Developing Design Spaces for Visualization

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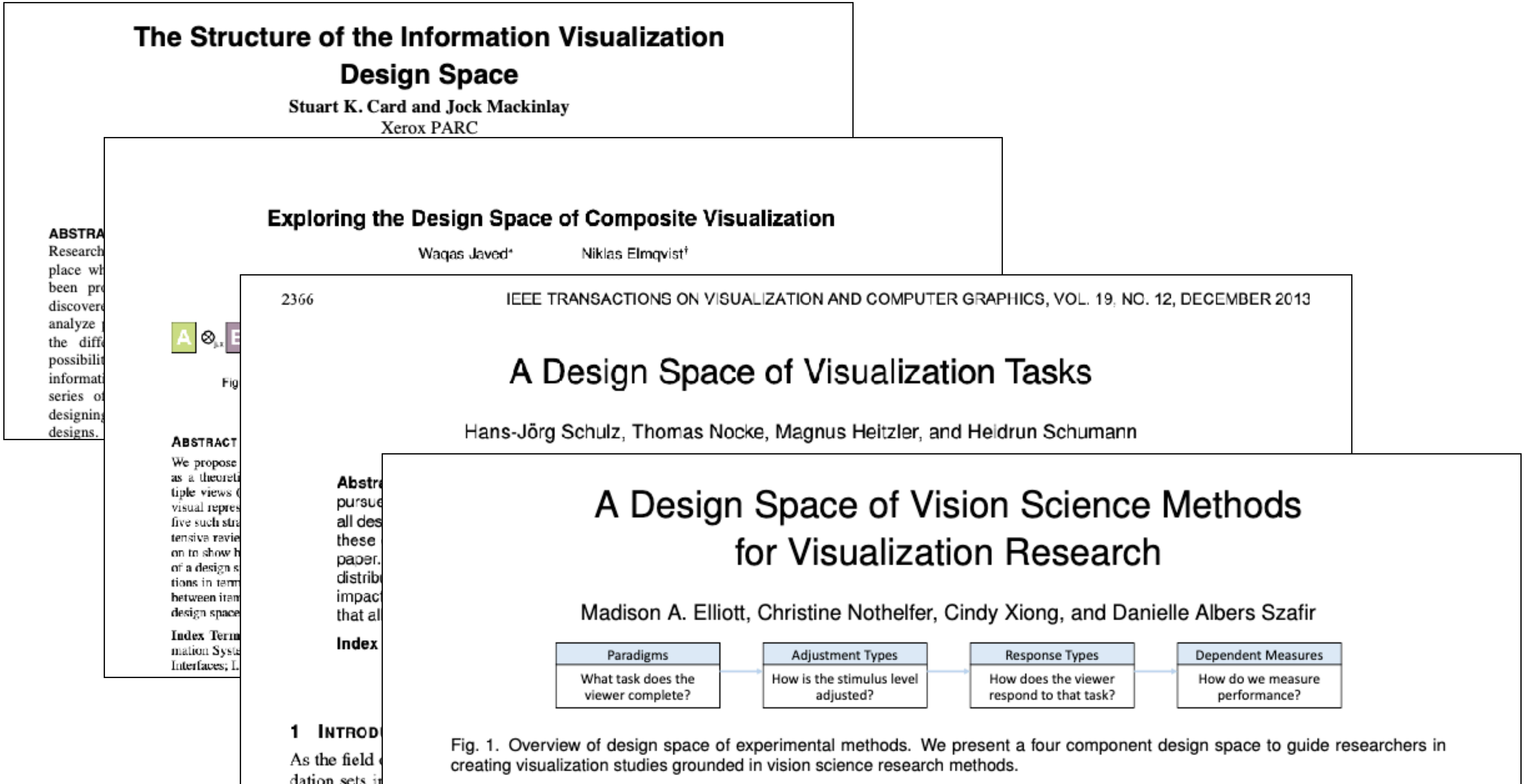
Stanford HCI Seminar
4 March 2022, virtual

http://www.cs.ubc.ca/~tmm/talks.html#stanf22

@tamaramunzner

Design spaces: Continuing theme



The Structure of the Information Visualization Design Space

Stuart K. Card and Jock Mackinlay
Xerox PARC

ABSTRA
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designs.

Exploring the Design Space of Composite Visualization

Waqas Javed* Niklas Elmqvist†

Fig

ABSTRACT
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Interfaces; I

2366 IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, VOL. 19, NO. 12, DECEMBER 2013

A Design Space of Visualization Tasks

Hans-Jörg Schulz, Thomas Nocke, Magnus Heitzler, and Heidrun Schumann

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Index

1 INTROD
As the field
dation sets

A Design Space of Vision Science Methods for Visualization Research

Madison A. Elliott, Christine Nothelfer, Cindy Xiong, and Danielle Albers Szafir

Paradigms	Adjustment Types	Response Types	Dependent Measures
What task does the viewer complete?	How is the stimulus level adjusted?	How does the viewer respond to that task?	How do we measure performance?

Fig. 1. Overview of design space of experimental methods. We present a four component design space to guide researchers in creating visualization studies grounded in vision science research methods.

Design spaces: **What** are they?

- impose **systematic structure** on set of possibilities for specific problem
  - to capture the key variables at play
  - to support **reasoning about design choices**

- delineate
  - **cross-cutting** / independent / orthogonal
  - **axes** / dimensions / categories

- many names
  - design spaces, taxonomies, typologies, classifications, frameworks, models, ...
  - space within which to express design patterns *[Javed/Elmqvist]*

Design spaces: What are they **for**?

- describe and analyze portions of design space to **understand differences** among designs & **suggest new** possibilities *[Card & Mackinlay 1997]*

- design spaces provide an **actionable** structure for systematically reasoning about solutions *[Elliott et al 2020]*

- taxonomies increase **cognitive efficiency** & support **inferences** *[Ralph. Toward Methodological Guidelines for Process Theories & Taxonomies in Software Engineering. IEEE TSE 2020]*
  - by grouping similar instances together to facilitate **reasoning about classes** rather than instances

Design spaces: How to **assess**?

- Michel Beaudoin-Lafon, *Designing Interaction, not Interfaces. AVI 2004.*
  - **descriptive** power: ability to describe significant range of existing examples
  - **evaluative** power: ability to help assess multiple design alternatives
  - **generative** power: ability to help designers create new designs

Design spaces: How to **create**?

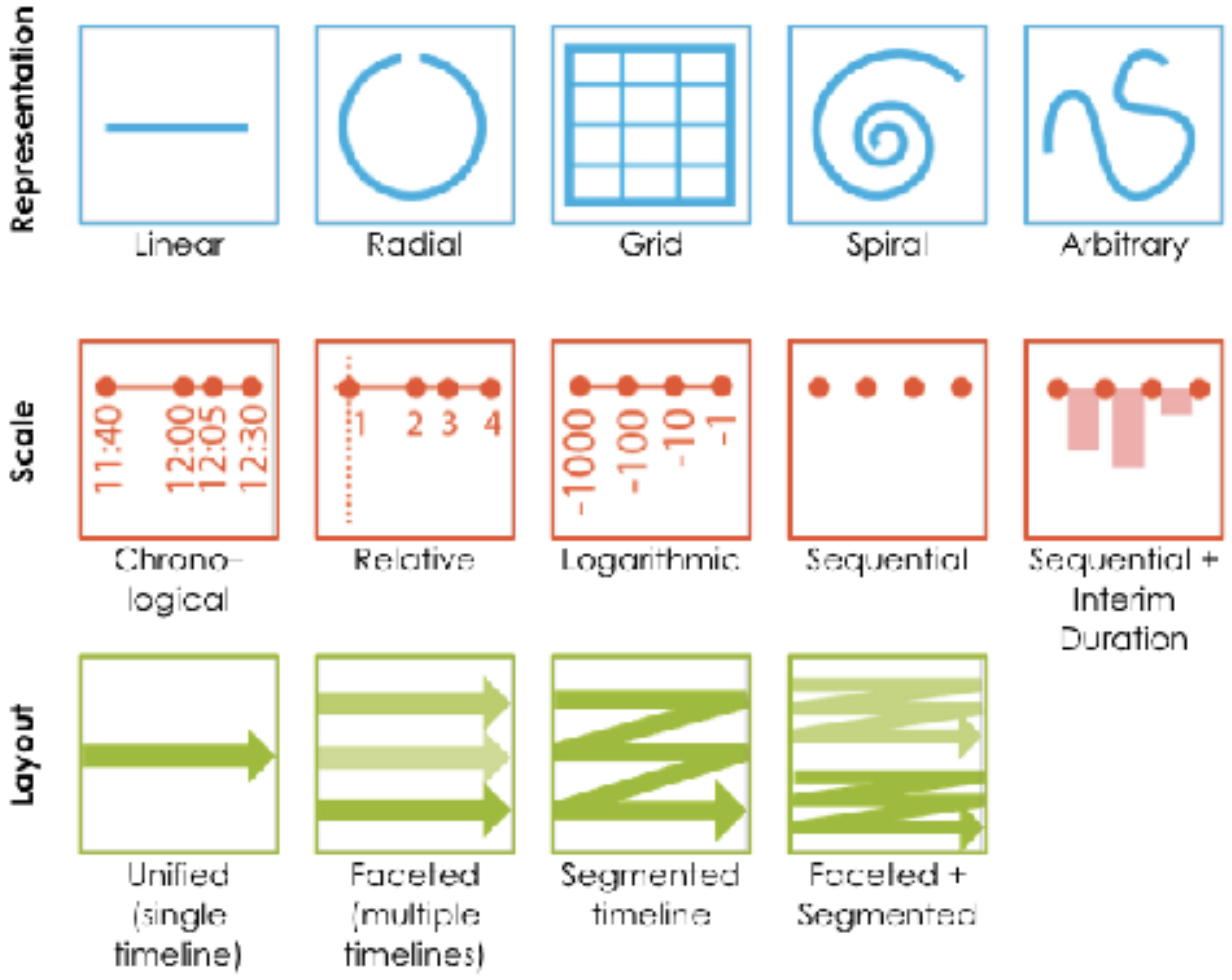
- **open coding** source material
  - grounded theory / thematic analysis / qualitative analysis
- **literature** review
  - synthesize across existing theories, compare & contextualize
- personal **reflection**
  - reflective synthesis

- complex combinations...

Design spaces: Multiple examples

- datatype: temporal, **timeline** visual encoding
- domain: **genomic epidemiology**, paper figure visual encoding
- domain: **journalism**, data **wrangling** activities
- domain agnostic: **abstract tasks**

Timelines



Timelines Revisited

A Design Space and Considerations for Expressive Storytelling

https://timelinesrevisited.github.io/

https://timelinestoryteller.com

Timelines Revisited: A Design Space and Considerations for Expressive Storytelling
Brehmer, Lee, Bach, Henry Riche, Munzner. IEEE TVCG 23(9):2151-2164

Matt
Brehmer

Bongshin
Lee

Benjamin
Bach

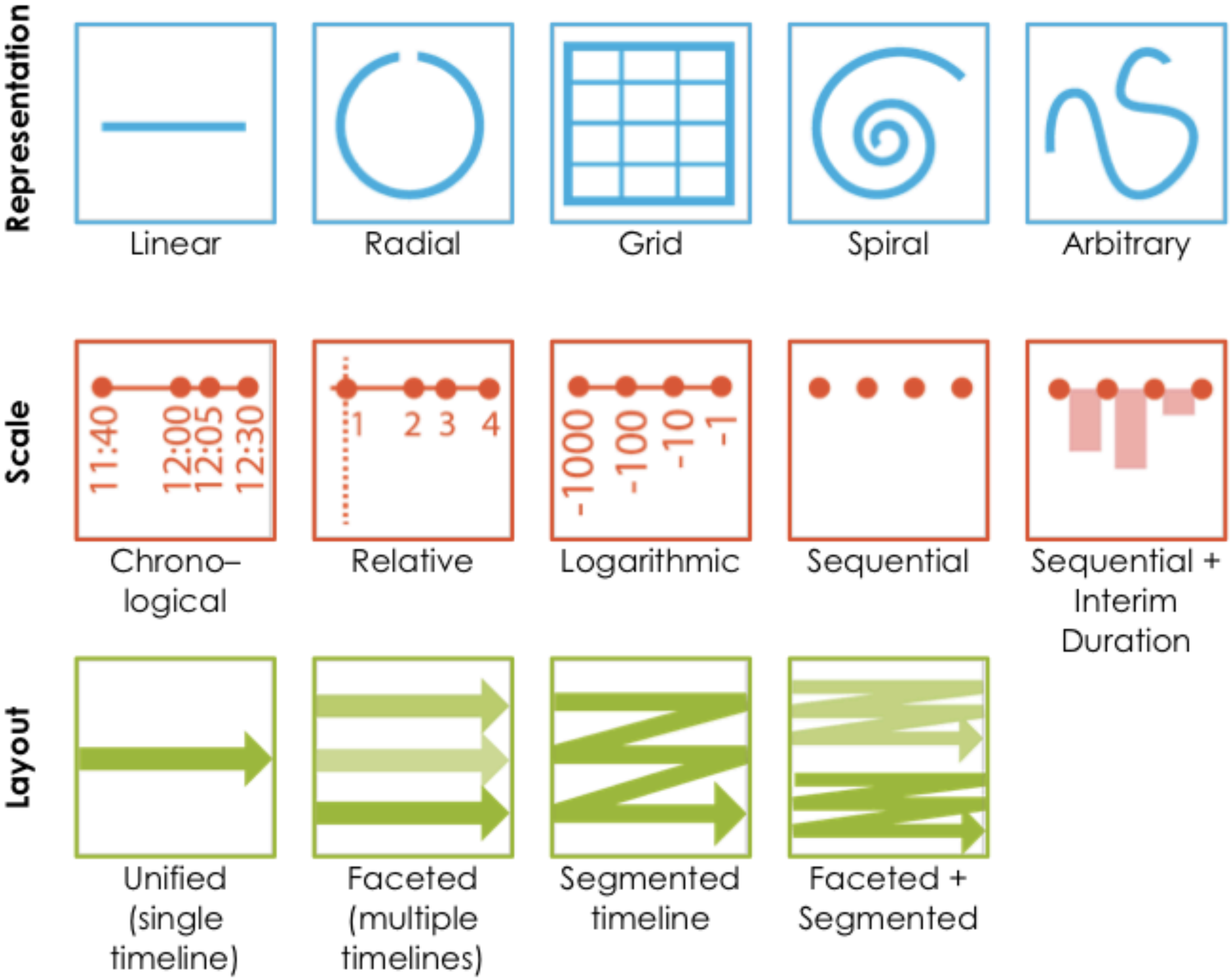
Nathalie
Henry Riche

Design space with three axes

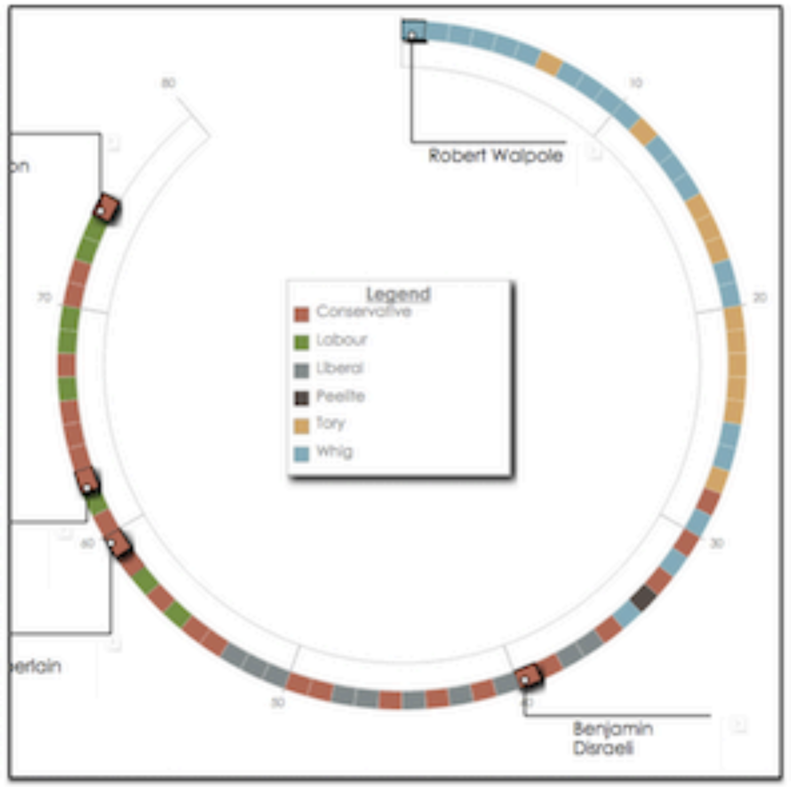
- representation

- scale

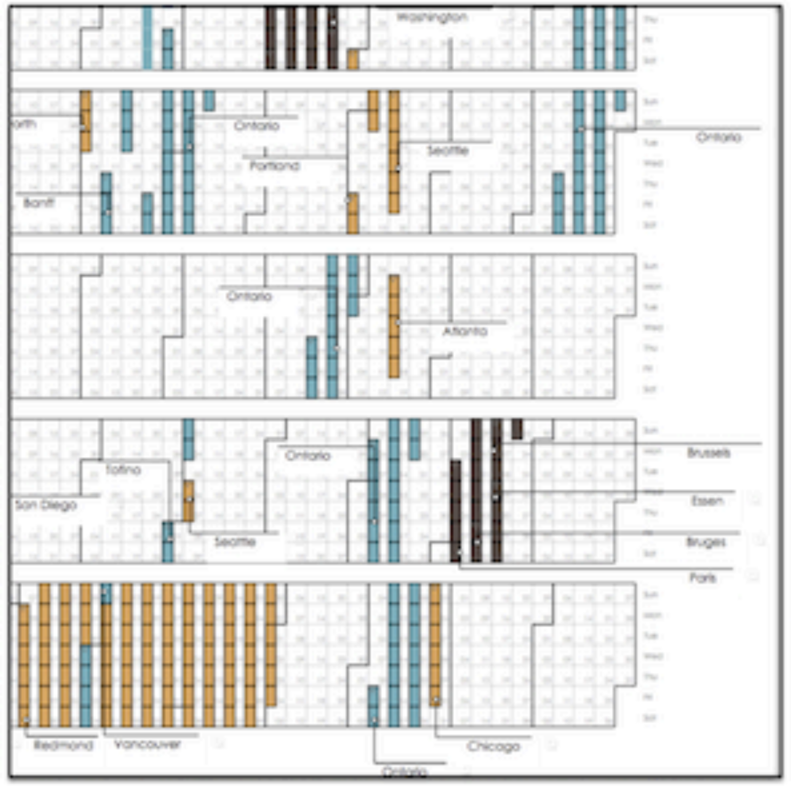
- layout



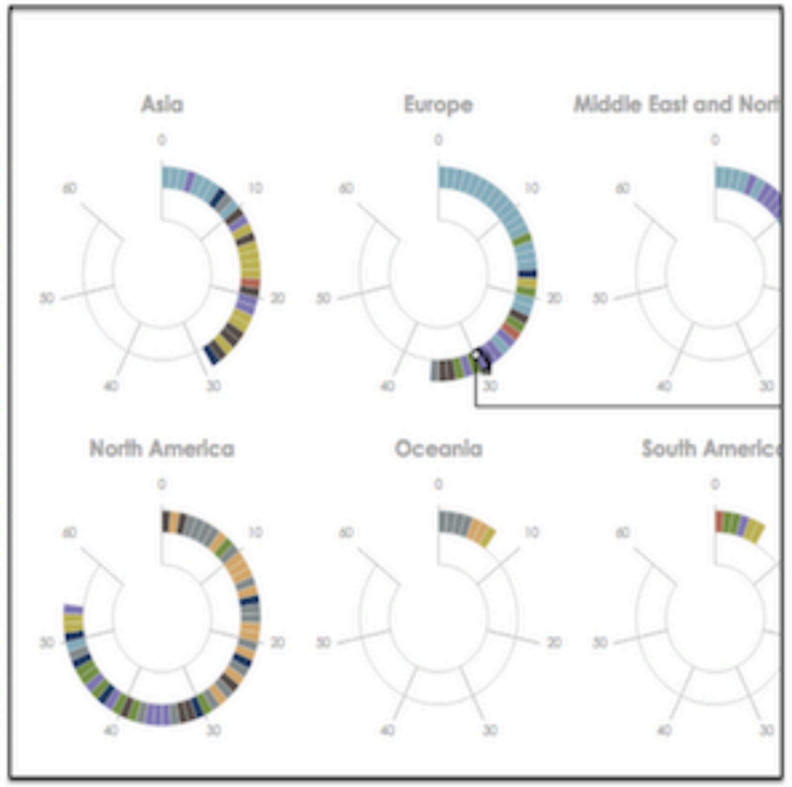
Combinations: Characterize narrative, perceptual



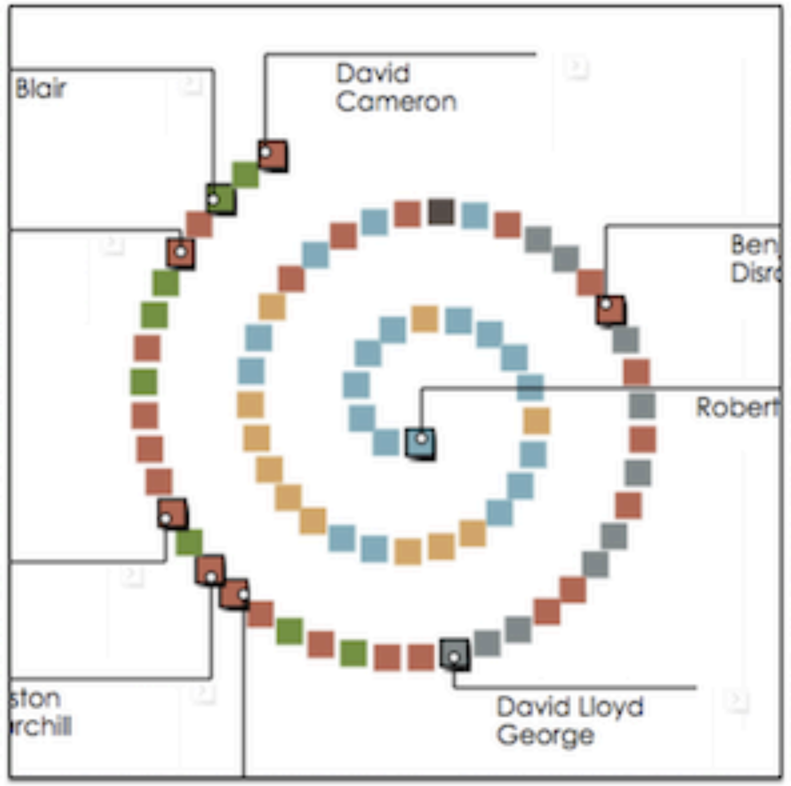
Narrative point: present a sequence of events.
Perceptual task: arc position judgments.
Comment: square aspect ratio.



Narrative point: compare chronology, duration, periodicity of events over months, weeks, days.
Perceptual task: count and position judgments.
Comment: only supports consecutive events.



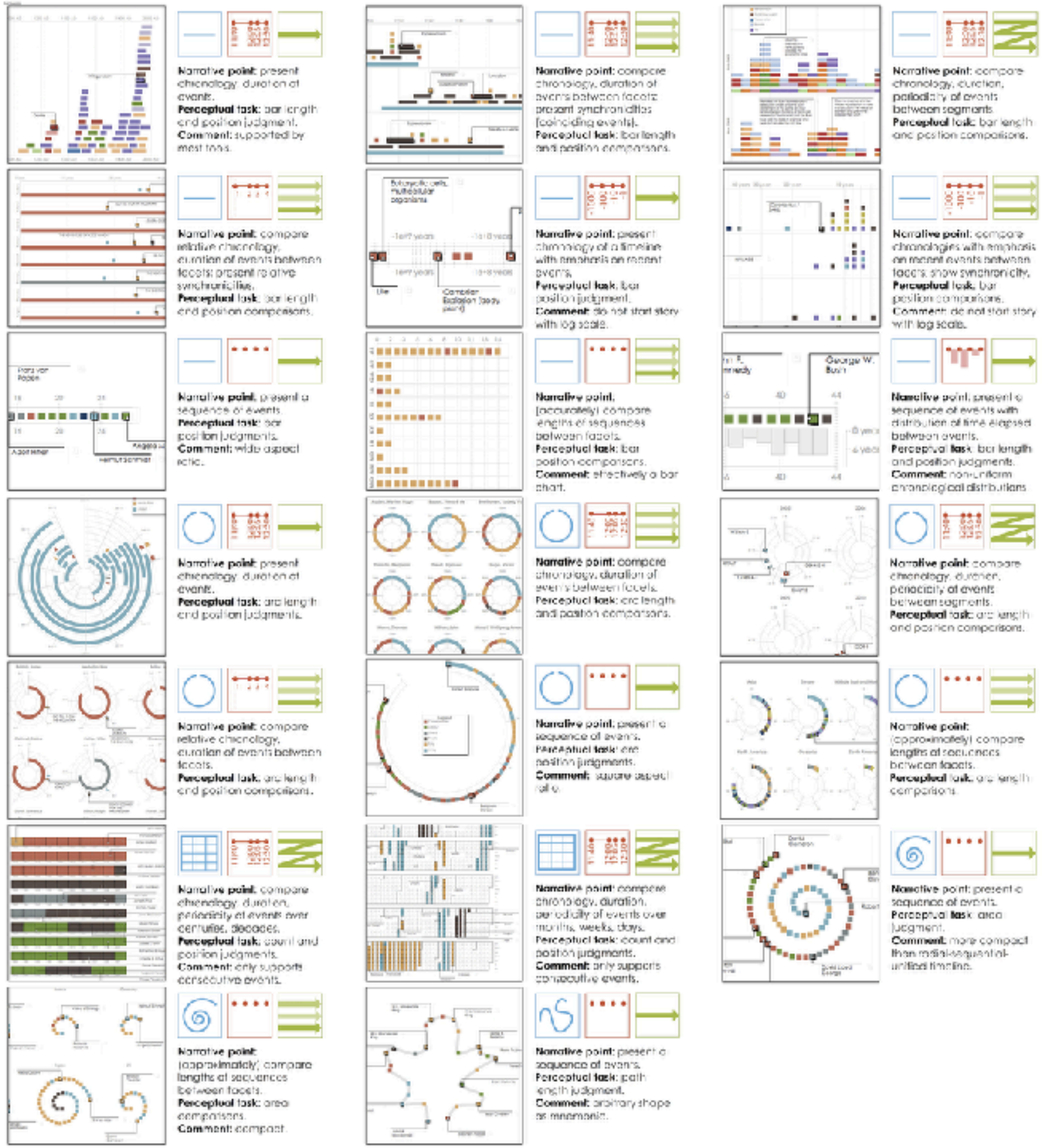
Narrative point: (approximately) compare lengths of sequences between facets.
Perceptual task: arc length comparisons.



Narrative point: present a sequence of events.
Perceptual task: area judgment.
Comment: more compact than radial-sequential-unified timeline.

Viable combinations

- 20 out of 100
- criteria
  - purposeful
  - interpretable
  - generalizable



Process

- **create** design space
    - **assemble** source material corpus: 145 timeline visualizations & timeline tools
    - **open code** group timelines together, select example for group, sketch alternatives
    - result: 3-axis design space

- **analyze** design space
    - 24 unique combinations (of 100) found in corpus
    - 20 we deemed viable

Assessment & adoption

- descriptive power
  - **validated** coverage through checking 118 additional timelines ("test set")
    - all timelines can be described (263 total)
    - 253 characterized as viable
- generative power
  - **implemented** sandbox authoring software for 20 viable designs
    - & transitions between them
  - **created** designs for 28 representative datasets
    - 7 full story videos
- adoption
  - **open sourced** & distributed as Microsoft **product**
    - free browser version at https://timelinestoryteller.com/
    - free add-on for PowerBI

Genomic Epidemiology

A systematic method for surveying data visualizations and a resulting genomic epidemiology visualization typology:

GEViT

Anamaria Crisan
@amcrisan

Jenn Gardy
@jennifergardy

https://amcrisan.github.io/gevit

A systematic method for surveying data visualizations and a resulting genomic epidemiology visualization typology: GEViT.
Crisan, Gardy, Munzner. Oxford Bioinformatics 35(10):1668-1676, 2018.

Propose typology creation method: mixed qual and quant

- Analyzed research articles
- Some analyses are automated (🤖) and others are manual (👤)

Analysis Phase

Literature Analysis 🤖

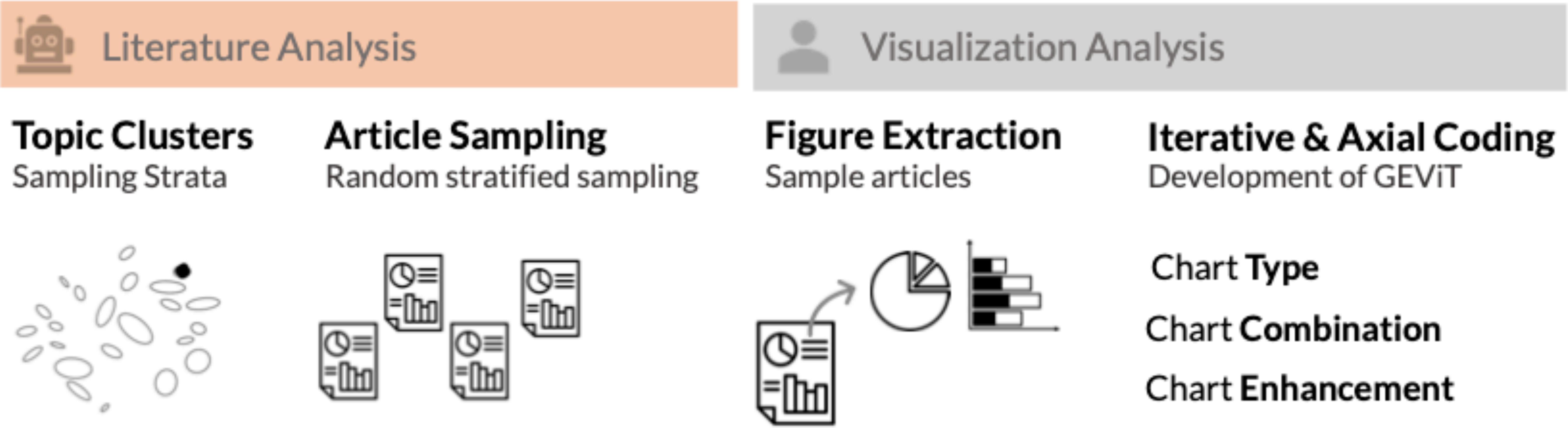
Visualization Analysis

Qualitative Analysis 👤

Quantitative Analysis 🤖

Use method to develop typology in specific domain

- Developed a Genomic Epidemiology Visualization Typology (GEViT)



Literature Analysis

Visualization Analysis

Topic Clusters
Sampling Strata

Article Sampling
Random stratified sampling

Figure Extraction
Sample articles

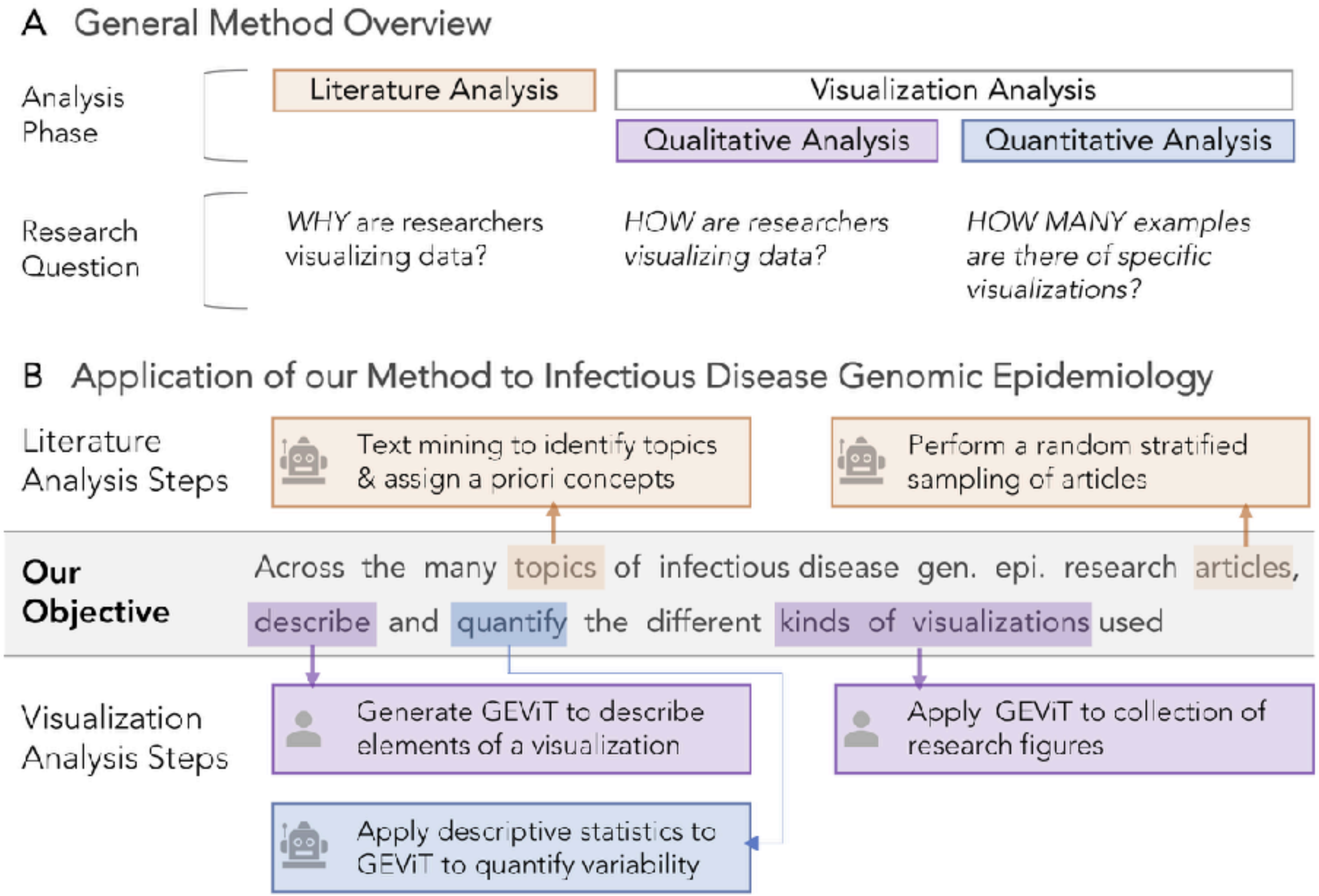
Iterative & Axial Coding
Development of GEViT

Chart **Type**

Chart **Combination**

Chart **Enhancement**

Domain prevalence design space



A General Method Overview

Analysis Phase	Literature Analysis	Visualization Analysis: Qualitative Analysis	Visualization Analysis: Quantitative Analysis
Research Question	*WHY are researchers visualizing data?*	*HOW are researchers visualizing data?*	*HOW MANY examples are there of specific visualizations?*

B Application of our Method to Infectious Disease Genomic Epidemiology

Literature Analysis Steps

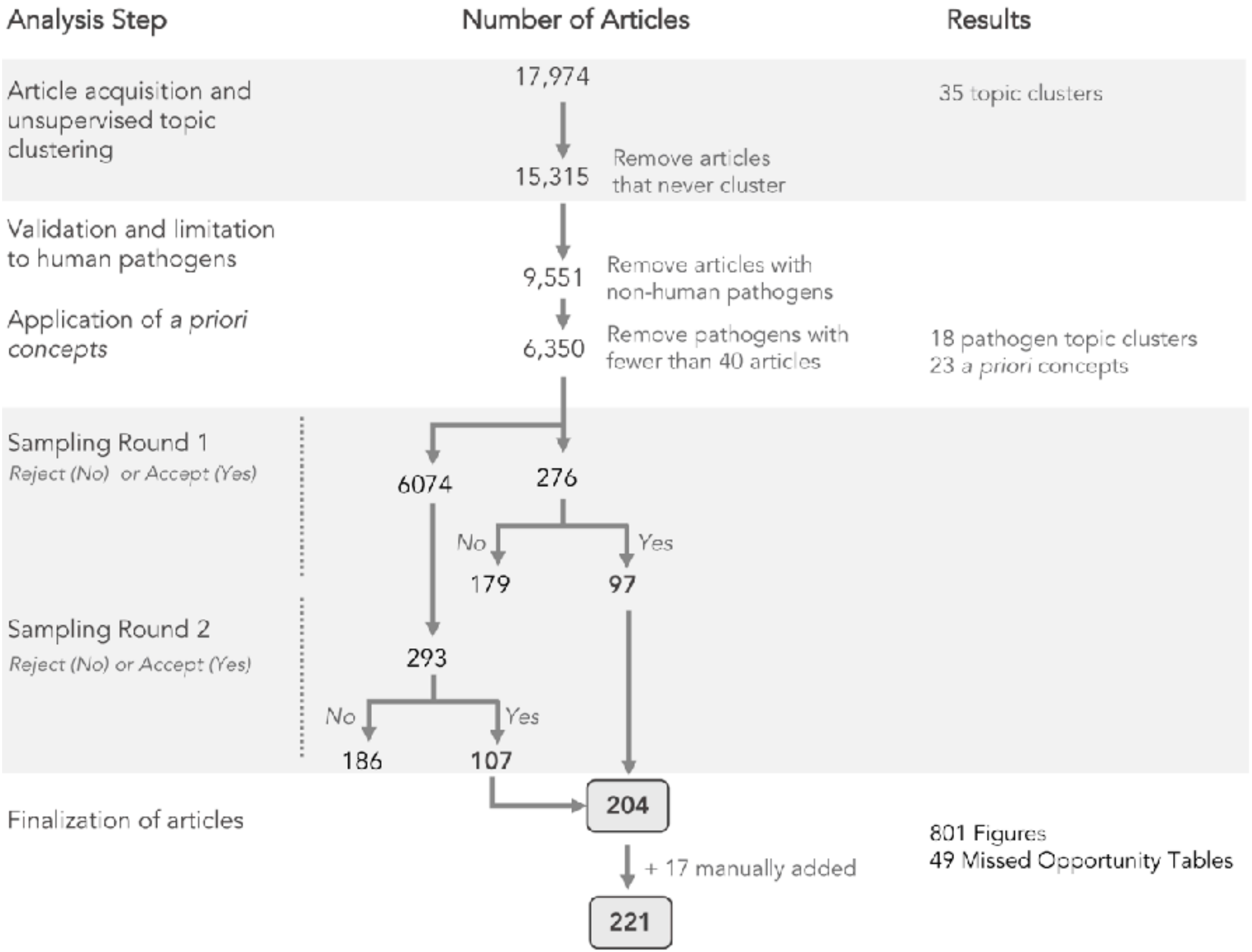
- Text mining to identify topics & assign a priori concepts
- Perform a random stratified sampling of articles

Our Objective Across the many topics of infectious disease gen. epi. research articles, describe and quantify the different kinds of visualizations used

Visualization Analysis Steps

- Generate GEViT to describe elements of a visualization
- Apply GEViT to collection of research figures
- Apply descriptive statistics to GEViT to quantify variability

By the numbers



Analysis Step

Number of Articles

Results

Article acquisition and unsupervised topic clustering

17,974

15,315

Remove articles that never cluster

35 topic clusters

Validation and limitation to human pathogens

9,551

Remove articles with non-human pathogens

Application of *a priori* concepts

6,350

Remove pathogens with fewer than 40 articles

18 pathogen topic clusters
23 *a priori* concepts

Sampling Round 1

Reject (No) or Accept (Yes)

6074

276

No

Yes

179

97

Sampling Round 2

Reject (No) or Accept (Yes)

293

No

Yes

186

107

Finalization of articles

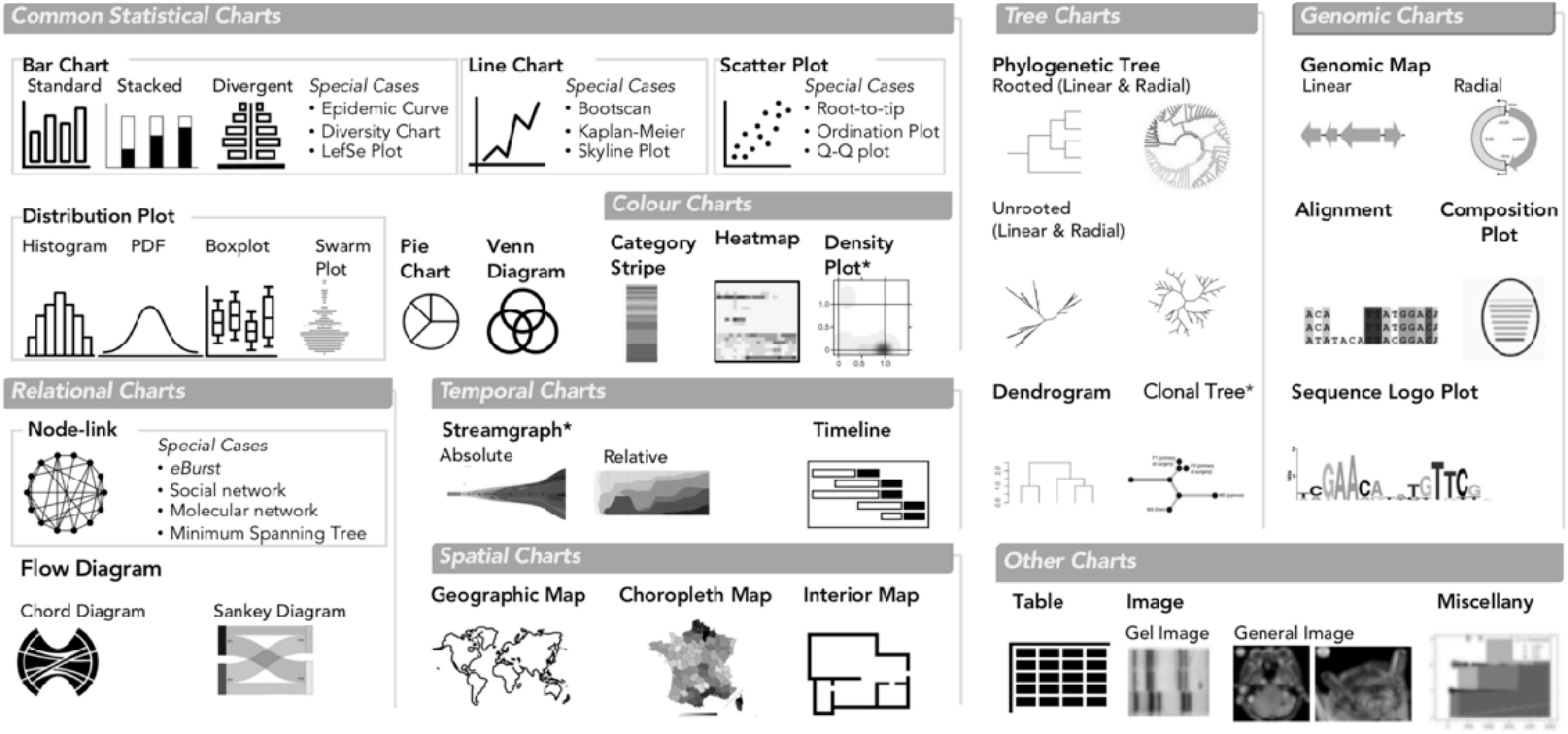
204

+ 17 manually added

221

801 Figures
49 Missed Opportunity Tables

Design space axis: Chart types used in genEpi



Design space axis: Chart combinations of heterogeneous data

Spatially Aligned

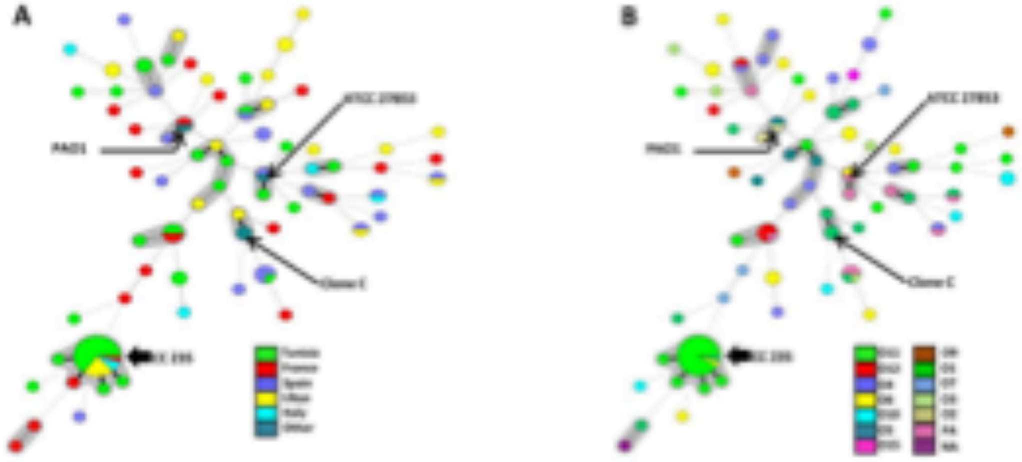
Horizontal / Vertical Alignment

20%

Small Multiples

Chart Alignment

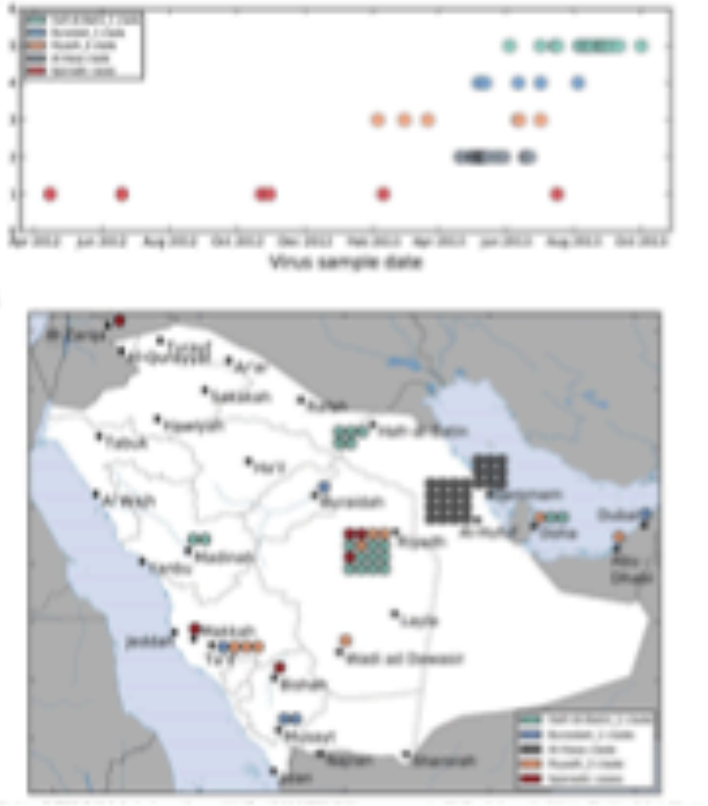
17%



Visually Aligned

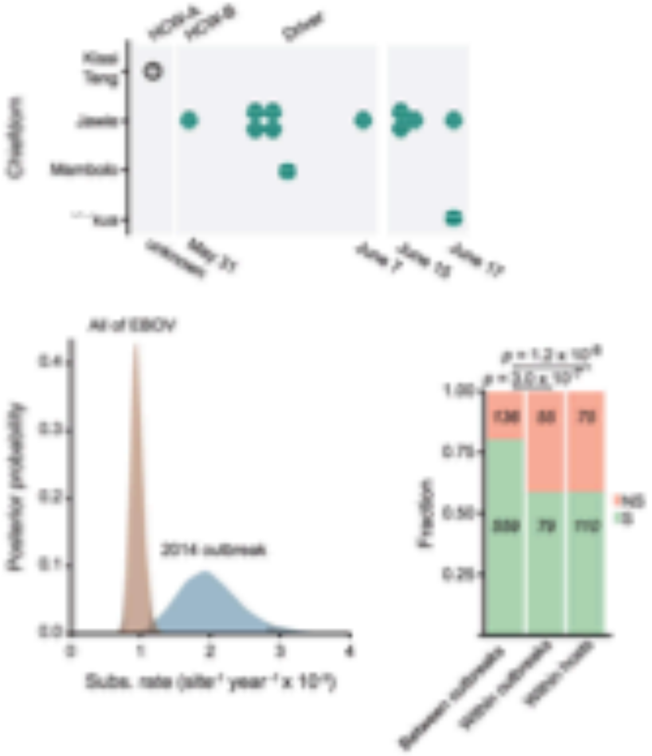
Colour / Shape Alignment

14%

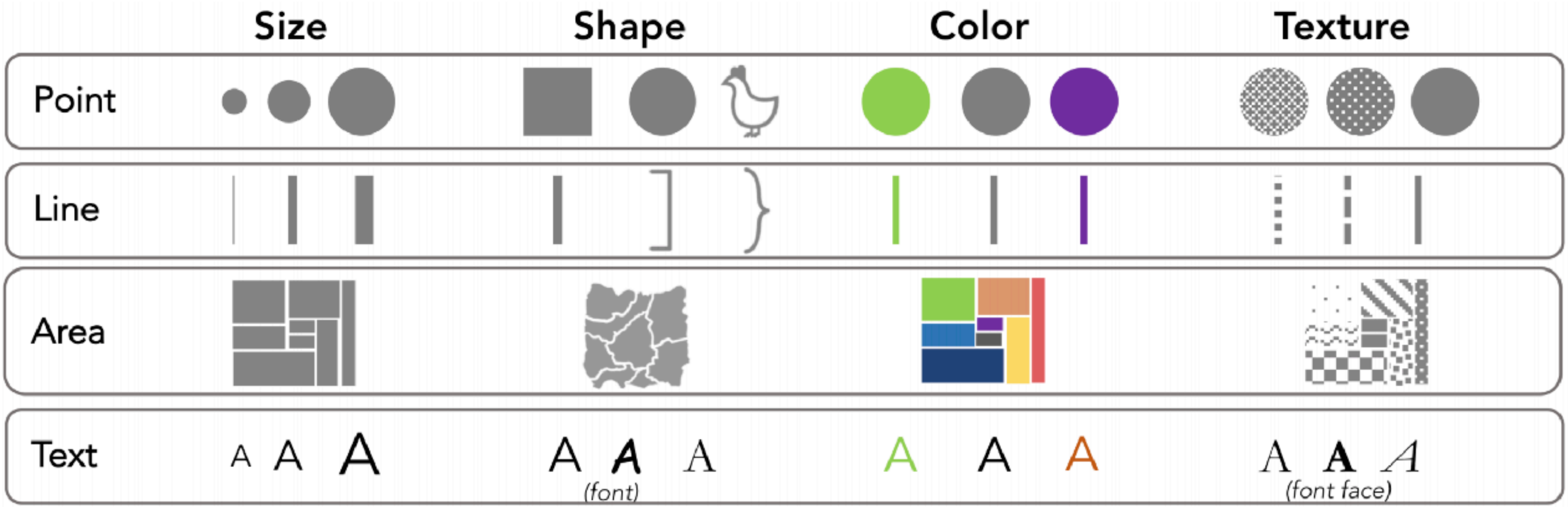


Unaligned

9%

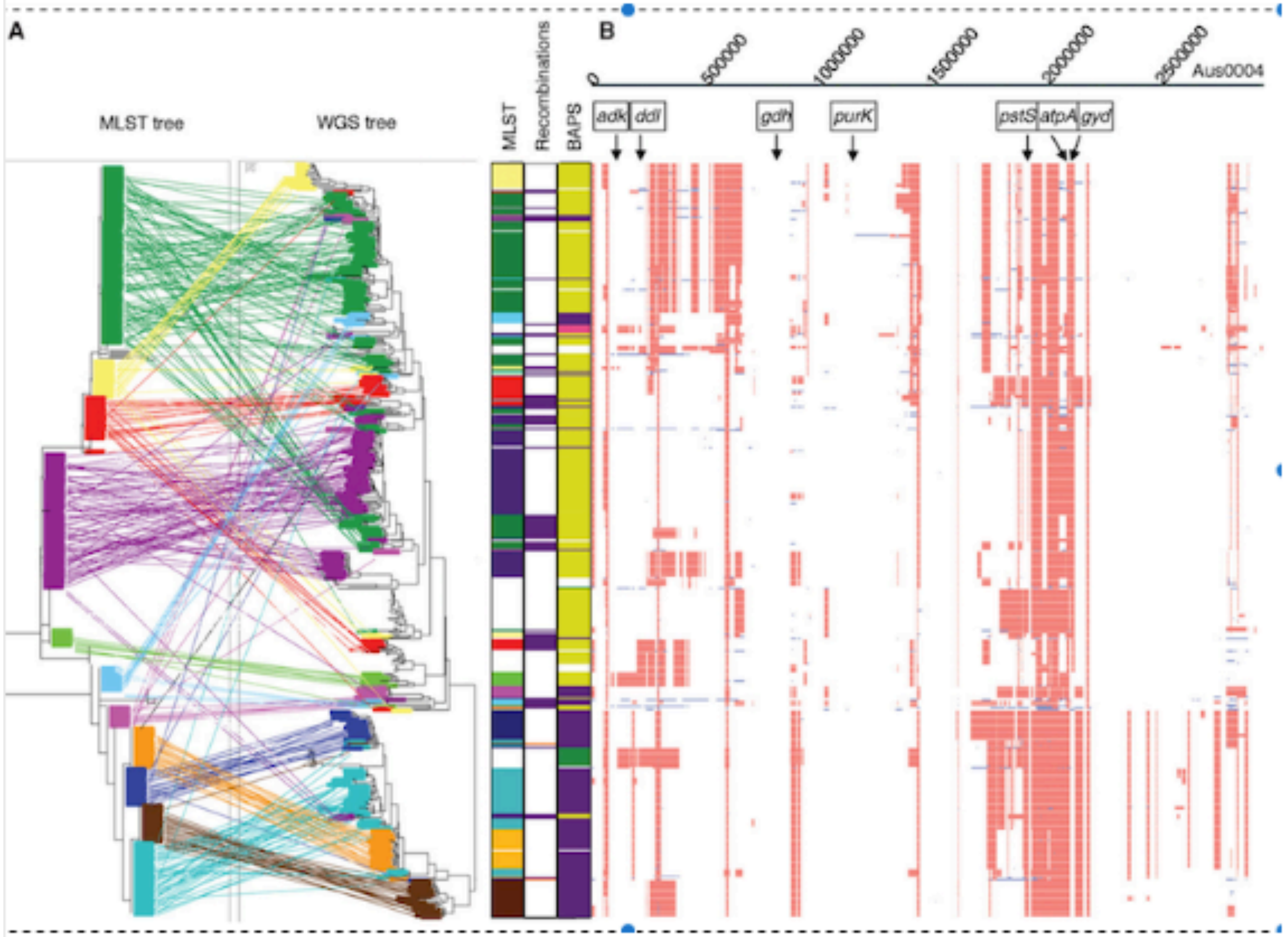


Design space axis: Enhancement choices, atop base chart types

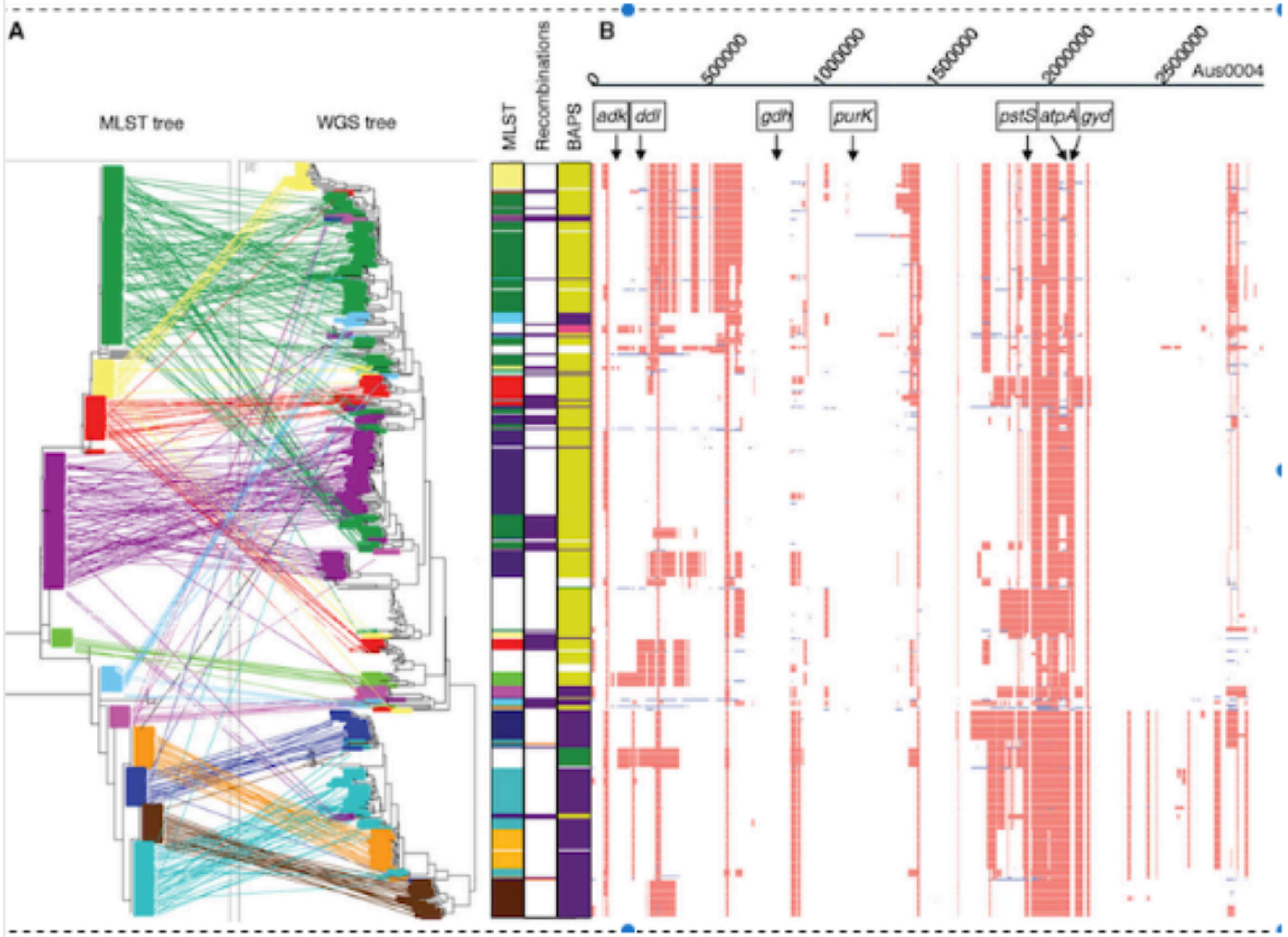


Current Practice >80% of all figures have some enhancement

GEViT example



GEViT example

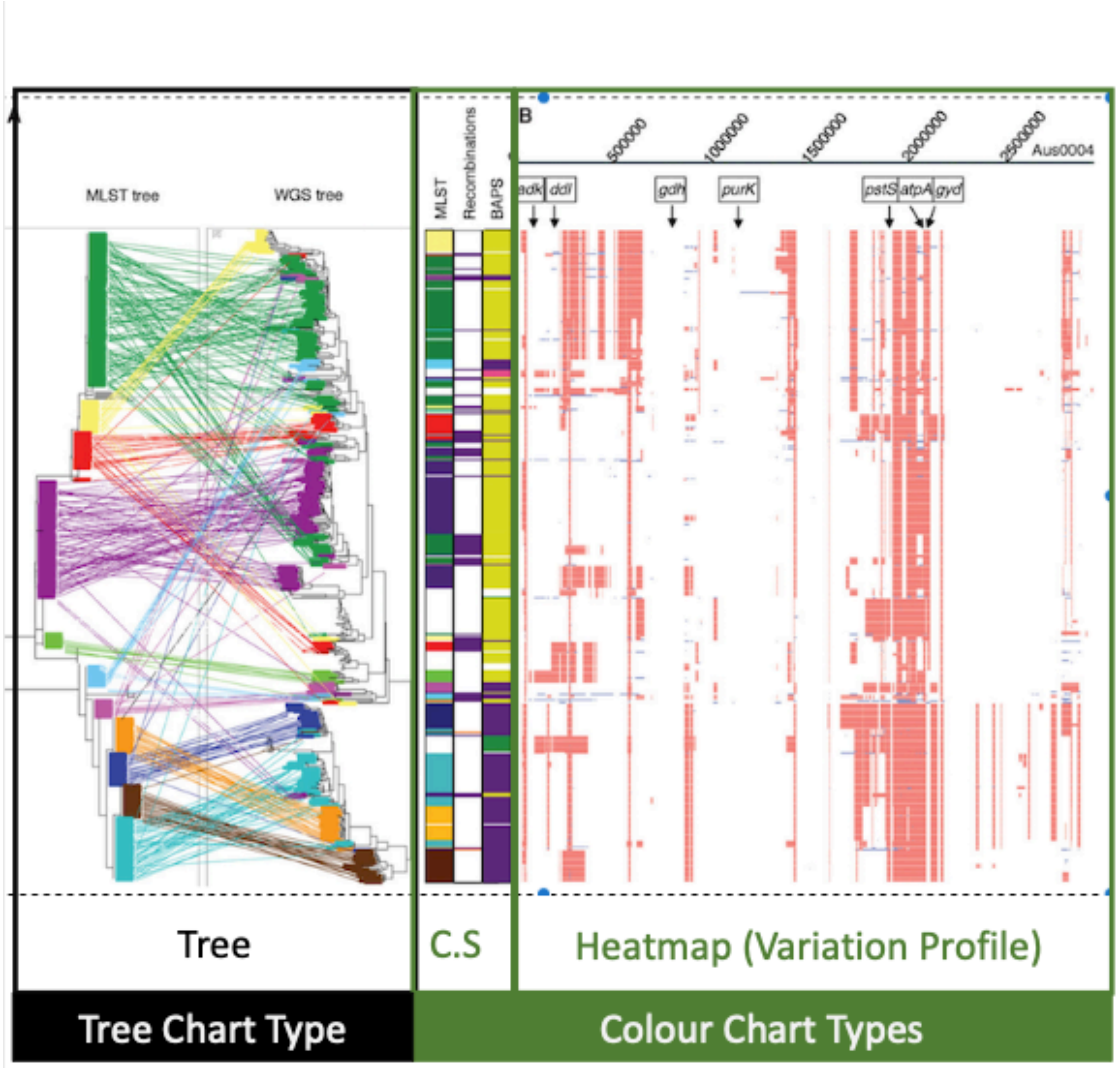


Visualization Breakdown

Literature Analysis **(why)**

- ***Pathogen**: Enterococcus faecium*

GEViT example



Visualization Breakdown

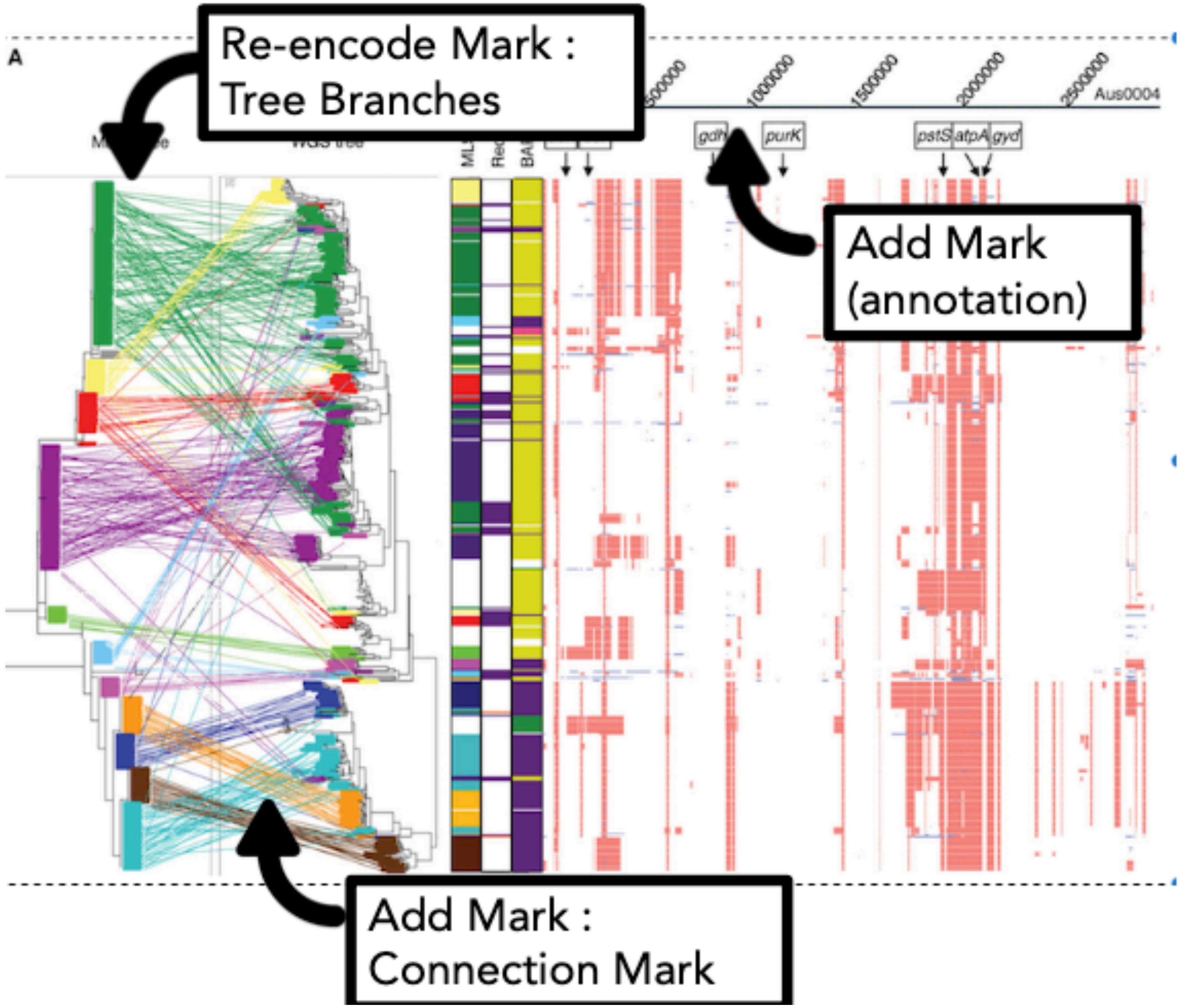
Literature Analysis ***(why)***

- ***Pathogen**: Enterococcus faecium*

Visualization Analysis ***(how)***

Chart Type	Tree (Rooted Phylogenetic Tree) Category Stripe Heatmap (Variation Profile)
Chart Combination	Spatially Aligned (*horizontal*)

GEViT example



Re-encode Mark : Tree Branches

Add Mark (annotation)

Add Mark : Connection Mark

Visualization Breakdown

Literature Analysis ***(why)***

- ***Pathogen****: Enterococcus faecium*

Visualization Analysis ***(how)***

Chart Type	Tree (Rooted Phylogenetic Tree) Category Stripe Heatmap (Variation Profile)	
Chart Combination	Spatially Aligned (*horizontal)*	
Chart Enhancement	Re-encode Marks	Tree – *branches*
	Add Marks	Tree - *Connection Marks*
	Add Mark *(unstructured)*	Heatmap – *Textboxes*

Assessment

- descriptive power
  - provided common language for describing data visualization in genEpi
  - established gap: **unmet tooling needs**
    - no existing tool handled full complexity of what people do manually
- evaluative power
  - **revealed shortfalls** in practices of some genEpi stakeholders
    - eg overuse of text
- generative power
  - validated in followup GEViTRec work
    - **build** automatic recommender system using domain prevalence design space

GEViTRec:

Data Reconnaissance Through Recommendation Using a Domain-Specific Visualization Prevalence Design Space

Anamaria Crisan
@amcrisan

Shannah Fisher

Jenn Gardy
@jennifergardy

https://github.com/amcrisan/GEVitRec

GEViTRec: Data Reconnaissance Through Recommendation Using a Domain-Specific Visualization Prevalence Design Space.
Crisan, Fisher, Gardy, Munzner. IEEE TVCG to appear, 2022.

Data Wrangling

An Actionable Framework for Multi-Table Data Wrangling

From an Artifact Study of Computational Journalism

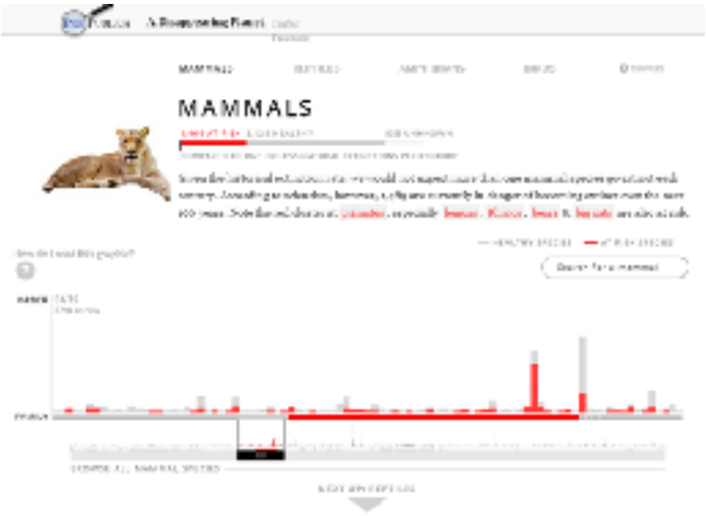
Steve
Kasica
@stevekasica

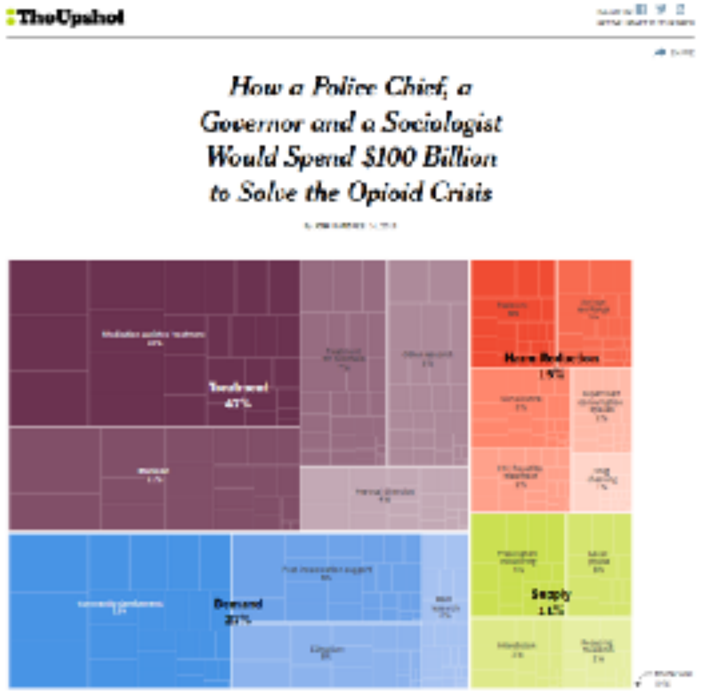
Charles
Berret
@cberret

http://www.cs.ubc.ca/group/infovis/pubs/2020/table-scraps/

An Actionable Framework for Multi-Table Data Wrangling From an Artifact Study of Computational Journalism.
Kasica, Berret, Munzner. IEEE TVCG 27(2):957-966 2021. (Proc. InfoVis 2020).

Journalists are data wranglers…


MAMMALS

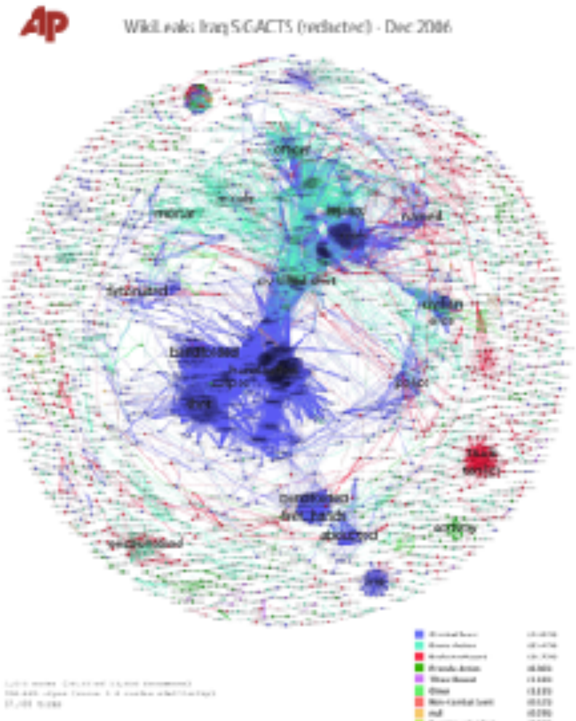

TheUpshot

How a Police Chief, a Governor and a Sociologist Would Spend $100 Billion to Solve the Opioid Crisis


The New York Times

BLACK AMERICANS BEAR THE BRUNT AS DEATHS CLIMB

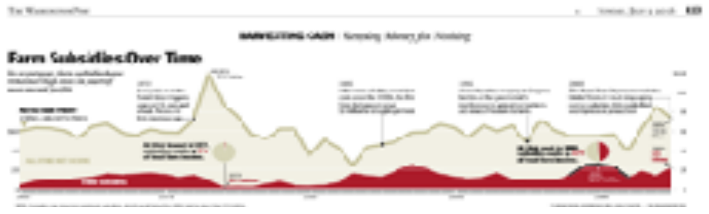

What Would It Take To Turn Red States Blue?

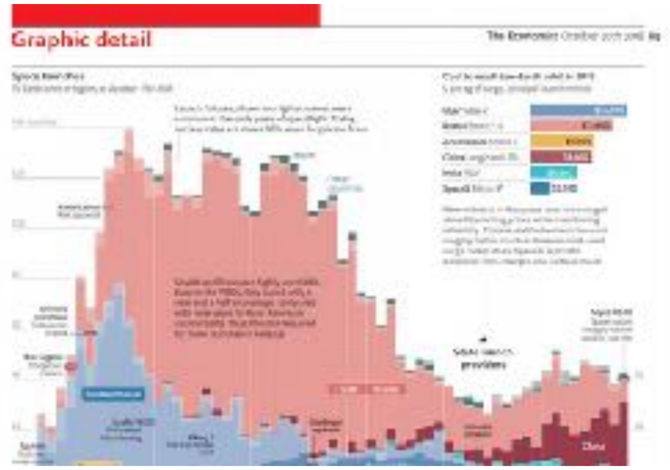

AP

WikiLeaks: Iraq SIGACTS (redacted) - Dec 2006


Battling Infectious Diseases in the 20th Century: The Impact of Vaccines

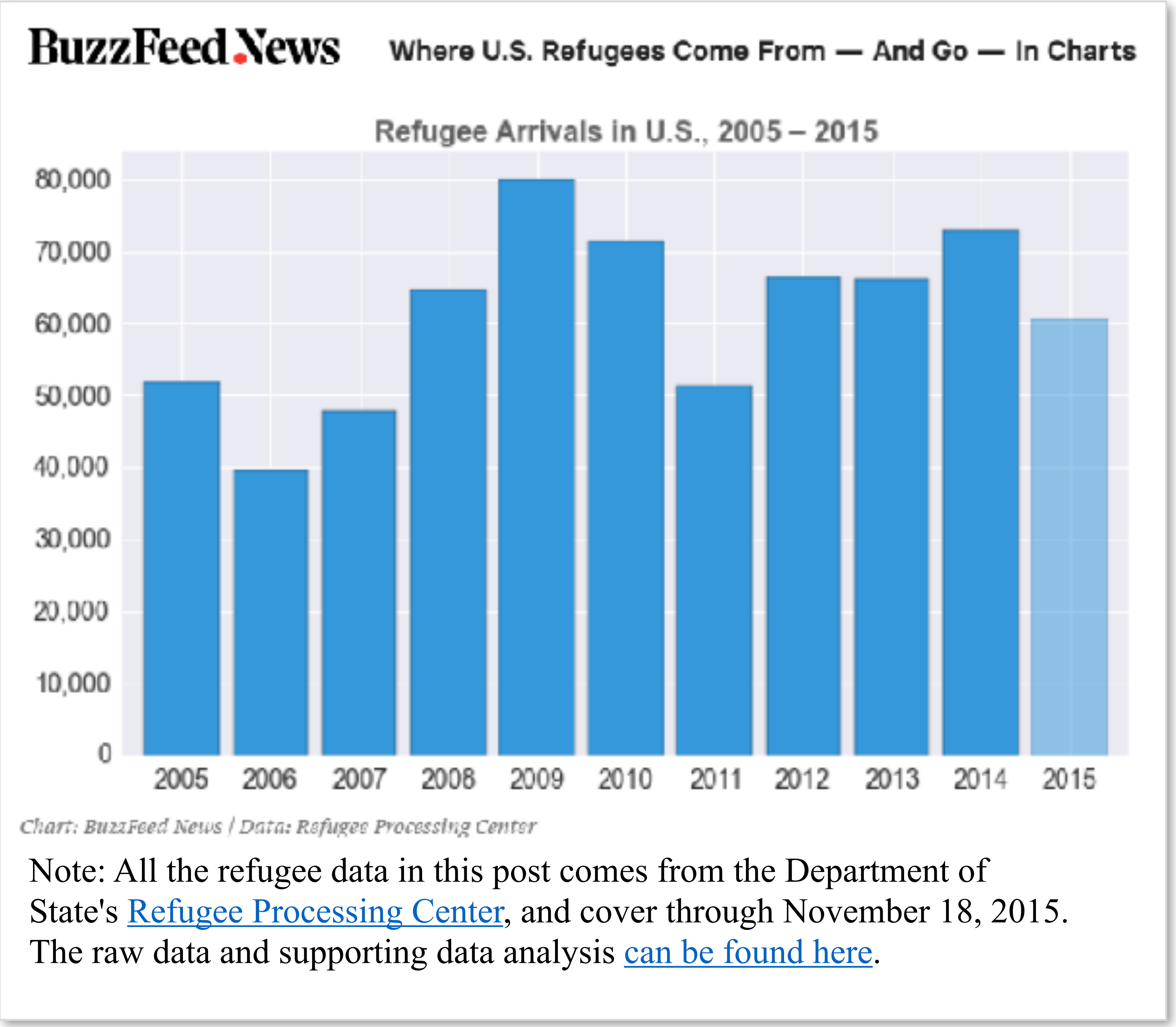
Measles


Farm Subsidies Over Time


Graphic detail

…who show their work publicly

- lots of wrangling behind the scenes
- enter the "**nerd box**"
  - article sidebars or snippet
  - provide / link
    - methods, analysis materials
- publish code/data to public **repos**
  - hundreds on GitHub & Observable
- editorial **transparency**
  - public can scrutinize
  - colleague can reproduce



BuzzFeed News Where U.S. Refugees Come From — And Go — In Charts

Chart: BuzzFeed News / Data: Refugee Processing Center

Note: All the refugee data in this post comes from the Department of State's Refugee Processing Center, and cover through November 18, 2015. The raw data and supporting data analysis can be found here.

Process overview

What are the wrangling practices of journalists with programming skills?

Technical observation

Repo selection

Qualitative coding

Process overview

What are the wrangling practices of journalists with programming skills?

Technical observation

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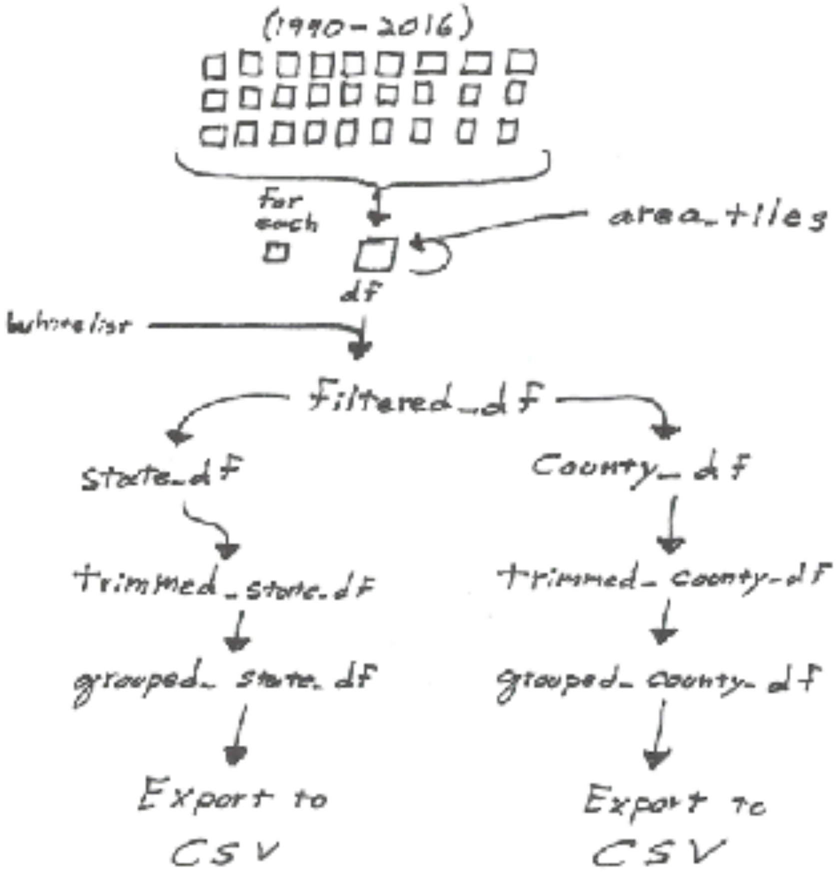
Data-flow sketches



Process overview

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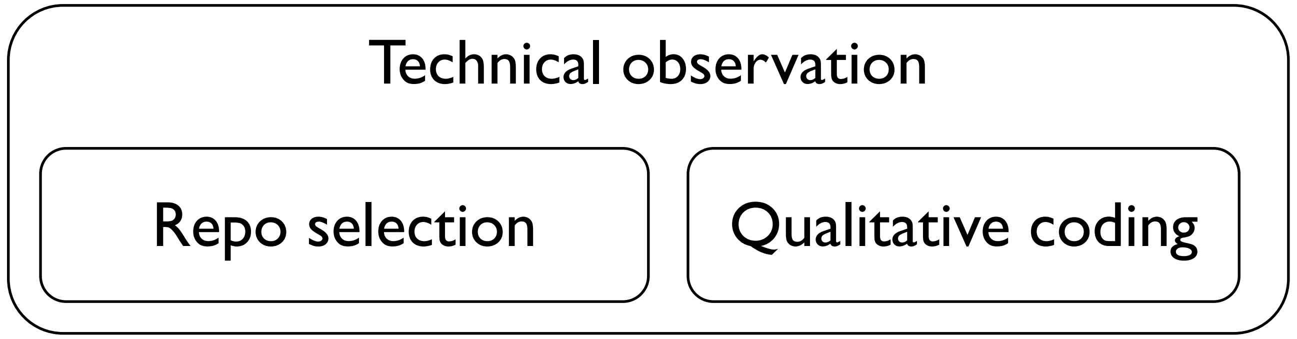


Technical observation

Repo selection

Qualitative coding

Taxonomies of data wrangling in computational journalism - initial

Process overview

What are the wrangling practices of journalists with programming skills?

- Technical observation
  - Repo selection
  - Qualitative coding

Taxonomies of data wrangling in computational journalism - initial

Which practices align with or diverge from existing characterizations?

- Literature search
  - Term harmonization
  - Gap discovery

Process overview

What are the wrangling practices of journalists with programming skills?

Technical observation

- Repo selection
- Qualitative coding

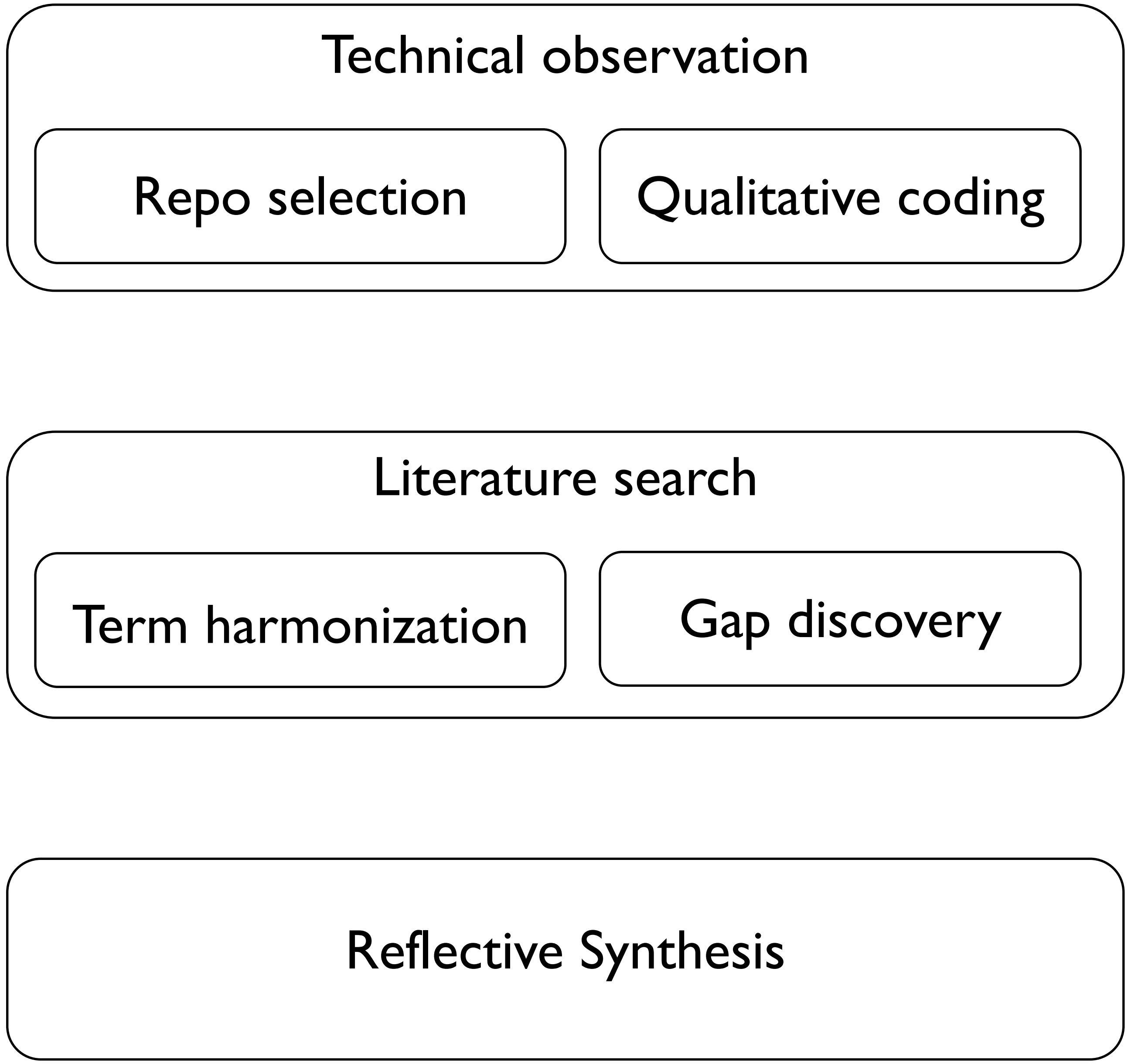
Which practices align with or diverge from existing characterizations?

Literature search

- Term harmonization
- Gap discovery

Taxonomies of data wrangling in computational journalism - finalized

Process overview



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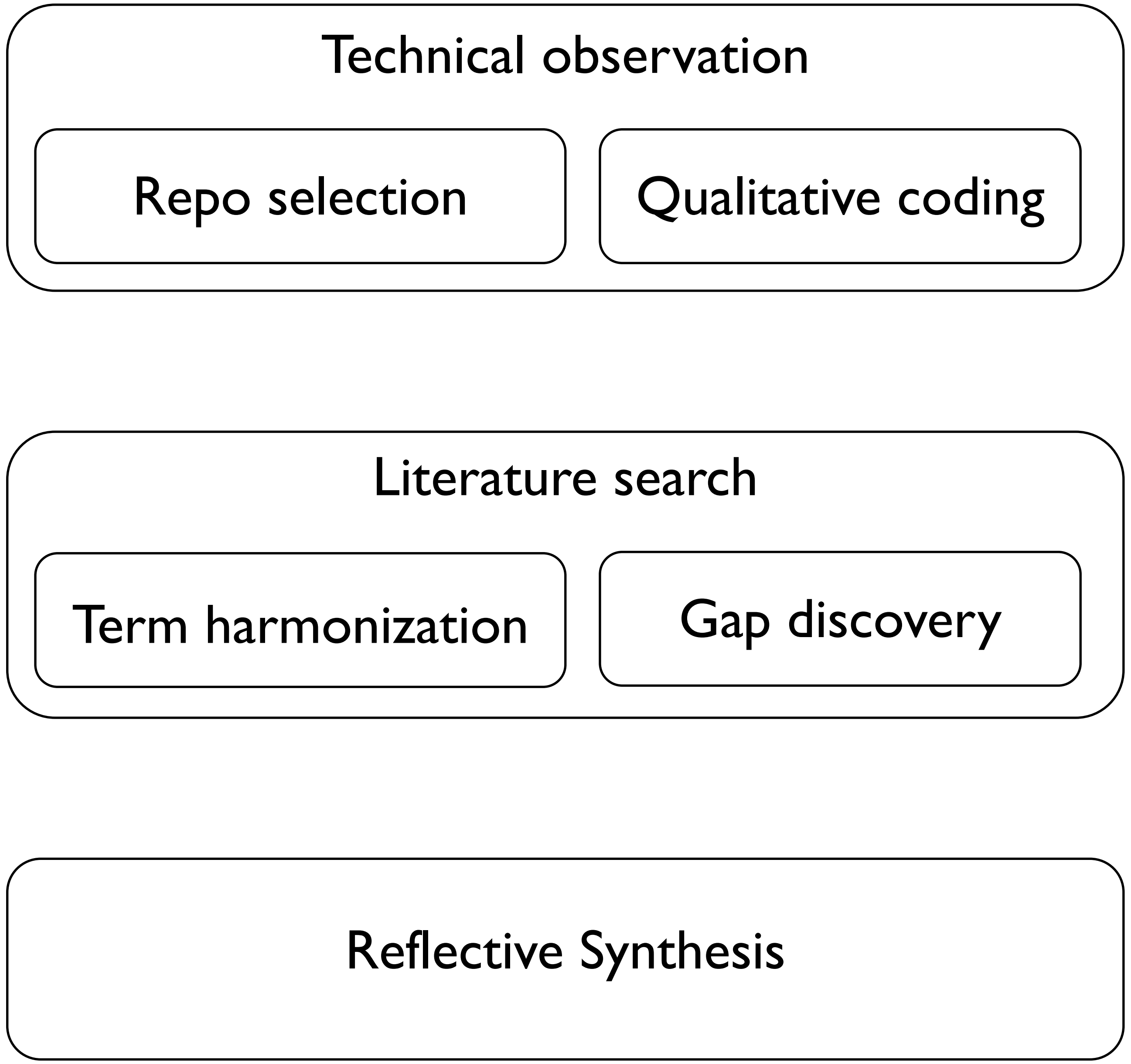
Taxonomies of data wrangling in computational journalism

How to re-characterize wrangling to match the observed practices?

Reflective Synthesis

Process overview



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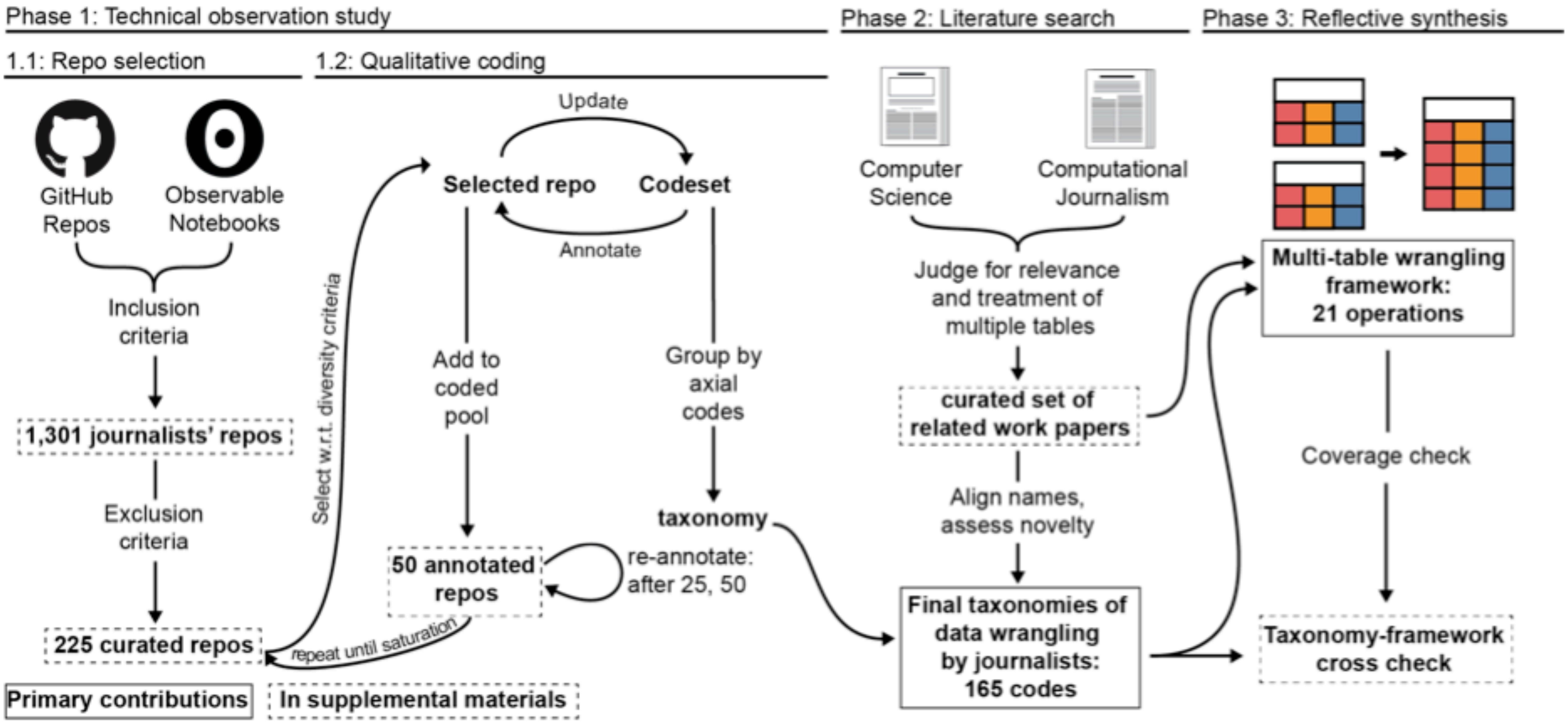
Taxonomies of data wrangling in computational journalism

How to re-characterize wrangling to match the observed practices?

Reflective Synthesis

Multi-table framework of data wrangling

By the numbers



Two taxonomies of data wrangling in journalism

- **Actions** taken by journalists
- **Process** interpreted by researchers
- **descriptive** power: excellent
  - total codes: 165
  - max depth: 5 levels
- **generative** power: limited

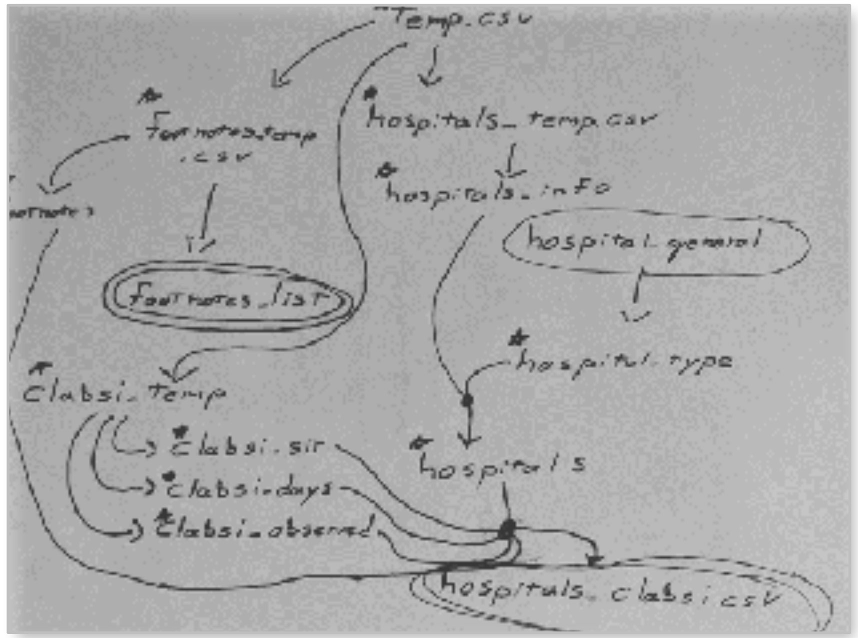
Actions

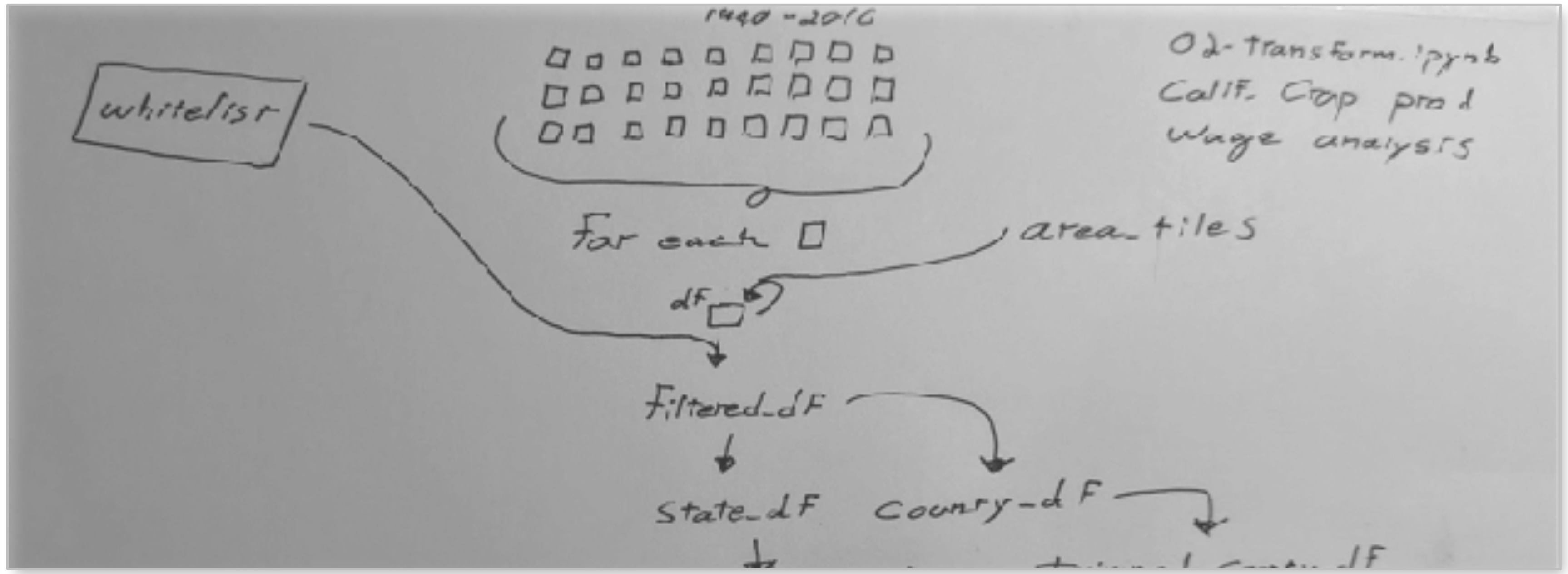
- Import
- Clean
- Merge
- Profile
- Drive
- Transform
- Export

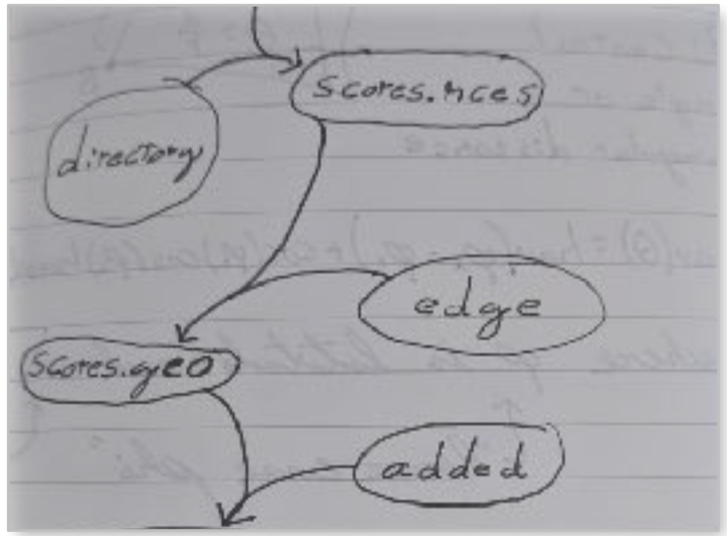
Process

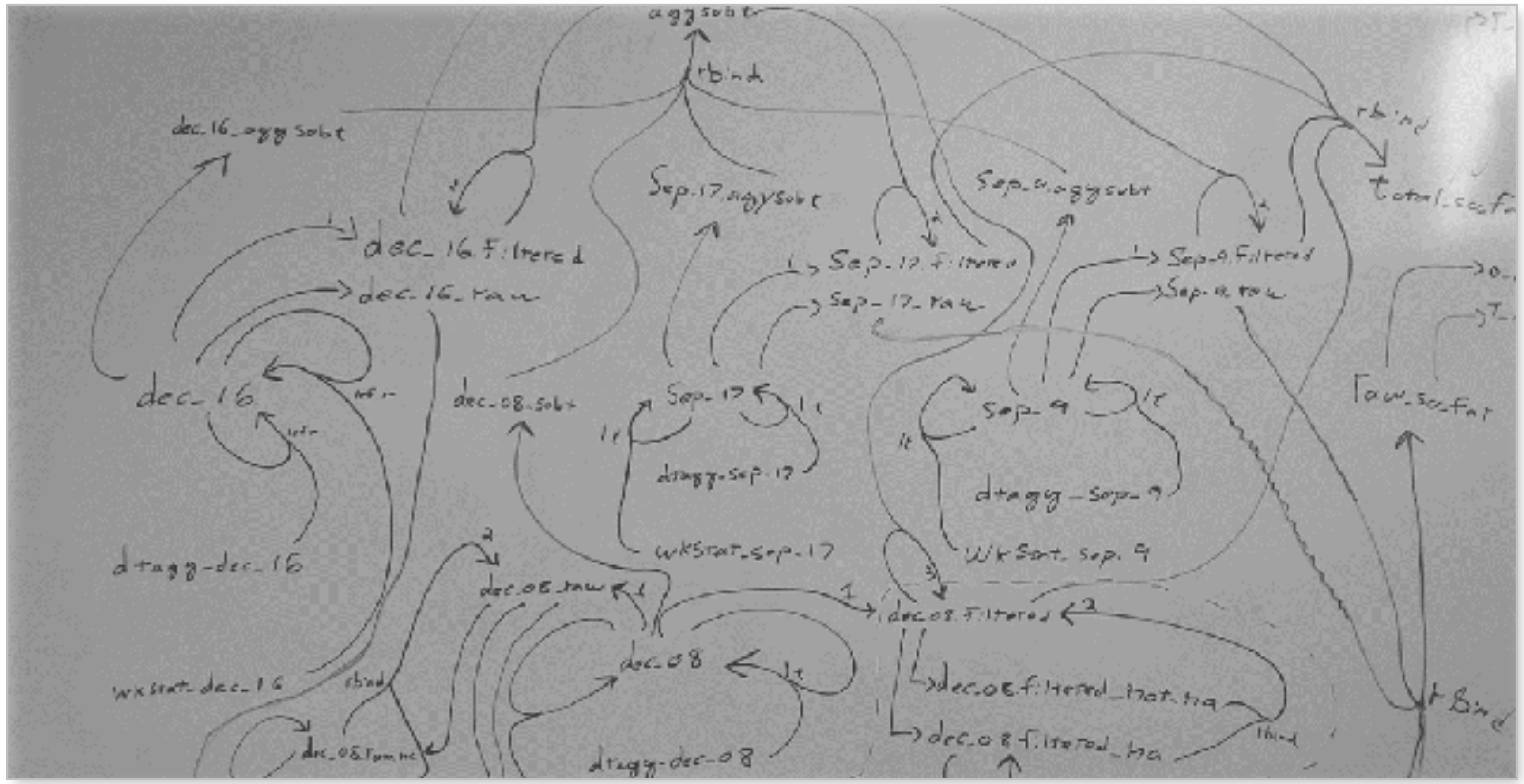
- Source
- Workflow
- Cause
- Themes
- Analysis
- Management
- Pain Points

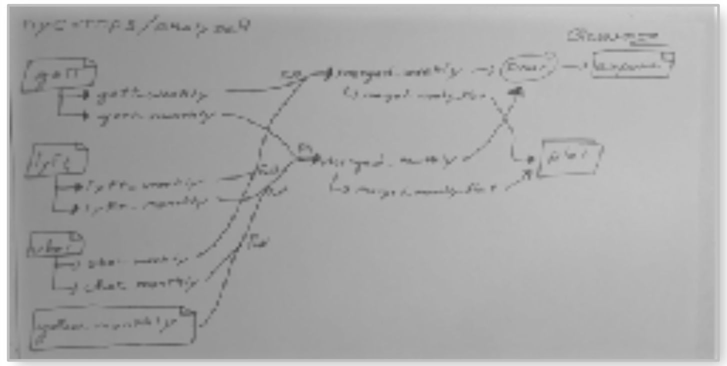
Key finding: journalists use many, many tables





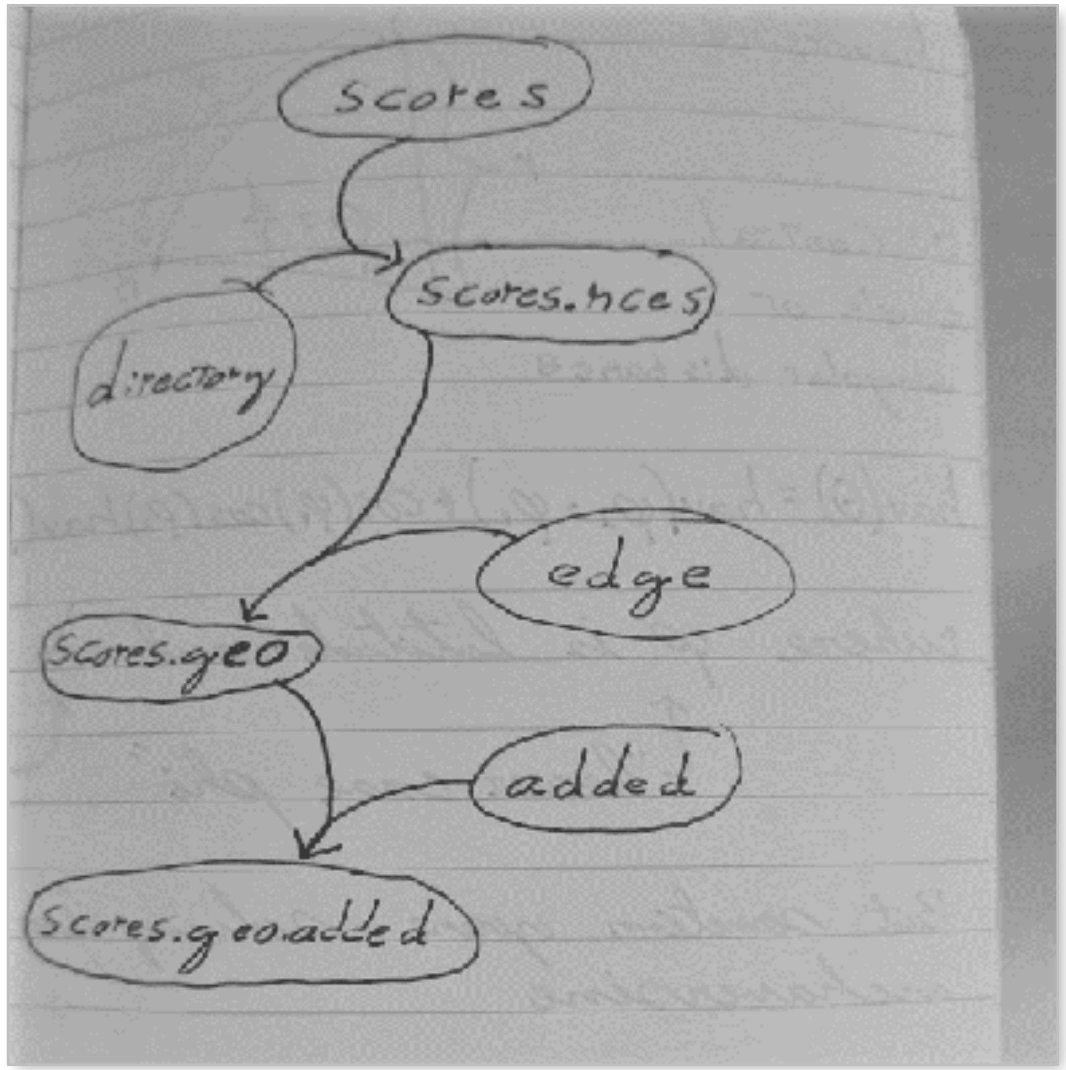






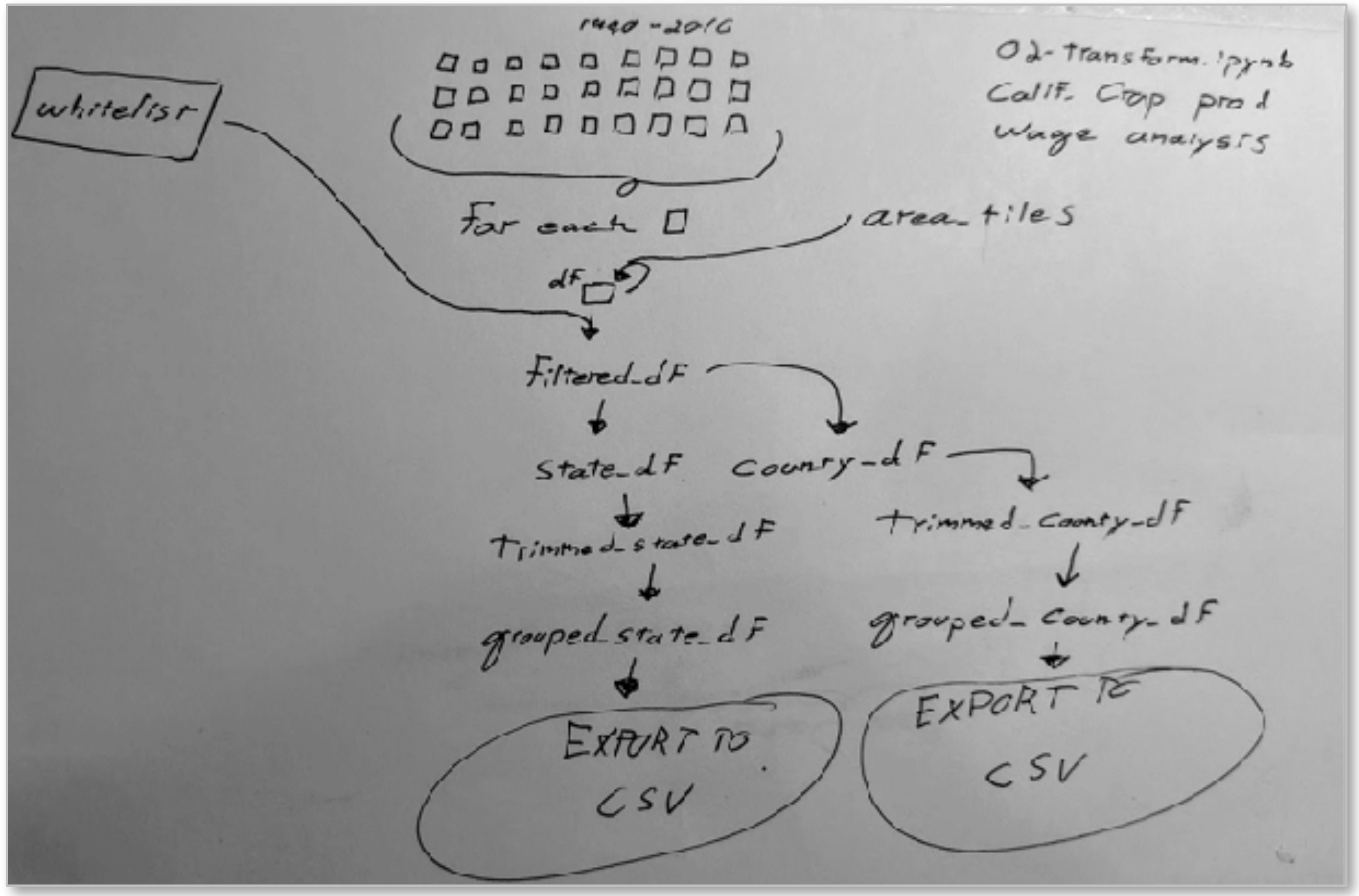
Key finding: journalists use many, many tables

- workflow complexity varies greatly



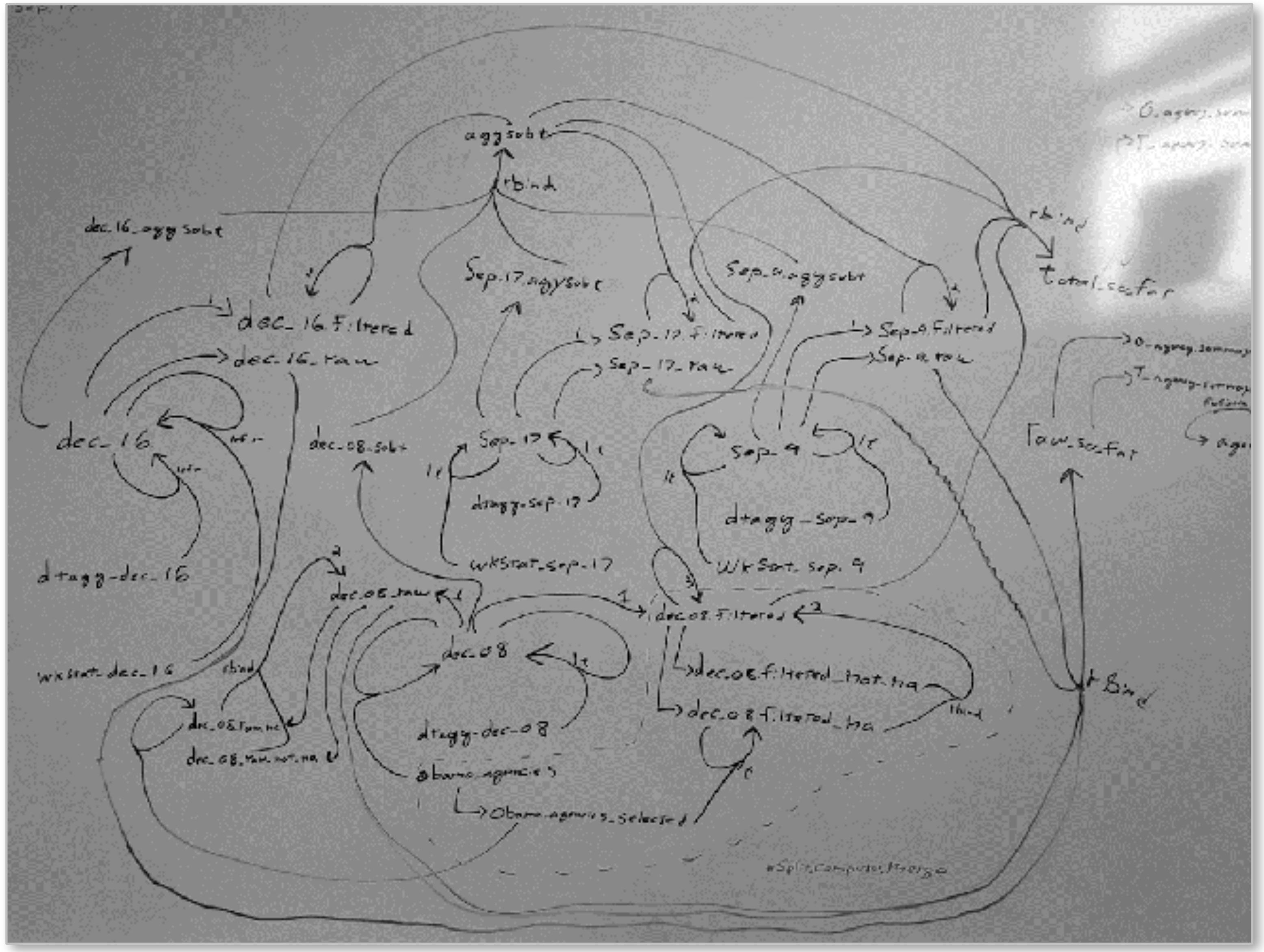
Key finding: journalists use many, many tables

- workflow complexity varies greatly
- current interactive wrangling applications do not scale well



Key finding: journalists use many, many tables

- workflow complexity varies greatly
- current interactive wrangling applications do not scale well
- re-characterize wrangling design space to match these observed practices



Two axes of multi-table wrangling design space

Two axes of multi-table wrangling design space

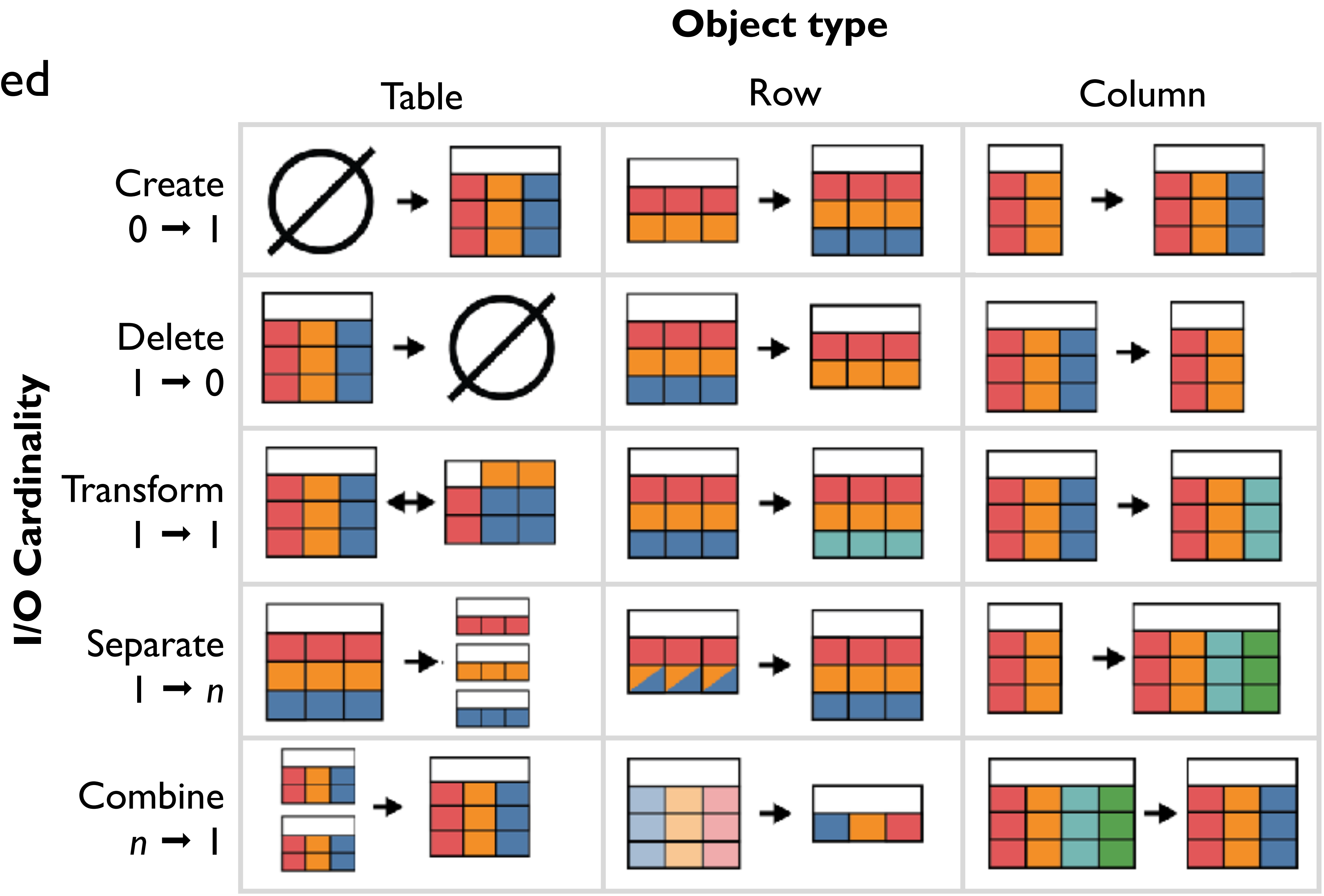
	Object type		
	Table	Row	Column

Two axes of multi-table wrangling design space

			Object type	
		Table	Row	Column
I/O Cardinality	Create 0 → 1			
	Delete 1 → 0			
	Transform 1 → 1			
	Separate 1 → *n*			
	Combine *n* → 1			

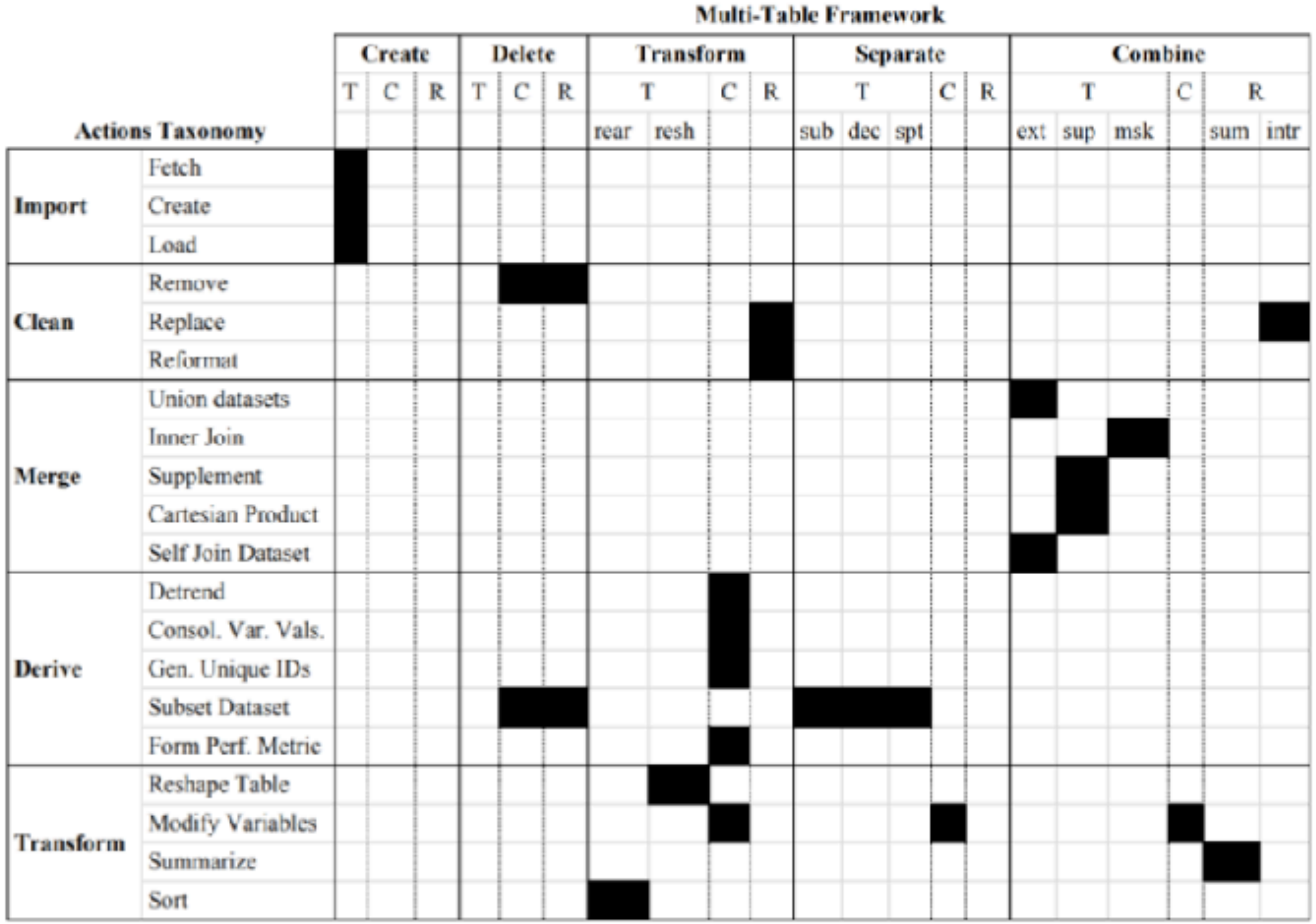
Multi-table data wrangling design space

- concise and actionable
  - **generative** power achieved
  - suitable framework for building tool



Assessment: Cross-check

- cross-check coverage of multi-table framework vs actions taxonomy
  - verify descriptive power



Multi-Table Framework

		Create			Delete			Transform				Separate					Combine					
		T	C	R	T	C	R	T		C	R	T			C	R	T			C	R	
Actions Taxonomy								rear	resh			sub	dec	spt			ext	sup	msk		sum	intr
Import	Fetch	■																				
	Create	■																				
	Load	■																				
Clean	Remove					■	■															
	Replace										■											■
	Reformat										■											
Merge	Union datasets																■					
	Inner Join																		■			
	Supplement																	■				
	Cartesian Product																	■				
	Self Join Dataset																■					
Derive	Detrend									■												
	Consol. Var. Vals.									■												
	Gen. Unique IDs									■												
	Subset Dataset					■	■					■	■	■								
	Form Perf. Metric									■												
Transform	Reshape Table								■													
	Modify Variables									■					■					■		
	Summarize																				■	
	Sort							■														

Abstract Tasks

Matt Brehmer
@mattbrehmer

A Multi-Level Typology of Abstract Visualization Tasks

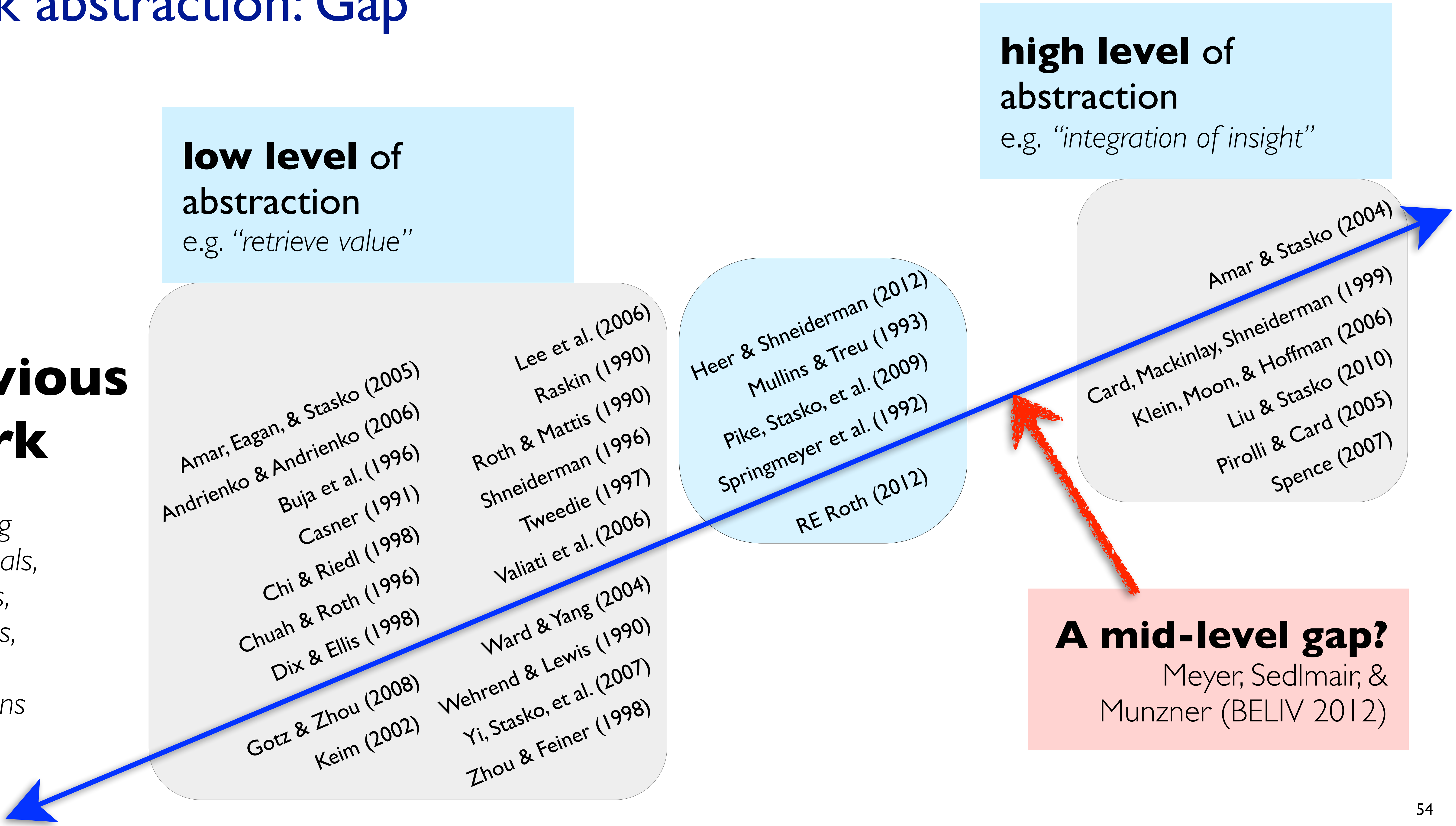
https://www.cs.ubc.ca/labs/imager/tr/2013/MultiLevelTaskTypology/

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

Task abstraction: Gap

Previous Work

Classifying Tasks, Goals, Intentions, Objectives, Activities, Interactions



low level of abstraction
e.g. *"retrieve value"*

Amar, Eagan, & Stasko (2005)
Andrienko & Andrienko (2006)
Buja et al. (1996)
Casner (1991)
Chi & Riedl (1998)
Chuah & Roth (1996)
Dix & Ellis (1998)
Gotz & Zhou (2008)
Keim (2002)

Lee et al. (2006)
Raskin (1990)
Roth & Mattis (1990)
Shneiderman (1996)
Tweedie (1997)
Valiati et al. (2006)
Ward & Yang (2004)
Wehrend & Lewis (1990)
Yi, Stasko, et al. (2007)
Zhou & Feiner (1998)

Heer & Shneiderman (2012)
Mullins & Treu (1993)
Pike, Stasko, et al. (2009)
Springmeyer et al. (1992)

RE Roth (2012)

high level of abstraction
e.g. *"integration of insight"*

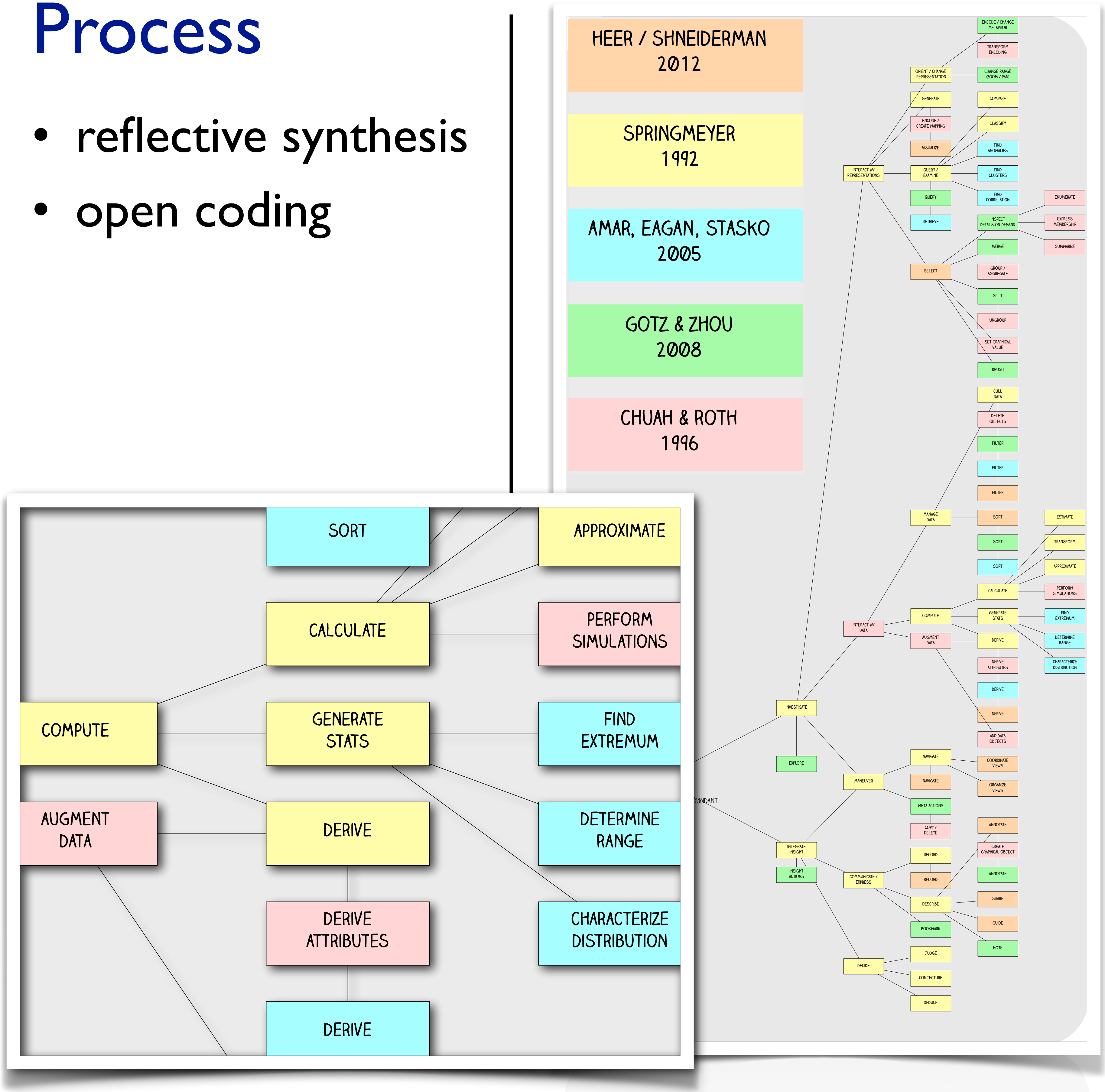
Amar & Stasko (2004)

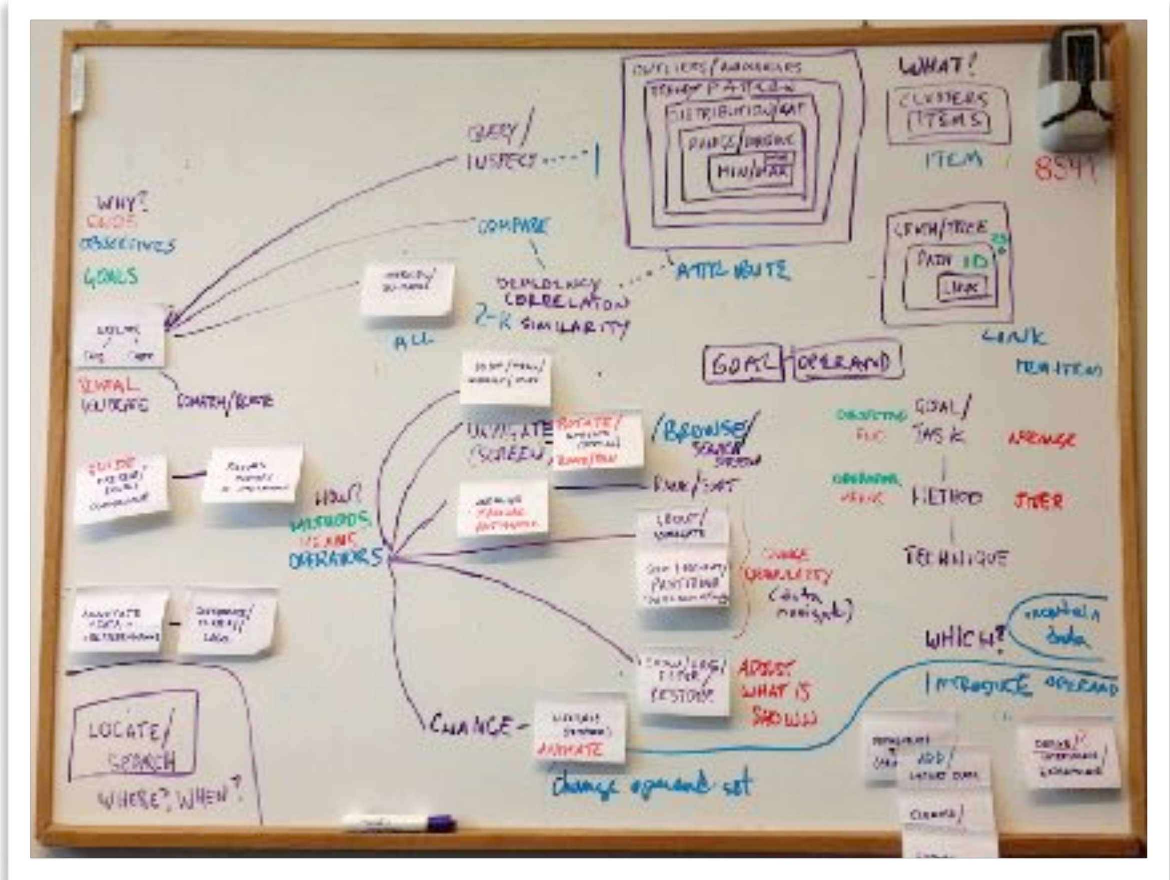
Card, Mackinlay, Shneiderman (1999)
Klein, Moon, & Hoffman (2006)
Liu & Stasko (2010)
Pirolli & Card (2005)
Spence (2007)

A mid-level gap?
Meyer, Sedlmair, & Munzner (BELIV 2012)

Process

- reflective synthesis
- open coding

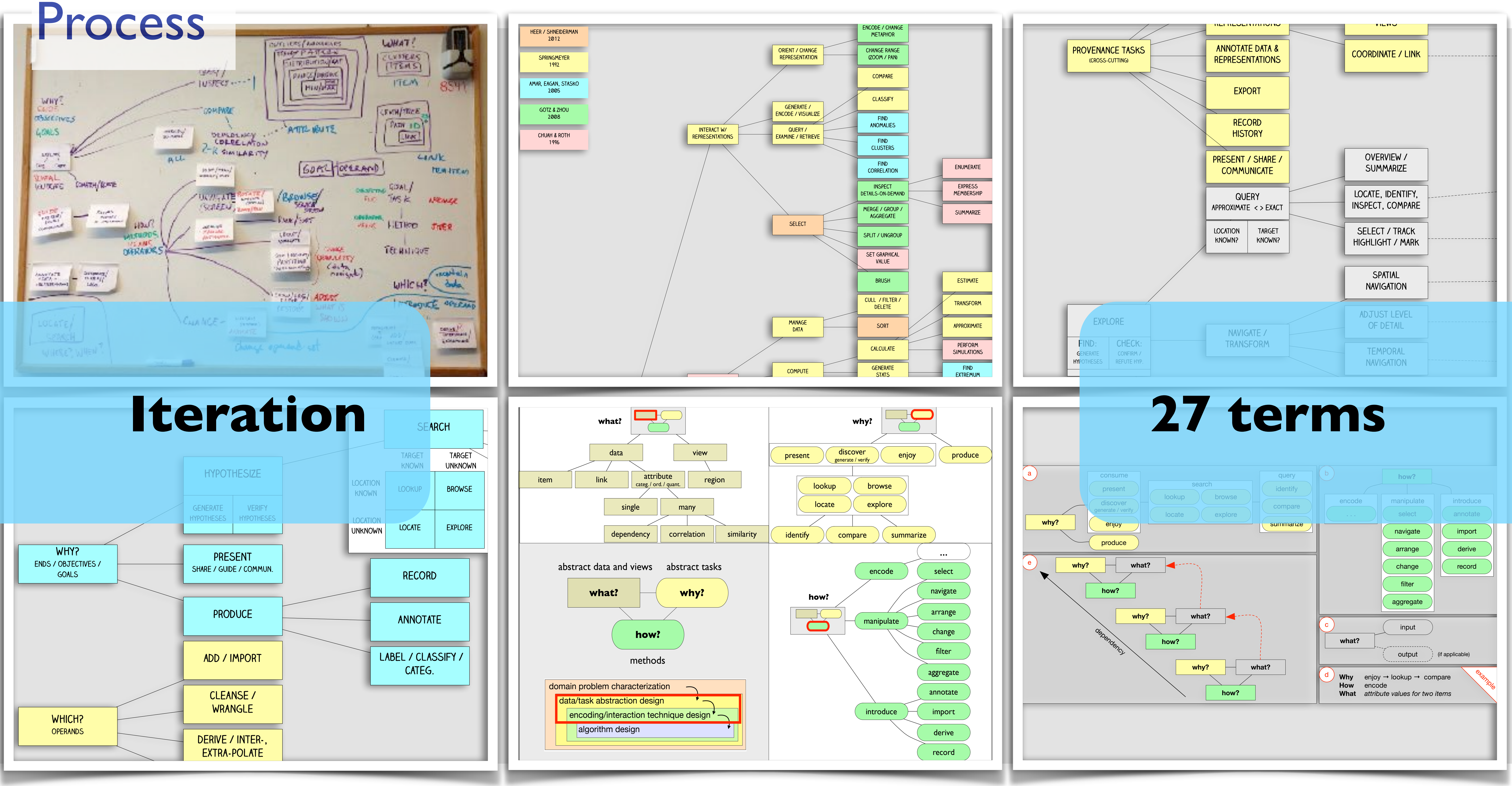




1. read and think
2. *code*: arrange and abstract
3. simplify and repeat…

open coding of literature
rather than empirical study with human subjects

Process

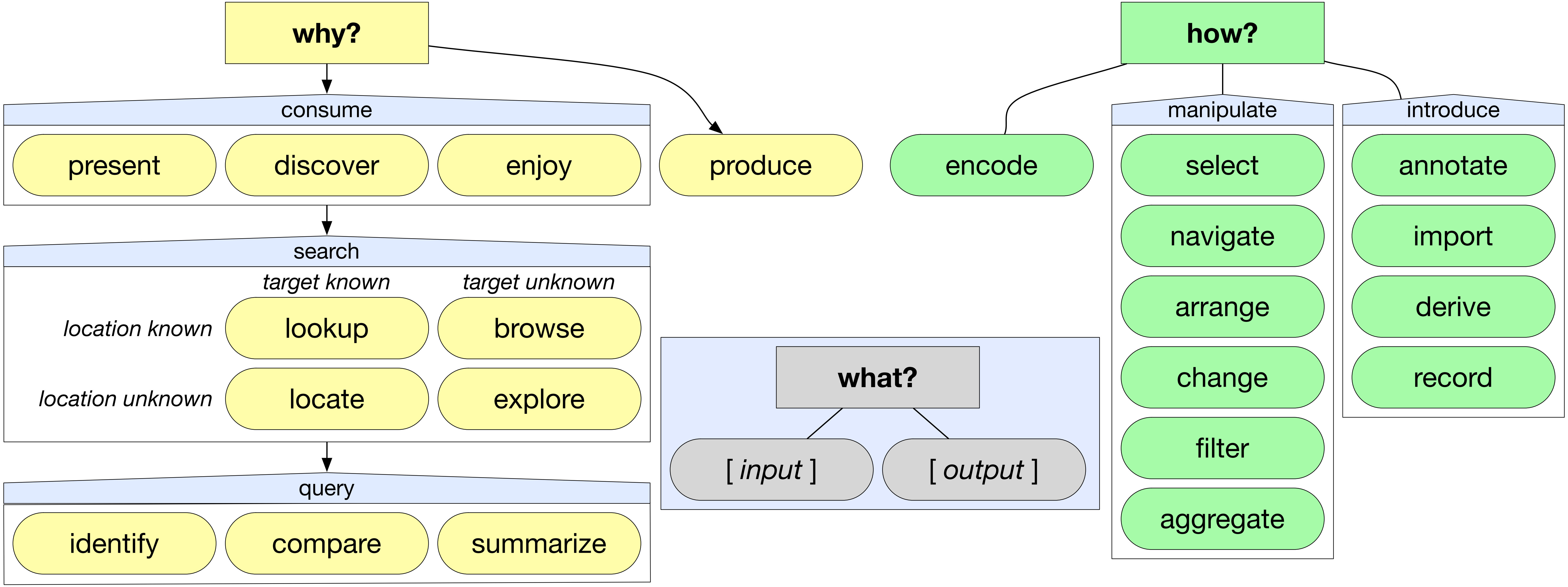


Iteration

27 terms

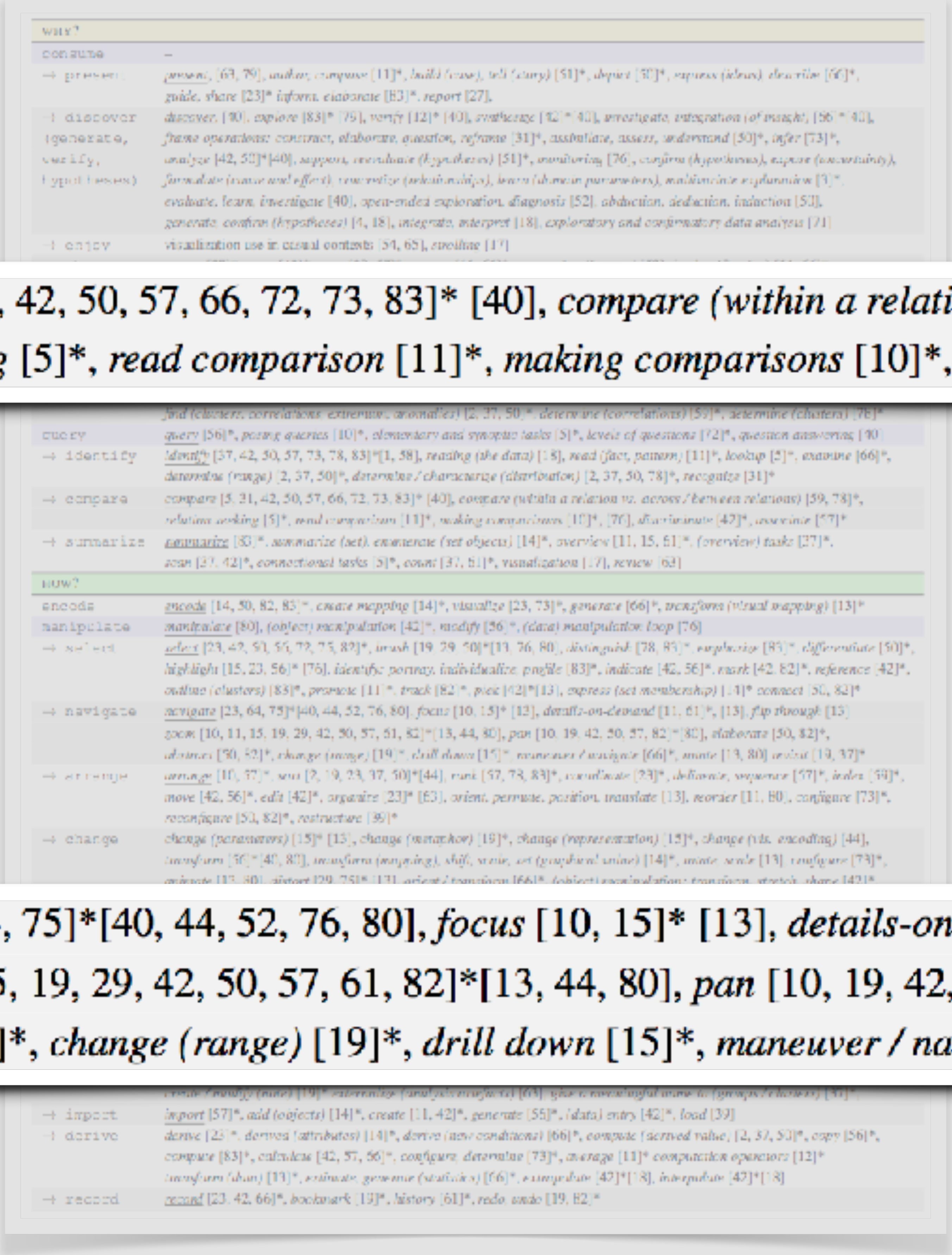
Final design space: three axes

- why, what, how



Mapping terms

Mapping our **Vocabulary** to Previous Work



→ `compare`	*compare* [5, 31, 42, 50, 57, 66, 72, 73, 83]* [40], *compare (within a relation vs. across / between relations)* [59, 78]*, *relation seeking* [5]*, *read comparison* [11]*, *making comparisons* [10]*, [76], *discriminate* [42]*, *associate* [57]*
→ `navigate`	*navigate* [23, 64, 75]*[40, 44, 52, 76, 80], *focus* [10, 15]* [13], *details-on-demand* [11, 61]*, [13], *flip through* [13] *zoom* [10, 11, 15, 19, 29, 42, 50, 57, 61, 82]*[13, 44, 80], *pan* [10, 19, 42, 50, 57, 82]*[80], *elaborate* [50, 82]*, *abstract* [50, 82]*, *change (range)* [19]*, *drill down* [15]*, *maneuver / navigate* [66]*, *rotate* [13, 80] *revisit* [19, 37]*

← **Table 1**:
lookup table of

Our **27** terms
(left column)

Terms from **30** extant classification systems

(right column)

Directionality

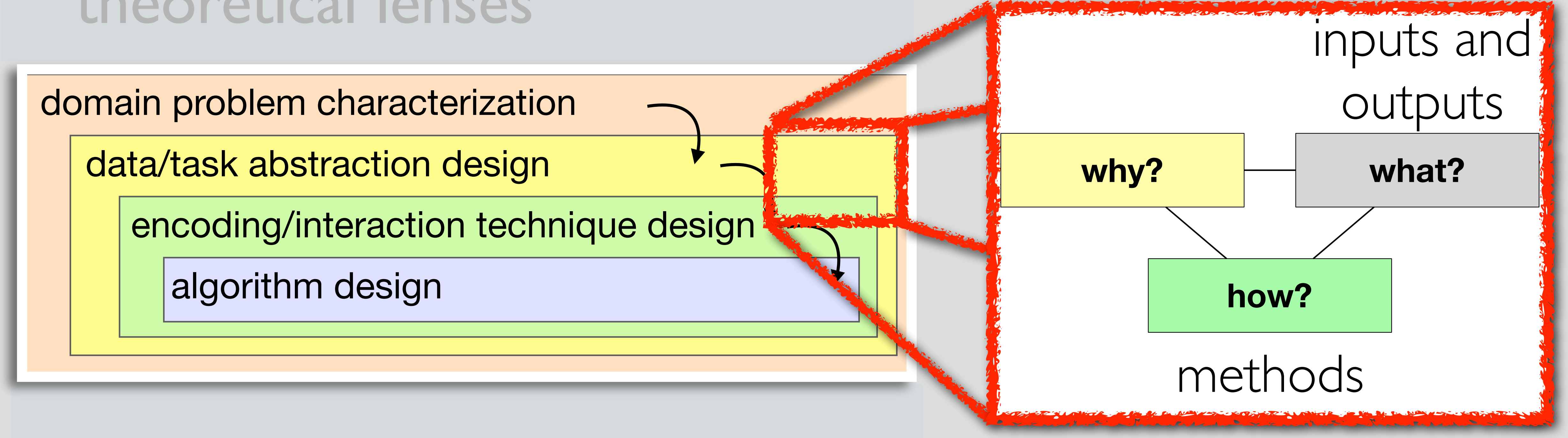
Constructing a Typology

Bottom-Up

previous classification systems

Top-Down

theoretical lenses



Stages of Action [1] +
Gulf of Goal Formation [2],
Distributed Cognition [3], *Sensemaking* [4],
Play Theory [5], ***Nested Model*** [6]

[1] Norman (1988)

[2] Lam (TVCG 2008)

[3] e.g. Hollan et al. (2000)

[4] e.g. Pirolli and Card (2005)

[5] Stephenson (1967) ,Toms (2000)

[6] Munzner (TVCG 2009)

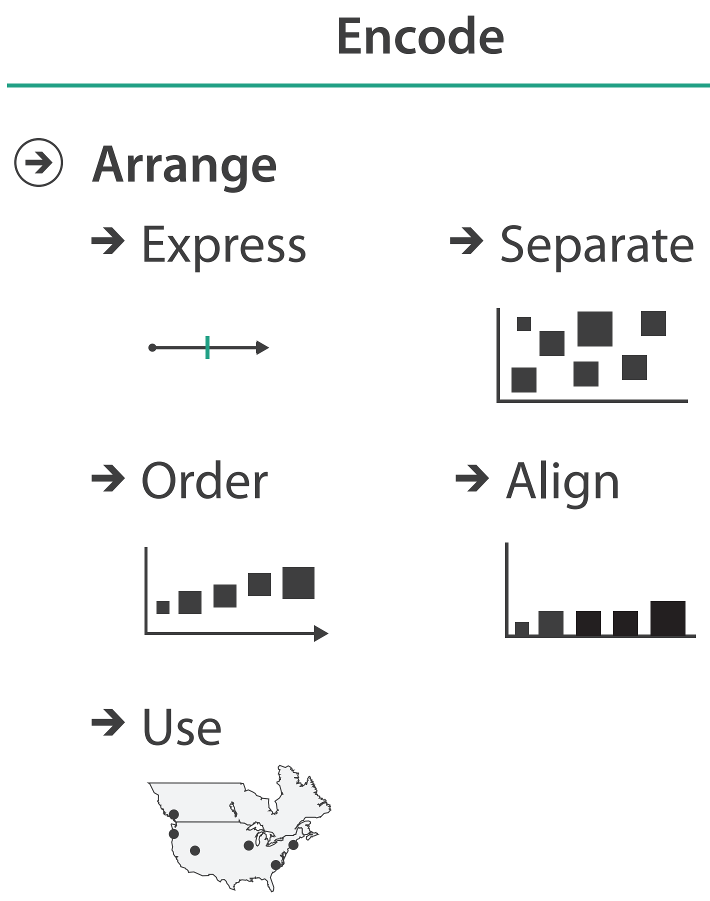
Assessment & adoption

- **descriptive** power
  - analyze & compare task sequences, clarify means and ends
- **generative** power
  - early stages of problem-driven work: abstracting & requirements gathering
- **evaluative** power
  - codeset for field studies, task set for lab studies

- adoption
  - hundreds of papers

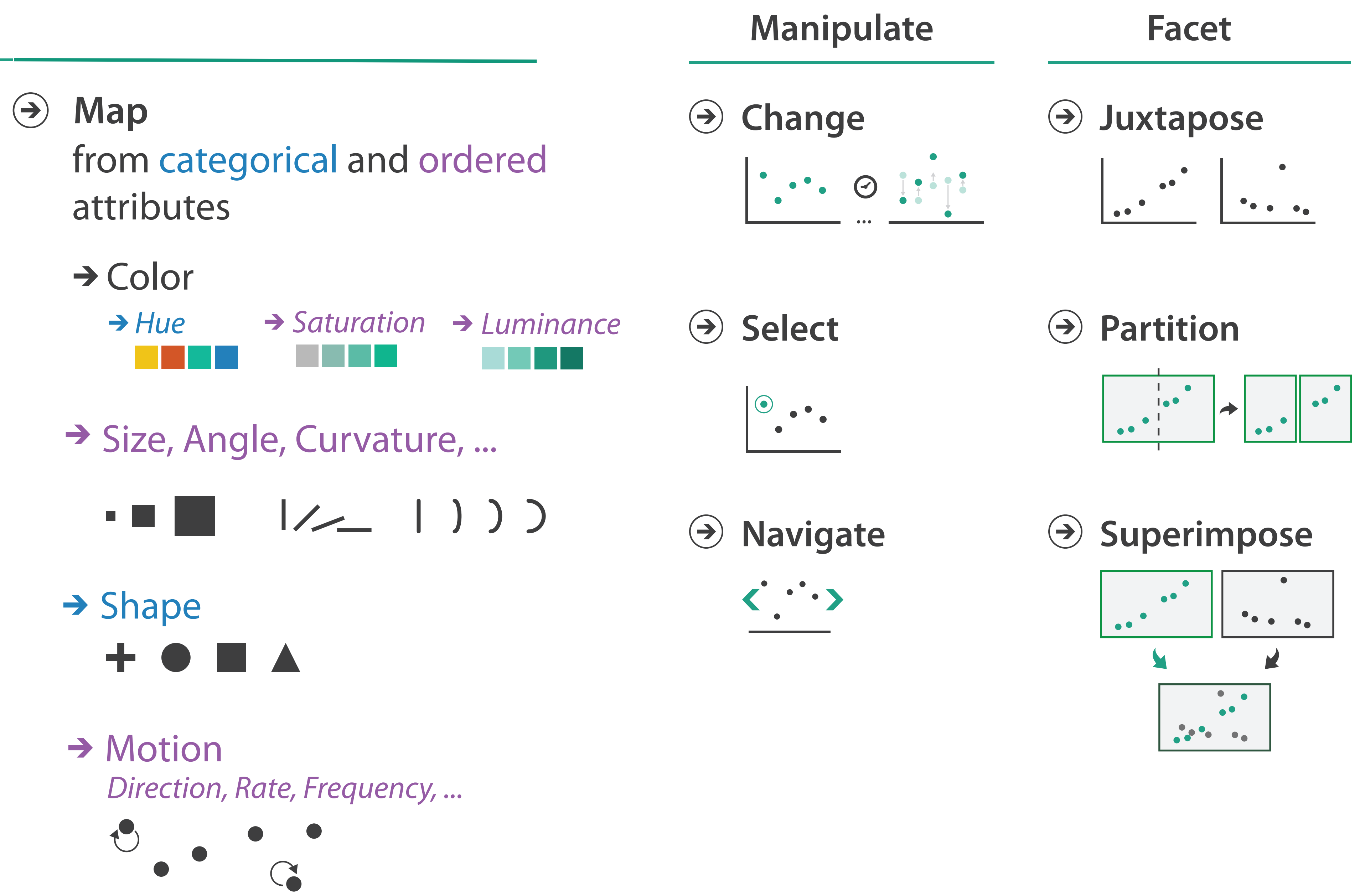
VAD Book: Visualization Analysis and Design

How?



Encode

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



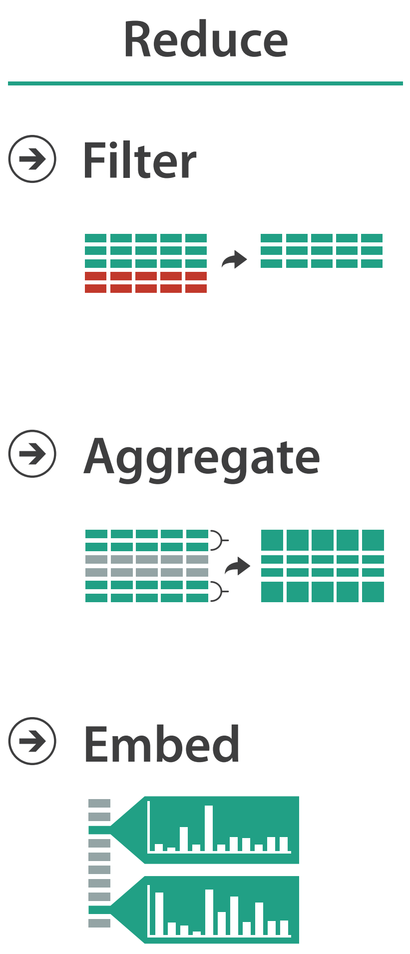
- Map
  from categorical and ordered attributes
  - Color
    - *Hue*
    - *Saturation*
    - *Luminance*
  - Size, Angle, Curvature, ...
  - Shape
  - Motion
    Direction, Rate, Frequency, ...

Manipulate

- Change
- Select
- Navigate

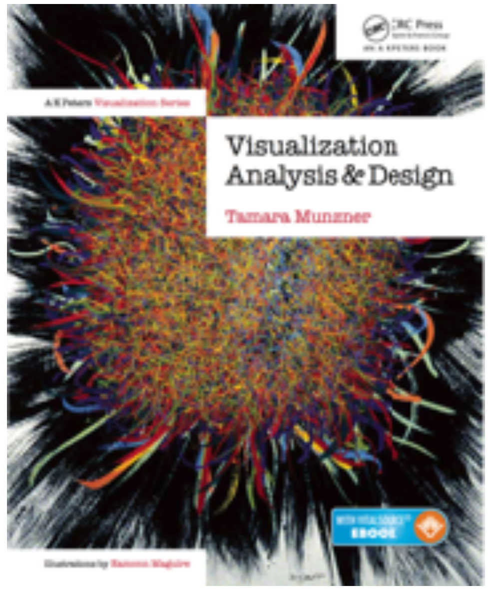
Facet

- Juxtapose
- Partition
- Superimpose

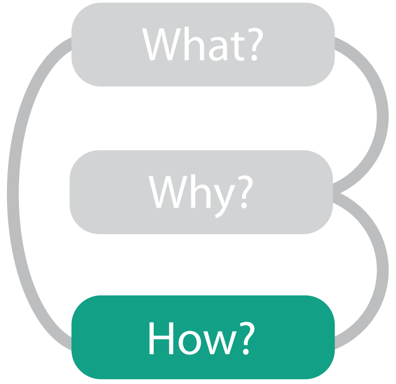


Reduce

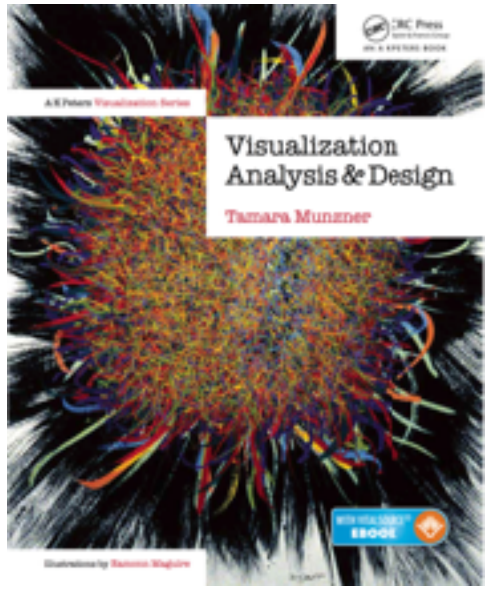
- Filter
- Aggregate
- Embed



Visualization Analysis and Design. Munzner.
CRC/Routledge, AK Peters Visualization Series, 2014.



VAD Book



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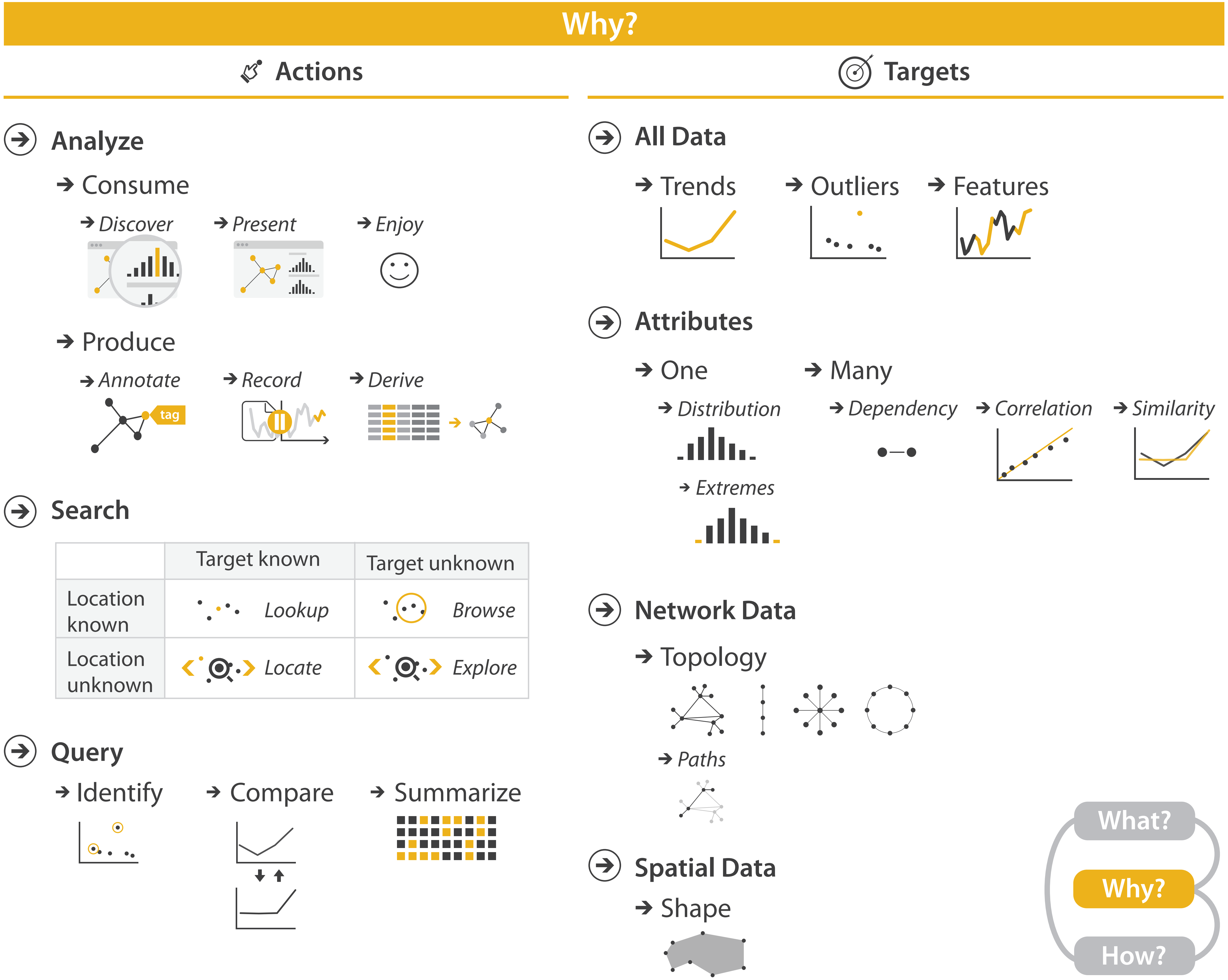


Why?

Actions

Analyze

- Consume
  - *Discover*
  - *Present*
  - *Enjoy*
- Produce
  - *Annotate*
  - *Record*
  - *Derive*

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

Network Data

- Topology
  - *Paths*

Spatial Data

- Shape

Specificity / # Populations	Explore	Describe	Explain	Confirm
Single	Discover Observation	Describe Observation	Identify Main Cause	Collect Evidence
Multiple		Compare Entities	Explain Differences	Evaluate Hypothesis

Heidi
Lam

Melanie
Tory
@vizstudylady

Bridging From Goals to Tasks

with Design Study Analysis Reports

http://www.cs.ubc.ca/labs/imager/tr/2017/GoalsToTasks/

design space: analysis goals

source material: analysis reports extracted from design study papers

Bridging From Goals to Tasks With Design Study Analysis Reports.
Lam, Tory, Munzner. IEEE TVCG 24(1):435-445 (Proc. InfoVis 2017).

Summary: Multiple design spaces

Design Space	**Open Coding Source Material**	**Sampling Strategy**	**Reflective Synthesis Timing**	**Vis Research Literature**
timeline visual encoding	standalone timelines	assembled corpus	early	some source material
genEpi visual encoding	figures from papers	stratified random sampling with topic clusters	-	-
wrangling activities	software from repos	diversity criteria	late	terms: light mapping
abstract **tasks**	tasks from papers	comprehensive	early	terms: thorough mapping

Summary: Multiple design spaces

Design Space	**Descriptive Power**	**Generative Power**	**Descriptive vs Generative**	**Evaluative Power**
timeline visual encoding	validated against test set	software implementation of authoring system, used to create example gallery/videos	analysis to characterize viable subset	
genEpi visual encoding	systematic method yields comprehensive coverage	software implementation of automatic recommender (followup)	*same (detailed)*	
wrangling activities	high precision, gaps / divergence found for domain	concise framework (followup implementation TBD)	develop entirely new framework	
abstract **tasks**	widespread adoption	widespread adoption	*same (concise)*	widespread adoption

Design spaces: How to assess? Larger context: theory types

- Ben Shneiderman, *Designing the User Interface:* descriptive, explanatory, prescriptive, predictive
- Paul Ralph,
  Toward Methodological Guidelines for Process Theories & Taxonomies in Software Engineering, IEEE TSE 2020
  - theory types
    - theories for **understanding**: organizing what is happening into useful categories (taxonomies)
    - **process** theories: how something happens (often taxonomies++)
    - **variance** theories: why something happens, causal relationships between constructs
      - predictive
  - relevant criteria for taxonomies
    - **yes**: parsimony, transferability, theoretical saturation
    - **sometimes**: utility, originality, resonance/believability, testability
    - **no**: statistical generalizability, construct validity, internal validity, conclusion validity

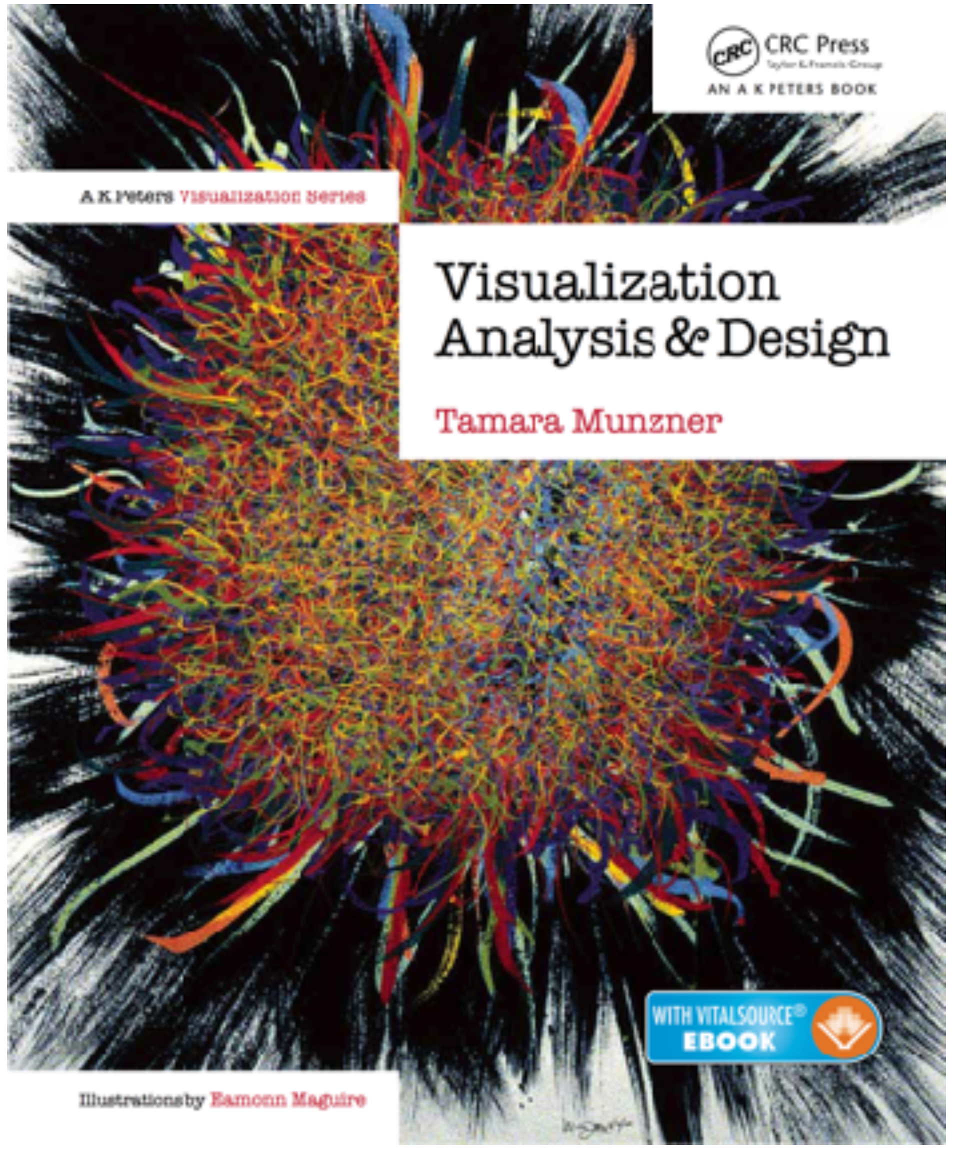
More information

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#stanf22

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

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

@tamaramunzner



Visualization Analysis and Design. Munzner. *CRC Press, AK Peters Visualization Series, 2014.*