How to Measure Legislative District Compactness
If You Only Know it When You See it\textsuperscript{1}

Gary King\textsuperscript{2}

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Harvard University

University of Minnesota, 9/12/2019

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

Control redistricting

Fundamental to Democracy

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
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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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  - 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

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

\[ \frac{X}{Y} \approx 1.30 \]
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Squarish districts more compact than long thin ones
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\[ \frac{5}{27} \]
Measure 1: Length/Width Ratio of Min Bounding Box

Squarish districts more compact than long thin ones

In both districts: $\frac{X}{Y} \approx 1.30$
Measure 2: Reock, District / Bounding Circle Areas

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

Circular districts are most compact

\[ \frac{X}{Y + X} \approx 0.376 \]
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\frac{X}{Y + X} \approx 0.376/27
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Measure 2: Reock, District / Bounding Circle Areas
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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7/27
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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

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
New Measure: Y-Symmetry, area of symmetric reflection
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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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Computer vision algorithm identifies “objects” in photos
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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

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!
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<table>
<thead>
<tr>
<th>Convex Hull</th>
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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 it.

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:

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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:

\( \binom{20}{2} = 190 \) pairs \( \approx 2 \) 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;
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- Saves time:
  - 1 task vs 190 comparisons
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Paired Comparisons (Fechner 1860; Thurstone 1912) v Ranking (very old, rarely used)

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Utterly fails on inter- and intra-coder reliability
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  - Much easier: \( \binom{20}{2} = 190 \text{ pairs} \) v \( 20! \approx 2 \text{ quintillion ranks} \)

- Why Ranking is actually better (at least in our application)

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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Intercoder Reliability of Pairs
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Paired Comparisons: only slightly better than chance;
Intercoder Reliability of Pairs

Paired Comparisons: only slightly better than chance; Pairs implied by ranks: better
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Paired Comparisons: better than chance; Pairs implied by ranks: much better
Intercoder Reliability on Ranks

\[ \rho = 0.77 \]
Intercoder Reliability on Ranks

\[ \rho = 0.77 \]

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

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Intracoder Reliability on Ranks

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Intracoder Reliability on Ranks

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Random

Ranking
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, etc.
- Geometric: Perimeter, area, vertices, polygons, vertex variance, edge length variance, etc.
- New: X-axis symmetry, Y-axis symmetry, Significant Corners, etc.

Ensemble of predictive methods: least squares, AdaBoosted decision trees, SVM, random forests, etc.

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 = \( f(\text{shape}) \)
So we can measure it. Can we model it?

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- **Training data**: Outcome variable from human rankings
So we can measure it. Can we model it?

Goal: Compactness score = f(shape)

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- **Outcome measure**: A district’s rank (in a set of 100)
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Goal: Compactness score = \( f(\text{shape}) \)

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- **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—squirish, 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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*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

Predict Test Set from 5 Training Sets

\[ \rho = 0.91 \]
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
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What do you think?

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

Reock

Boyce-Clark

Length/Width

24/27
### What do you think?

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<th>Our measure:</th>
<th>COMPACT</th>
<th>noncompact</th>
<th>noncompact</th>
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Reock
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Length/Width
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Length/Width

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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

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For more information

AaronRKaufman.com

GaryKing.org

MayyaKomisarchik.com

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