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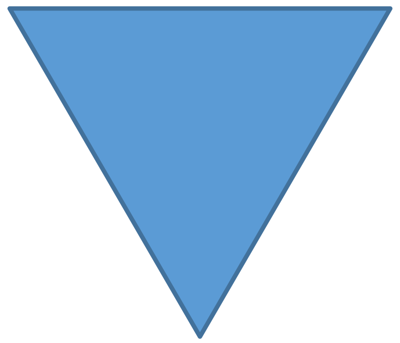
Visualization for Data Science
DS-4630 / CS-5630 / CS-6630

Visualization for Data Science Tasks, Design and Evaluation

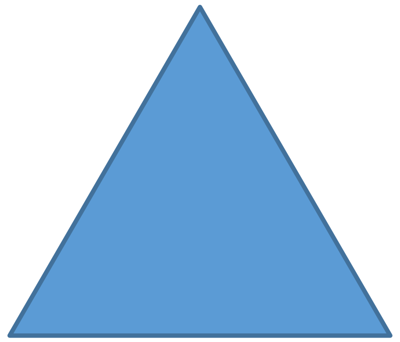
Tasks Analysis

Problem-Driven vs Technique- Driven

- problem-driven
  - top-down approach
  - identify a problem encountered by users
  - design a solution to help users work more effectively sometimes called a design study



- technique-driven
  - bottom-up approach
  - invent new visualization techniques or algorithms
  - classify or compare against other idioms and algorithms



A Nested Model for Visualization Design and Validation

Tamara Munzner, *Member, IEEE*

Abstract—We present a nested model for the visualization design and validation with four layers: characterize the task and data in the vocabulary of the problem domain, abstract into operations and data types, design visual encoding and interaction techniques, and create algorithms to execute techniques efficiently. The output from a level above is input to the level below, bringing attention to the design challenge that an upstream error inevitably cascades to all downstream levels. This model provides prescriptive guidance for determining appropriate evaluation approaches by identifying threats to validity unique to each level. We also provide three recommendations motivated by this model: authors should distinguish between these levels when claiming contributions at more than one of them, authors should explicitly state upstream assumptions at levels above the focus of a paper, and visualization venues should accept more papers on domain characterization.

Index Terms—Models, frameworks, design, evaluation.

1 Introduction

Many visualization models have been proposed to guide the creation and analysis of visualization systems [8, 7, 10], but they have not been tightly coupled to the question of how to evaluate these systems. Similarly, there has been significant previous work on evaluating visualization [9, 33, 42]. However, most of it is structured as an enumeration of methods with focus on *how* to carry them out, without prescriptive advice for *when* to choose between them.

The impetus for this work was dissatisfaction with a flat list of evaluation methodologies in a recent paper on the process of writing visualization papers [29]. Although that previous work provides some guidance for when to use which methods, it does not provide a full framework to guide the decision or analysis process.

In this paper, we present a model that splits visualization design into levels, with distinct evaluation methodologies suggested at each level based on the threats to validity that occur at that level. The four levels are: characterize the tasks and data in the vocabulary of the problem domain, abstract into operations and data types, design visual encoding and interaction techniques, and create algorithms to execute these techniques efficiently. We conjecture that many past visualization designers did carry out these steps, albeit implicitly or subconsciously, and not necessarily in that order. Our goal in making these steps more

systems, and compare our model to previous ones. We provide recommendations motivated by this model, and conclude with a discussion of limitations and future work.

2 Nested Model

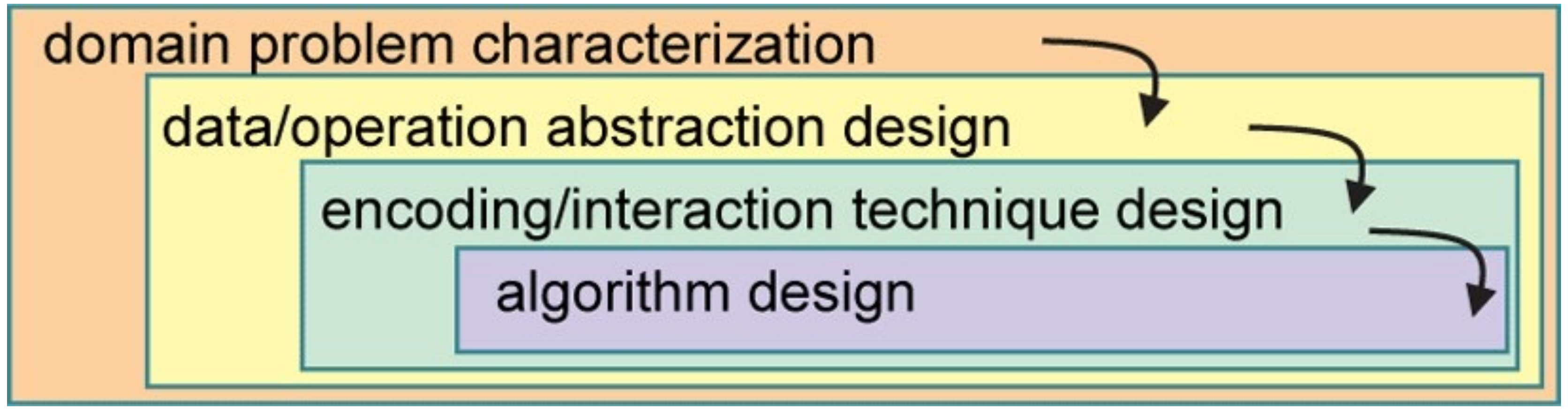
Figure 1 shows the nested four-level model for visualization design and evaluation. The top level is to characterize the problems and data of a particular domain, the next level is to map those into abstract operations and data types, the third level is to design the visual encoding and interaction to support those operations, and the innermost fourth level is to create an algorithm to carry out that design automatically and efficiently. The three inner levels are all instances of design problems, although it is a different problem at each level.

These levels are nested; the output from an *upstream* level above is input to the *downstream* level below, as indicated by the arrows in Figure 1. The challenge of this nesting is that an upstream error inevitably cascades to all downstream levels. If a poor choice was made in the abstraction stage, then even perfect visual encoding and algorithm design will not create a visualization system that solves the intended problem.

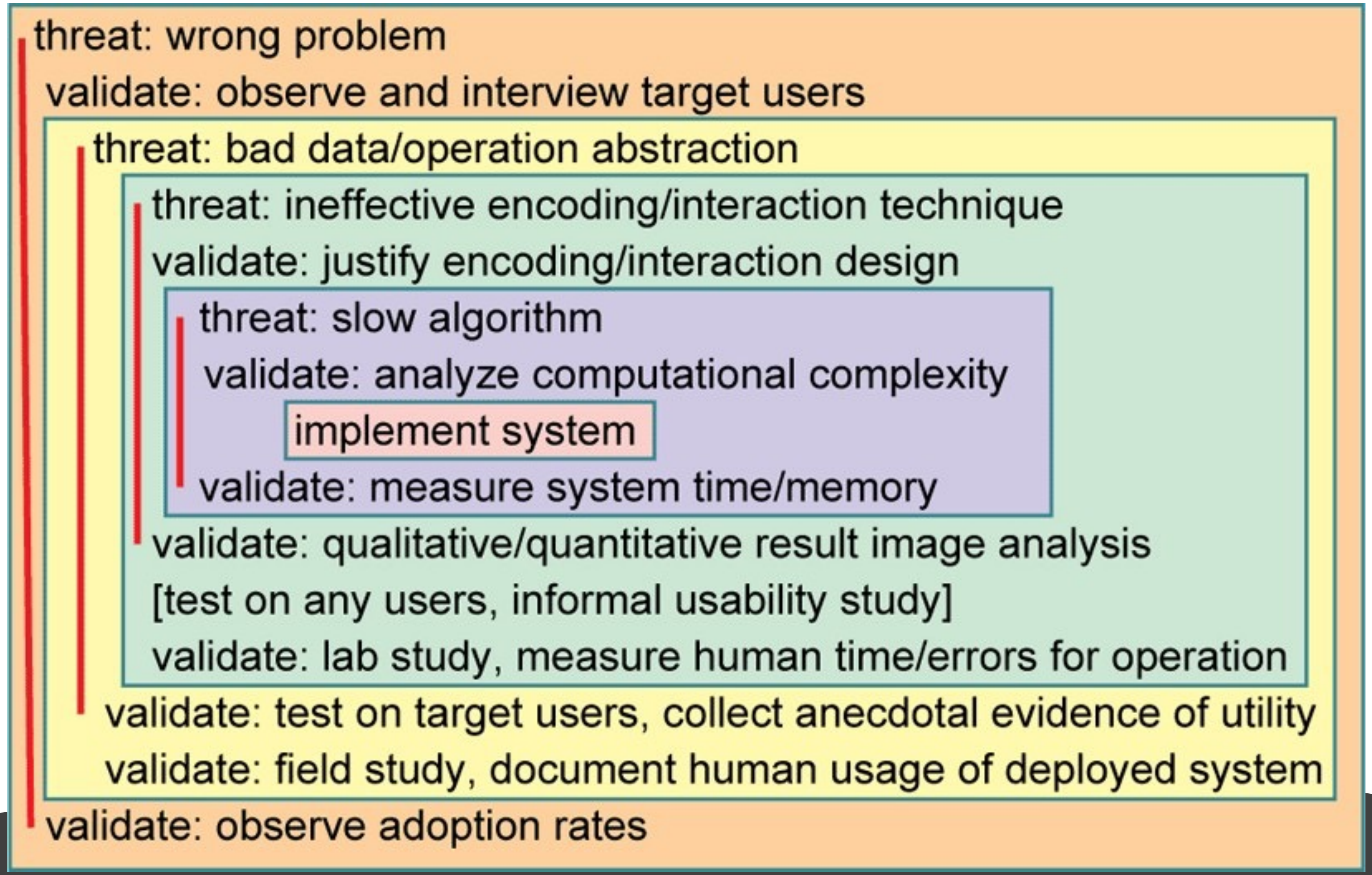
Purpose of the Nested Model

- capture design decisions
  - what is the justification behind your design?
- analyze aspects of the design process
  - broken apart into four different concerns
- validate early & often
  - avoid making ineffective solutions

Nested Model for Visualization Design



Design



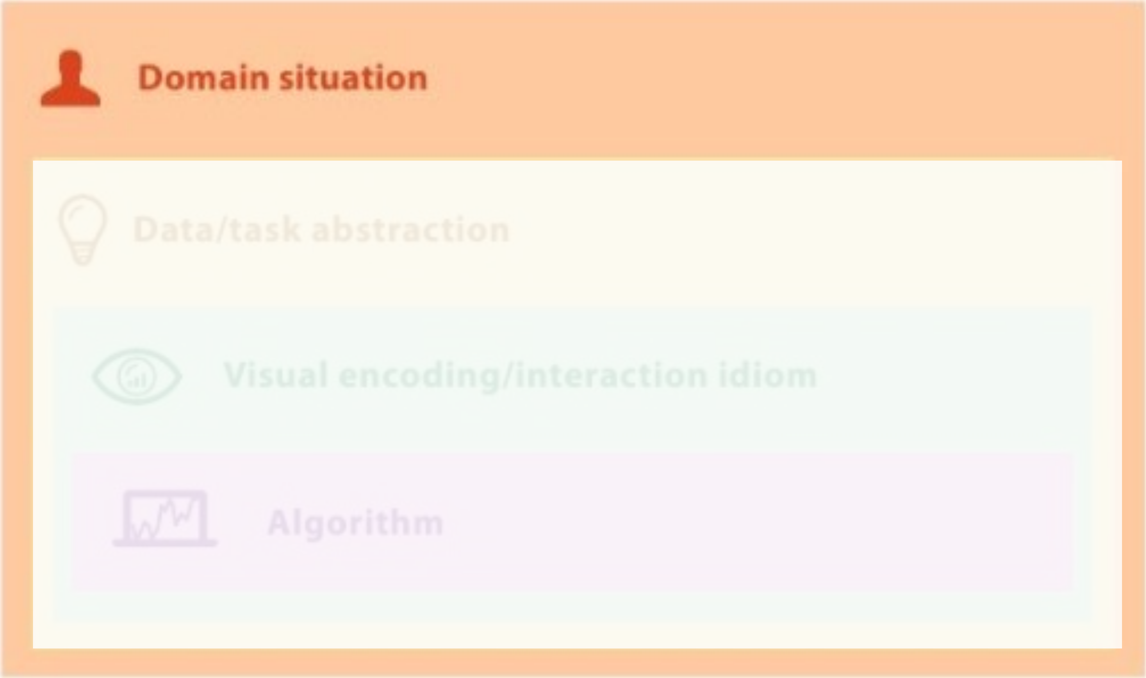
Threats & Evaluation

Design Process

Understand Domain Problem → Map to Abstract Task → Identify & Implement SuitableTechnique

Data Type & Other Factors ↗ (Identify & Implement SuitableTechnique)

Domain Characterization



- details of an application domain
- group of users, target domain, their questions, & their data
  - varies wildly by domain
  - must be specific enough to continue with
- cannot just ask people what they do
  - introspection is hard!

Domain Problem Characterization

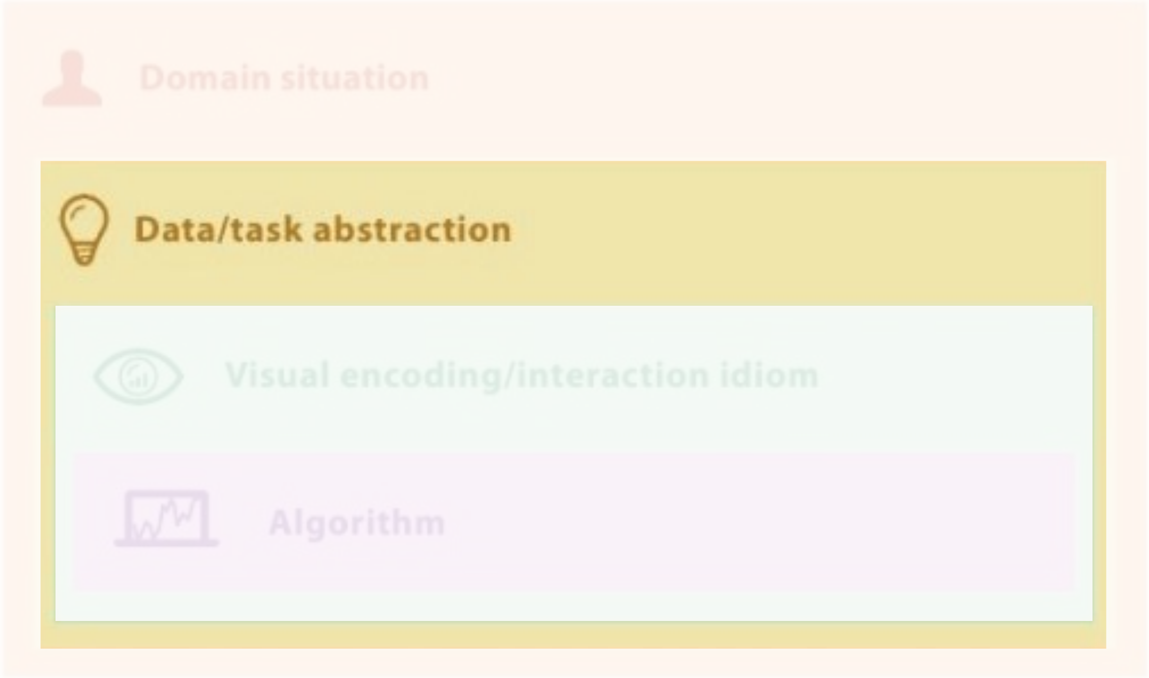
- Infinite numbers of domain tasks
- Can be broken down into simpler abstract tasks
- We know how to address the abstract tasks!

- Identify task – data combination: solutions probably exist

Example: Find Good Movies

- I want to identify good movies in genres I like.
- Domain: general population, movie enthusiasts

Data & Task Abstraction

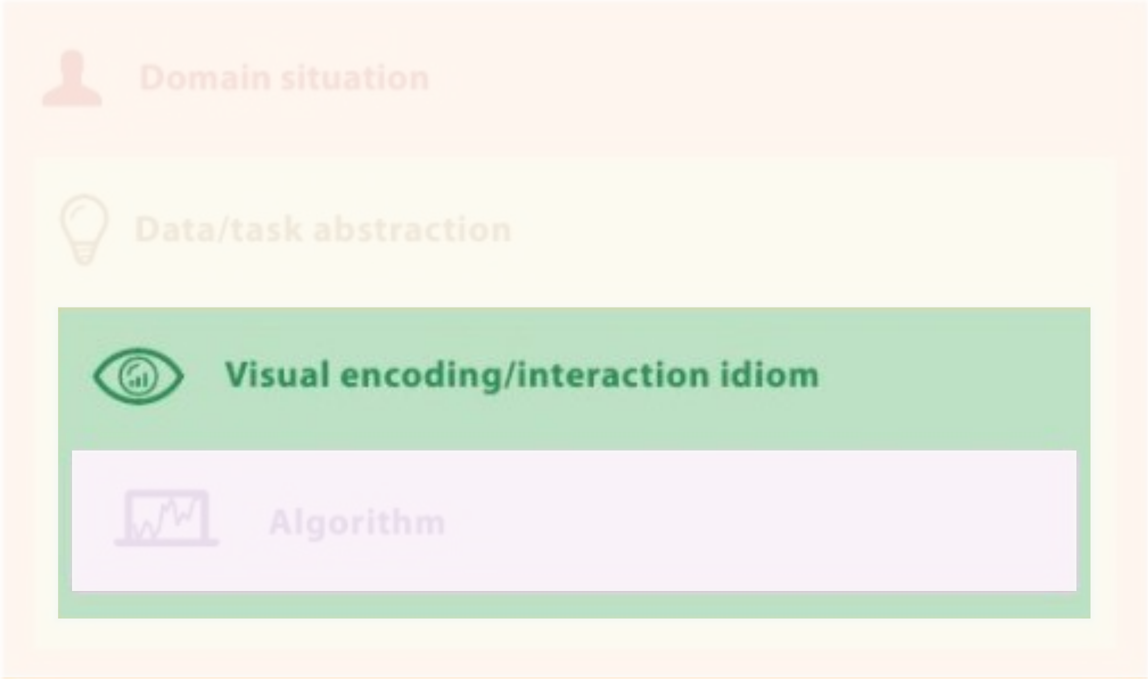


- the what-why, map into generalized terms
- identify tasks that users wish to perform or already do
- find data types and good model of the data
- sometimes must transform the data for a better solution
    - this can be varied and guided by the specific task

Example: Find Good Movies

- What is a good movie for me?
  - Highly rated by critics?
  - Highly rated by audiences?
  - Successful at the box office?
  - Similar to movies I liked?
  - Specific Genres?
- Data Sources: IMDB, Rotten Tomatoes, …

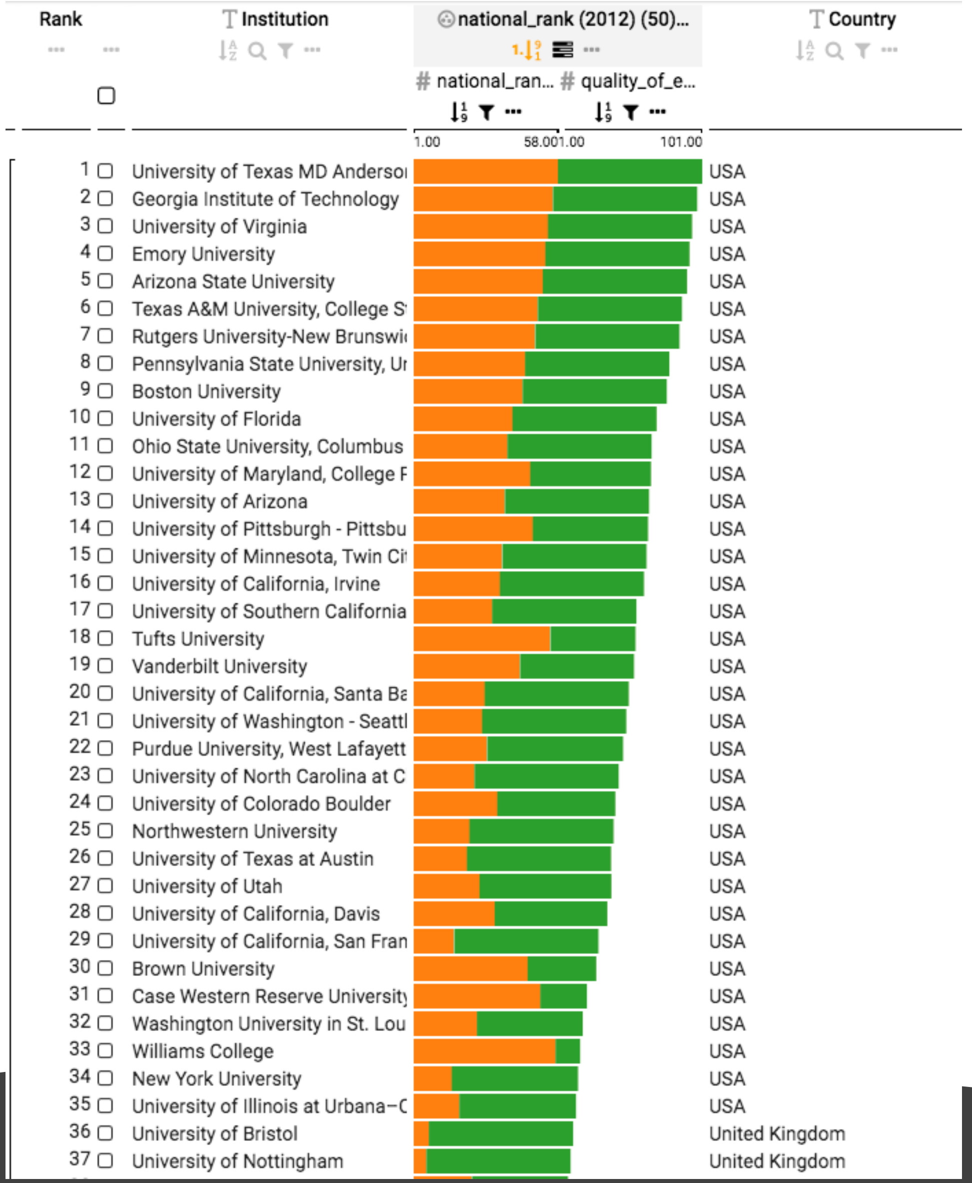
Encodings & Interactions



- the design of visualization techniques
  - visual encodings interactions
- ways to create and manipulate the visual representation of data
- decisions on these may be separate or intertwined
- visualization design principles drive decisions

Example: Find Good Movies

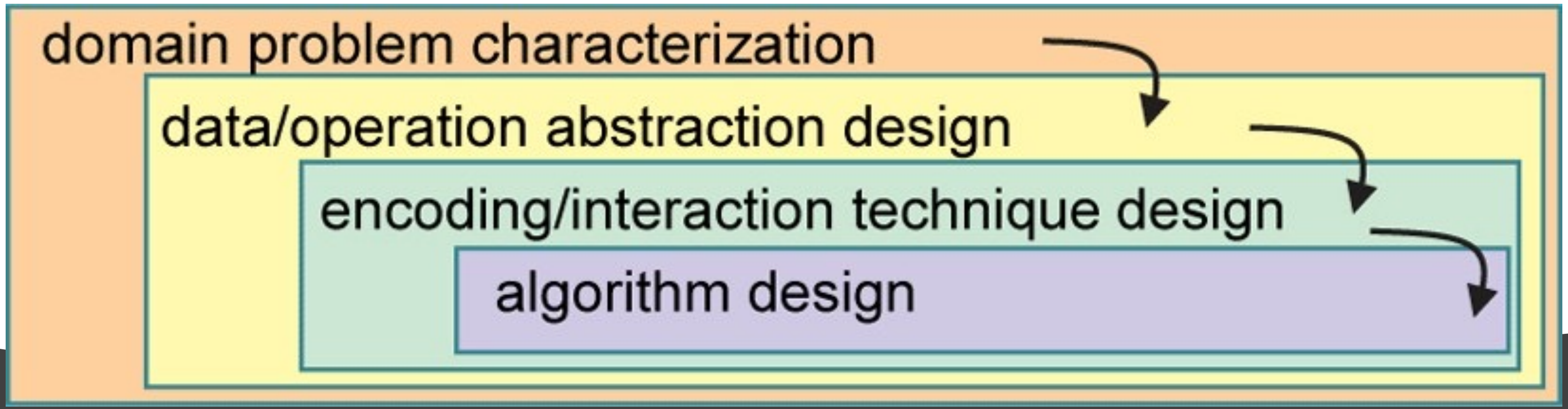
- Combination of audience ratings and critics ratings, filtered by genre.
- Idiom: stacked bar chart for ratings filter interface for genre



Task Abstraction Exercise

You have been approached by a geneticist to help with a visualization problem. She has **gene expression data** (data that measures the activity of the genes) for **30 cancer tissue samples**. She is applying an experimental drug to **see whether the cancer tissue dies** as she hopes, but she finds that **only some samples show the desired effect**. She believes that the difference between the samples is caused by differential expression (**different activity**) **of genes in a particular pathway**, i.e., an interaction network of genes. She would like to understand **which genes are likely to cause the difference**, and **what role they play in that pathway**.

- Objective 1: Task Abstraction
- Objective 2: Encoding Design



Task Abstraction

- …only some samples show the desired effect.

    -> derive two groups of samples

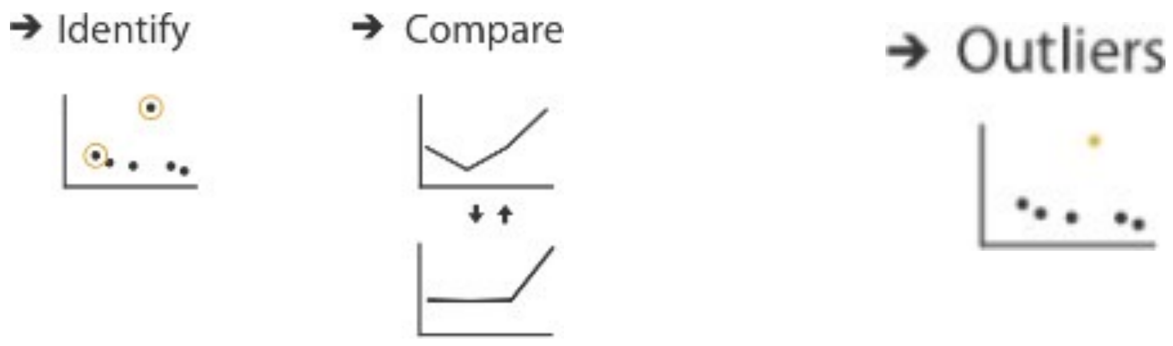
Task Abstraction

- … the difference between the samples is caused by differential expression (different activity) of genes in a particular pathway. She would like to understand which genes are likely to cause the difference

-> identify those genes

-> compare gene expression of pathway genes between two groups

-> identify the outliers

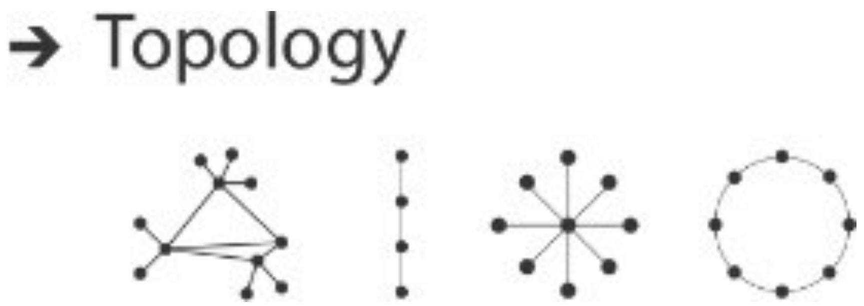


Task Abstraction

- She would like to understand which genes are likely to cause the difference, and what role they play in that pathway.

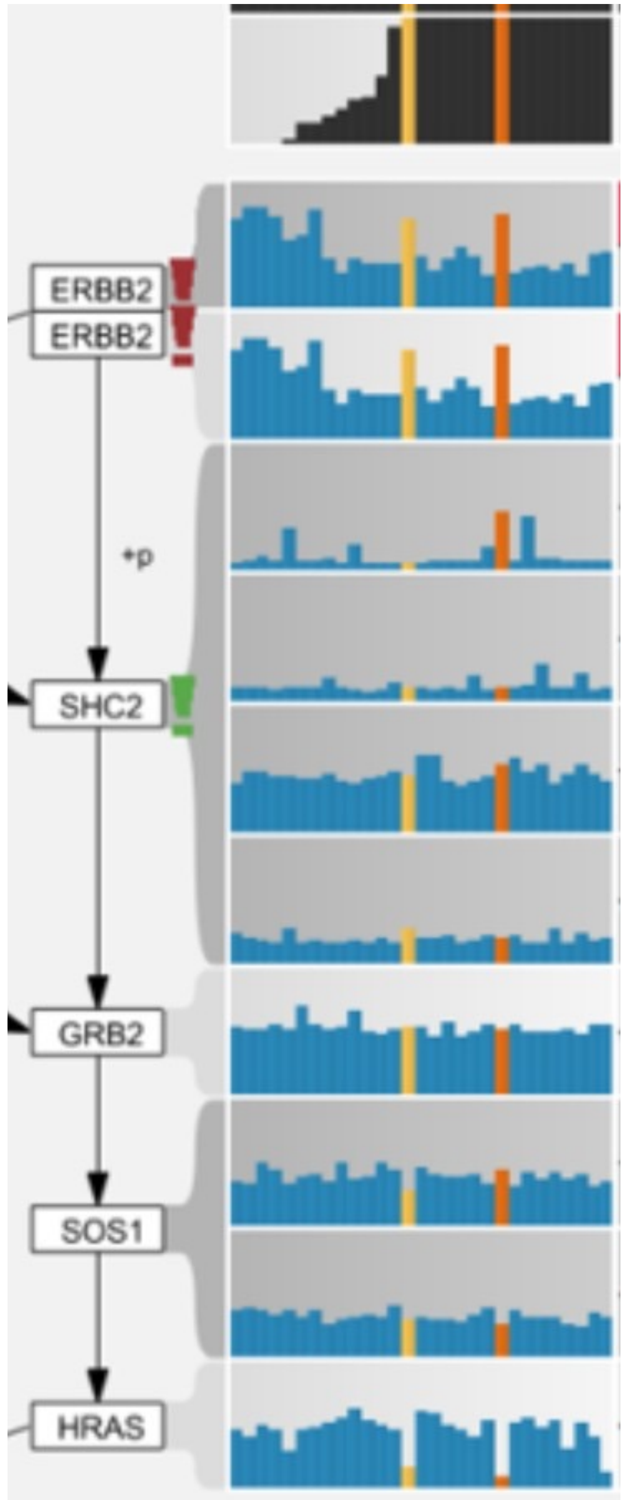
  -> Locate the outlier in the network

  -> Explore the topology

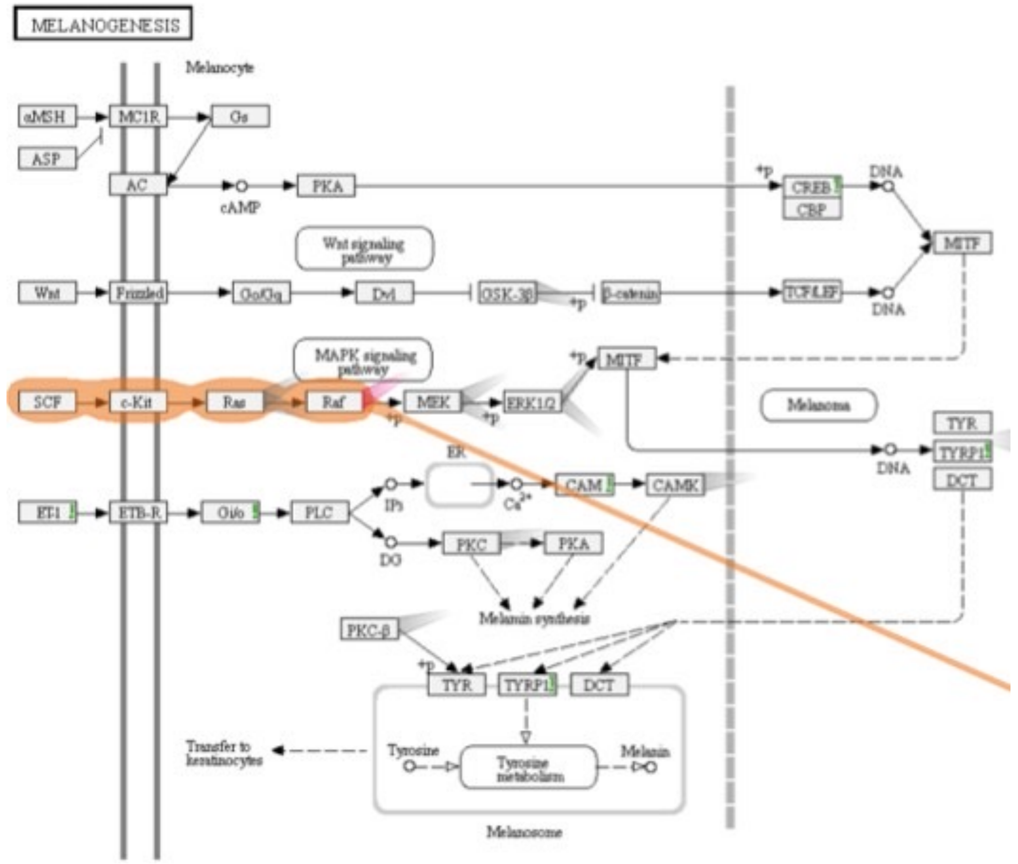


Encoding Design

- Tabular Data, 30 samples, 30 genes Compare groups, spot outliers
  - Dimensionality Reduction? — Doesn't show raw data, not great to compare groups.
  - Scatterplot Matrices? — 30 Dimensions is too much -> Scalability
  - Parallel Coordinates? — 30 Dimensions is a lot, coloring for comparison necessary
  - Heat Maps? — Work! Spatial separation of groups.
  - Bar Charts? — Work even better! 30x30 still feasible, encoding advantage



Encoding Design



- Network, 30 genes
- Explore Topology, Lookup Nodes
  - Matrix? — Doesn’t work for topology tasks
  - Treemap? — Doesn’t work for general networks
  - Node-Link Diagram? — Works well. Combine with Table through highlighting.

Designing Visualizations

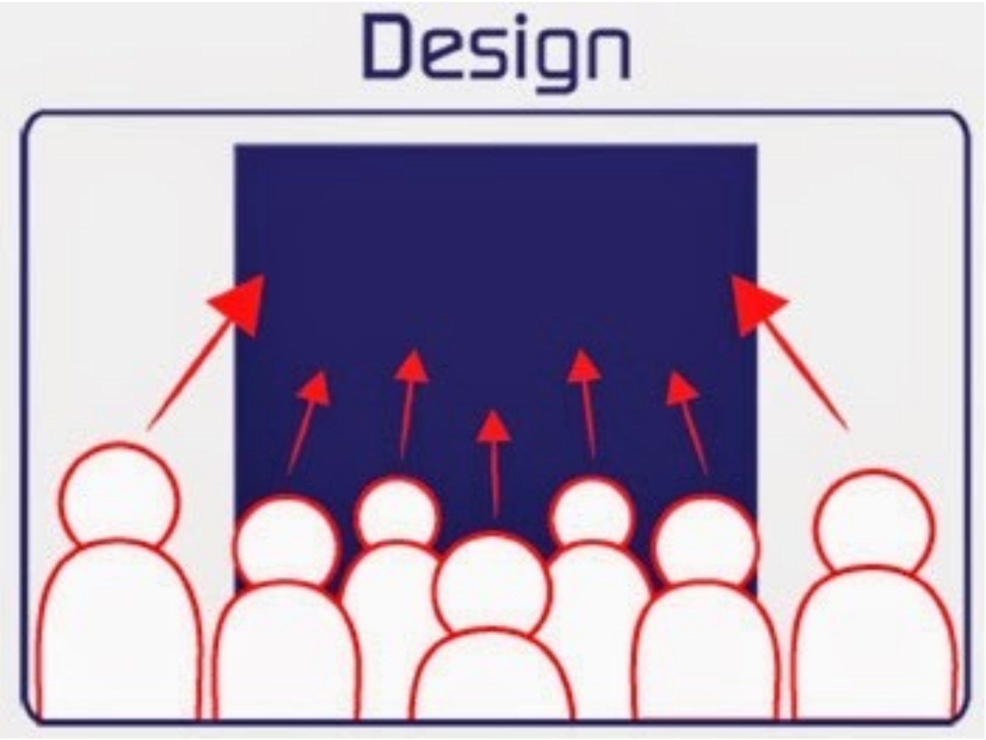
What is Design?

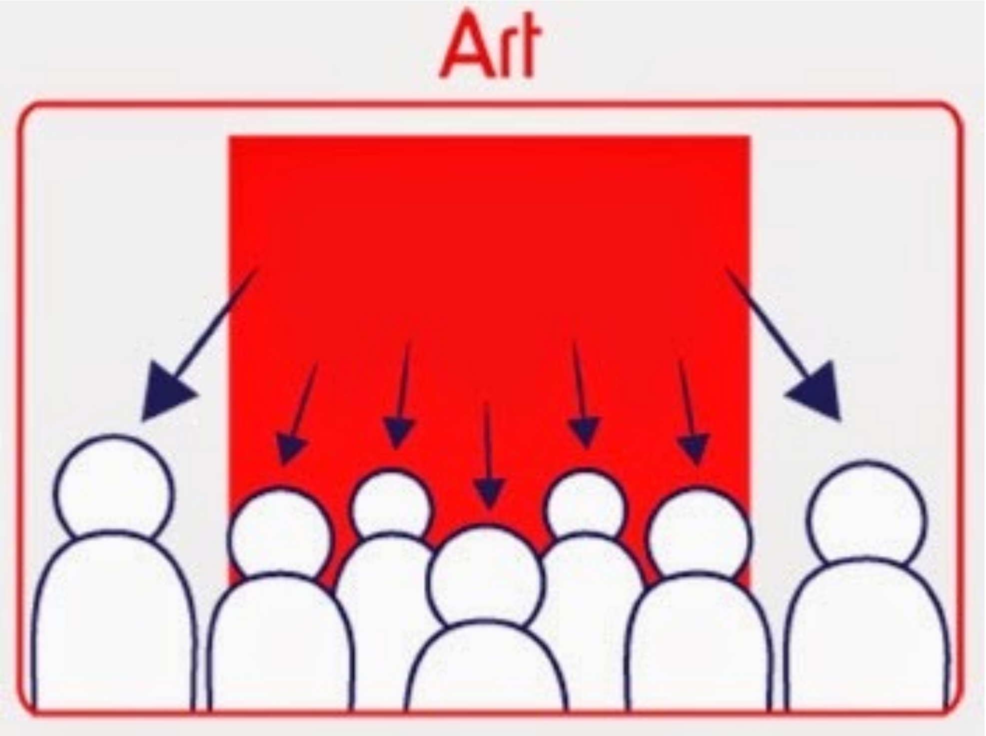
- creating something new to solve a problem
- can be used to make buildings, chairs, user interfaces, etc.
- design is used in many fields
- many possible users or tasks

https://www.youtube.com/watch?v=hUhisi2FBuw

What is Design Not?

- just making things pretty
- art – appreciation of beauty or emotions invoked
- something without a clear purpose
- building without justification or evidence





http://woodyart211.blogspot.com/2015/01/art-vs-design-comments.html

Form & Function

- commonly: “form follows function”
- function can constrain possible forms
- form depends on tasks that must be achieved
- “the better defined the goals of an artifact, the narrower the variety of forms it can adopt”

–Alberto Cairo

http://img.weburbanist.com/wp-content/uploads/2015/05/sculptural-furniture-main-960x481.jpg

When do we Design?

- wicked problems
  - no clear problem definition
  - solutions are either good enough or not good enough
  - multiple solutions exist, not true/false no clear point to stop with a solution
- examples of non-wicked (“tame”) problems
  - mathematics, chess, puzzles

Tacoma Narrows Bridge

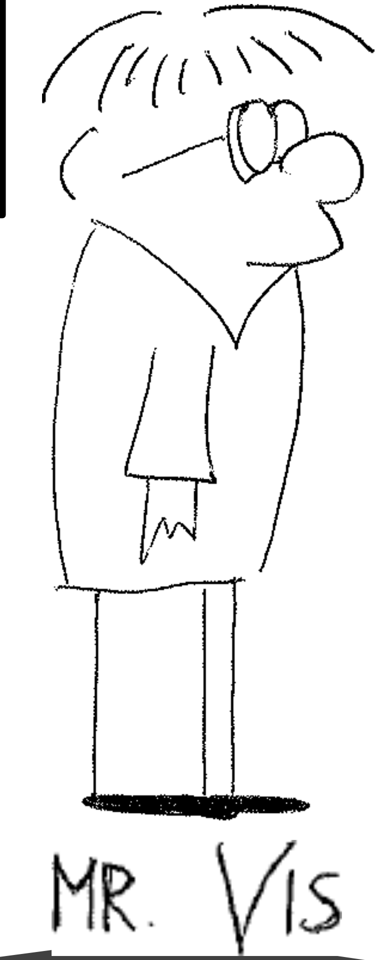
Why does Design Matter for Vis?

- many ineffective visualization combinations
- users with unique problems & data
- variations of tasks
- large design space

Pitfall

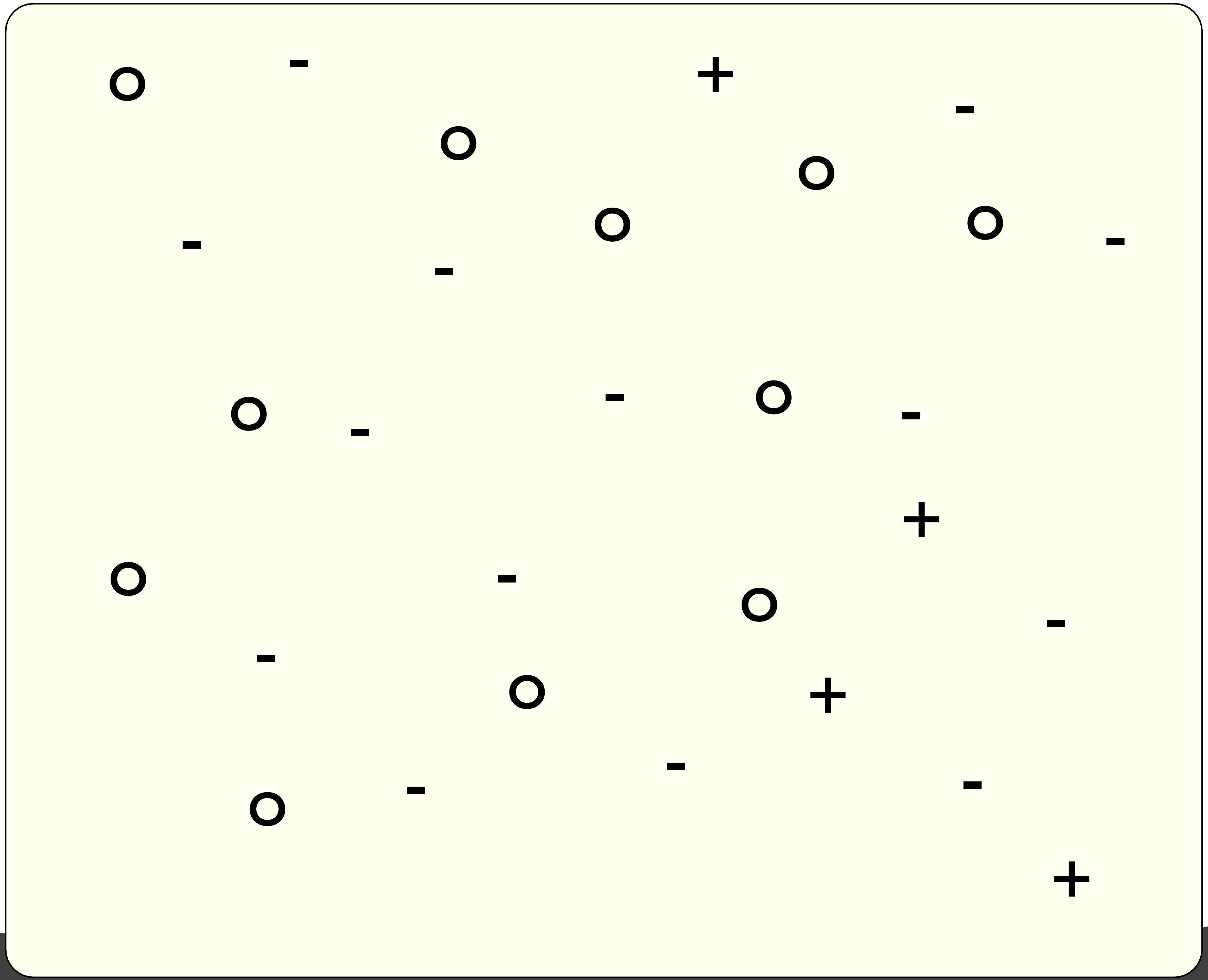
PREMATURE DESIGN COMMITMENT

Of course they need the cool **technique** I built last year!



Metaphor

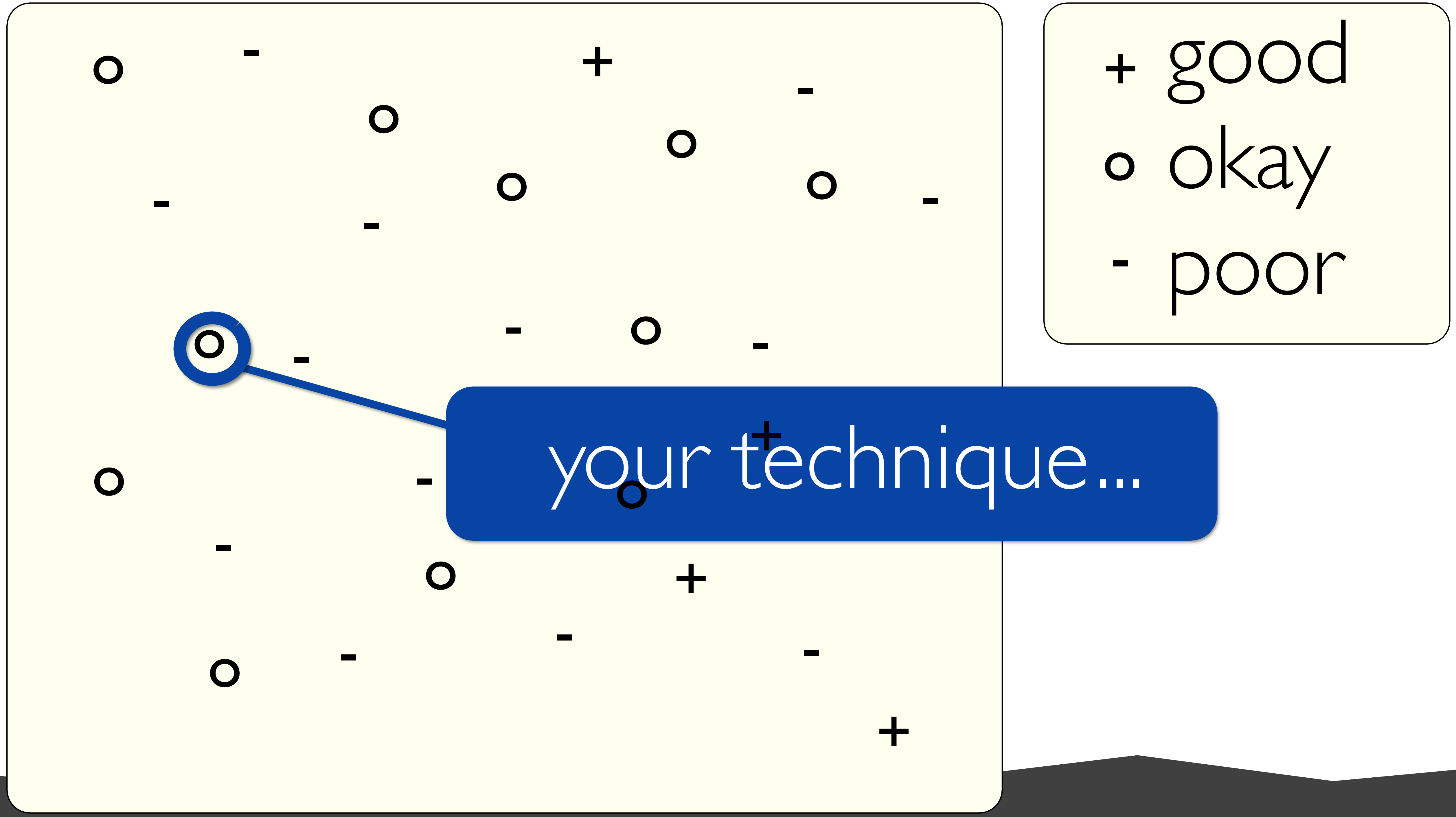
Design Space



+ good
o okay
- poor

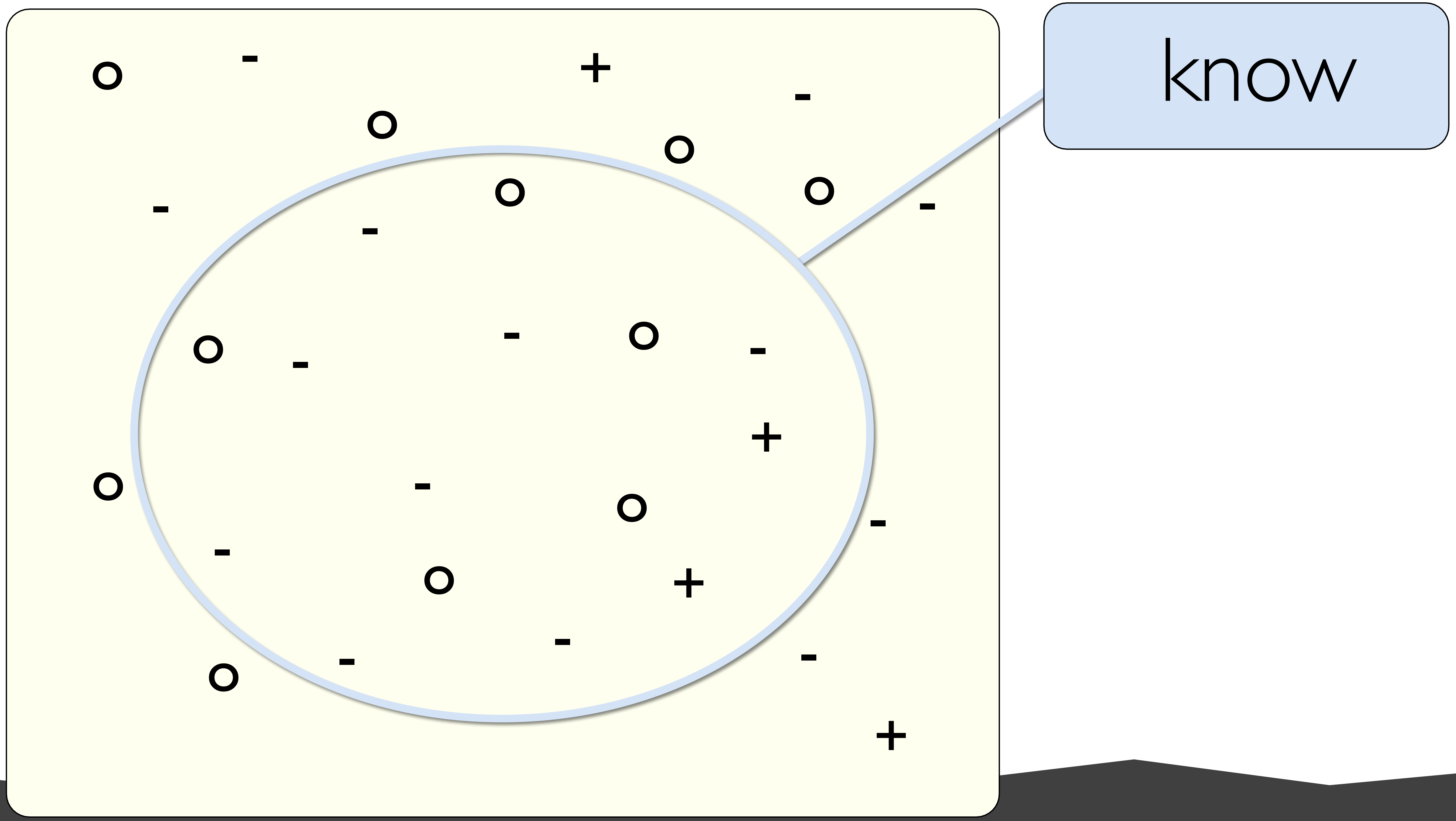
Metaphor

Design Space



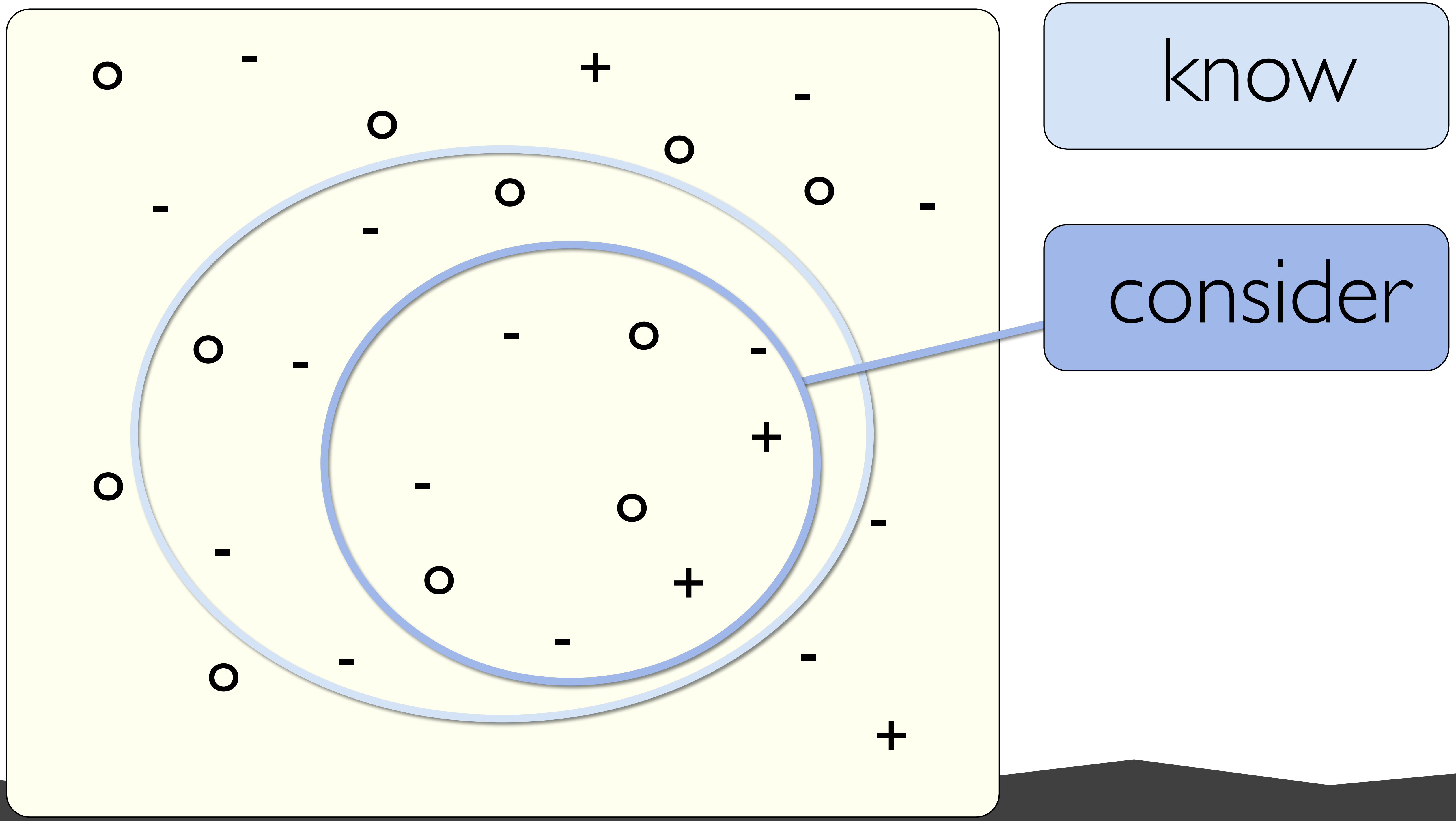
Metaphor

Design Space



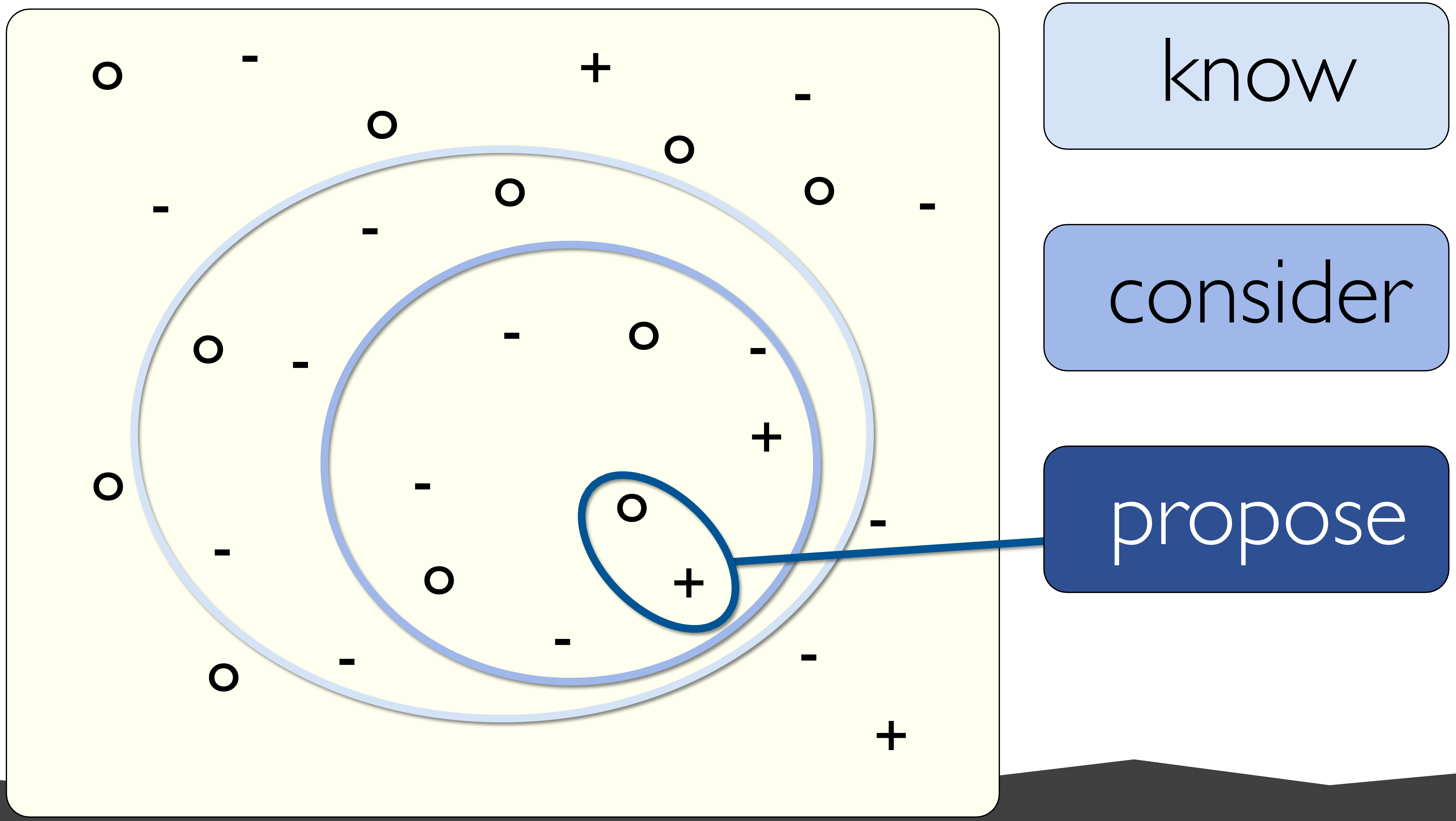
Metaphor

Design Space

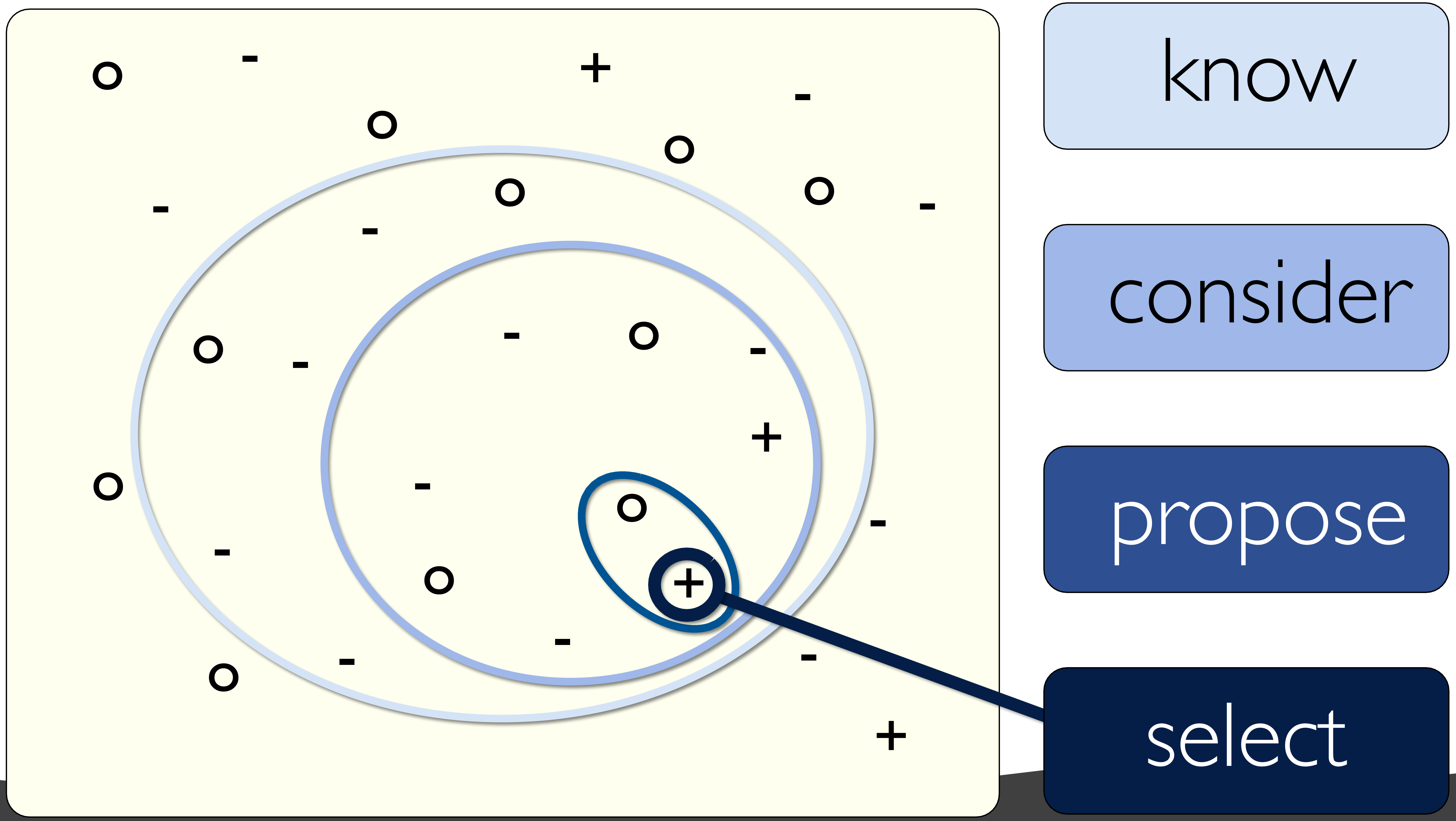


Metaphor

Design Space



Metaphor
Design Space



Metaphor

Design Space

+ good
o okay
- poor

consider

propose

select

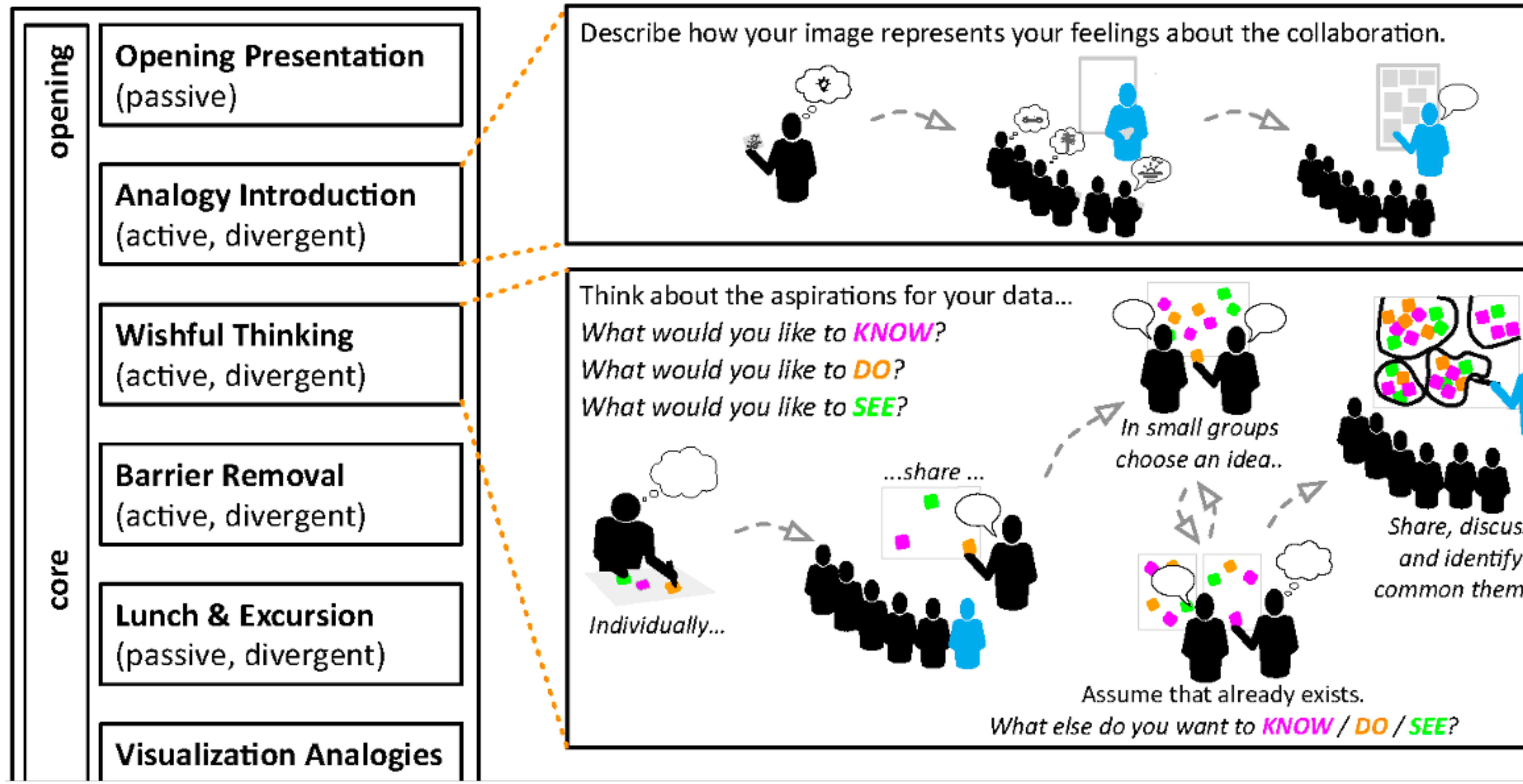
Think broad!

by T. Munzner

Design Methods

Creativity Workshops

- goals:
  - generate design requirements
  - promote creativity
- combined a variety of techniques:
  - wishful thinking
  - constraint removal
  - excursion
  - analogical reasoning
  - storyboarding
- measured prototypes for appropriateness, novelty, & surprise



http://vdl.sci.utah.edu/CVOWorkshops/


Wishful-thinking Questions
Recall a recent experience analyzing copy number, and possibly other genetic data. Record answers to the following questions about this analysis, using one post-it note per idea.
What would you like to know from this data?
What would you like to be able to do?
What would you like to see?

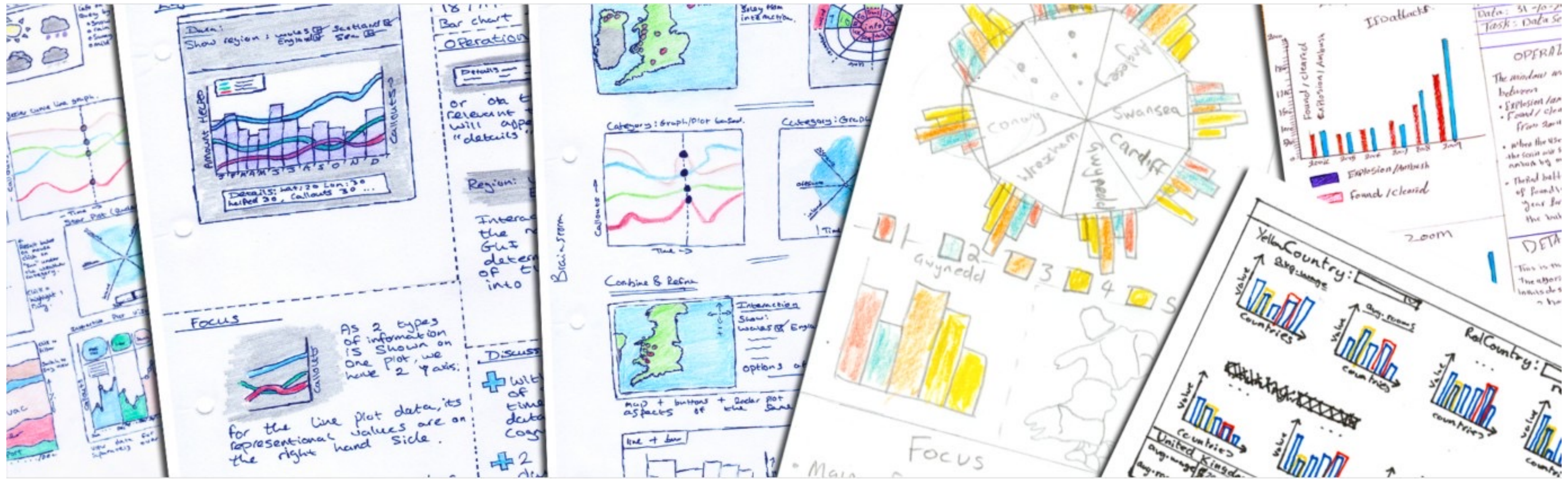
Parallel Prototyping

- Develop multiple designs in parallel
- Example: graphic design
- serial vs parallel design: create & critique

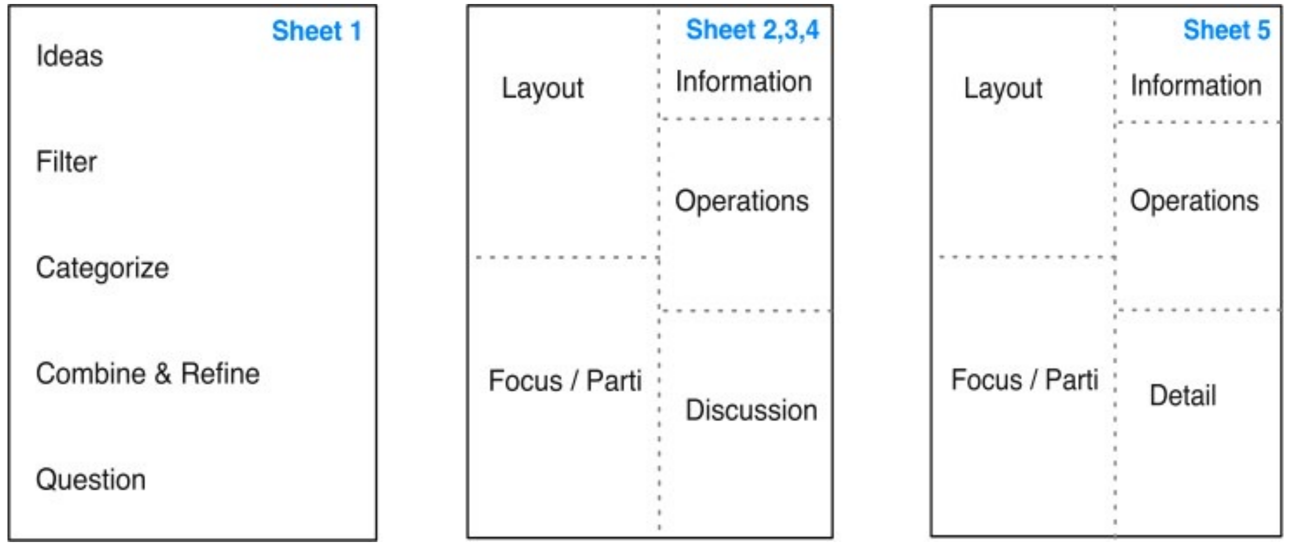
Parallel prototyping leads to better design results, more divergence, and increased self-efficacy. Dow, S.P., Glassco, A., Kass, J., Schwarz, M.,

Five-Design Sheets

- tailored to visualization design
  - in industry and classroom use sketching as a way to plan



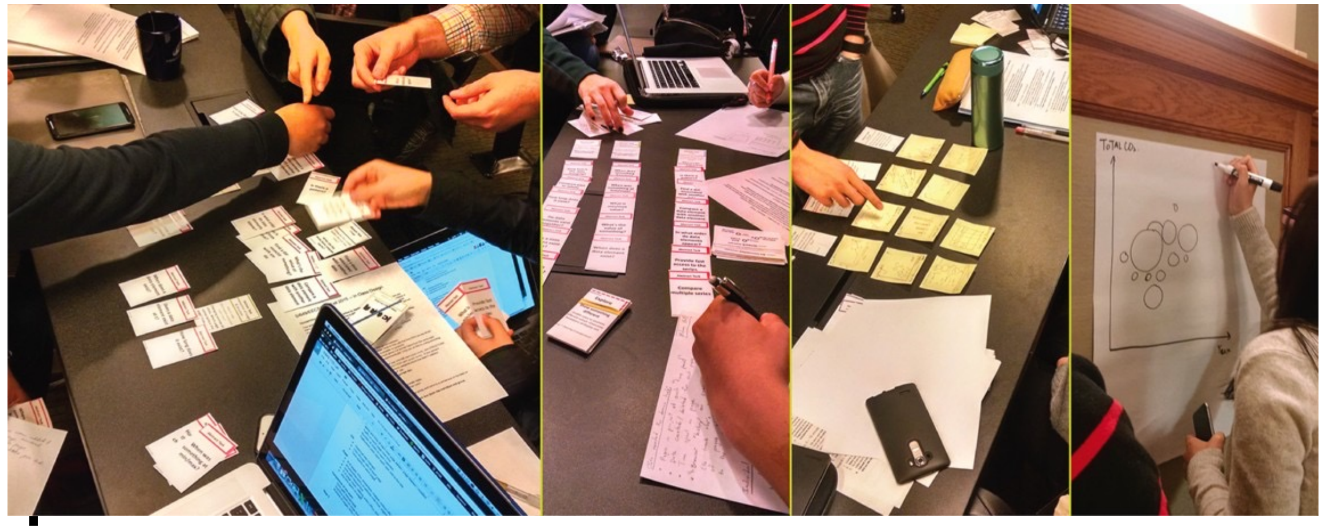
- the design sheets:
  - #1 brainstorm solutions to a task #2-4 different principle designs
  - #5 converge on design to implement



Sketching designs using the Five Design-Sheet methodology. Roberts, J.C., Headleand, C. and Ritsos, P.D., IEEE InfoVis, 2015.

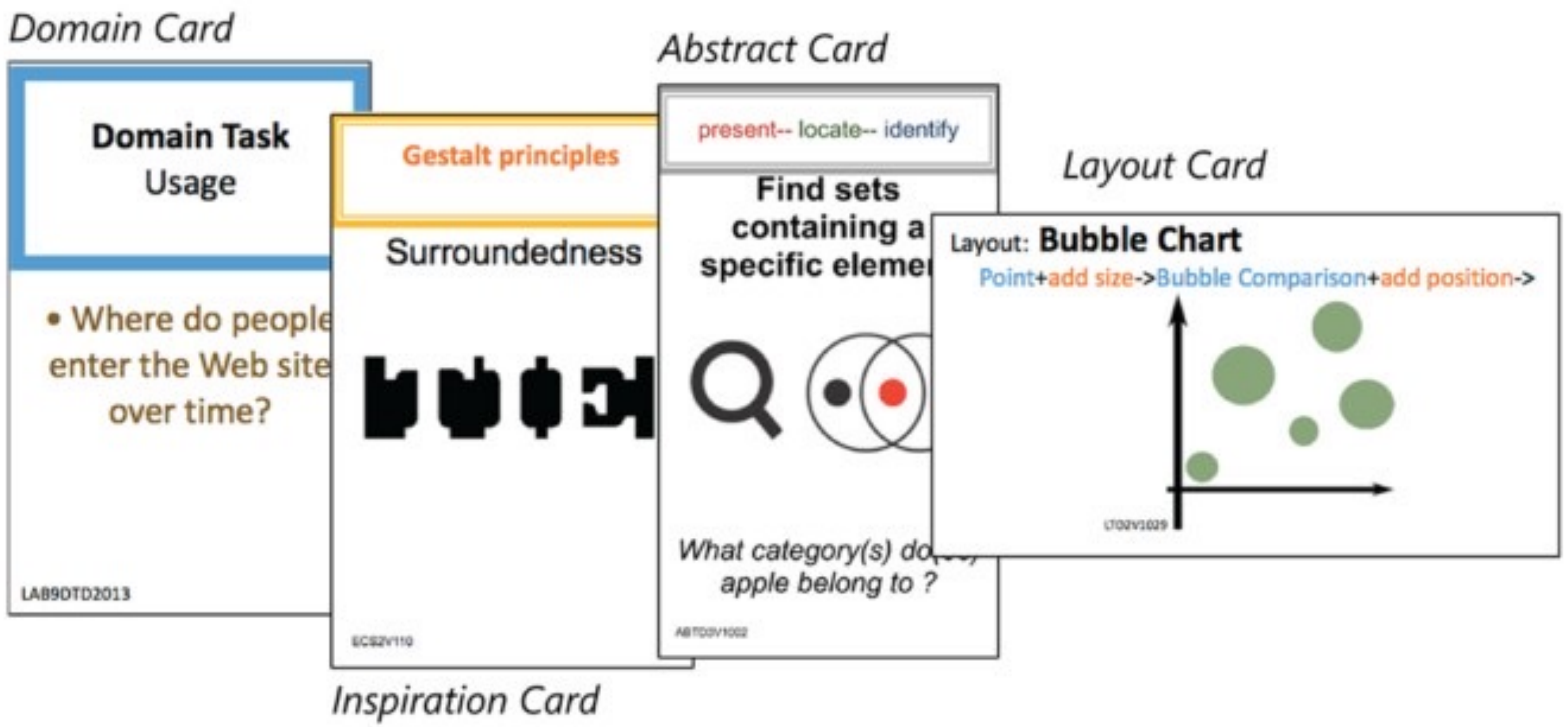
http://fds.design/

VizIt Cards



VizIt Cards: A card-based toolkit for infovis design education. He, S. and Adar, E., IEEE InfoVis, 2016.

- different cards to assist with visualization design
- types of cards
  - domain
  - inspiration
  - abstract
  - layout



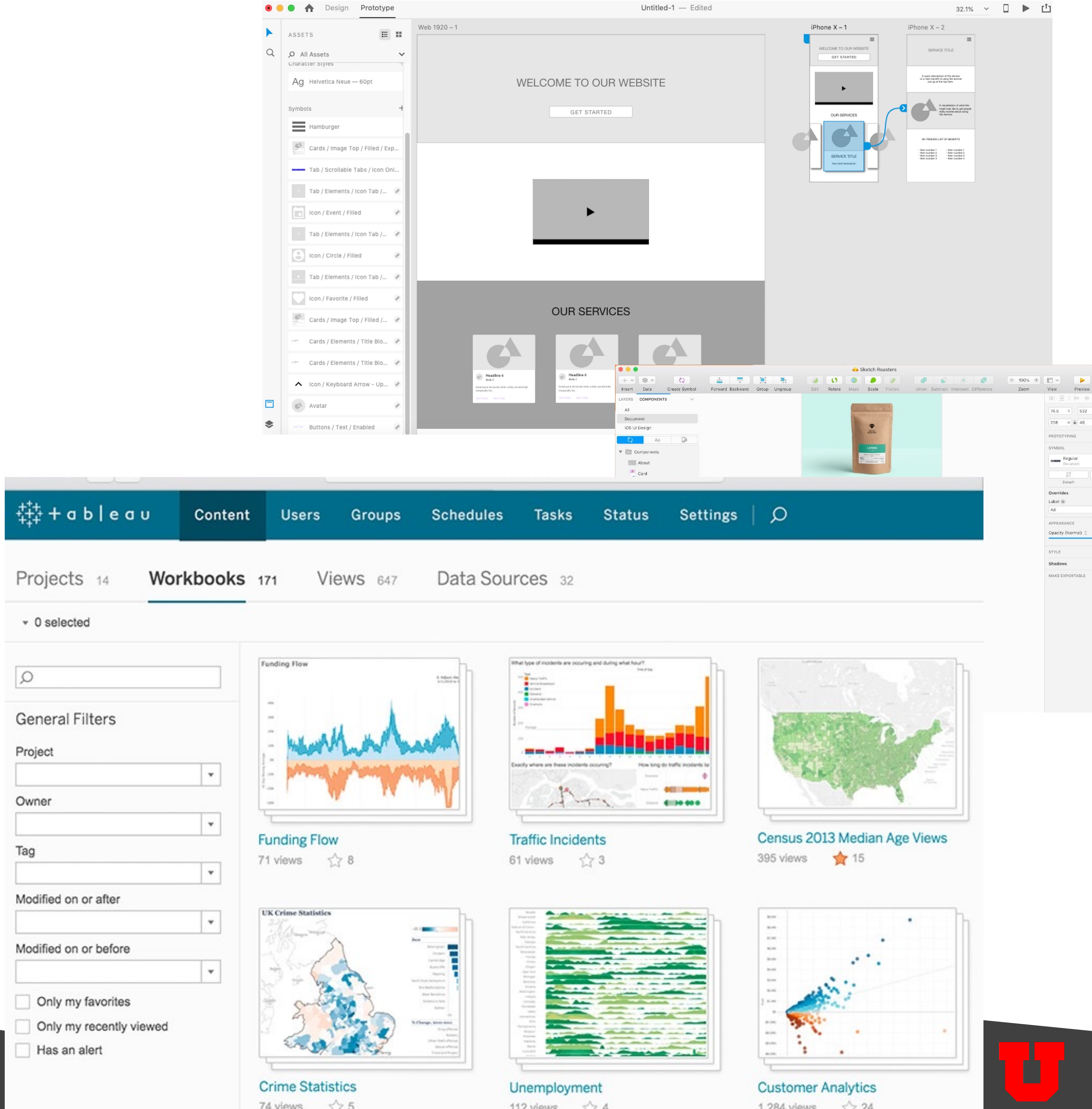
- aim to help students design, compare, collaborate, apply, and synthesize
- http://vizitcards.org

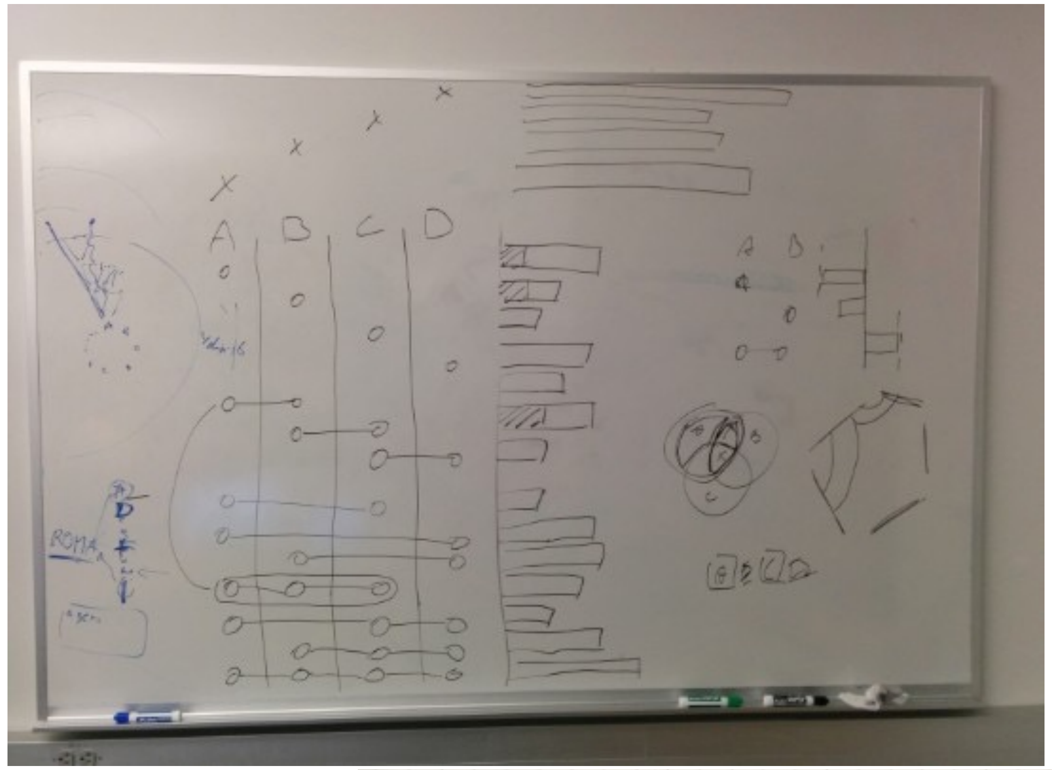
Wireframing

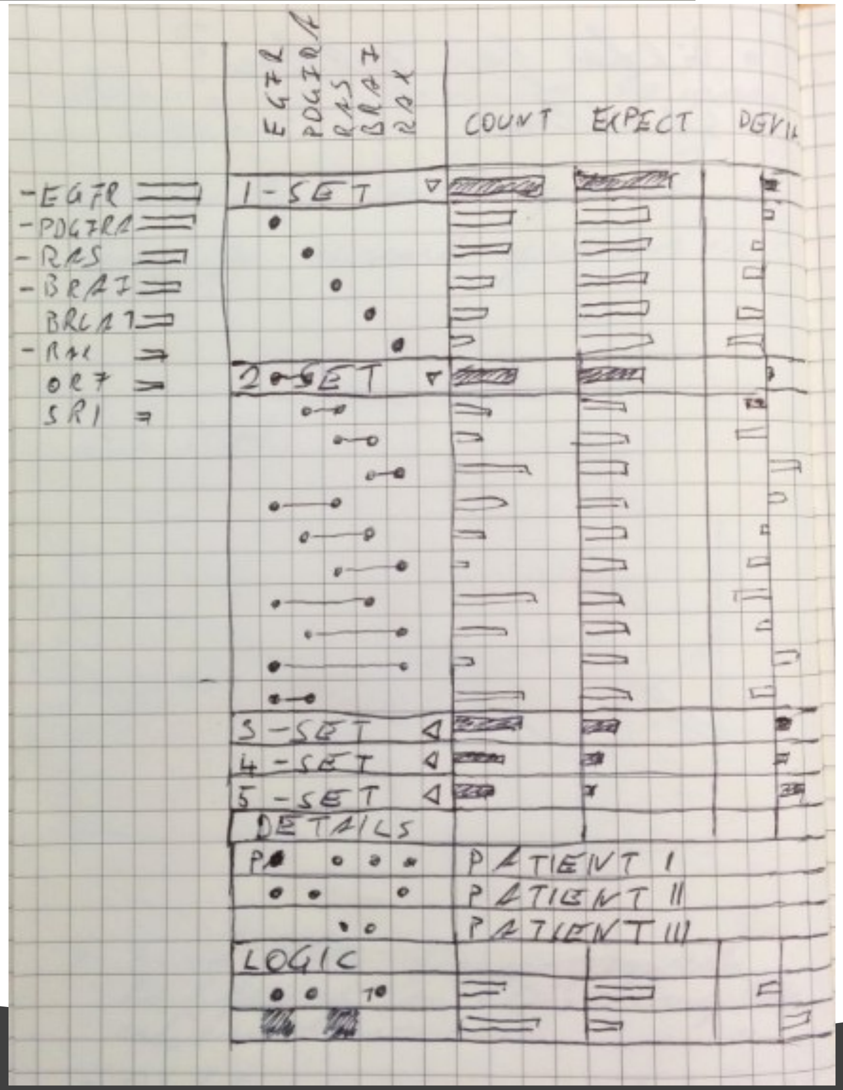
- Dedicated Tools like Figma, Adobe XD, or Sketch

- PowerPoint, Keynote, Illustrator

- Need Data: Tableau

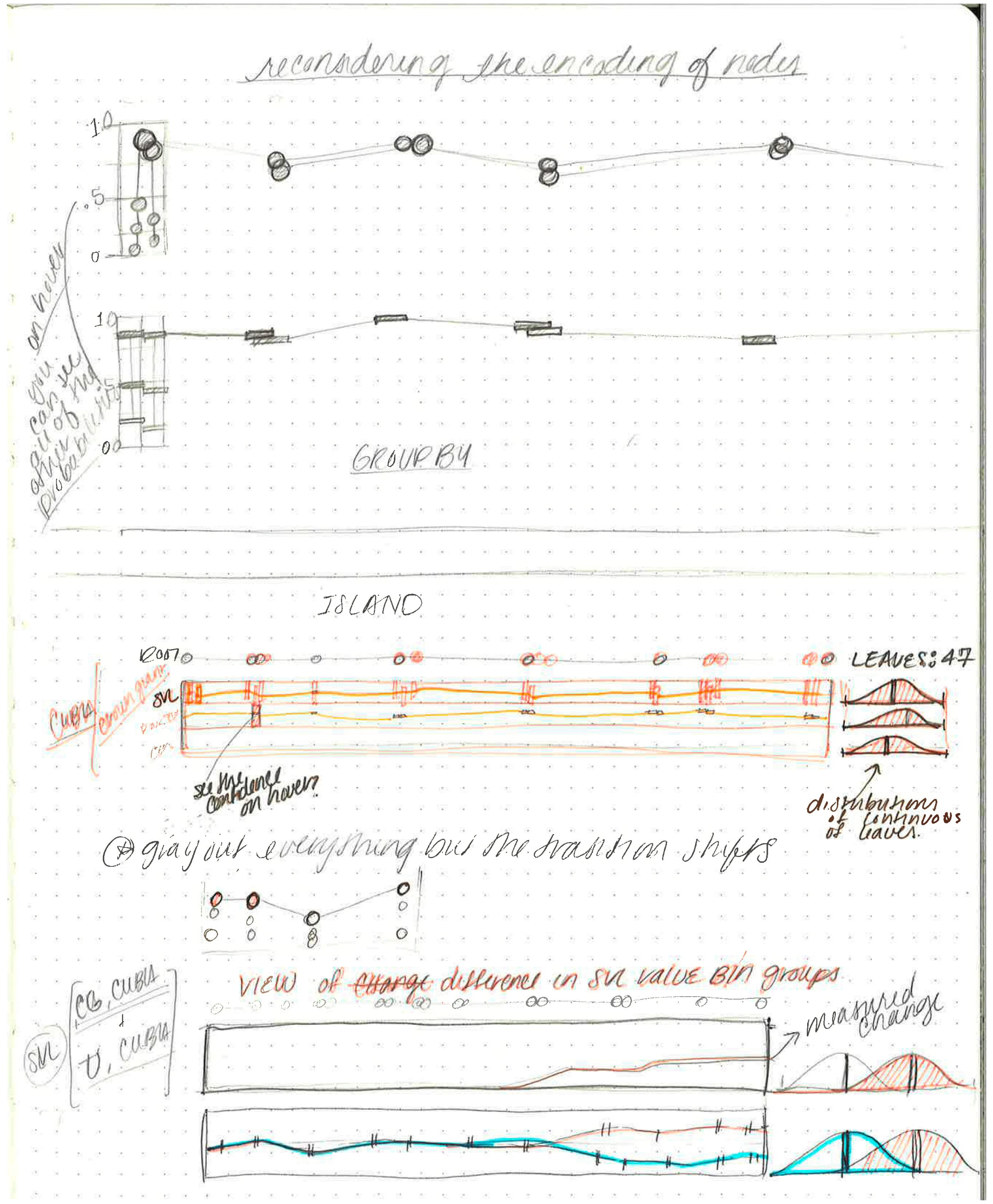




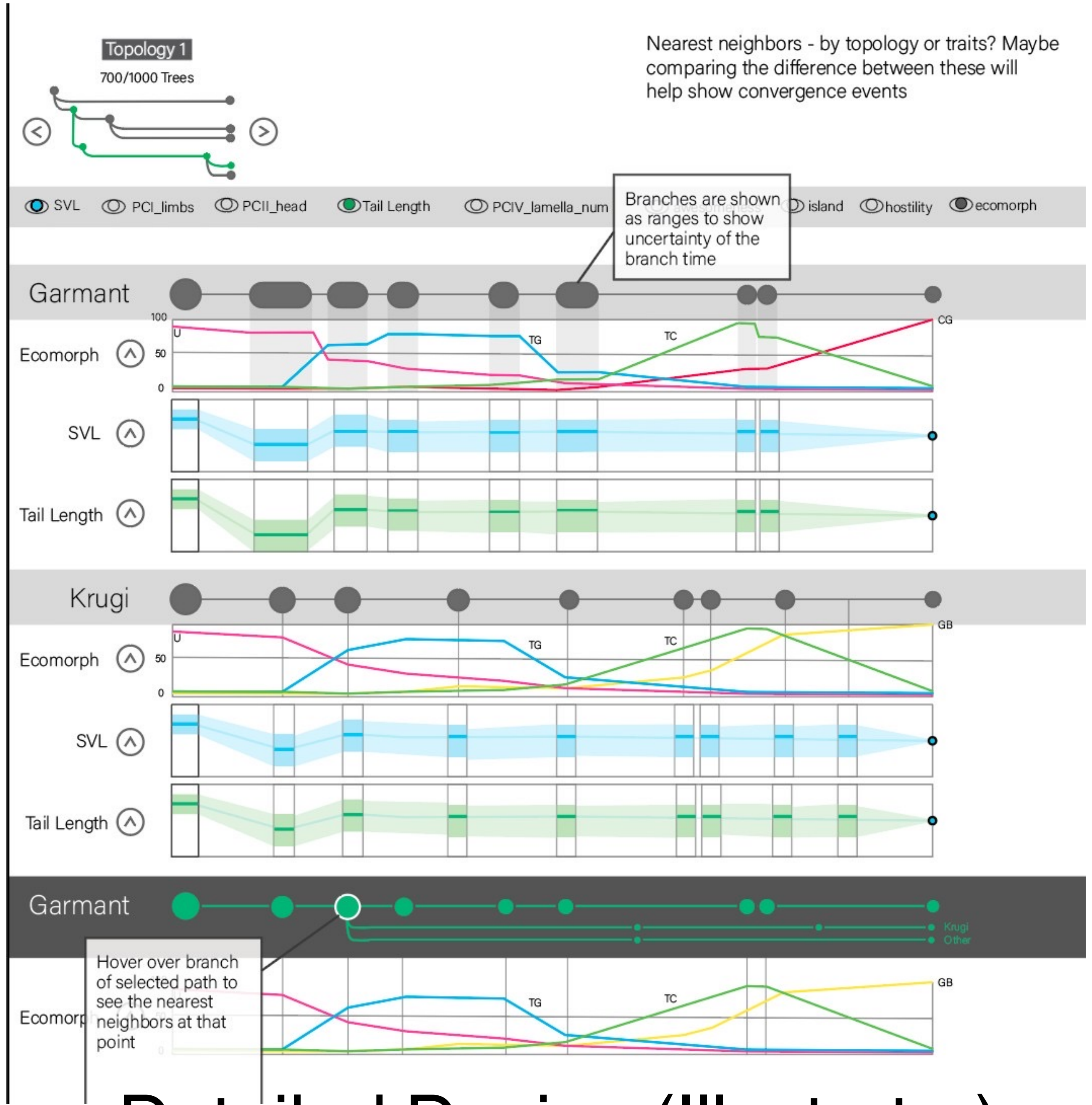

COUNT
EXPECT
1-SET
2-SET
3-SET
4-SET
5-SET
DETAILS
PATIENT I
PATIENT II
PATIENT III
LOGIC


UpSet - Visualizing Intersecting Sets
Choose Dataset
Movies Genres (17 sets, 4 attributes)
Load Data
About UpSet
UpSet for R
First, aggregate by
Sets
Then, aggregate by
Don't Aggregate
Sort by
Degree
Cardinality
Deviation
Aggregates
Collapse All
Expand All
Row Height
Large
Data
Min Degree:
Max Degree:
Hide Empty Intersections
Dataset Information
Name: Movies Genres
Sets: 17
Attributes: 6
Elements: 3883
Author: grouplens
Description: MovieLens ratings dataset, curated and filtered by Alsallakh.
Source: http://grouplens.org/d...
Set Selection
Batch Add Sets
Sort Sets
Query
No Set
Action
Adventure
Cardinality
Deviation
Release Date
Average Rating
Times Watched
Element Visualizations
Scatterplot
Element Queries
Query Filters
Subset | Sets
Name
Contains
Query Results
Name
Release Date
Average Rating
Times Watched
Set Count
Jumanji (1995)
Tom and Huck (1995)
GoldenEye (1995)
Cutthroat Island (1995)

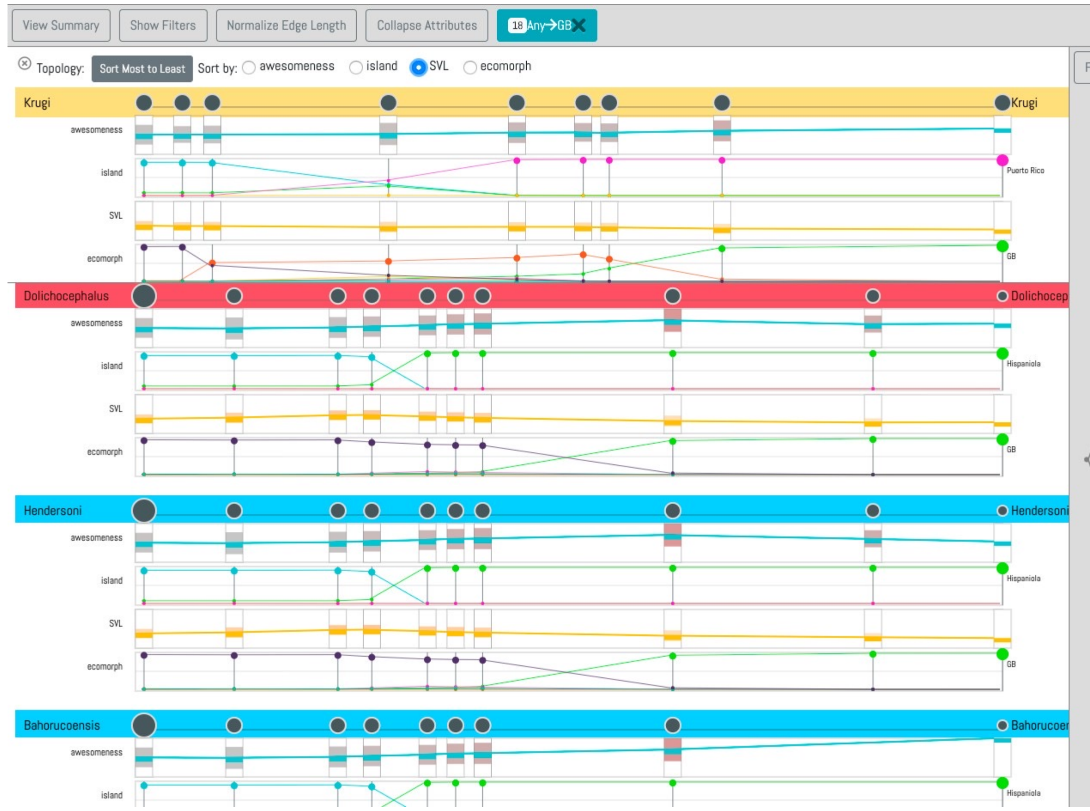
Implementation



Sketch

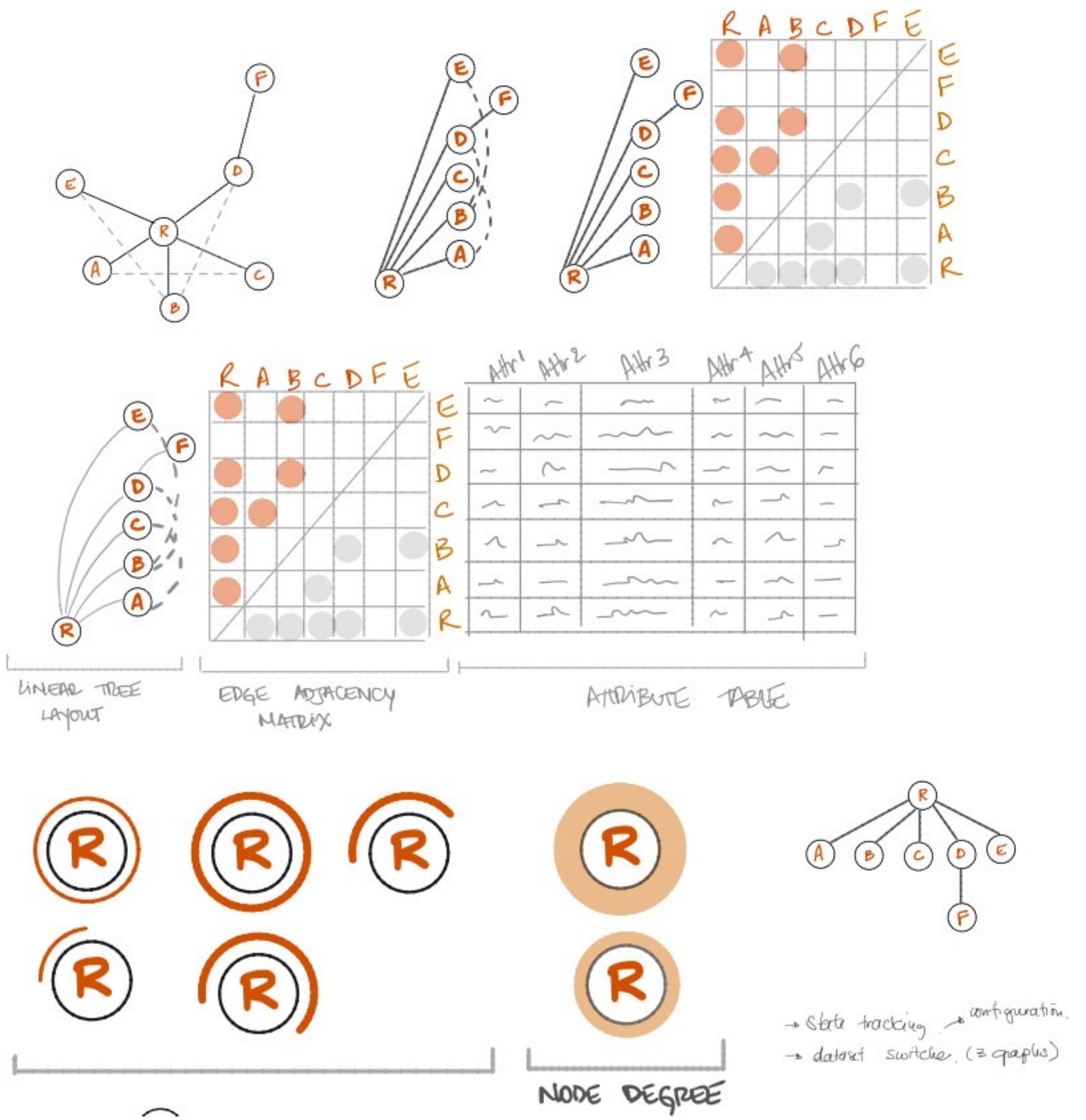


Detailed Design (Illustrator)

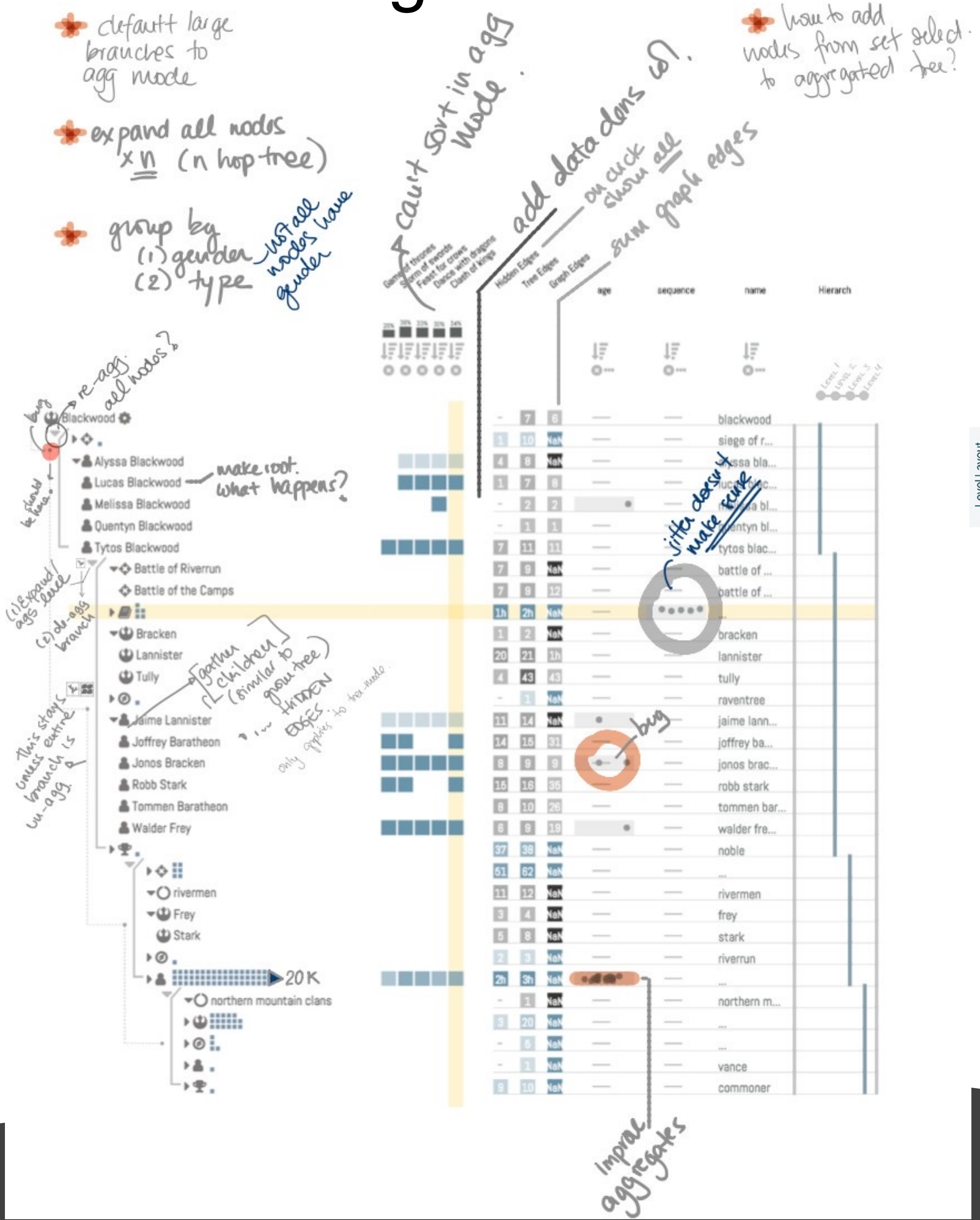


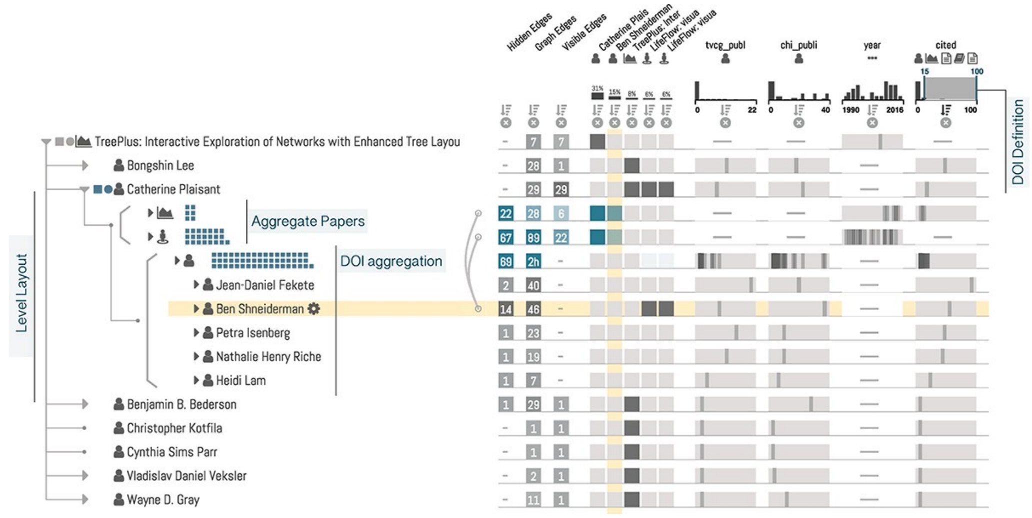
Implementation

Sketch



Design Review





Interactive Prototyping

- “create a **paper-based simulation of an interface** to test interaction with a user”

Methods to support human-centred design. Maguire, M., International Journal of Human-Computer Studies, 2001.

- received more suggestions than digital

- users requested more features to add

- hypothesis that paper prototyping stimulates creativity and interaction

Other Methods

- interviews/observations
- qualitative analysis
- personas
- data sketches
- coding

Evaluation

Evaluating Information Visualizations

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1 Introduction

Information visualization research is becoming more established, and as a result, it is becoming increasingly important that research in this field is validated. With the general increase in information visualization research there has also been an increase, albeit disproportionately small, in the amount of empirical work directly focused on information visualization. The purpose of this paper is to increase awareness of empirical research in general, of its relationship to information visualization in particular; to emphasize its importance; and to encourage thoughtful application of a greater variety of evaluative research methodologies in information visualization.

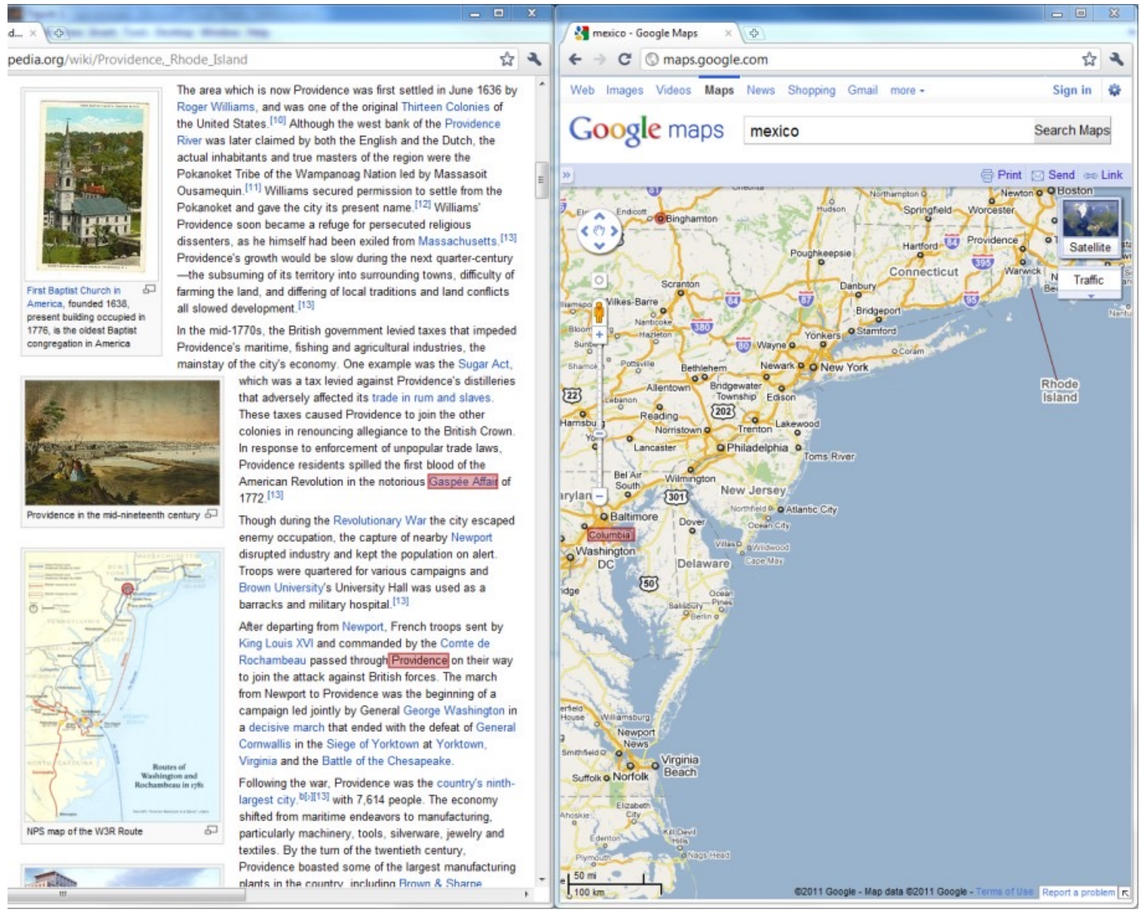
One reason that it may be important to discuss the evaluation of information visualization, in general, is that it has been suggested that current evaluations are not convincing enough to encourage widespread adoption of information visualization tools [57]. Reasons given include that information visualizations are often evaluated using small datasets, with university student participants, and using simple tasks. To en-

Role of Evaluation / Validation

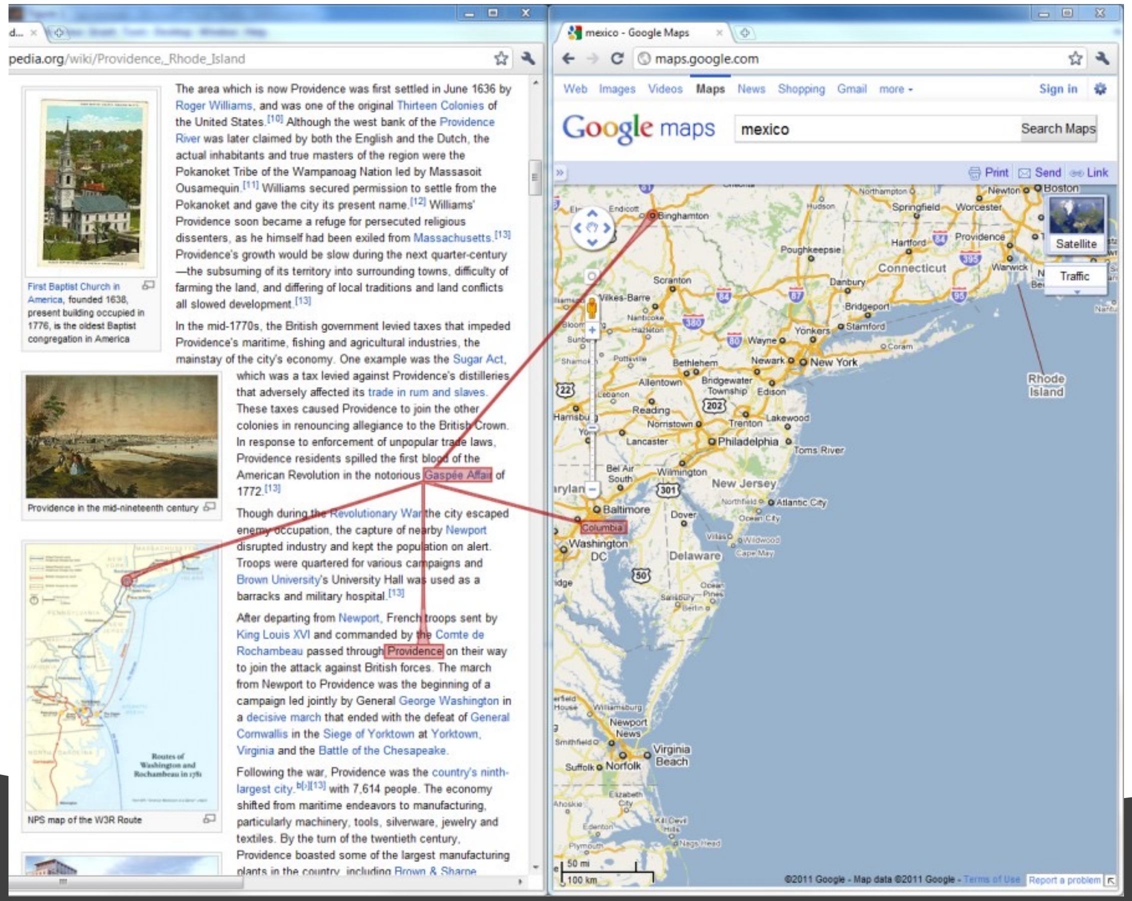
- Goals:
  - avoid ineffective solutions justify solutions
- Dimensions:
  - Perception vs Technique/System
    - Is size a better visual channel than angle?
    - Is my visualization system any good?
- Unique vs Comparison
  - Can I easily compare my vis to others?
  - Is mine one of a kind?
- Usability Testing:
  - Check for problems with system

Example: Three Linking Techniques Perception / Comparison

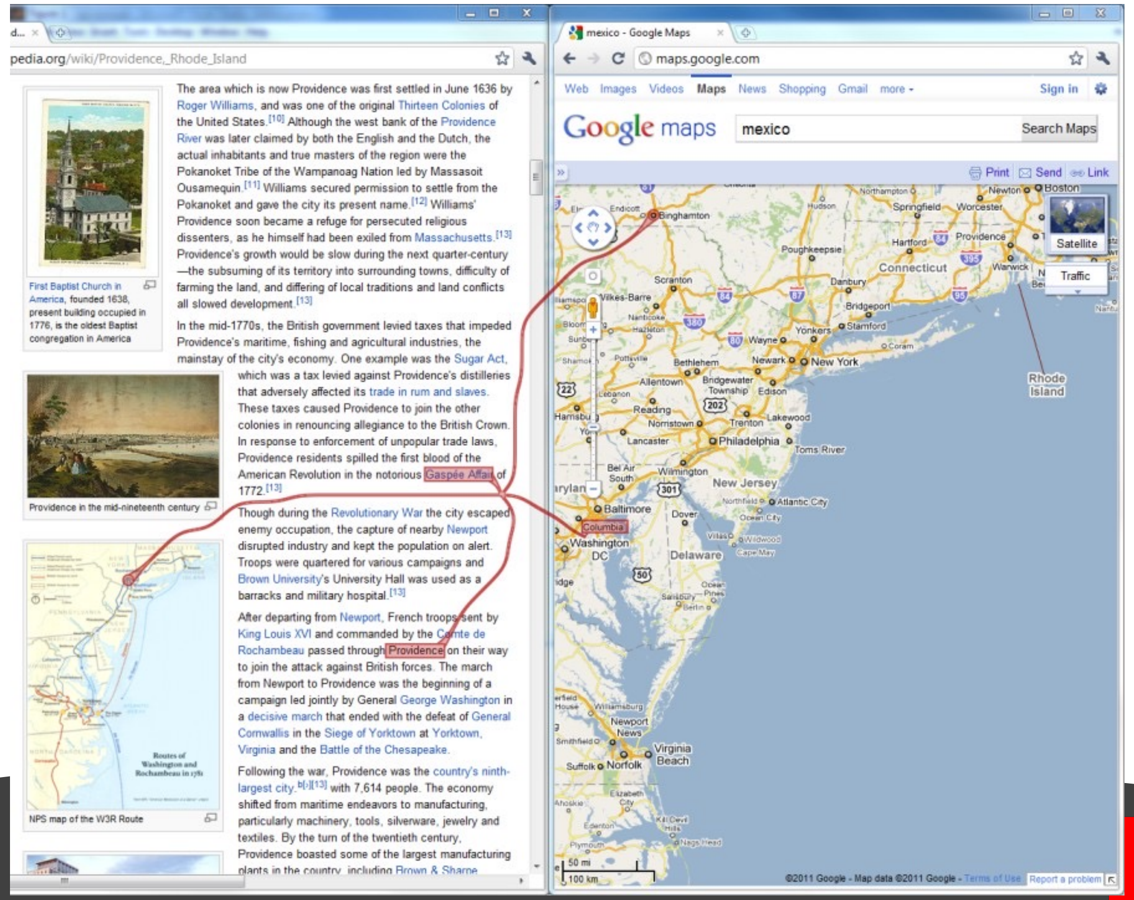
Frame-Based Highlighting



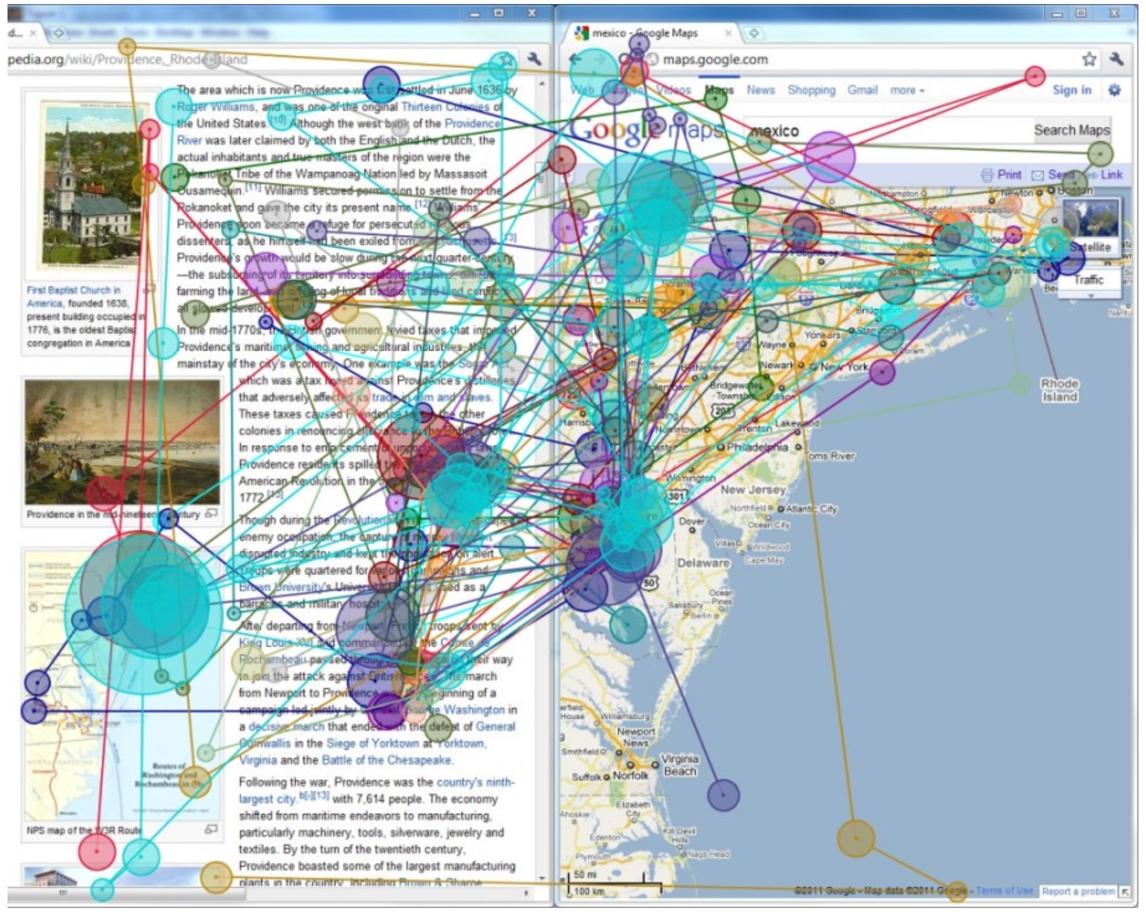
Straight Visual Links



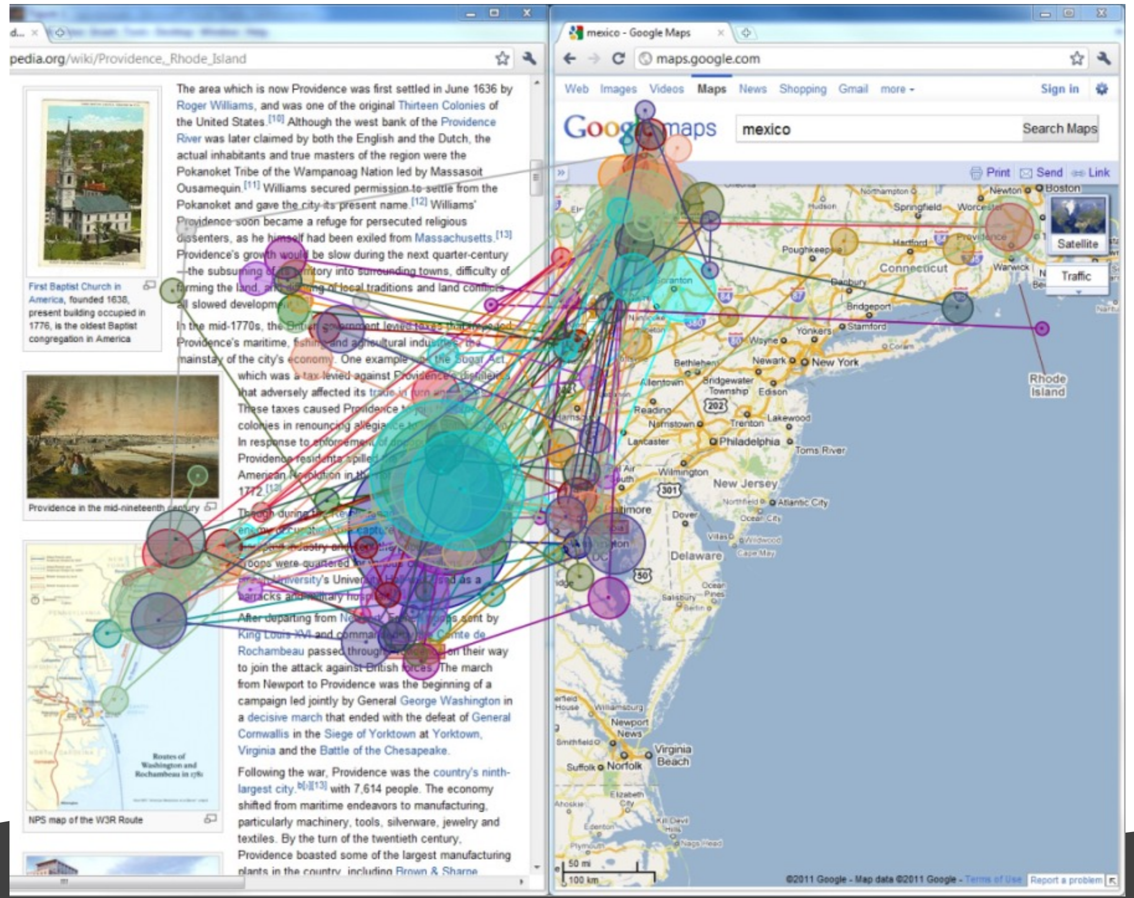
Context-Preserving Visual Links



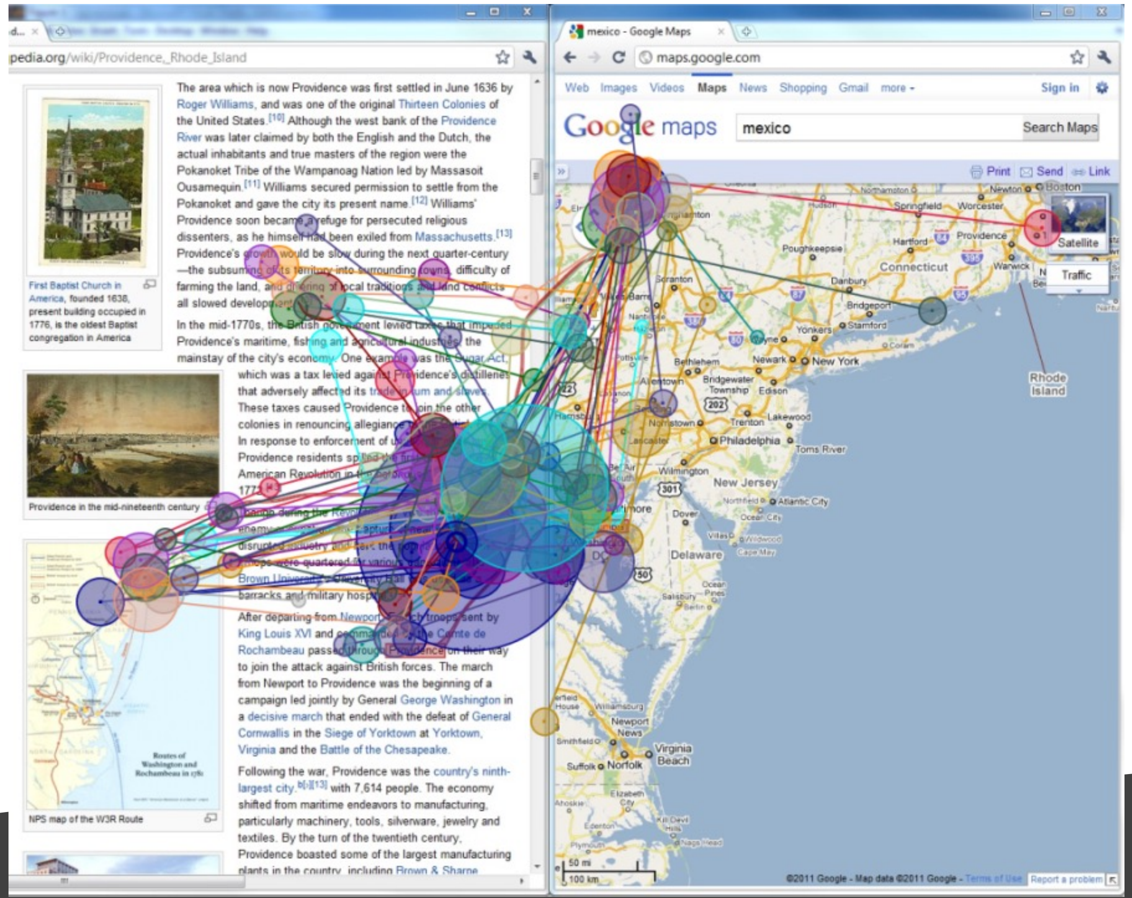
Gaze Plots
Frame-Based Highlighting



Straight Visual Links



Context-Preserving Visual Links



What evaluation methods are there?

- Controlled experiment
  - Laboratory, Crowd-Sourced
- Interviews / questionnaires
  - Unstructured, structured, semi-structured
- Field observation, lab observation
  - Video / audio analysis
  - Coding / classification of user behavior (speech, gestures)
- Case studies

Certainty over what causes differences
Not realistic (ecological validity)

↕

High ecological validity
Uncertain what causes differences

[Lam 2011]

What evaluation methods are there?

- Algorithmic performance measurement
- Heuristic evaluation
  - Judge compliance with recognized metrics/usability methods (the heuristics)
- Usability testing, e.g., thinking aloud tests
- Wizard of Oz
  - Human simulates response of system
  - Test functionality before it's implemented
- Eye tracker evaluation
- Expert evaluation
- Insight-based evaluation
- Log analysis

Patterns for visualization evaluation

Authors: Niklas Elmqvist, Ji Soo Yi Authors Info & Claims

BELIV '12: Proceedings of the 2012 BELIV Workshop: Beyond Time and Errors - Novel Evaluation Methods for Visualization • October 2012 • Article No.: 12 • Pages 1–8 • https://doi.org/10.1145/2442576.2442588

Published: 14 October 2012 Publication History

ABSTRACT

We propose a patterns-based approach to evaluating data visualization: a set of general and reusable solutions to commonly occurring problems in evaluating tools, techniques, and systems for visual sensemaking. Patterns have had significant impact in a wide array of disciplines, particularly software engineering, and we believe that they provide a powerful lens for looking at visualization evaluation by offering practical, tried-and-tested tips and tricks that can be adopted immediately. The 12 patterns presented here have also been added to a freely editable Wiki repository. The motivation for creating this evaluation pattern language is to (a) disseminate hard-won experience on visualization evaluation to researchers and practitioners alike; to (b) provide a standardized vocabulary for designing

Quantitative vs. Qualitative Evaluation

- Quantitative Methods
  - Objective metrics, measurements
  - Use numbers / statistics for interpreting data
- Qualitative Methods
  - Subjective metrics
  - Description of situations, events, people, interactions, and observed behaviors, the use of direct quotations from people about their experiences, attitudes, beliefs, and thoughts
  - Focused on understanding how people make meaning of and experience their environment or world

Typical Metrics

Objective Metrics

- Task completion time
- Errors (number, percent,…)
- Percent of task completed
- Ratio of successes to failures
- Number of repetitions
- Number of commands used
- Number of failed commands
- Physiological data (heart rate,…)
- Numbers of insights
- …

Subjective Metrics

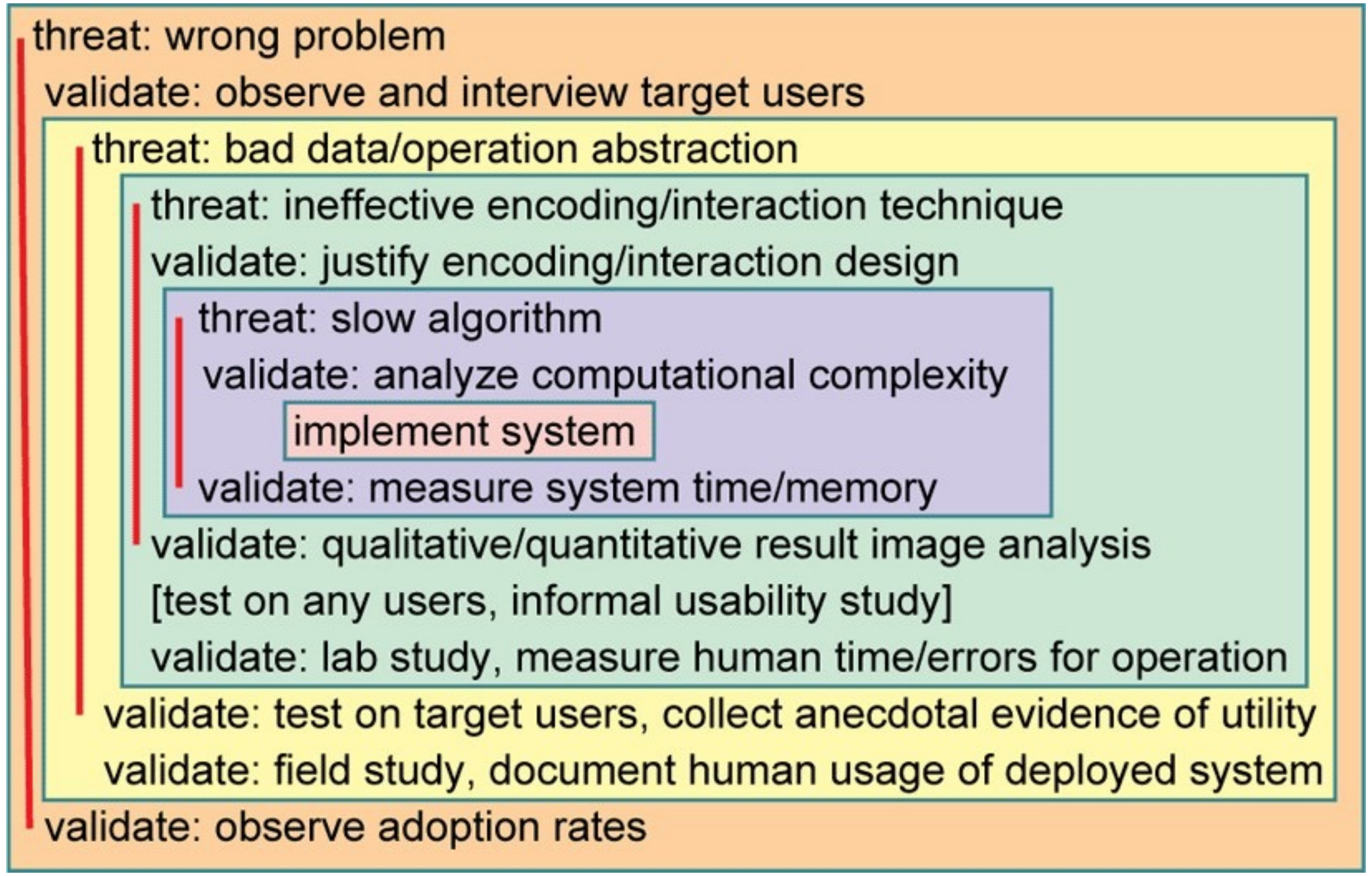
- Ratings
- Rankings
- User satisfaction
- Subjective performance
- Ease of use
- Intuitiveness
- Judgments
- Comments and Feedback
- …

Internal vs. External Validity

- Internal Validity – can you trust your experiment
  - High when tested under controlled lab conditions
  - Observed effects are due to the test conditions (and not random variables)
- External Validity – is your experiment representative of real world usage
  - High when interface is tested in the field, e.g. handheld device tested in museum
  - Results are valid in real world
- The Trade-off
  - The more akin to real-world situations, the more the experiment is susceptible to uncontrolled sources of variation

Scope of Evaluation

- Pre-design
  - e.g., to understand potential users' work environment and workflow
- Design
  - e.g., to scope a visual encoding and interaction design space based on human perception and cognition
- Prototype
  - e.g., to see if a visualization has achieved its design goals, to see how a prototype compares with the current state-of-the-art systems or techniques
- Deployment
  - e.g., to see how a visualization influences workflow and work processes, to assess the visualization's effectiveness and uses in the field
- Re-design
  - e.g., to improve a current design by identifying usability problems



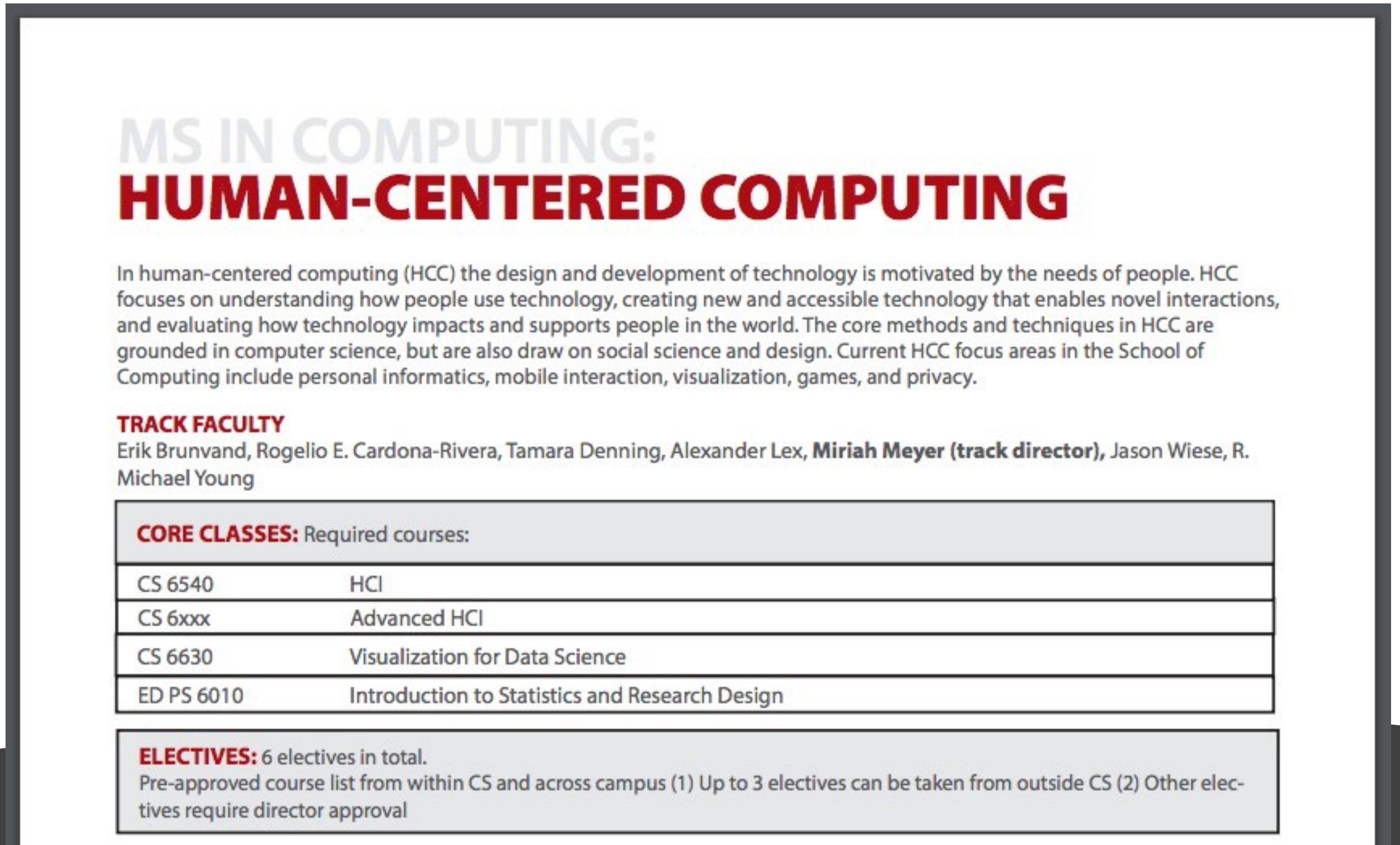
Added value should be obvious!

Develop new methods/interface/software that are so awesome, cool, impressive, compelling, fascinating, and exciting that reviewers, colleagues, users are totally convinced just by looking at your work and some examples.

— Jarke van Wijk, Capstone Talk @ IEEE VIS 2013

More on this Topic

- CS 6540 – HCI
- CS 6963 – Advanced HCI
- ED PS 6010 – Intro Statistics and Research Design
- DES 5710 – Product Design and Development
- ANTH 6169 – Ethnographic Methods
- ED PS 6030 – Introduction to Research Design



MS IN COMPUTING:
HUMAN-CENTERED COMPUTING

In human-centered computing (HCC) the design and development of technology is motivated by the needs of people. HCC focuses on understanding how people use technology, creating new and accessible technology that enables novel interactions, and evaluating how technology impacts and supports people in the world. The core methods and techniques in HCC are grounded in computer science, but are also draw on social science and design. Current HCC focus areas in the School of Computing include personal informatics, mobile interaction, visualization, games, and privacy.

TRACK FACULTY
Erik Brunvand, Rogelio E. Cardona-Rivera, Tamara Denning, Alexander Lex, **Miriah Meyer (track director),** Jason Wiese, R. Michael Young

CORE CLASSES: Required courses:	
CS 6540	HCI
CS 6xxx	Advanced HCI
CS 6630	Visualization for Data Science
ED PS 6010	Introduction to Statistics and Research Design

ELECTIVES: 6 electives in total.
Pre-approved course list from within CS and across campus (1) Up to 3 electives can be taken from outside CS (2) Other electives require director approval