Visualization Analysis & Design

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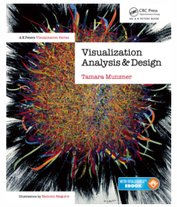

UBC CS Faculty Lecture Series
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http://www.cs.ubc.ca/~tmm/talks.html#vad15fls **@tamaramunzner**

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.

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 (e.g. exploratory analysis of scientific data)
  - presentation of known results
  - stepping stone to better understanding of requirements before developing models
  - help developers of automatic solution refine/debug, 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

[Cerebral Visualizing Multiple Experimental Conditions on a Graph with Biological Context, Barsky, Munzner, Gardy, and Kincaid. IEEE TVCG (Proc. InfoVis) 14(6):1253-1260, 2008]

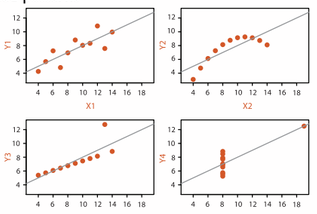
Why represent all the data?

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

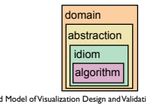
Anscombe's Quartet

Identical statistics	
x mean	9
x variance	10
y mean	8
y variance	4
x/y correlation	1

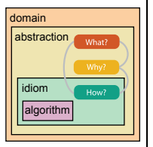


Analysis framework: Four levels, three questions

- *domain* situation
  - who are the target users?
- *abstraction*
  - translate from specifics of domain to vocabulary of vis
  - **what** is shown? **data abstraction**
    - often don't just draw what you're given: transform to new form
  - **why** is the user looking at it? **task abstraction**
- *idiom*
  - **how** is it shown?
    - **visual encoding idiom**: how to draw
    - **interaction idiom**: how to manipulate
- *algorithm*
  - efficient computation



[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]



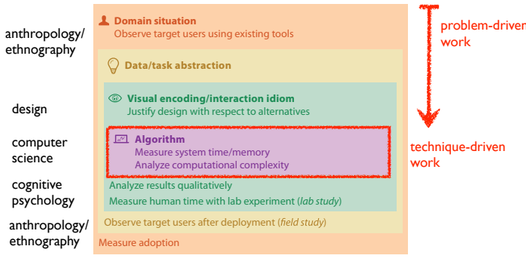
[A Multi-Level Typology of Abstract Visualization Tasks Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).]

Why is validation difficult?

- different ways to get it wrong at each level

Why is validation difficult?

- solution: use methods from different fields at each level



[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

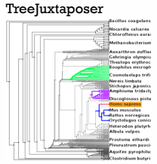
Why analyze?

- imposes a structure on huge design space
  - scaffold to help you think systematically about choices
  - analyzing existing as stepping stone to designing new

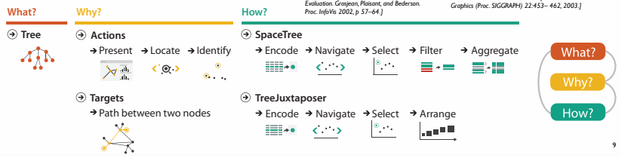
SpaceTree

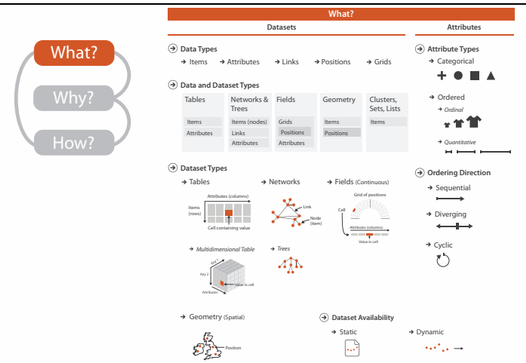
[SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation. Grosjean, Plaisant, and Bederson. Proc. InfoVis 2002, p. 57–64.]

TreeJuxtaposer



[TreeJuxtaposer: Scalable Tree Comparison Using Focus +Context With Guaranteed Visibility. ACM Trans. on Graphics (Proc. SIGGRAPH) 22:453– 462, 2003.]

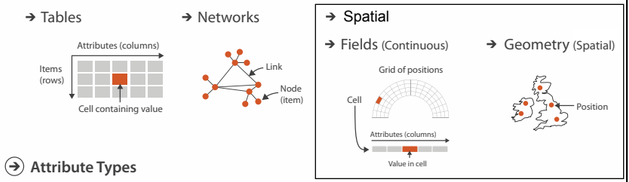




Types: Datasets and data

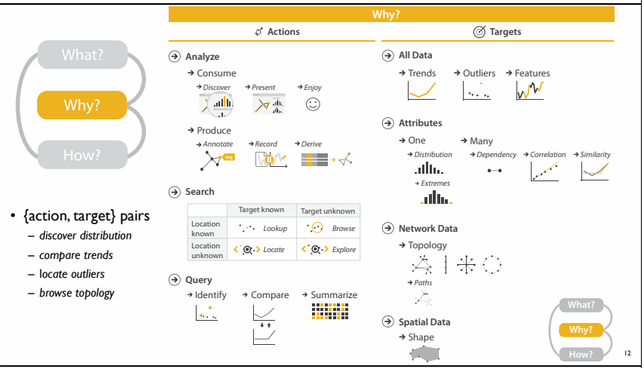
Dataset Types

- Tables
- Networks
- Spatial
  - Fields (Continuous)
  - Geometry (Spatial)



Attribute Types

- Categorical
- Ordered
  - Ordinal
  - Quantitative



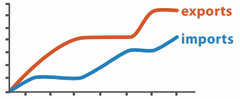
- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*

Actions 1: Analyze

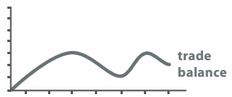
- consume
  - discover vs present
    - classic split
    - aka explore vs explain
  - enjoy
    - newcomer
    - aka casual, social
- produce
  - annotate, record
  - derive
    - crucial design choice

Derive

- don't just draw what you're given!
  - decide what the right thing to show is
  - create it with a series of transformations from the original dataset
  - draw that
- one of the four major strategies for handling complexity



Original Data



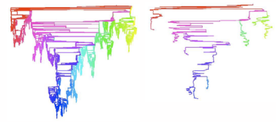
trade balance = exports – imports

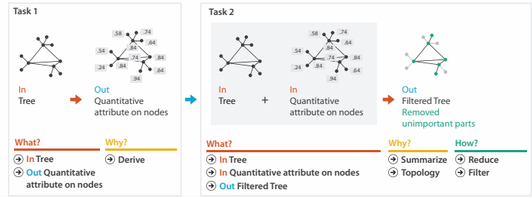
Derived Data

Analysis example: Derive one attribute

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

[Using Strahler numbers for real time visual exploration of huge graphs. Auber. Proc. Intl. Conf. Computer Vision and Graphics, pp. 56–69, 2002.]





Actions II: Search

- what does user know?
  - target, location

Search

	Target known	Target unknown
Location known	Lookup	Browse
Location unknown	Locate	Explore

Actions III: Query

- what does user know?
  - target, location
- how much of the data matters?
  - one, some, all
- analyze, search, query
  - independent choices for each

→ Search

	Target known	Target unknown
Location known	Lookup	Browse
Location unknown	Locate	Explore

→ Query

→ Identify → Compare → Summarize

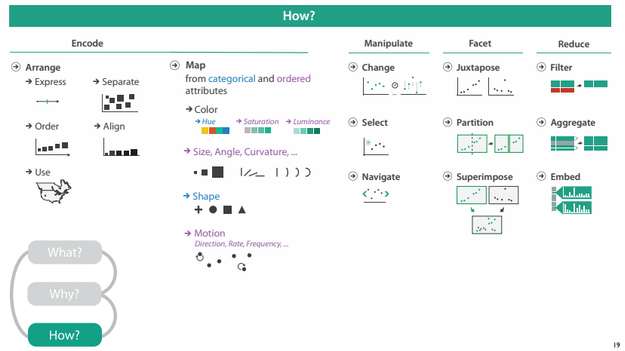
Targets

→ All Data
→ Trends → Outliers → Features

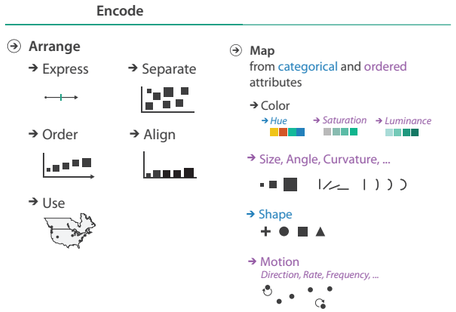
→ Attributes
→ One → Many
→ Distribution → Dependency → Correlation → Similarity
→ Extremes

→ Network Data
→ Topology
→ Paths

→ Spatial Data
→ Shape



How to encode: Arrange space, map channels

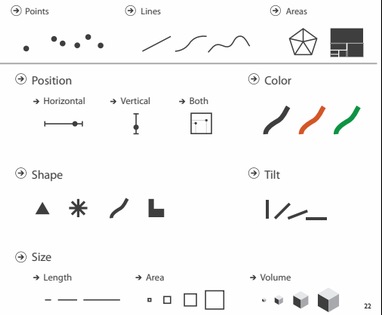


Encoding visually

- analyze idiom structure

Definitions: Marks and channels

- marks
  - geometric primitives
- channels
  - control appearance of marks

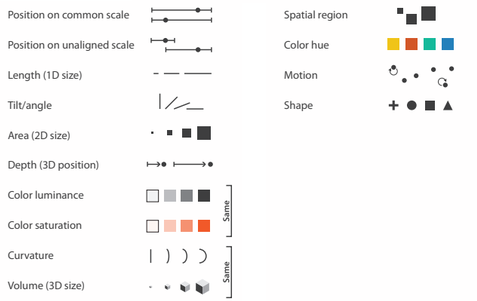


Encoding visually with marks and channels

- analyze idiom structure
  - as combination of marks and channels

1:	2:	3:	4:
vertical position	vertical position horizontal position	vertical position horizontal position color hue	vertical position horizontal position color hue size (area)
mark: line	mark: point	mark: point	mark: point

Channels



Channels: Matching Types

→ **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 principle
  - match channel and data characteristics

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)

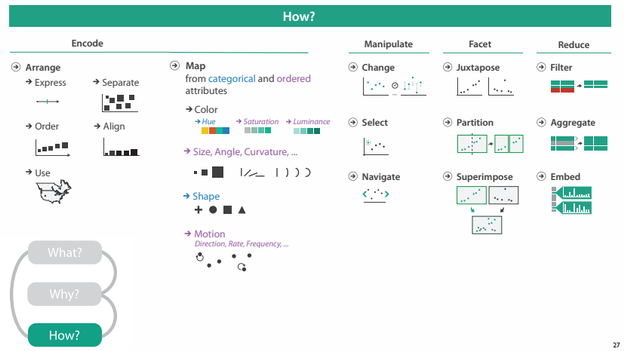
Best → Least Effectiveness

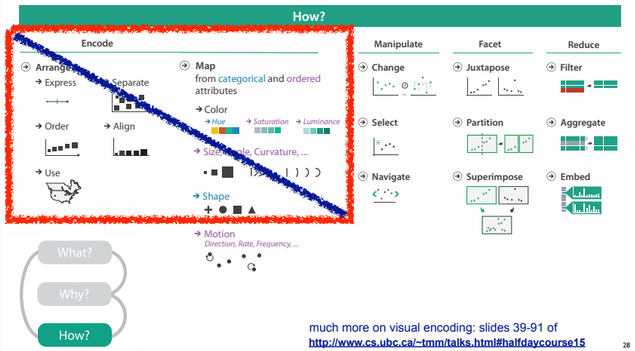
→ **Identity Channels: Categorical Attributes**

Spatial region
Color hue
Motion
Shape

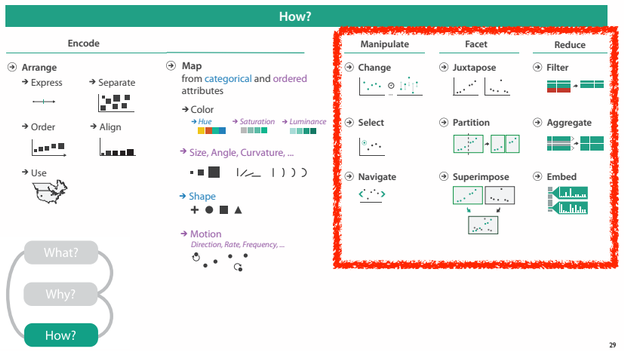
- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

more on channels: slides 30-38 of
http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse15





much more on visual encoding: slides 39-91 of
http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse15



How to handle complexity: 3 more strategies + 1 previous

Manipulate
→ Change
→ Select
→ Navigate

Facet
→ Juxtapose
→ Partition
→ Superimpose

Reduce
→ Filter
→ Aggregate
→ Embed

→ Derive

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

How to handle complexity: 3 more strategies + 1 previous

Manipulate
→ Change
→ Select
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→ Filter
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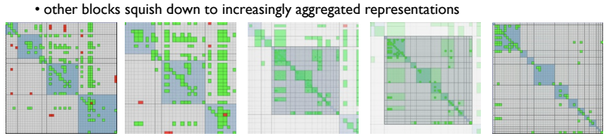
→ Embed

→ Derive

- change over time
  - most obvious & flexible of the 4 strategies

Idiom: **Animated transitions**

- smooth transition from one state to another
  - alternative to jump cuts
  - support for item tracking when amount of change is limited
- example: multilevel matrix views
  - scope of what is shown narrows down
    - middle block stretches to fill space, additional structure appears within
    - other blocks squish down to increasingly aggregated representations



[Using Multilevel Call Matrices in Large Software Projects. van Ham. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 227–232, 2003.]

How to handle complexity: 3 more strategies + 1 previous

Manipulate
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→ *Derive*

- facet data across multiple views

Facet

- Juxtapose
- Partition
- Superimpose

→ Coordinate Multiple Side By Side Views

→ Share Encoding: Same/Different

→ *Linked Highlighting*

→ Share Data: All/Subset/None

→ Share Navigation

Idiom: **Linked highlighting** System: **EDV**

- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - ***multiform***
- data: all shared

[Visual Exploration of Large Structured Datasets. Wills. Proc. New Techniques and Trends in Statistics (NTTS), pp. 237–246. IOS Press, 1995.]

Idiom: **bird's-eye maps** System: **Google Maps**

- encoding: same
- data: subset shared
- navigation: shared
  - bidirectional linking
- differences
  - viewpoint
  - (size)
- ***overview-detail***

[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]

Idiom: **Small multiples** System: **Cerebral**

- encoding: same
- data: none shared
  - different attributes for node colors
  - (same network layout)
- navigation: shared

[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

Coordinate views: Design choice interaction

Encoding	Data: All	Data: Subset	Data: None
Same	Redundant	Overview/ Detail	Small Multiples
Different	Multiform	Multiform, Overview/ Detail	No Linkage

- why juxtapose views?
  - benefits: eyes vs memory
    - lower cognitive load to move eyes between 2 views than remembering previous state with single changing view
  - costs: display area, 2 views side by side each have only half the area of one view

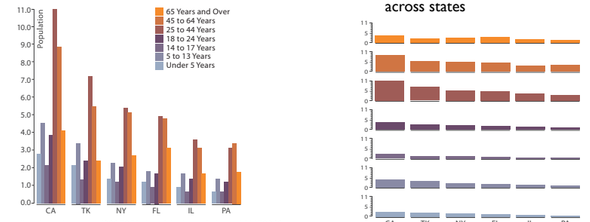
Partition into views

- how to divide data between views
  - encodes association between items using spatial proximity
  - major implications for what patterns are visible
  - split according to attributes
- design choices
  - how many splits
    - all the way down: one mark per region?
    - stop earlier, for more complex structure within region?
  - order in which attribs used to split
  - how many views

→ Partition into Side-by-Side Views

Partitioning: List alignment

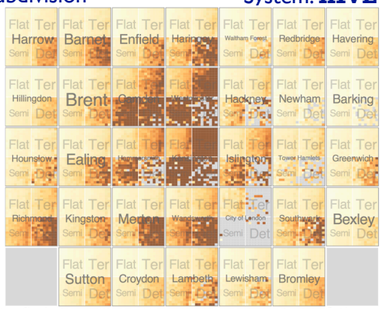
- single bar chart with grouped bars
  - split by state into regions
    - complex glyph within each region showing all ages
  - compare: easy within state, hard across ages
- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across states



http://blocks.org/mbostock/3887051 http://blocks.org/mbostock/4679202

Partitioning: Recursive subdivision System: **HIVE**

- split by neighborhood
- then by type
- 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



[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

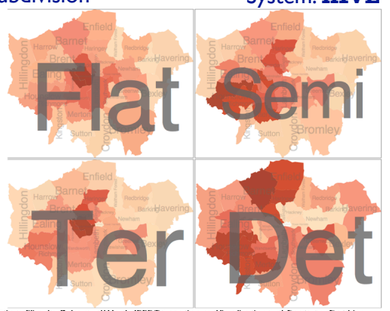
Partitioning: Recursive subdivision System: **HIVE**

- switch order of splits
  - type then neighborhood
- switch color
  - by price variation
- type patterns
  - within specific type, which neighborhoods inconsistent

[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision System: **HIVE**

- different encoding for second-level regions
  - choropleth maps



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How to handle complexity: 3 more strategies + 1 previous

Manipulate
- Change
- Select
- Navigate

Facet
- Juxtapose
- Partition
- Superimpose

Reduce
- Filter
- Aggregate
- Embed

→ *Derive*

- reduce what is shown within single view

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, facet, change, derive

Reducing Items and Attributes

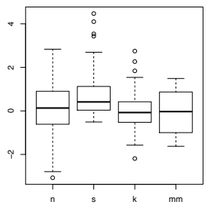
→ Filter
- → Items
- → Attributes

→ Aggregate
- → Items
- → Attributes

Reduce
- Filter
- Aggregate
- Embed

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



[40 years of boxplots. Wickham and Stryjewski. 2012. had.co.nz]

Idiom: **Dimensionality reduction for documents**

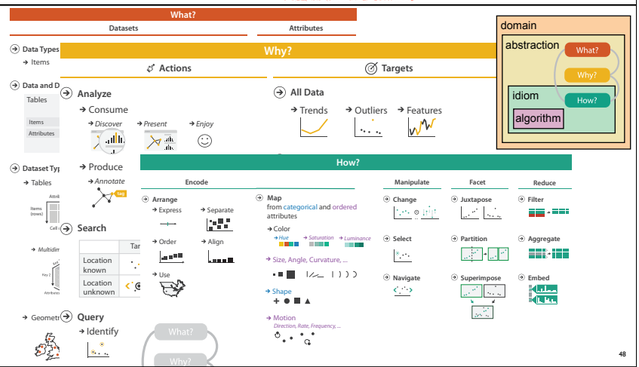
- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space

Task 1
In: HD data → Out: 2D data

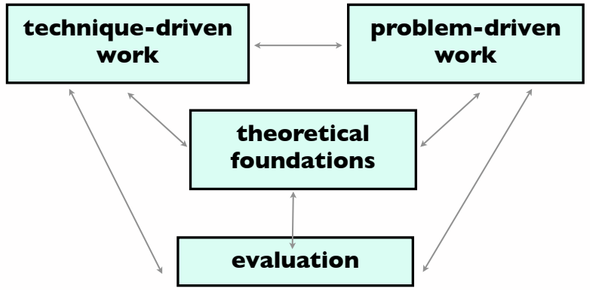
Task 2
In: 2D data → Out: Scatterplot Clusters & points

Task 3
In: Scatterplot Clusters & points → Out: Labels for clusters

What?	Why?	How?
In High-dimensional data	Produce	Encode
Out 2D data	Derive	Navigate
		Select
In 2D data	Discover	
Out Scatterplot Clusters & points	Explore	
	Identify	
In Scatterplot Clusters & points	Produce	
Out Labels for clusters	Annotate	

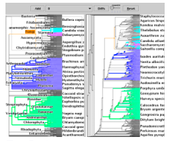


A quick taste of my own work!



Technique-driven: Graph drawing

T F P E



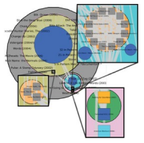
James Slack

Kristian Hildebrand

TreeJuxtaposer

Daniel Archambault

David Auber (Bordeaux)



TopoLayout
SPF
Grouse
GrouseFlocks
TugGraph

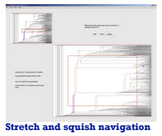
Evaluation: Graph drawing

T F P E

Dmitry Nekrasovski

Adam Bodnar

Joanna McGrenere (UBC)



Stretch and squish navigation

Jessica Dawson

Joanna McGrenere (UBC)

Search set model of path tracing

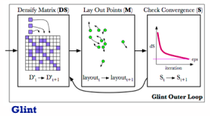
Technique-driven: Dimensionality reduction

T F P E

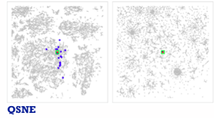
Stephen Ingram

Glimmer

DimStiller



Glint

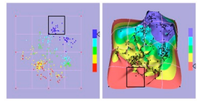


QSNE

Evaluation: Dimensionality reduction

T F P E

Melanie Tory



Points vs landscapes for dimensionally reduced data

Guidance on DR & scatterplot choices

Michael Sedlmair

Melanie Tory (UVic)

Taxonomy of cluster separation factors

Problem-driven: Genomics

T F P E

Aaron Barsky

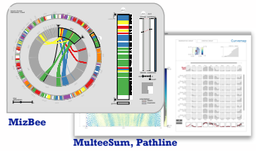
Jenn Gardy (Microbio)

Robert Kincaid (Agilent)

Cerebral

Miriah Meyer

Hanspeter Pfister (Harvard)



MizBee

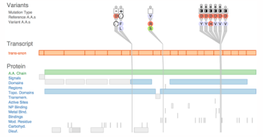
MulteeSum, Pathline

Problem-driven: Genomics, fisheries

T F P E

Joel Ferstay

Cydney Nielsen (BC Cancer)



Variant View

Vismon

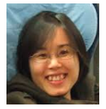
Maryam Booshehrian

Torsten Moeller (SFU)

Problem-driven: Many domains

T F P E

Heidi Lam



Diane Tang (Google)

SessionViewer: web log analysis

Peter McLachlan

Stephen North (AT&T Research)

LiveRAC: systems time-series

Evaluation: Focus+Context

T F P E

Heidi Lam

Ron Rensink (UBC)

Distortion impact on search/memory

Heidi Lam

Robert Kincaid (Agilent)

Separate vs integrated views

Journalism

T F P E

Matt Brehmer

Stephen Ingram

Jonathan Stray (Assoc Press)

Overview

Johanna Fulda (Sud. Zeitung)

Matt Brehmer

TimeLineCurator

Theoretical foundations

T F P E

- Visual Encoding Pitfalls
  - Unjustified Visual Encoding
  - Hammer In Search Of Nail
  - 2D Good, 3D Better
  - Color Cacophony
  - Rainbows Just Like In The Sky
- Strategy Pitfalls
  - What I Did Over My Summer
  - Least Publishable Unit
  - Dense As Plutonium
  - Bad Slice and Dice

Papers Process & Pitfalls

Nested Model

Design Study Methodology

Michael Sedlmair

Miriah Meyer

Abstract Tasks

Matt Brehmer

More Information

@tamaramunzner

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Visualization Analysis and Design.
Munzner. A K Peters Visualization Series, CRC Press, Visualization Series, 2014.