Marks Revisited: Beyond Bertin

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http://www.cs.ubc.ca/~tmm/talks.html#northeastern24
Co-conspirators

• Richard Brath
  – Uncharted Software

• Mara Solen, Francis Nguyen, Ryan Smith
  – UBC CS infovis course TAs

• also useful discussions with
  – Enrico Bertini, Hanspeter Pfister, Arvind Satyanarayan, Maureen Stone, Martin Wattenberg
Marks and channels: Foundational model

- decompose visual encoding into marks & channels
  - marks
    - geometric primitives
    - represent data items
  - channels
    - control appearance of marks
    - representing data attributes

- widely used
  - Bertin 1967
    - Semiology of Graphics
### Channels: Rankings

#### Magnitude Channels: Ordered Attributes
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

#### Identity Channels: Categorical Attributes
- Spatial region
- Color hue
- Motion
- Shape

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### Expressiveness Types and Effectiveness Ranks

- **Expressiveness**
  - match channel and data characteristics

- **Effectiveness**
  - channels differ in accuracy of perception
  - two-value ratio judgements, Cleveland & McGill 1987
Talk outline

• explain current marks & channels model
• walk through many questions that arise when teaching it
• present preliminary ideas towards an alternative model
Current Marks & Channels Model
Visual encoding model

• analyze idiom structure as combination of marks and channels
Visual encoding model

• analyze idiom structure as combination of marks and channels

idiom: bar chart

1 channel: vertical position

mark: line
Visual encoding model

• analyze idiom structure as combination of marks and channels

idiom: bar chart

1 channel: vertical position
mark: line

idiom: scatterplot

2 channels: vertical position, horizontal position
mark: point
Visual encoding model

• analyze idiom structure as combination of marks and channels

idiom: bar chart

1 channel:
vertical position
mark: line

idiom: scatterplot

2 channels:
vertical position
horizontal position
mark: point

3 channels:
vertical position
horizontal position
color hue
mark: point
Visual encoding model

• analyze idiom structure as combination of marks and channels

idiom: bar chart

idiom: scatterplot

1 channel: vertical position
mark: line

2 channels: vertical position horizontal position
mark: point

3 channels: vertical position horizontal position color hue
mark: point

4 channels: vertical position horizontal position color hue size (area)
mark: point
Visual encoding model: Tabular data

• marks for items of tabular data

idiom: bar chart  idiom: scatterplot

1 channel: vertical position
mark: line

2 channels: vertical position horizontal position
mark: point

3 channels: vertical position horizontal position color hue
mark: point

4 channels: vertical position horizontal position color hue size (area)
mark: point
Visual encoding model: Spatial data

• marks for items of spatial data

idiom: choropleth map

channels:
position
color (saturation)

mark: area

http://bl.ocks.org/mbostock/4060606
Visual encoding model: Network data

• marks for items and marks for links

idiom: node-link diagram
channel: position
marks: point for items/nodes, connection line for links

idiom: treemap
channel: position
marks: area for items/nodes, containment area for parent-child links

Node–Link Diagram Treemap

Why analyze visual encodings?

• marks & channels model is a **design space**
  – **descriptive** power: ability to describe significant range of existing examples
  – **evaluative** power: ability to help assess multiple design alternatives
  – **generative** power: ability to help designers create new designs
    • criteria: Michel Beaudoin-Lafon, Designing Interaction, not Interfaces. AVI 2004.

• many names: taxonomies, typologies, classifications, frameworks, models, grammars...
  – delineate: axes / dimensions / categories
    • that are cross-cutting / independent / orthogonal

• design spaces help us reason
  – impose systematic & actionable structure on set of possibilities for specific problem
    • to support reasoning about design choices
    • capture the key variables at play
    • increase cognitive efficiency & support inferences by grouping similar instances together to facilitate reasoning about classes
Design spaces in visualization: continuing theme

The Structure of the Information Visualization Design Space
Stuart K. Card and Jock Mackinlay
Xerox PARC

Exploring the Design Space of Composite Visualization
Waqas Javed* Niklas Elmqvist†

A Design Space of Visualization Tasks
Hans-Jörg Schulz, Thomas Nocke, Magnus Heitzler, and Heidrun Schumann

A Design Space of Vision Science Methods for Visualization Research
Madison A. Elliott, Christine Nothelfer, Cindy Xiong, and Danielle Albers Szafir

1 INTRODUCTION
As the field of visualization research continues to evolve, there is an increasing need for a more comprehensive understanding of the design space of visualization tools. This study aims to explore the design space of composite visualizations, which encompass a wide range of visual elements and interaction techniques. The goal is to provide researchers with a structured framework to analyze and design new visualization interfaces.

The Structure of the Information Visualization Design Space

The design space of information visualization is complex and multidimensional. To better understand and navigate this space, researchers have proposed various frameworks and models. This article presents a comprehensive model that categorizes the design space into several dimensions, allowing for a more systematic exploration of visualization design.

Exploring the Design Space of Composite Visualization

Composite visualizations combine multiple visual elements to create a single, integrated representation. This approach can be particularly powerful for complex data analysis tasks. The article explores the design space of composite visualizations, identifying key dimensions and strategies for effective design.

A Design Space of Visualization Tasks

Understanding the tasks that visualization tools support is crucial for effective design. The article presents a design space of visualization tasks, which considers factors such as task complexity, user expertise, and the nature of the data being visualized. This framework helps designers make informed decisions about which visualization techniques to employ.

A Design Space of Vision Science Methods for Visualization Research

Vision science methods are essential for evaluating the effectiveness of visualization tools. This article proposes a design space for vision science methods, covering factors such as image quality, stimulus presentation, and observer response. This framework will aid researchers in selecting appropriate methods for their studies.
### How?

**Encode**

- **Arrange**
  - Express
  - Separate
- **Order**
  - Align
- **Use**

**Manipulate**

- **Map**
  - from *categorical* and *ordered* attributes
- **Color**
  - *Hue*
  - *Saturation*
  - *Luminance*
- **Size, Angle, Curvature, ...**
- **Shape**
  - +, ●, □, ▲
- **Motion**
  - *Direction, Rate, Frequency, ...*

**Facet**

- **Change**
  - ...
  - ...

**Reduce**

- **Filter**
  - ...
  - ...
- **Aggregate**
  - ...
  - ...
- **Embed**
  - ...
  - ...

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*Visualizations Analyze & Design (Second Edition)*

*Image Source: [Rethinking book design space: Visualization Analysis & Design 2e](https://example.com)*
Teaching Challenges
Teaching design space: analyze visual encoding & map to data

• assignment: analyze existing encoding with marks & channels
  – Visual channels used?
    • Channel X encodes attribute Y
    • Channel X encodes attribute Y
  – Marks used?
    • Mark of type X encodes item Y
    • Mark of type X encodes item Y

• rationale
  – reverse-engineering existing designs will help students generate future designs
Teaching: Bertini in-class exercises, catalyst for questions

• decoding marks & channels
  – https://enrico.bertini.io/teaching

https://flowingdata.com/2016/06/28/distributions-of-annual-income/

https://pudding.cool/2017/03/redraft/
Quiz: Name marks/channels

• Shooting Media Coverage
  • marks
    – A: points
    – B: lines
    – C: areas
  • channels
    – A: position
    – B: color
    – C: length
    – D: area
    – E: angle

https://twitter.com/MonaChalabi/status/1158779046693679106?s=20
Quiz: Name marks/channels

• Tax Rates
• marks
  – A: points
  – B: lines
  – C: areas
• channels
  – A: position
  – B: color
  – C: length
  – D: area
  – E: angle

Quiz: Name marks

• points? lines? areas?

Many, many questions

• so what?
  – evidence that this design space could be improved!
Channels: Model evolves, heavily studied

- effectiveness rankings
- expressiveness matches, data & task

Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design
Jeffrey Heer and Michael Bostock

IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, VOL. 20, NO. 13, DECEMBER 2014
25

Ranking Visualizations of Correlation Using Weber's Law
Lane Harrison, Fumeng Yang, Steven Franconeri, Remco Chang

Abstract—Despite years of research identifying the best visualizations for perception of correlation, there is no widely accepted method for ranking visualization effectiveness. We present a method that 1) bestows reputations on visualizations based on their perceived effectiveness, 2) formulates judgment prop models to provide a consensus measure.

ACM Classification: I.5.2 [Information interaction]; User Interface—Evaluation

General Terms: Experimentation, Human

Keywords: Information visualization, user study, evaluation, Mechanical Turk

INTRODUCTION
"Crowdsourcing" is a relatively new phrase, but its roots are centuries old. Users, in essence, are being asked to summarize others' perceptions and provide a consensus view. The collected data is then used to make predictions about the general population. This technique has been successfully used in a variety of domains, including content aggregation, sentiment analysis, and more. However, it is important to note that these results are not infallible and may be subject to bias or error.

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Marks: Model stays static

• model inherited from Bertin (Semiology of Graphics, 1967)
  – never questioned

• geometric motivation
  – geometric primitives have dimensions
  – how could we argue with math?!
Mark/channel analysis: scope & limits

• model scope: one mark for one data item
  – multiple marks for one item: glyphs, multiple views
  – one mark for many items: aggregation, filtering

Encoding vs decoding models

- **Encoding** model: what should visualization **designer** do?
  - prescriptive model, providing guidance for design

- **Decoding** model: how will visualization **viewer** interpret?
  - predictive model, informed by vision science & perception research
  - predicting viewer response differs from inferring or reverse-engineering designer intent when encoding!
Encode vs decode: Where do models diverge?

• idiom: pie chart
  – **encode**: area marks with angle channel: **2D area varies**
    • ordered radially, uniform length
  – accuracy: area less accurate than rectilinear aligned position/length
  – **decode**: not angle! probably arc length, maybe also area
    • https://eagereyes.org/blog/2016/an-illustrated-tour-of-the-pie-chart-study-results

• idiom: coxcomb chart
  – **encode**: marks with length channel: **1D length varies**
    • ordered radially, uniform width
    • more direct analog to bar charts, but using radial layout
  – what's the mark type?
    • line, because it's length coded?
    • area, because area varies too?
Encode vs decode: Where do models diverge?

- **encode:** 1D size (length)
- **decode/perceive:** 2D area
- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt mark length!
- **bar chart safer**
  - uniform width, so area is linear with mark length
    - both radial & rectilinear cases
- **encode vs decode divergence**
  - if channels differ, which "wins"?
Alternative Ideas
Constraints

• consider marks and channels as imposing constraints
  – when does mark type constrain channel use?
  – when does using one channel constrain another channel?
Channel use: what does it mean?

• Does channel size encode attribute?
  – yes? sizes differ
    • according to dog name in alphabetical order
  – no! size differences not meaningful
    • just emerges from choice of layout, radial vs rectilinear
    • not a "real" attribute encoding

• Can we use size channel to encode another attribute?
  – no! not free
  – it's "taken" already, would change meaning

• Size channel is Unavailable
Channel Availability Model

• Encoded: which channels directly used to encode attributes?
  – clear meaning
  – multiple channels can be directly used for redundant encoding

• Free: which channels free to encode another attribute?
  – without changing usability of existing encoding

• Unavailable: which channels unavailable / precluded / taken?
  – because of mark type?
  – because of idiom/algorihm design specifics?
  – because other channels used?
Area marks: Rethinking

• area marks is a terrible name
  – other marks all have graphical area too
    • allowing us to encode with color
    • computer graphics point of view: they're all just polygons
  – there's also an "area" channel, which is confusingly different
  – area is not the only channel in play with these marks!
Area marks

• obvious example: choropleth maps

• what can we do to California? could we encode additional data?
  – cannot shrink/grow (size channel)
  – cannot translate (position channel)
  – cannot rotate (orientation channel)
  – cannot reshape (shape channel)
  – why not?
    • would lose meaning of that mark: boundary is the data
    • also lose meaning for other occluded marks

• "area" mark is not specific enough
  – AreaPositionOrientationShape mark?? nah...
  – idea: interlocking

Interlocking (area) marks

• many channels locked down with interlocking marks
  – boundary encodes meaning
  – cannot change size, shape, position, orientation
  – mark type imposes constraints

• but...
  what about cartograms?
  – cannot change just one mark (California)
  – but could change them all!

• interlocking marks as global constraint:
  – cannot change just one independently
  – but can change all simultaneously!
    • typically with algorithm

https://worldmapper.org/us-presidential-election-2020/
Interlocking marks: Non-spatial

- example with non-spatial data?
- treemaps
  - show hierarchy with containment, not connection
  - encode additional attribute with area/size
- again, cannot change just one mark alone
  - but could recompute layout to change all at once
- combined layout of all marks together carries meaning
  - unlike spatial data mark boundaries
    - individual mark boundaries have no intrinsic meaning

Quiz: Name that mark

- UFC fights: points? lines? areas?

Analyzing marks

• what type of mark?
  – line?
    • no, not length coded
  – point mark with rectangular shape?
    • 2020: yes!
    • 2023: no!
      – cannot change position / size / orientation
  – area?
    • 2020: no, area/shape does not convey meaning
    • 2023: yes!
      – fully interlocking
      – position, size, shape, orientation all locked

Interlocking marks: Tile heatmaps

• 2D matrix/grid as index
  – position in use as index
  – size/area & shape & orientation all equal (& locked down)

• simplest possible case of interlocking marks?
  – more regular than choropleths or treemaps
  – but underlying similarities

• full extent of cell used for color coding
  – different from using a point mark within the cell

Spatially ordered treemaps.
Wood and Dykes.

Interlocking marks: Circle packings

- also are interlocking marks, **not** size-coded point marks
  - more like treemap than scatterplot!
- channel availability analysis: customized circle packing
  - Encoded channels
    - horizontal position: encodes tax rate
    - color: rate, redundant with horizontal position
    - size (2D area): market cap
  - Free channels
    - motion
  - Unavailable channels
    - vertical position: used by algorithm to avoid overlap & minimize gaps
    - shape & orientation equal and unavailable: can't just change, would need to redo layout

Interlocking marks: Circle packings

• customized circle packings are special case
  – including beeswarm plots

• general circle packing
  – algorithmic constraint: no overlaps, minimal gaps
  • position unavailable since used by algorithm

• Dorling cartogram
  – can treat as special case of circle packing, with additional constraints to maintain relative position from geographic location
  – throw away shape by regularizing to circles
  – add size coding
Interlocking? Election maps roundup

- yes interlocking
  - A: already covered
  - B/C: equal-area algorithm simplifies shape

- yes interlocking
  - E/F multi-level
  - top level: interlocking marks
  - bottom level: square units
    - E/F: countability for votes
    - F whitespace: population density

- no, point marks
  - size coded by area

https://www.anychart.com/blog/2020/11/06/election-maps-us-vote-live-results/
Distinguishing marks through constraints

• highly constrained: interlocking marks
  – many channels unavailable: size, position, shape, orientation
  – proposal: rename from "area" to "interlocking"

• unconstrained: point marks
  – can encode more info with any channel at all!
    • size, position, shape, orientation
    • color, motion, ...
  – does "point" imply circular shape?
    • proposal: is "unconstrained" a better / more evocative name?

• so... what about line marks?
Line marks: Rethinking

- do line charts use line marks?
  - construct connections between points
    - trend task: emphasize relationships between items
    - may or may not show points explicitly
  - no! not like bar charts or lollipop charts do...

- line chart encodes many items, not just one
  - with many piecewise-linear segments or smooth curve
Line marks: Naming two cases separately?

• line segments showing single item, vs curved lines showing multiple items
  – should we reason about them separately instead of analyzing them together?
  – line segment: express single quantitative attribute for one item with length
    • single mark represents single item of data
    • proposal: call these "segments"
  – curved / complex lines
    • proposal: call these "paths"
    • single mark represents many items of data
Line marks vs point marks

• what's relationship between length channel and length of line?
  – exactly the same? confusingly different?

• how does line segment differ from "length-coded point mark"?
  – two numbers, either centroid/length or max/min

• proposal: what if line segment marks and point marks belong in same "singleton" category?
  – to distinguish from multi-item marks
Line marks vs area marks

• what's the border between line path marks and area marks?
  – if path is wide enough, is it an area?
  – what if there's information shown in region inside path, within its boundary?
    • different color for inside vs outside, or even text?

• what about the region below path?...

Line charts vs filled area charts

• should we reason differently about
  – line chart boundary vs filled area chart interior?
  – stacked area charts vs streamgraphs?
  – discrete stacked bar charts vs continuous streamgraphs?

• what matters?
  – boundary vs interior?
  – discrete vs continuous
  – occlusion?


https://d3-graph-gallery.com/line.html
https://d3-graph-gallery.com/area.html
https://d3-graph-gallery.com/stackedarea.html
https://d3-graph-gallery.com/streamgraph.html
Boundaries vs interiors

• proposal: if path is closed, call it a "boundary"
  – (maybe also if path is infinite)
  – all boundaries also define "interior" region
  – distinction may or may not be visually highlighted

• proposal: use name "filled" mark instead of "area"
  – then interlocking marks are a special case of filled marks
Alternative mark types model
Constraints & Channel Availability

• consider marks and channels as imposing constraints
  – when does mark type constrain channel use?
  – **when does using one channel constrain another channel?**

• Channel Availability Model
  – Encoded: which channels directly used to encode attributes?
    • clear meaning
    • multiple channels can be directly used for redundant encoding
  – Free: which channels free to encode another attribute?
    • without changing usability of existing encoding
  – Unavailable: which channels unavailable / precluded / taken?
    • because of mark type?
    • because of idiom/algorithmdesign specifics?
    • **because other channels used?**
General dependencies: Position

• need fine-grained ability to specify for adequate descriptive power
  – rectilinear (horizontal and/or vertical)
    • high precision because perceptually aligned
      – depth (3D position): very low precision
  – radial (angular position and/or radial distance)
    • lower precision, no perceptual alignment

• general dependencies for unavailability?
  – cannot use both rectilinear and radial simultaneously
    • in same layer, using one type precludes other
  – but horizontal doesn't preclude vertical & vice versa

• position is shared / global
  – with respect to specific coordinate frame shared across many marks
General dependencies: Size

- 1D (length) << 2D (area) << 3D (volume)

- dependencies for unavailability?
  - larger dimension subsumes smaller ones
    - encode with area channel means length channel unavailable
    - volume means area & length unavailable
  - but not vice versa: can augment from length to area
    - add second attribute for 1D size coding in other direction

- size is local, in contrast to shared position
  - can be independent across marks

https://www.forthgo.com/blog/2019/12/18/bar-mekko-chart-study/
General dependencies: Position vs length

• alignment
  – position (horizontal and/or vertical) is usually shortcut for "aligned position", highest precision channel of all
    • reference frame of explicit axis
    • implicit boundaries of view / window / region

• general dependencies: position (1D) vs length (1D size)?
  – for line marks, position encoded implies length encoded
  – but not vice versa: can have length without position

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https://twitter.com/MonaChalabi/status/11587704693879106

Channel Dependencies/Hierarchy proto-model musings

- position (shared)
  - rectilinear
    - horizontal pos (aligned)
    - vertical pos (aligned)
  - depth
  - radial
    - angular position
    - radial distance
- parallel

- size (local)
  - 1D length
  - 2D area
  - 3D volume

- orientation (local)
  - color
    - hue
    - saturation
    - luminance
  - shape
  - motion
Shared vs local example

- shared locks down local, but can use local without shared
Multi-level analysis required for many cases

– small multiples: juxtaposed views
  • vertical position within row: algorithmic, avoid occlusion
  • vertical position across rows: encodes job type attribute

https://flowingdata.com/2016/06/28/distributions-of-annual-income/
Multi-level analysis needed: Grouped bar charts

• Encoded
  – vertical position encodes quantitative attributes
    • shootings & coverage counts
  – length (1D size) redundantly encodes same thing
  – color encodes categorical attrib (shooting vs coverage)
  – horizontal position
    • low-level (within group) encodes counts, redundant w/ color
    • high-level (across groups) encodes race (shooting & coverage)

• Unavailable
  – any other position channel (radial) precluded

• Free
  – motion, shape, ...
From marks to glyphs: multiple marks/item

• glyphs: more than one mark per item
  – grouped bars
  – stacked bars

• multiple views
  – bar chart small multiples

https://observablehq.com/@d3/stacked-bar-chart/2
https://blocks.roadtolarissa.com/mbostock/4679202
Multi-level analysis required for many cases

– small multiples: juxtaposed views
  • vertical position within row: algorithmic, avoid occlusion
  • vertical position across rows: encodes job type attribute

– nesting:
  multi-scale
  views / glyphs

https://flowingdata.com/2016/06/28/distributions-of-annual-income/

https://www.anychart.com/blog/2020/11/06/election-maps-us-vote-live-results/
Unit encodings

• point marks
  – general case: quantity only!
  – position channel not necessarily in use
• often constrained by idiom
  – then need **multi-level interpretation**
    • top level: interlocking mark
      – rectilinear: support counting width & height separately
    • bottom level: unit point marks
      – can be independently color-coded (or interactively highlighted)
Conclusion: Preliminary steps towards answers?

- **Old marks/channels models**
  - marks, based on Bertin's geometry: 0D points, 1D lines, 2D areas, 3D volumes
  - channel rankings by accuracy, based on Cleveland & McGill two-value ratio task

- **Alternative marks/channels proto-models**
  - channel-based constraint analysis, channel availability: Encoded, Free, Unavailable
  - mark types model, mark-based constraints
    - Unconstrained / Singleton, for single items (points & simple line segments)
    - Paths, for multiple items (complex lines)
    - Filled & Interlocking, with boundary & interiors (areas)
  - channel dependency proto-model
    - distinguish coordinate frame positions as shared, vs size & orientation as local
  - multi-level mark type analysis

- do these help think and reason about design space of visual encodings?
More stuff

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#northeastern24

- more questions? thoughts on answers??

- book
  http://www.cs.ubc.ca/~tmm/vadbook

- full courses, papers, videos, software, talks
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm