Training Sets
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\[ \rho = 0.91 \]
Model Validation: 6-Fold Cross-validation

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\[
\begin{align*}
\text{Test Set: 1} & \quad \rho = 0.91 \\
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\text{Test Set: 3} & \quad \rho = 0.96 \\
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\end{align*}
\]
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![Graph showing correlation to predicted ranks for different groups of respondents.](image-url)
What do you think?
What do you think?

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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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For more information

AaronRKaufman.com
GaryKing.org
MayyaKomisarchik.com

Paper, data, software, slides:  j.mp/Compactness