Evaluating Encodings for Bivariate Edges in Adjacency Matrices

Jorge Acosta-Hernández, Alexander Lex, Tingying He

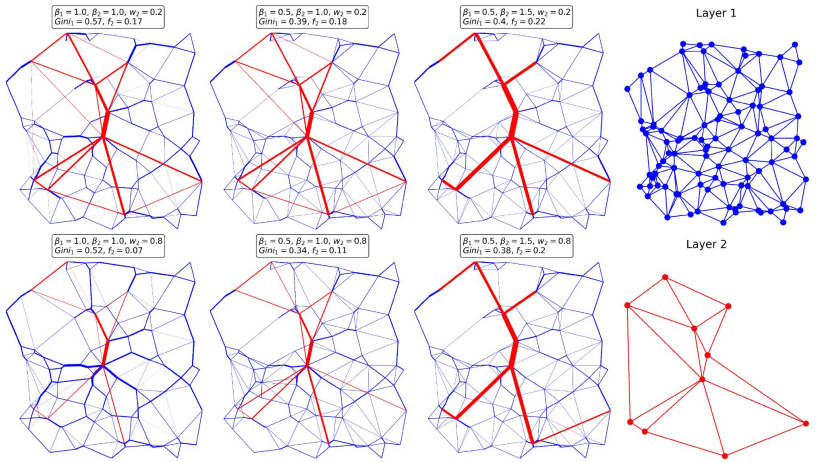
EuroVis 2026, June 2026

Multivariate networks occur in many real-world domains

Multilayer social networks reveal the social complexity of a cooperatively breeding bird

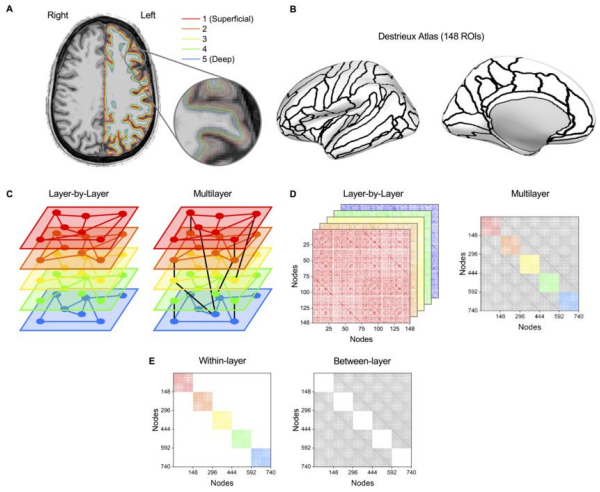
Optimal Transport in Multilayer Networks for Traffic Flow Optimization

Abdullahi Adinoyi Ibrahim *, Alessandro Lonardi * and Caterina De Bacco *



Multilayer network analysis across cortical depths in 7-T resting-state fMRI

Parker Kotlarz[1,2], Kaisu Lankinen[1,3], Maria Hakonen[1,3], Tori Turpin[4], Jonathan R. Polimeni[1,3,5], and Jyrki Ahveninen[1,3]

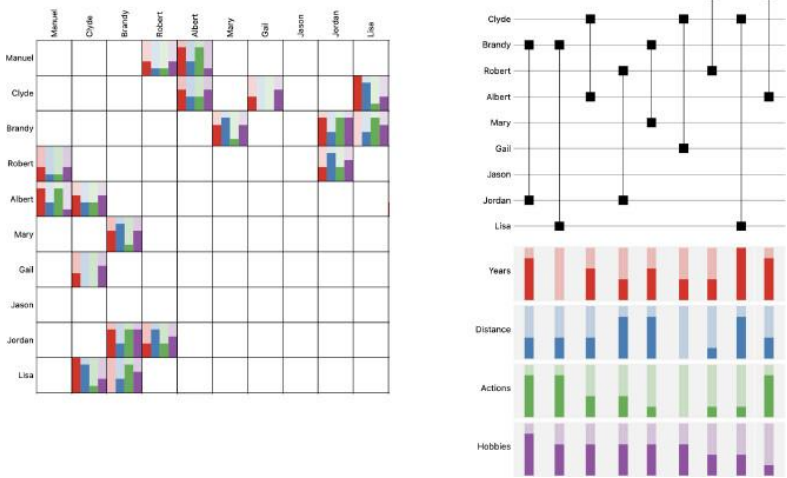


Prior work have explored MVN AMs encodings

Exploring the Design Space of BioFabric Visualization for Multivariate Network Analysis

J. Fuchs[1] F. L. Dennig[1] M.-V. Heinle[1] D. A. Keim[1] and S. Di Bartolomeo[1]

[1]University of Konstanz, Germany



Weighted Graph Comparison Techniques for Brain Connectivity Analysis

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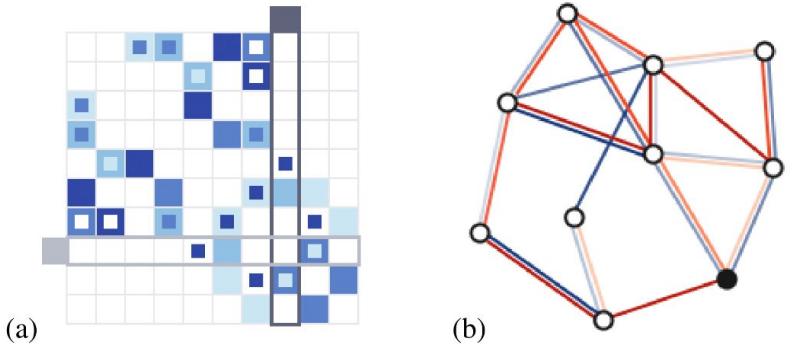
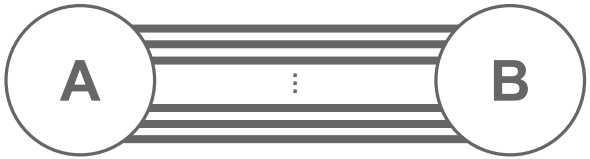


What if we add more attributes?

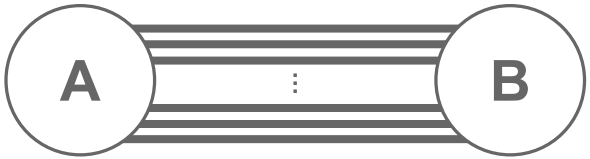
1. Many edge attributes



Attribute1	40
Attribute2	125
Attribute3	75
⋮	
Attribute28	75
Attribute29	170
Attribute30	35

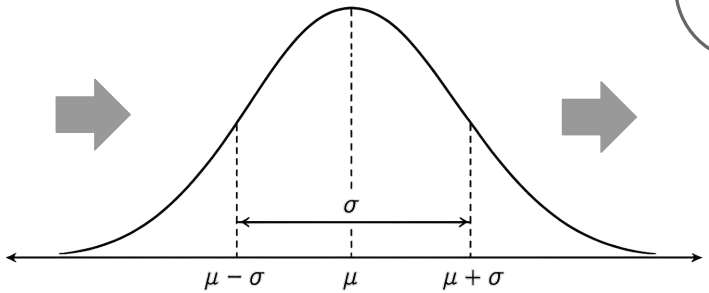
Our approach

1. Many edge attributes



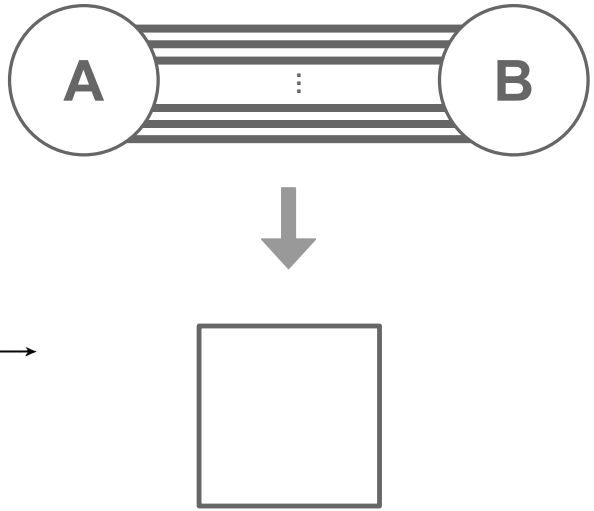
Attribute1	40
Attribute2	125
Attribute3	75
⋮	
Attribute28	75
Attribute29	170
Attribute30	35

2. Summarize



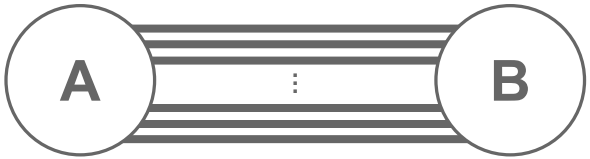
μ = 85
σ = 45

3. Encode the summary



Best technique to encode two quantitative attributes?

1. Many edge values

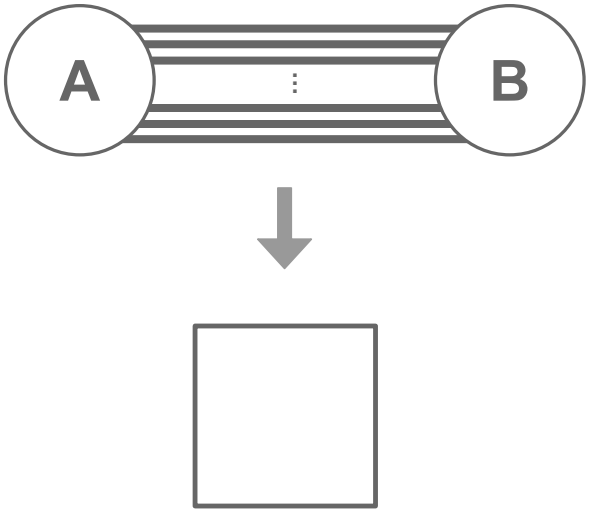


Attribute1	40
Attribute2	125
Attribute3	75
⋮	
Attribute28	75
Attribute29	170
Attribute30	35

2. Summarize them

μ = 55
σ = 20

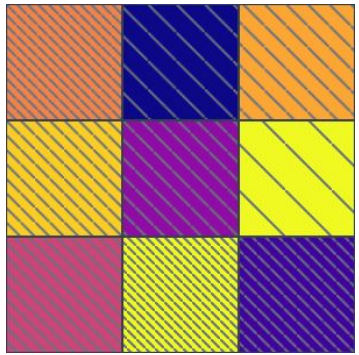
3. Encode two values



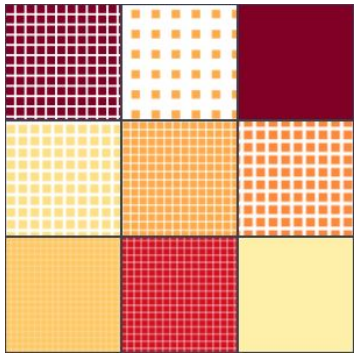
Design Space Characterization

The cell as a whole

- Cell is the only visual mark
- Attributes encoded through properties of the cell
- Compact design, limited perceptual separability



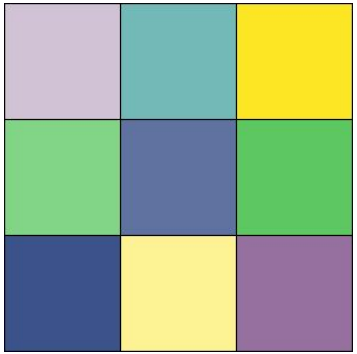
Hue & Hatching



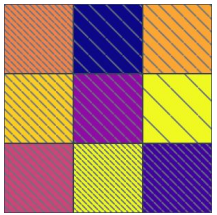
Hue & Squares

Technique selection - The cell as a whole

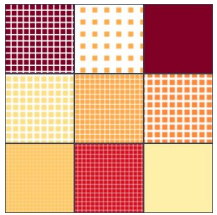
- Selected technique:
  - **Bivariate Color**
- Mean = Hue
- Standard deviation = Lightness
- Common and Visually compact



Hue & Lightness



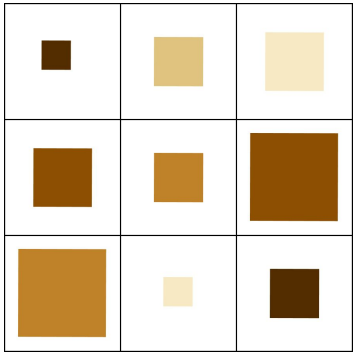
Hue & Hatching



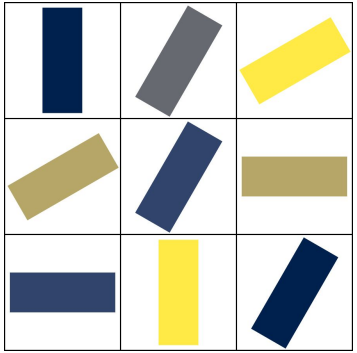
Hue & Squares

One overlaid mark

- Adds one mark inside each cell
- One attribute can use the cell, while other uses the added mark
- Both attributes encoded by the added mark
- Balance compactness and separation



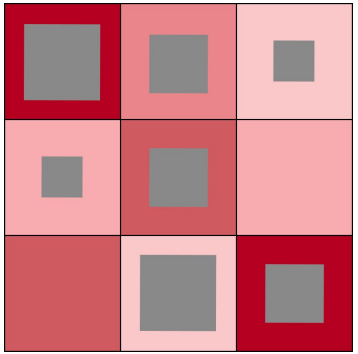
Mark Hue & Size



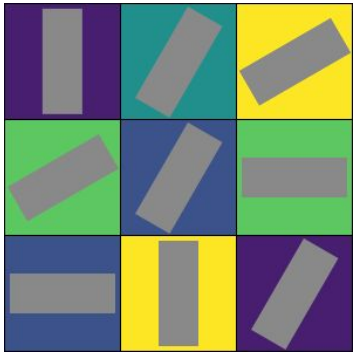
Mark Hue & Angle

Technique selection - One overlaid mark

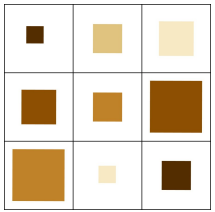
- Selected techniques:
  - **Mark angle**
  - **Mark Size**
- Same strategy, different mark channel
- Tests the effect of the mark channel



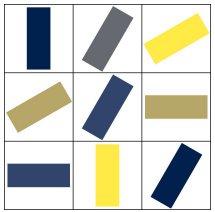
Hue & Mark Size



Hue & Mark Angle



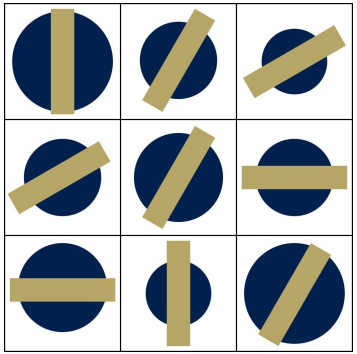
Mark Hue & Size



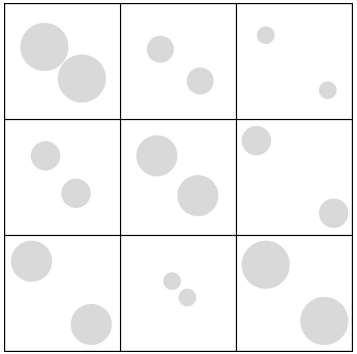
Mark Hue & Angle

Two overlaid marks

- Adds two marks inside each cell
- Each mark is assigned to one edge attribute
- The cell as a neutral container
- Supports separability, but increases within-cell complexity



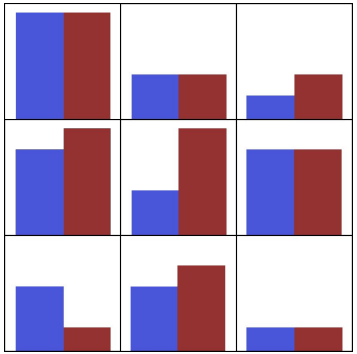
Mark Radius &
Mark Angle



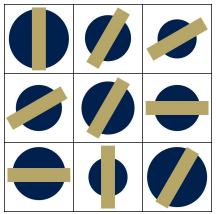
Mark Radius &
Mark Position

Technique selection - Two overlaid marks

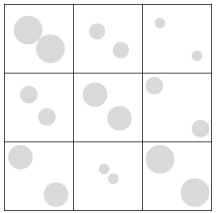
- Selected technique:
  - **Embedded bars**
- Already used
- Strong channel
- Good separation between attributes



Bars



Mark Radius &
Mark Angle



Mark Radius &
Mark Position

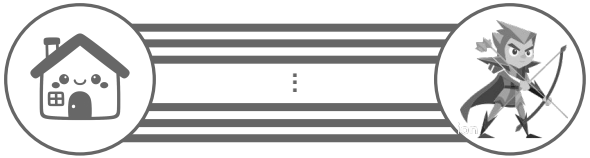
Evaluation Study Design

Research Questions

- RQ1: How do the selected edge encoding techniques compare in **task performance** on common MVN tasks?
  - 8 MVN tasks
  - Structural, Attribute and Estimation tasks
- RQ2: How do the selected edge encoding techniques compare in **perceived readability**?
  - PREVis scale 4 constructs measured with 7-point Likert scales
- RQ3: How do the selected edge encoding techniques compare in **perceived aesthetics**?
  - BeauVis scale 5 concepts measured with 7-point Likert scales

Data: Airline Fares

- Real-world data, ecological validity
- Sufficiently dense and attribute-rich networks
- Familiar topic



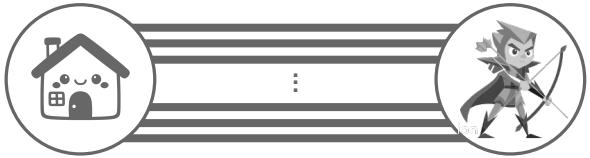
Jet2 $20

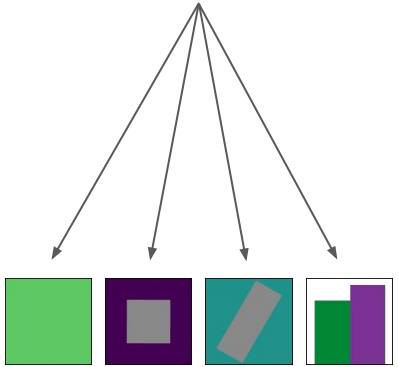
RYANAIR $75

vueling $40

Aer Lingus $55

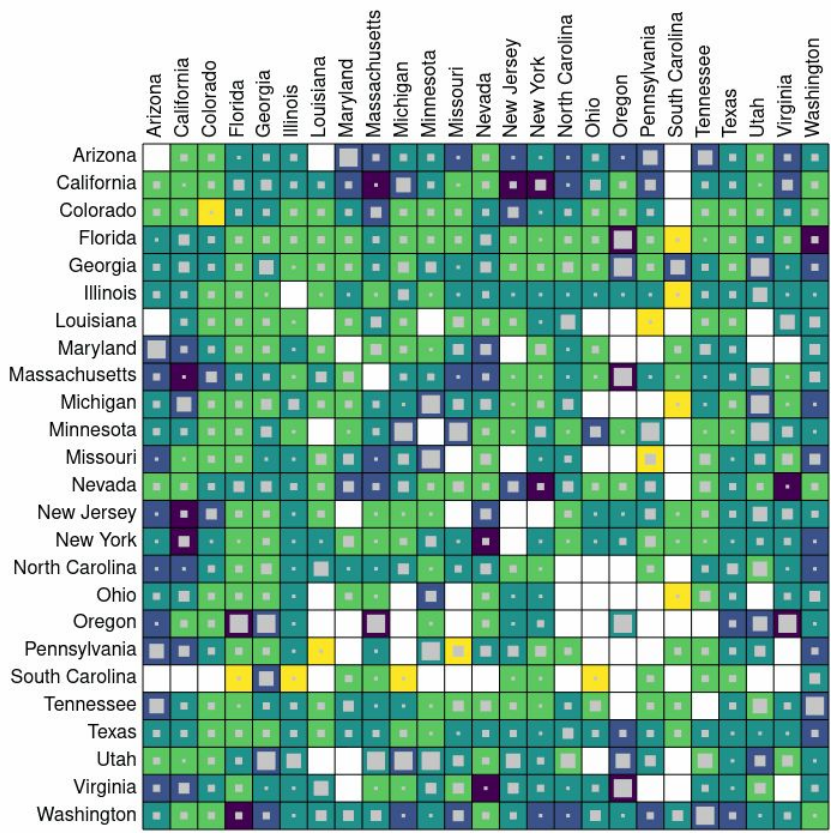
μ = 55
σ = 20





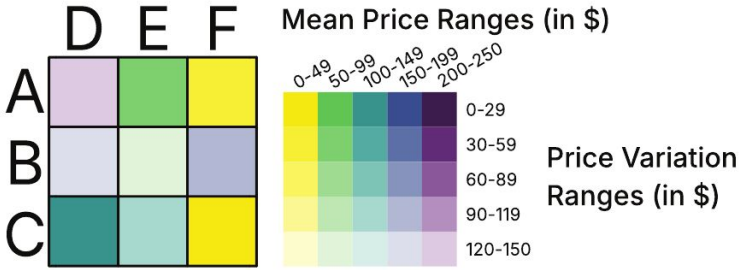
Stimuli Design

- Matrix size:
  - 25 nodes
  - Network density = 0.7
  - 23 × 23 px cells

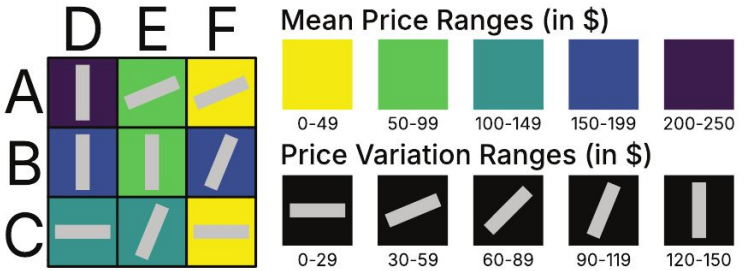


Stimuli Design

- Matrix size:
  - 25 nodes
  - Network density = 0.7
  - 23 × 23 px cells
- Viridis:
  - Perceptually uniform multihue scale
  - Robust for color-vision deficiencies



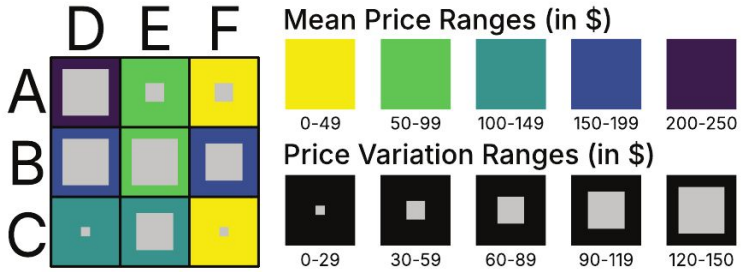
Color



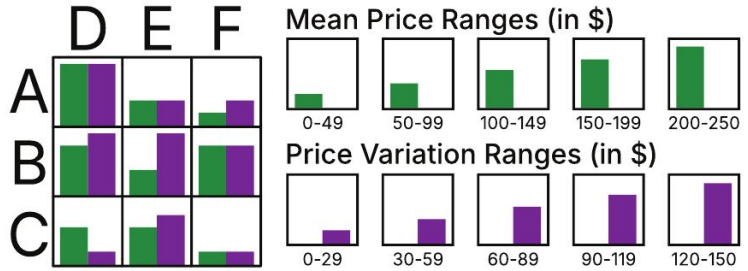
Mark angle

Stimuli Design

- Matrix size:
  - 25 nodes
  - Network density = 0.7
  - 23 × 23 px cells
- Viridis:
  - Perceptually uniform multihue scale
  - Robust for color-vision deficiencies
- 5 interpretable ranges:
  - Simple and interpretable



Mark size



Bars

Study Setting

- Procedure:
    1. Introduction to network data + Questions
    2. Introduction to encoding technique + Training
    3. Multivariate network tasks + Attention checks
    4. Subjective judgements:
        a. PREVis
        b. BeauVis
    5. User feedback + demographics
- Between Subjects with 156 participants
- Implemented with reVISit

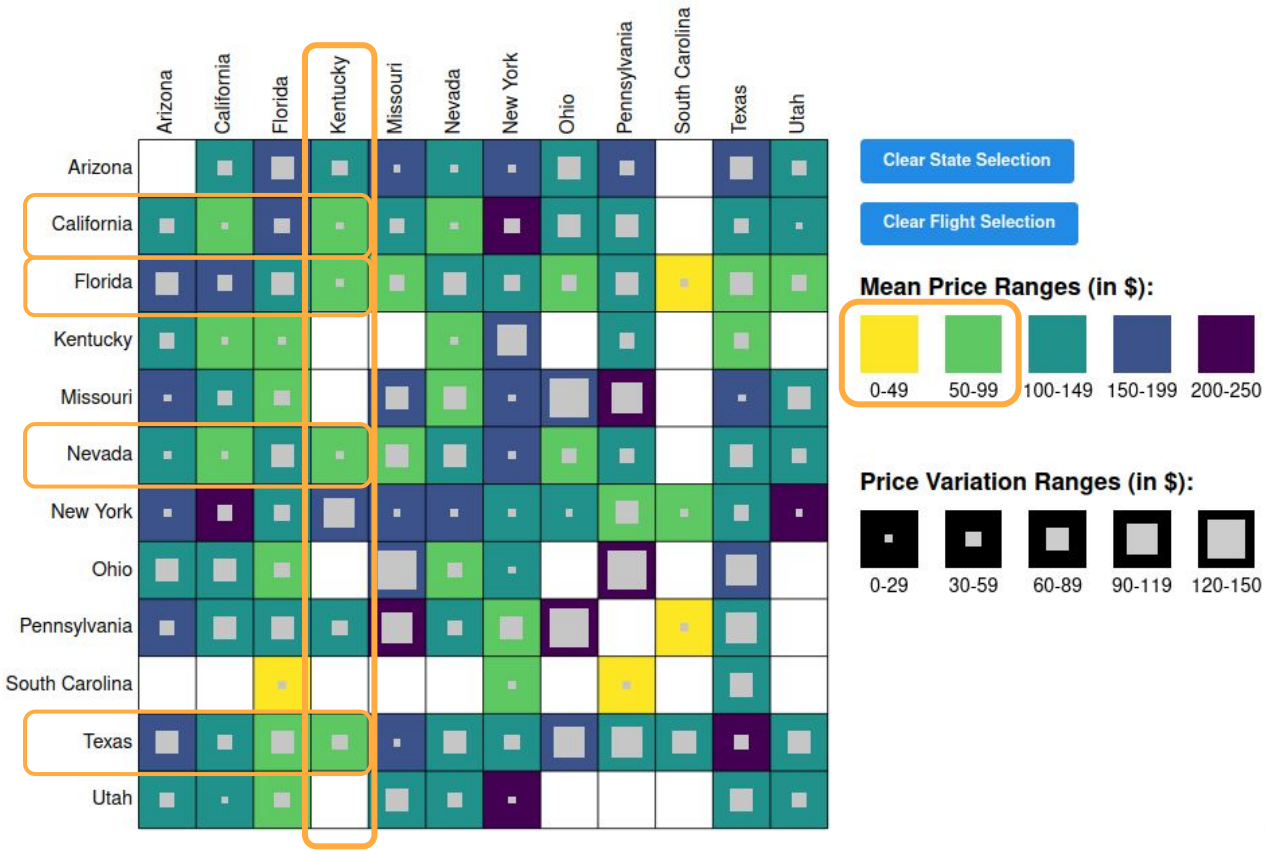
https://tinyurl.com/bvnv-study

Example of a Training task

Task:
Training: Select all states connected to Kentucky with a mean price below $100.

Selected States: *

Check Answer | Next



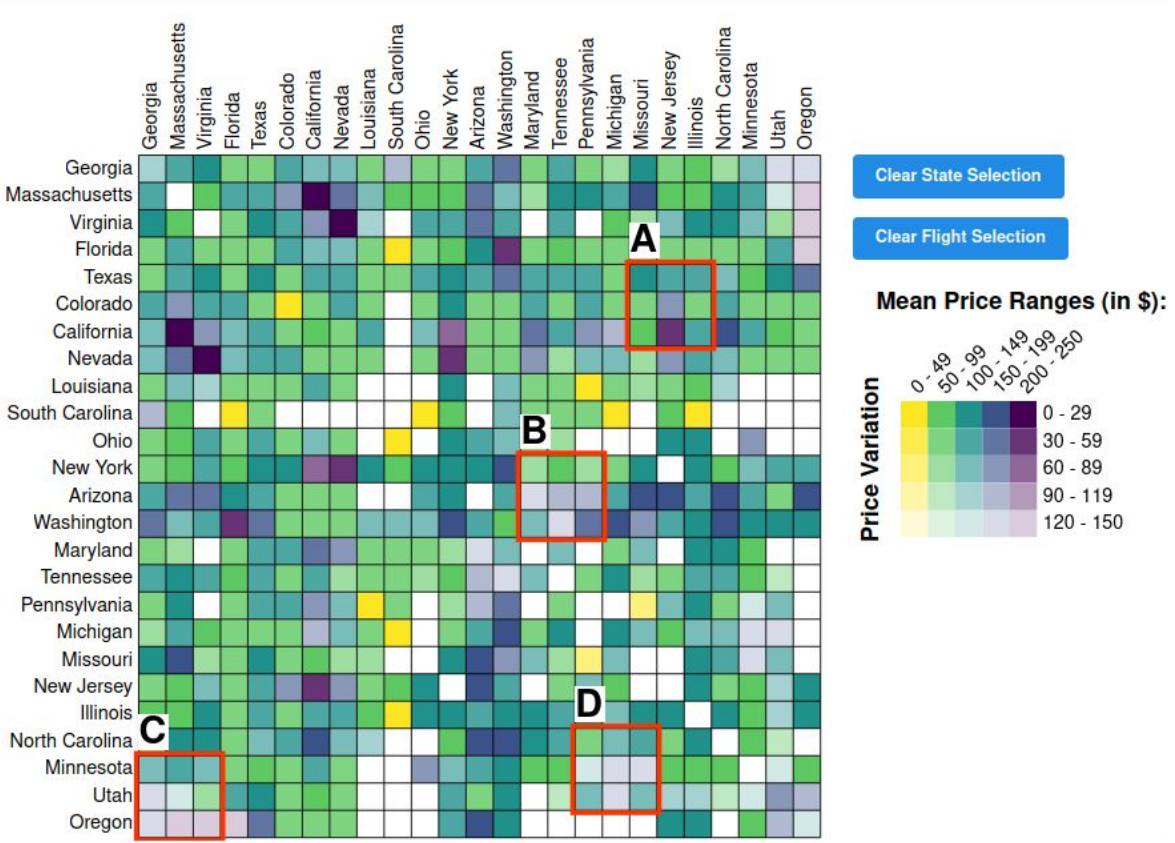
Example of a Evaluation task

Task:
Which cluster shows the highest price variation?

Select a cluster: *

- A
- B
- C
- D

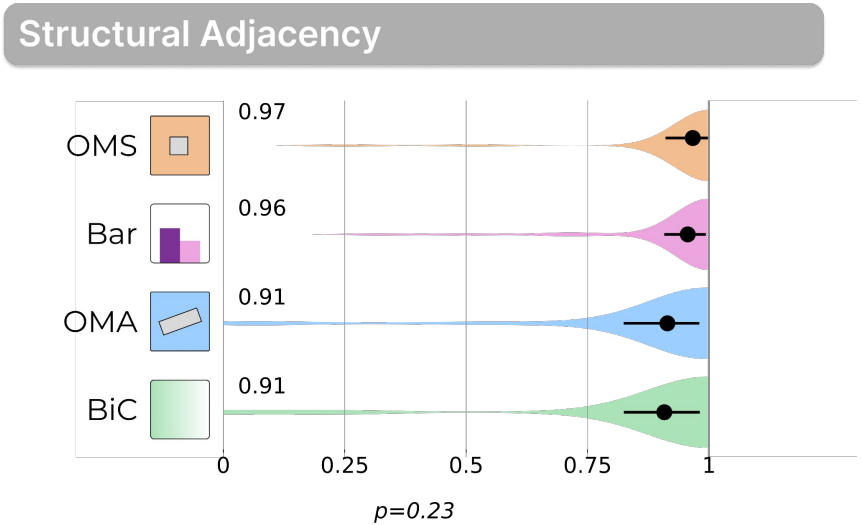
Next



Results
&
Design Implications

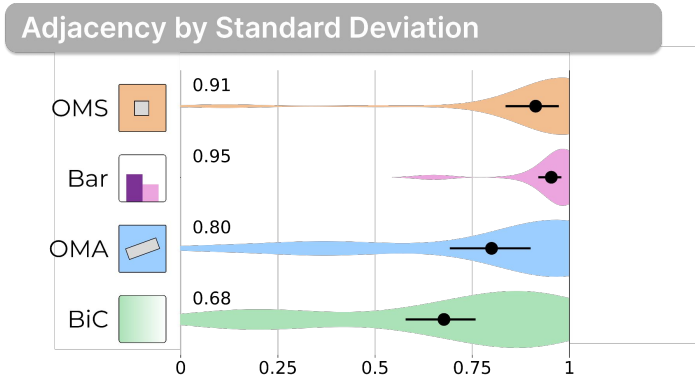
Encodings don’t affect structure

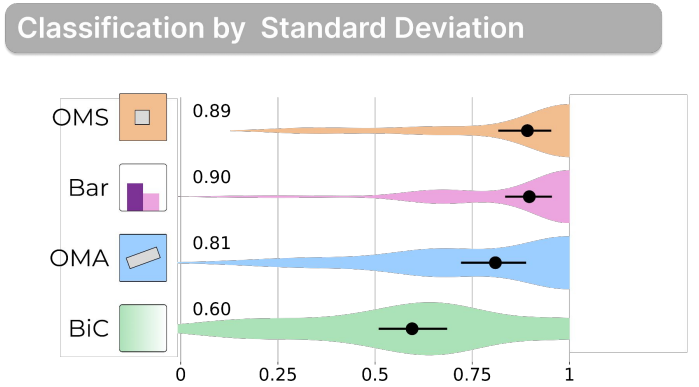
- Performance ≥ 90% in all conditions
- No significant differences
- All designs preserve basic topology



Mark size and Bars are the top performers

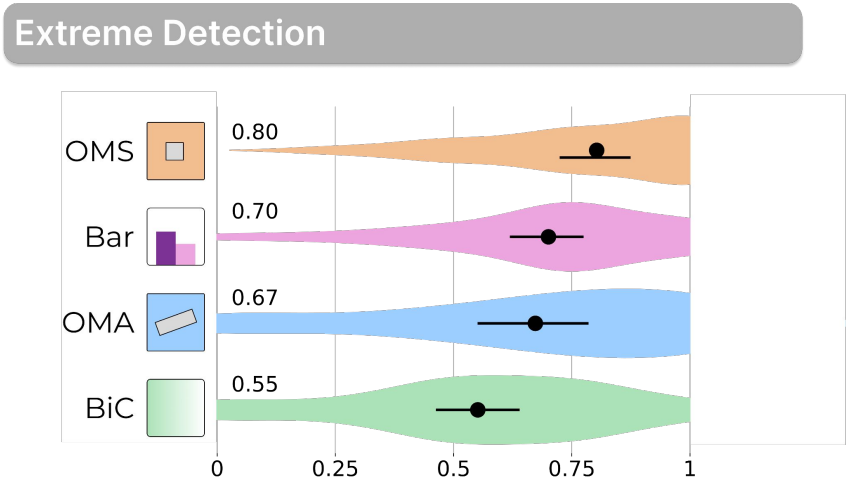
- Top Performance >90% in 6/8 tasks
- Mark Size and Bars perform similarly
- Generally above Mark Angle and Color





Extremes are easier to spot with Mark Size

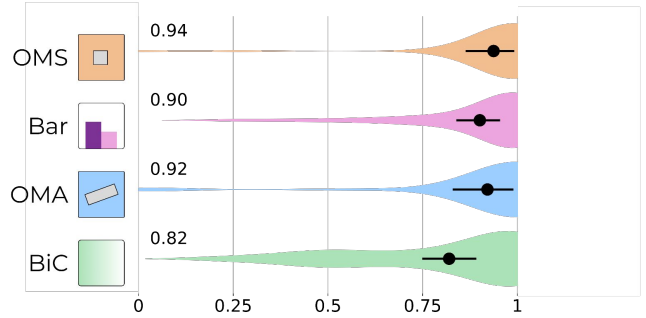
- 10 percentage points above Bars
- Hue + size supports outlier scanning



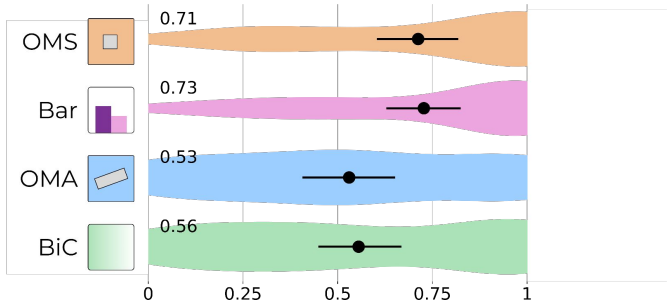
Performance declines when attributes are combined

- Performance >90% in tasks involving one attribute
- Performance drops 10–20 percentage points in multiattribute tasks
- Combining attributes increases errors

Adjacency by Mean

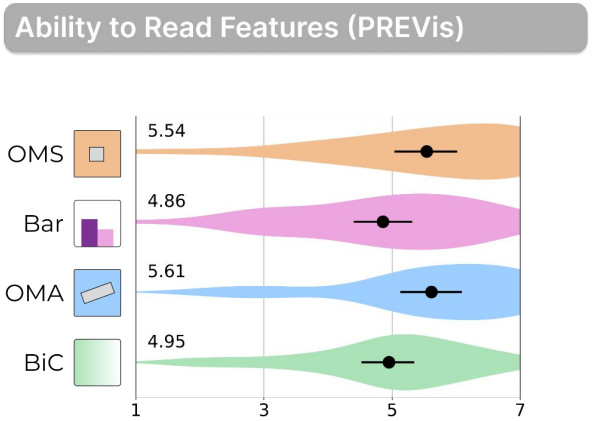


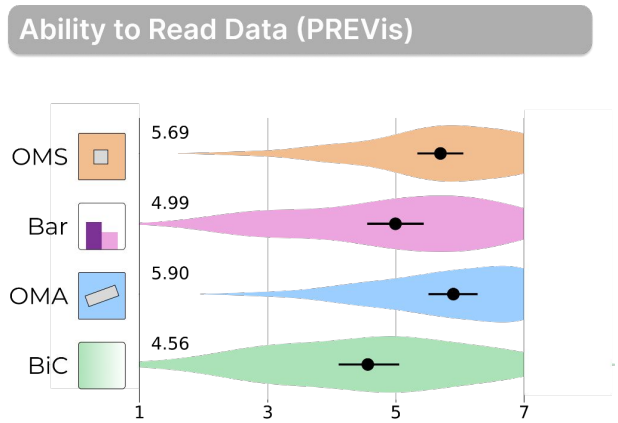
Adjacency by Mean & Standard Deviation



Perceived Readability

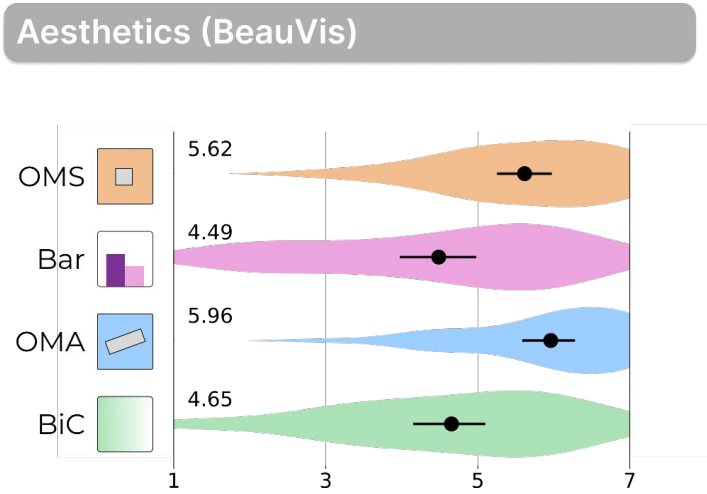
- Single-mark encodings rated highest
- Bars and Color rated lower
- Perceived Readability ≠ Performance





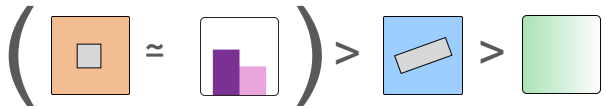
Perceived Aesthetics

- Single-mark encodings rated highest
- Bars and Color rated lower
- Aesthetics closely aligned with perceived readability



Design guidelines for small-cell dense AMs

- Use Mark size by default
  - Best trade-off between accuracy and user acceptance
- Consider Bars as a strong alternative
  - Competitive performance, but perceived as less readable
- Reserve Mark angle for coarse judgments
  - Strong subjective ratings, less stable accuracy
- Avoid Color for quantitative comparisons
  - Compact, but low separability in small cells



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https://tinyurl.com/bvnv-study

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SCI
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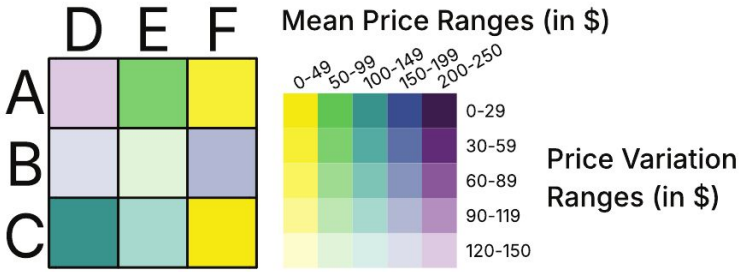
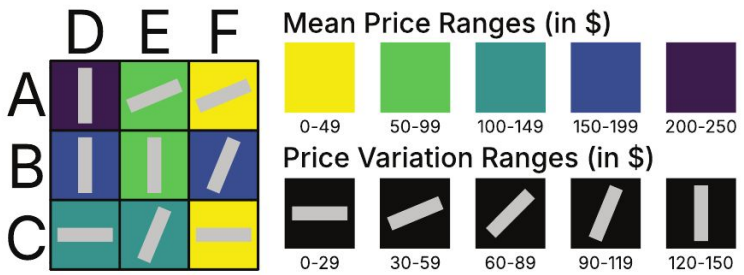
CCS
visualization design lab

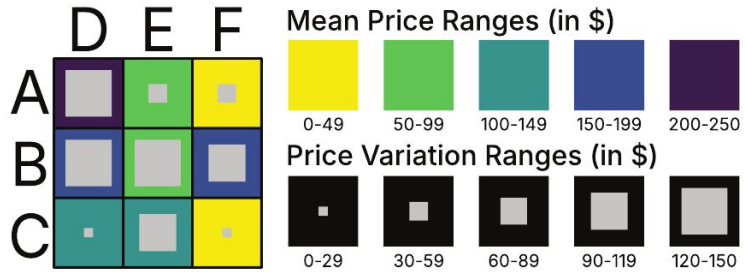
Stimuli Legends



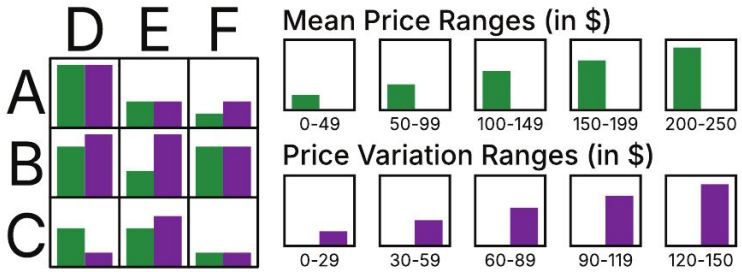
Color



Mark angle

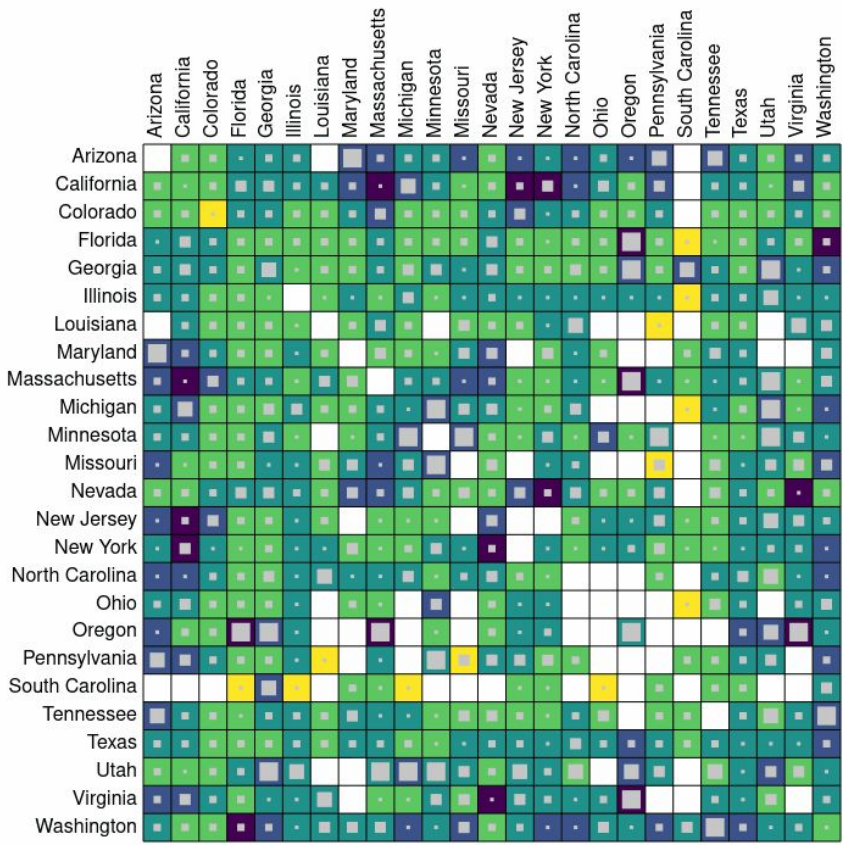


Mark size



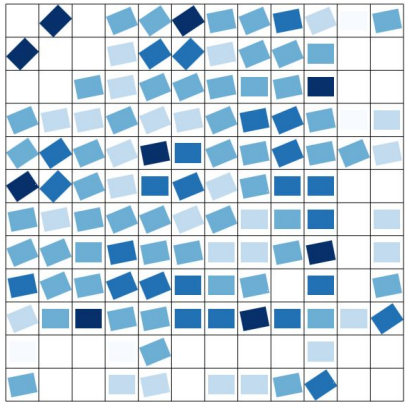
Bars

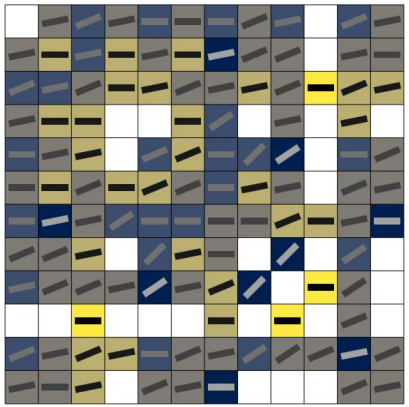
Stimuli Design

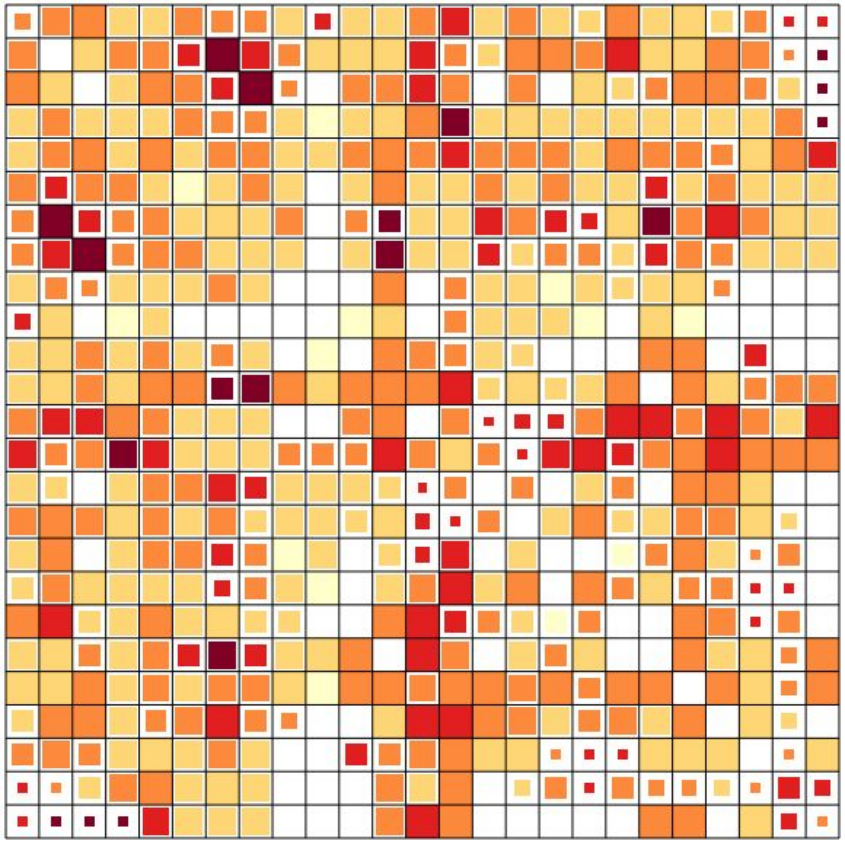


Experimentation Prototype

https://tinyurl.com/bvnv-prototype





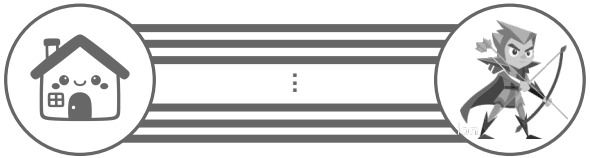


156 participants

- Age 35 ± 11
- Experience with AMs 2.6 ± 1
- Gender balanced 78M / 71F / 7
- Education Mode Bachelor

Data: Airline Fares

1. Many fares per route



Jet2 $20

RYANAIR $75

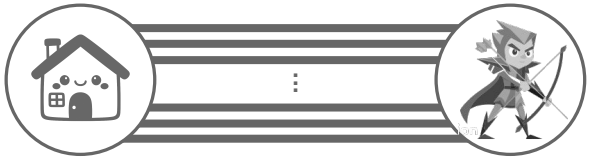
vueling $40

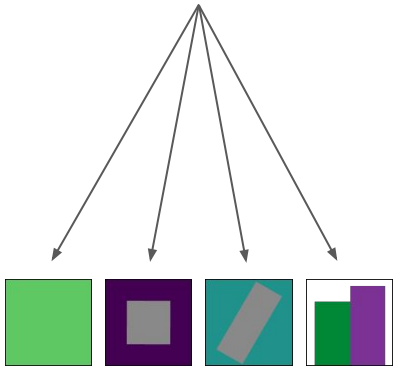
Aer Lingus $55

2. Summarize distribution

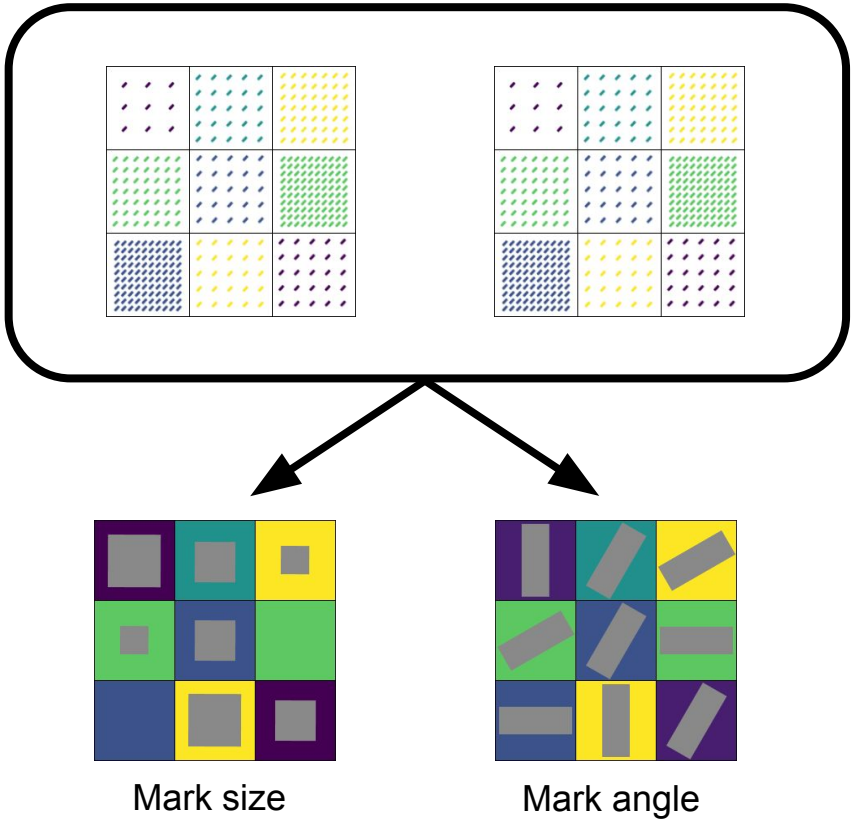
$\mu = 55$
$\sigma = 20$

3. Encode summaries





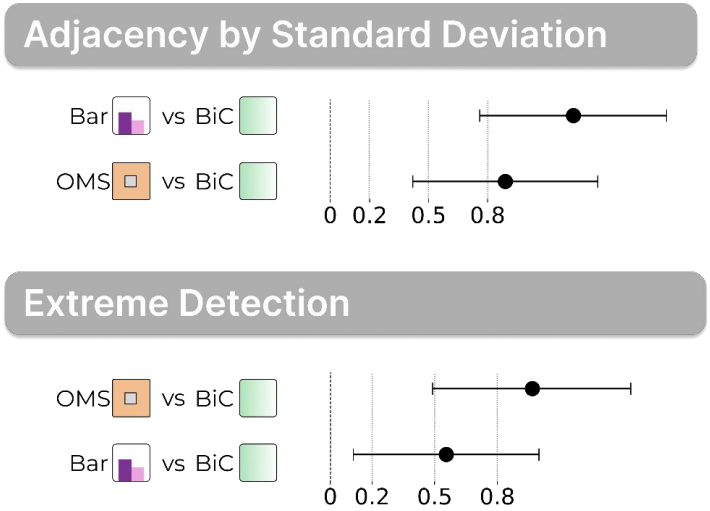
Technique selection - One overlaid mark



- Same strategy, different channel
- Area, common channel
- Angle might benefit of the grid
- Assess how mark channel affects performance

Bivariate color was the weakest performer

- Lowest performance in 5/8 tasks
- **Weak** in **dispersion-based tasks**
- Shows **medium to large effects** against top performers

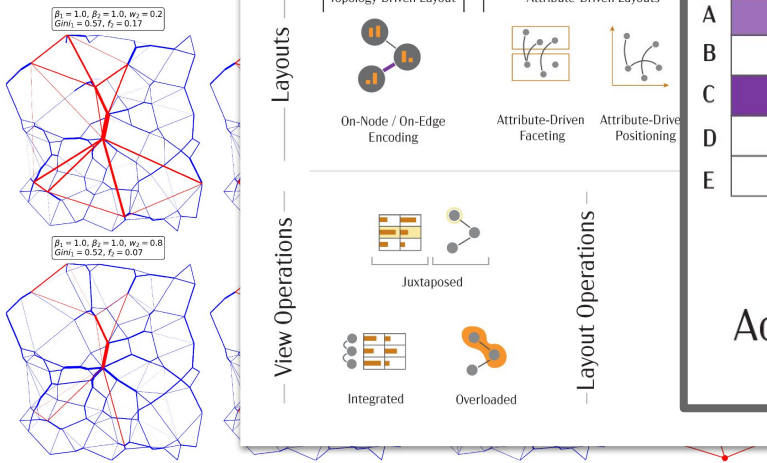


Multivariate networks occur in many real-world domains

Multilayer socia
complexity of a

Optimal Transpo
Flow Optimizati

Abdullahi Adinoyi Ibrahim *



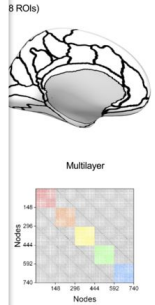
The State of the Art in Visualizing Multivariate Networks

C. Nobre[1], M. Meyer[1], M. Streit[2], and A. Lex[1]

[1]University of Utah, Utah, USA
[2]Johannes Kepler University Linz, Austria

cross cortical
te fMRI

en[1,3], Tori Turpin[4],
eninen[1,3]

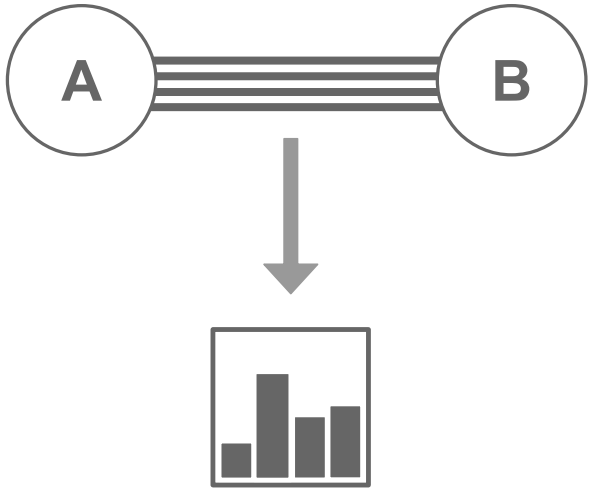


Current approaches tested a few attributes

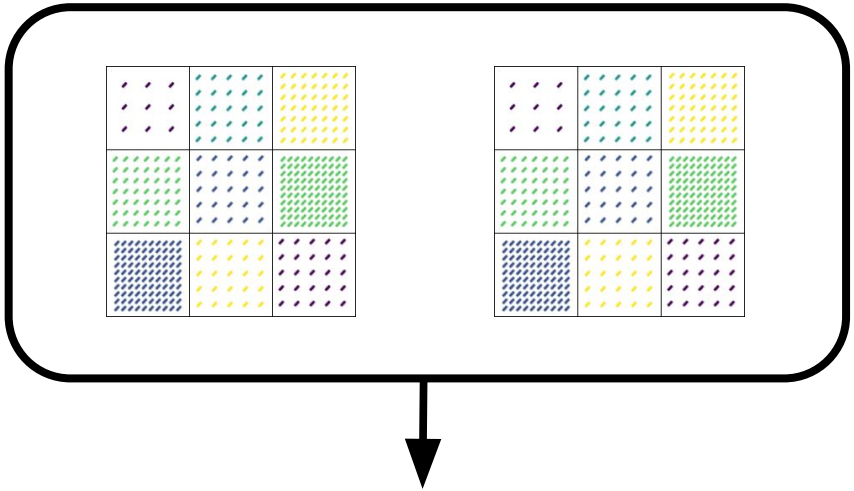
1. Edge attributes

Attribute1	20
Attribute2	75
Attribute3	40
Attribute4	55

2. Directly Encode



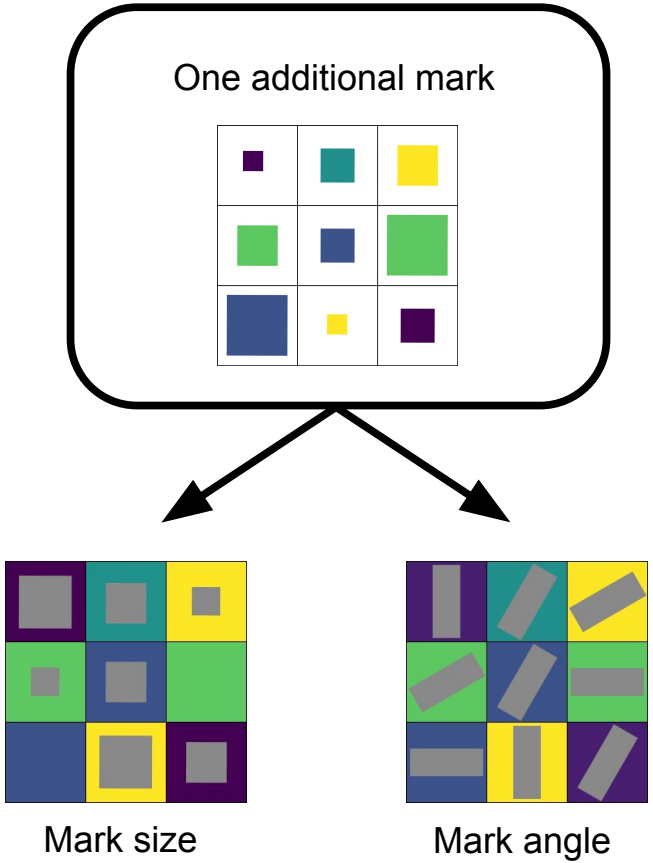
Technique selection - Two overlaid marks



Bars

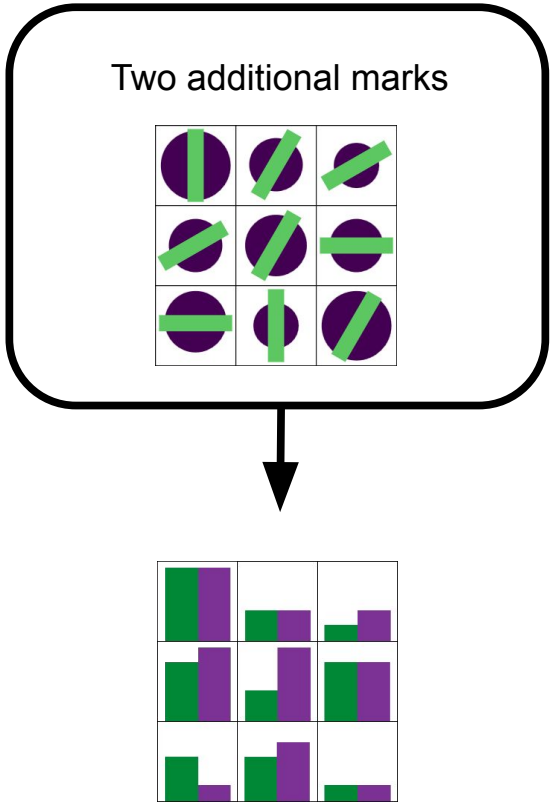
- Already used
- Length is a strong channel
- Separation between attributes

Technique selection



- Same strategy, different channel for std
- Area, common channel
- Angle might benefit of the matrix grid
- Comparing them assess how mark channel affects performance

Technique selection



- Already used
- Length is a strong channel
- Clear separation between attributes