

A Heuristic Approach to Value-Driven Evaluation of Visualizations

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National
Laboratories**

Evaluating the utility of
visualizations is difficult

Value of Visualization

- Move beyond ability to support (just) question-answering
 - Often evident in benchmark task-focused user studies
- Assess broader, more holistic benefits that communicates "big picture" importance and context of data

Value of Visualization

$$V_{\text{alue}} = T_{\text{ime}} + I_{\text{nsight}} + E_{\text{ssence}} + C_{\text{onfidence}}$$

Value of Visualization

$$V_{\text{value}} = T_{\text{ime}} + I_{\text{nsight}} + E_{\text{ssence}} + C_{\text{onfidence}}$$

Ability to minimize the total **time**
needed to answer a wide variety of
questions about the data

Value of Visualization

$$V_{\text{alue}} = T_{\text{ime}} + I_{\text{nsight}} + E_{\text{ssence}} + C_{\text{onfidence}}$$

Ability to spur and discover **insights**
or insightful questions about the
data

Value of Visualization

$$V_{\text{alue}} = T_{\text{ime}} + I_{\text{nsight}} + \mathbf{E}_{\text{ssence}} + C_{\text{onfidence}}$$

Ability to convey an overall **essence** or take-away sense of the data

Value of Visualization

$$V_{\text{alue}} = T_{\text{ime}} + I_{\text{nsight}} + E_{\text{ssence}} + C_{\text{onfidence}}$$

Ability to generate **confidence**
and trust about the data, its
domain and context

Value of Visualization

$$V_{\text{alue}} = T_{\text{ime}} + I_{\text{nsight}} + E_{\text{ssence}} + C_{\text{onfidence}}$$

Goal: Operationalize this conceptual approach

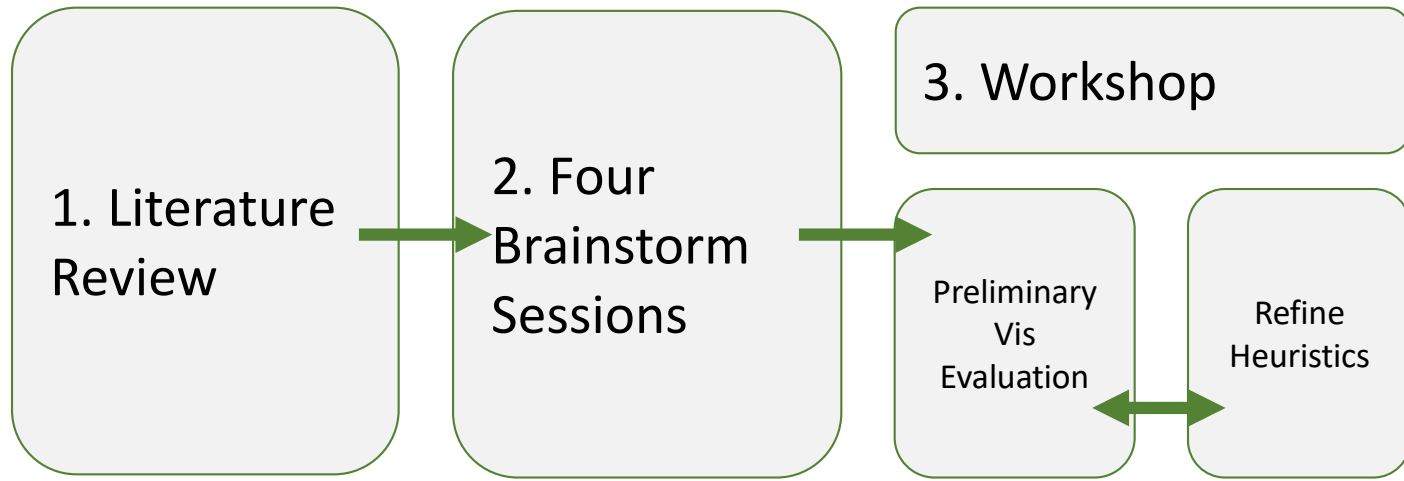
Design of the Methodology

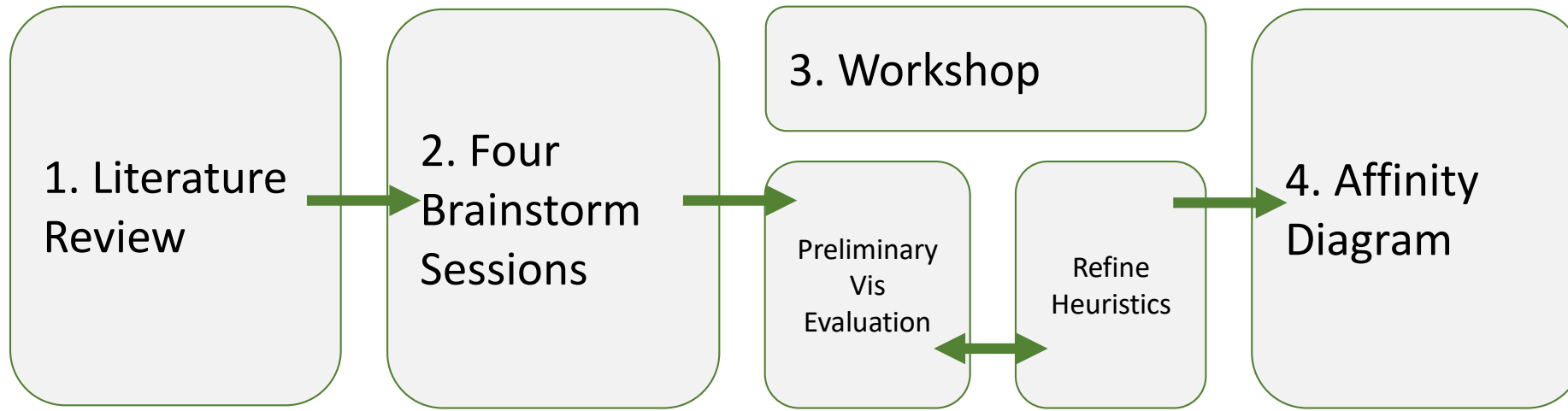
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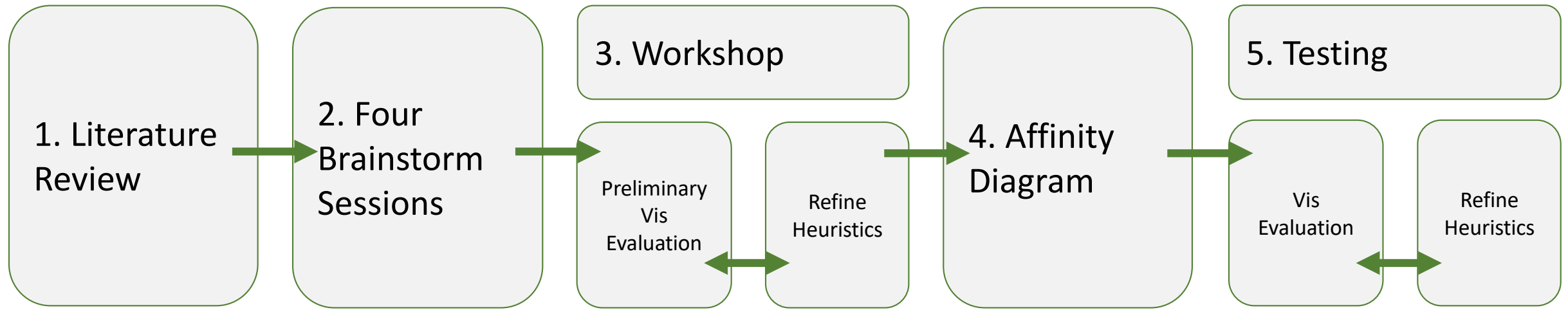
1. Literature
Review



2. Four
Brainstorm
Sessions

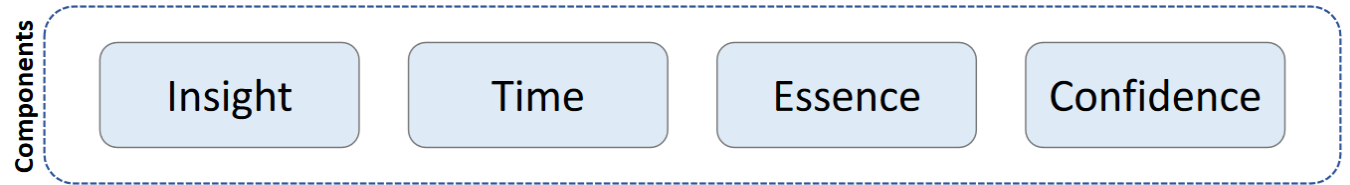




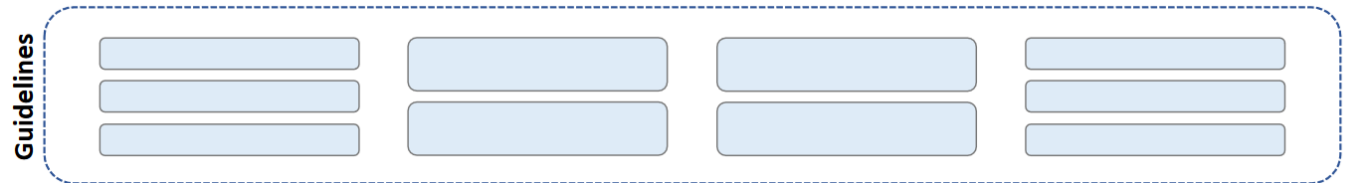


Hierarchical Value Framework

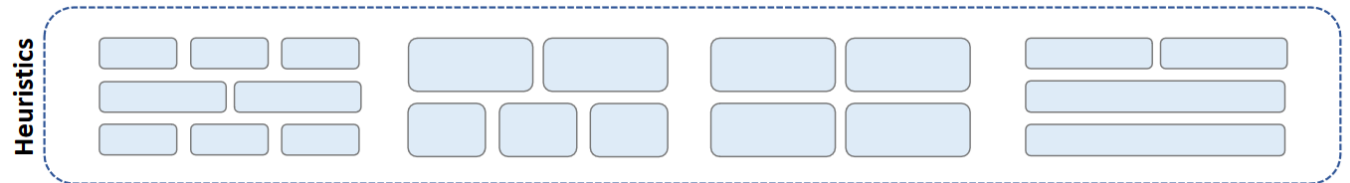
4 high-level components



2-3 mid-level guidelines



1-3 low-level heuristics



21 total heuristics

| Value of Visualization | | |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Insight | <p>The visualization facilitates answering questions about the data</p> <p>The visualization provides a new or better understanding of the data</p> <p>The visualization provides opportunities for serendipitous discoveries</p> | <p>The visualization exposes individual data cases and their attributes</p> <p>The visualization facilitates perceiving relationships in the data like patterns & distributions of the variables</p> <p>The visualization promotes exploration of relationships among different aggregation levels of the data</p> <p>The visualization helps generate data-driven questions</p> <p>The visualization helps identify unusual or unexpected, yet valid, data characteristics or values</p> <p>The visualization provides useful interactive capabilities to help investigate the data in multiple ways</p> <p>The visualization shows multiple perspectives about the data</p> <p>The visualization uses an effective representation of the data that shows related and partially related data cases</p> |
| Time | <p>The visualization affords rapid parallel comprehension for efficient browsing</p> <p>The visualization provides mechanisms for quickly seeking specific information</p> | <p>The visualization provides a meaningful spatial organization of the data</p> <p>The visualization provides key characteristics of the data at a glance</p> <p>The interface supports reorganizing the visualization by the data's attribute values</p> <p>The visualization supports smooth transitions between different levels of detail in viewing the data</p> <p>The visualization avoids complex syntactic querying by providing direct interaction</p> |
| Essence | <p>The visualization provides a big picture perspective of the data</p> <p>The visualization provides an understanding of the data beyond individual data cases</p> | <p>The visualization provides an effective, comprehensive and accessible overview of the data</p> <p>The visualization presents the data by providing a meaningful visual schema</p> <p>The visualization facilitates generalizations and extrapolations of patterns and conclusions</p> <p>The visualization helps understand how variables relate in order to accomplish different analytic tasks</p> |
| Confidence | <p>The visualization helps avoid making incorrect inferences</p> <p>The visualization facilitates learning more broadly about the domain of the data</p> <p>The visualization helps understand data quality</p> | <p>The visualization uses meaningful and accurate visual encodings to represent the data</p> <p>The visualization avoids using misleading representations</p> <p>The visualization promotes understanding data domain characteristics beyond the individual data cases and attributes</p> <p>If there were data issues like unexpected, duplicate, missing, or invalid data, the visualization would highlight those issues</p> |

| Value of Visualization | | |
|------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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Insight

Insight

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The visualization provides opportunities for serendipitous discoveries

Insight

...

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The visualization provides opportunities for serendipitous discoveries

The visualization provides useful interactive capabilities to help investigate the data in multiple ways

The visualization shows multiple perspectives about the data

The visualization uses an effective representation of the data that shows related and partially related data cases

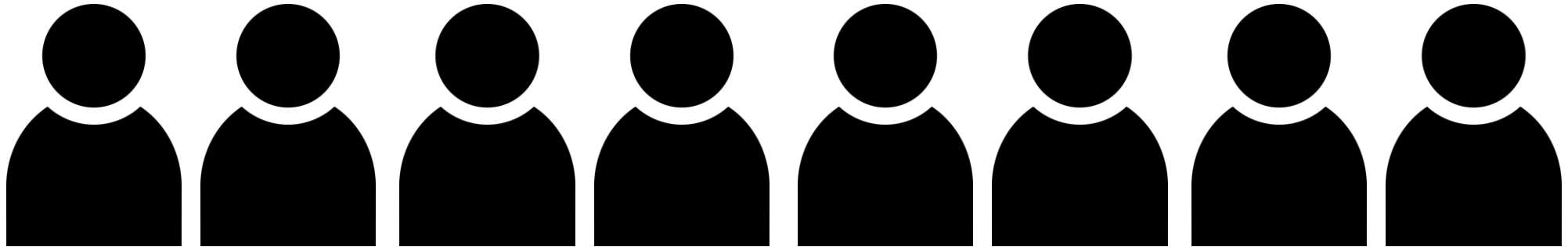
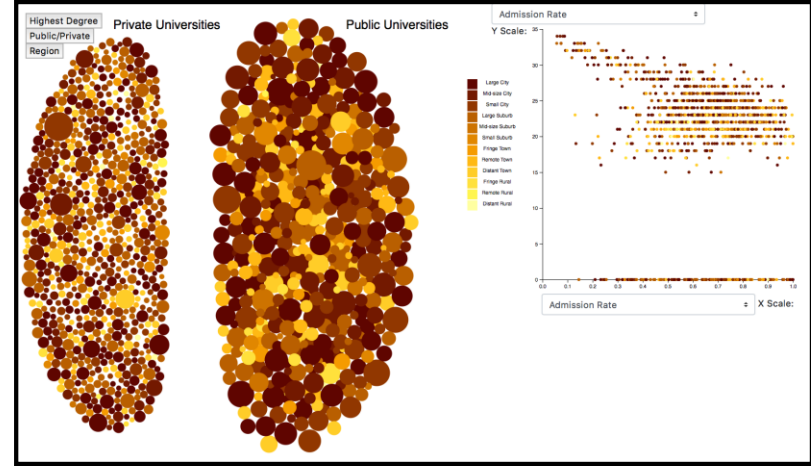
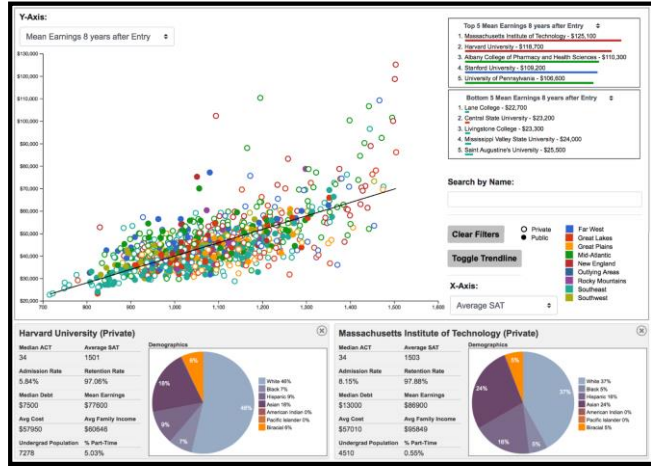
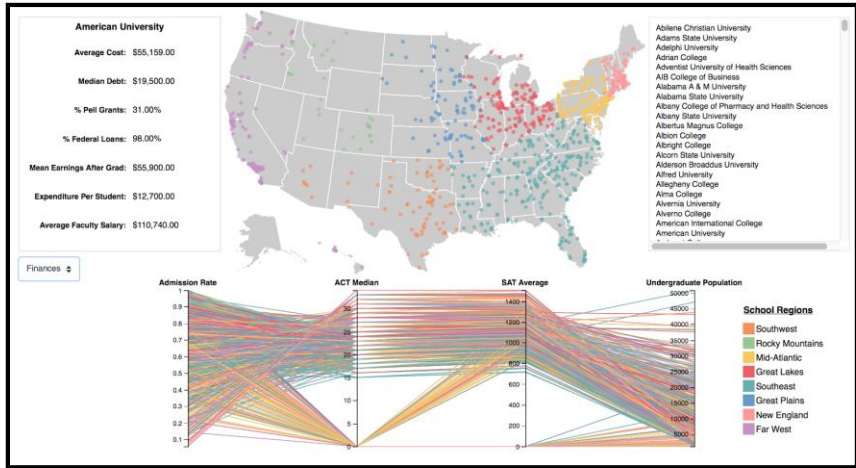
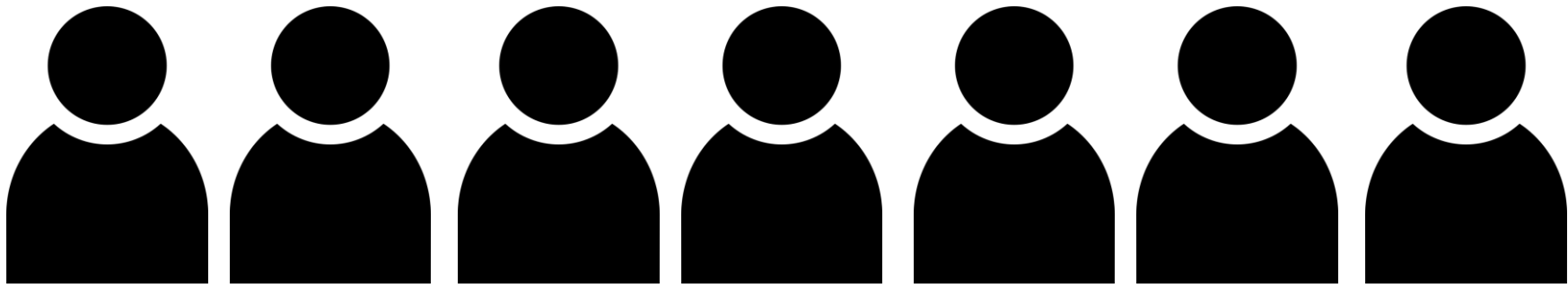
Methodology

- Raters: people with substantial data visualization + domain knowledge
- 7-point likert ratings + n/a
- Scores averaged so each guideline & component counted equal
- Scope: Interactive visualizations



Value = T + I + E + C

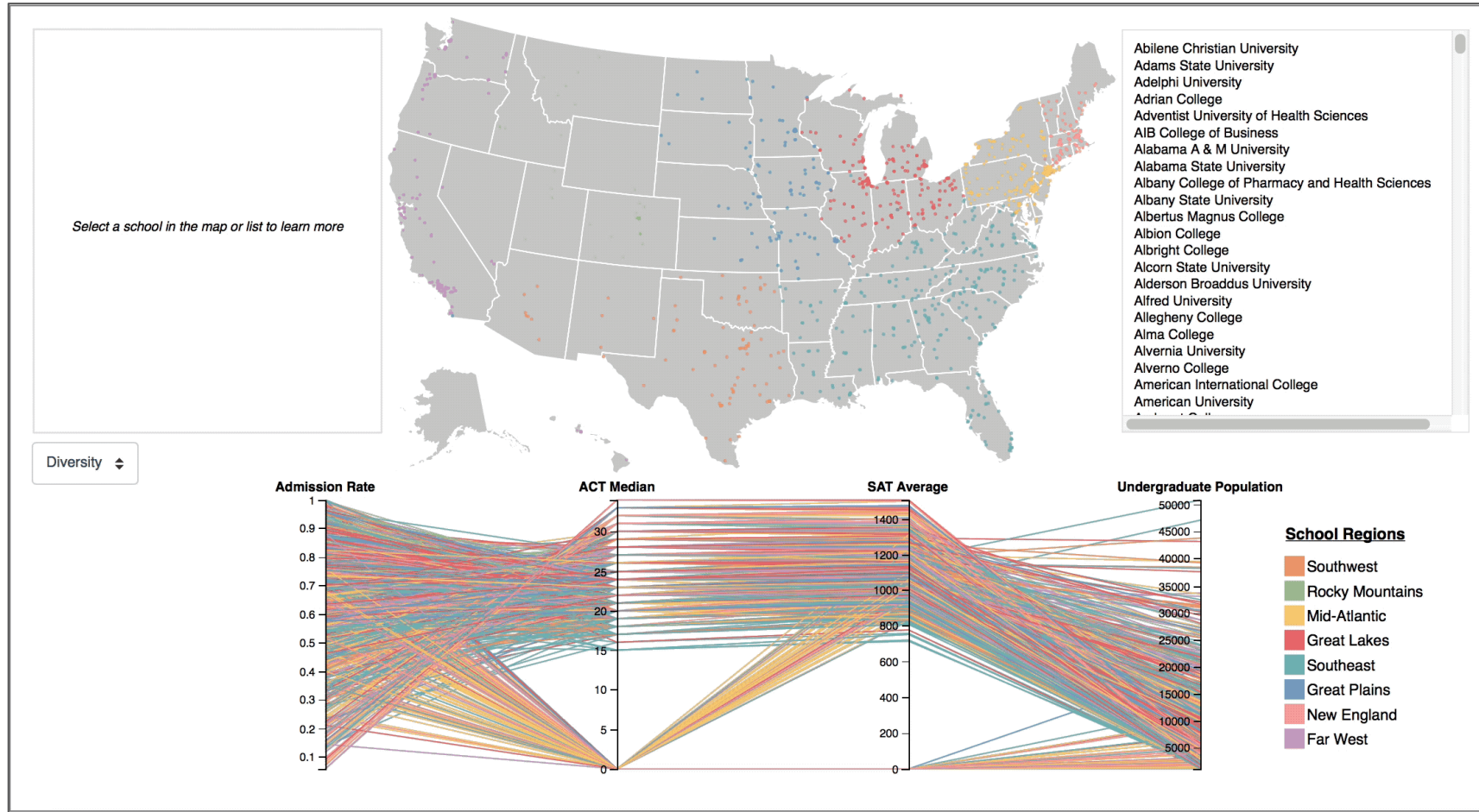
Assessing the Methodology



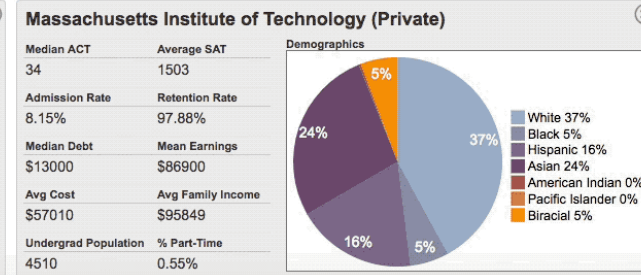
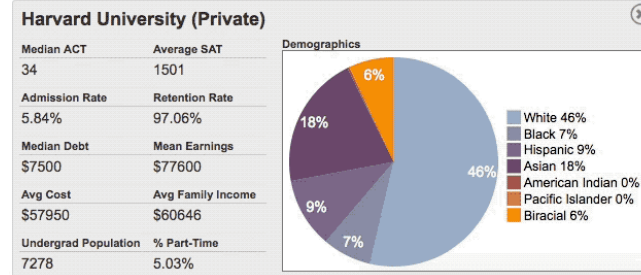
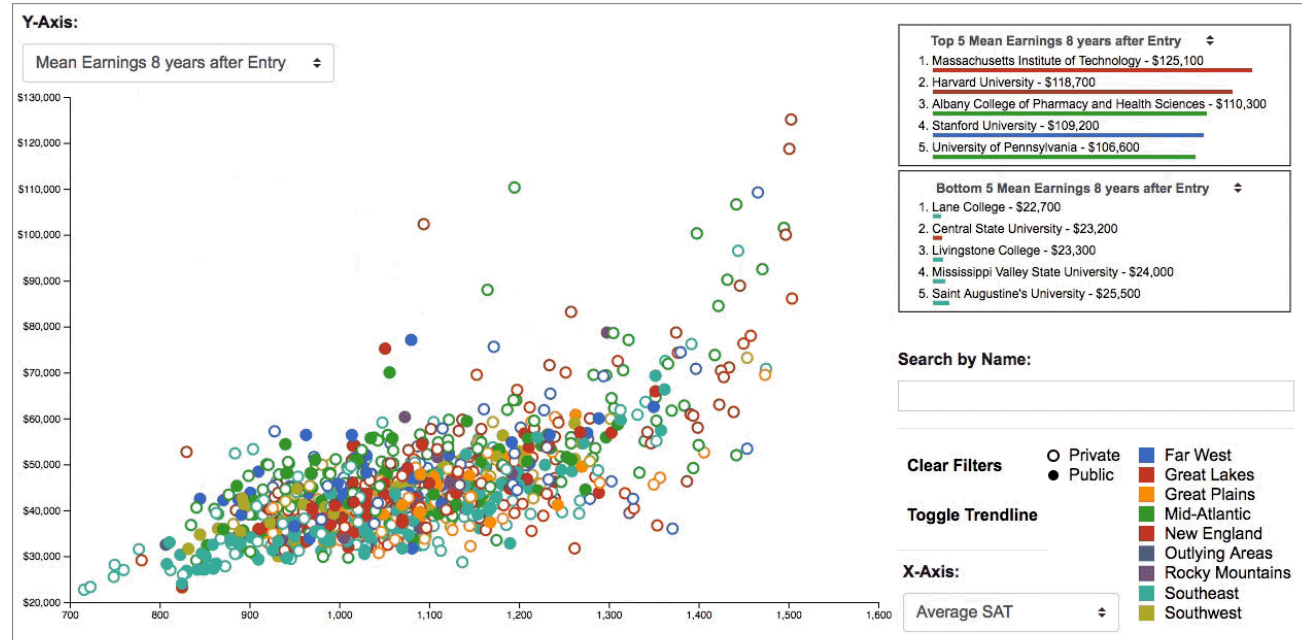
- 12 male, 3 female
- 6 researchers, 8 professors, 1 software engineer
- 7-30 years of experience (mean 14)

- Interactive
- Undergraduate course project
- US college dataset

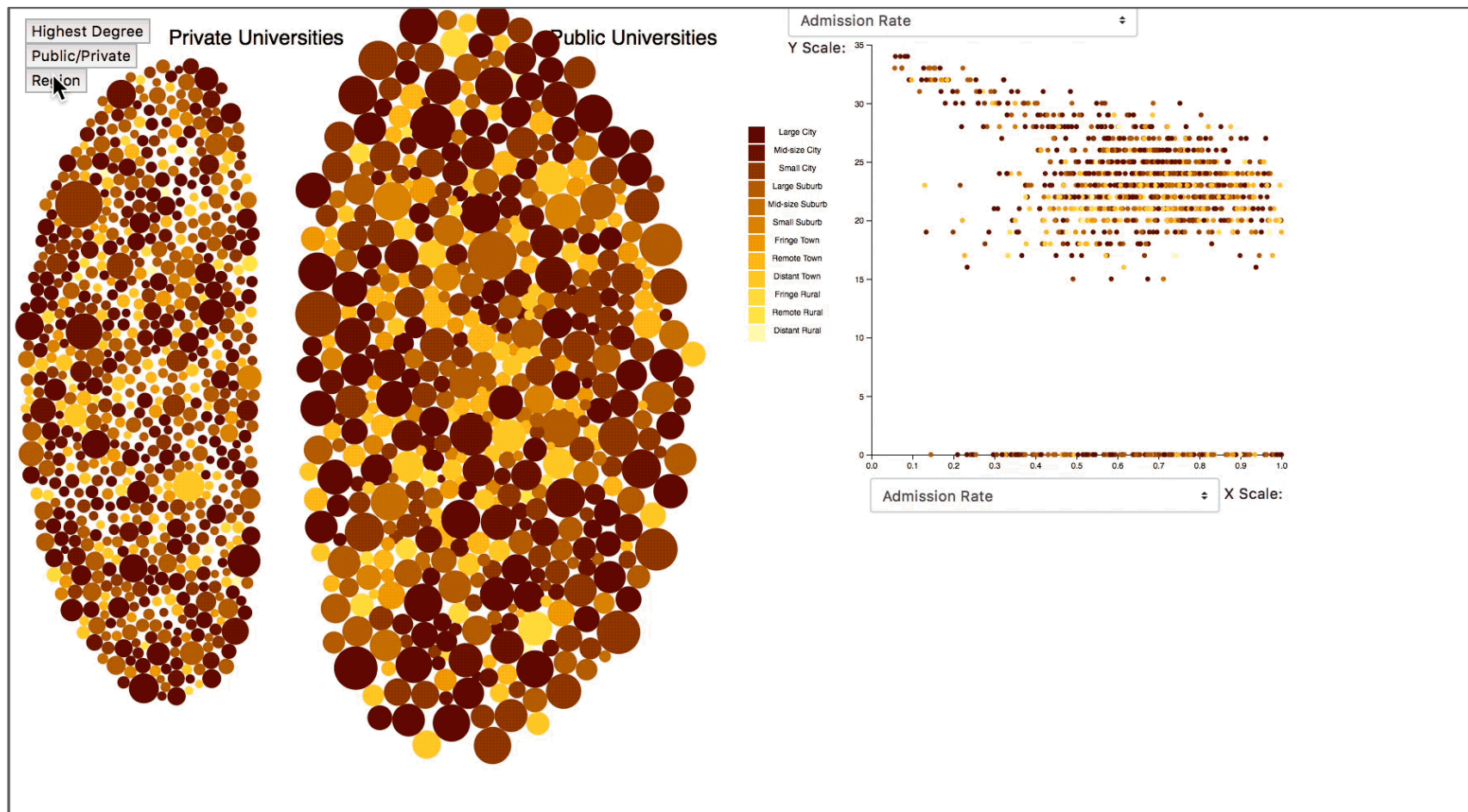
Vis A



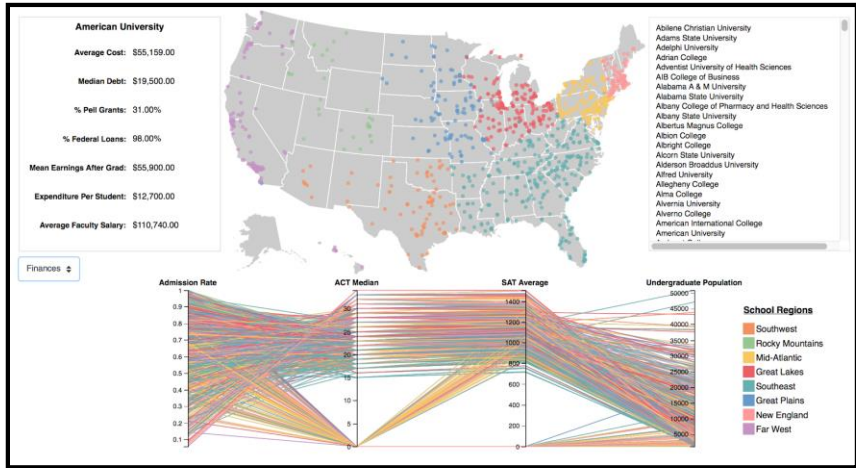
Vis B



Vis C



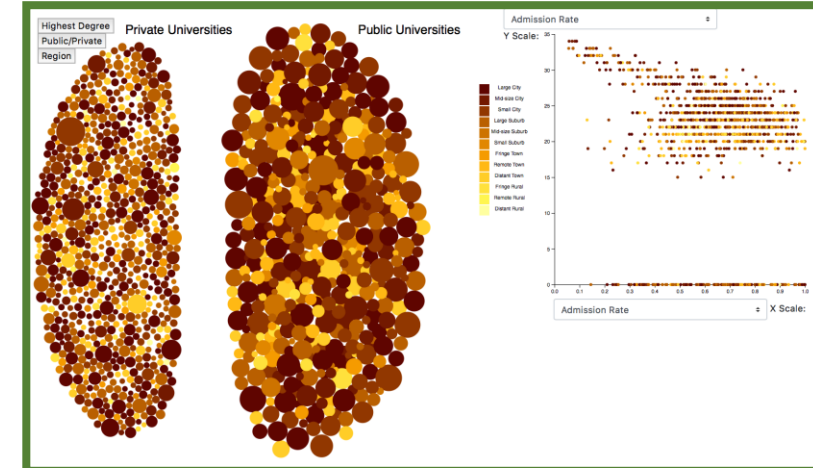
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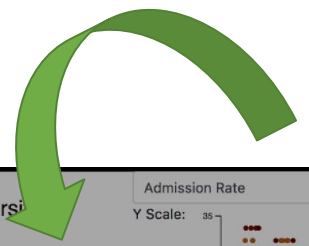
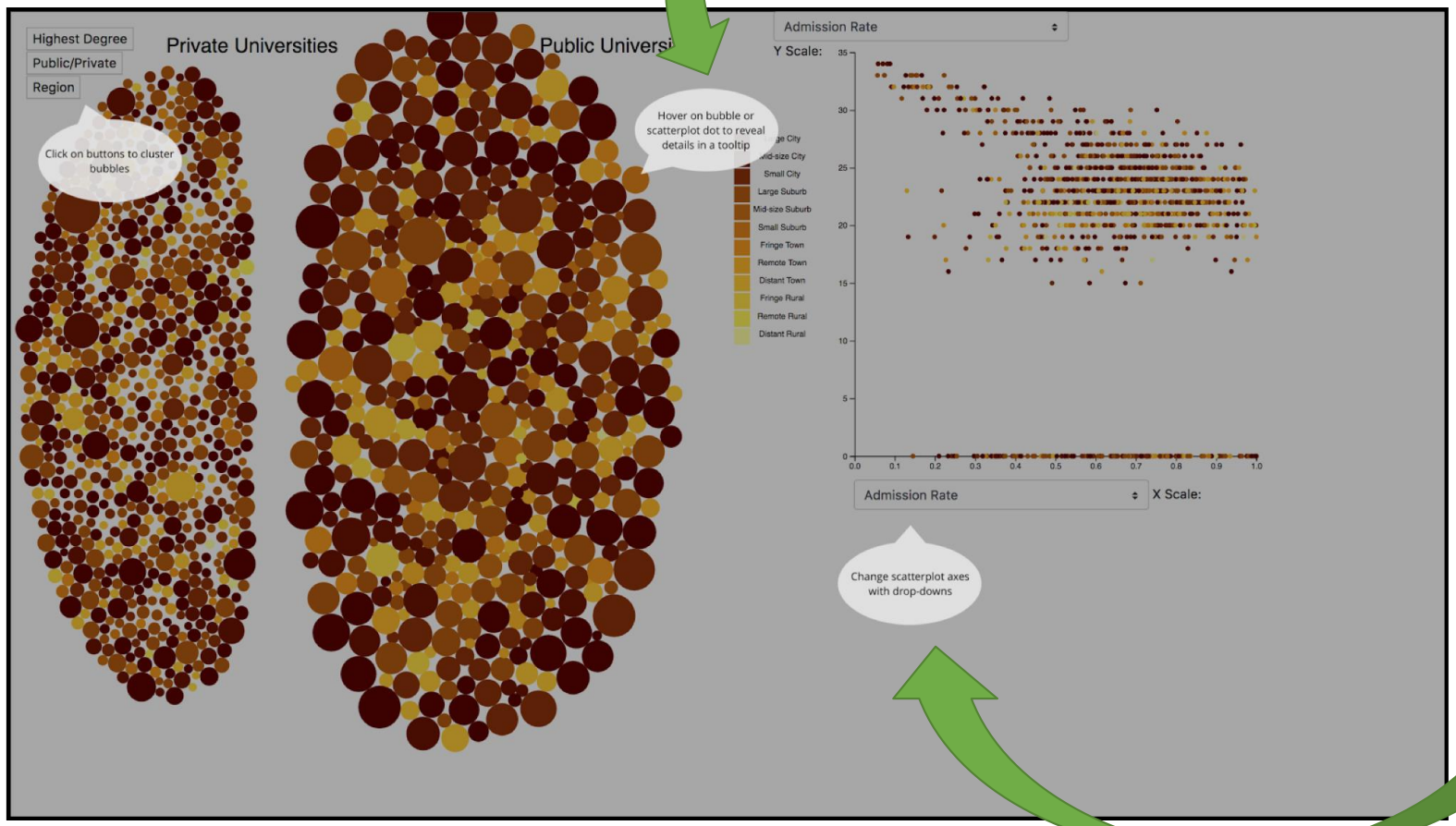


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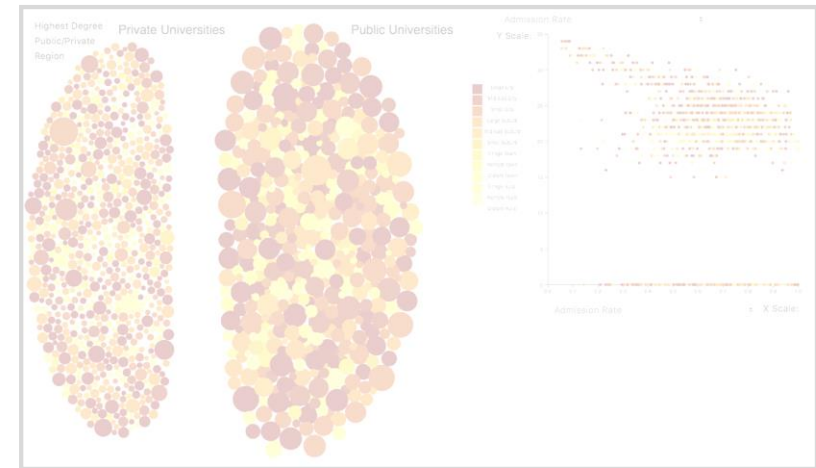
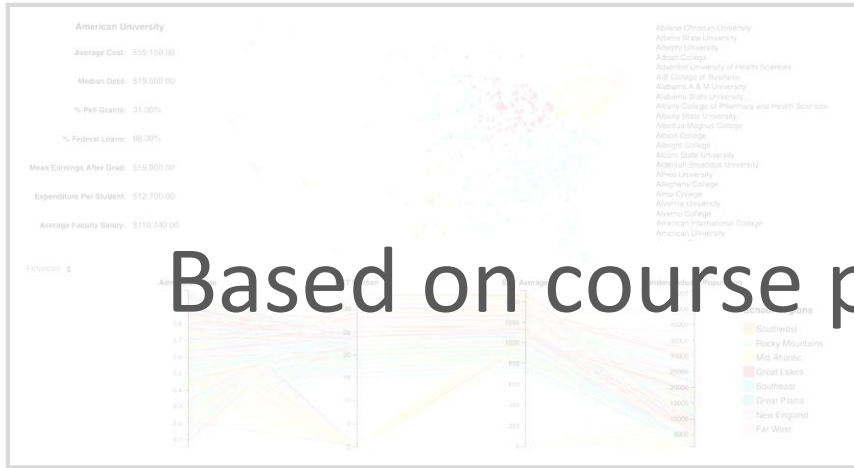
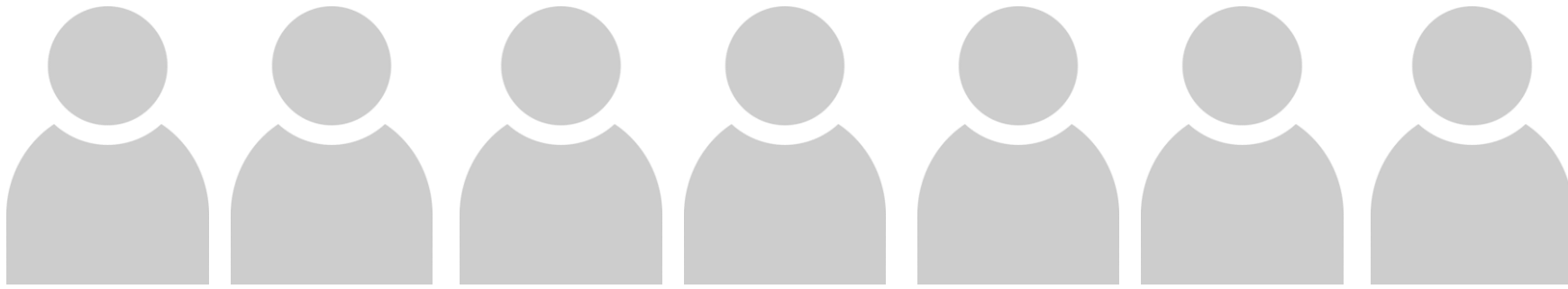
1





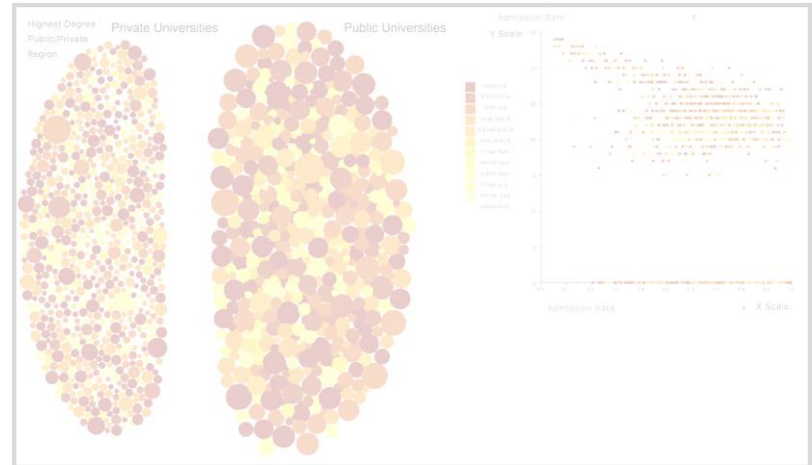
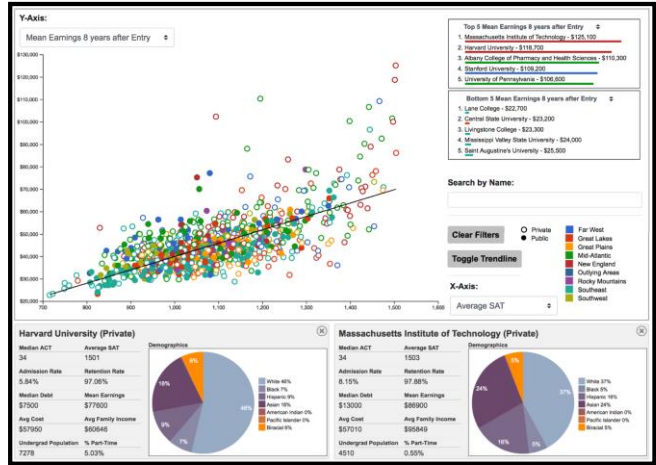
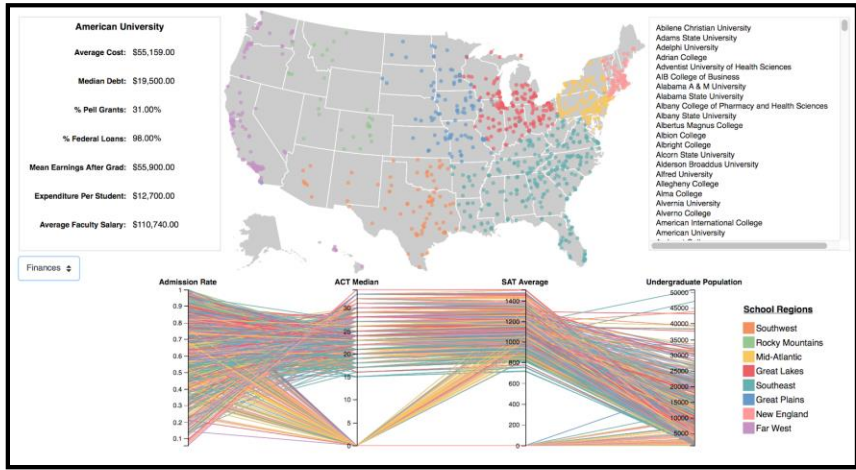
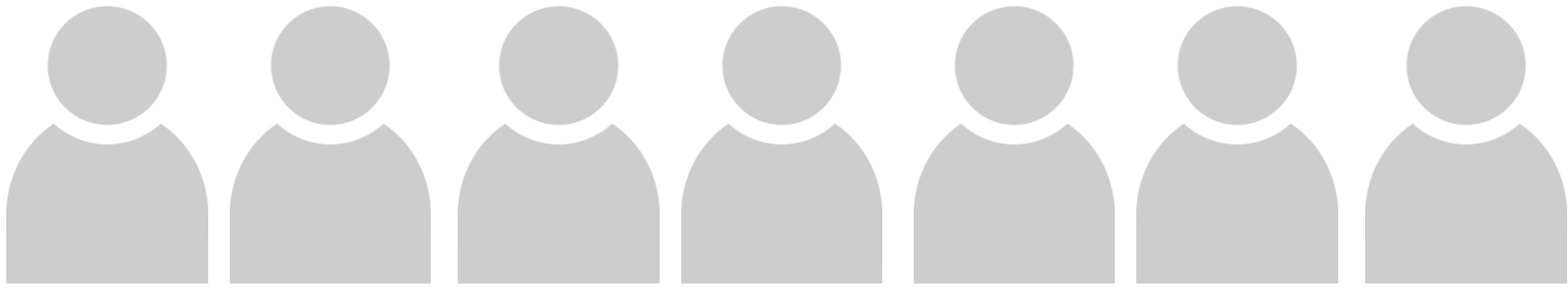
Insight

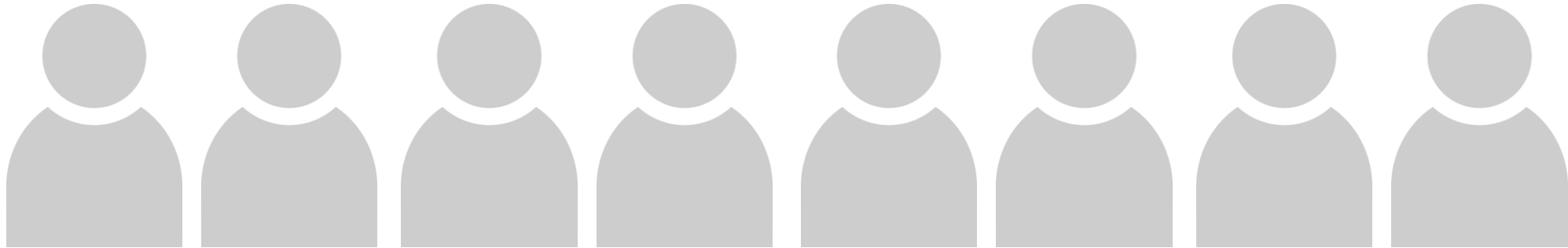
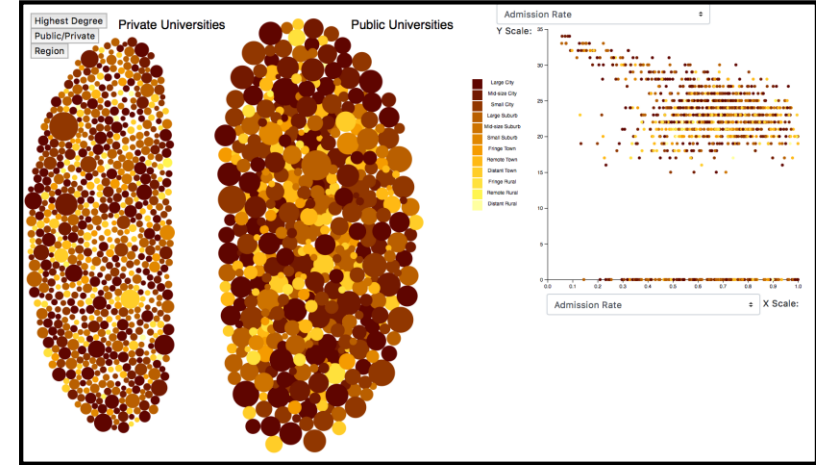
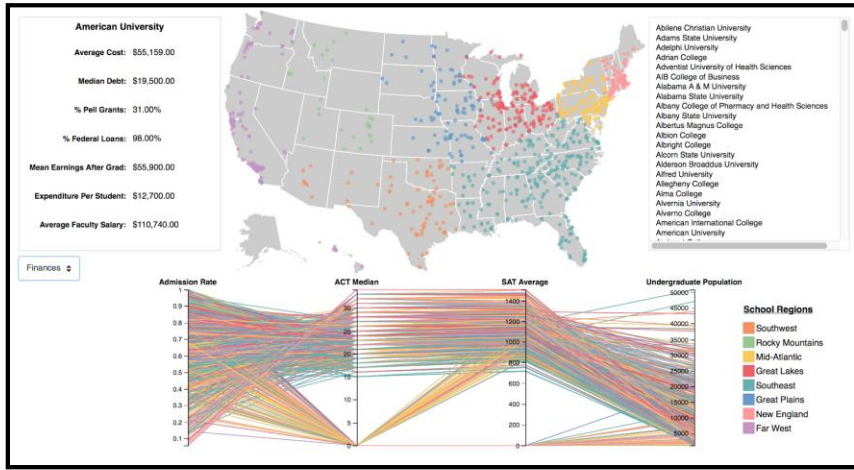
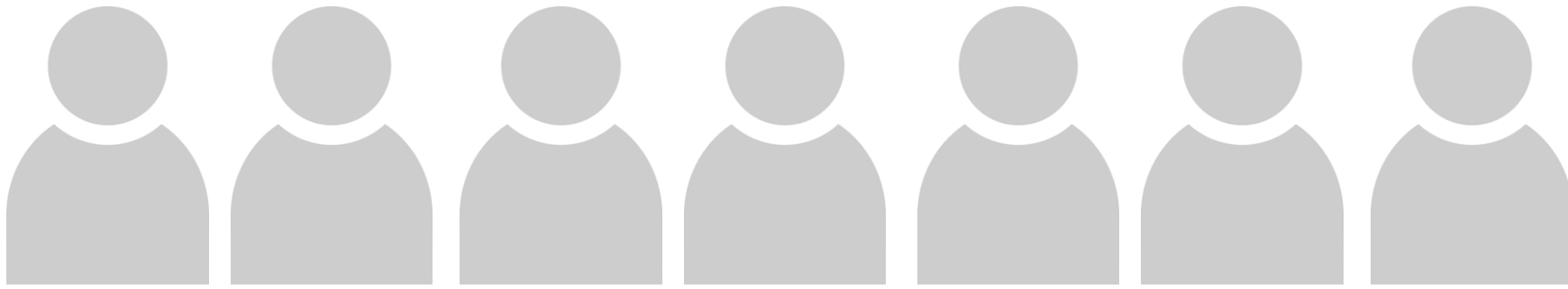
| The visualization facilitates answering questions about the data | How would you rate your agreement with the following statements? | | | | | | | | How would you rate your confidence in your response? (1 - very low to 4 - very high) | | | | [OPTIONAL] |
|-------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|-----------------------|-----------------------|----------------------------|-----------------------|-----------------------|-----------------------|-----------------------|--------------------------------------------------------------------------------------|-----------------------|-----------------------|-----------------------|----------------------------|
| | Strongly Disagree | Disagree | Somewhat Disagree | Neither Agree nor Disagree | Somewhat Agree | Agree | Strongly Agree | NA | 1 | 2 | 3 | 4 | Reasons for your responses |
| The visualization exposes individual data cases and their attributes | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="text"/> |
| The visualization facilitates perceiving relationships in the data like patterns & distributions of the variables | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="text"/> |
| The visualization promotes exploration of relationships among different aggregation levels of the data | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="text"/> |
| The visualization provides a new or better understanding of the data | How would you rate your agreement with the following statements? | | | | | | | | How would you rate your confidence in your response? (1 - very low to 4 - very high) | | | | [OPTIONAL] |
| | Strongly Disagree | Disagree | Somewhat Disagree | Neither Agree nor Disagree | Somewhat Agree | Agree | Strongly Agree | NA | 1 | 2 | 3 | 4 | Reasons for your responses |
| The visualization helps generate data-driven questions | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="text"/> |
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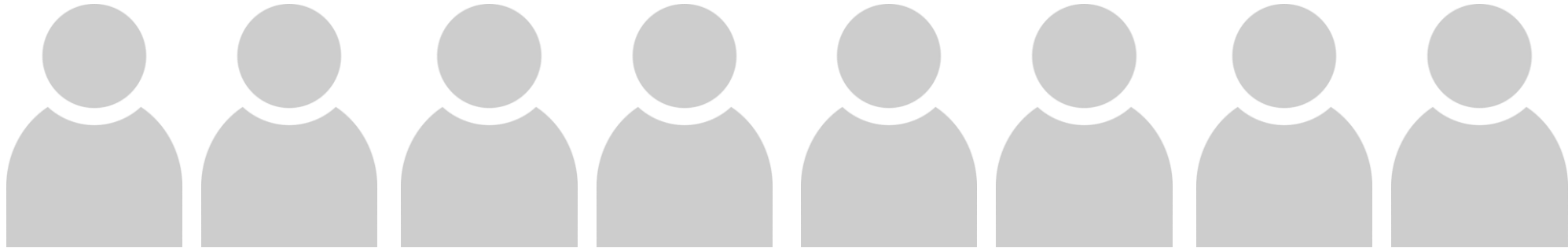
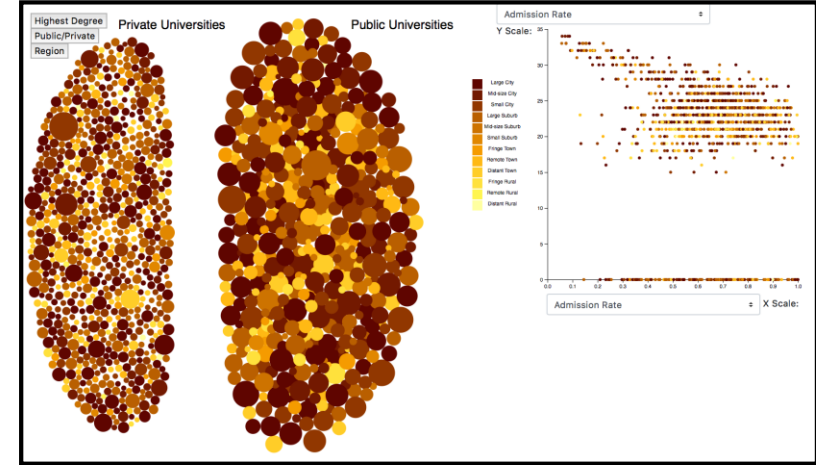
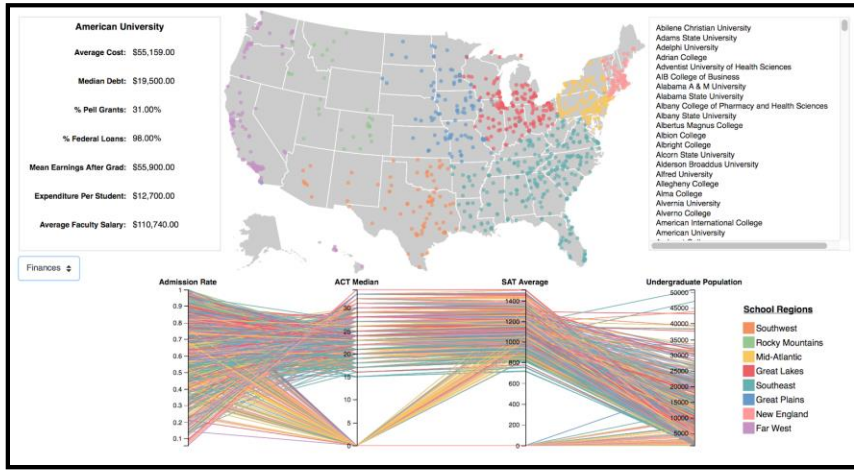
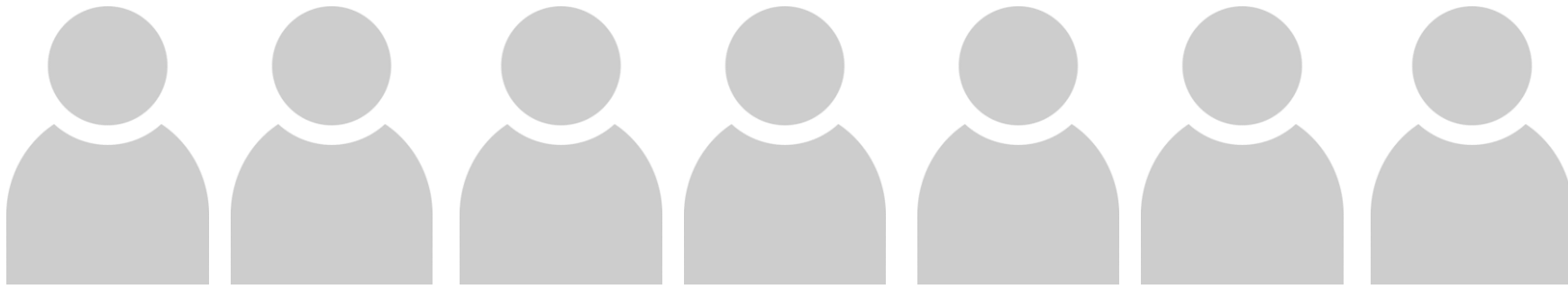


Based on course project grades...

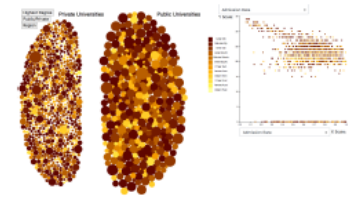








Results

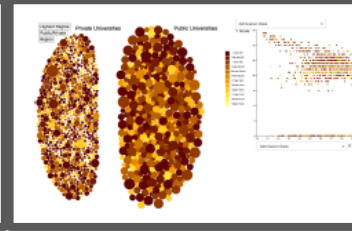


| | Vis A | Vis B | Vis C | Average |
|------|-------|-------|-------|---------|
| P15 | 6.09 | 6.01 | 5.00 | 5.70 |
| P14 | 5.08 | 5.51 | 4.94 | 5.18 |
| P10 | 4.45 | 5.99 | 4.74 | 5.06 |
| P5 | 5.05 | 6.24 | 3.69 | 4.99 |
| P1 | 5.11 | 5.30 | 3.95 | 4.79 |
| P4 | 4.39 | 5.24 | 4.50 | 4.71 |
| P3 | 4.52 | 5.71 | 3.76 | 4.66 |
| P13 | 5.60 | 5.90 | 2.49 | 4.66 |
| P8 | 4.08 | 5.89 | 3.55 | 4.51 |
| P9 | 3.96 | 5.37 | 4.05 | 4.46 |
| P2 | 4.20 | 4.58 | 4.44 | 4.41 |
| P7 | 4.24 | 4.78 | 3.62 | 4.21 |
| P11 | 4.42 | 4.11 | 4.10 | 4.21 |
| P6 | 4.78 | 4.68 | 2.81 | 4.09 |
| P12 | 4.23 | 4.06 | 3.98 | 4.09 |
| Avg. | 4.67 | 5.30 | 3.96 | |



Best

Worst



| | Vis A | Vis B | Vis C | Average |
|------|-------|-------|-------|---------|
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| P12 | 4.23 | 4.06 | 3.98 | 4.09 |
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Inter-Rater Reliability

- Mean for each vis on each heuristic
- Results:
 - Vis A: $r = 0.68$, $t(13) = 3.33$, $p < 0.01$;
 - Vis B: $r = 0.75$, $t(13) = 4.06$, $p < 0.01$;
 - Vis C: $r = 0.54$, $t(13) = 2.29$, $p < 0.05$;

Inter-Rater Reliability

- Component-level analysis
- Results:
 - Insight: $r = 0.56$, $t(13) = 2.46$, $p < 0.05$;
 - Confidence: $r = 0.55$, $t(13) = 2.40$, $p < 0.05$;
 - Essence: $r = 0.49$, $t(13) = 2.03$, $p = 0.06^*$;
 - Time: $r = 0.58$, $t(13) = 2.55$, $p < 0.05$;

- Average confidence in heuristic: 3.22 ± 0.70



- None had an average confidence < 3

- Confidence rating of 1 given to a total of 5 heuristics

“The visualization promotes exploration of relationships among different aggregation levels of the data”

“The visualization promotes exploration of relationships among different aggregation levels of the data”

between individual data cases as well as different groupings of data cases”



| | | |
|-------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| terminology | <p><i>data case</i>- refers to an instance of the data set; synonymous with data item or data point</p> <p><i>attribute</i>- refers to properties of the data cases in the data set; synonymous with feature, dimension, or variable</p> <p><i>relationship in the data</i>- refers to attributes among the data, such as correlations, clusters, or distributions</p> | |
| Insight | <p>The visualization facilitates answering questions about the data</p> | <p>The visualization exposes individual data cases and their attributes</p> <p>The visualization facilitates perceiving relationships in the data like patterns & distributions of the variables</p> <p>The visualization promotes exploring relationships (between individual data cases as well as different groupings of data cases) (among different aggregation levels of the data)</p> |
| | <p>The visualization provides a new or better understanding of the data</p> | <p>The visualization helps generate data-driven questions</p> <p>The visualization helps identify unusual or unexpected, yet valid, data characteristics or values</p> |
| | <p>The visualization provides opportunities for serendipitous discoveries</p> | <p>The visualization provides useful interactive capabilities to help investigate the data in multiple ways</p> |
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| | <p>The visualization provides mechanisms for quickly seeking specific information</p> | <p>The interface supports (using different attributes of the data to reorganize the visualization's appearance) (reorganizing the visualization by the data's attribute values)</p> |
| | | <p>The visualization supports smooth transitions between different levels of detail in viewing the data</p> <p>The visualization avoids complex (commands and textual queries) (syntactic querying) by providing direct interaction (with the data representation)</p> |
| Essence | <p>The visualization provides a big picture perspective of the data</p> | <p>The visualization provides (an effective) a comprehensive and accessible overview of the data</p> <p>The visualization presents the data by providing a meaningful visual schema</p> |
| | <p>The visualization provides an understanding of the data beyond individual data cases</p> | <p>The visualization facilitates generalizations and extrapolations of patterns and conclusions</p> <p>The visualization helps understand how variables relate in order to accomplish different analytic tasks</p> |
| Confidence | <p>The visualization helps avoid making incorrect inferences</p> | <p>The visualization uses meaningful and accurate visual encodings to represent the data</p> <p>The visualization avoids using misleading representations</p> |
| | <p>The visualization facilitates learning more broadly about the domain of the data</p> | <p>The visualization promotes understanding data domain characteristics beyond the individual data cases and attributes</p> |
| | <p>The visualization helps understand data quality</p> | <p>If there were data issues like unexpected, duplicate, missing, or invalid data, the visualization would highlight those issues</p> |





≥ 5



≤ 4



Discussion

Discussion

- Subjective interpretation of heuristics
- 5 raters
- Independence of components

Applications

- Grading visualization course projects
- Formative design feedback
- Low-cost evaluation in academic or commercial settings

MILC

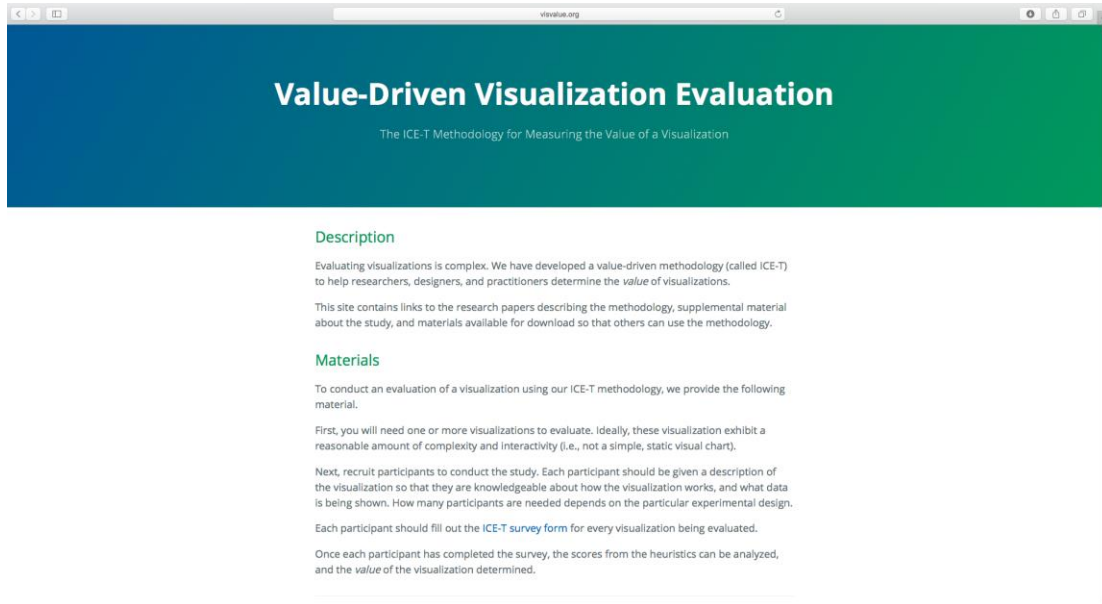


ICE-T



B. Shneiderman and C. Plaisant. Strategies for evaluating information visualization tools: **Multi-dimensional in-depth long-term case studies**, BELIV 2006.

visvalue.org



Thank you!

