Visualization Analysis & Design

What's Vis, and Why Do It? (Ch 1)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner
Defining visualization (vis)

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.
Defining visualization (vis)

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Why?...
Why have a human in the loop?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.
Why have a human in the loop?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.
Why have a human in the loop?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

• don’t need vis when fully automatic solution exists and is trusted
• many analysis problems ill-specified
  – don’t know exactly what questions to ask in advance
• possibilities
  – long-term use for end users (ex: exploratory analysis of scientific data)
  – presentation of known results (ex: New York Times Upshot)
  – stepping stone to assess requirements before developing models
  – help automatic solution developers refine & determine parameters
  – help end users of automatic solutions verify, build trust
Why use an external representation?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- external representation: replace cognition with perception

Why use an external representation?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

• external representation: replace cognition with perception

Why depend on vision?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- human visual system is high-bandwidth channel to brain
  - overview possible due to background processing
    - subjective experience of seeing everything simultaneously
    - significant processing occurs in parallel and pre-attentively
- sound: lower bandwidth and different semantics
  - overview not supported
    - subjective experience of sequential stream
- touch/haptics: impoverished record/replay capacity
  - only very low-bandwidth communication thus far
- taste, smell: no viable record/replay devices
Why represent all the data?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- summaries lose information, details matter
  - confirm expected and find unexpected patterns
  - assess validity of statistical model

**Anscombe’s Quartet**

<table>
<thead>
<tr>
<th>Identical statistics</th>
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</thead>
<tbody>
<tr>
<td>x mean</td>
<td>9</td>
</tr>
<tr>
<td>x variance</td>
<td>10</td>
</tr>
<tr>
<td>y mean</td>
<td>7.5</td>
</tr>
<tr>
<td>y variance</td>
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</tr>
<tr>
<td>x/y correlation</td>
<td>0.816</td>
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What resource limitations are we faced with?

Vis designers must take into account three very different kinds of resource limitations: those of computers, of humans, and of displays.

• computational limits
  – computation time, system memory

• display limits
  – pixels are precious & most constrained resource
  – **information density**: ratio of space used to encode info vs unused whitespace
    • tradeoff between clutter and wasting space
    • find sweet spot between dense and sparse

• human limits
  – human time, human memory, human attention
Why analyze?
• imposes structure on huge design space
  – scaffold to help you think systematically about choices
  – analyzing existing as stepping stone to designing new
  – most possibilities ineffective for particular task/data combination
Why analyze?

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Why analyze?

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**What?**
- Tree

**Why?**
- Actions
  - Present
  - Locate
  - Identify

- Targets
  - Path between two nodes

**How?**
- **SpaceTree**
  - Encode
  - Navigate
  - Select
  - Filter
  - Aggregate

- **TreeJuxtaposer**
  - Encode
  - Navigate
  - Select
  - Arrange

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Visualization Analysis & Design

Analysis: Nested Model (Ch 4)

Tamara Munzner
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Analysis framework: Four levels, three questions

• *domain situation*
  – who are the target users?

Analysis framework: Four levels, three questions

• **domain situation**
  – who are the target users?

• **abstraction**
  – translate from specifics of domain to vocabulary of vis
    • **what** is shown? data abstraction
    • **why** is the user looking at it? task abstraction

Analysis framework: Four levels, three questions

• domain situation
  – who are the target users?

• abstraction
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• idiom
  – how is it shown?
    • visual encoding idiom: how to draw
    • interaction idiom: how to manipulate

Analysis framework: Four levels, three questions

- **domain situation**
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- **idiom**
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate

- **algorithm**
  - efficient computation

Nested model

- downstream: cascading effects

Nested model

- downstream: cascading effects
- upstream: iterative refinement

Why is validation difficult?

- different ways to get it wrong at each level

- **Domain situation**
  - You misunderstood their needs

- **Data/task abstraction**
  - You’re showing them the wrong thing

- **Visual encoding/interaction idiom**
  - The way you show it doesn’t work

- **Algorithm**
  - Your code is too slow

Why is validation difficult?

- solution: use methods from different fields at each level
Why is validation difficult?

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Why is validation difficult?

- solution: use methods from different fields at each level

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Design:
- Visual encoding/interaction idiom
  - Justify design with respect to alternatives

Computer science:
- Algorithm
  - Measure system time/memory
  - Analyze computational complexity

Cognitive psychology:
- Analyze results qualitatively
- Measure human time with lab experiment (lab study)

---

Why is validation difficult?

- solution: use methods from different fields at each level

**Domain situation**
Observe target users using existing tools

**Data/task abstraction**

**Visual encoding/interaction idiom**
Justify design with respect to alternatives

**Algorithm**
- Measure system time/memory
- Analyze computational complexity

**Anthropology/ethnography**
- Analyze results qualitatively
- Measure human time with lab experiment (*lab study*)
- Observe target users after deployment (*field study*)
- Measure adoption

**Design**

**Computer science**

**Cognitive psychology**

Why is validation difficult?

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- **Domain situation**
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    - Justify design with respect to alternatives
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Avoid mismatches

**Domain situation**
Observe target users using existing tools

**Data/task abstraction**

- **Visual encoding/interaction idiom**
  Justify design with respect to alternatives

- **Algorithm**
  Measure system time/memory
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  Analyze results qualitatively
  Measure human time with lab experiment (lab study)

Observe target users after deployment (field study)

Measure adoption

computational benchmarks do not confirm idiom design

Avoid mismatches

**Domain situation**
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- **Visual encoding/interaction idiom**
  Justify design with respect to alternatives

- **Algorithm**
  Measure system time/memory
  Analyze computational complexity

  Analyze results qualitatively
  Measure human time with lab experiment (*lab study*)

  Observe target users after deployment (*field study*)

  Measure adoption

lab studies do not confirm task abstraction

computational benchmarks do not confirm idiom design

Visualization Analysis & Design

Data Abstraction (Ch 2)

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What does data mean?
What does data mean?

14, 2.6, 30, 30, 15, 100001

• What does this sequence of six numbers mean?
What does data mean?

14, 2.6, 30, 30, 15, 100001

• What does this sequence of six numbers mean?
  – two points far from each other in 3D space?
What does data mean?

14, 2.6, 30, 30, 15, 100001

• What does this sequence of six numbers mean?
  – two points far from each other in 3D space?
  – two points close to each other in 2D space, with 15 links between them, and a weight of 100001 for the link?
What does data mean?

14, 2.6, 30, 30, 15, 100001

• What does this sequence of six numbers mean?
  – two points far from each other in 3D space?
  – two points close to each other in 2D space, with 15 links between them, and a weight of 100001 for the link?
  – something else??
What does data mean?

14, 2.6, 30, 30, 15, 100001

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Basil, 7, S, Pear
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Basil, 7, S, Pear

• What about this data?
What does data mean?

14, 2.6, 30, 30, 15, 100001

• What does this sequence of six numbers mean?
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Basil, 7, S, Pear

• What about this data?
  – food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month
What does data mean?

14, 2.6, 30, 30, 15, 100001

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Basil, 7, S, Pear

• What about this data?
  – food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month
  – Basil Point neighborhood of city had 7 inches of snow cleared by the Pear Creek Limited snow removal service
What does data mean?

14, 2.6, 30, 30, 15, 100001

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  – something else??

Basil, 7, S, Pear

• What about this data?
  – food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month
  – Basil Point neighborhood of city had 7 inches of snow cleared by the Pear Creek Limited snow removal service
  – lab rat Basil made 7 attempts to find way through south section of maze, these trials used pear as reward food
Now what?

- semantics: real-world meaning

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Now what?

• semantics: real-world meaning
• data types: structural or mathematical interpretation of data
  – item, link, attribute, position, (grid)
  – different from data types in programming!

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Items & Attributes

• item: individual entity, discrete
  – eg patient, car, stock, city
  – "independent variable"

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item: person
Items & Attributes

• item: individual entity, discrete
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• attribute: property that is measured, observed, logged...
  – eg height, blood pressure for patient
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attributes: name, age, shirt size, fave fruit

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item: person
Other data types

• links
  – express relationship between two items
  – e.g. friendship on Facebook, interaction between proteins

• positions
  – spatial data: location in 2D or 3D
  – pixels in photo, voxels in MRI scan, latitude/longitude

• grids
  – sampling strategy for continuous data
Dataset types

- **Tables**
  - flat table
    - one item per row
    - each column is attribute
    - cell holds value for item-attribute pair

- **Attributes**
- **Items**

### Attributes: name, age, shirt size, fave fruit

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item: person
### Dataset types

#### Tables
- **Flat Table**
  - One item per row
  - Each column is an attribute
  - Cell holds value for item-attribute pair
  - Unique key (could be implicit)

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</tbody>
</table>

- **Item:** person

- **Attributes (columns):** name, age, shirt size, favorite fruit

- **Items (rows):** Amy, Basil, Clara, Desmond, Ernest, Fanny, George, Hector, Ida, Amy

#### Diagram
- **Attributes (columns):** name, age, shirt size, favorite fruit
- **Items (rows):** Amy, Basil, Clara, Desmond, Ernest, Fanny, George, Hector, Ida, Amy
- **Cell containing value:**
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</tr>
</tbody>
</table>
Dataset types

- multidimensional tables
  - indexing based on multiple keys
  - eg genes, patients
Dataset types

- **network/graph**
  - nodes (vertices) connected by links (edges)
  - tree is special case: no cycles
    - often have roots and are directed
Dataset types

- **Tables**
  - Items
  - Attributes

- **Networks & Trees**
  - Items (nodes)
  - Links
  - Attributes

- **Fields**
  - Grids
  - Positions
  - Attributes

- **Spatial**
- **Fields (Continuous)**

- **Trees**
Spatial fields

• attribute values associated w/ cells
• cell contains value from continuous domain
  – eg temperature, pressure, wind velocity
• measured or simulated

➡️ Spatial
➡️ Fields (Continuous)

Grid of positions

Cell

Attributes (columns)

Value in cell
Spatial fields

• attribute values associated w/ cells
• cell contains value from continuous domain
  – eg temperature, pressure, wind velocity
• measured or simulated
• major concerns
  – sampling:
    where attributes are measured
  – interpolation:
    how to model attributes elsewhere
  – grid types
Spatial fields

- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated

- major concerns
  - sampling: where attributes are measured
  - interpolation: how to model attributes elsewhere
  - grid types

- major divisions
  - attributes per cell: scalar (1), vector (2), tensor (many)
## Dataset Types

<table>
<thead>
<tr>
<th>Tables</th>
<th>Networks &amp; Trees</th>
<th>Fields (Continuous)</th>
<th>Geometry (Spatial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Items</td>
<td>Items (nodes)</td>
<td>Grids</td>
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</tr>
<tr>
<td>Attributes</td>
<td>Links</td>
<td>Positions</td>
<td>Positions</td>
</tr>
</tbody>
</table>

### Tables
- **Items**: rows
- **Attributes**: columns
- **Cell containing value**

### Networks
- **Link**: connections between nodes
- **Node (item)**

### Trees
- **Cell**: structure of nodes and branches
- **Attributes (columns)**
- **Value in cell**

### Fields (Continuous)
- **Grid of positions**
- **Attributes (columns)**
- **Value in cell**

### Geometry (Spatial)
- **Position**
Geometry

- shape of items
- explicit spatial positions / regions
  - points, lines, curves, surfaces, volumes
- boundary between computer graphics and visualization
  - graphics: geometry taken as given
  - vis: geometry is result of a design decision
Dataset types

Tables
- Items
- Attributes

Networks & Trees
- Items (nodes)
- Links
- Attributes

Fields
- Grids
- Positions

Geometry
- Items
- Positions

Clusters, Sets, Lists
- Items

Spatial

Fields (Continuous)

Geometry (Spatial)
Collections

• how we group items
Collections

• how we group items
• sets
  – unique items, unordered
Collections

• how we group items
• sets
  – unique items, unordered
• lists
  – ordered, duplicates possible
Collections

• how we group items
• sets
  – unique items, unordered
• lists
  – ordered, duplicates possible
• clusters
  – groups of similar items
## Dataset and data types

### Data and Dataset Types

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</tbody>
</table>

### Data Types

- **Items**
- **Attributes**
- **Links**
- **Positions**
- **Grids**
Attribute types

• which classes of values & measurements?
  
• categorical (nominal)
  – compare equality
  – no implicit ordering

• ordered
  – ordinal
  • less/greater than defined
  – quantitative
  • meaningful magnitude
  • arithmetic possible
<table>
<thead>
<tr>
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<th>Order Priority</th>
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<th>Product Base Margin</th>
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</tr>
</tbody>
</table>
Other data concerns

 Attribute Types

- Categorical
- Ordered
- Ordinal
- Quantitative

 Ordering Direction

- Sequential
- Diverging
- Cyclic

 Dataset Availability

- Static
- Dynamic
Data abstraction: Three operations

• translate from domain-specific language to generic visualization language

• identify dataset type(s), attribute types

• identify cardinality
  – how many items in the dataset?
  – what is cardinality of each attribute?
    • number of levels for categorical data
    • range for quantitative data

• consider whether to transform data
  – guided by understanding of task
Data vs conceptual models

• data model
  – mathematical abstraction
    • sets with operations, eg floats with * / - +
    • variable data types in programming languages

• conceptual model
  – mental construction (semantics)
  – supports reasoning
  – typically based on understanding of tasks [stay tuned!]

• data abstraction process relies on conceptual model
  – for transforming data if needed
Data vs conceptual model, example
Data vs conceptual model, example

• data model: floats
  – 32.52, 54.06, -14.35, ...
Data vs conceptual model, example

• data model: floats
  – 32.52, 54.06, -14.35, ...

• conceptual model
  – temperature
Data vs conceptual model, example

• data model: floats
  – 32.52, 54.06, -14.35, ...

• conceptual model
  – temperature

• multiple possible data abstractions
Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...

- conceptual model
  - temperature

- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready
Data vs conceptual model, example

- **data model**: floats
  - 32.52, 54.06, -14.35, ...

- **conceptual model**
  - temperature

- **multiple possible data abstractions**
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready
  - above freezing, below freezing: categorical
    - task: decide if I should leave the house today
Derived attributes

- derived attribute: compute from originals
  - simple change of type
  - acquire additional data
  - complex transformation

Original Data

Derived Data

\[ \text{trade balance} = \text{exports} - \text{imports} \]
Analysis example: Derive one attribute

- **Strahler number**
  - centrality metric for trees/networks
  - derived quantitative attribute
  - draw top 5K of 500K for good skeleton

### What?

- **Data Types**
  - Items
  - Attributes
  - Links
  - Positions
  - Grids

- **Data and Dataset Types**
  - **Tables**
    - Items
    - Attributes
  - **Networks & Trees**
    - Items (nodes)
    - Links
    - Attributes
  - **Fields**
    - Grids
    - Positions
  - **Geometry**
    - Items
    - Positions
  - **Clusters, Sets, Lists**
    - Items

- **Dataset Types**
  - **Tables**
  - **Networks**
  - **Fields (Continuous)**

- **Geometry (Spatial)**

- **Dataset Availability**
  - Static
  - Dynamic

### Why?

### How?
Visualization Analysis & Design

Task Abstraction (Ch 3)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner
From domain to abstraction
From domain to abstraction

- domain characterization: details of application domain
From domain to abstraction

• domain characterization: details of application domain
  – group of users, target domain, their questions & data
    • varies wildly by domain
    • must be specific enough to get traction
From domain to abstraction

• domain characterization: details of application domain
  – group of users, target domain, their questions & data
    • varies wildly by domain
    • must be specific enough to get traction
  – domain questions/problems
    • break down into simpler abstract tasks
From domain to abstraction

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• abstraction: data & task
  – map what and why into generalized terms
From domain to abstraction

• domain characterization:
  details of application domain
  – group of users, target domain, their questions & data
    • varies wildly by domain
    • must be specific enough to get traction
  – domain questions/problems
    • break down into simpler abstract tasks

• abstraction: data & task
  – map what and why into generalized terms
    • identify tasks that users wish to perform, or already do
    • find data types that will support those tasks
      – possibly transform /derive if need be
Design process

Characterize Domain Situation

Map Domain-Language Task to Abstract Task

Map Domain-Language Data Description to Data Abstraction

Identify/Create Suitable Idiom/Technique

Identify/Create Suitable Algorithm
Task abstraction: Actions and targets

• very high-level pattern

• \{action, target\} pairs
  – discover distribution
  – compare trends
  – locate outliers
  – browse topology
Task abstraction: Actions and targets

• very high-level pattern

• actions
  – analyze
    • high-level choices
  – search
    • find a known/unknown item
  – query
    • find out about characteristics of item

• \{action, target\} pairs
  – discover distribution
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Task abstraction: Actions and targets

• very high-level pattern

• actions
  – analyze
    • high-level choices
  – search
    • find a known/unknown item
  – query
    • find out about characteristics of item

• targets
  – what is being acted on

• \{action, target\} pairs
  – discover distribution
  – compare trends
  – locate outliers
  – browse topology
Actions: Analyze

- **consume**
  - discover vs present
    - classic split
    - aka explore vs explain
  - enjoy
    - newcomer
    - aka casual, social

- **produce**
  - annotate, record
  - derive
    - crucial design choice
Actions: Search
### Actions: Search

- **what does user know?**
  - target, location

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<thead>
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<th>Target unknown</th>
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<td><img src="browse_icon" alt="Browse" /></td>
<td><img src="explore_icon" alt="Explore" /></td>
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**Actions: Search**

- **what does user know?**
  - target, location

- **lookup**
  - ex: word in dictionary
    - alphabetical order

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</tr>
</thead>
<tbody>
<tr>
<td>Target known</td>
<td>Target unknown</td>
</tr>
<tr>
<td>Lookup</td>
<td>Browse</td>
</tr>
<tr>
<td>Locate</td>
<td>Explore</td>
</tr>
</tbody>
</table>
Actions: Search

- what does user know?
  - target, location

- lookup
  - ex: word in dictionary
    - alphabetical order

- locate
  - ex: keys in your house
  - ex: node in network
**Actions: Search**

- **what does user know?**
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  - ex: word in dictionary
    - alphabetical order
- **locate**
  - ex: keys in your house
  - ex: node in network
- **browse**
  - ex: books in bookstore

---

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  – ex: word in dictionary
    • alphabetical order

• locate
  – ex: keys in your house
  – ex: node in network

• browse
  – ex: books in bookstore

• explore
  – ex: find cool neighborhood in new city

Search

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https://bl.ocks.org/heybignick/3fa287b8bbece7743bb72310a03b86ede
**Actions: Query**

- how much of the data matters?
  - one: identify
  - some: compare
  - all: summarize

- Query
- Identify
- Compare
- Summarize
Actions

- independent choices for each of these three levels
  - analyze, search, query
  - mix and match
Task abstraction: Targets
Task abstraction: Targets

- All Data
  - Trends
  - Outliers
  - Features
Task abstraction: Targets

All Data

- Trends
- Outliers
- Features

Attributes

- One
  - Distribution
  - Extremes
- Many
  - Dependency
  - Correlation
  - Similarity
Task abstraction: Targets

- **All Data**
  - Trends
  - Outliers
  - Features

- **Attributes**
  - One
    - Distribution
    - Extremes
  - Many
    - Dependency
    - Correlation
    - Similarity

- **Network Data**
  - Topology
  - Paths
Task abstraction: Targets

- **All Data**
  - Trends
  - Outliers
  - Features

- **Attributes**
  - One
    - Distribution
    - Extremes
  - Many
    - Dependency
    - Correlation
    - Similarity

- **Network Data**
  - Topology
    - Paths

- **Spatial Data**
  - Shape
Abstraction

• these \{action, target\} pairs are good starting point for vocabulary
  – but sometimes you'll need more precision!
• rule of thumb
  – systematically remove all domain jargon

• interplay: task and data abstraction
  – need to use data abstraction within task abstraction
    • to specify your targets!
    • but task abstraction can lead you to transform the data
  – iterate back and forth
    • first pass data, first pass task, second pass data, ...
Means and ends

Why?
How?
What?

Why?
How?
What?

Why?
How?
What?
- \{\text{action, target}\} \text{ pairs}
  - discover distribution
  - compare trends
  - locate outliers
  - browse topology
Visualization Analysis & Design

Marks & Channels (Ch 5) I

Tamara Munzner
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Visual encoding

• how to systematically analyze idiom structure?
Visual encoding

- how to systematically analyze idiom structure?
Visual encoding

• how to systematically analyze idiom structure?

• marks & channels
  – marks: represent items or links
  – channels: change appearance of marks based on attributes
Marks for items

• basic geometric elements

0D 1D 2D

Points Lines Interlocking Areas

• 3D mark: volume, rarely used
Marks for links

- **Containment**

- **Connection**

vialab.science.uoit.ca/portfolio/bubblesets

Containment can be nested

[Untangling Euler Diagrams, Riche and Dwyer, 2010]
Channels

• control appearance of marks
  – proportional to or based on attributes

• many names
  – visual channels
  – visual variables
  – retinal channels
  – visual dimensions
  – ...

 negói.  

- Position
  - Horizontal
  - Vertical
  - Both

- Color

- Shape

- Tilt

- Size
  - Length
  - Area
  - Volume
Definitions: Marks and channels

- marks
  - geometric primitives
Definitions: Marks and channels

• marks
  – geometric primitives

• channels
  – control appearance of marks
Definitions: Marks and channels

- **marks**
  - geometric primitives

- **channels**
  - control appearance of marks

- **channel properties differ**
  - type & amount of information that can be conveyed to human perceptual system
Visual encoding

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

• analyze idiom structure as combination of marks and channels

1: vertical position

mark: line
Visual encoding

• analyze idiom structure as combination of marks and channels

1: vertical position
mark: line

2: vertical position
horizontal position
mark: point
Visual encoding

• analyze idiom structure as combination of marks and channels

1: vertical position
mark: line

2: vertical position
horizontal position
mark: point

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

• analyze idiom structure as combination of marks and channels

1: vertical position
mark: line

2: vertical position
horizontal position
mark: point

3: vertical position
horizontal position
color hue
mark: point

4: vertical position
horizontal position
color hue
size (area)
mark: point
Redundant encoding

- multiple channels
  - sends stronger message
  - but uses up channels

Length and Luminance
Marks as constraints

- math view: geometric primitives have dimensions

- Points
- Lines
- Interlocking Areas

0D 1D 2D
Marks as constraints

- **math view:** geometric primitives have dimensions
  - Points: 0D
  - Lines: 1D
  - Interlocking Areas: 2D

- **constraint view:** mark type constrains what else can be encoded
  - Points: 0 constraints on size, can encode more attributes w/ size & shape
  - Lines: 1 constraint on size (length), can still size code other way (width)
  - Interlocking areas: 2 constraints on size (length/width), cannot size or shape code
    - Interlocking: size, shape, position
Marks as constraints

• math view: geometric primitives have dimensions
  - Points (0D)
  - Lines (1D)
  - Interlocking Areas (2D)

• constraint view: mark type constrains what else can be encoded
  - points: 0 constraints on size, can encode more attributes w/ size & shape
  - lines: 1 constraint on size (length), can still size code other way (width)
  - interlocking areas: 2 constraints on size (length/width), cannot size or shape code
    • interlocking: size, shape, position

• quick check: can you size-code another attribute
  - or is size/shape in use?
Scope of analysis

• simplifying assumptions: one mark per item, single view

• later on
  – multiple views
  – multiple marks in a region (glyph)
  – some items not represented by marks (aggregation and filtering)
When to use which channel?

**expressiveness**
- match channel type to data type

**effectiveness**
- some channels are better than others
Channels: Rankings

- 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)

Spatial region
- Color hue
- Motion
- Shape
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

- **Expressiveness**
  - match channel and data characteristics
Channels: Rankings

**Magnitude Channels: Ordered Attributes**
- Position on common scale
- Position on unaligned scale
- Length (1D size)
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- Color saturation
- Curvature
- Volume (3D size)

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

**Attribute Types**
- Categorical
- Ordered
- Ordinal
- Quantitative

**Expressiveness**
- match channel and data characteristics
  - magnitude for ordered
    - how much? which rank?
  - identity for categorical
    - what?
Channels: Rankings

**Magnitude Channels: Ordered Attributes**

- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
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**Identity Channels: Categorical Attributes**

- Spatial region
- Color hue
- Motion
- Shape

• **expressiveness**
  - match channel and data characteristics

• **effectiveness**
  - channels differ in accuracy of perception
Channels: Rankings

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- Volume (3D size)

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

- **expressiveness**
  - match channel and data characteristics
- **effectiveness**
  - channels differ in accuracy of perception
  - spatial position ranks high for both
Grouping

- containment
- connection

Marks as Links

- Containment
- Connection

Identity Channels: Categorical Attributes

- proximity
  - same spatial region
- similarity
  - same values as other categorical channels

Spatial region

Color hue

Motion

Shape
Visualization Analysis & Design

Marks & Channels (Ch 5) II

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Channel effectiveness

- accuracy: how precisely can we tell the difference between encoded items?
- discriminability: how many unique steps can we perceive?
- separability: is our ability to use this channel affected by another one?
- popout: can things jump out using this channel?
Accuracy: Fundamental theory

• length is accurate: linear
• others magnified or compressed
  — exponent characterizes

Steven’s Psychophysical Power Law: $S = I^N$

$S = \text{sensation}$

$I = \text{intensity}$
Accuracy: Vis experiments

Discriminability: How many usable steps?

- must be sufficient for number of attribute levels to show
  - linewidth: few bins

[mappa.mundi.net/maps/maps_014/telegeography.html]
Separability vs. Integrality

Position
+ Hue (Color)

Fully separable

2 groups each
Separability vs. Integrality

Position
+ Hue (Color)

Size
+ Hue (Color)

Fully separable

Some interference

2 groups each

2 groups each
Separability vs. Integrality

Position
+ Hue (Color)

2 groups each
Fully separable

Size
+ Hue (Color)

2 groups each
Some interference

Width
+ Height

Some/significant interference
3 groups total: integral area
Separability vs. Integrality

Position
+ Hue (Color)

Size
+ Hue (Color)

Width
+ Height

Red
+ Green

Fully separable

Some interference

Some/significant interference

Major interference

2 groups each

2 groups each

3 groups total: integral area

4 groups total: integral hue
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
Popout

• find the red dot
  – how long does it take?
• parallel processing on many individual channels
  – speed independent of distractor count
  – speed depends on channel and amount of difference from distractors
• serial search for (almost all) combinations
  – speed depends on number of distractors
• many channels
  – tilt, size, shape, proximity, shadow direction, ...
Popout

- many channels
  - tilt, size, shape, proximity, shadow direction, ...
- but not all!
  - parallel line pairs do not pop out from tilted pairs
Factors affecting accuracy

- alignment
- distractors
- distance
- common scale / alignment
Relative vs. absolute judgements

• perceptual system mostly operates with relative judgements, not absolute
Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  – that’s why accuracy increases with common frame/scale and alignment

Relative vs. absolute judgements

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  – Weber’s Law: ratio of increment to background is constant

Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that’s why accuracy increases with common frame/scale and alignment
  - Weber’s Law: ratio of increment to background is constant
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement

\[\text{length} \quad \text{position along unaligned common scale} \quad \text{position along aligned scale}\]
Relative luminance judgements

• perception of luminance is contextual based on contrast with surroundings

http://persci.mit.edu/gallery/checkershadow
Relative luminance judgements

• perception of luminance is contextual based on contrast with surroundings

[Image of checkered surface with a green cylinder and a vertical bar]
Relative color judgements

- color constancy across broad range of illumination conditions

http://www.purveslab.net/seeforyourself/
Relative color judgements

- color constancy across broad range of illumination conditions
Visualization Analysis & Design

Arrange Tables (Ch 7) I

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University of British Columbia
@tamaramunzner
Focus on Tables

Dataset Types

- **Tables**
  - Attributes (columns)
  - Items (rows)
  - Cell containing value

- **Multidimensional Table**
  - Key 1
  - Key 2
  - Attributes
  - Value in cell

- **Networks**
  - Link
  - Node (item)

- **Trees**

- **Spatial**
  - Fields (Continuous)
  - Geometry (Spatial)
  - Grid of positions
  - Cell
  - Attributes (columns)
  - Value in cell

- **Position**
Keys and values

• **key**
  – independent attribute
  – used as unique index to look up items
  – simple tables: 1 key
  – multidimensional tables: multiple keys

• **value**
  – dependent attribute, value of cell
Keys and values

- **key**
  - independent attribute
  - used as unique index to look up items
  - simple tables: 1 key
  - multidimensional tables: multiple keys

- **value**
  - dependent attribute, value of cell

- classify arrangements by keys used
  - 0, 1, 2, ...

- **Express Values**
  - 0 Keys
  - 1 Key
    - List
  - 2 Keys
    - Matrix
Idiom: **scatterplot**

- **express** values (magnitudes)
  - quantitative attributes
- no keys, only values

Idiom: **scatterplot**

- **express** values (magnitudes)
  - quantitative attributes
- no keys, only values
  - data
    - 2 quant attrs
  - mark: points
  - channels
    - horiz + vert position

[Scatterplots](19:1 (2010), 3–28.)
Idiom: **scatterplot**

- **express** values (magnitudes)
  - quantitative attributes

- no keys, only values
  - data
    - 2 quant attrs
  - mark: points
  - channels
    - horiz + vert position

- tasks
  - find trends, outliers, distribution, correlation, clusters

- scalability
  - hundreds of items

---

Scatterplots: Encoding more channels

- additional channels viable since using point marks
  - color
  - size (1 quant attribute, used to control 2D area)
    - note radius would mislead, take square root since area grows quadratically
  - shape

https://www.d3-graph-gallery.com/graph/bubble_basic.html
Scatterplot tasks
Scatterplot tasks

• correlation

https://www.mathisfun.com/data/scatter-xy-plots.html
Scatterplot tasks

- correlation

- clusters/groups, and clusters vs classes

https://www.mathsisfun.com/data/scatter-xy-plots.html

https://www.cs.ubc.ca/labs/imager/tr/2014/DRVisTasks/
Some keys

- 0 Keys
- Express Values

1 Key
- List

2 Keys
- Matrix
Some keys: Categorical regions

- Separate
- Order
- Align
Regions: Separate, order, align

- Separate
- Order
- Align

- regions: contiguous bounded areas distinct from each other
  - separate into spatial regions: one mark per region (for now)
- use categorical or ordered attribute to separate into regions
  - no conflict with expressiveness principle for categorical attributes
- use ordered attribute to order and align regions

- 1 Key
  - List
- 2 Keys
  - Matrix
Separated and aligned and ordered

• best case
Separated and aligned but not ordered

- limitation: hard to know rank. what's 4th? what's 7th?
Separated but not aligned or ordered

- limitation: hard to make comparisons with size (vs aligned position)
Idiom: **bar chart**

- **one key, one value**
  - data
    - 1 categ attrib, 1 quant attrib
  - mark: lines
- **channels**
  - length to express quant value
  - spatial regions: one per mark
    - separated horizontally, aligned vertically
    - ordered by quant attrib
      » by label (alphabetical), by length attrib (data-driven)
- **task**
  - compare, lookup values
- **scalability**
  - dozens to hundreds of levels for key attrib [bars], hundreds for values
Idiom: stacked bar chart

• one more key
  – data
    • 2 categ attrib, 1 quant attrib
  – mark: vertical stack of line marks
    • **glyph**: composite object, internal structure from multiple marks
  – channels
    • length and color hue
    • spatial regions: one per glyph
      – aligned: full glyph, lowest bar component
      – unaligned: other bar components
  – task
    • part-to-whole relationship
  – scalability: asymmetric
    • for stacked key attrib, 10-12 levels [segments]
    • for main key attrib, dozens to hundreds of levels [bars]
Idiom: **streamgraph**

- generalized stacked graph
  - emphasizing horizontal continuity
    - vs vertical items
- data
  - 1 categ key attrib (movies)
  - 1 ordered key attrib (time)
  - 1 quant value attrib (counts)
- derived data
  - geometry: layers, where height encodes counts
  - 1 quant attrib (layer ordering)

**Idiom: Streamgraph**

- generalized stacked graph
  - emphasizing horizontal continuity
    - vs vertical items
- data
  - 1 categ key attrib (movies)
  - 1 ordered key attrib (time)
  - 1 quant value attrib (counts)
- derived data
  - geometry: layers, where height encodes counts
  - 1 quant attrib (layer ordering)
- scalability
  - hundreds of time keys
  - dozens to hundreds of movies keys
    - more than stacked bars: most layers don’t extend across whole chart


Idiom: **dot / line chart**

• one key, one value
  – data
    • 2 quant attribs
  – mark: points
    AND line connection marks between them

– channels
  • aligned lengths to express quant value
  • separated and ordered by key attrib into horizontal regions
Idiom: **dot / line chart**

- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    AND line connection marks between them
- channels
  - aligned lengths to express quant value
  - separated and ordered by key attrib into horizontal regions
- task
  - find trend
    - connection marks emphasize ordering of items along key axis by explicitly showing relationship between one item and the next
- scalability
  - hundreds of key levels, hundreds of value levels
Choosing bar vs line charts

• depends on type of key attrib
  – bar charts if categorical
  – line charts if ordered

• do not use line charts for categorical key attribs
  – violates expressiveness principle
  • implication of trend so strong that it overrides semantics!
    – “The more male a person is, the taller he/she is”

Chart axes: label them!

• best practice to label
  – few exceptions: individual small multiple views could share axis label

https://xkcd.com/833/
Chart axes: avoid cropping y axis

• include 0 at bottom left or slope misleads

[Truncating the Y-Axis: Threat or Menace? Correll, Bertini, & Franconeri, CHI 2020.]
Chart axes: avoid cropping y axis

- include 0 at bottom left or slope misleads
  - some exceptions (arbitrary 0, small change matters)

[Truncating the Y-Axis: Threat or Menace? Correll, Bertini, & Franconeri, CHI 2020.]
Idiom: **Indexed line charts**

- **data:** 2 quant attribs
  - 1 key + 1 value

- **derived data:** new quant value attrib
  - index
  - plot instead of original value

- **task:** show change over time
  - principle: normalized, not absolute

- **scalability**
  - same as standard line chart

[Image of indexed line chart]

https://public.tableau.com/profile/ben.jones#!/vizhome/CAStateRevenues/Revenues
Idiom: **Gantt charts**

- one key, two (related) values
  - data
    - 1 categ attrib, 2 quant attribs
  - mark: line
    - length: duration
- channels
  - horiz position: start time (+end from duration)
- task
  - emphasize temporal overlaps & start/end dependencies between items
- scalability
  - dozens of key levels [bars]
  - hundreds of value levels [durations]

Idiom: Slopegraphs

• two values
  – data
    • 2 quant value attrs
    • (1 derived attr: change magnitude)
  – mark: point + line
    • line connecting mark between pts
  – channels
    • 2 vertical pos: express attr value
    • (linewidth/size, color)
  – task
    • emphasize changes in rank/value
  – scalability
    • hundreds of value levels
    • dozens of items

https://public.tableau.com/profile/ben.jones#!/vizhome/Slopegraphs/Slopegraphs
2 Keys

- 0 Keys
- Express Values
- 1 Key
- 2 Keys

- Dense
- Space
- f_i
- 1
- 2
- 3
- Many
- List
- Recursive Subdivision
- Volume
- Matrix
- Rectilinear
- Parallel
- Radial

ARRANGE TABLES
EXPRESS VALUES
SEPARATE, ORDER, ALIGN REGIONS
AXIS ORIENTATION
LAYOUT DENSITY
Idiom: **heatmap**

- **two keys, one value**
  - data
    - 2 categ attrs (gene, experimental condition)
    - 1 quant attrib (expression levels)
  - marks: point
    - separate and align in 2D matrix
      - indexed by 2 categorical attributes
  - channels
    - color by quant attrib
      - (ordered diverging colormap)
  - task
    - find clusters, outliers
  - scalability
    - 1M items, 100s of categ levels, ~10 quant attrib levels
Heatmap reordering

https://blogs.sas.com/content/iml/2018/05/02/reorder-variables-correlation-heat-map.html
Idiom: **cluster heatmap**

- in addition
  - derived data
    - 2 cluster hierarchies
  - dendrogram
    - parent-child relationships in tree with connection line marks
    - leaves aligned so interior branch heights easy to compare
  - heatmap
    - marks (re-)ordered by cluster hierarchy traversal
    - task: assess quality of clusters found by automatic methods
Visualization Analysis & Design

Tables (Ch 7) II

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Axis Orientation

- Rectilinear
- Parallel
- Radial
Idioms: radial bar chart, star plot

• star plot
  – line mark, radial axes meet at central point

• radial bar chart
  – line mark, radial axes meet at central ring
  – channels: length, angle/orientation

• bar chart
  – rectilinear axes, aligned vertically

• accuracy
  – length not aligned with radial layouts
    • less accurately perceived than rectilinear aligned

Idiom: radar plot

• radial line chart
  – point marks, radial layout
  – connecting line marks

• avoid unless data is cyclic
“Radar graphs: Avoid them (99.9% of the time)”

Idioms: **pie chart, coxcomb chart**

- **pie chart**
  - **interlocking area** marks with angle channel: **2D area varies**
    - separated & ordered radially, uniform height
  - accuracy: area less accurate than rectilinear aligned line length
  - **task: part-to-whole judgements**

- **coxcomb chart**
  - line marks with length channel: **1D length varies**
    - separated & ordered radially, uniform width
  - direct analog to radial bar charts

- **data**
  - 1 categ key attrib, 1 quant value attrib

---

Coxcomb / nightingale rose / polar area chart

- invented by Florence Nightingale:
  Diagram of the Causes of Mortality in the Army in the East
Coxcomb: perception

- encode: 1D length
- decode/perceive: 2D area

- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt line mark length!

- bar chart safer: uniform width, so area is linear with line mark length
  - both radial & rectilinear cases
Pie charts: perception

• some empirical evidence that people respond to arc length
  – decode/perceive: not angles
  – maybe also areas?…

• donut charts no worse than pie charts


Pie charts: best practices

- not so bad for two (or few) levels, for part-to-whole task

https://eagereyes.org/pie-charts
Pie charts: best practices

• not so bad for two (or few) levels, for part-to-whole task
• dubious for several levels if details matter

https://eagereyes.org/pie-charts
Pie charts: best practices

• not so bad for two (or few) levels, for part-to-whole task
• dubious for several levels if details matter
• terrible for many levels

https://eagereyes.org/pie-charts
Idioms: **normalized stacked bar chart**

- task
  - part-to-whole judgements
- **normalized stacked bar chart**
  - stacked bar chart, normalized to full vert height
  - single stacked bar equivalent to full pie
    - high information density: requires narrow rectangle
- **pie chart**
  - information density: requires large circle

---

[http://blocks.org/mbostock/3886208](http://blocks.org/mbostock/3886208)
[http://blocks.org/mbostock/3887235](http://blocks.org/mbostock/3887235)
[http://blocks.org/mbostock/3886394](http://blocks.org/mbostock/3886394)
Idiom: **glyphmaps**

- rectilinear good for linear vs nonlinear trends

- radial good for cyclic patterns
  - evaluating periodicity


Axis Orientation

- **Rectilinear**
- **Parallel**
- **Radial**
Axis Orientation

- Rectilinear
- Parallel
- Radial
**Idiom: SPLOM**

- **scatterplot matrix (SPLOM)**
  - rectilinear axes, point mark
  - all possible pairs of axes
  - scalability
    - one dozen attribs
    - dozens to hundreds of items

Wilkinson et al., 2005
Idioms: **parallel coordinates**

- scatterplot limitation
  - visual representation with orthogonal axes
  - can show only two attributes with spatial position channel

---

**Table**

<table>
<thead>
<tr>
<th></th>
<th>Math</th>
<th>Physics</th>
<th>Dance</th>
<th>Drama</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>95</td>
<td>70</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>80</td>
<td>60</td>
<td>50</td>
<td></td>
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<td>65</td>
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<td>90</td>
<td>90</td>
<td></td>
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<tr>
<td>50</td>
<td>40</td>
<td>95</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>80</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>


Idioms: **parallel coordinates**

- **scatterplot limitation**
  - visual representation with orthogonal axes
  - can show only two attributes with spatial position channel
- **alternative: line up axes in parallel to show many attributes with position**
  - item encoded with a line with $n$ segments
  - $n$ is the number of attributes shown
- **parallel coordinates**
  - parallel axes, jagged line for item
  - rectilinear axes, item as point
    - axis ordering is major challenge
  - scalability
    - dozens of attribs
    - hundreds of items

---

*Table*

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</tr>
</tbody>
</table>

*after [Visualization Course Figures. McGuffin, 2014.](http://www.michaelmcguffin.com/courses/vis/)*
Task: Correlation

• scatterplot matrix
  – positive correlation
    • diagonal low-to-high
  – negative correlation
    • diagonal high-to-low
  – uncorrelated: spread out

• parallel coordinates
  – positive correlation
    • parallel line segments
  – negative correlation
    • all segments cross at halfway point
  – uncorrelated
    • scattered crossings

https://www.mathsisfun.com/data/scatter-xy-plots.html

Parallel coordinates, limitations

• visible patterns only between neighboring axis pairs

• how to pick axis order?
  – usual solution: reorderable axes, interactive exploration
  – same weakness as many other techniques
    • downside of interaction: human-powered search
  – some algorithms proposed, none fully solve
Orientation limitations

- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible
Orientation limitations

• rectilinear: scalability wrt #axes
  • 2 axes best, 3 problematic, 4+ impossible
• parallel: unfamiliarity, training time
Orientation limitations

• rectilinear: scalability wrt #axes
  • 2 axes best, 3 problematic, 4+ impossible
• parallel: unfamiliarity, training time
• radial: perceptual limits
  – polar coordinate asymmetry
    • angles lower precision than length
    • nonuniform sector width/size depending on radial distance
  – frequently problematic
    • but sometimes can be deliberately exploited!
      – for 2 attrs of very unequal importance

Layout density

Layout Density

- Dense

- Space-Filling
Idiom: Dense software overviews

• data: text
  – text + 1 quant attrib per line
• derived data:
  – one pixel high line
  – length according to original
• color line by attrib
• scalability
  – 10K+ lines

Arrange tables

Express Values

Separate, Order, Align Regions

Separate

Order

Align

Axis Orientation

Rectilinear

Parallel

Radial

Layout Density

Dense

List

Recursive Subdivision

Matrix

Rectilinear

Parallel

Radial

1 Key

2 Keys

3 Keys

Many Keys
**How?**

**Encode**

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

**Map**
from **categorical** and **ordered** attributes

- **Color**
  - **Hue**
  - **Saturation**
  - **Luminance**
- **Size, Angle, Curvature, ...**
- **Shape**
  - (+ ● ■ △)
- **Motion**
  - Direction, Rate, Frequency, ...

**Manipulate**

- **Change**
- **Select**
- **Navigate**

**Facet**

- **Juxtapose**
- **Partition**
- **Superimpose**

**Reduce**

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

---

What?

Why?

How?
<table>
<thead>
<tr>
<th>Encode</th>
<th>Manipulate</th>
<th>Facet</th>
<th>Reduce</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arrange</strong></td>
<td><strong>Map</strong></td>
<td><strong>Juxtapose</strong></td>
<td><strong>Filter</strong></td>
</tr>
<tr>
<td>➔ Express</td>
<td>➔ Color</td>
<td>➔ Select</td>
<td>➔ Aggregate</td>
</tr>
<tr>
<td>➔ Order</td>
<td>➔ Size, Angle, Curvature, ...</td>
<td>➔ Partition</td>
<td>➔ Embed</td>
</tr>
<tr>
<td>➔ Use</td>
<td>➔ Shape</td>
<td>➔ Navigate</td>
<td></td>
</tr>
</tbody>
</table>
Visualization Analysis & Design

Interactive Views (Ch 11/12)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner
How to handle complexity: I previous strategy

- Derive

• derive new data to show within view
How to handle complexity: 1 previous strategy + 2 more

Derive

• derive new data to show within view
• change view over time
• facet across multiple views

Manipulate

Change

Facet

Juxtapose

Select

Partition

Navigate

Superimpose

Actions

• derive new data to show within view
• change view over time
• facet across multiple views
Manipulate View
Manipulate

Change over Time

[Diagram of data points changing over time]
Change over time

• change any of the other choices
  – encoding itself
  – parameters
  – arrange: rearrange, reorder
  – aggregation level, what is filtered...
  – interaction entails change

• powerful & flexible
Idiom: Re-encode

made with Tableau, http://tableausoftware.com
Idiom: **Change parameters**

- **widgets and controls**
  - sliders, buttons, radio buttons, checkboxes, dropdowns/comboboxes
- **pros**
  - clear affordances, self-documenting (with labels)
- **cons**
  - uses screen space
- **design choices**
  - separated vs interleaved
  - controls & canvas

[Growth of a Nation](http://laurenwood.github.io/) made with D3
Idiom: **Change order/arrangement**

- **what:** simple table
- **how:** data-driven reordering
- **why:** find extreme values, trends

[Sortable Bar Chart](https://observablehq.com/@d3 sortable-bar-chart)

*made with D3*
Idiom: **Reorder**

- **what:** table with many attributes
- **how:** data-driven reordering by selecting column
- **why:** find correlations between attributes

System: **DataStripes**

[http://carlmanaster.github.io/datastripes/]

*made with D3*
Idiom: **Change alignment**

- stacked bars
  - easy to compare
    - first segment
    - total bar
- align to different segment
  - supports flexible comparison

System: **LineUp**

Idiom: **Animated transitions - visual encoding change**

- smooth transition from one state to another
  - alternative to jump cuts, supports item tracking
    - best case for animation
  - staging to reduce cognitive load

Idiom: **Animated transition - tree detail**

- animated transition
  - network drilldown/rollup

[Collapsible Tree](https://observablehq.com/@d3/collapsible-tree)
Manipulate

Change over Time

Select
Interaction technology

• what do you design for?
  – mouse & keyboard on desktop?
    • large screens, hover, multiple clicks
  – touch interaction on mobile?
    • small screens, no hover, just tap
  – gestures from video / sensors?
    • ergonomic reality vs movie bombast
  – eye tracking?

Data visualization and the news - Gregor Aisch (37 min)
vimeo.com/182590214

I Hate Tom Cruise - Alex Kauffmann (5 min)
www.youtube.com/watch?v=QXLfT9sFcbc
Selection

• selection: basic operation for most interaction
• design choices
  – how many selection types?
    • interaction modalities
      • click/tap (heavyweight) vs hover (lightweight but not available on most touchscreens)
      • multiple click types (shift-click, option-click, …)
      • proximity beyond click/hover (touching vs nearby vs distant)
    • application semantics
      – adding to selection set vs replacing selection
      – can selection be null?
        – ex: toggle so nothing selected if click on background
      – primary vs secondary (ex: source/target nodes in network)
      – group membership (add/delete items, name group, …)
Highlighting

• highlight: change visual encoding for selection targets
  – visual feedback closely tied to but separable from selection (interaction)

• design choices: typical visual channels
  – change item color
    • but hides existing color coding
  – add outline mark
  – change size (ex: increase outline mark linewidth)
  – change shape (ex: from solid to dashed line for link mark)

• unusual channels: motion
  – motion: usually avoid for single view
    • with multiple views, could justify to draw attention to other views
Manipulate

- **Change over Time**

- **Select**

- **Navigate**

  - **Item Reduction**
    - Zoom
      - Geometric or Semantic
    - Pan/Translate
    - Constrained
Manipulate

- Change over Time
- Select

Navigate

- Zoom
  - Geometric
- Pan/Translate
- Constrained
  - Attribute Reduction
  - Item Reduction
  - Slice
  - Cut
  - Project
Navigate: Changing viewpoint/visibility

- change viewpoint
  - changes which items are visible within view

- camera metaphor
  - pan/translate/scroll
  - move up/down/sideways

*Navigate*

*Pan/Translate*
Idiom: Scrollytelling

• how: navigate page by scrolling (panning down)

• pros:
  – familiar & intuitive, from standard web browsing
  – linear (only up & down) vs possible overload of click-based interface choices

• cons:
  – full-screen mode may lack affordances
  – scrolljacking, no direct access
  – unexpected behaviour
  – continuous control for discrete steps

[How to Scroll, Bostock](https://bost.ocks.org/mike/scroll/)
https://eagereyes.org/blog/2016/the-scrollytelling-scourge
Navigate: Changing viewpoint/visibility

• change viewpoint
  – changes which items are visible within view

• camera metaphor
  – pan/translate/scroll
    • move up/down/sideways
  – rotate/spin
    • typically in 3D
  – zoom in/out
    • enlarge/shrink world == move camera closer/further
    • geometric zoom: standard, like moving physical object
Navigate: Unconstrained vs constrained

• unconstrained navigation
  – easy to implement for designer
  – hard to control for user
    • easy to overshoot/undershoot

• constrained navigation
  – typically uses animated transitions
  – trajectory automatically computed based on selection
    • just click; selection ends up framed nicely in final viewport
Idiom: **Animated transition + constrained navigation**

- example: geographic map
  - simple zoom, only viewport changes, shapes preserved

[Zoom to Bounding Box](https://observablehq.com/@d3/zoom-to-bounding-box)
Navigate: Reducing attributes

• continuation of camera metaphor
  – slice
    • show only items matching specific value for given attribute: slicing plane
    • axis aligned, or arbitrary alignment
  – cut
    • show only items on far slide of plane from camera
  – project
    • change mathematics of image creation
      – orthographic
      – perspective
      – many others: Mercator, cabinet, ...

Interaction benefits

• interaction pros
  – major advantage of computer-based vs paper-based visualization
  – flexible, powerful, intuitive
    • exploratory data analysis: change as you go during analysis process
    • fluid task switching: different visual encodings support different tasks
  – animated transitions provide excellent support
    • empirical evidence that animated transitions help people stay oriented
Interaction limitations

• interaction has a time cost
  – sometimes minor, sometimes significant
  – degenerates to human-powered search in worst case
• remembering previous state imposes cognitive load
• controls may take screen real estate
  – or invisible functionality may be difficult to discover (lack of affordances)
• users may not interact as planned by designer
  – NYTimes logs show ~90% don’t interact beyond scrollytelling - Aisch, 2016
Visualization Analysis & Design

*Interactive Views (Ch 11/12) II*

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner
How to handle complexity: 1 previous strategy + 2 more

- Derive

• derive new data to show within view
• change view over time
• facet across multiple views

<table>
<thead>
<tr>
<th>Manipulate</th>
<th>Facet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>Juxtapose</td>
</tr>
<tr>
<td>Select</td>
<td>Partition</td>
</tr>
<tr>
<td>Navigate</td>
<td>Superimpose</td>
</tr>
</tbody>
</table>
Multiple Views
Facet

- Juxtapose

- Partition

- Superimpose
Facet

- **Juxtapose**

- **Partition**

- **Superimpose**
Juxtapose and coordinate views

- Share Encoding: Same/Different
  - Linked Highlighting

- Share Data: All/Subset/None

- Share Navigation
Idiom: **Linked highlighting**

- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom

- encoding: different
  - multiform

- data: all shared
  - all **items** shared
  - different **attributes** across the views

- aka: brushing and linking

Linked views: Directionality

• unidirectional vs bidirectional linking
  – bidirectional almost always better!

http://pbeshai.github.io/linked-highlighting-react-vega-redux/
https://medium.com/@pbesh/linked-highlighting-with-react-d3-js-and-reflux-16e9c0b2210b
Idiom: **Overview-detail views**

- **encoding**: same or different
  - ex: same (birds-eye map)
- **data**: subset shared
  - viewpoint differences:
    - subset of data items
- **navigation**: shared
  - bidirectional linking
- **other differences**
  - (window size)

**System: Google Maps**

Idiom: **Overview-detail navigation**

- encoding: same or different
- data: subset shared
- navigation: shared
  - unidirectional linking
  - select in small overview, change extent in large detail view

https://observablehq.com/@uwdata/interaction
Idiom: **Tooltips**

- popup information for selection
  - hover or click
  - specific case of detail view: provide useful additional detail on demand
  - beware: does not support overview!
    - always consider if there's a way to visually encode directly to provide overview
    - “If you make a rollover or tooltip, assume nobody will see it. If it's important, make it explicit.“
      - Gregor Aisch, NYTimes

[https://www.highcharts.com/demo/dynamic-master-detail]


Idiom: **Small multiples**

- **encoding:** same
  - ex: line charts
- **data:** none shared
  - different slices of dataset
    - items or attributes
    - ex: stock prices for different companies

[https://bl.ocks.org/mbostock/1157787]
Interactive small multiples

- linked highlighting:
  analogous item/attribute across views
  - same year highlighted across all charts if hover within any chart

[https://bl.ocks.org/ColinEberhardt/3c780088c363d1515403f50a87a87121]
[https://blog.scottlogic.com/2017/04/05/interactive-responsive-small-multiples.html]
[http://projects.flowingdata.com/tut/linked_small_multiples_demo/]
Example: Combining many interaction idioms

System: Buckets

- multiform
- multidirectional linked highlighting of small multiples
- tooltips

http://buckets.peterbeshai.com/
Juxtapose views: tradeoffs

• juxtapose costs
  – display area
    • 2 views side by side: each has only half the area of one view

• juxtapose benefits
  – cognitive load: eyes vs memory
    • lower cognitive load: move eyes between 2 views
    • higher cognitive load: compare single changing view to memory of previous state
Juxtapose vs animate

• animate: hard to follow if many scattered changes or many frames
  – vs easy special case: animated transitions

Juxtapose vs animate

- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions
- juxtapose: easier to compare across small multiples
  - different conditions (color), same gene (layout)

## View coordination: Design choices

<table>
<thead>
<tr>
<th>Encoding</th>
<th>Data</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Subset</td>
</tr>
<tr>
<td>Same</td>
<td>Redundant</td>
<td>Overview/Detail</td>
</tr>
<tr>
<td>Different</td>
<td>Multiform</td>
<td>Multiform, Overview/Detail</td>
</tr>
</tbody>
</table>
Idiom: **Reorderable lists**

- list views
  - easy lookup
  - useful when linked to other views

- how many views is ok vs too complex?
  - open research question

Facet

- **Juxtapose**

- **Partition**

- **Superimpose**
Partition into views

• how to divide data between views
  – split into regions by attributes
  – encodes association between items using spatial proximity
  – order of splits has major implications for what patterns are visible

Partition into Side-by-Side Views
Partitioning: Grouped vs small-multiple bars

- single bar chart with grouped bars
  - split by state into regions
    - complex glyph within each region showing all ages
  - compare: easy within state, hard across ages

- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across states

[https://observablehq.com/@d3/grouped-bar-chart]

[https://bl.ocks.org/mbostock/4679202]
Partitioning: Recursive subdivision

- split by neighborhood
- then by type
  - flat, terrace, semi-detached, detached
- then time
  - years as rows
  - months as columns
- color by price

neighborhood patterns
- where it’s expensive
- where you pay much more for detached type

---

Partitioning: Recursive subdivision

- switch order of splits
  - type then neighborhood

- switch color
  - by price variation

- type patterns
  - within specific type, which neighborhoods inconsistent

System: HIVE

Partitioning: Recursive subdivision

- different encoding for second-level regions
  - choropleth maps

System: HIVE

Facet

- **Juxtapose**

- **Partition**

- **Superimpose**
Superimpose layers

• layer: set of objects spread out over region
  – each set is visually distinguishable group
  – extent: whole view

• design choices
  – how many layers, how to distinguish?
    • encode with different, nonoverlapping channels
    • two layers achievable, three with careful design
  – small static set, or dynamic from many possible?
Static visual layering

• foreground layer: roads
  – hue, size distinguishing main from minor
  – high luminance contrast from background
• background layer: regions
  – desaturated colors for water, parks, land areas
• user can selectively focus attention
Idiom: **Trellis plots**

- superimpose within same frame
  - color code by year

- partitioning
  - split by site, rows are barley varieties

- main-effects ordering
  - derive value of median for group
  - order rows within view by variety median
  - order views themselves by site median

Superimposing limits (static)

- few layers, more lines
  - up to a few dozen lines
  - but not hundreds

- superimpose vs juxtapose: empirical study
  - same size: all multiples, vs single superimposed
    - superimposed: local tasks
    - juxtaposed: global tasks, esp. for many charts

Dynamic visual layering

• interactive, based on selection
• one-hop neighbour highlighting

click (heavyweight)

hover (fast)

https://mariandoerk.de/edgemaps/demo/
How?

Encode

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

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

Manipulate

- **Change**
- **Select**
- **Navigate**

Facet

- **Juxtapose**
- **Partition**
- **Superimpose**

Reduce

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

What?

Why?

How?
Visualization Analysis & Design

Spatial Data (Ch 9)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner
Focus on Spatial

Dataset Types

- **Tables**
  - Attributes (columns)
  - Items (rows)
  - Cell containing value
  - Multidimensional Table

- **Networks**
  - Link
  - Node (item)
  - Trees

- **Spatial**
  - Fields (Continuous)
  - Geometry (Spatial)
  - Grid of positions
  - Value in cell

Dataset Types

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- **Networks**
  - Link
  - Node (item)
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  - Geometry (Spatial)
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### Encode

<table>
<thead>
<tr>
<th>Arrange</th>
<th>Express</th>
<th>Separate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order</td>
<td>Align</td>
<td></td>
</tr>
</tbody>
</table>

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

### Manipulate

<table>
<thead>
<tr>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Change" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Select</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2" alt="Select" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Navigate</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Navigate" /></td>
</tr>
</tbody>
</table>

### Facet

<table>
<thead>
<tr>
<th>Juxtapose</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4" alt="Juxtapose" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partition</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image5" alt="Partition" /></td>
</tr>
</tbody>
</table>

### Reduce

<table>
<thead>
<tr>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image6" alt="Filter" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image7" alt="Aggregate" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Superimpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image8" alt="Superimpose" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Embed</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image9" alt="Embed" /></td>
</tr>
</tbody>
</table>
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**

**What?**

**Why?**

**How?**
Spatial data

• use given spatial position
• when?
  – dataset contains spatial attributes and they have primary importance
  – central tasks revolve around understanding spatial relationships

• examples
  – geographical/cartographic data
  – sensor/simulation data
Geographic Maps
Geographic Map

Interlocking marks

- **shape** coded
- **area** coded
- **position** coded

- cannot encode another attribute with these channels, they're "taken"
Thematic maps

• show spatial variability of attribute ("theme")
  – combine geographic / reference map with (simple, flat) tabular data
  – join together
    • region: interlocking area marks (provinces, countries with outline shapes)
      – also could have point marks (cities, locations with 2D lat/lon coords)
    • region: categorical key attribute in table
      – use to look up value attributes

• major idioms
  – choropleth
  – symbol maps
  – cartograms
  – dot density maps
Idiom: choropleth map

• use given spatial data
  – when central task is understanding spatial relationships
• data
  – geographic geometry
  – table with 1 quant attribute per region
• encoding
  – position:
    use given geometry for area mark boundaries
  – color:
    sequential segmented colormap

http://bl.ocks.org/mbostock/4060606
Beware: Population maps trickiness!

[ https://xkcd.com/1138 ]
Beware: Population maps trickiness!

• spurious correlations: most attributes just show where people live

[https://xkcd.com/1138]
Beware: Population maps trickiness!

• spurious correlations: most attributes just show where people live

• consider when to normalize by population density
  • encode raw data values
    – tied to underlying population
  • but should use normalized values
    – unemployed people per 100 citizens, mean family income

[ https://xkcd.com/1138 ]
Beware: Population maps trickiness!

• spurious correlations: most attributes just show where people live

• consider when to normalize by population density
  • encode raw data values
    – tied to underlying population
  • but should use normalized values
    – unemployed people per 100 citizens, mean family income

• general issue
  – absolute counts vs relative/normalized data
  – failure to normalize is common error

[https://xkcd.com/1138]
Choropleth maps: Recommendations

• only use when central task is understanding spatial relationships
• show only one variable at a time
• normalize when appropriate
• be careful when choosing colors & bins
• best case: regions are roughly equal sized
Choropleth map: Pros & cons

• pros
  – easy to read and understand
  – well established visualization (no learning curve)
  – data is often collected and aggregated by geographical regions

• cons
  – most effective visual variable used for geographic location
  – visual salience depends on region size, not true importance wrt attribute value
    • large regions appear more important than small ones
  – color palette choice has a huge influence on the result
Idiom: Symbol maps

- symbol is used to represent aggregated data (mark or glyph)
  - allows use of size and shape and color channels
    - aka proportional symbol maps, graduated symbol maps
- keep original spatial geometry in the background
- often a good alternative to choropleth maps
Symbol maps with glyphs

Shares of agricultural, forest and settlement area

Source: National Atlas of Agricultural Land Use 4.4
Symbol map: Pros & cons

• pros
  – somewhat intuitive to read and understand
  – mitigate problems with region size vs data salience
    • marks: symbol size follows attribute value
    • glyphs: symbol size can be uniform

• cons
  – possible occlusion / overlap
    • symbols could overlap each other
    • symbols could occlude region boundaries
  – complex glyphs may require explanation / training
Idiom: **Contiguous cartogram**

• interlocking marks:
  shape, area, and position coded

• derive new interlocking marks
  – based on combination of original interlocking marks and new quantitative attribute

• algorithm to create new marks
  – input: target size
  – goal: shape as close to the original as possible
  – requirement: maintain constraints
    • relative position
    • contiguous boundaries with their neighbours
Idiom: **Grid Cartogram**

- uniform-sized shapes arranged in rectilinear grid
- maintain approximate spatial position and arrangement
Cartogram: Pros & cons

• pros
  – can be intriguing and engaging
  – best case: strong and surprising size disparities
  – non-contiguous cartograms often easier to understand

• cons
  – require substantial familiarity with original dataset & use of memory
    • compare distorted marks to memory of original marks
    • mitigation strategies: transitions or side by side views
  – major distortion is problematic
    • may be aesthetically displeasing
    • may result in unrecognizable marks
  – difficult to extract exact quantities
Idiom: **Dot density maps**

- visualize distribution of a phenomenon by placing dots
- one symbol represents a constant number of items
  - dots have uniform size & shape
  - allows use of color channel
- task:
  - show spatial patterns, clusters
Dot density maps: Pros and cons

• pros
  – straightforward to understand
  – avoids choropleth non-uniform region size problems

• cons
  – challenge: normalization, just like choropleths
    • show population density (correlated with attribute), not effect of interest
  – perceptual disadvantage:
    difficult to extract quantities
  – performance disadvantage:
    rendering many dots can be slow
Map Projections

- mathematical functions that map 3D surface geometry of the Earth to 2D maps
- all projections of sphere on plane necessarily distort surface in some way
- interactive: philogb.github.io/page/myriahedral/ and jasondavies.com/maps/
Mercator Projection

» Heavily distorts country sizes; particularly close to the poles.
Visualization Analysis & Design

Color (Ch 10)

Tamara Munzner
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@tamaramunzner
Idiom design choices: Visual encoding

**Encode**

- **Arrange**
  - Express
  - Order
  - Use

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

**What?**

**Why?**

**How?**
Idiom design choices: Beyond spatial arrangement

**Encode**

- **Arrange**
  - Express
  - Order
  - Use

- **Separate**

- **Align**

**Map**

- from **categorical** and **ordered** attributes

- **Color**
  - Hue
  - Saturation
  - Luminance

- **Size, Angle, Curvature, ...**

- **Shape**

- **Motion**
  - Direction, Rate, Frequency, ...
Channels: What's up with color?

### 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

---

**Expression Types and Effectiveness Ranks**

Best

Effectiveness

Least

Same
Decomposing color
Decomposing color

• first rule of color: do not (just) talk about color!
  – color is confusing if treated as monolithic
Decomposing color

• first rule of color: do not (just) talk about color!
  – color is confusing if treated as monolithic

• decompose into three channels
  – ordered can show magnitude
    • **luminance**: how bright (B/W)
    • **saturation**: how colourful
  – categorical can show identity
    • **hue**: what color

![Luminance](image1)
![Saturation](image2)
![Hue](image3)
Decomposing color

• first rule of color: do not (just) talk about color!
  – color is confusing if treated as monolithic

• decompose into three channels
  – ordered can show magnitude
    • luminance: how bright (B/W)
    • saturation: how colourful
  – categorical can show identity
    • hue: what color

• channels have different properties
  – what they convey directly to perceptual system
  – how much they can convey
    • how many discriminable bins can we use?
Color Channels in Visualization
Categorical vs ordered color

Categorical color: limited number of discriminable bins

• human perception built on relative comparisons

[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]
Categorical color: limited number of discriminable bins

• human perception built on relative comparisons
  – great if color contiguous

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Categorical color: limited number of discriminable bins

• human perception built on relative comparisons
  – great if color contiguous
  – surprisingly bad for absolute comparisons

[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]
Categorical color: limited number of discriminable bins

• human perception built on relative comparisons
  – great if color contiguous
  – surprisingly bad for absolute comparisons

• noncontiguous small regions of color
  – fewer bins than you want
  – rule of thumb: 6-12 bins, including background and highlights

[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]
Categorical color: limited number of discriminable bins

Mapping the Human 'Diseasome'

Researchers created a map linking different diseases, represented by circles, to the genes they share in common, represented by squares.

Related Articles: Redefining Disease. Genes and All.
Ordered color: limited number of discriminable bins

Gregor Aisch, vis4.net/blog/posts/choropleth-maps/
Ordered color: Rainbow is poor default

• problems
  – perceptually unordered
  – perceptually nonlinear
Ordered color: Rainbow is poor default

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Ordered color: Rainbow is poor default

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• benefits
  – fine-grained structure visible and nameable


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• alternatives
  – large-scale structure: fewer hues


Ordered color: Rainbow is poor default

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• benefits
  – fine-grained structure visible and nameable

• alternatives
  – large-scale structure: fewer hues
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis]


Viridis / Magma: sequential colormaps

- monotonically increasing luminance, perceptually uniform
- colorful, colorblind-safe
  - R, python, D3

https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html
Ordered color: Rainbow is poor default

• problems
  – perceptually unordered
  – perceptually nonlinear

• benefits
  – fine-grained structure visible and nameable

• alternatives
  – large-scale structure: fewer hues
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis]

• legit for categorical
  – segmented saturated rainbow is good!
Interaction between channels: Not fully separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation

http://colorbrewer2.org/
Interaction between channels: Not fully separable

• color channel interactions
  – size heavily affects salience
  – small regions need high saturation
  – large regions need low saturation

• saturation & luminance:
  – not separable from each other!
  – also not separable from transparency

http://colorbrewer2.org/
Interaction between channels: Not fully separable

- **color channel interactions**
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation

- **saturation & luminance:**
  - not separable from each other!
  - also not separable from transparency
  - small separated regions: 2 bins safest (use only one of these channels), 3-4 bins max
  - contiguous regions: many bins (use only one of these channels)

http://colorbrewer2.org/
Color Palettes
Color palettes: univariate

→ Categorical

• categorical
  • aim for maximum distinguishability
  • aka qualitative, nominal

Color palettes: univariate

- Categorical
  - [Image of color palettes]

- Ordered
  - Sequential
  - Diverging

- diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints

- sequential
  - ramp luminance or saturation

---

Color palettes: univariate

- Categorical
- Ordered
  - Sequential
  - Diverging

- Diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints
- Sequential
  - ramp luminance or saturation
  - if multi-hue, good to order by luminance

Color palettes: univariate

→ Categorical

→ Ordered
  → \textit{Sequential}
  → \textit{Diverging}
  → Cyclic

\textit{cyclic multihue}

\url{https://github.com/d3/d3-scale-chromatic}

\url{https://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html}
Color palette design considerations: univariate

- segmented vs. continuous?
- diverging vs. sequential vs. cyclic?
- single-hue vs. two-hue vs. multi-hue?
- perceptually linear?
- ordered by luminance?
- colorblind safe?

https://github.com/d3/d3-scale-chromatic
Colormaps: bivariate

- Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

- bivariate best case
  - binary in one of the directions

# d3.schemePaired <>

Colormaps: bivariate

- Categorical
- Ordered
  - Sequential
- Bivariate

Colormaps

- Categorical
  ![Categorical Colormap]

- Ordered
  - Sequential
  - Diverging

- Bivariate
  ![Bivariate Colormap]

use with care!

- bivariate can be very difficult to interpret
- when multiple levels in each direction

---

Visualization Analysis & Design

Color (Ch 10) II

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@tamaramunzner
Decomposing color

• decompose into three channels
  – ordered can show magnitude
    • **luminance**: how bright (B/W)
    • **saturation**: how colourful
  – categorical can show identity
    • **hue**: what color
Color Deficiency
Luminance

• need luminance for edge detection
  – fine-grained detail only visible through luminance contrast
  – legible text requires luminance contrast!

Opponent color and color deficiency

- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
  - edge detection through luminance contrast
- 2 chroma channels
  - red-green (a*) & yellow-blue axis (b*)
Opponent color and color deficiency

• perceptual processing before optic nerve
  – one achromatic luminance channel (L*)
  – edge detection through luminance contrast
  – 2 chroma channels
  – red-green (a*) & yellow-blue axis (b*)

• “colorblind”: degraded acuity, one axis
  – 8% of men are red/green color deficient
  – blue/yellow is rare

Designing for color deficiency: Check with simulator

Normal vision
Deuteranope green-weak
Protanope red-weak
Tritanope blue-weak

https://www.color-blindness.com/coblis-color-blindness-simulator/
Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape

Color deficiency: Reduces color to 2 dimensions

Normal

Protanope

Deuteranope

Tritanope

Designing for color deficiency: Blue-Orange is safe
Visualization Analysis & Design

Color (Ch 10) III

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Color Spaces
Many color spaces

- Luminance ($L^*$), hue (H), saturation (S)
  - good for encoding
Many color spaces

- Luminance ($L^*$), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
Many color spaces

- Luminance ($L^*$), hue ($H$), saturation ($S$)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
RGB

• RGB: good for display hardware
RGB

- RGB: good for display hardware

- poor for encoding & interpolation
Many color spaces

- Luminance ($L^*$), hue (H), saturation (S)
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  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
Many color spaces

• Luminance (L*), hue (H), saturation (S)
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  – but not standard graphics/tools colorspace

• RGB: good for display hardware
  – poor for encoding & interpolation

• CIE LAB (L*a*b*): good for interpolation
Many color spaces

- Luminance ($L^*$), hue ($H$), saturation ($S$)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB ($L^*a^*b^*$): good for interpolation
  - hard to interpret, poor for encoding
Perceptual colorspace: L*a*b*

- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)

Perceptual colorspace: L*a*b*

- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)

- CIE LAB
  - perceptually uniform
    - great for interpolating
  - complex shape
    - poor for encoding

https://en.wikipedia.org/wiki/CIELAB_color_space
Many color spaces

• Luminance (L*), hue (H), saturation (S)
  – good for encoding
  – but not standard graphics/tools colorspace

• RGB: good for display hardware
  – poor for encoding & interpolation

• CIE LAB (L*a*b*): good for interpolation
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- CIE LAB ($L^*a^*b^*$): good for interpolation
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- HSL/HSV: somewhat better for encoding
HSL/HSV

• HSL/HSV: somewhat better for encoding
  – hue/saturation wheel intuitive
• saturation
  – in HSV (single-cone) desaturated = white
  – in HSL (double-cone) desaturated = grey

HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation

HSL/HSV: Pseudo-perceptual colorspace

- HSL better than RGB for encoding **but beware**
  - $L$ lightness $\neq L^*$ luminance

Corners of the RGB color cube

L from HLS
**All the same**

Luminance values

---

Many color spaces

- Luminance ($L^*$), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace

- RGB: good for display hardware
  - poor for encoding & interpolation

- CIE LAB ($L^*a^*b^*$): good for interpolation
  - hard to interpret, poor for encoding

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance ($L^*$)
Color Contrast & Naming
Interaction with the background

Contrast
The difference between foreground and background colors determines text legibility.
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance
Interaction with the background: tweaking yellow for visibility

- marks with medium luminance on a background with high luminance
Interaction with the background: tweaking yellow for visibility

• change luminance of marks depending on background
Color/Lightness constancy: Illumination conditions

Image courtesy of John McCann via Maureen Stone
Color/Lightness constancy: Illumination conditions

Image courtesy of John McCann via Maureen Stone
Contrast with background
Contrast with background

Black and blue? White and gold?

https://imgur.com/hxJjUQB

https://en.wikipedia.org/wiki/The_dress
Bezold Effect: Outlines matter
Color Appearance

• given L, a*, b*, can we tell what color it is?
  – no, it depends

• chromatic adaptation
• luminance adaptation
• simultaneous contrast
• spatial effects
• viewing angle
• …
Color naming
Color naming

Color names if you're a girl...

Maraschino
Cayenne
Maroon
Plum
Eggplant
Grape
Orchid
Lavender
Carnation
Strawberry
Bubblegum
Magenta
Salmon
Tangerine
Cantaloupe
Banana
Lemon
Honeydew
Lime
Spring
Clover
Fern
Moss
Flora
Sea Foam
Spindrift
Teal
Sky
Turquoise

Color names if you're a guy...

Red
Purple
Pink
Orange
Yellow
Green
Blue

Doghouse Diaries
"We take no as an answer."
Color naming

*Actual color names if you’re a girl ...*  
*Actual color names if you’re a guy ...*

https://blog.xkcd.com/2010/05/03/color-survey-results/
Color naming

• nameability affects
  – communication
  – memorability

• can integrate into color models
  – in addition to perceptual considerations

https://blog.xkcd.com/2010/05/03/color-survey-results/
Color is just part of vision system

• Does not help perceive
  – Position
  – Shape
  – Motion
  – …
Map Other Channels
Angle / tilt / orientation channel

- different mappings depending on range used

Sequential ordered line mark or arrow glyph

Diverging ordered arrow glyph

Cyclic ordered arrow glyph

- nonlinear accuracy
  - high: exact horizontal, vertical, diagonal (0, 45, 90 degrees)
  - lower: other orientations (eg 37 vs 38 degrees)
Map other channels

- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
Map other channels

- **size**
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor

- **shape**
  - complex combination of lower-level primitives
  - many bins
Map other channels

• size
  – aligned length best
  – length accurate
  – 2D area ok
  – 3D volume poor

• shape
  – complex combination of lower-level primitives
  – many bins

• motion
  – highly separable against static
    • great for highlighting (binary)
  – use with care to avoid irritation
Visualization Analysis & Design

Reduce: Aggregation & Filtering (Ch 13)

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@tamaramunzner
How to handle complexity: 3 previous strategies

- Derive
  - Derive new data to show within view
  - Change view over time
  - Facet across multiple views

- Manipulate
  - Change
  - Select
  - Navigate

- Facet
  - Juxtapose
  - Partition
  - Superimpose
How to handle complexity: 3 previous strategies + 1 more

- Derive
  - derive new data to show within view
  - change view over time
  - facet across multiple views
  - reduce items/attributes within single view

### Manipulate
- Change
  ![Change Diagram]
- Select
  ![Select Diagram]
- Navigate
  ![Navigate Diagram]

### Facet
- Juxtapose
  ![Juxtapose Diagram]
- Partition
  ![Partition Diagram]
- Superimpose
  ![Superimpose Diagram]

### Reduce
- Filter
  ![Filter Diagram]
- Aggregate
  ![Aggregate Diagram]
- Embed
  ![Embed Diagram]
Reduce items and attributes

• reduce/increase: inverses

• filter
  – pro: straightforward and intuitive
    • to understand and compute
  – con: out of sight, out of mind
Reduce items and attributes

• reduce/increase: inverses

• filter
  – pro: straightforward and intuitive
    • to understand and compute
  – con: out of sight, out of mind

• aggregation
  – pro: inform about whole set
  – con: difficult to avoid losing signal

• not mutually exclusive
  – combine filter, aggregate
  – combine reduce, change, facet
Filter

• eliminate some elements
  – either items or attributes

• according to what?
  – any possible function that partitions dataset into two sets
    • attribute values bigger/smaller than x
    • noise/signal

• filters vs queries
  – query: start with nothing, add in elements
  – filters: start with everything, remove elements
  – best approach depends on dataset size

Reducing Items and Attributes

Filter

→ Items

→ Attributes
Idiom: **FilmFinder**

- dynamic queries/filters for items
  - tightly coupled interaction and visual encoding idioms, so user can immediately see results of action

Idiom: **cross filtering**

- item filtering
- coordinated views/controls combined
  - all scented histogram bisliders update when any ranges change

System: **Crossfilter**

[Diagram showing time of day, arrival delay, and distance with interactive sliders]

http://square.github.io/crossfilter/
https://observablehq.com/@uwdata/interaction
Aggregate

• a group of elements is represented by a smaller number of derived elements

⇒ Aggregate

⇒ Items

⇒ Attributes
Idiom: histogram

- static item aggregation
- task: find distribution
- data: table
- derived data
  - new table: keys are bins, values are counts
- bin size crucial
  - pattern can change dramatically depending on discretization
  - opportunity for interaction: control bin size on the fly
Idiom: scented widgets

- augmented widgets show *information scent*
  - better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider
Idiom: **scented widgets**

- augmented widgets show *information scent*
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Idiom: scented widgets

- augmented widgets show *information scent*
  - better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider


Scented histogram bisliders: detailed

**Idiom: boxplot**

- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown
- scalability
  - unlimited number of items!

[40 years of boxplots. Wickham and Stryjewski. 2012]
Idiom: **Continuous scatterplot**

- static item aggregation
- data: table
- derived data: table
  - key attribs x,y for pixels
  - quant attrib: overplot density
- dense space-filling 2D matrix
- color:
  - sequential categorical hue + ordered luminance colormap
- scalability
  - no limits on overplotting: millions of items

Spatial aggregation

- **MAUP: Modifiable Areal Unit Problem**
  - changing boundaries of cartographic regions can yield dramatically different results
  - zone effects

[http://www.e-education.psu.edu/geog486/l4_p7.html, Fig 4.cg.6]

- scale effects

Gerrymandering: MAUP for political gain

Three different ways to divide 50 people into five districts:

1. Perfect representation
   - 60% blue, 40% red
   - 3 blue districts, 2 red districts
   - BLUE WINS

2. Compact, but unfair
   - 5 blue districts, 0 red districts
   - BLUE WINS

3. Neither compact nor fair
   - 2 blue districts, 3 red districts
   - RED WINS

A real district in Pennsylvania:
Democrats won 51% of the vote but only 5 out of 18 house seats

WASHINGTONPOST.COM/WONKBLOG
Adapted from Stephen Nass

https://www.washingtonpost.com/news/wonk/wp/2015/03/01/this-is-the-best-explanation-of-gerrymandering-you-will-ever-see/
Dynamic aggregation: Clustering

• clustering: classification of items into similar bins
  – based on similarity measure
  – hierarchical algorithms produce "similarity tree": cluster hierarchy
    • agglomerative clustering: start w/ each node as own cluster, then iteratively merge

• cluster hierarchy: derived data used w/ many dynamic aggregation idioms
  – cluster more homogeneous than whole dataset
    • statistical measures & distribution more meaningful
Idiom: **Hierarchical parallel coordinates**

- dynamic item aggregation
- derived data: **cluster hierarchy**
- encoding:
  - cluster band with variable transparency, line at mean, width by min/max values
  - color by proximity in hierarchy

Attribute aggregation: Dimensionality reduction

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space
    - capture most of variance with minimal error
  - use when you can’t directly measure what you care about
    - true dimensionality of dataset conjectured to be smaller than dimensionality of measurements
    - latent factors, hidden variables

![Diagram of tumor measurement data: 9D measured space to derived data: 2D target space with benign and malignant categories.]
**Idiom:** Dimensionality reduction for documents

**Task 1**

<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD data</td>
<td>2D data</td>
</tr>
</tbody>
</table>

**What?**
- In High-dimensional data
- Out 2D data

**Why?**
- Produce
- Derive

**Task 2**

<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D data</td>
<td>Scatterplot Clusters &amp; points</td>
</tr>
</tbody>
</table>

**What?**
- In 2D data
- Out Scatterplot
- Out Clusters & points

**Why?**
- Discover
- Explore
- Identify

**How?**
- Encode
- Navigate
- Select

**Task 3**

<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scatterplot Clusters &amp; points</td>
<td>Labels for clusters</td>
</tr>
</tbody>
</table>

**What?**
- In Scatterplot
- In Clusters & points
- Out Labels for clusters

**Why?**
- Produce
- Annotate
How?

Encode

- **Arrange**
  - Express
  - Separate

- **Order**
  - Align

- **Use**

Map

- from **categorical** and **ordered** attributes
- **Color**
  - Hue
  - Saturation
  - Luminance
- **Size, Angle, Curvature, ...**

- **Shape**
  - + • ■ ▲

- **Motion**
  - Direction, Rate, Frequency, ...

Manipulate

- **Change**
  - ...

- **Select**
  - ...

- **Navigate**
  - ...

Facet

- **Juxtapose**

- **Partition**

- **Superimpose**

Reduce

- **Filter**

- **Aggregate**

- **Embed**

What?

Why?

How?
Visualization Analysis & Design

Embed: Focus+Context (Ch 14)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner
How to handle complexity: 4 strategies

Derive

- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view

Manipulate

- Change

Facet

- Juxtapose

Reduce

- Filter

- Aggregate

- Embed

Actions

- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view
Embed: Focus+Context

• combine focus + context info within single view
  – vs standard navigation within view
  – vs multiple views
Embed: Focus+Context

• combine focus + context info within single view
  – vs standard navigation within view
  – vs multiple views

• elide data
  – selectively filter and aggregate
Idiom: **DOITrees Revisited**

- focus+context choice: elide
  - some items dynamically filtered out
  - some items dynamically aggregated together
  - some items shown in detail

Embed: Focus+Context

- combine focus + context info within single view
  - vs standard navigation within view
  - vs multiple views

- elide data
  - selectively filter and aggregate

- distort geometry
  - carefully chosen to integrate F+C
Idiom: **Fisheye Lens**

- **F+C choice: distort geometry**
  - shape: radial
  - focus: single extent
  - extent: local
  - metaphor: draggable lens

[D3 Fisheye Lens](https://bost.ocks.org/mike/fisheye/)
Embed: Focus+Context

• combine focus + context info within single view
  – vs standard navigation within view
  – vs multiple views

• elide data
  – selectively filter and aggregate

• distort geometry: design choices
  – region shape: radial, rectilinear, complex
  – how many regions: one, many
  – region extent: local, global
  – interaction metaphor
Distortion costs and benefits

• benefits
  – combine focus and context information in single view

• costs
  – length comparisons impaired
    • topology comparisons unaffected: connection, containment
  – effects of distortion unclear if original structure unfamiliar
  – object constancy/tracking may be impaired

Visualization Analysis & Design

Network Data (Ch 9)

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Network data

• networks
  - model relationships between things
    • aka graphs
  - two kinds of items, both can have attributes
    • nodes
    • links

• tree
  - special case
  - no cycles
    • one parent per node
Network tasks: topology-based and attribute-based

• topology based tasks
  – find paths
  – find (topological) neighbors
  – compare centrality/importance measures
  – identify clusters / communities

• attribute based tasks (similar to table data)
  – find distributions, ...

• combination tasks, incorporating both
  – example: find friends-of-friends who like cats
    • topology: find all adjacent nodes of given node
    • attributes: check if has-pet (node attribute) == cat
Node-link diagrams

- nodes: point marks
- links: line marks
  - straight lines or arcs
  - connections between nodes
- intuitive & familiar
  - most common
  - many, many variants

Node-Link Diagrams
Connection Marks
- NETWORKS
- TREES

Free

Styled

Fixed

HJ Schulz 2006
Criteria for good node-link layouts

• minimize
  – edge crossings, node overlaps
  – distances between topological neighbor nodes
  – total drawing area
  – edge bends

• maximize
  – angular distance between different edges
  – aspect ratio disparities

• emphasize symmetry
  – similar graph structures should look similar in layout
Criteria conflict

- most criteria NP-hard individually
- many criteria directly conflict with each other

Schulz 2004
Optimization-based layouts

• formulate layout problem as optimization problem
• convert criteria into weighted cost function
  – \( F(\text{layout}) = a \times [\text{crossing counts}] + b \times [\text{drawing space used}] + \ldots \)
• use known optimization techniques to find layout at minimal cost
  – energy-based physics models
  – force-directed placement
  – spring embedders
Force-directed placement

• physics model
  – links = springs pull together
  – nodes = magnets repulse apart

• algorithm
  – place vertices in random locations
  – while not equilibrium
    • calculate force on vertex
      – sum of
        » pairwise repulsion of all nodes
        » attraction between connected nodes
    • move vertex by \( c \times \text{vertex\_force} \)

Force-directed placement properties

• strengths
  – reasonable layout for small, sparse graphs
  – clusters typically visible
  – edge length uniformity

• weaknesses
  – nondeterministic
  – computationally expensive: $O(n^3)$ for $n$ nodes
    • each step is $n^2$, takes $\sim n$ cycles to reach equilibrium
  – naive FD doesn't scale well beyond 1K nodes
  – iterative progress: engaging but distracting
Idiom: **force-directed placement**

- **visual encoding**
  - link connection marks, node point marks

- **considerations**
  - spatial position: no meaning directly encoded
    - left free to minimize crossings
    - proximity semantics?
      - sometimes meaningful
      - sometimes arbitrary, artifact of layout algorithm
    - tension with length
      - long edges more visually salient than short

- **tasks**
  - explore topology; locate paths, clusters

- **scalability**
  - node/edge density $E < 4N$

Idiom: **circular layouts / arc diagrams (node-link)**

- restricted node-link layouts: lay out nodes around circle or along line
- data
  - original: network
  - derived: node ordering attribute (global computation)
- considerations: node ordering crucial to avoid excessive clutter from edge crossings
  - examples: before & after barycentric ordering

Adjacency matrix representations

• derive adjacency matrix from network
Adjacency matrix examples

Matrix Representations

Examples:

HJ Schulz 2007
Node order is crucial: Reordering

https://bost.ocks.org/mike/miserables/
Adjacency matrix

Well suited for neighborhood-related TBTs

-van Ham et al. 2009
-Shen et al. 2007

Not suited for path-related TBTs

good for topology tasks related to neighborhoods (node 1-hop neighbors)

bad for topology tasks related to paths
Structures visible in both

cliques
bicliques
clusters

http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png
Idiom: **adjacency matrix view**

- **data**: network
  - transform into same data/encoding as heatmap
- **derived data**: table from network
  - 1 quant attrib
    - weighted edge between nodes
  - 2 categ attribs: node list $\times$ 2
- **visual encoding**
  - cell shows presence/absence of edge
- **scalability**
  - 1K nodes, 1M edges
Node-link vs. matrix comparison

- node-link diagram strengths
  - topology understanding, path tracing
  - intuitive, flexible, no training needed
- adjacency matrix strengths
  - focus on edges rather than nodes
  - layout straightforward (reordering needed)
  - predictability, scalability
  - some topology tasks trainable
- empirical study
  - node-link best for small networks
  - matrix best for large networks
    - if tasks don’t involve path tracing!

Idiom: **NodeTrix**

- hybrid nodelink/matrix
- capture strengths of both

Trees
Node-link trees

• Reingold-Tilford
  – tidy drawings of trees
    • exploit parent/child structure
  – allocate space: compact but without overlap
    • rectilinear and radial variants


– nice algorithm writeup
  http://billmill.org/pymag-trees/
  http://bl.ocks.org/mbostock/4339184
  http://bl.ocks.org/mbostock/4063550
Idiom: radial node-link tree

• data
  – tree

• encoding
  – link connection marks
  – point node marks
  – radial axis orientation
    • angular proximity: siblings
    • distance from center: depth in tree

• tasks
  – understanding topology, following paths

• scalability
  – 1K - 10K nodes (with/without labels)
Link marks: Connection and containment

- marks as links (vs. nodes)
  - common case in network drawing
  - 1D case: connection
    - ex: all node-link diagrams
    - emphasizes topology, path tracing
    - networks and trees
  - 2D case: containment
    - ex: all treemap variants
    - emphasizes attribute values at leaves (size coding)
    - only trees

Idiom: **treemap**

- **data**
  - tree
  - 1 quant attrib at leaf nodes

- **encoding**
  - area containment marks for hierarchical structure
  - rectilinear orientation
  - size encodes quant attrib

- **tasks**
  - query attribute at leaf nodes
  - ex: disk space usage within filesystem

- **scalability**
  - 1M leaf nodes

---

Idiom: implicit tree layouts (sunburst, icicle plot)

• alternative to connection and containment: position
  – show parent-child relationships only through relative positions

Treemap
  containment

Sunburst
  position (radial)

Icicle Plot
  position (rectilinear)
Idiom: implicit tree layouts (sunburst, icicle plot)

- alternative to connection and containment: position
  - show parent-child relationships only through relative positions

Treemap
  - containment
  - only leaves visible

Sunburst
  - position (radial)
  - inner nodes & leaves visible

Icicle Plot
  - position (rectilinear)
  - inner nodes & leaves visible
Idiom: implicit tree layouts (sunburst, icicle plot)

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Tree drawing idioms comparison

Comparison: tree drawing idioms

- data shown
  - link relationships
  - tree depth
  - sibling order

Comparison: tree drawing idioms

• data shown
  – link relationships
  – tree depth
  – sibling order

• design choices
  – connection vs containment link marks
  – rectilinear vs radial layout
  – spatial position channels

Comparison: tree drawing idioms

• data shown
  – link relationships
  – tree depth
  – sibling order

• design choices
  – connection vs containment link marks
  – rectilinear vs radial layout
  – spatial position channels

• considerations
  – redundant? arbitrary?
  – information density?
    • avoid wasting space
    • consider where to fit labels!

treevis.net: Many, many options!

https://treevis.net/
Arrange networks and trees

Node–Link Diagrams
Connection Marks

Adjacency Matrix
Derived Table

Enclosure
Containment Marks

Implicit
Spatial Position
Visualization Analysis & Design

Rules of Thumb (Ch 6)

Tamara Munzner
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Rules of Thumb

• Guidelines and considerations, not absolute rules
  – when to use 3D? when to use 2D?
  – when to use eyes instead of memory?
  – when does immersion help?
  – when to use overviews?
  – how long is too long?
  – which comes first, form or function?
Unjustified 3D all too common, in the news and elsewhere

http://viz.wtf/post/137826497077/eye-popping-3d-triangles
http://viz.wtf/post/139002022202/designer-drugs-ht-ducqn
Depth vs power of the plane

- high-ranked spatial position channels: **planar** spatial position – not depth!

**Magnitude Channels:**

**Ordered Attributes**

- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
Depth vs power of the plane

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- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)

Steven’s Psychophysical Power Law: $S = I^N$
No unjustified 3D: Danger of depth

• we don’t really live in 3D: we see in 2.05D
  – acquire more info on image plane quickly from eye movements
  – acquire more info for depth slower, from head/body motion

We can only see the outside shell of the world
Occlusion hides information

- occlusion
- interaction can resolve, but at cost of time and cognitive load

Perspective distortion loses information

• perspective distortion
  – interferes with all size channel encodings
  – power of the plane is lost!

[Visualizing the Results of Multimedia Web Search Engines. Mukherjea, Hirata, and Hara. InfoVis 96]
3D vs 2D bar charts

- 3D bars: very difficult to justify!
  - perspective distortion
  - occlusion

- faceting into 2D almost always better choice

[http://perceptualedge.com/files/GraphDesignIQ.html]
Tilted text isn’t legible

- text legibility
  - far worse when tilted from image plane

- further reading
  

No unjustified 3D example: Time-series data

- extruded curves: detailed comparisons impossible

[Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc. InfoVis 99.]
No unjustified 3D example: Transform for new data abstraction

- derived data: cluster hierarchy
- juxtapose multiple views: calendar, superimposed 2D curves

[Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc. InfoVis 99.]
Justified 3D: shape perception

- benefits outweigh costs when task is shape perception for 3D spatial data
  - interactive navigation supports synthesis across many viewpoints

Justified 3D: Economic growth curve

• constrained navigation steps through carefully designed viewpoints

No unjustified 3D

• 3D legitimate for true 3D spatial data
• 3D needs very careful justification for abstract data
  – enthusiasm in 1990s, but now skepticism
  – be especially careful with 3D for point clouds or networks

No unjustified 2D

• consider whether network data requires 2D spatial layout
  – especially if reading text is central to task!
  – arranging as network means lower information density and harder label lookup compared to text lists

• benefits outweigh costs when topological structure/context important for task
  – be especially careful for search results, document collections, ontologies
Eyes beat memory

• principle: external cognition vs. internal memory
  – easy to compare by moving eyes between side-by-side views
  – harder to compare visible item to memory of what you saw

• implications for animation
  – great for choreographed storytelling
  – great for transitions between two states
  – poor for many states with changes everywhere
    • consider small multiples instead

literal         abstract

animation

show time with time  small multiples  show time with space
Resolution beats immersion

• immersion typically not helpful for abstract data
  – do not need sense of presence or stereoscopic 3D
  – desktop also better for workflow integration

• resolution much more important: pixels are the scarcest resource

• first wave: virtual reality for abstract data difficult to justify

• second wave: AR/MR (augmented/mixed reality) has more promise


Overview first, zoom and filter, details on demand

• influential mantra from Shneiderman


• overview = summary
  – microcosm of full vis design problem
Rule of thumb: **Responsiveness is required**

- *visual feedback: three rough categories*
Rule of thumb: **Responsiveness is required**

- **visual feedback: three rough categories**
  - **0.1 seconds: perceptual processing**
    - subsecond response for mouseover highlighting - ballistic motion
Rule of thumb: **Responsiveness is required**

- **visual feedback: three rough categories**
  - 0.1 seconds: *perceptual processing*
    - subsecond response for mouseover highlighting - ballistic motion
  - 1 second: *immediate response*
    - fast response after mouseclick, button press - Fitts’ Law limits on motor control
Rule of thumb: **Responsiveness is required**

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  - **10 seconds: brief tasks**
    - bounded response after dialog box - mental model of heavyweight operation (file load)
Rule of thumb: **Responsiveness is required**

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- **scalability considerations**
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  - highlight selection without complete redraw of view (graphics frontbuffer)
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- **scalability considerations**
  - highlight selection without complete redraw of view (graphics frontbuffer)
  - show hourglass for multi-second operations (check for cancel/undo)
  - show progress bar for long operations (process in background thread)
  - rendering speed when item count is large (guaranteed frame rate)
Function first, form next

- dangerous to start with aesthetics
  - usually impossible to add function retroactively
Function first, form next

• dangerous to start with aesthetics
  – usually impossible to add function retroactively

• start with focus on functionality
  – possible to improve aesthetics later on, as refinement
  – if no expertise in-house, find good graphic designer to work with
  – aesthetics do matter! another level of function
    • visual hierarchy, alignment, flow
    • Gestalt principles in action
Form: Basic graphic design ideas
Form: Basic graphic design ideas

What Goes Around
Comes Around
Lessons from hitchhiking across the country
Robin Williams
January 1, 2005
Form: Basic graphic design ideas

- proximity
  - do group related items together
  - avoid equal whitespace between unrelated
Form: Basic graphic design ideas

• proximity
  – do group related items together
  – avoid equal whitespace between unrelated

• alignment
  – do find/make strong line, stick to it
  – avoid automatic centering
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  – if not identical, then very different
  – avoid not quite the same
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  – do unify by pushing existing consistencies

• contrast
  – if not identical, then very different
  – avoid not quite the same

  – fast read, very practical to work through whole thing
Best practices: Labelling

• make visualizations as self-documenting as possible
  – meaningful & useful title, labels, legends
    • axes and panes/subwindows should have labels
      – and axes should have good mix/max boundary tick marks
    • everything that’s plotted should have a legend
      – and own header/labels if not redundant with main title
  • use reasonable numerical format
    – avoid scientific notation in most cases

[https://xkcd.com/833/]

507
Rules of Thumb Summary

• No unjustified 3D
  – Power of the plane
  – Disparity of depth
  – Occlusion hides information
  – Perspective distortion dangers
  – Tilted text isn’t legible

• No unjustified 2D

• Eyes beat memory

• Resolution over immersion

• Overview first, zoom and filter, details on demand

• Responsiveness is required

• Function first, form next
### How?

<table>
<thead>
<tr>
<th>Encode</th>
<th>Manipulate</th>
<th>Facet</th>
<th>Reduce</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arrange</strong></td>
<td><strong>Map</strong></td>
<td><strong>Facet</strong></td>
<td><strong>Reduce</strong></td>
</tr>
<tr>
<td>➔ Express</td>
<td>➔ Change</td>
<td>➔ Juxtapose</td>
<td>➔ Filter</td>
</tr>
<tr>
<td>➔ Order</td>
<td>➔ Color</td>
<td>➔ Select</td>
<td>➔ Aggregate</td>
</tr>
<tr>
<td>➔ Align</td>
<td>➔ Hue</td>
<td>➔ Partition</td>
<td>➔ Embed</td>
</tr>
<tr>
<td>➔ Use</td>
<td>➔ Saturation</td>
<td>➔ Navigate</td>
<td></td>
</tr>
</tbody>
</table>

- **Map**
  - from *categorical* and *ordered* attributes
  - **Color**
    - **Hue**
    - **Saturation**
    - **Luminance**
  - **Size, Angle, Curvature, ...**
  - **Shape**
    - □ □ □ □ □ □
  - **Motion**
    - *Direction, Rate, Frequency, ...*
    - ◇ ◇ ◇ ◇ ◇ ◇
Visualization Analysis & Design

Wrapup

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What?

Datasets

- Data Types
  - Items
  - Attributes
  - Links
  - Positions
  - Grids

- Data and Dataset Types
  - Tables
  - Networks & Trees
  - Fields
  - Geometry
  - Clusters, Sets, Lists

- Dataset Types
  - Tables
  - Networks
  - Fields (Continuous)
    - Attributes (columns)
    - Items (rows)
    - Cell containing value
    - Multidimensional Table
  - Trees
    - Link
    - Node (item)

Attributes

- Attribute Types
  - Categorical
    - 
  - Ordered
    - Ordinal
    - Quantitative

- Ordering Direction
  - Sequential
  - Diverging
  - Cyclic

Domain

- Abstraction
- Why?
- Idiom
- How?
- Algorithm

Geometry (Spatial)
D

Why?

Actions

Analyze

→ Consume
  → Discover
  → Present
  → Enjoy

→ Produce
  → Annotate
  → Record
  → Derive

Search

<table>
<thead>
<tr>
<th>Target known</th>
<th>Target unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location known</td>
<td>Location unknown</td>
</tr>
<tr>
<td>··· Look up</td>
<td>··· Browse</td>
</tr>
<tr>
<td>Location known</td>
<td>Location unknown</td>
</tr>
<tr>
<td>··· Locate</td>
<td>··· Explore</td>
</tr>
</tbody>
</table>

Query

→ Identify
→ Compare
→ Summarize

Attributes

→ All Data
  → Trends
  → Outliers
  → Features

→ Attributes
  → One
    → Distribution
    → Extremes
  → Many
    → Dependency
    → Correlation
    → Similarity

Network Data

→ Topology
  → Paths
→ Explore

domain

abstraction

What?

Why?

idiom

algorithm

How?
<table>
<thead>
<tr>
<th>Datasets</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What?</strong></td>
<td><strong>Why?</strong></td>
</tr>
<tr>
<td><strong>Actions</strong></td>
<td><strong>Targets</strong></td>
</tr>
<tr>
<td><strong>How?</strong></td>
<td><strong>domain</strong></td>
</tr>
</tbody>
</table>

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

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

**Manipulate**
- Change
- Juxtapose

**Facet**
- Partition

**Reduce**
- Filter
- Aggregate
- Superimpose
- Embed
More information

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