Visual Encoding of Dissimilarity Data via Topology-Preserving Map Deformation*

CPSC 547: Information Visualization

Felix Grund

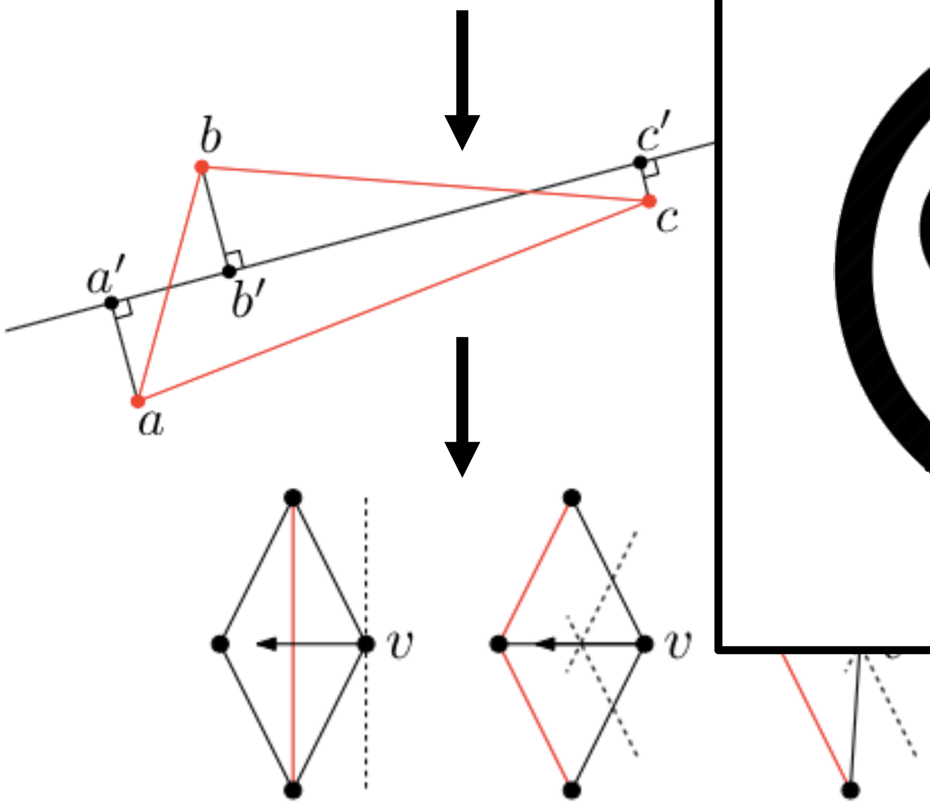
*Cartography

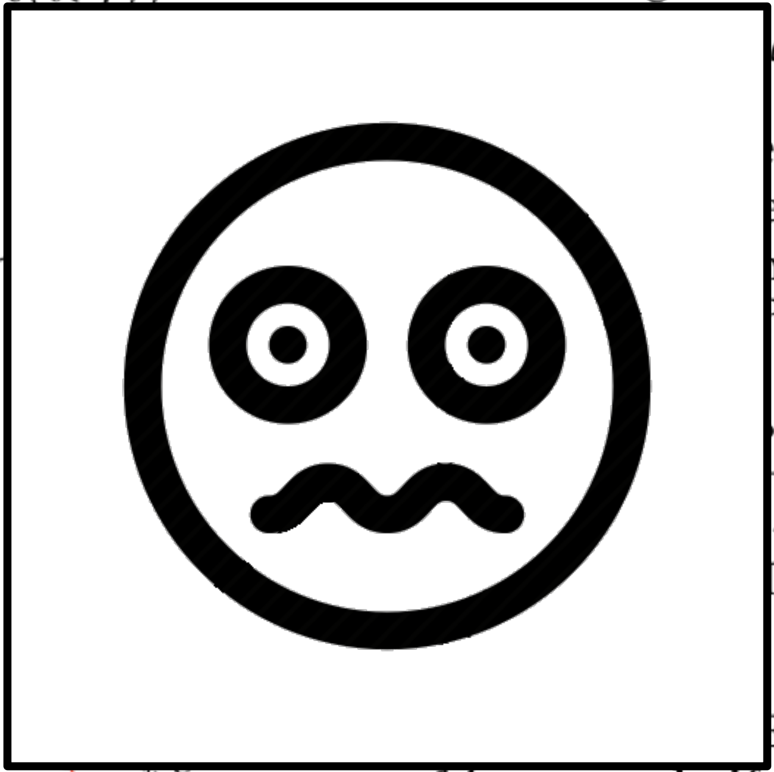
Source: https://lesleygrainger.com

We love maps!

But when it comes to science…

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} w_{ij} \left(d_{ij} - \mathrm{dist}(i,j)\right)^2$$





The high-level flow of this method is given below:

amicConstraintMDS

gradient info for *stress* at current config.
ent vector from gradient info
mal unconstrained step-size for $\vec{d}$
oint **p** in current config.

←component of $\vec{d}$ for point **p**
—limiting factor for faces adjacent to **p**
←$\mathbf{p} + \min(l, \alpha)\vec{d}_{\mathbf{p}}$
riangle(a, b, c)
Constraint Violated
then (a, b, c)←ProcrustesProject(a, b, c) [13]
dge under stress
do if Flipping topologically safe
then Flip Edge
while StressReduction > epsilon

Let’s split the title…

Visual Encoding of Dissimilarity Data via Topology-Preserving Map Deformation

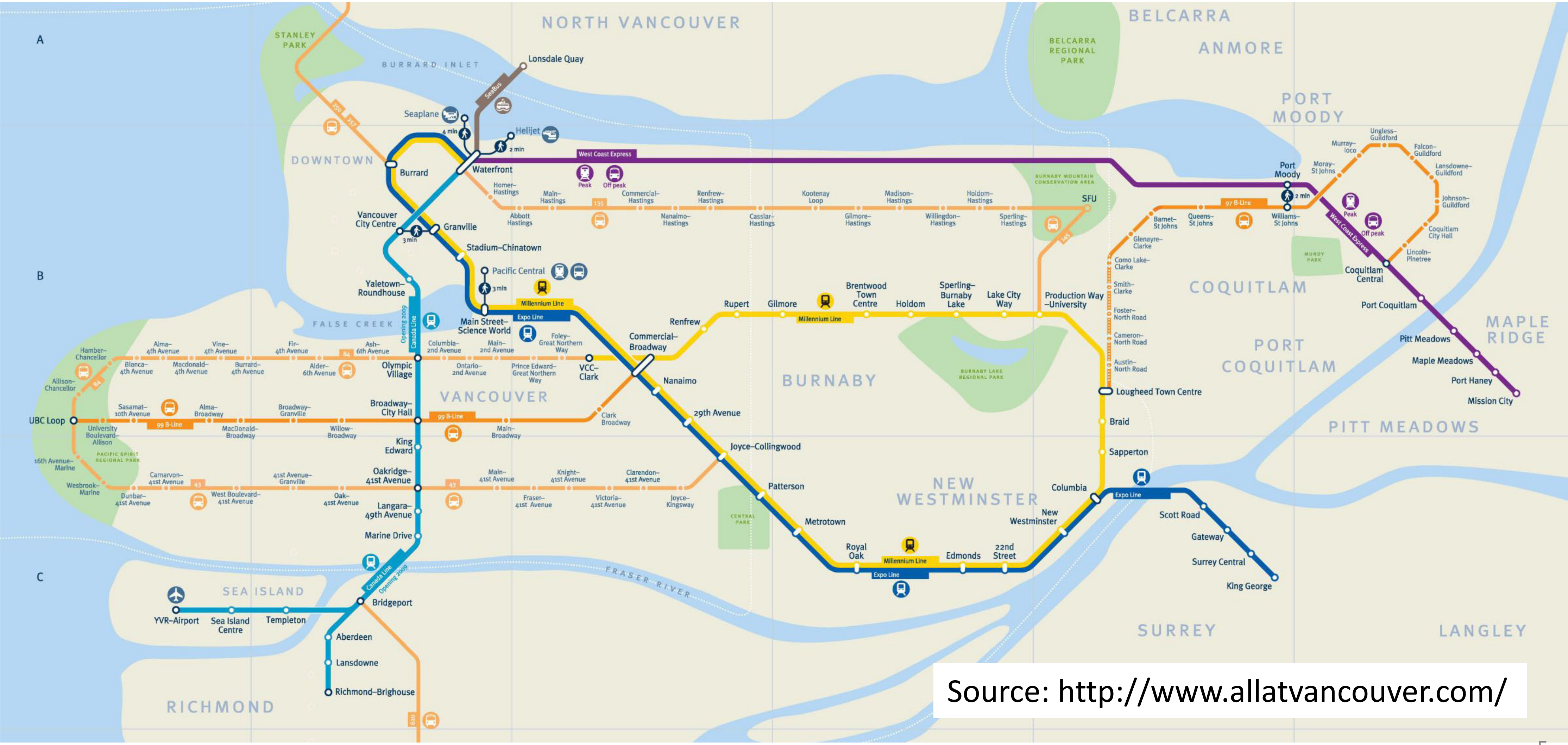
We visualize…

...things that are different…

…by changing a map…

…without losing regional structure.

“We visualize things (that are different) by changing a map without losing regional structure.”

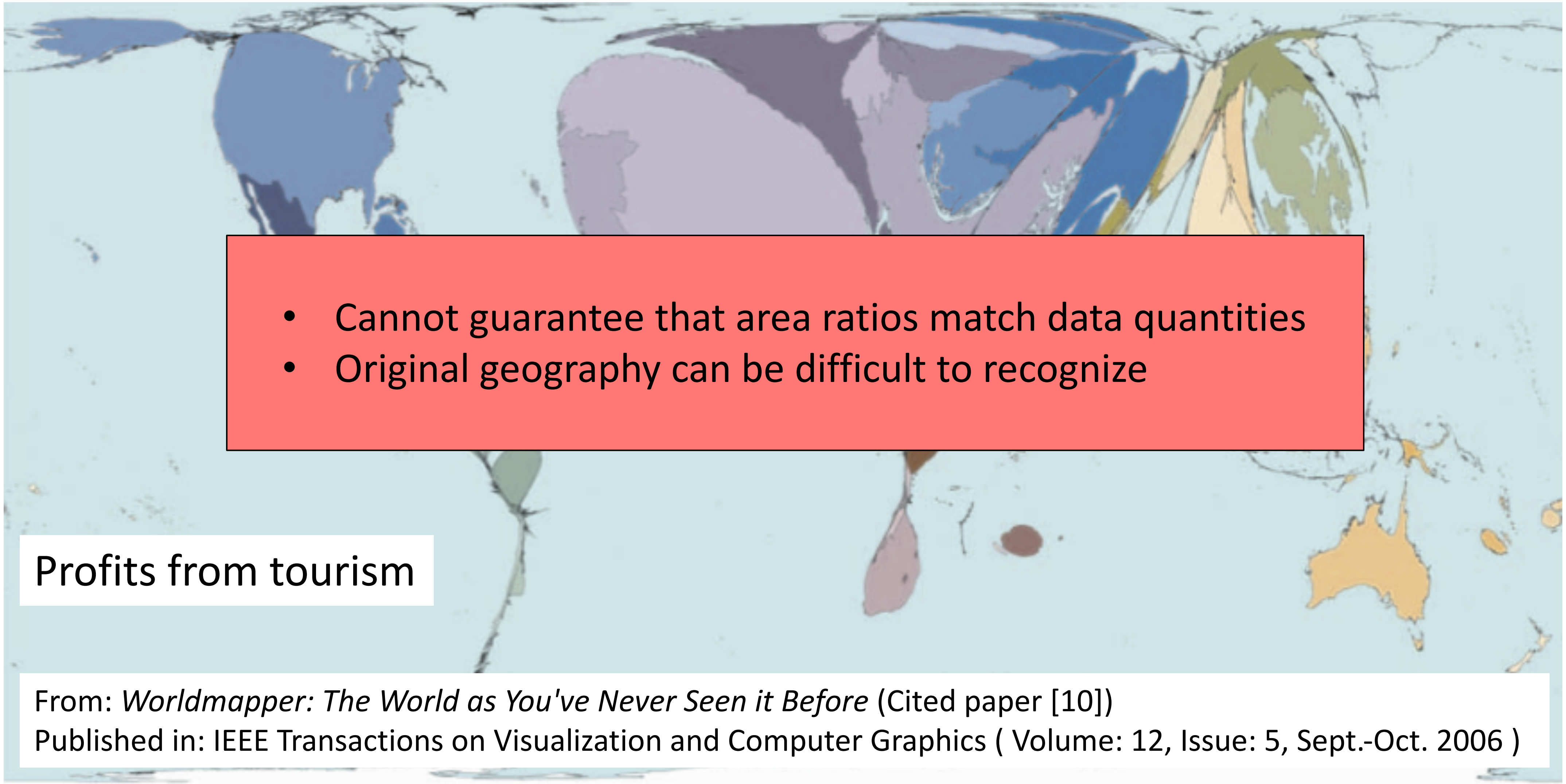


Source: http://www.allatvancouver.com/

Background (1) – Cartograms

- Deformation of map such that
  - geographic regions correspond to quantitative value
  - but adjacencies and shapes are preserved
- Have been used to show a variety of attributes
- Create flashy juxtaposition between geography and data

Background (2) – Cartogram Example



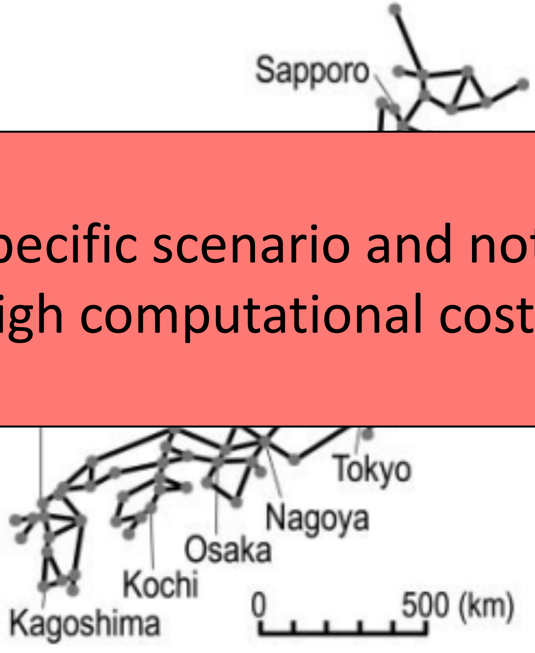
- Cannot guarantee that area ratios match data quantities
- Original geography can be difficult to recognize

Profits from tourism

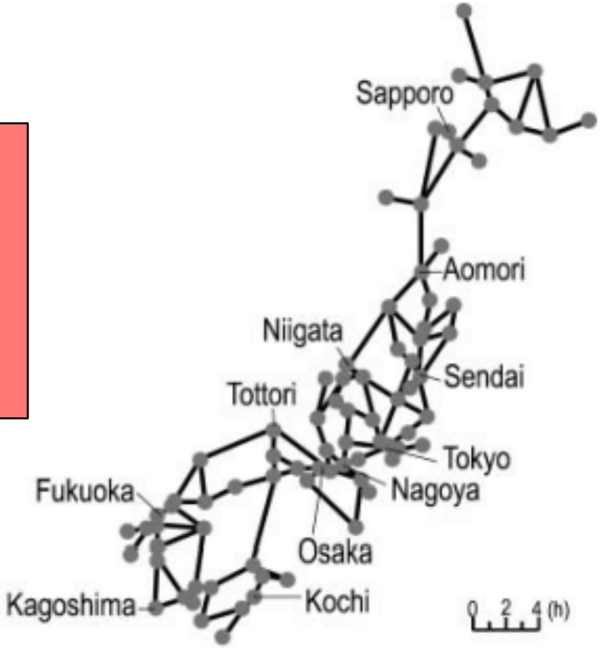
From: *Worldmapper: The World as You've Never Seen it Before* (Cited paper [10])
Published in: IEEE Transactions on Visualization and Computer Graphics (Volume: 12, Issue: 5, Sept.-Oct. 2006)

Background (3) – Travel Time Maps

- Focus on special case of transportation network (locations/distances)
- Deform map so travel times become edge lengths



- Specific scenario and not generic
- High computational cost



From: *A new algorithm for distance cartogram construction* (Cited paper [35])
Published in: International Journal of Geographical Information Science (ISSN: 1365-8816)

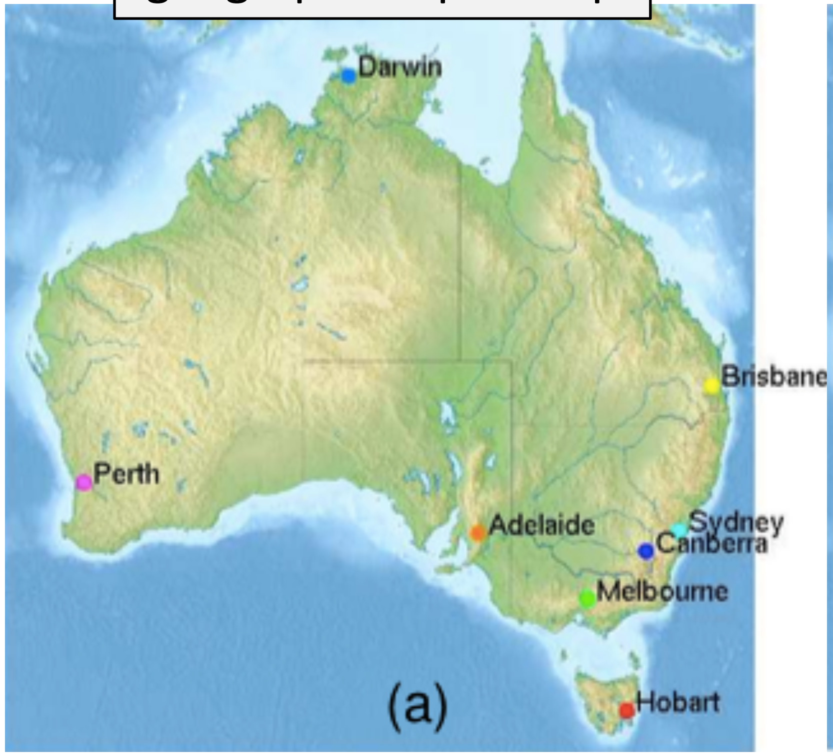
Contribution

- New map deformation technique that
  - preserves topology
  - balances preserving geographic shape with conveying data
- Instead of simple scalar values and regions (cartogram)
  - take a complete weighted graph between locations
  - move the locations such that distance corresponds to weights
  - but only as closely as possible
- Encode dissimilarity between locations as edge weights
  - distance in deformed map then related to data dissimilarity
  - enable to compare distances between locations and attributes
- Overcome limitations of deformation with visual overlays
- Deformation in response to interaction (with good performance)

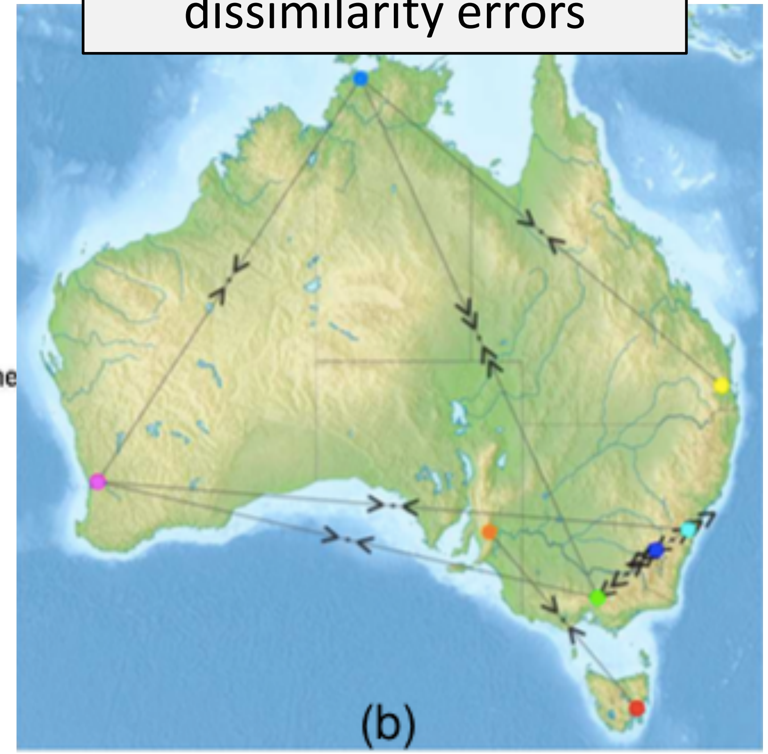
First impression...

House price increases in Australia 2013

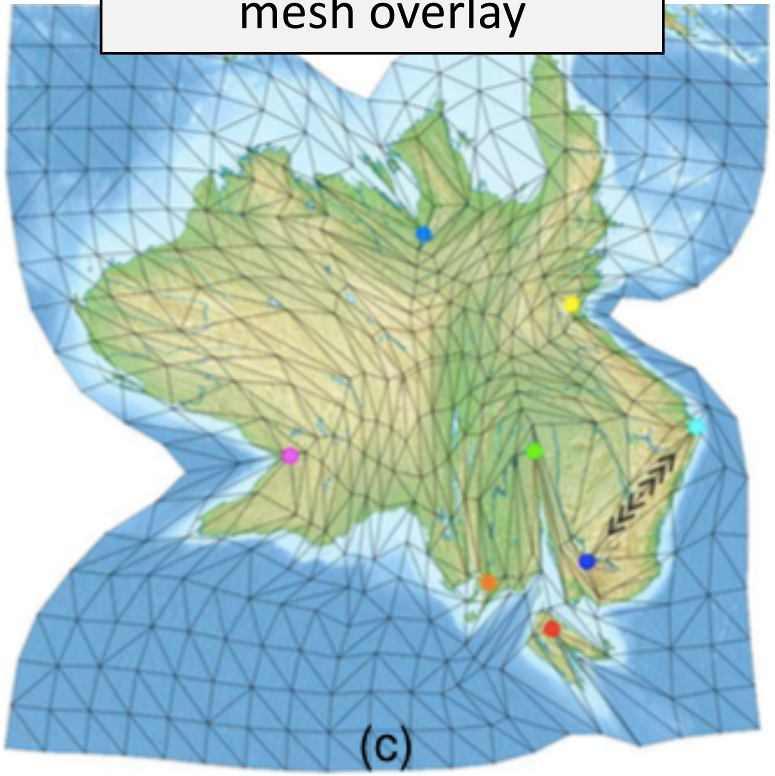
geographic input map



glyphs showing significant dissimilarity errors



deformed map with mesh overlay



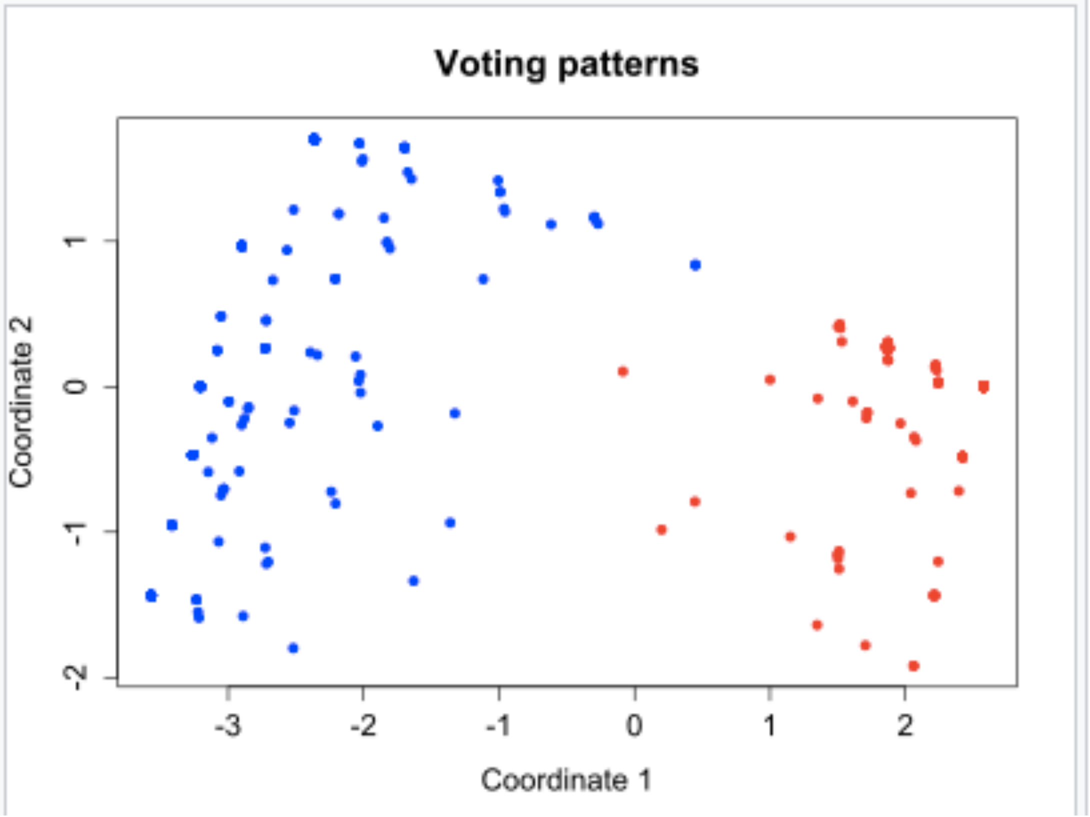
All from paper Fig. 1

Technique:
Topology preserving multidimensional scaling

???

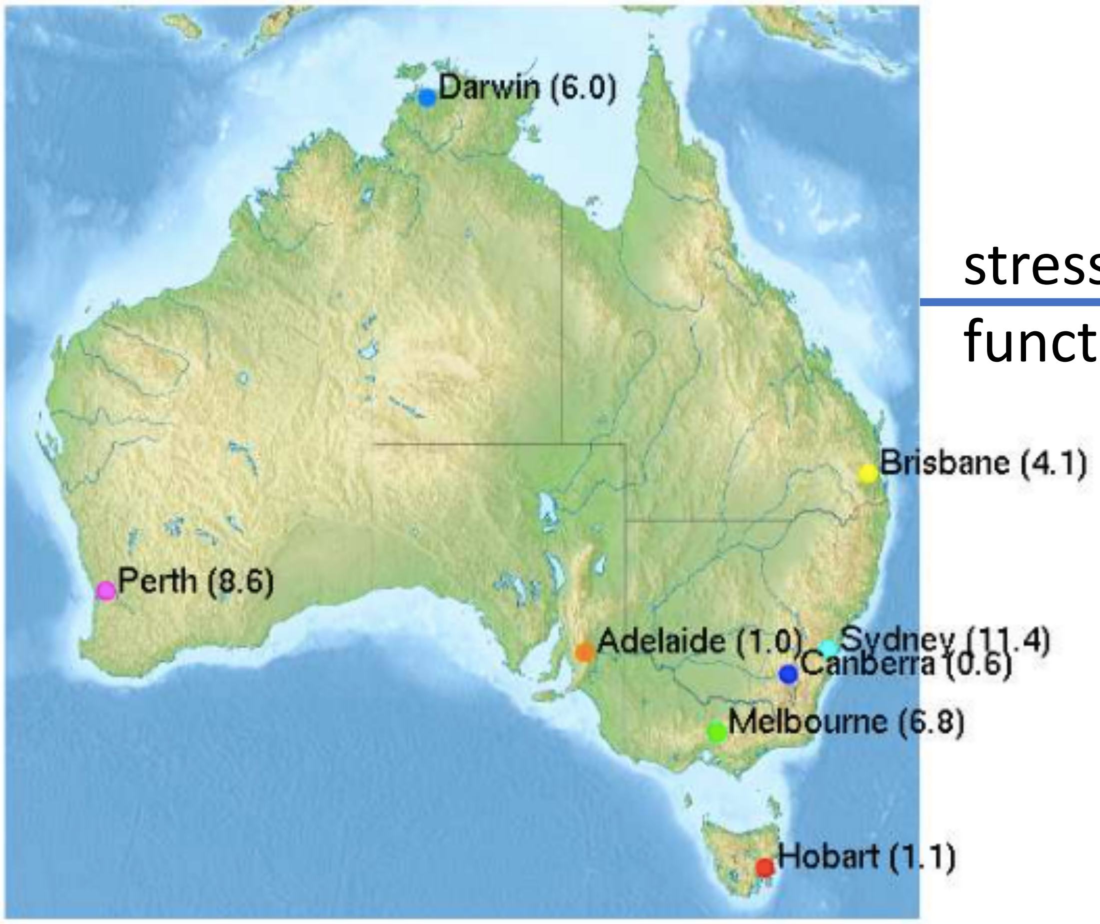
Background: Multidimensional Scaling (MDS)

- Visualizes level of (dis-)similarity of individual cases of a dataset
- Achieved by minimizing *stress function* over positions of data points
- Plot with “minimal stress”: distance between points is proportional to dissimilarity

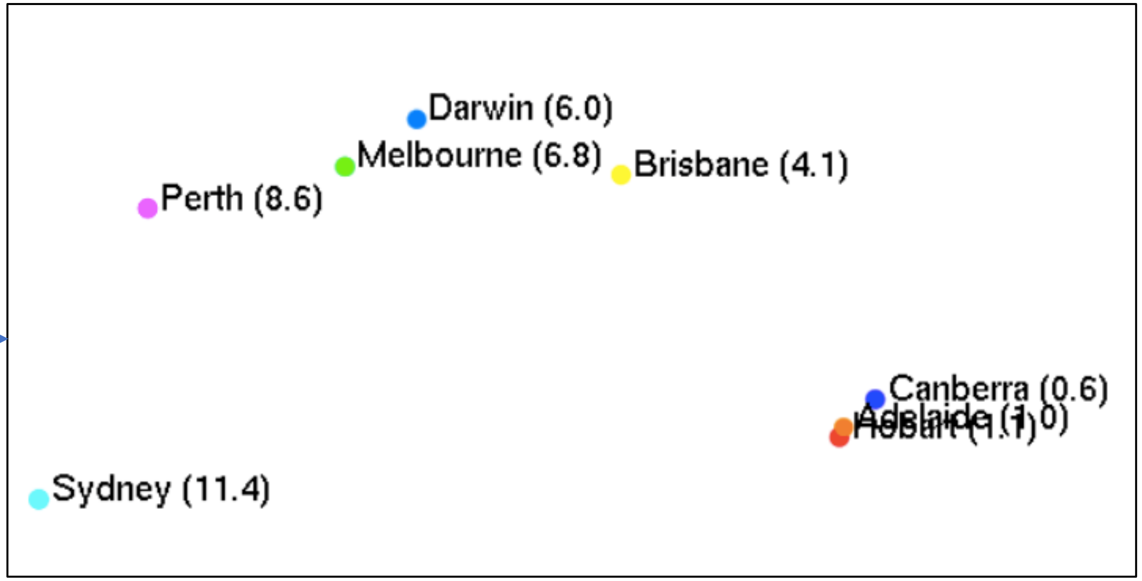


MDS applied to voting patterns in US house of representatives - blue: democrats, red: republicans (Source: Wikipedia)

House price increases in Australia 2013



stress function



Paper Figs. 2a + 2b

- Left: Topology
- Right: MDS => topology is lost!
- This paper: MDS but preserve Topology

Approach

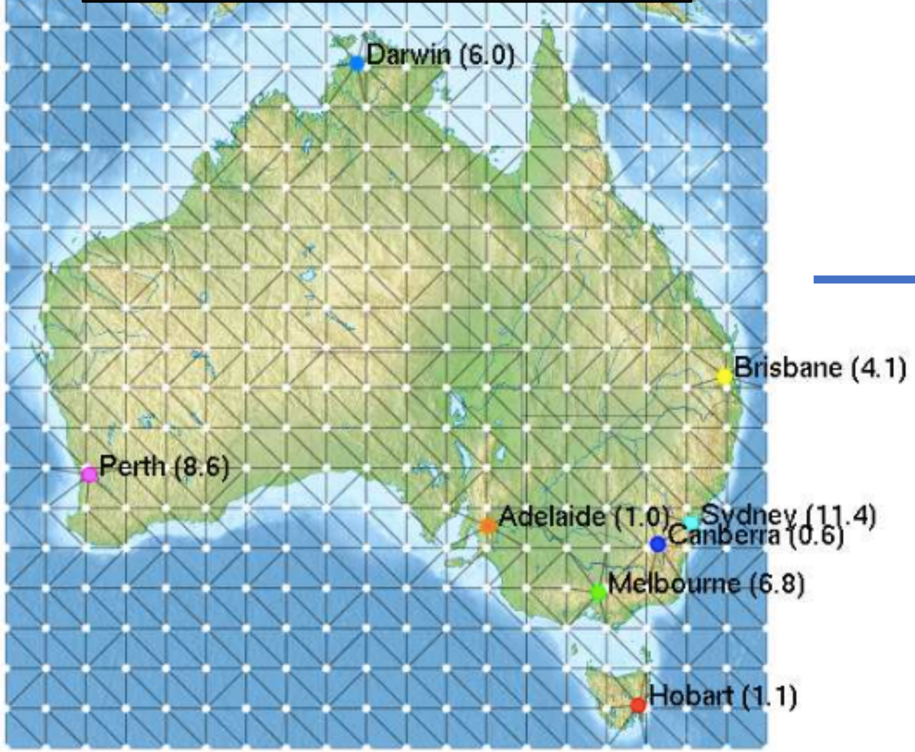
- MDS of data points in deformable mesh
- Original map image is mapped onto mesh incrementally through transformations
- Mesh may be deformed
- Constraint: mesh and data vertices cannot pass through mesh edges
- <u>3 steps</u>
    1. Deform map to follow points (MDS)
    2. Preserve map topology
    3. Enable interaction by *dynamic mesh modification*

Step 1: deform map to follow points

- Map with triangular mesh overlay
  - Edges of triangles: *Delaunay triangulation* (?)
  - “no point in P is inside the circumcircle of any triangle” (Wikipedia)
- Vertices: geographic locations + ”helper points”
  - add bendpoints
  - regularize and preserve topology
- New stress function with helper points to model both:
  - degree of fit of the data points to their ideal separation
  - degree of deformation of the mesh

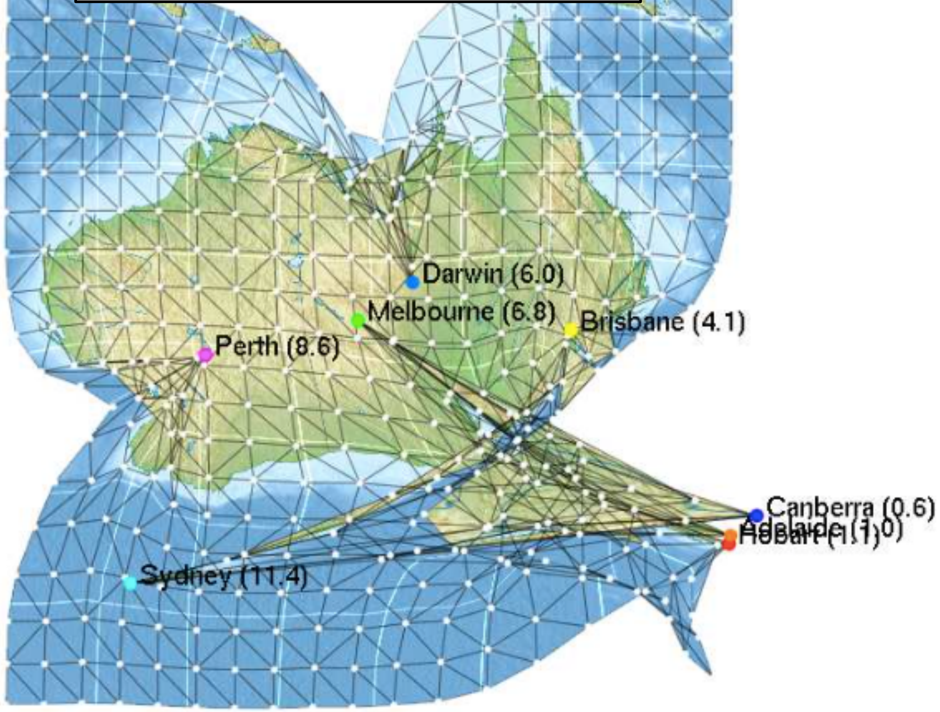
Step 1: deform map to follow points (cont.)

Map with mesh overlay



Paper Fig. 3a

Minimal stress result



Paper Fig. 3b

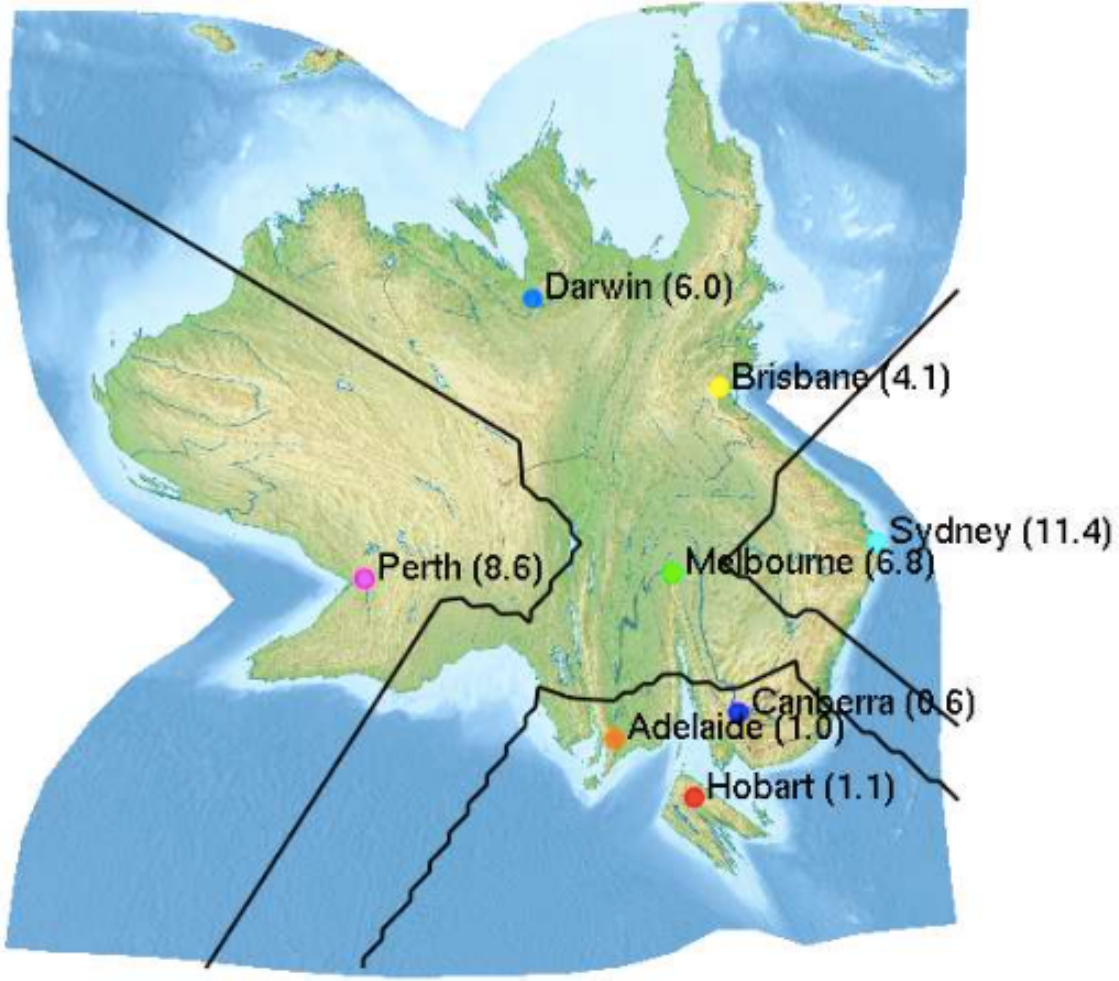
Problem: points are different from topology => map is distorted beyond recognition

Step 2: preserve mesh topology

- Idea: preserve orientation of triangles in the mesh
- Constraint in the deformation:
  - No inverted triangles
  - Minimum height for triangles
- Algorithm for stress reduction by iteratively refining triangles
  - Start with the original deformation and run through all triangles
  - Correct triangle's orientation to meet constraints with minimal change
  - Repeat until satisfying overall configuration is found

Step 2: preserve mesh topology (cont.)

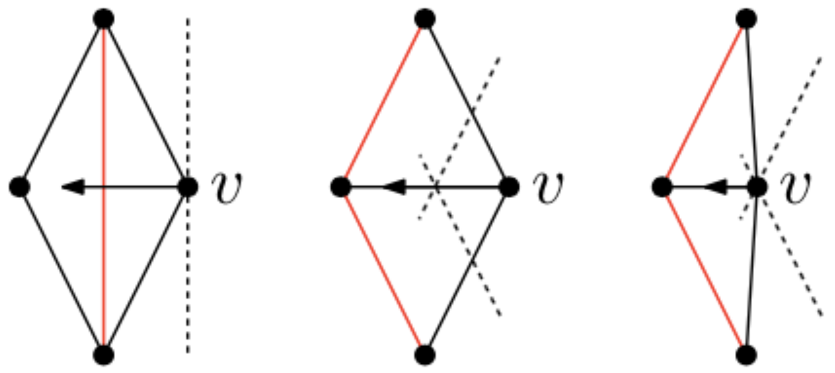
- Result: MDS with topology constraint
- Isolines highlight similar areas



Paper Fig. 3c

Step 3: dynamic mesh modification

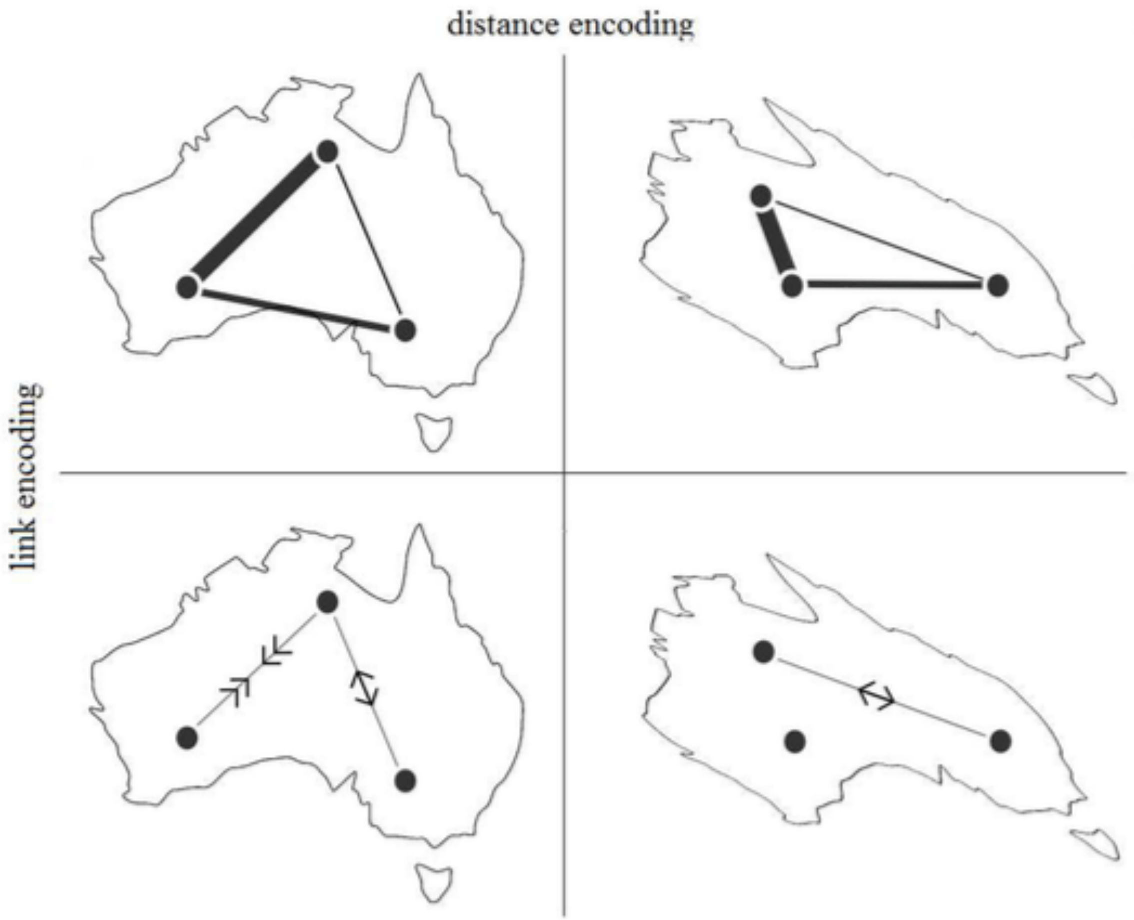
- Challenge: interactive setting
  - Impossible to predict where points will move
- Solution: update mesh while stress reduction algorithm is running
  - Options: adding/removing points vs. changing edges
  - Decision: changing edges is sufficient *(edge flipping)*
  - After edge flip: minimal height constraint not violated and points can move
- Again: preserve topology!
  - by constraints on flips



Paper Fig. 5

Visual Design

- Deformation: incomplete representation of complex dissimilarities
- Solution: combine map deformation with overlays
  - Show dissimilarities with visual links
  - Show errors in map distance using error glyphs



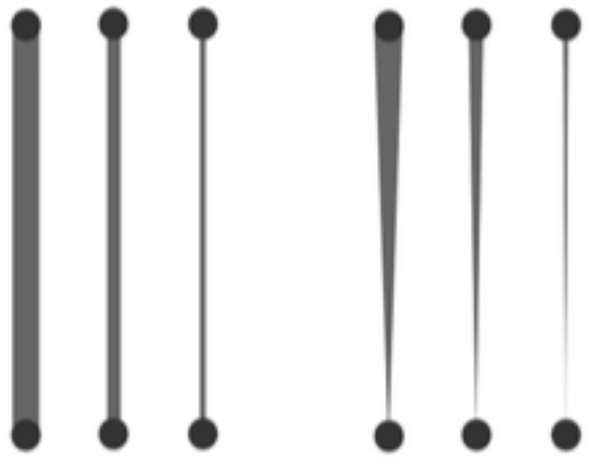
Paper Fig. 7

Visual Design Part 1: Visual Links

- Goal: convey dissimilarity and geographical data
- Solution: visual links
- Challenge: maps are dense representation and links should
  - be distinguishable from background map
  - limit clutter of the background map
  - encode weight
  - encode directionality

Visual Design Part 1: Visual Links (cont.)

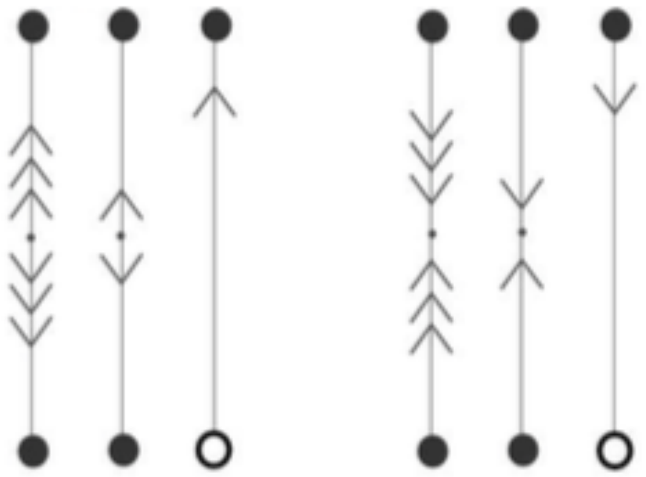
- Decisions:
  - Grayscale: distinguishable from background map
  - Thin lines and pencil-like marks: avoid clutter
  - Weights: thickness
  - Directions: tapered links



Paper Fig. 8a

Visual Design Part 1: Visual Links (cont.)

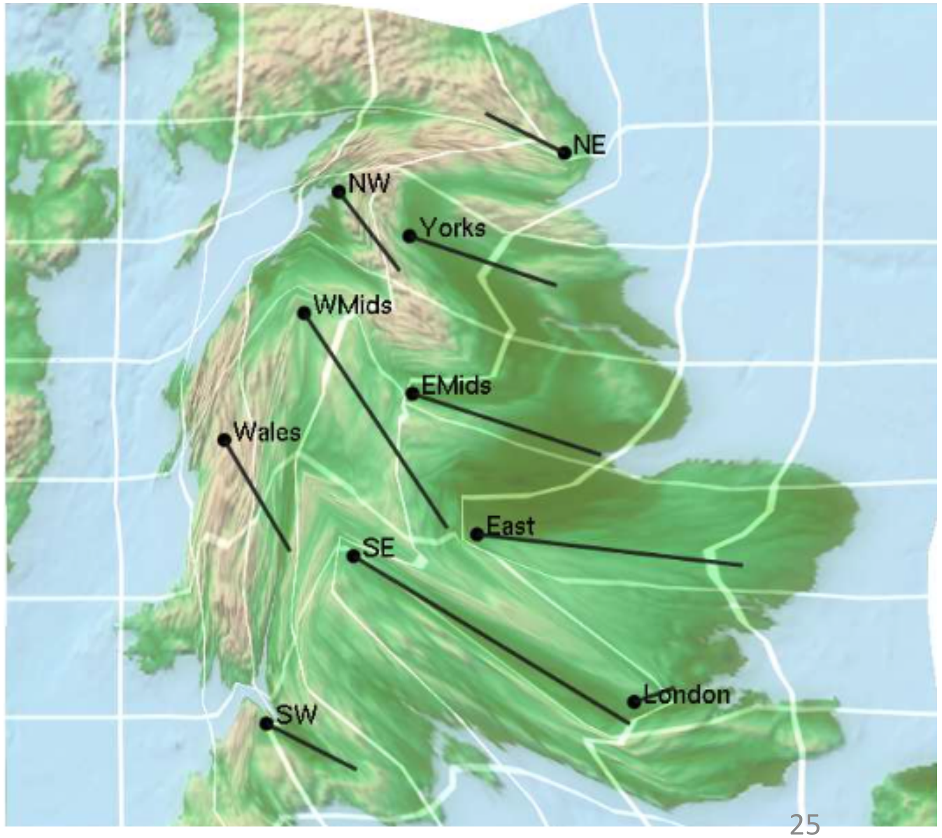
- Problem: not all links can be shown due to clutter
- Solution: Glyphs highlighting difference betw. dissimilarty and spatial separation
- Decisions:
  - Look and feel of error bars
  - Discrete over continuous (three bins)
  - Symbols existent in cartography



Paper Fig. 8d

Visual Design Part 2: Deforming the Map

- Map deformation shows dissimilarities with fewer visual overlays
- Problem: required background knowledge on map
- Solution: modify map design to convey deformation
  - Grid cells are enlarged or shrunk
  - Link current position with previous position



Paper Fig. 10b

Visual Design Part 2: Deforming the Map (cont.)

- Interaction
  - Selection of nodes
  - Filtering of links
  - Switch from general deformed view to centered view with selected points
  - Change stress threshold to show and hide glyphs
  - Config. panel for different encoding combinations => enable comparisons
- Redrawing after each iteration of algorithm

Application Case Studies

- Rail travel-times in the UK
- Socioeconomic data in the UK
- Power grid data in Australia

Demo

Technique Evaluation

- Measure performance: indicate responsiveness for interactive usage
- Datasets: house prices, power grid, socioeconomic data
  - Applied with different grid sizes
- Techniques: unconstrained, constrained, constrained dynamic mesh
- Results:
  - Dynamic mesh is most effective in reducing stress and improve performance (with constraints on grid size)
  - Summary: algorithm is fast enough to compute deformation with interaction
  - Limitation: 30 data points at most

What – Why – How

- What (data):
  - Geographical maps (with arbitrary encoding already present)
  - Arbitrary (dis)similarity data associated with locations
- What (derived):
  - Complete weighted graph
- Why (tasks):
  - Highlight (dis)similarity between locations in terms of underlying attributes
- How (encode):
  - Map deformation
  - Nodes for locations and weighted, directed graph edges (connection marks)
  - Discrete error glyphs on edges
  - Deformed grid
  - Links indicating location before deformation
  - Isolines for areas of high similarity

What – Why – How (cont.)

- How (reduce):
  - Selection of nodes
  - Filtering of nodes
  - Change stress threshold
- How (facet):
  - Switch from general deformed view to centered view with selected points
- How (manipulate):
  - Change encoding combinations
- (some other encoding techniques in case studies)
- Scale: max 30 data points (authors stay vague)

Good

- Novel compromise of both deforming and preserving topology
  - Both are important!
- Novel ability of animation associated with map deformation
  - Algorithm and its performance with animation are impressive
- Good example how one technique can be enriched by another
  - Map deformation + visual overlays
- Visualization techniques are well explained and justified
  - Authors did a lot of research and consulted experts

Bad

- ☹ Hard to read ☹
  - Requires a lot of background knowledge
  - Some terms remain unexplained and unreferenced
- Encoding too many things
  - Even though authors explain how to avoid clutter, we still find it
- Visualization is hard to interpret
  - Also requires background knowledge
  - Even with the demo it's hard to understand what this is about
- Authors remain vague in scalability
  - Evaluation: 30 data points max
  - Theory vs. practical
- Suddenly additional encoding technique (e.g. aggregate data points) explained in case studies

Thank you.