Encoding with Patterns

A Design Space and Evaluations

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Ph.D. Thesis Defense

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Aviz Visual Analytics Project

LISN LABORATOIRE INTERDISCIPLINAIRE DES SCIENCES DU NUMÉRIQUE

Inria

université PARIS-SACLAY

Data is abundant

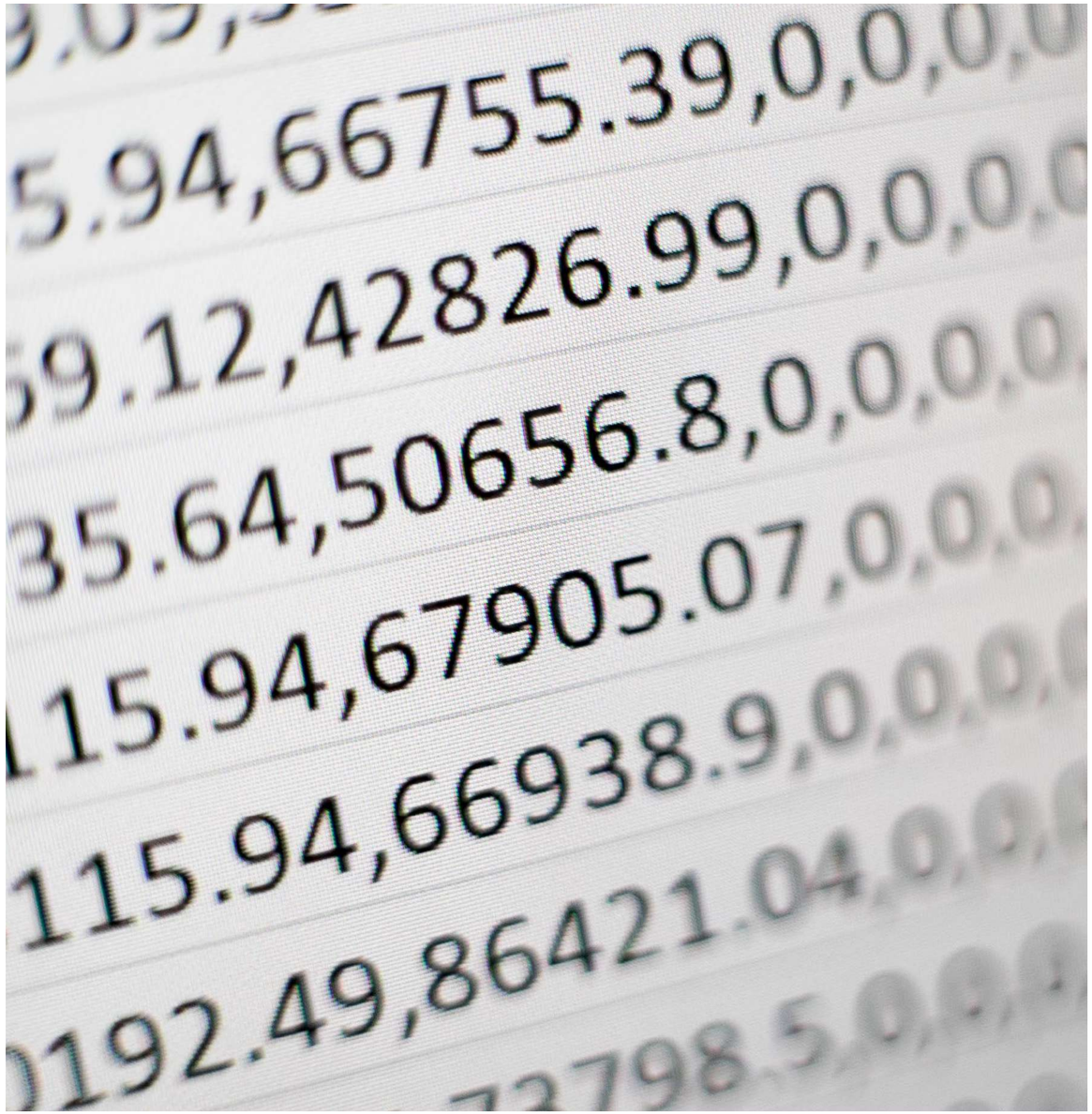


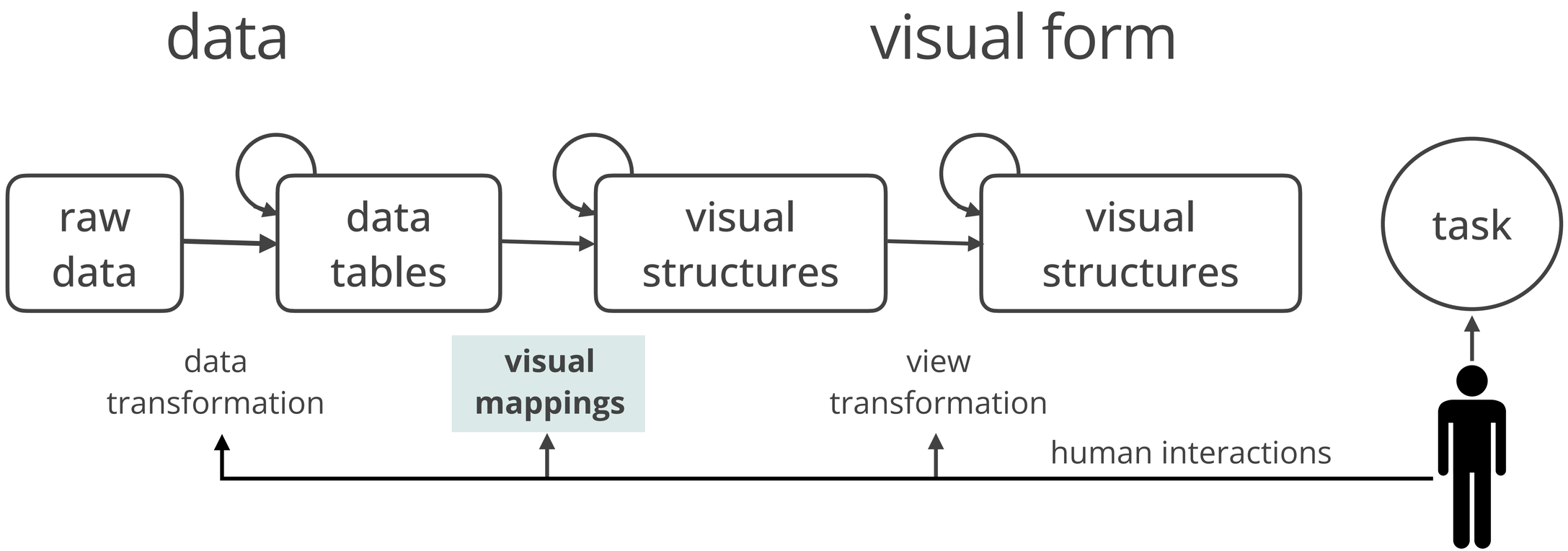
Image from https://unsplash.com/photos/white-printing-paper-with-numbers-Wpnoqo2plFA

Visualization

the use of computer-supported, interactive
visual representations of data
to amplify cognition [Card et al., 1999]

Image from https://unsplash.com/photos/turned-on-flat-screen-monitor-dBI_My696Rk

Transform data into visual representations

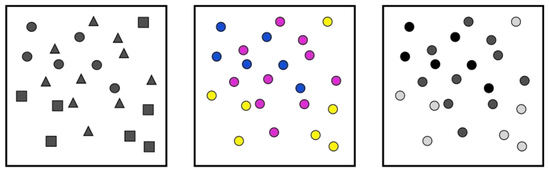


Information visualization reference model [Chi, 1999]

Visual mapping

mapping data values to graphical properties of graphical elements

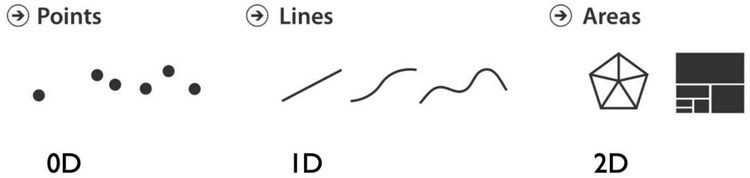
visual variables



...

Visual variable examples
[Olaya, 2018]

marks



Marks [Munzer, 2015]

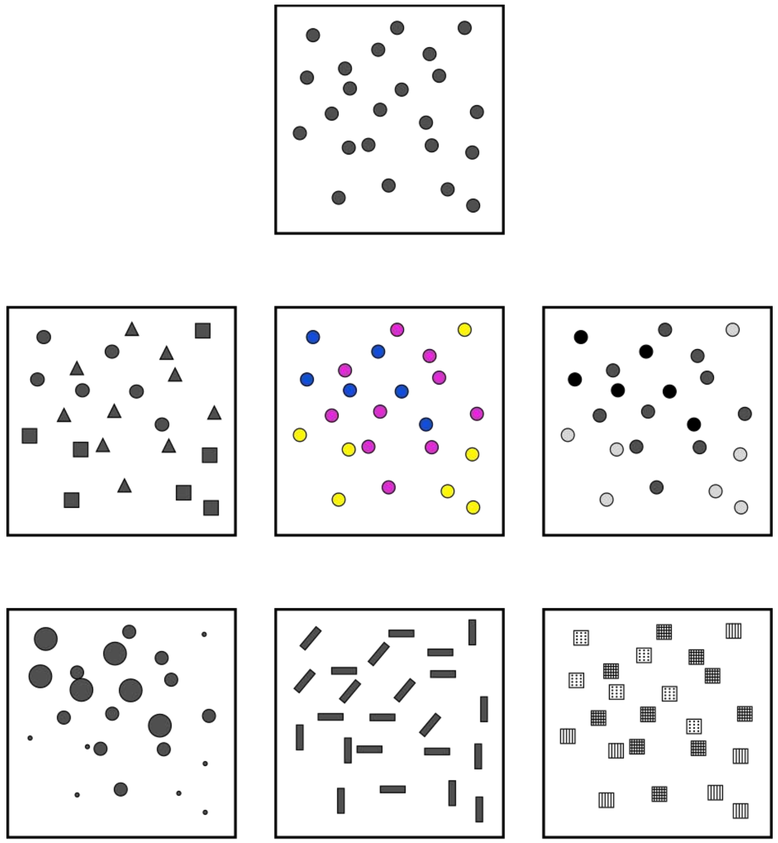
Jacques Bertin

(1918 – 2010)
a French cartographer and graphic designer

the first to systematically investigate the concept of visual variables

Image from Wikipedia (https://fr.wikipedia.org/wiki/Jacques_Bertin_(cartographe))

Initial list of visual variables by Bertin



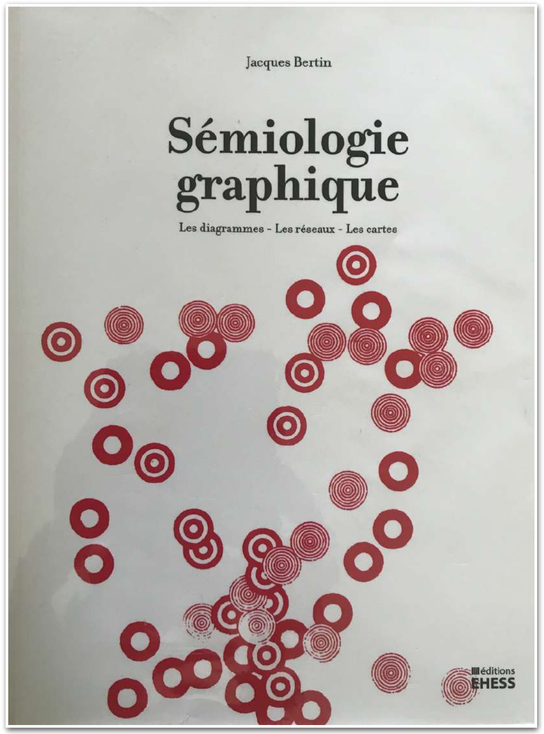
position

6 retinal variables

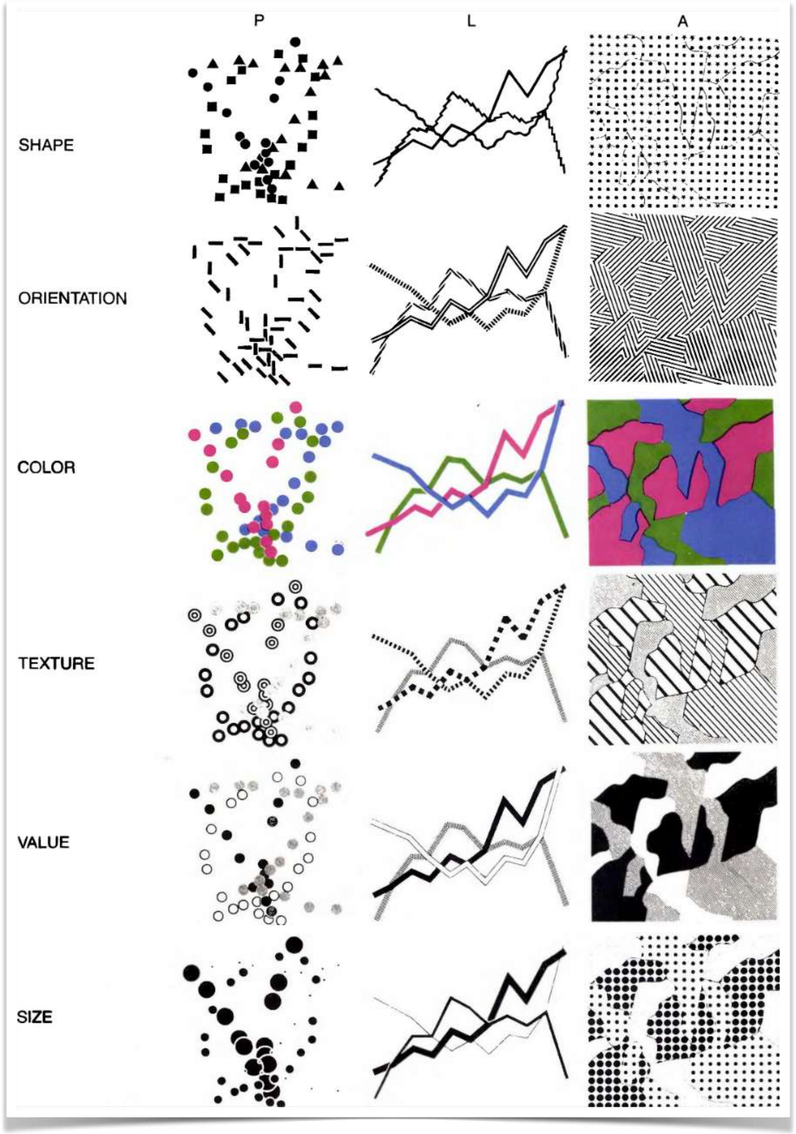
Initial list of visual variables [Bertin, 1967]
Image taken from [Olaya, 2018]

Semiology of Graphics

guidance of the usage of visual variables



Book: Semiology of Graphics

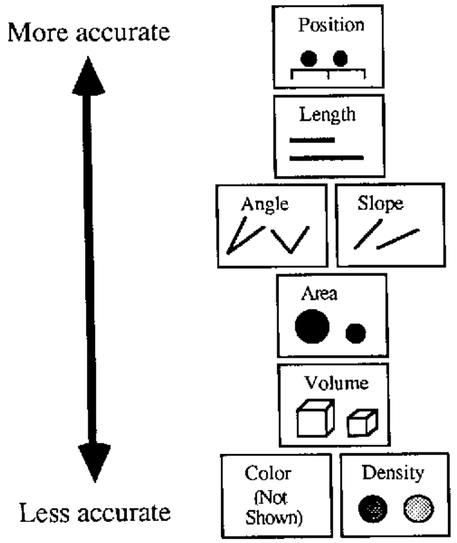


Retinal variables on point, line and area marks
[Bertin, 1967]

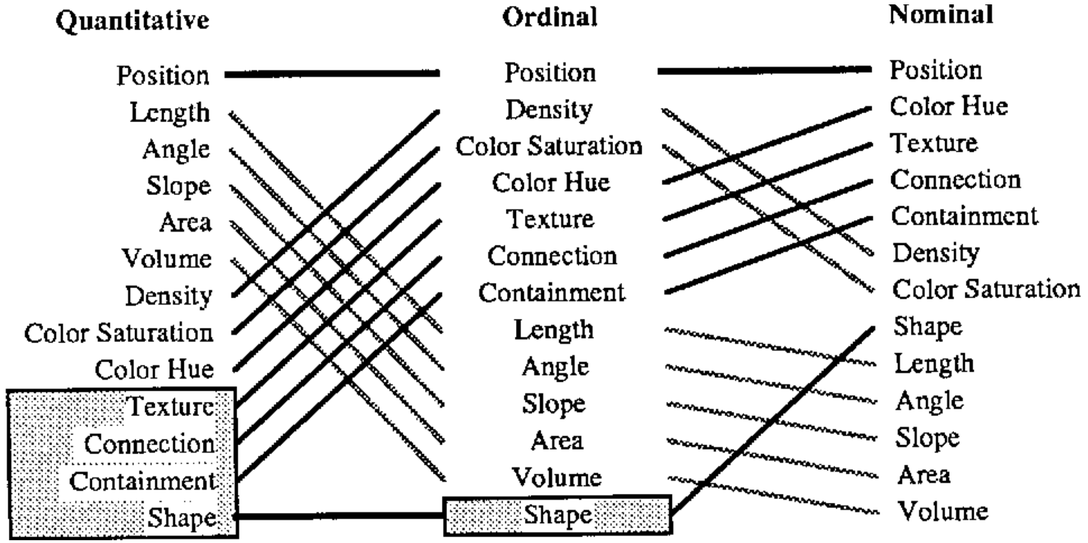
Image from https://commons.wikimedia.org/wiki/File:Bertin_semiologie-graphique.png

Visual variables

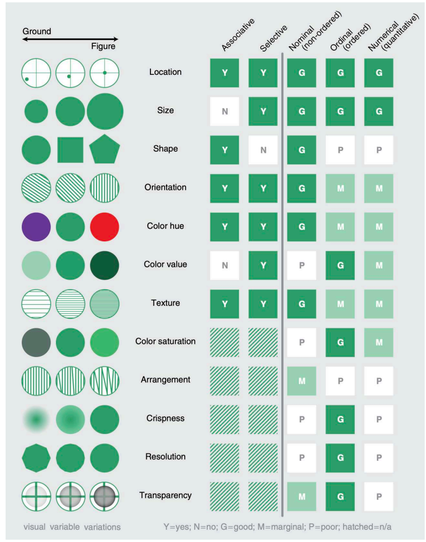
A foundational and influential framework for visualization research



[Cleveland and McGill, 1984]



[Mackinlay, 1986]

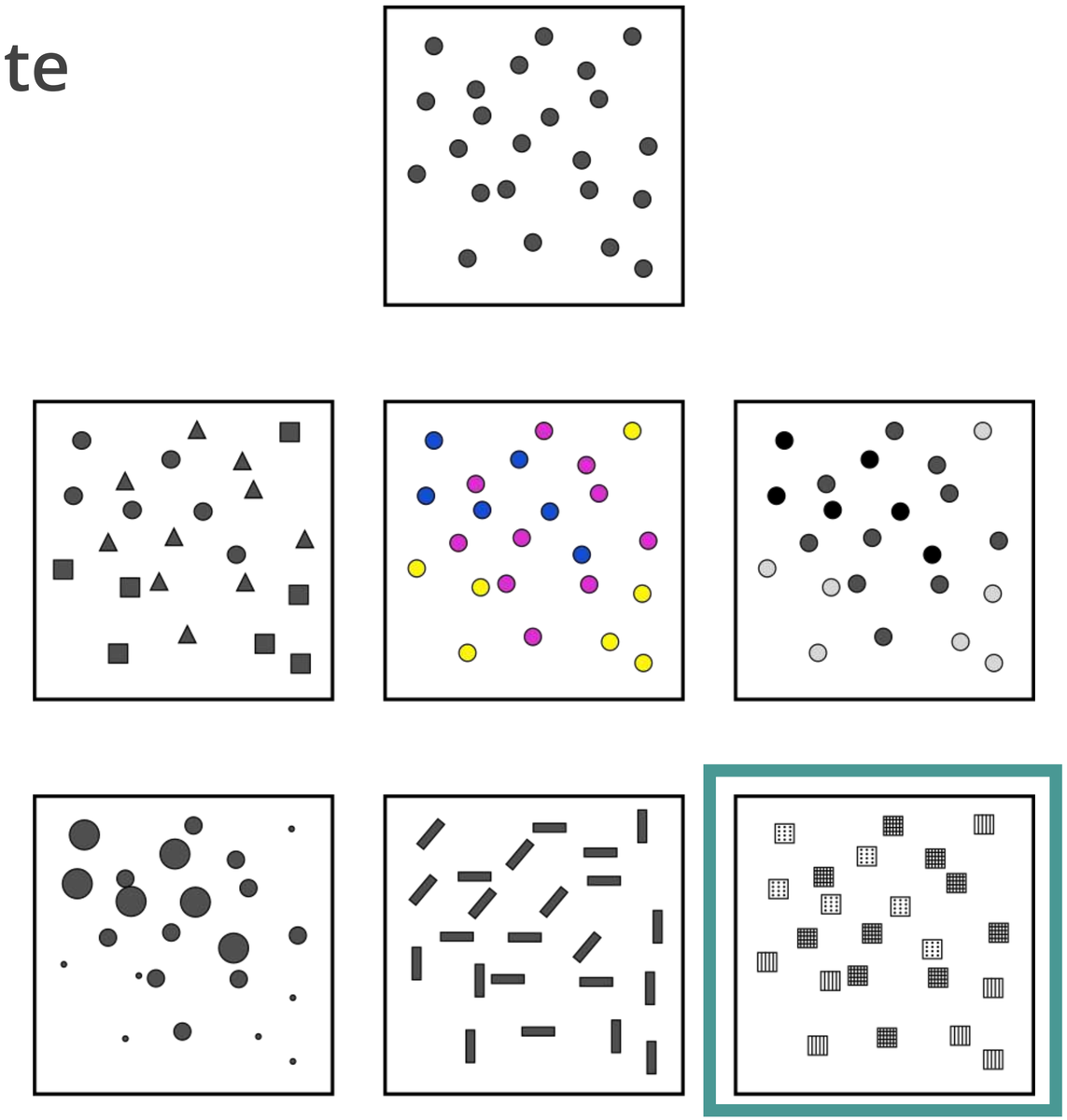


[Roth, 2017]

examples of subsequent research on visual variables

It is crucial to **identify** and **articulate**
the basic visual variables
that can be manipulated
to encode data effectively.

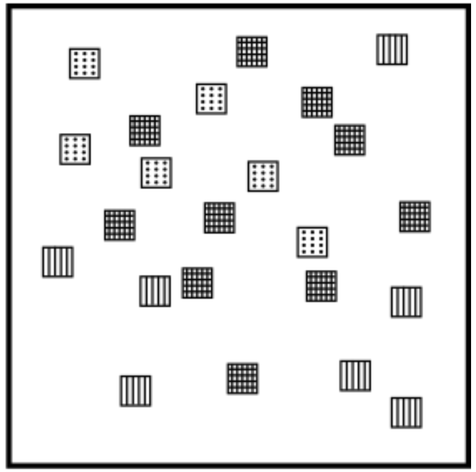
repetitive encoding



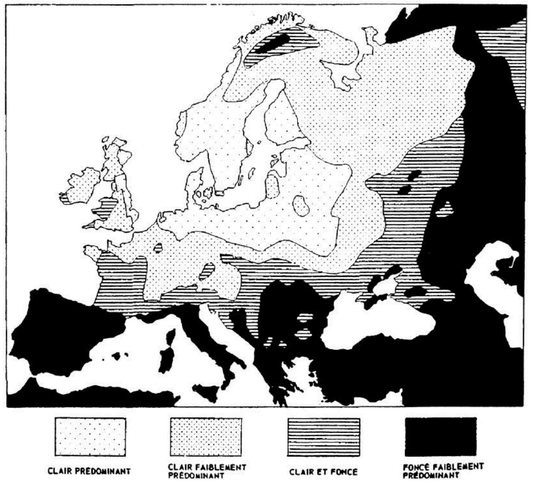
initial list of visual variables [Bertin, 1967]
image taken from [Olaya, 2018]

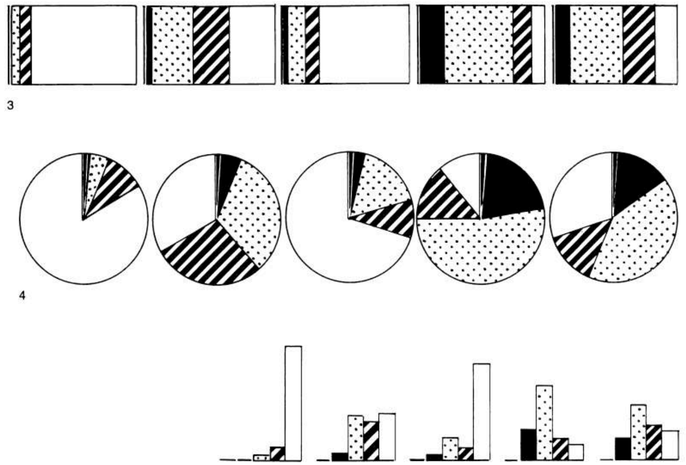
pattern (or texture?)

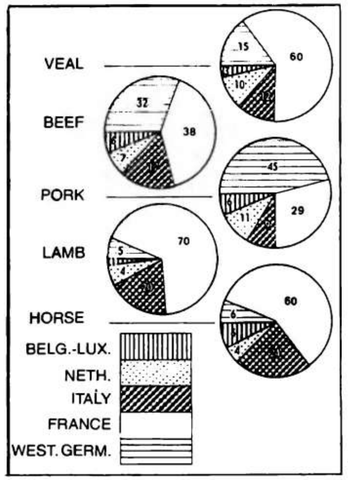
typically features repetitive dots or lines

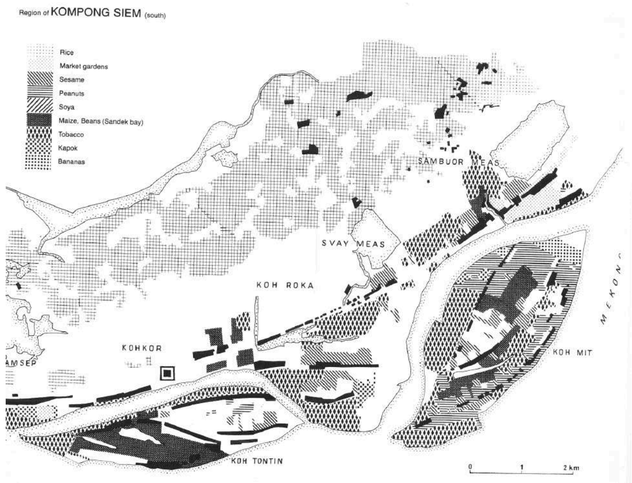


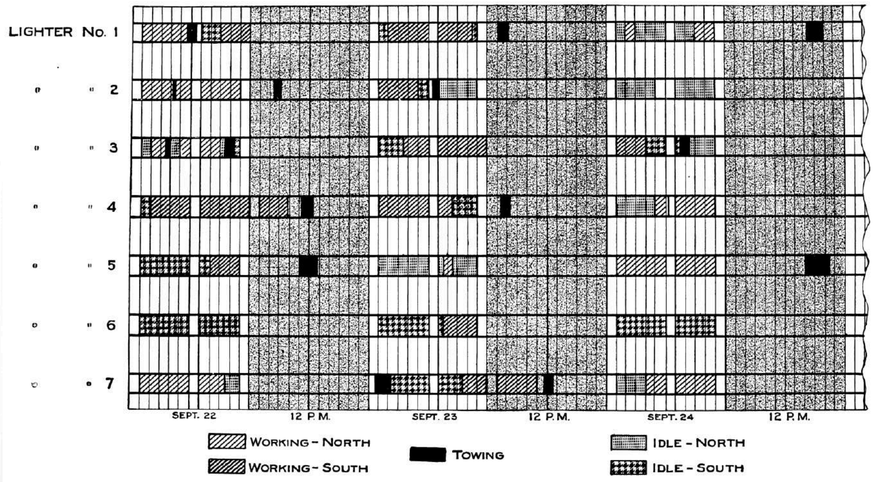
Popularity in the history

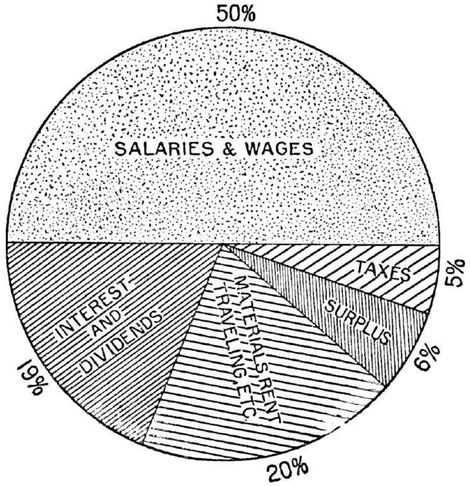








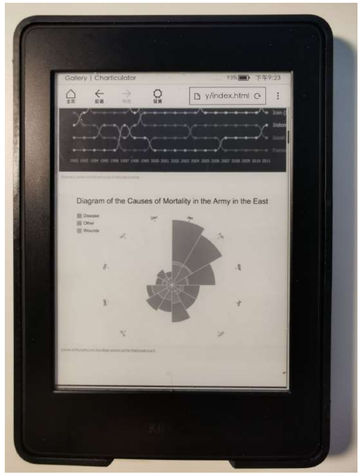


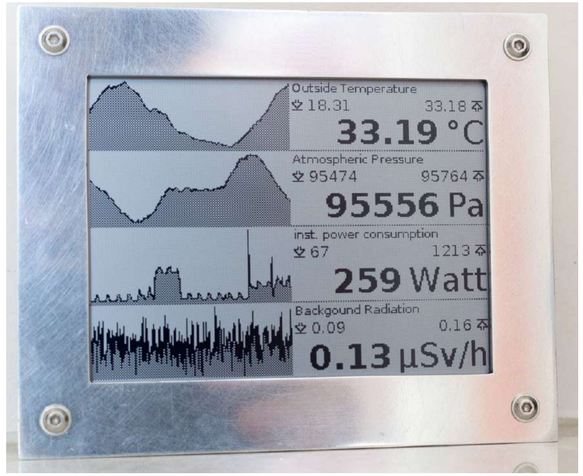


Images from J. Bertin, Semiology of Graphics: Diagrams, Networks, Maps, and W. C. Brinton, Graphic Methods for Presenting Facts

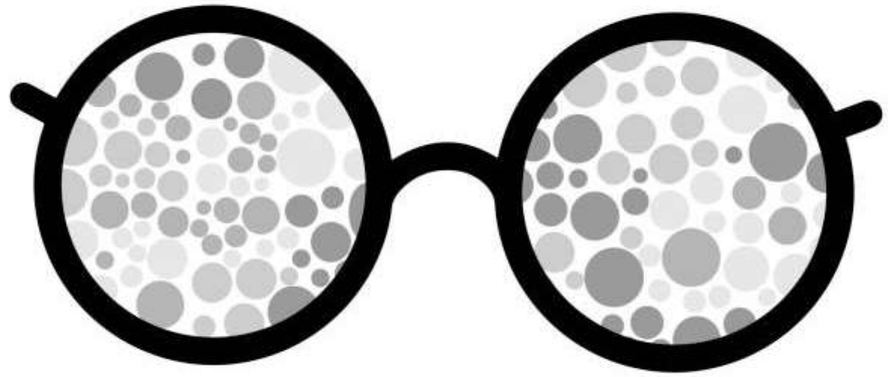
Broad application

enhance the accessibility of visualizations





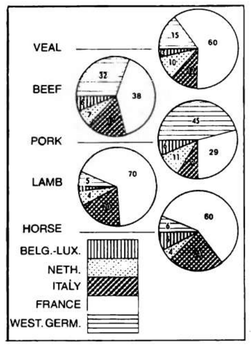
devices with limited color display capabilities

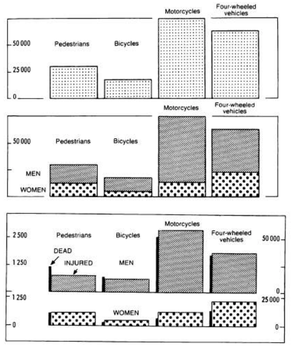


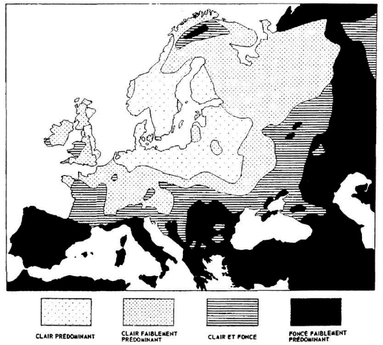
readers with color deficiencies or visual impairments

Research gap

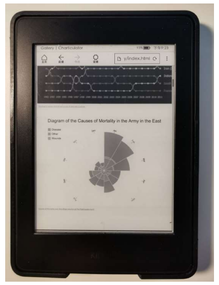
popularity in history

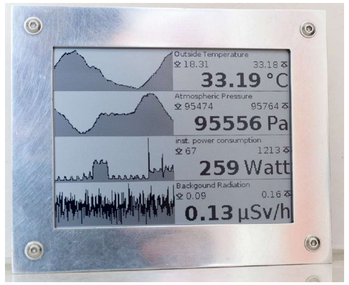


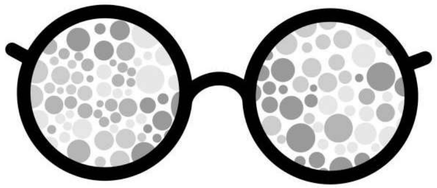




broad application

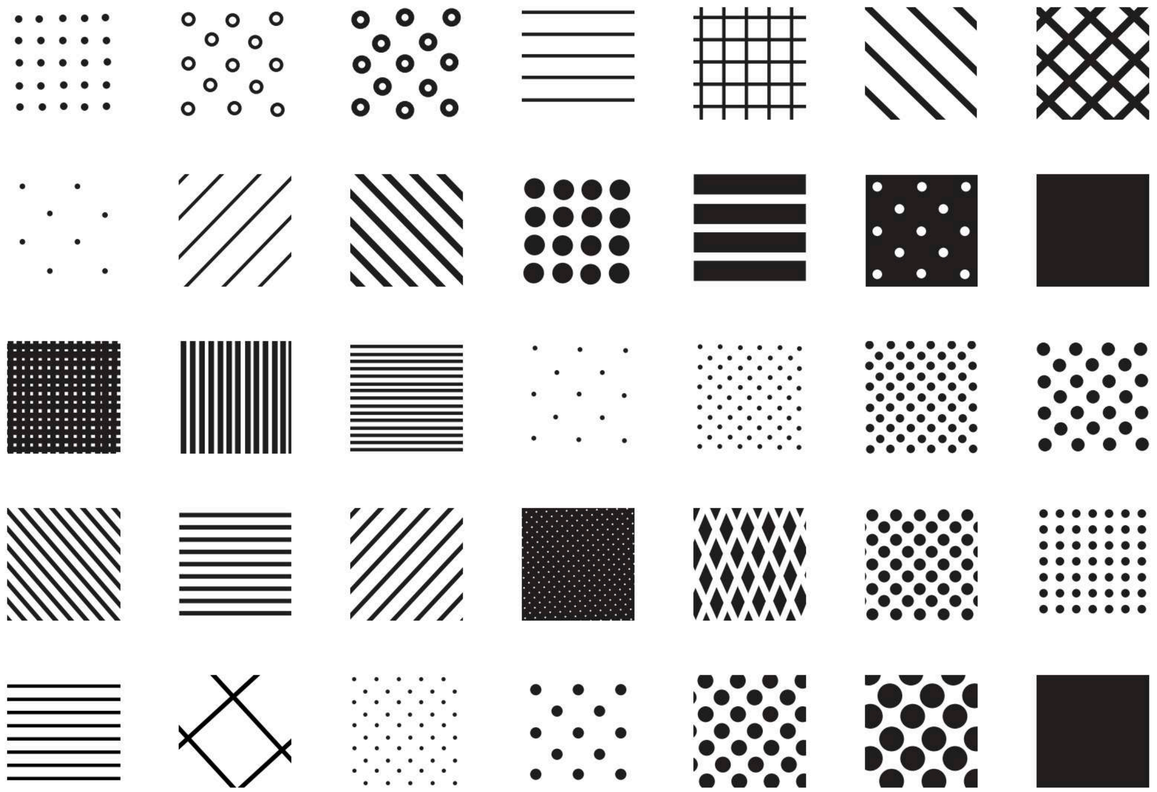






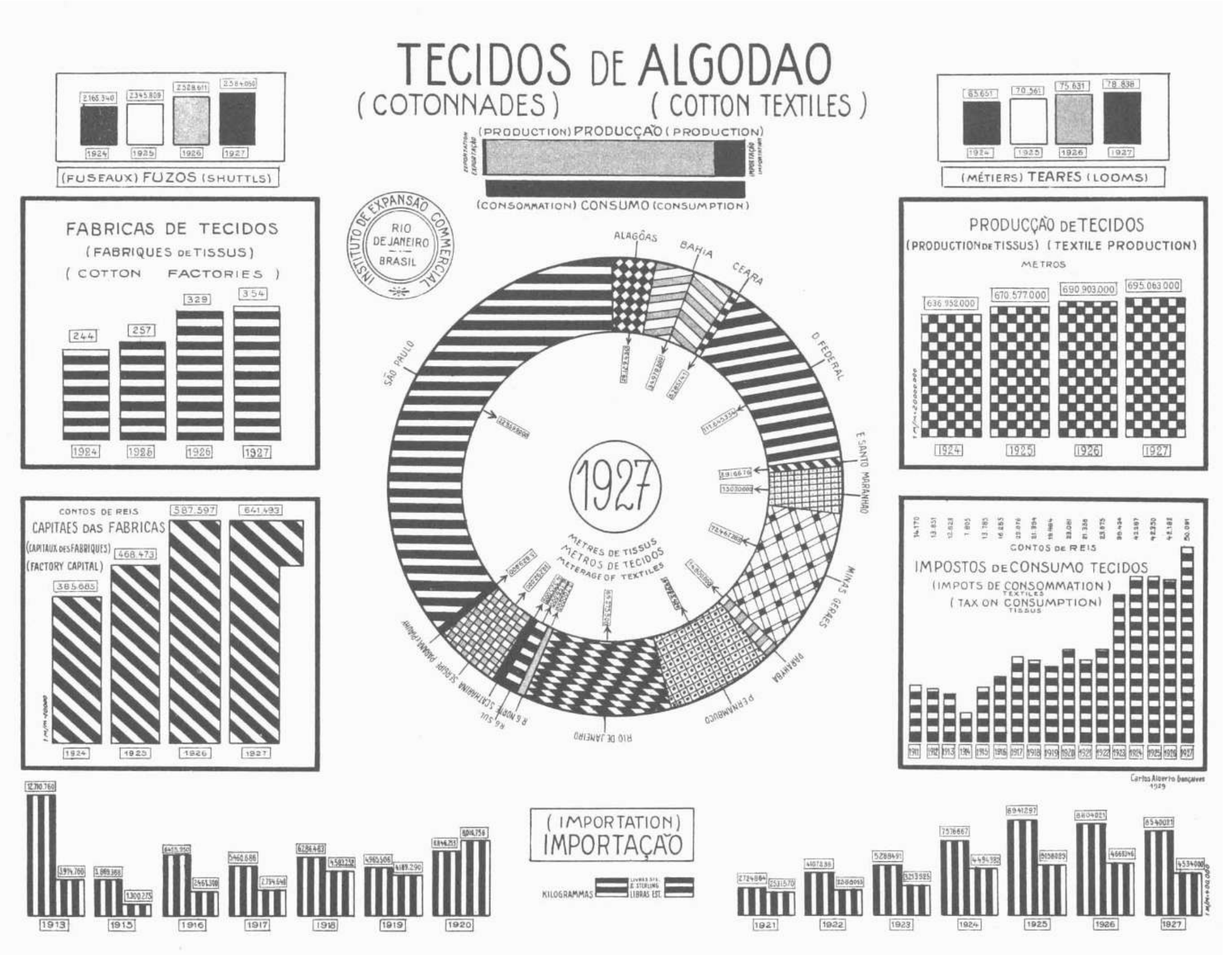
lack of **design guidelines** and **empirical research** on how to better use patterns for data encodings

Rich attributes



Variations of patterns

If used these attributes inappropriate…



[Tufte, 1983]

How to **aesthetically** and **effectively** use **patterns** for data visualization?

How to **aesthetically** and **effectively** use **patterns** for data visualization?

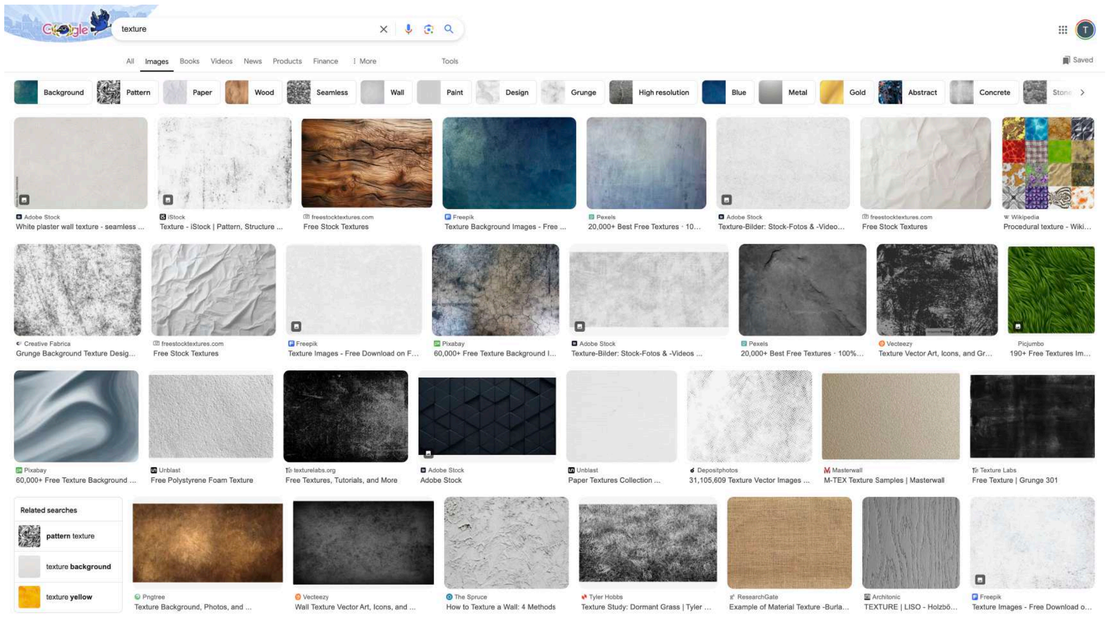
 Clarification of terminology	Which term is more suitable for describing this visual variable: *texture* or *pattern*?
 Design space of patterns	Which pattern attributes can we manipulate for encoding data?
 Empirical studies	How can we compare the aesthetic pleasure of visual data representations?
 Scale development	How can we aesthetically and effectively use b/w patterns for categorical data visualization?
 Discussion	Other contributions and future work
 Conclusion	Contributions of this thesis

Clarification of terminology

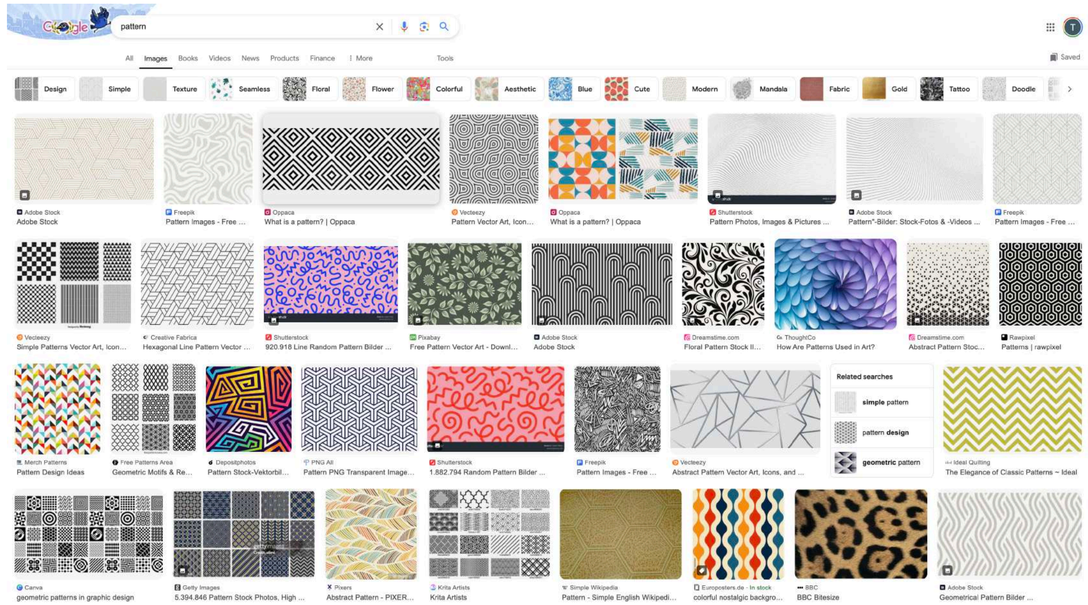
Which term is more suitable for describing this visual variable: *texture* or *pattern*?

Why is the term *texture* not suitable?

texture emphasis more on surface characteristics



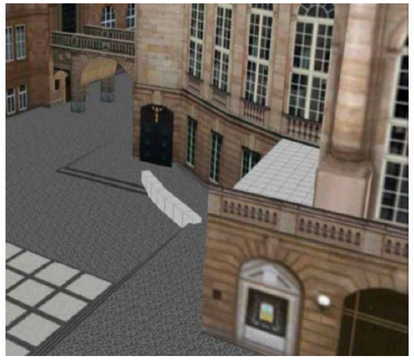
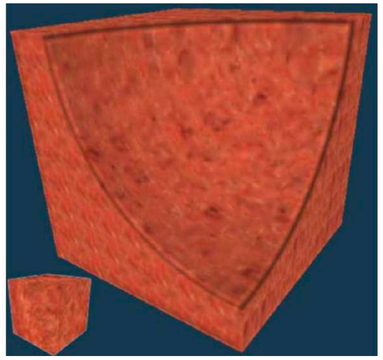
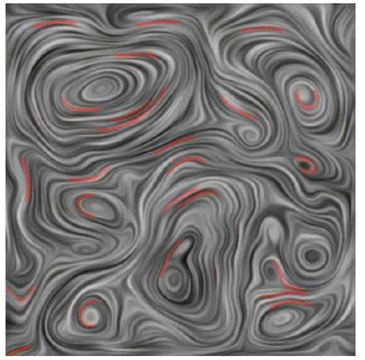
Google Image: ”texture"



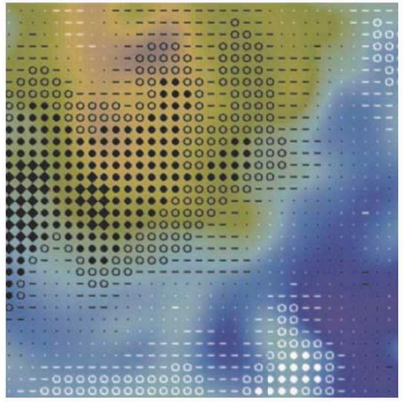
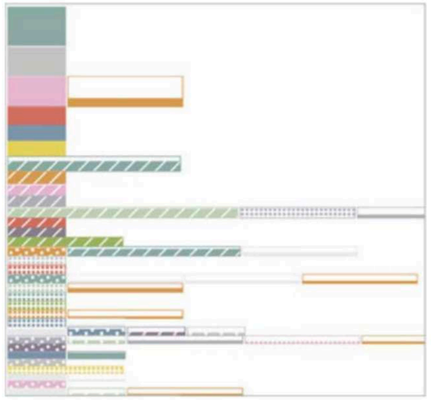
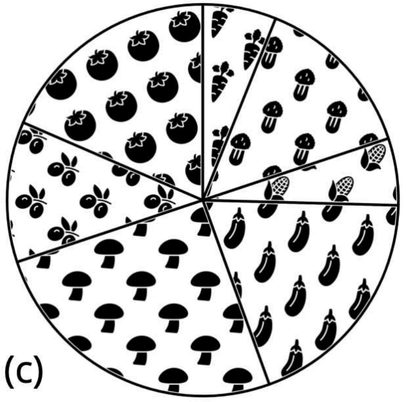
Google Image: ”pattern”

Why is the term *texture* not suitable?

texture is a widely used concept in computer graphics, which is different from visual variables.

(a)  (b)  (c) 

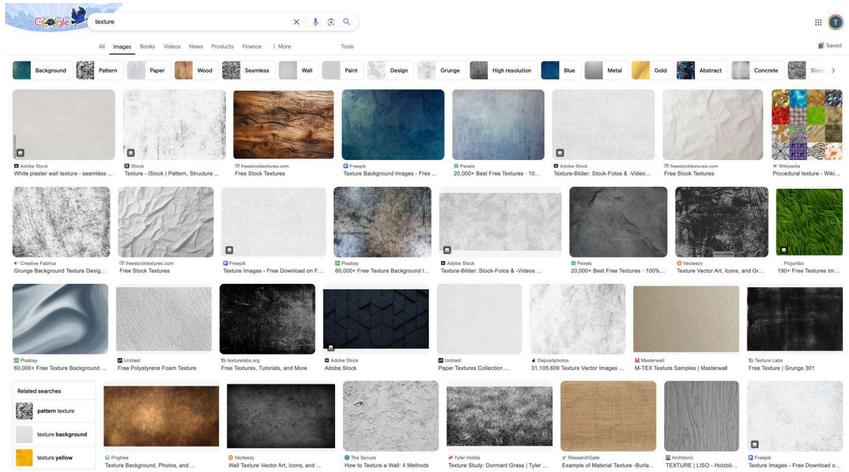
Textures in (a) surface rendering, (b) volume rendering, and (c) flow visualization

(a)  (b)  (c) 

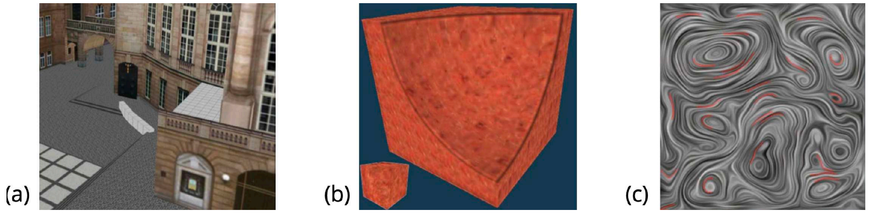
The visual variable that we recommend to call as “pattern"

Texture

Surface and material characteristics



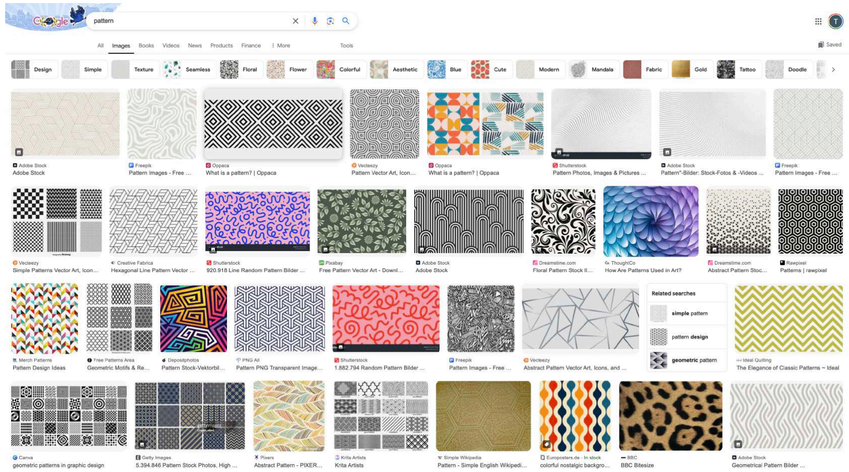
Google Image: ”texture"



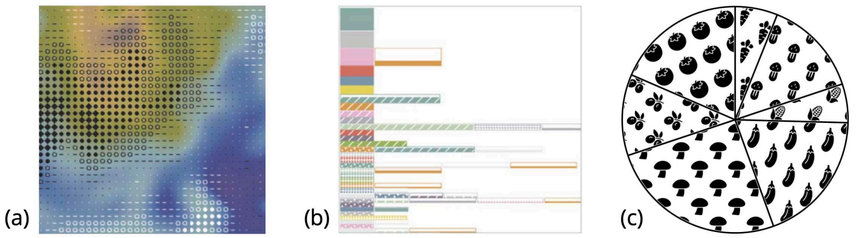
Textures in (a) surface rendering, (b) volume rendering, and (c) flow visualization

Pattern

Repetition and structure of elements



Google Image: ”pattern”

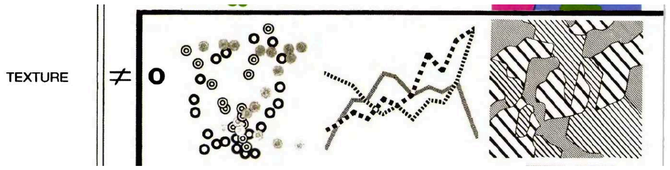


The visual variable that we recommend to call as “pattern"

3 interpretations of *texture* as a visual variable

Grain

Size+Spacing



[Bertin, 1967]

Spacing

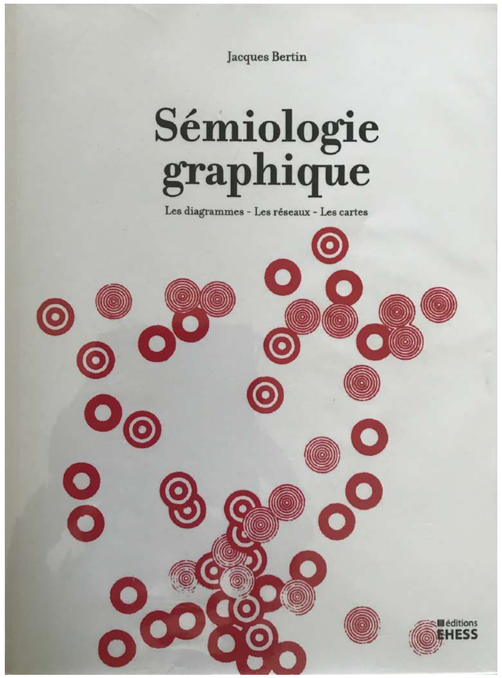
[Roth, 2017]

Pattern

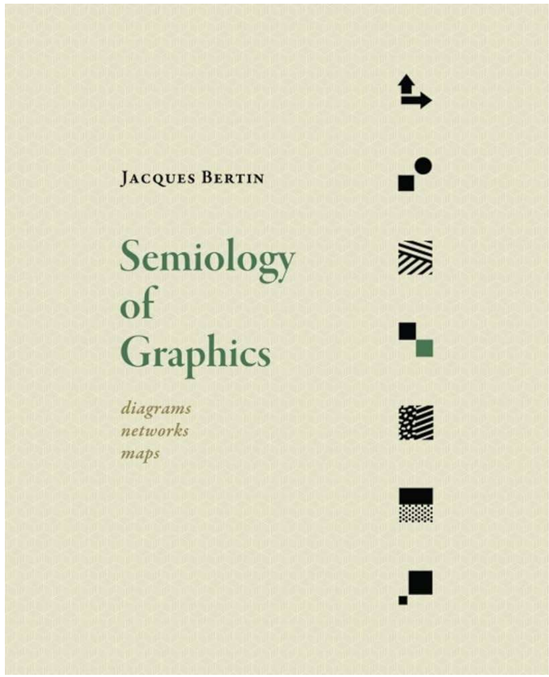
[Zeng and Battle, 2023]

3 interpretations of *texture* as a visual variable

This issue originates from the translation of Semiology of Graphics.



French version

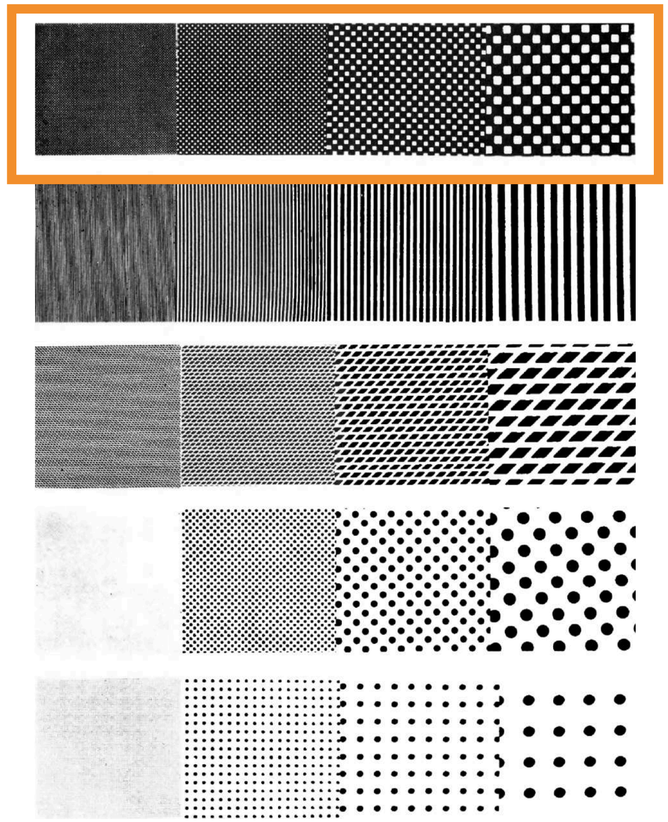


English version

Grain: The original term Bertin used

Grain in the French version → *Texture* in the English version

Variation of “grain"



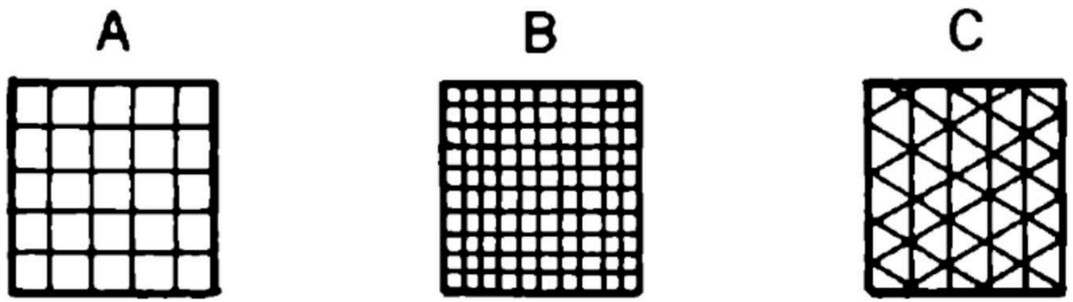
GRAIN

At a given value, the TEXTURE is the number of separable marks contained in a unitary area.

Change both the *size* and *spacing* of primitives simultaneously,
while maintaining a given ratio of black to white

Spacing: A misinterpretation in Bertin's book

*Bertin draws a rigorous distinction between texture (*grain* in French) and pattern (*texture* in French):



Grain

A and B differ in their texture, but there is no difference in pattern. The elementary shapes are the same. The notion of pattern explains the difference between A and C. The elementary shapes are different. A difference in "pattern" is essentially a difference in shape (translator's note)

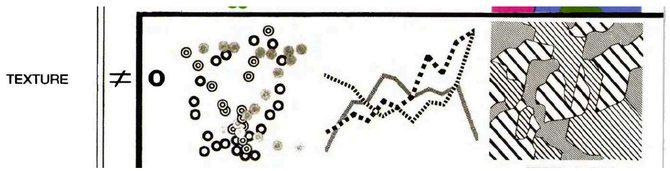
Translator's note from the English version of Bertin's book

A and B differ in their spacing between primitives

3 interpretations of *texture* as a visual variable

Grain

Size+Spacing



[Bertin, 1967]

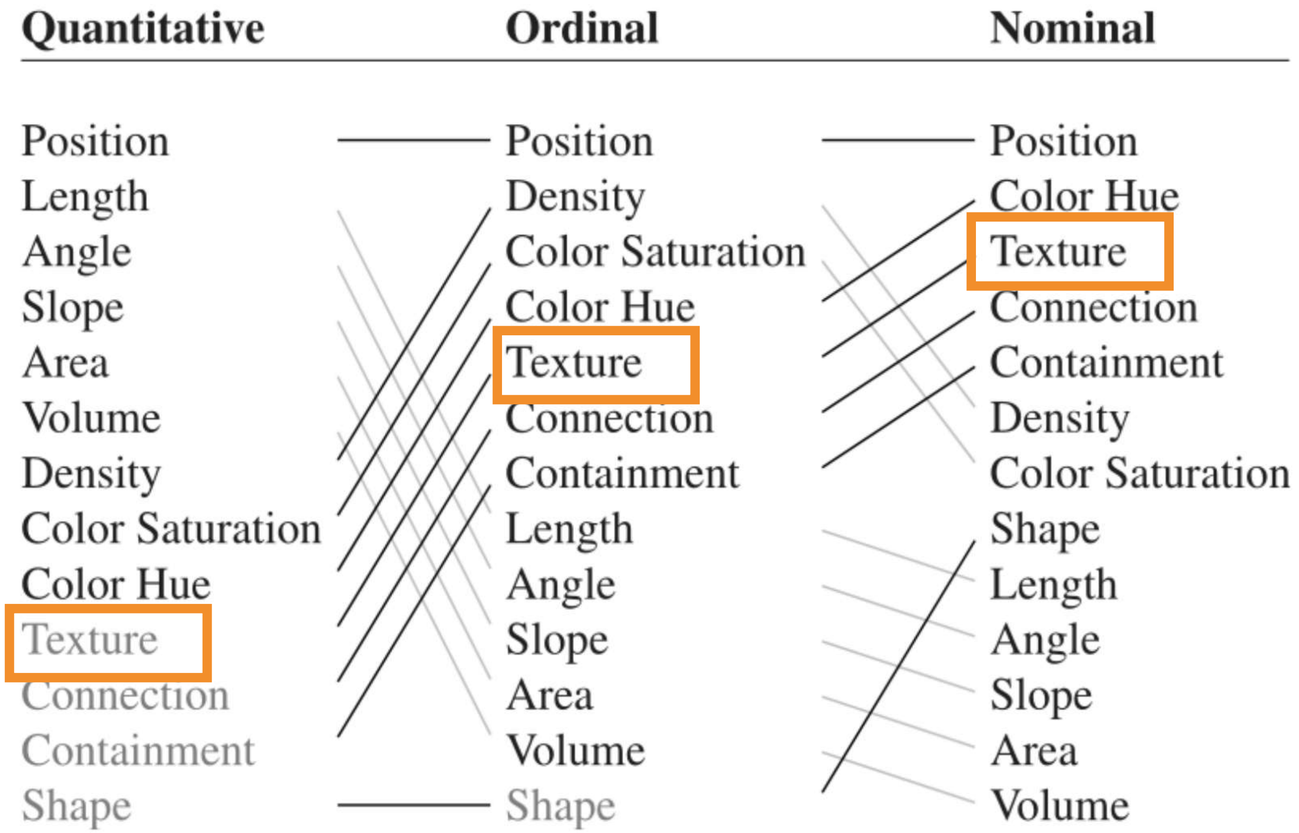
Spacing

[Roth, 2017]

Pattern

[Zeng and Battle, 2023]

What does *texture* mean in this context?

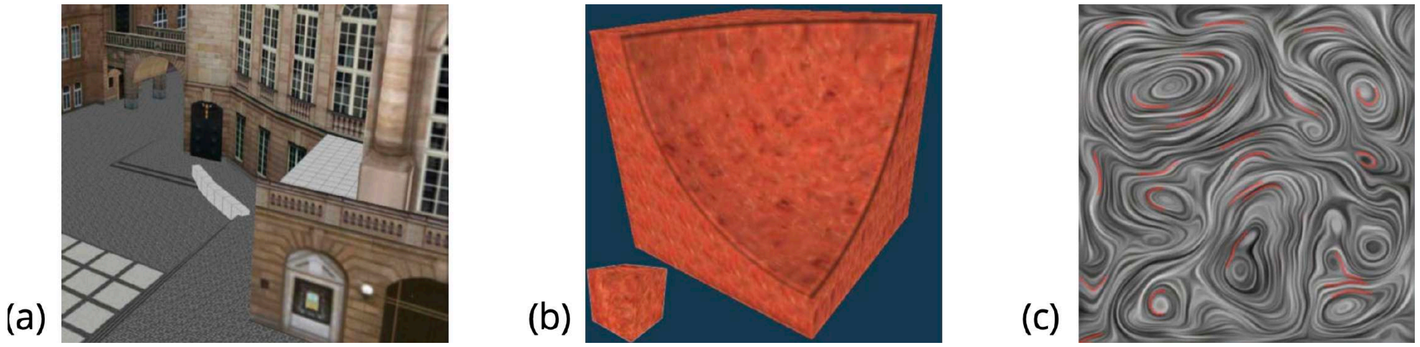


?

Effectiveness of Visual Channels [Mackinlay, 1986]

Issues with the term *texture*

- emphasis on surface characteristics
- different interpretations as a visual variable



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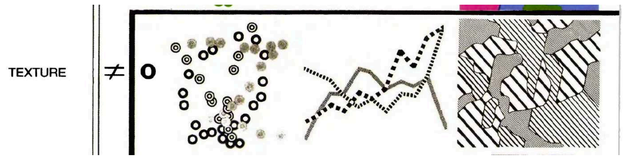
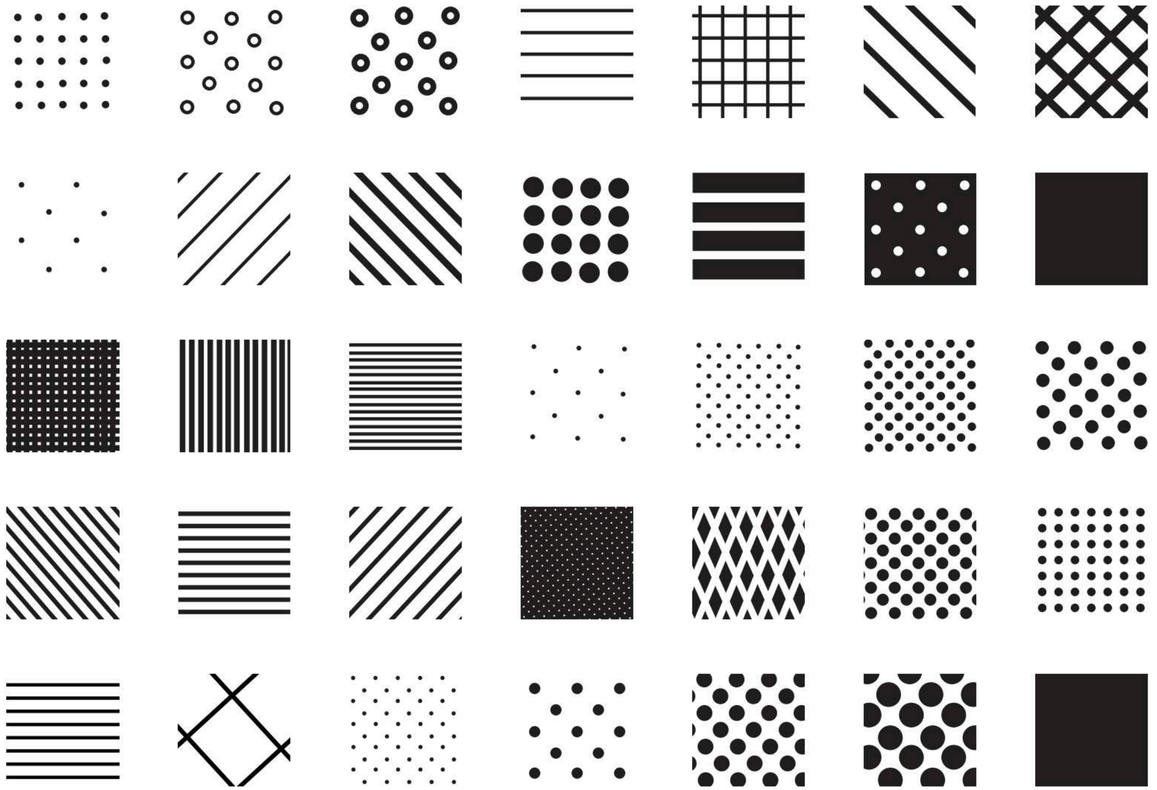


?

Pattern



Design Space of Patterns

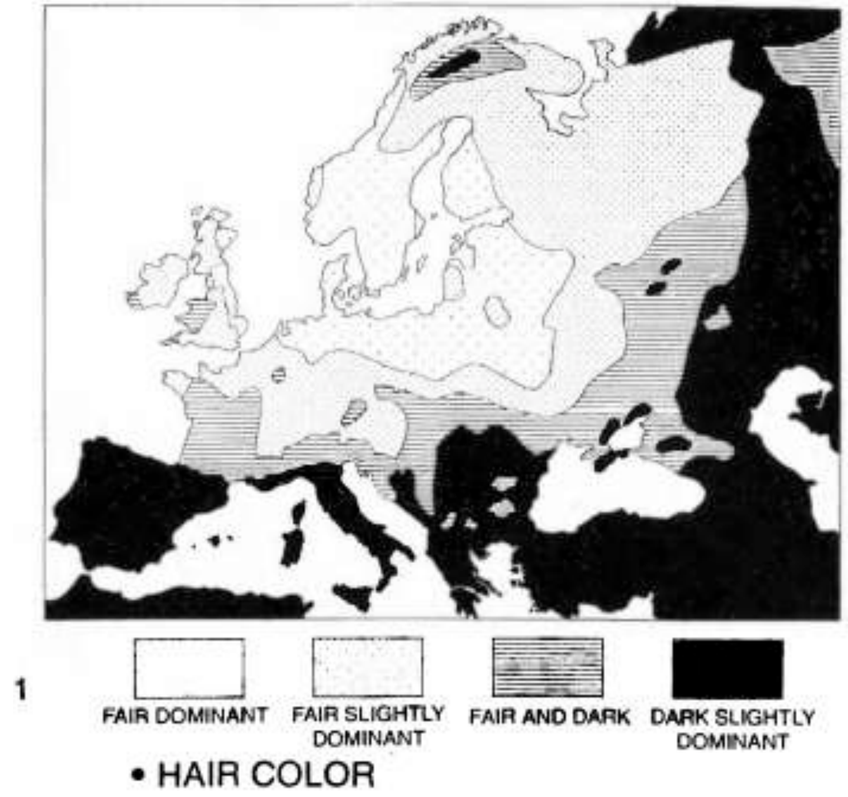
Which pattern attributes
can we manipulate for encoding data?

Bertin used a lot of patterns,
but he did NOT systematically discuss this concept.

Bertin unconsciously generated patterns
while trying to address the inherent limitations
of line and area marks.

Inherent limitations of line and area marks

- Line marks cannot change in orientation
- Area marks cannot change in size, shape, or orientation



[Bertin, 1967]

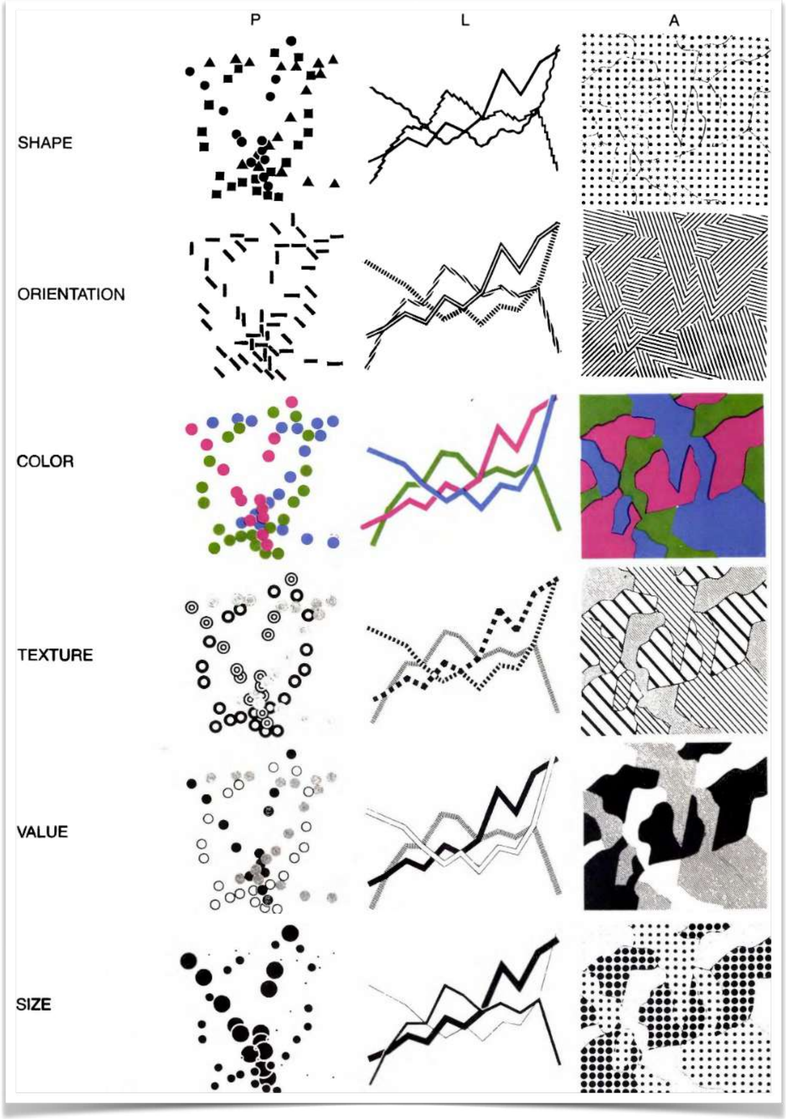
we cannot rotate a region without breaking

Its geographical meaning

Bertin applied all 6 retinal variables to point, line and area marks

6 retinal variables

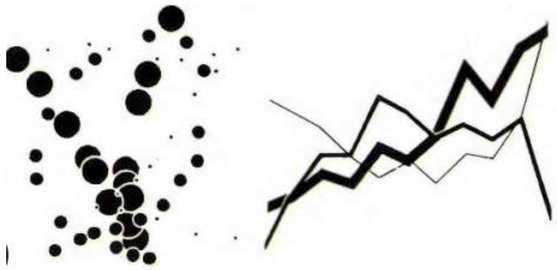
Point marks Line marks Area marks



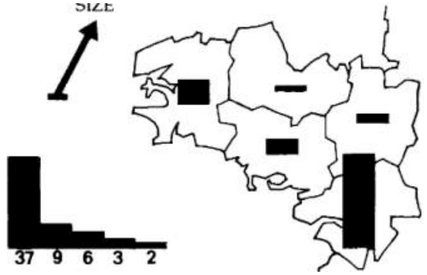
[Bertin, 1967]

Bertin’s inconsistent approaches

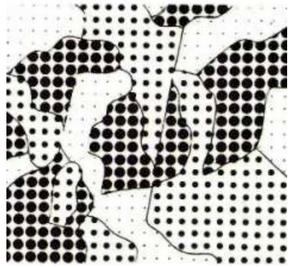
Take the visual variable size for example



Apply visual variables on marks directly



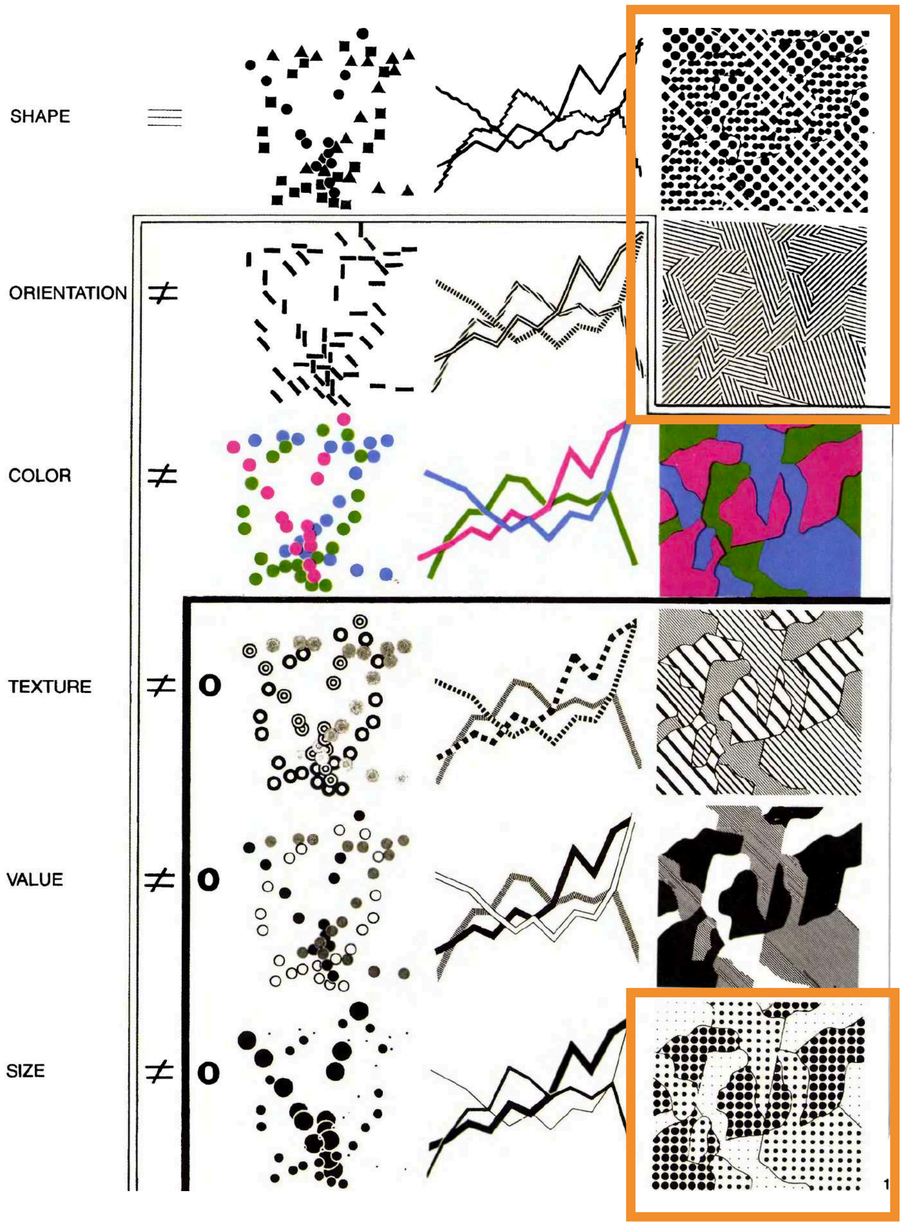
Add one additional marks



Add repetitive additional marks

Patterns

Bertin:
limited the use of patterns
not fully explored the concept



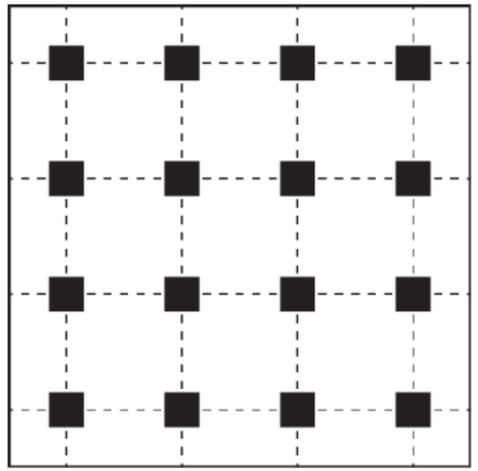
Pattern: Not only repetitive shape variation

From a single mark to a composite mark,
what new potentials patterns offer
for our use in encoding data?

Pattern

A pattern is composed of graphical primitives which can also serve as marks

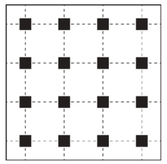
A single mark



A pattern

A single mark

Pattern (a group of marks)



Position → Spatial relationships

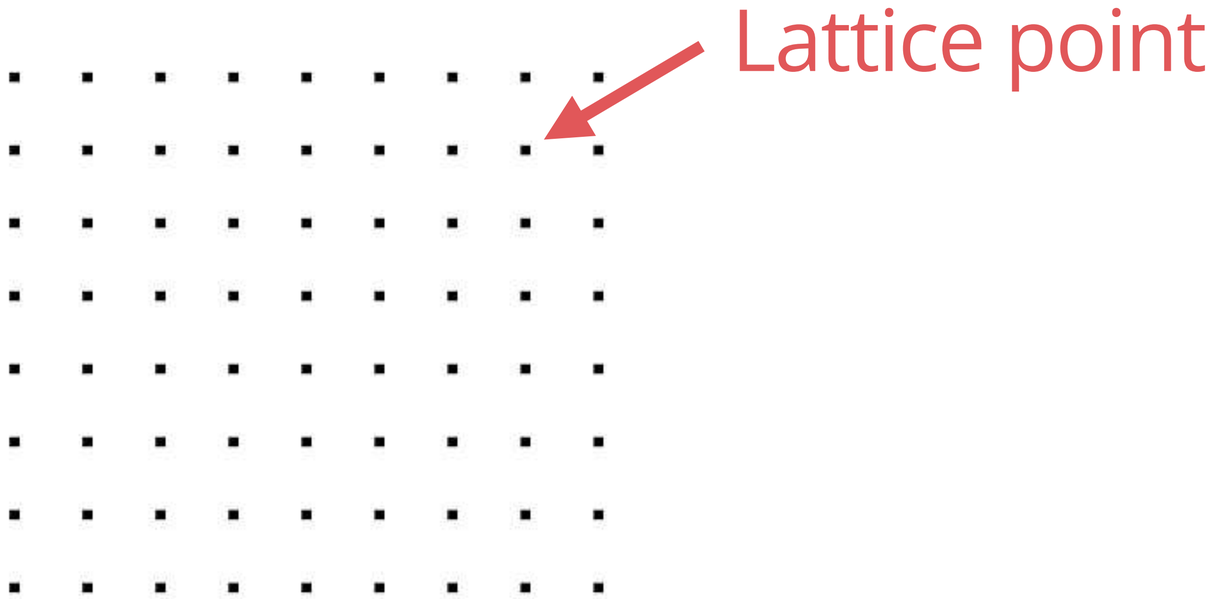
Appearance → Appearance relationships

Appearance of individual primitives

Pattern configuration

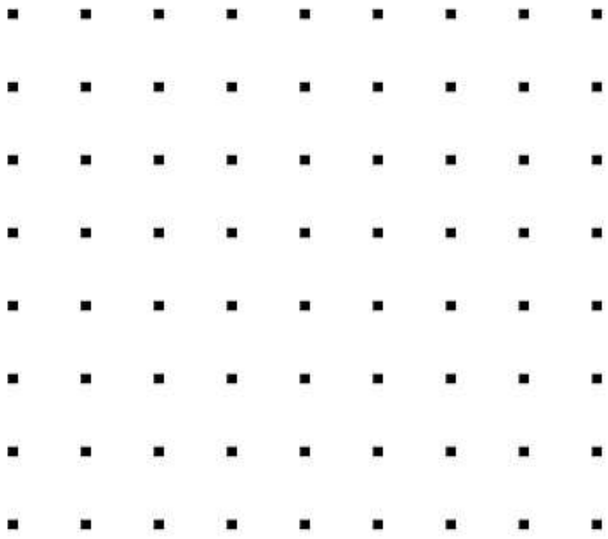
Basic structure for arranging primitives

- A lattice structure
- Lattice points: Predefined positions for primitives



Pattern configuration

The number of lattice dimensions influences the parameters required to define the lattice.

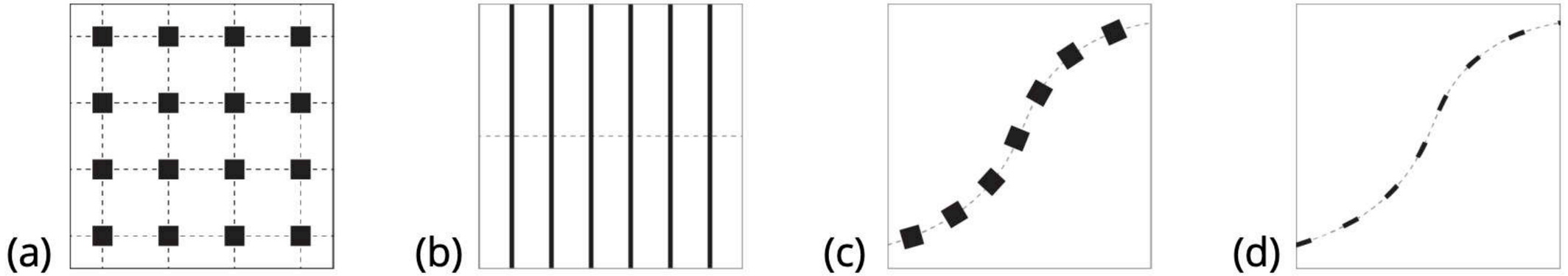


2D lattice

1D lattice

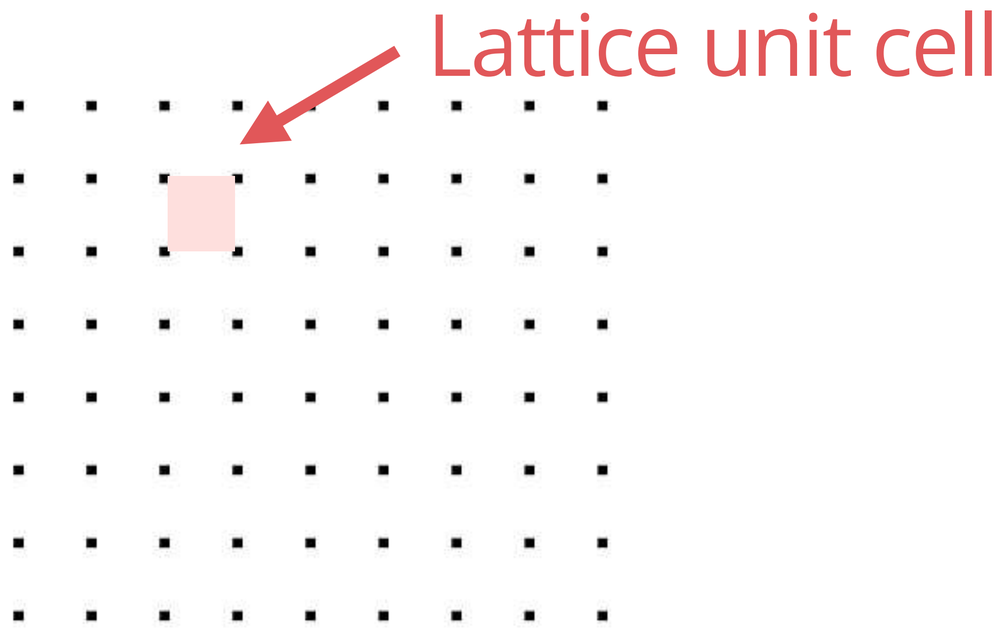
Pattern configuration

4 most common configuration of patterns

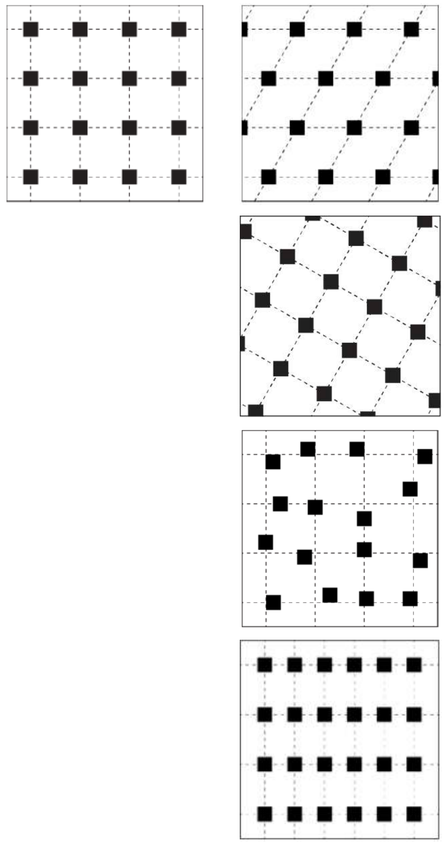


Define a lattice with lattice parameters

- Lattice unit cell: The smallest unit of a lattice
- The entire lattice can be generated by the repetitive tiling of the unit cells



Spatial relationship variables

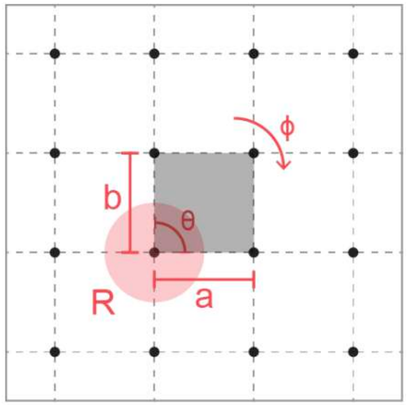


Θ: included angle of the unit cell

a and b: spacing between primitives

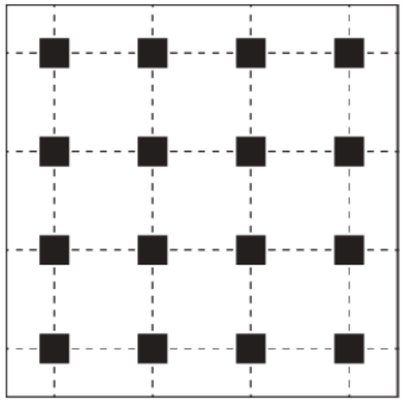
Φ: orientation of the unit cell

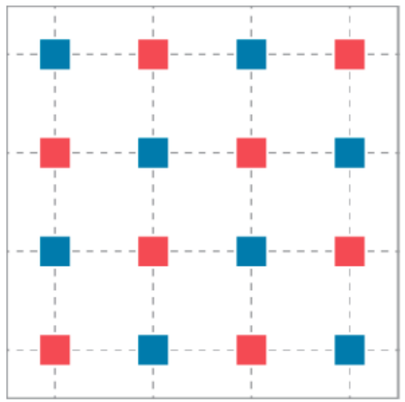
R: positional regularity



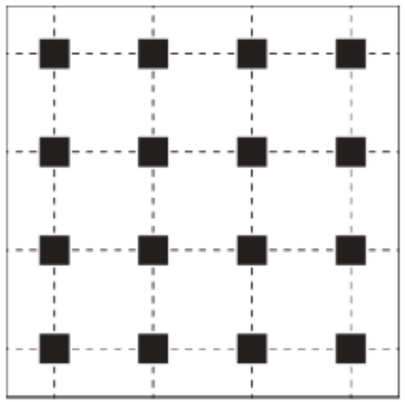
Appearance relationship variables

- Common patterns: Internal consistent
- Composite nature of pattern: Internal variation





Number of primitive groups



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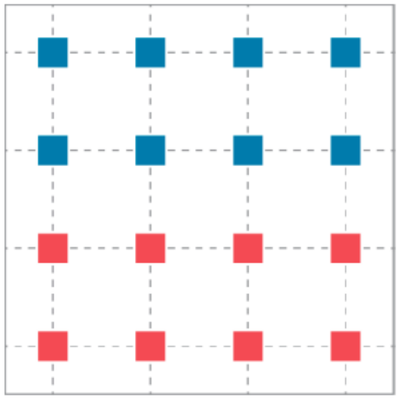

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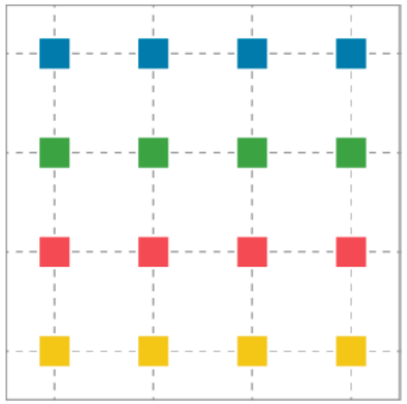
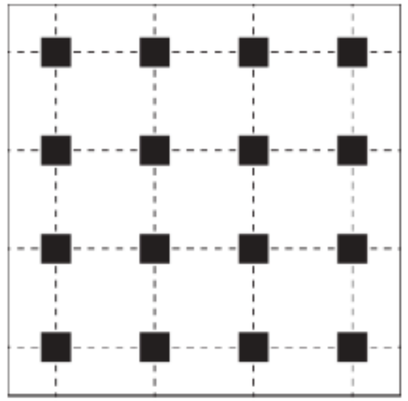


4

Ratio between each group



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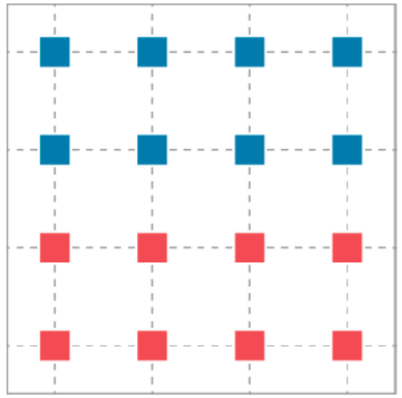
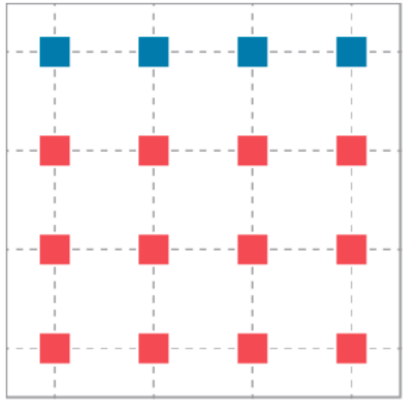


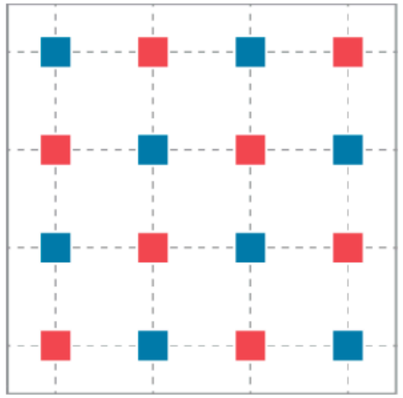
1:1

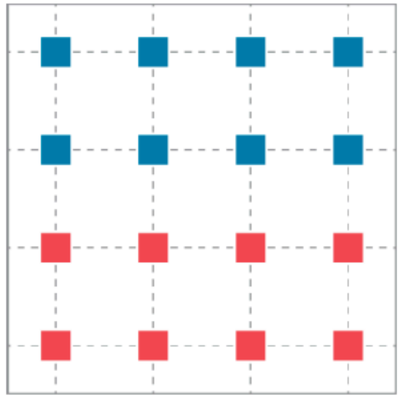


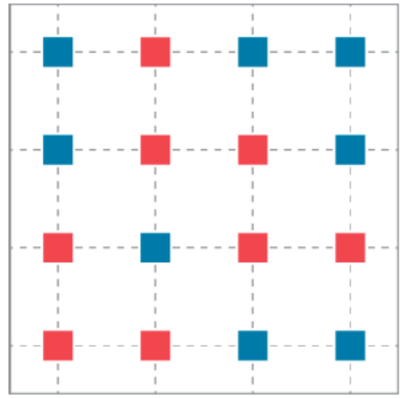
1: 3

Distribution style of different primitives

- How we place each group of primitives within the pattern
- Different from spatial arrangement





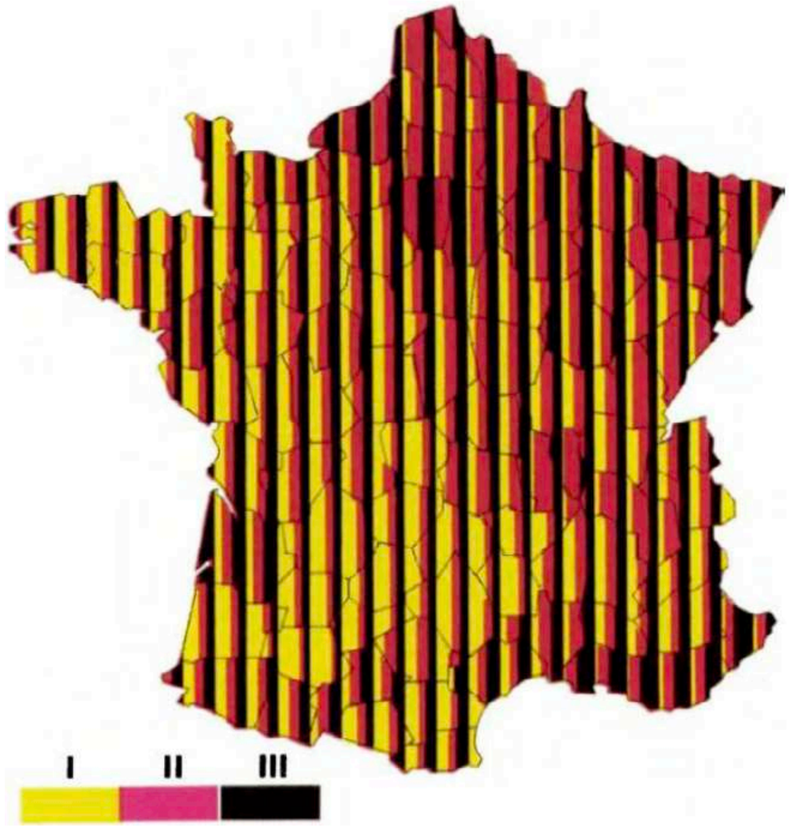


Appearance relationship variables

- Number of primitive groups
- Ratio between each group
- Distribution style of different primitives

Patterns with internal variation

Example of using appearance relationship variables

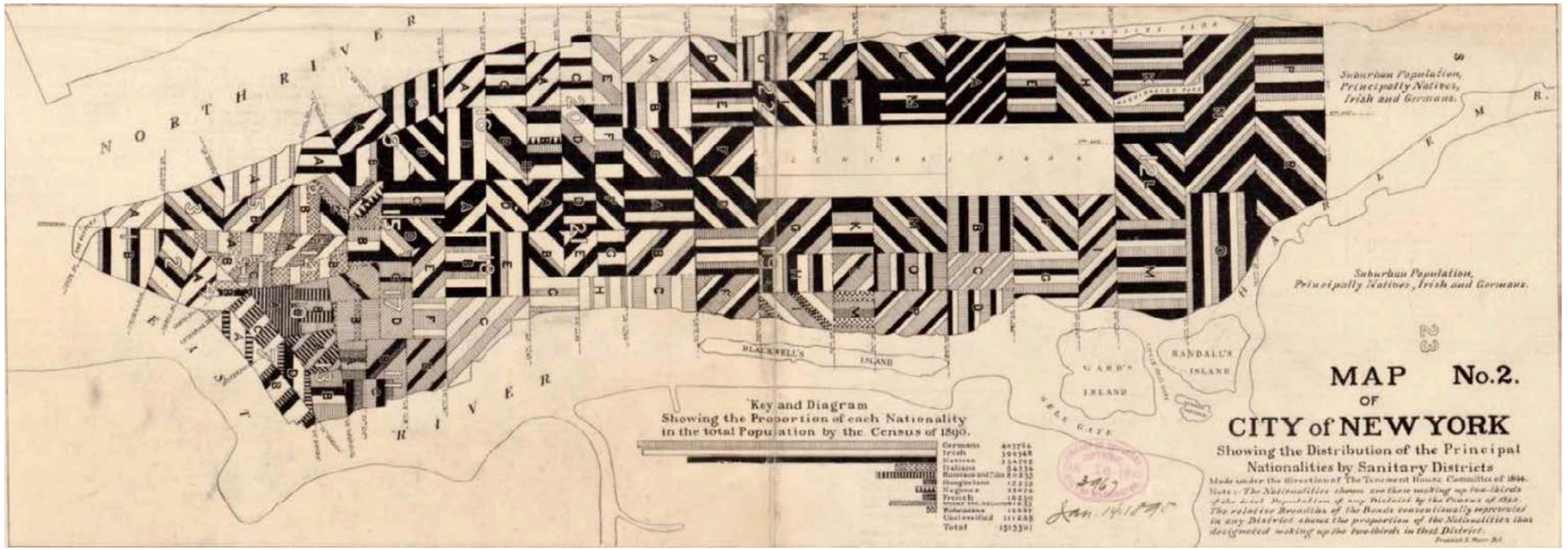


[Bertin, 1967]

Number of primitive groups: category I, II, III
Ratio between groups: ratios between category I, II, III

Patterns with internal variation

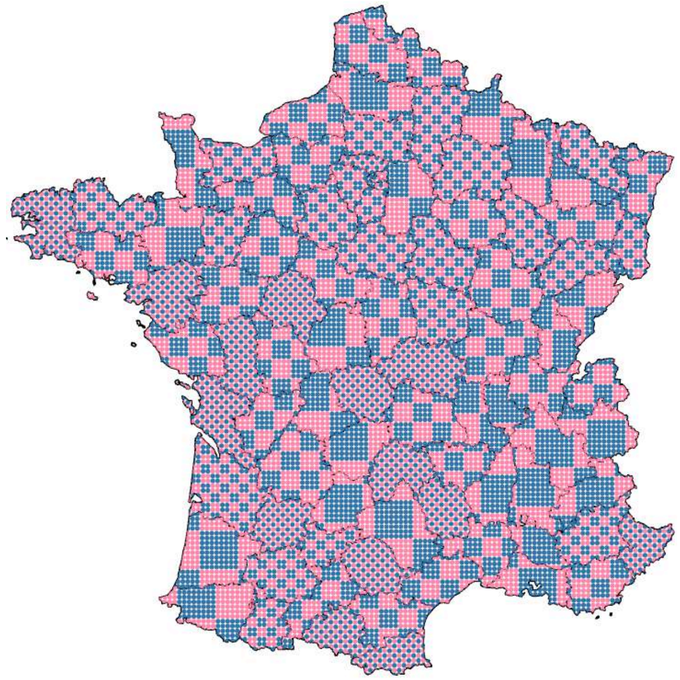
Example of using appearance relationship variables

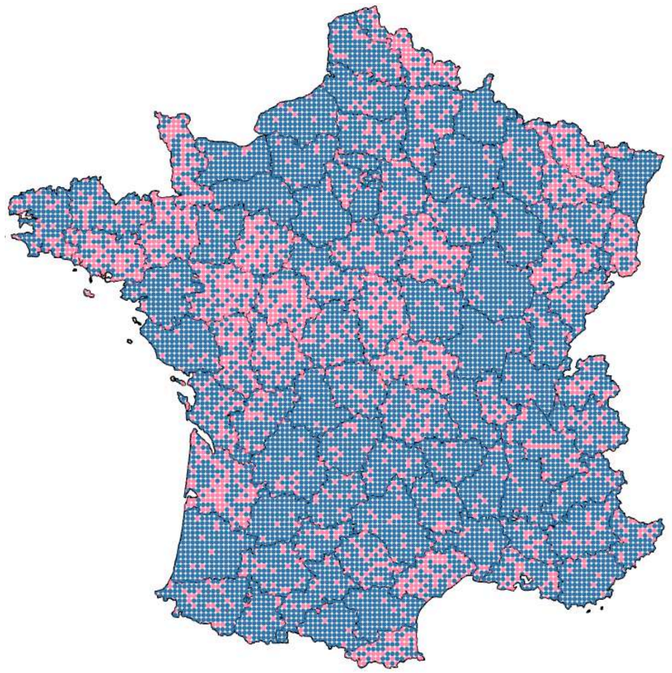


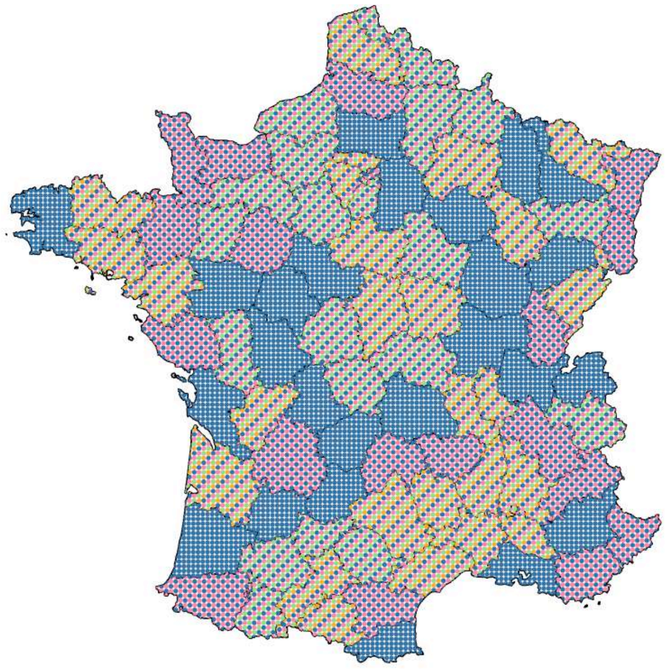
Number of primitive groups: nationality groups
Ratio between groups: ratios between nationality groups
Recursive usage of patterns

Patterns with internal variation

Example of using appearance relationship variables

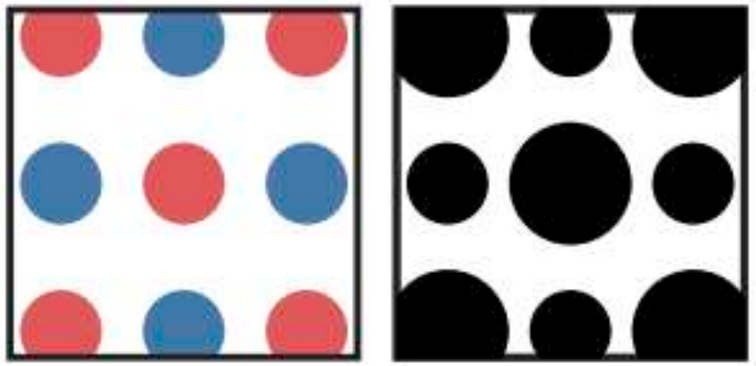






Retinal visual variables on each primitives

- same in primitive relationships
- different in rental variables

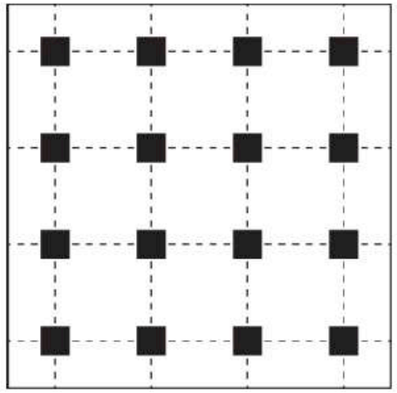


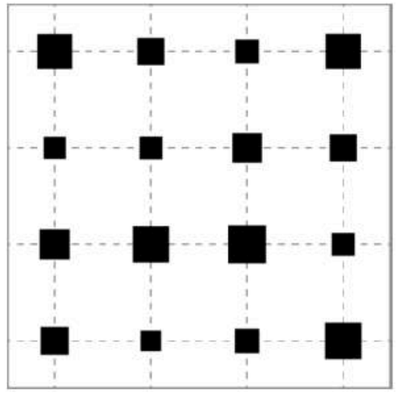
Retinal visual variables on each primitives

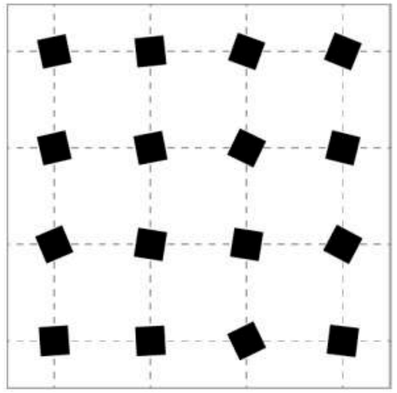
- not new variables introduced by pattern
- can use all retinal variables that can be applied to single marks on pattern

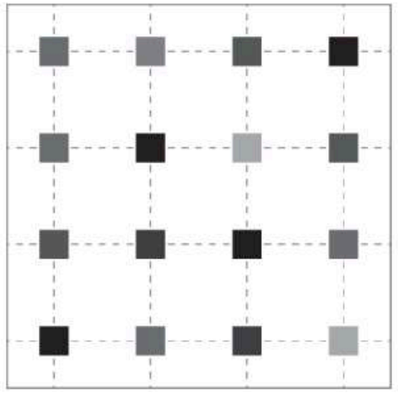
Regularity of retinal variables

a secondary visual variable characteristic



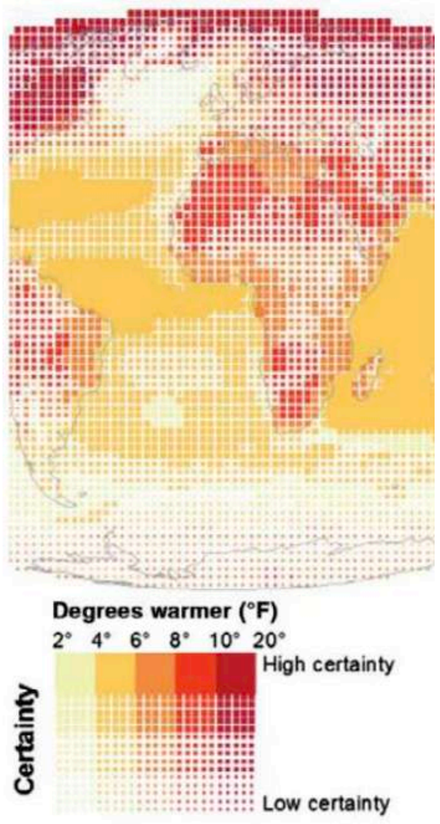




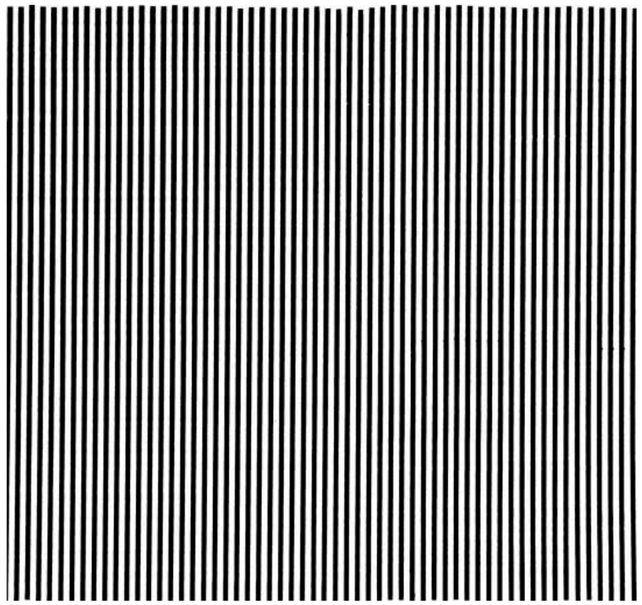


Emergent phenomenon

- Regional value
- Optical illusion



[Retchless and Brewer, 2015]



[Bertin, 1967]

Design space of pattern

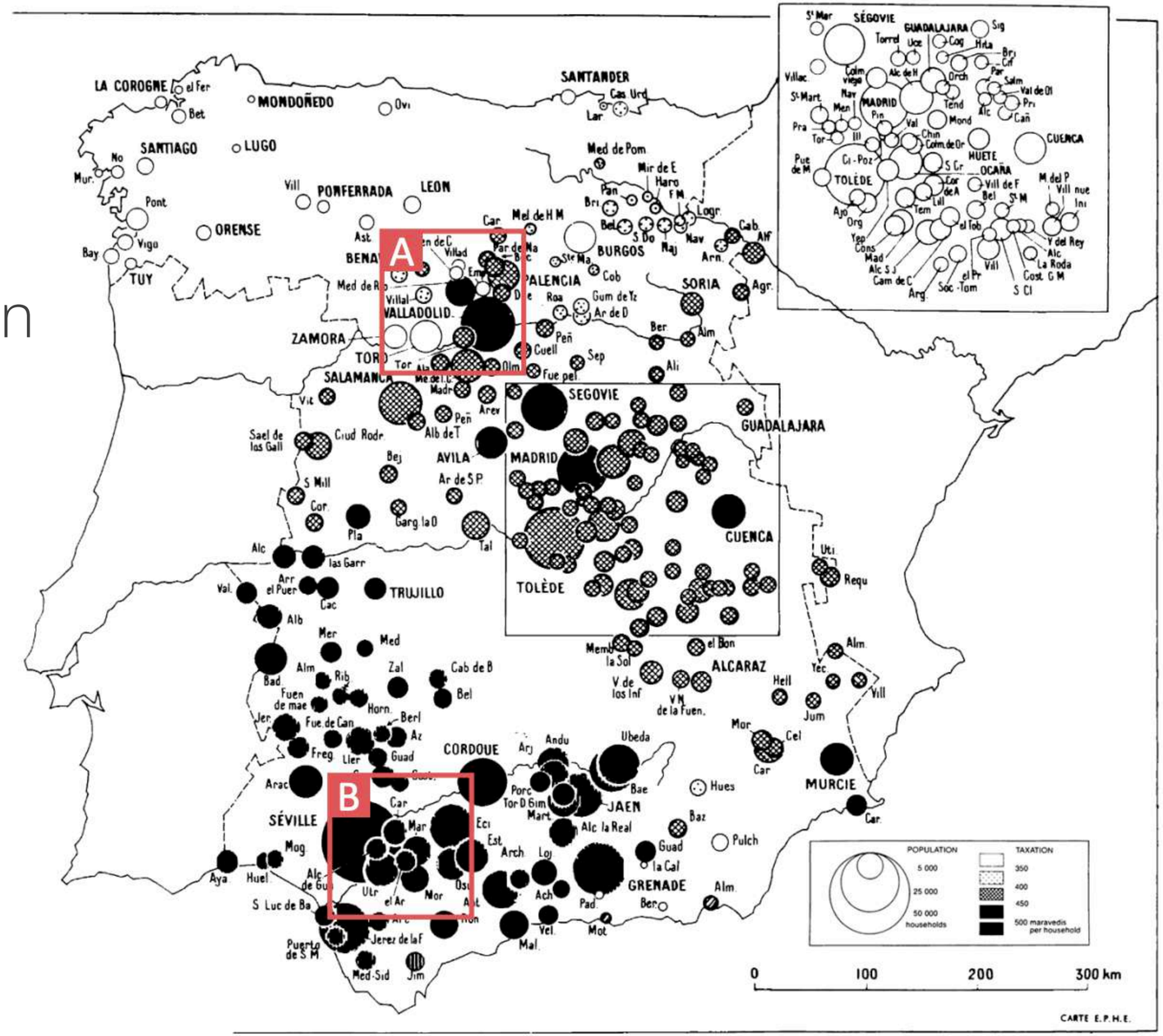
- Spatial relationships
  - Θ: the shape of the unit cell (included angle)
  - a & b: the size of the unit cell (primitive spacing)
  - Φ: orientation of the lattice
  - R: positional regularity
- Appearance relationships
  - Number of primitive groups
  - Ratio between each group
  - Distribution style of different primitives
- Individual appearance characteristics of primitives
  - Regularity of retinal variables

Design space of pattern

- Spatial relationships
  - Θ: the shape of the unit cell (included angle)
  - a and b: the size of the unit cell (spacing between primitives)
  - Φ: orientation of the lattice
  - R: positional regularity.
- Appearance relationships
  - Number of primitive groups
  - Ratio between each group
  - Distribution style of different primitives
- Individual appearance characteristics of primitives
  - Regularity of retinal variables

Directly encode geographical location into the position of primitives?

- Read at region level
- Create patterns
  - with regional information



Conclusion

- Elucidated the underlying thoughts in Bertin’s works and inconsistencies of Bertin’s methods
- Systematically summarize pattern variations
- Connect the concept of pattern to map reading process




Tingying He, Jason Dykes, Petra Isenberg, Tobias Isenberg. Toward an Understanding of ‘Pattern’ as a Visual Variable. In preparation.

Toward an Understanding of ‘Pattern’ as a Visual Variable

Tingying He, Jason Dykes, Petra Isenberg, Tobias Isenberg

***Abstract*—We draw upon broad and contrasting considerations of *pattern* as a visual variable to develop consolidated theory for explaining, exploring, and using patterns in visualization. We clarify ambiguities around the use of “pattern” and “texture” and show how seeing patterns as composites of sub-marks opens a wide design space. When we conceptualize patterns as rules that control the spatial relationship of sub-marks we can describe how the sub-marks’ appearances can differ from one another and systematically describe the composition and potential variation of the patterns based on a regular arrangement. We show how our conceptualization relates to existing visualization theory and highlight opportunities for visualization design. We also discuss the arrangement of patterns driven by geographical information within this conceptualization, further connecting patterns to the broader literature on maps.**

***Index Terms*—Pattern, visual variables, visualization theory, textures.**

I. Introduction

VISUALIZATION design at its very core relies on the mapping of data values to visual variables. Visual variables, also referred to as visual channels, are attributes of graphical elements—referred to as “marks”— whose appearance can be manipulated to encode data [41]. We have quite a few visual variables at our disposal such as *position*, *hue*, or *size* and their effectiveness ranking has been the subject of much research and discussion in our field [20], [35], [38]. Among the available visual variables is one that researchers have called *pattern* [33], typically featuring repetitive dots or lines . Visualization designers often use patterns when color is either limited or already encodes other data dimensions (e. g., [3], [4], [8], [9], [17], [45], [51], [55]).

When patterns are described as visual variables, researchers have also referred to them as *texture*. This interchangeability of the terms *pattern* and *texture* may arise from the blended use of these two terms in everyday language and the inclusion of *texture* in Bertin’s initial list of visual variables [3], [4]. However, to add to the confusion, the term *texture*, has a diverse set of meanings in the visualization research that goes beyond an understanding of texture as pattern . Researchers working on 3D representations, for example, often use *texture* to mean surface or volume characteristics of 3D objects, represented as realistic images [28], [32]. These textures typically have different visual characteristics and encoding goals from the patterns that are used as a visual variable in abstract data representation. Even in the specific context of discussing the visual variables used for abstract data representations, researchers may interpret the term *texture* as a variation of a specific dimension of a *pattern*, such as “granularity” (Bertin called it “grain” in French) , the spacing between the repeated elements , or the shape of these elements . We argue that this melange of terminology hinders the research community in investigating *pattern* as a visual variable or using this encoding effectively because research on patterns and the practice of using them are difficult to compare and situate in the absence of consistent terminology.

Inspired by the literature [15], [33], [41], [56], we therefore suggest to use the term *pattern* to describe a composite visual variable that consists of graphical primitives which can also serve as marks for data encoding. **Our first contribution** is an in-depth discussion and clarification of the terms *texture* and *pattern* in light of existing interpretations around both terms. As **our second contribution**, we further provide a conceptualization of *pattern* along with its potential variations which we can use for data encoding. We identify three sets of attributes of pattern: spatial relationships of primitives, appearance relationships of primitives, and individual appearance characteristics of primitives. Furthermore, we discuss directly encoding geographical information into the sub-marks and link the concept of *pattern* to the map reading process.

II. Texture and Pattern

Researchers often use the terms *pattern* (e. g., [30], [33], [52]) or *texture* (e. g., [25], [55], [58]) to describe a visual variable characterized by repeated elements . While both terms can make sense and are understandable, Carpendale [15], in her discussion of visual variables, suggest to use the term *texture* for “apparent surface quality of the material like wood or marble” and to use *pattern* for “repetitive use of shape variations.” We consider Carpendale’s recommendation reasonable and useful[1] due to two main issues associated with the term *texture*: (1) compared to *pattern*, the term *texture* has a broader meaning in visualization and related fields and often refers to different concepts (as we show in Fig. 1 and Fig. 2), making it less precise; and (2), even when *texture* specifically refers to a visual variable, it is subject to different interpretations [3], [4], [22], [29], [30], [48], [52]. In this section, we discuss the first

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[1]We agree that the term *texture* is best used in this sense but propose in Sect. III-C that *pattern* has broader possibilities beyond repetitive use of shape

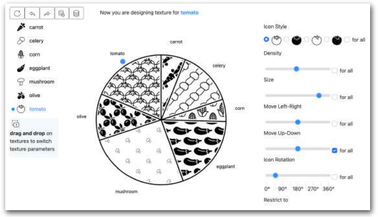
Empirical studies

How can we aesthetically and effectively
use black-and-white patterns
for categorical data visualization?

Geometric patterns

Iconic patterns

Three empirical experiments

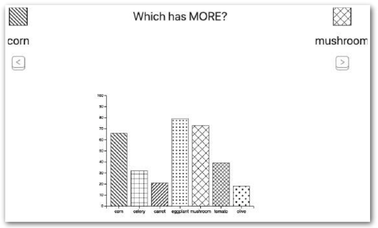


Experiment 1

Collect good pattern designs for visualizations from experts

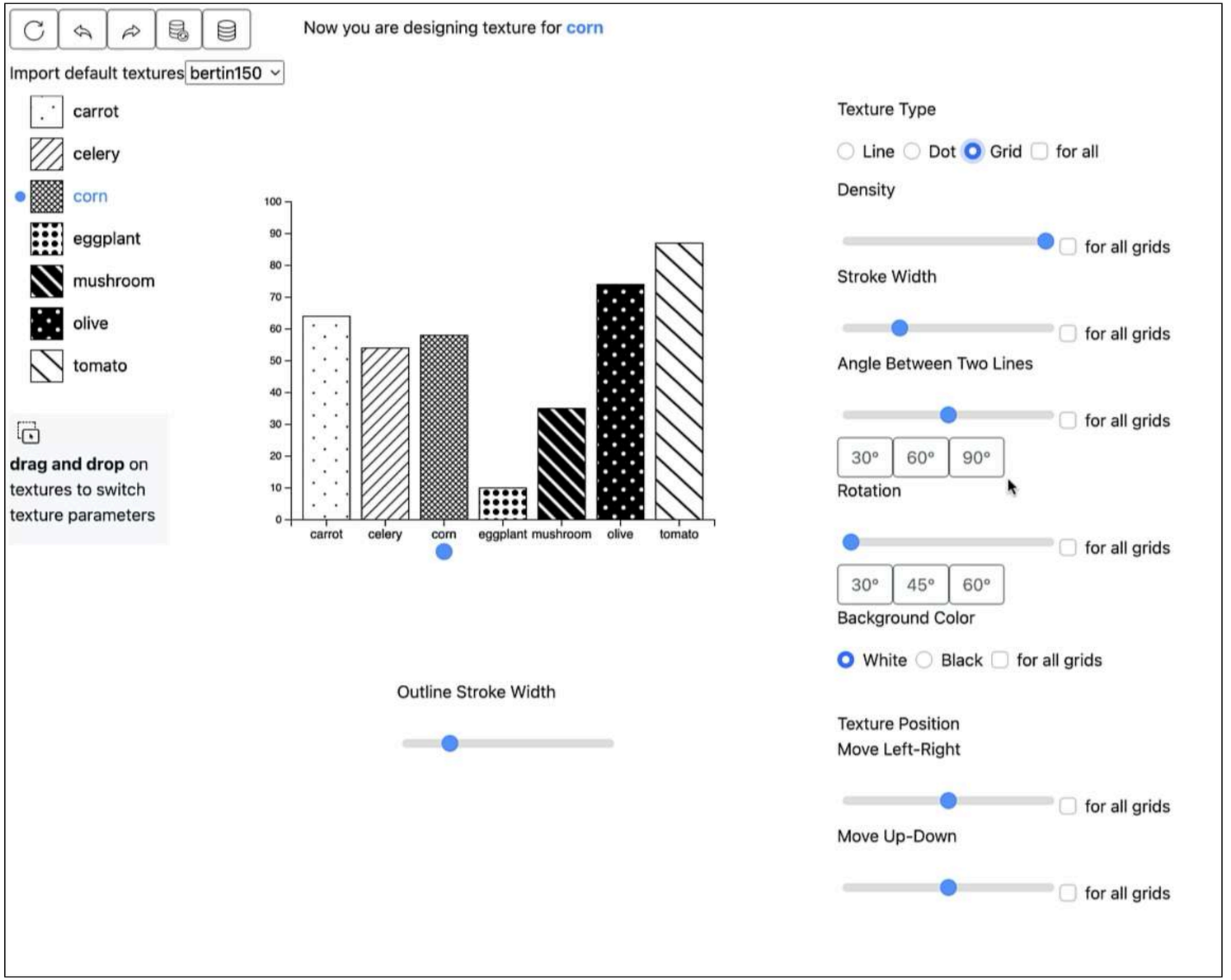
Experiment 2

Rate the collected designs based on visual appearance



Experiment 3:

Assess the top-rated designs regarding effectiveness and aesthetics



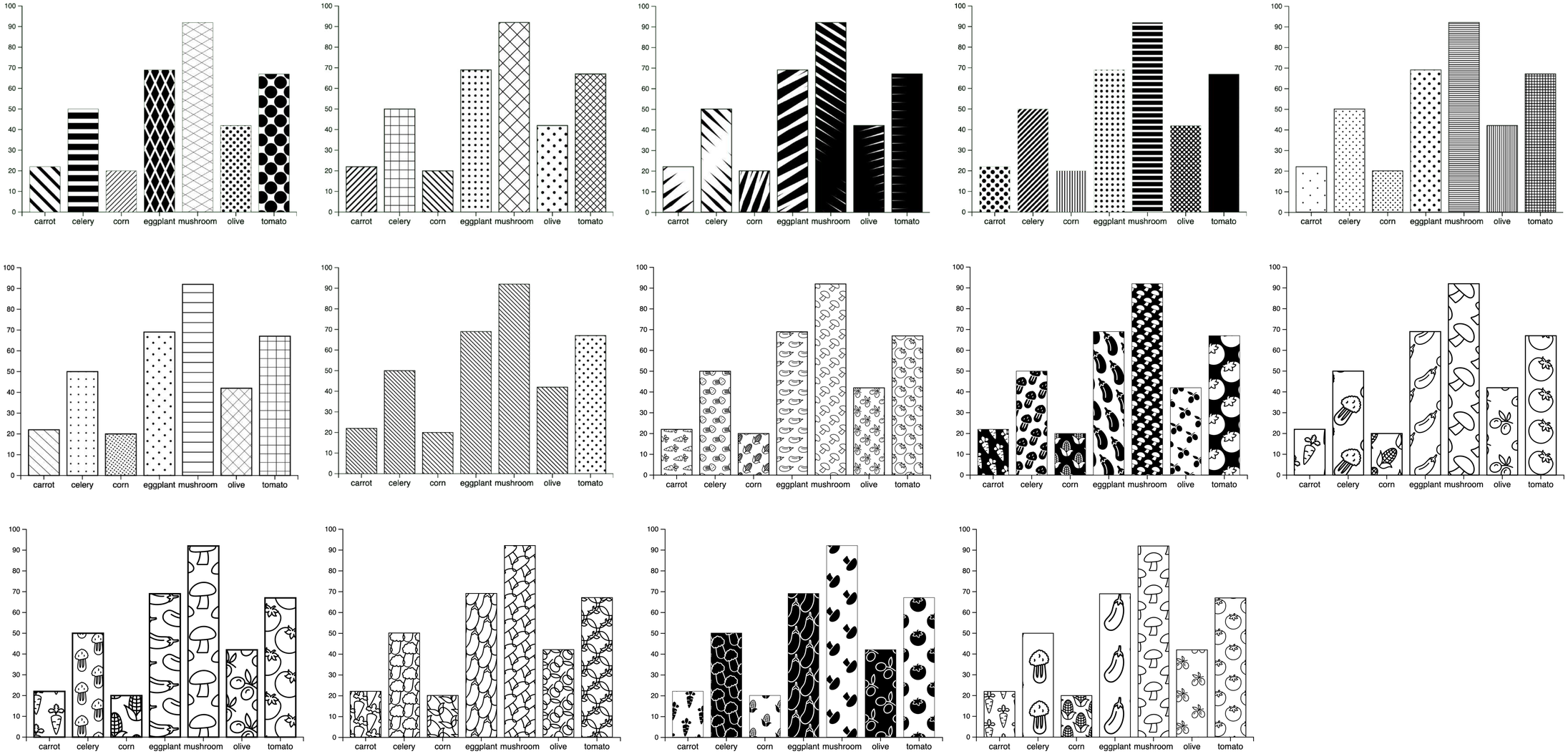
Our pattern design interface

Experiment design

- Mixed design
  - Between-subjects variable: chart type
  - Within-subject variable: pattern type
- Participants: 30 experts
  - 12 female, 18 male
  - Ages: mean = 40.1, SD = 14.4
  - Prior experience in visualization design: mean = 13.4 years, SD = 11.0 years

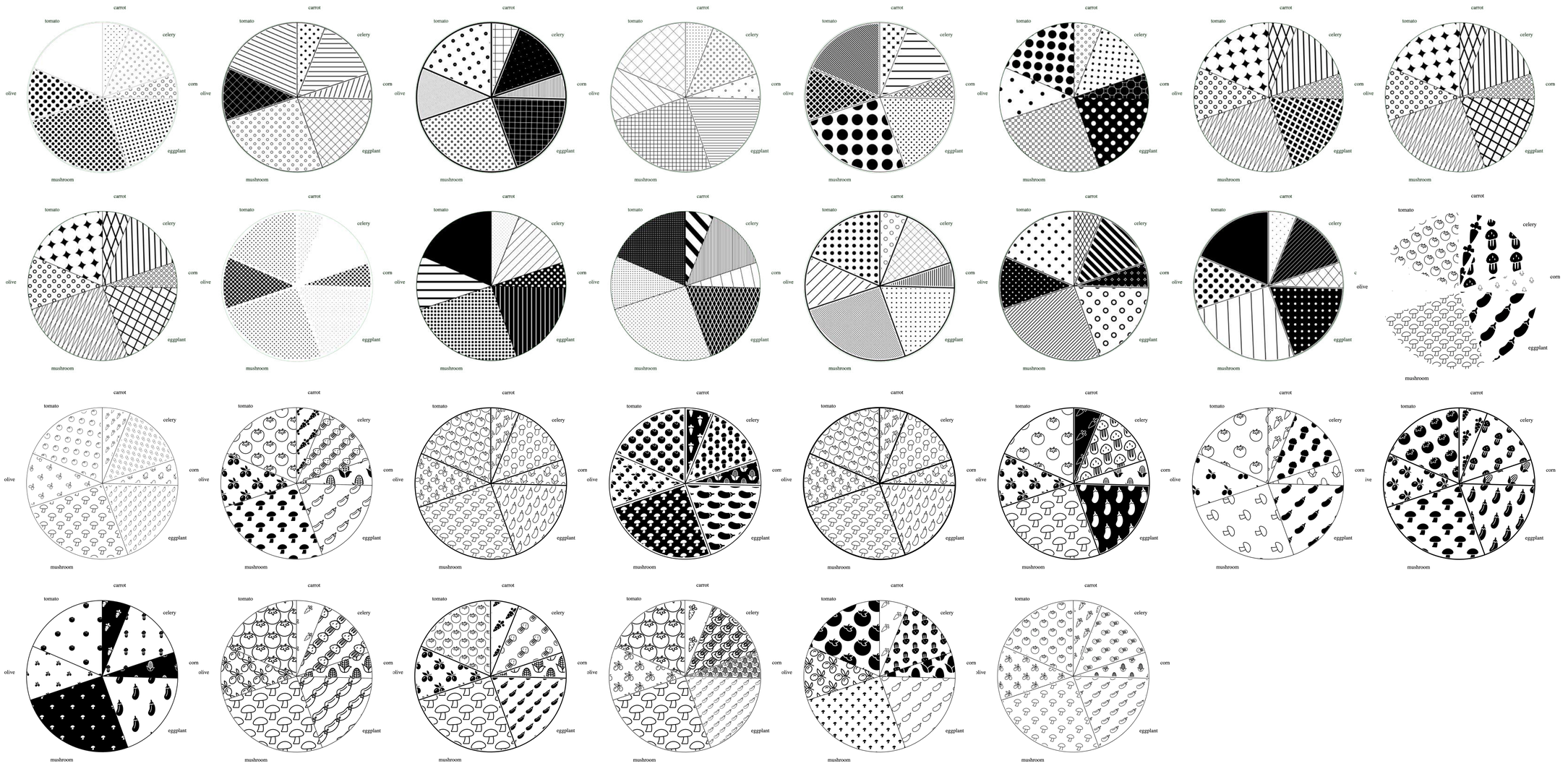
Experiment 1

Collect 66 designs from 30 experts - 14 bar charts



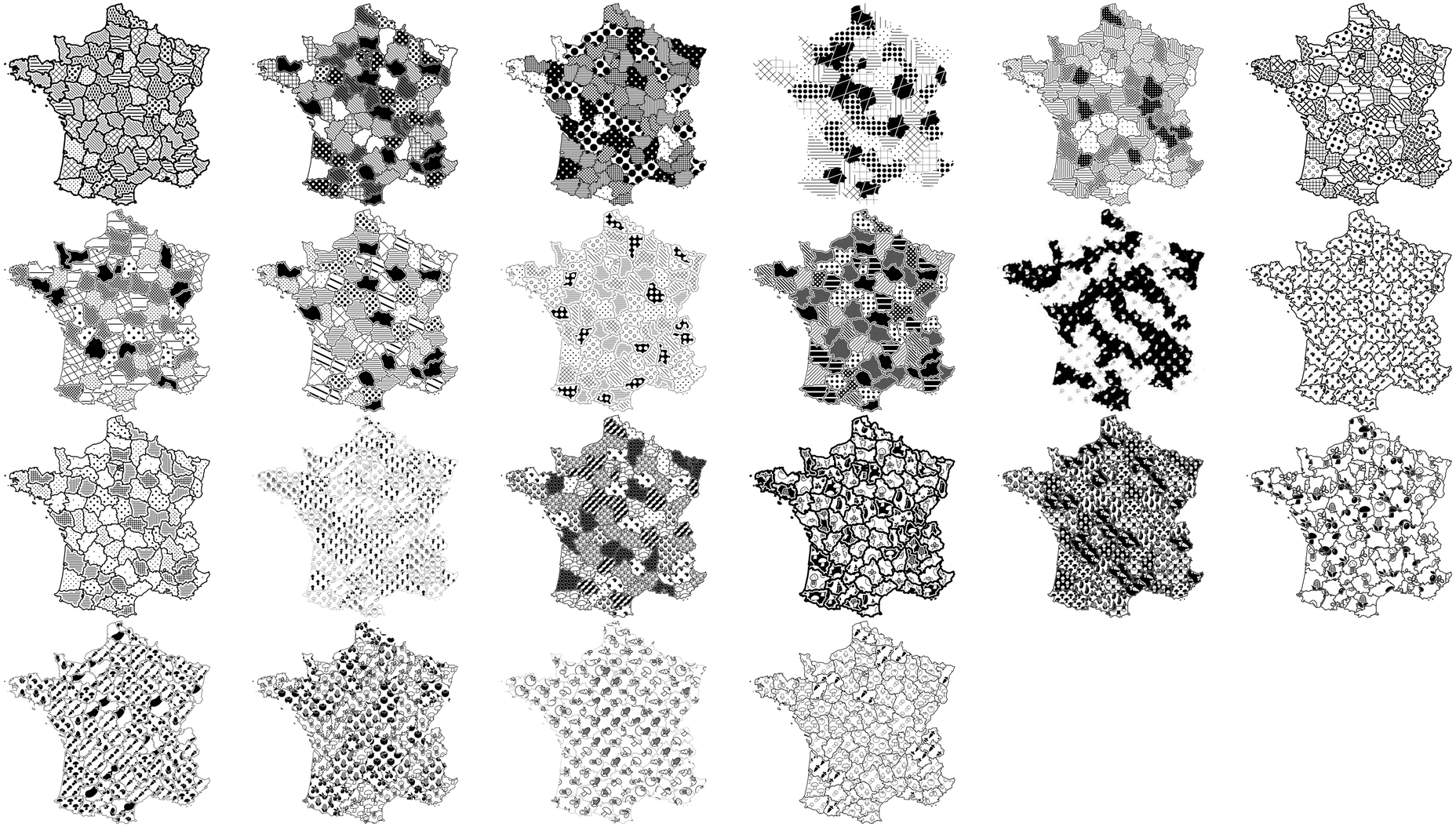
Experiment 1

Collect 66 designs from 30 experts - 30 pie charts



Experiment 1

Collect 66 designs from 30 experts - 22 maps



Experiment 1

Design strategies

- Readability
  - Distinguishability
  - Clarity
  - Semantic association
- Aesthetics
  - Visual appearance
  - Visual balance

Goal
"Visual distinctness (distinct) and consistency (consistent) in design"

Geometric
"For the geometric textures, I was aiming for textures that were not too bold and had roughly equal weight (balance) while being clearly distinct (distinct)"

Iconic
"I changed the icon size to reflect what they represented. (association) Also I centered the icons made it so that a complete icon (complete_icon) appeared near the bottom."

Goal
In general, I tried to make all columns distinguishable(distinct) given they are placed so close to each other, and then following either the same style or a rhythm of styles (consistent).

Geometric
same style or a rhythm of styles(consistent)
" For the geometric one, I used non-orthodox grid for all and from left to right, I put an increment on each grid strike so that it forms a gradient pattern. Meanwhile all grids are tiled as if pointing at the next column, up or down, resulting a sense of waves. I didn't a second style other than the grid because that would disturb the melody of the graph reading. "

Iconic
"For the icon one, I found the given example makes it hard to distinguish(distinct) columns, so my general strategy is bring a rhythm of color density to the graph by putting a black background next to a white one, repeat and so on so forth. Then I chose black icons with a little more details for all white background bars, and white stoked icons for all black bars to balance the visual (balance). "

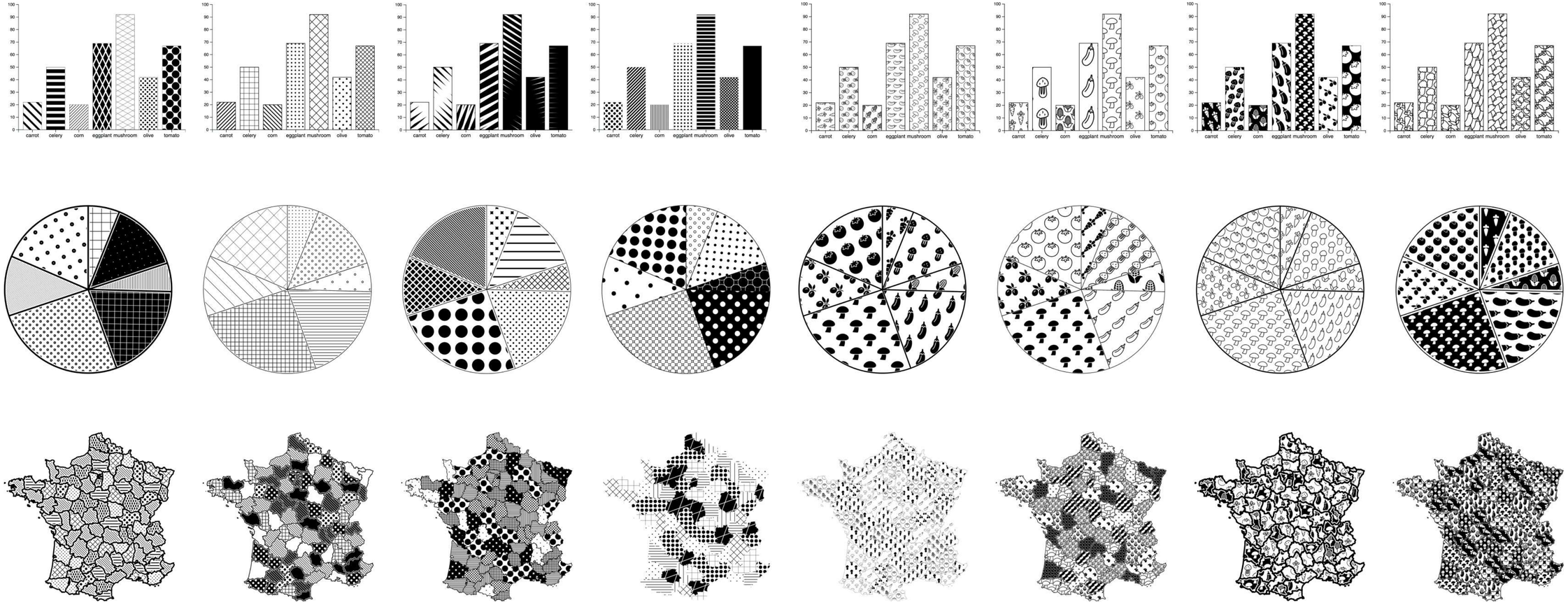
"Readable: [Clear]
- there should be no ambiguity as to what the icon represents => e.g keeping the details for the corn, choosing black background for light-colored vegetables,[association] slecting a rotation which wouldn't compromise the icon recognition while allowing maximum size (eg in their current design, the carrots / eggplants / celery should be placed using alternating gridlines so they wouldn't touch when turned at 45°)
- the 7 textures should be as distinct [Distinct] as possible (no ambiguity) => variations of angles and backgrounds

Experiment 2

How does the general public perceive collected patterns in terms of their visual appearance?

Experiment 2

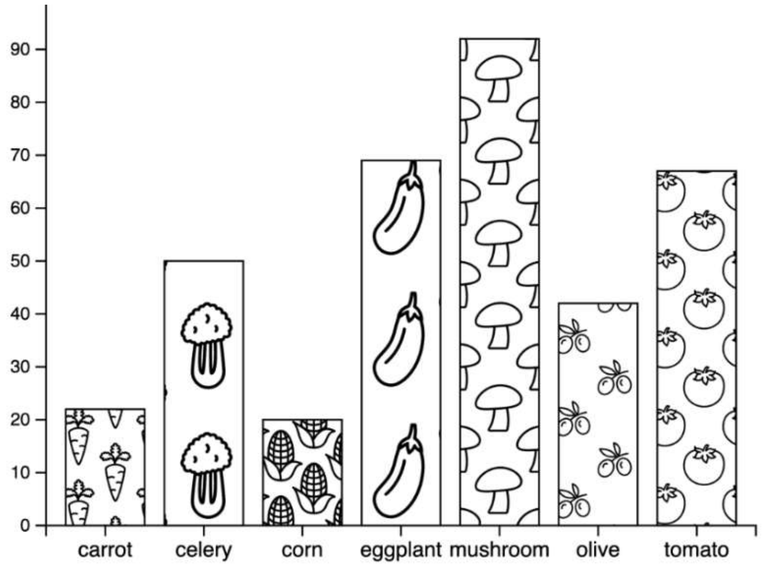
Stimuli: Represent different aesthetic styles



Experiment 2

Task: Rating

- 5 rating items from BeauVis scale measuring aesthetics
- 1 rating item measuring vibratory effect

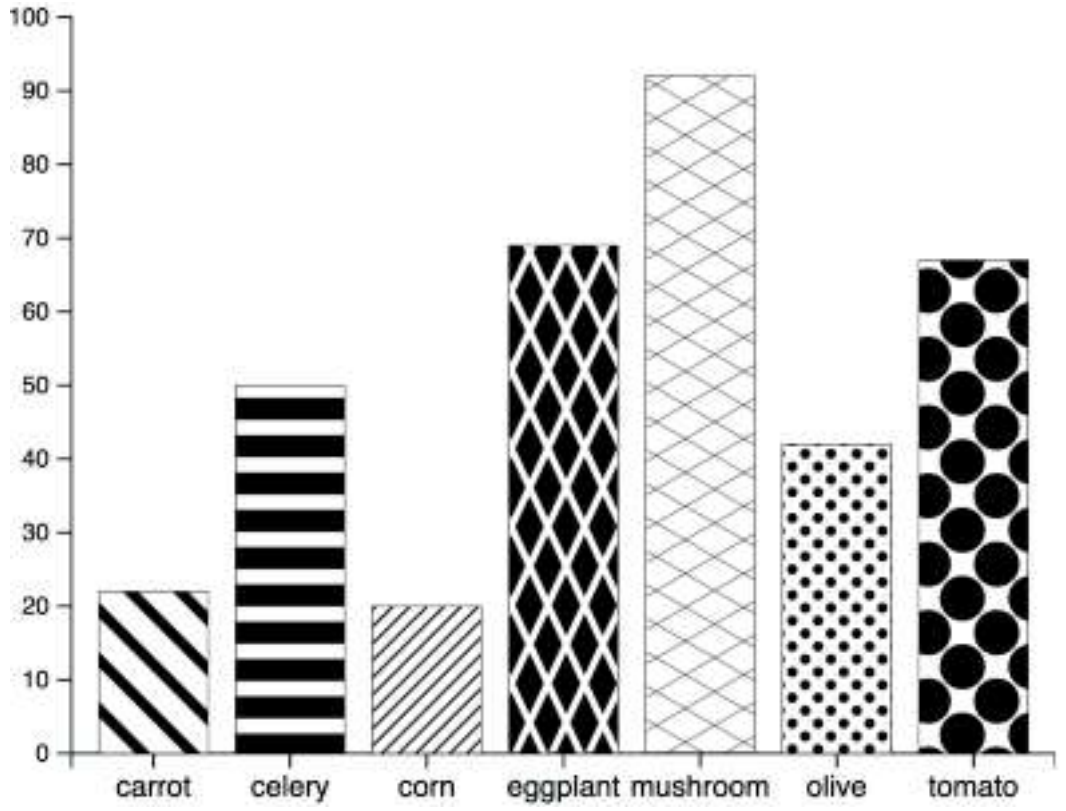


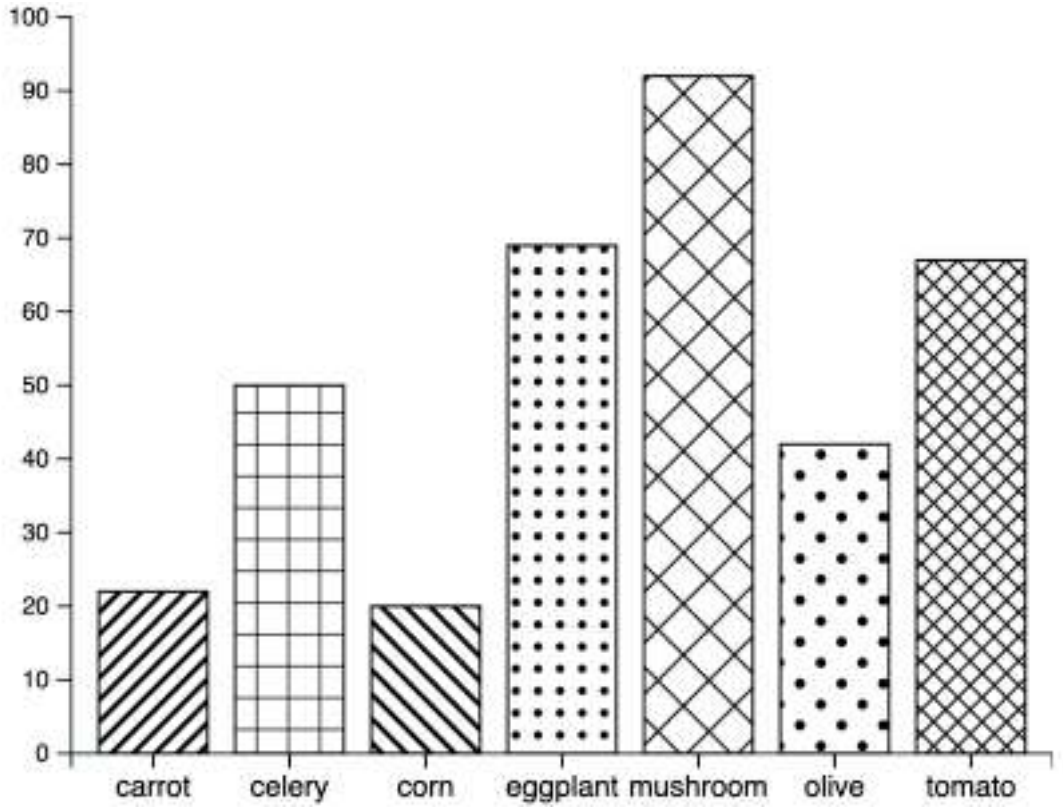
	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
This visualization is **appealing.**	○	○	○	○	○	○	○
This visualization is **pleasing.**	○	○	○	○	○	○	○
This visualization is **enjoyable.**	○	○	○	○	○	○	○
This visualization is **likable.**	○	○	○	○	○	○	○
This visualization is **nice.**	○	○	○	○	○	○	○
This visualization has a vibratory effect.	○	○	○	○	○	○	○

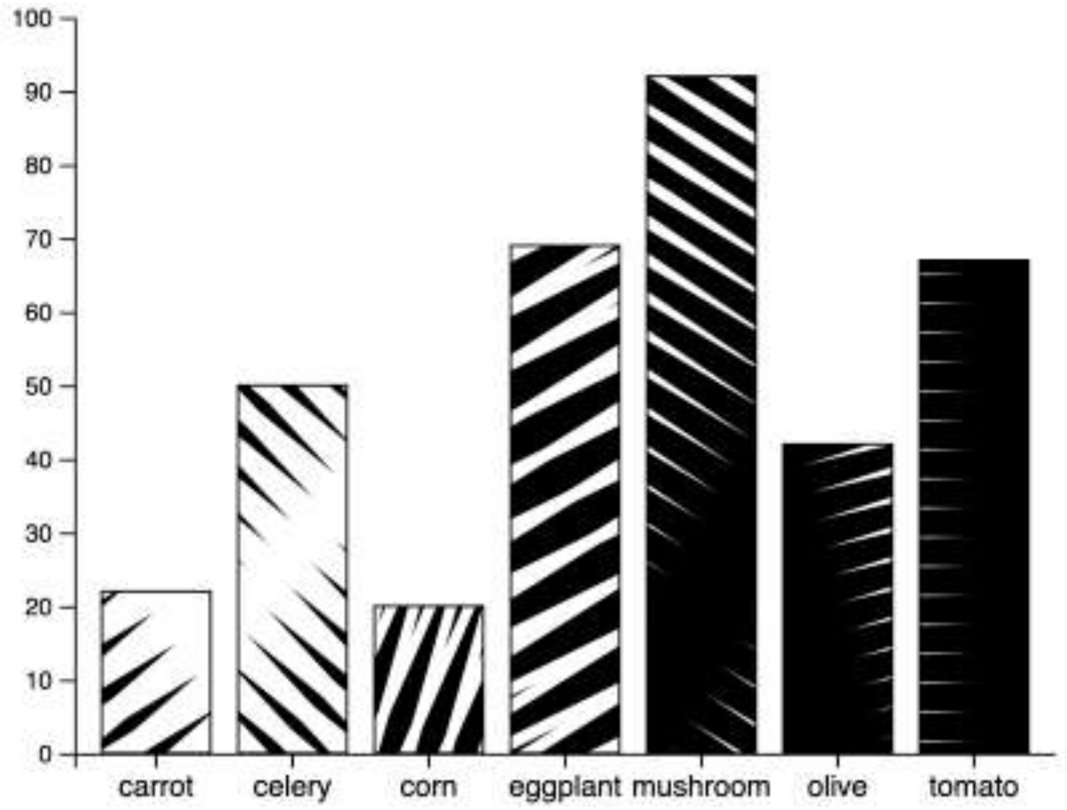
Experient 2 screenshot

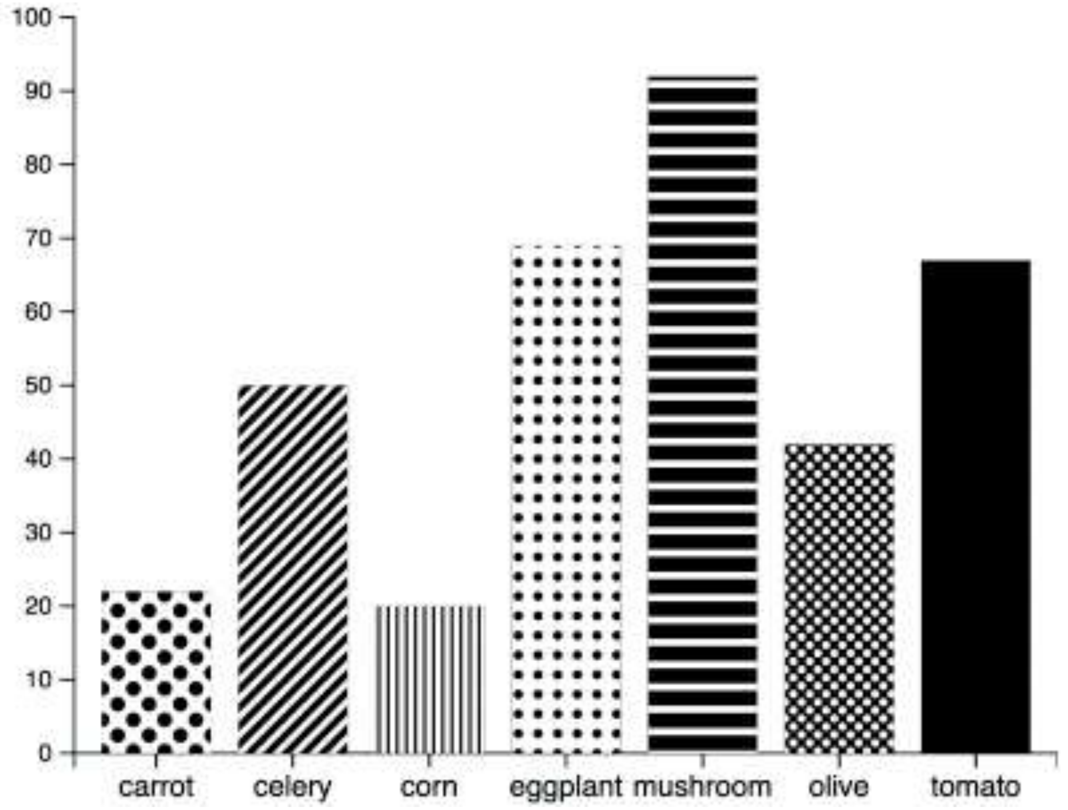
Task: Ranking

Based on overall preference









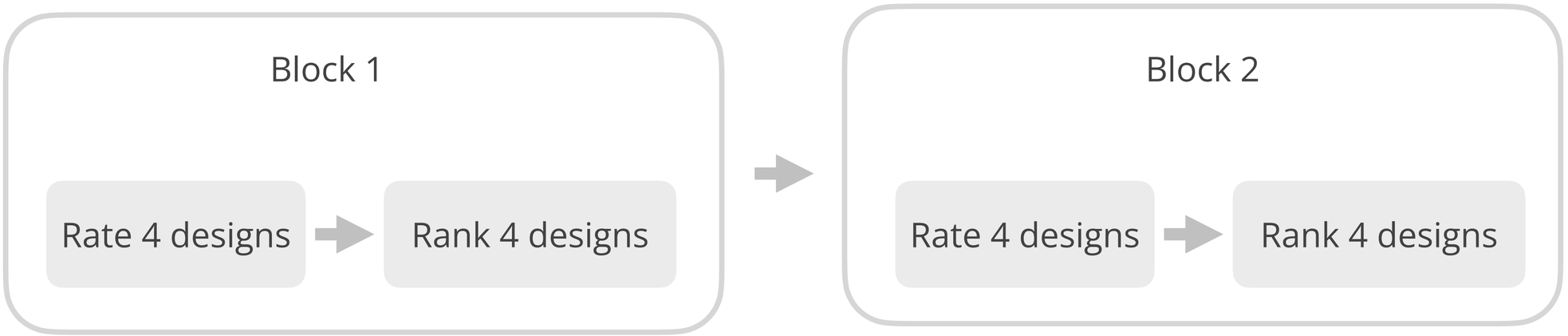
Experiment design

- Mixed design
  - Between-subjects variable: chart type
  - Within-subject variable: pattern type
- Participants: 150 from Prolific
  - 75 female, 75 male
  - Ages: mean = 28.2, SD = 8.9
  - Education: 87 Bachelor or equivalent, 27 Master's or equivalent, 3 PhD or equivalent, 33 other)
- 53 participated in the bar condition, 44 in the pie condition, and 53 in the map condition.

Experiment 2

Procedure

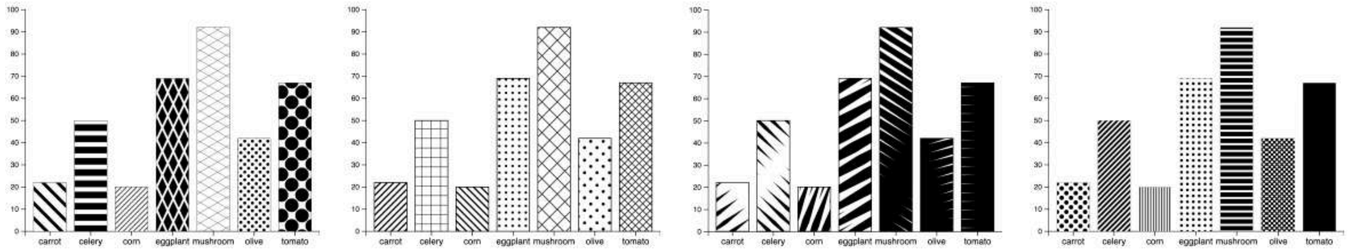
- Evaluate 8 designs in total
- 2 blocks by pattern types



Individual chart

- BeauVis score with distribution
- Count of being ranked first for overall preference
- Vibratory effect score

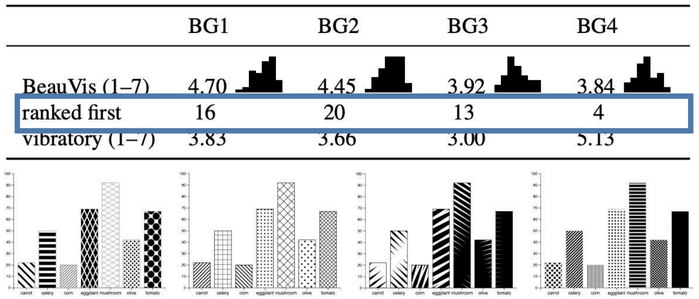
	BG1	BG2	BG3	BG4
BeauVis (1–7)	4.70	4.45	3.92	3.84
ranked first	16	20	13	4
vibratory (1–7)	3.83	3.66	3.00	5.13



Experiment 2: Results

Diverse preference among participants

- Uniform rating distributions of BeauVis score
- Each chart was ranked as the top choice by some participants



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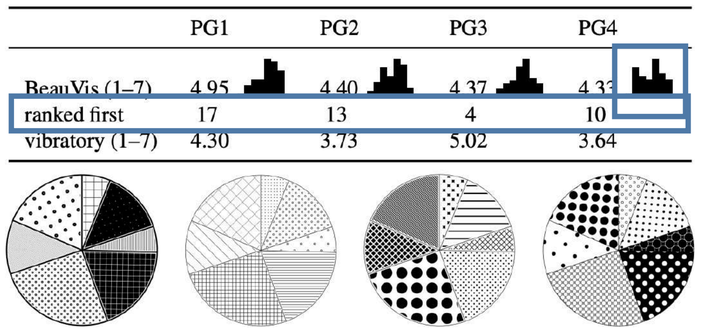
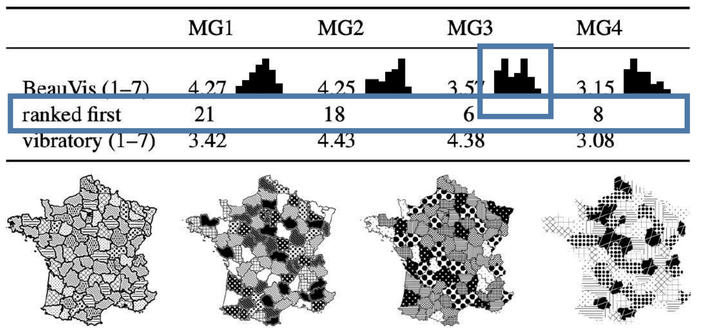
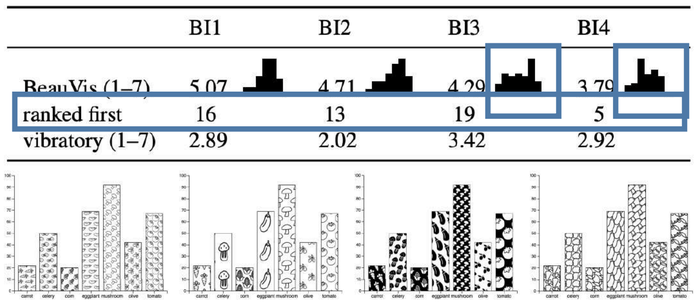


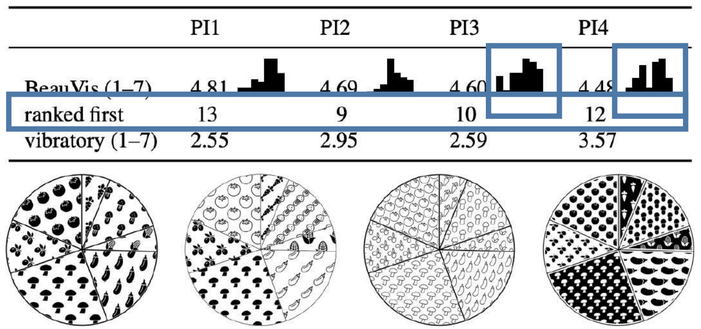
	PG1	PG2	PG3	PG4
BeauVis (1–7)	4.95	4.40	4.37	4.33
ranked first	17	13	4	10
vibratory (1–7)	4.30	3.73	5.02	3.64



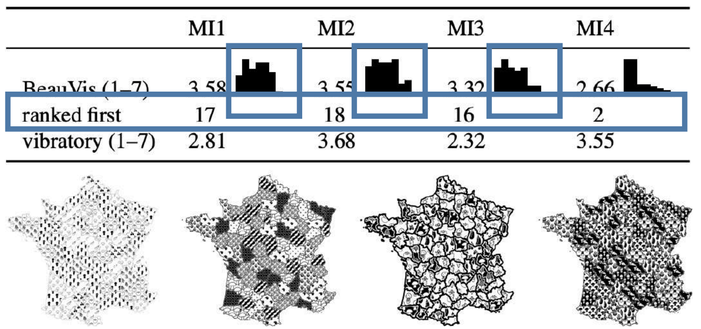
	MG1	MG2	MG3	MG4
BeauVis (1–7)	4.27	4.25	3.57	3.15
ranked first	21	18	6	8
vibratory (1–7)	3.42	4.43	4.38	3.08



	BI1	BI2	BI3	BI4
BeauVis (1–7)	5.07	4.71	4.29	3.79
ranked first	16	13	19	5
vibratory (1–7)	2.89	2.02	3.42	2.92



	PI1	PI2	PI3	PI4
BeauVis (1–7)	4.81	4.69	4.60	4.48
ranked first	13	9	10	12
vibratory (1–7)	2.55	2.95	2.59	3.57



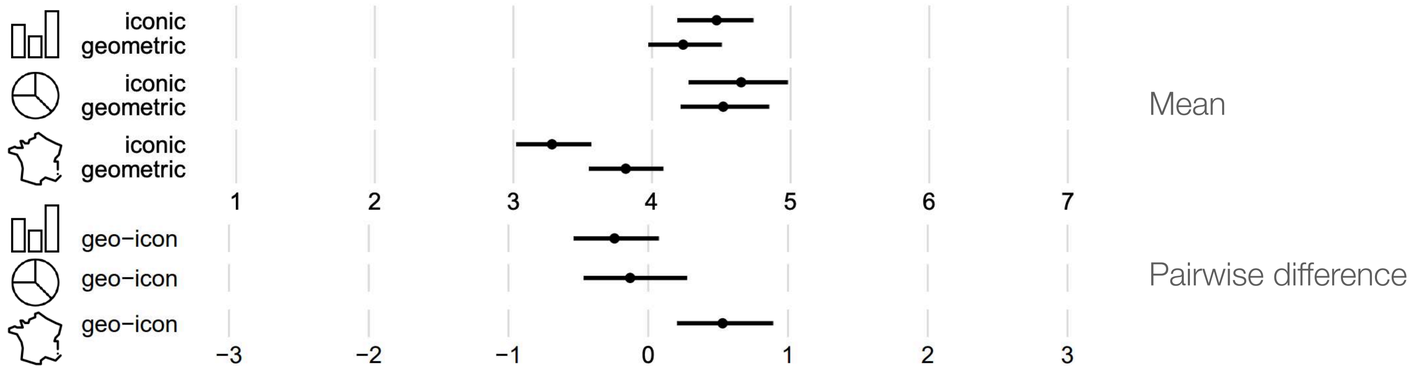
	MI1	MI2	MI3	MI4
BeauVis (1–7)	3.58	3.55	3.32	2.66
ranked first	17	18	16	2
vibratory (1–7)	2.81	3.68	2.32	3.55

Experiment 2

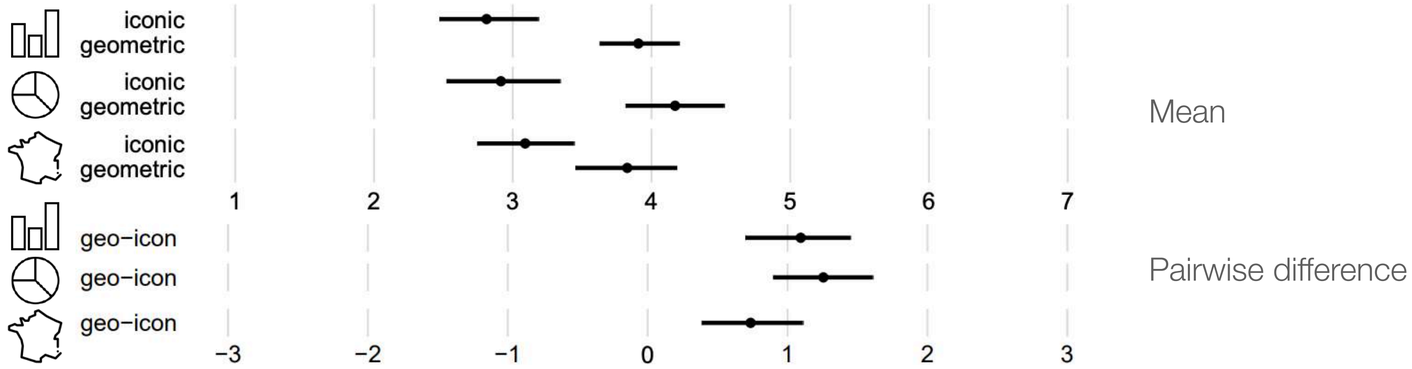
Compare geometric and iconic patterns

Report sample means and pairwise mean differences with 95% CIs

Aesthetics



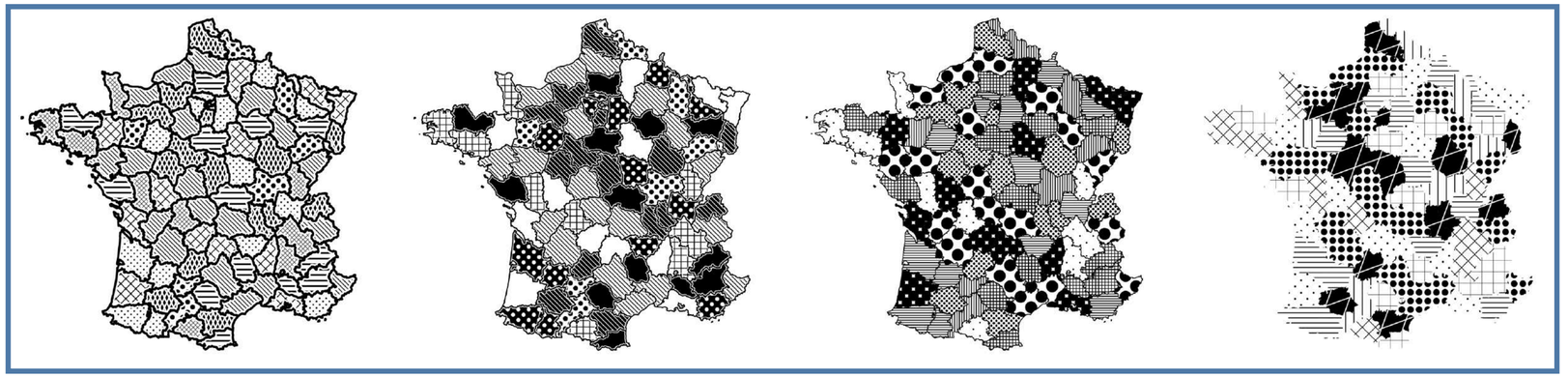
Vibratory effect

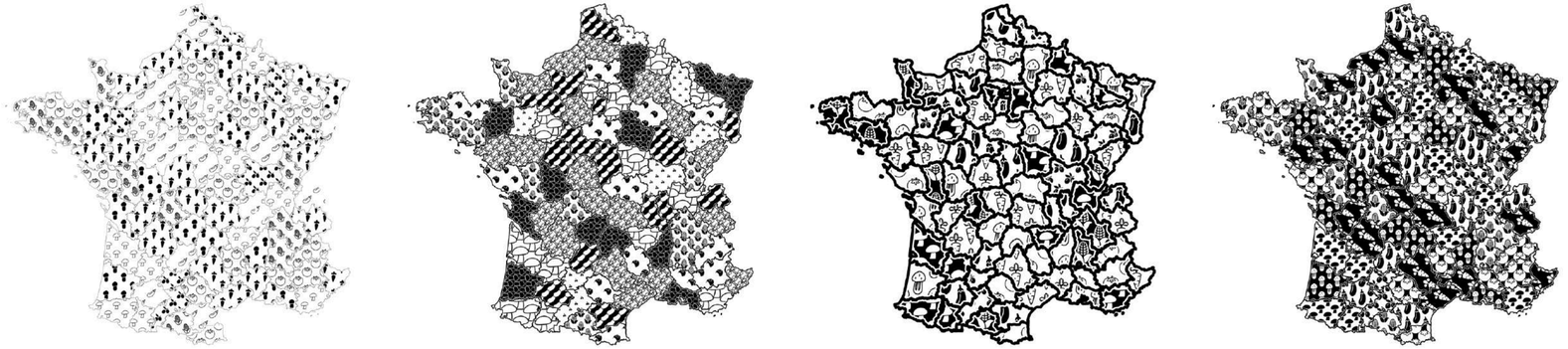


Experiment 2

Compare geometric and iconic textures

Geometric maps were perceived as **more aesthetic** than iconic maps



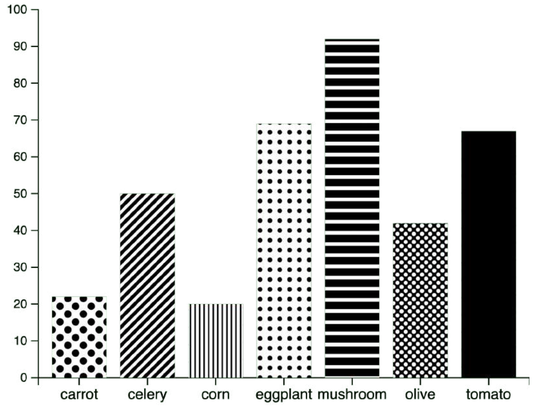


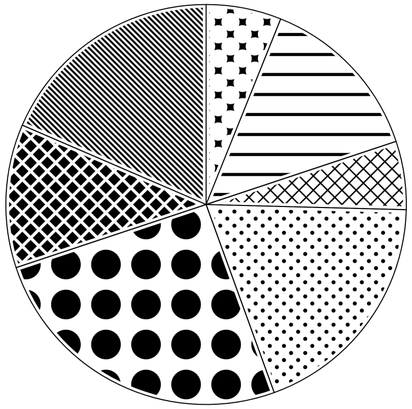
For **bar and pie charts**, there is **no evidence of difference** in aesthetic appeal between geometric and iconic patterns

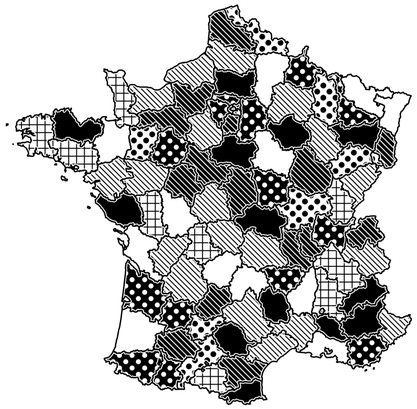
Experiment 2

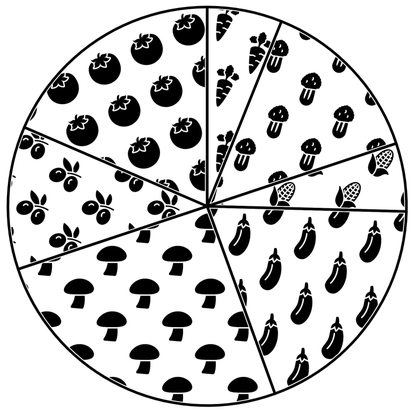
Compare geometric and iconic textures

Iconic patterns were perceived as **having a lower vibratory effect** for **all three chart types**









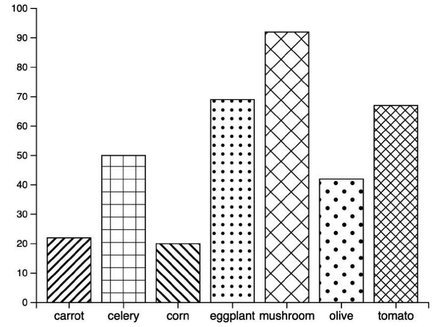
Experiment 3

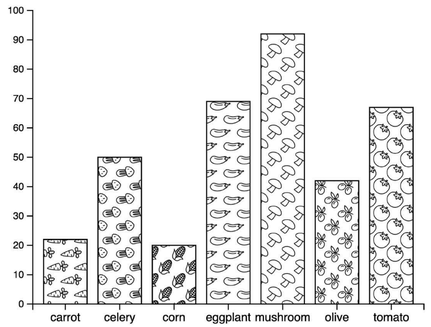
How does the use of patterns affect chart reading?

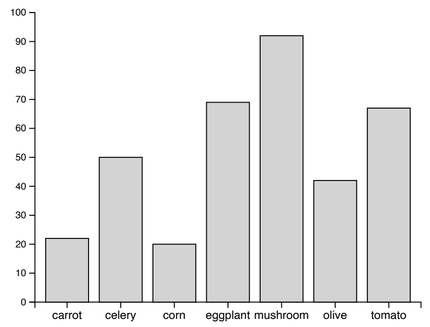
Experiment 3

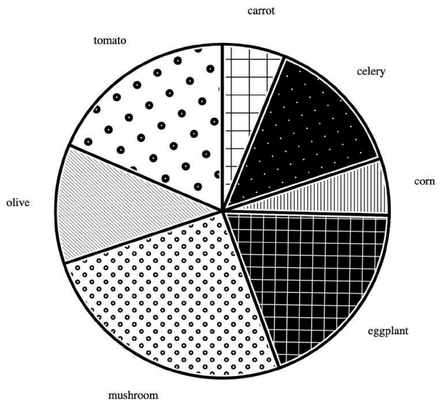
Stimuli

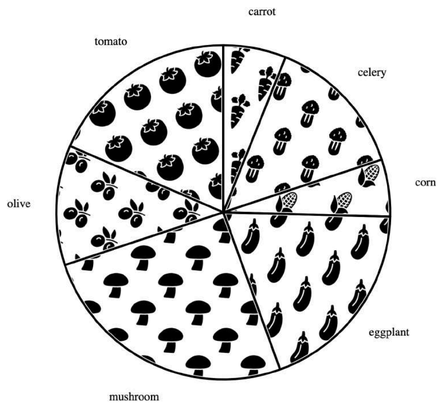
- Top-rated geometric and iconic patterns for bar and pie charts
- A unicolor fill as a baseline

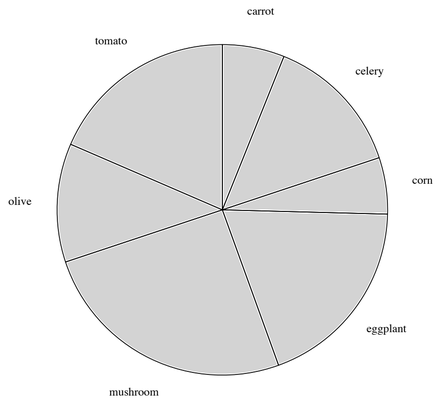










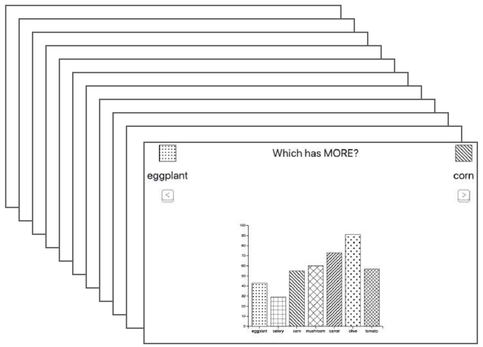


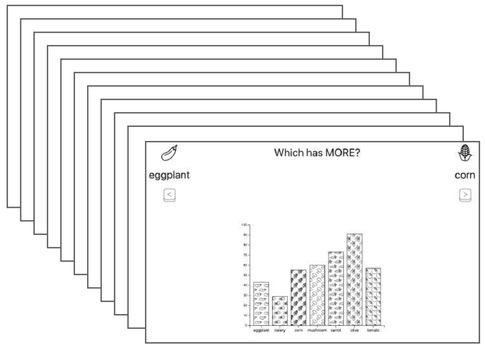
Experiment 3

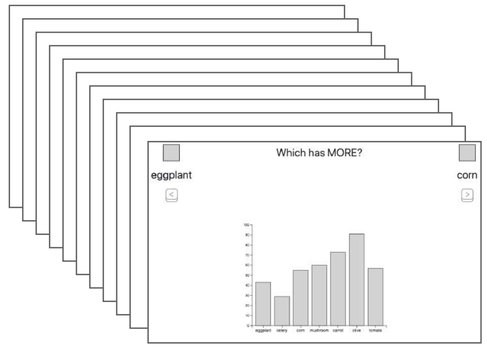
Experiment design

- 150 participants
- 60 trials per participant: 2 question types * 3 fill types * 10 datasets

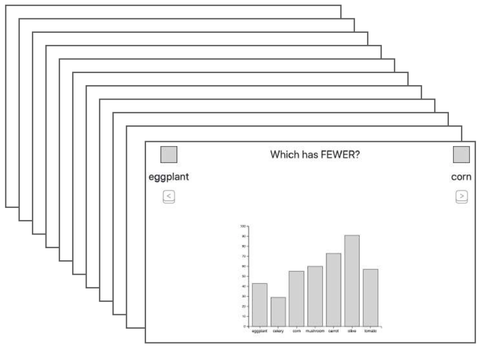
Which has MORE?

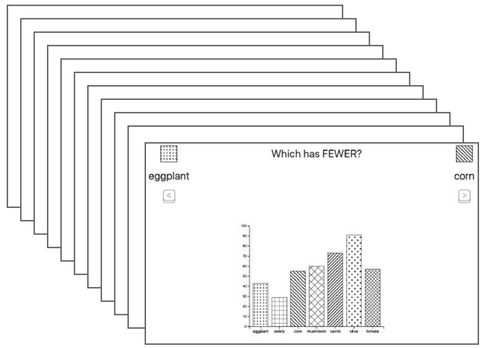


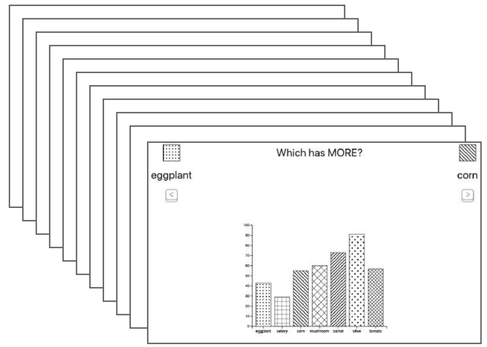




Which has FEWER?







carrot

Which has MORE?

olive

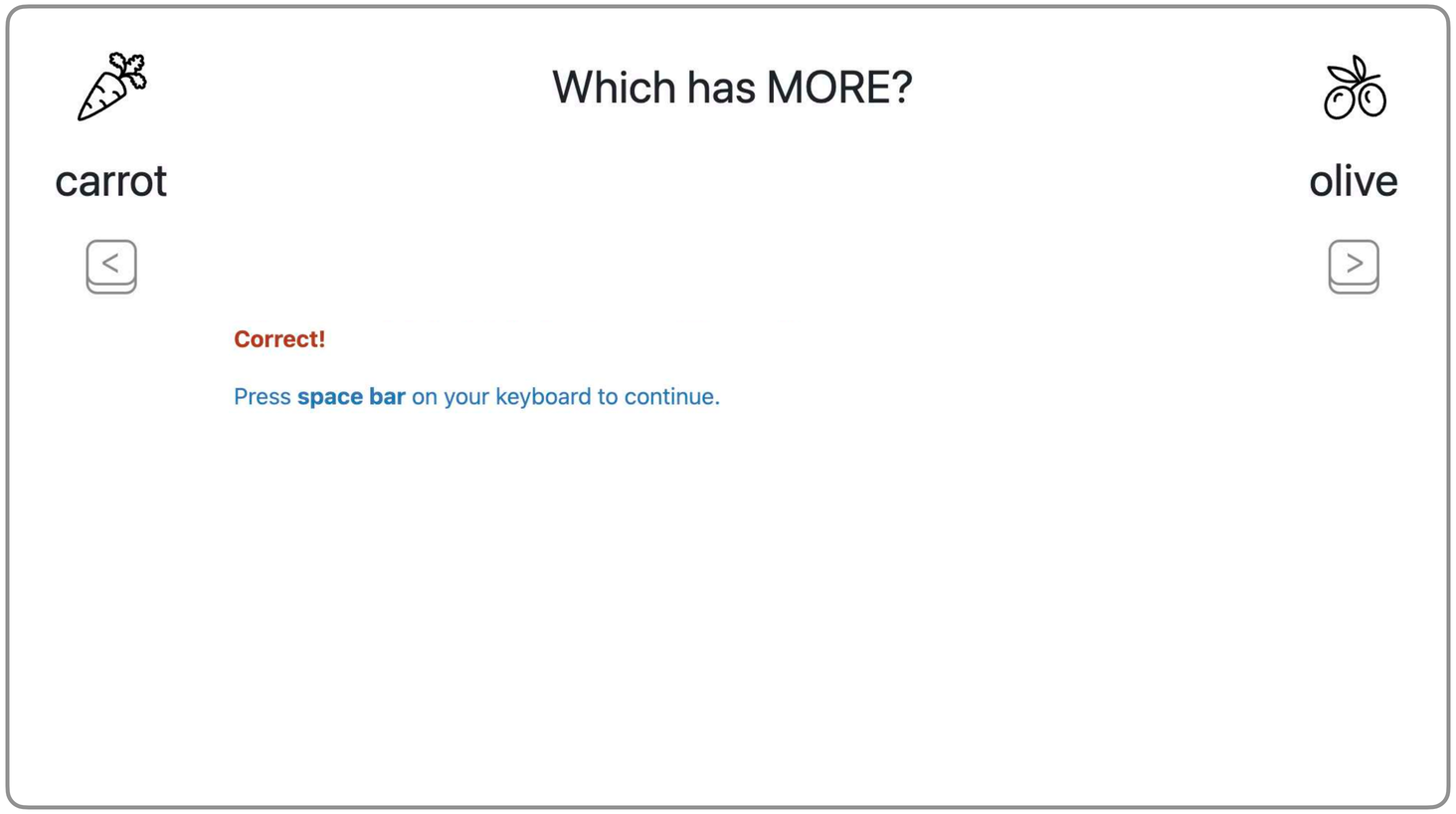
Take a moment to look at the two items and the question

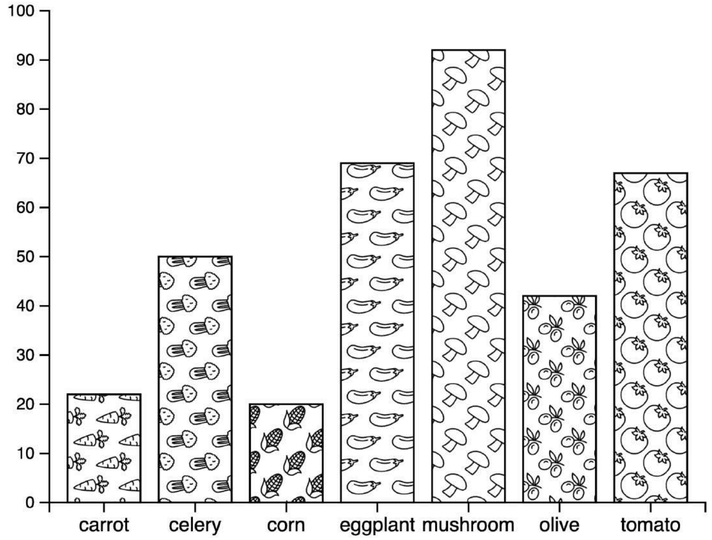
Put your fingers on the **left**  **and right**  **arrow keys** of your keyboard to prepare

Then press **space bar** on your keyboard to see the chart.

The charts will only appear **briefly**. So make sure you're ready...

The chart will only be displayed for 5 seconds

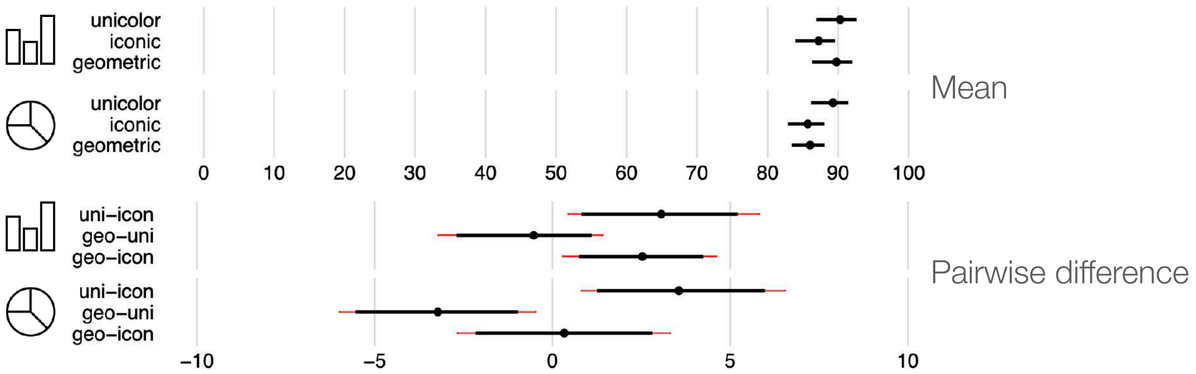

Which has MORE?
carrot
olive
<
>
Correct!
Press space bar on your keyboard to continue.



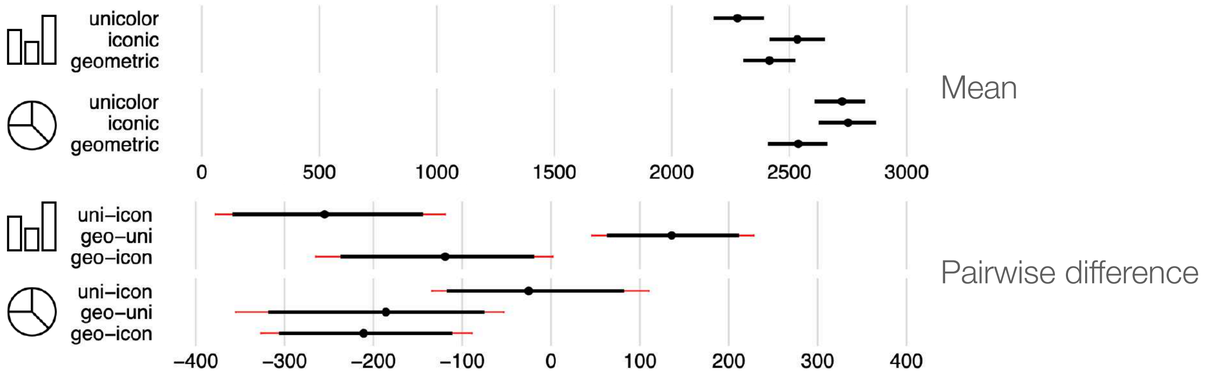
To what extent do you agree or disagree with the following statement: This visualization is ___.

	Strongly disagree	Disagree	Slightly disagree	Neutral	Slightly agree	Agree	Strongly agree
enjoyable	○	○	○	○	○	○	○
pleasing	○	○	○	○	○	○	○
likable	○	○	○	○	○	○	○
nice	○	○	○	○	○	○	○
appealing	○	○	○	○	○	○	○
readable	○	○	○	○	○	○	○

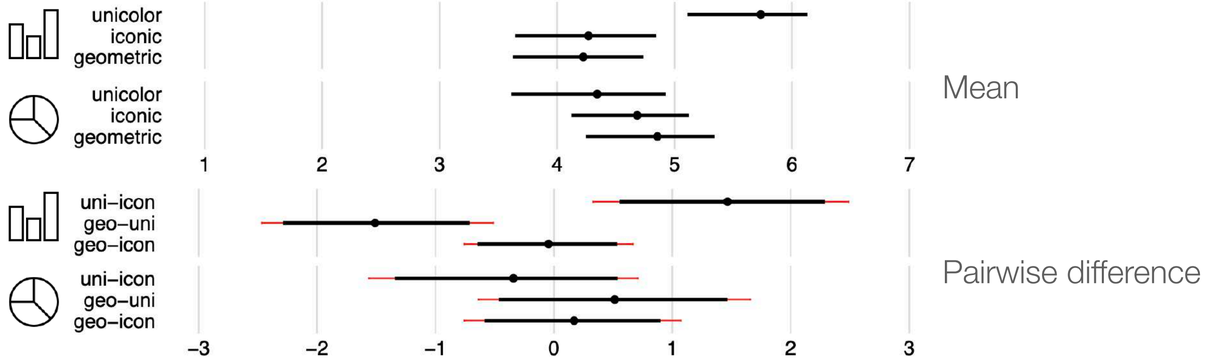
Correct rate



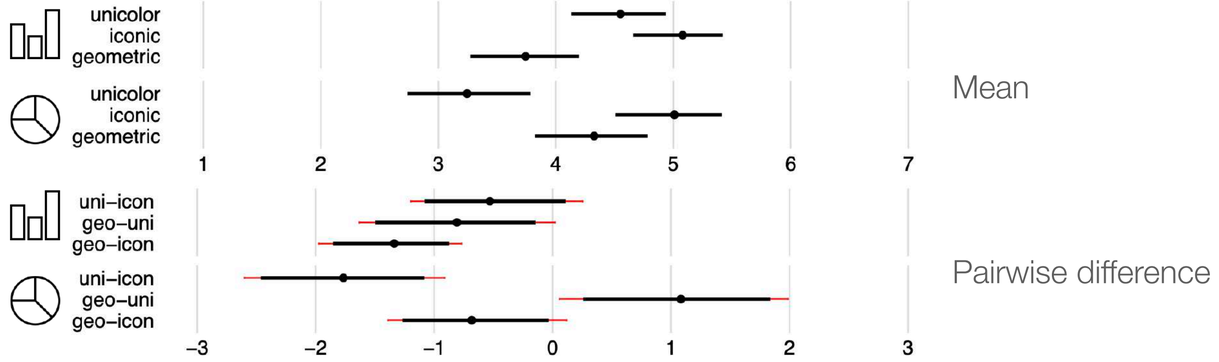
Response time



Readability score



Aesthetics: BeauVis score



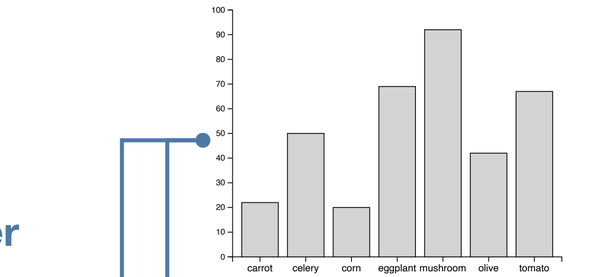
Correct rate

- only included participants with ≥ 90% accuracy (45x Bar, 41x Pie) in the subsequent analysis
- minimize the effect of random guesses

Experiment 3: Results

Response time

We only counted the **correct trials**

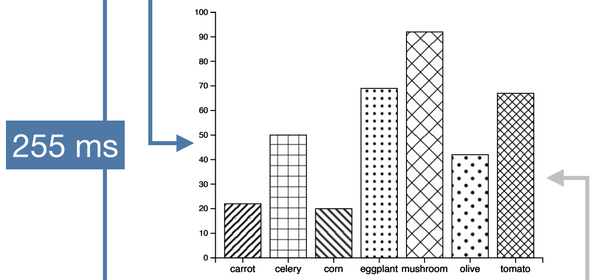


Mean

2279 ms

Faster

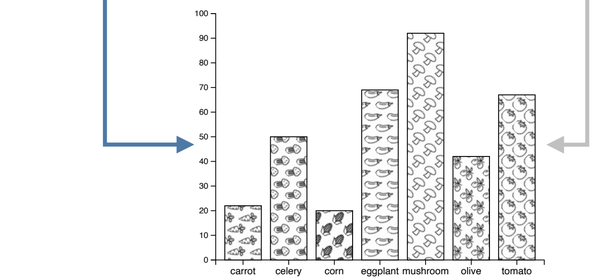
136 ms



2415 ms

255 ms

No difference

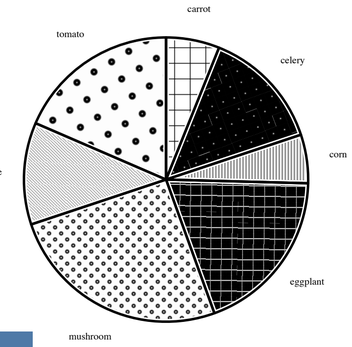


2534 ms

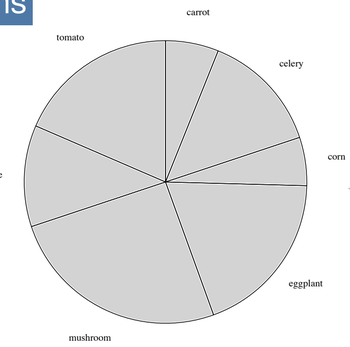
Mean

2539 ms

Faster



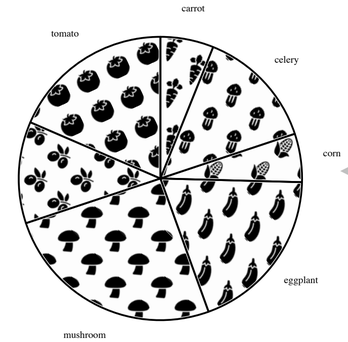
186 ms



2725 ms

211 ms

No difference

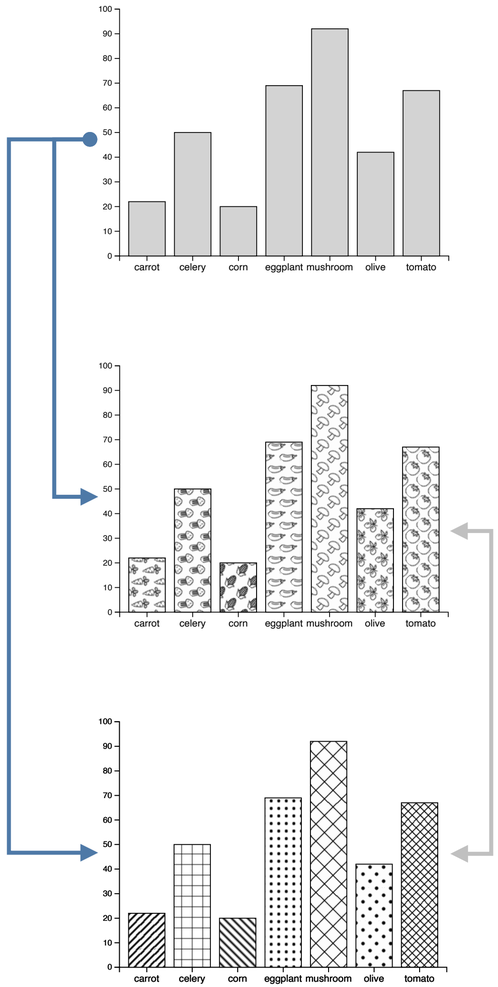


2750 ms

Experiment 3: Results

Readability

More readable



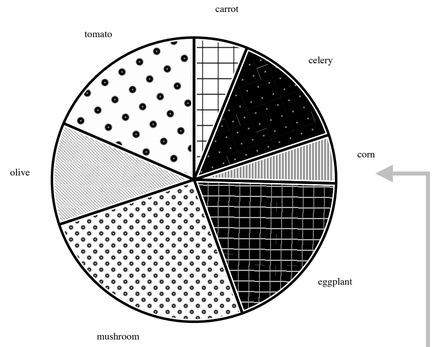
Mean

5.7

4.3

No difference

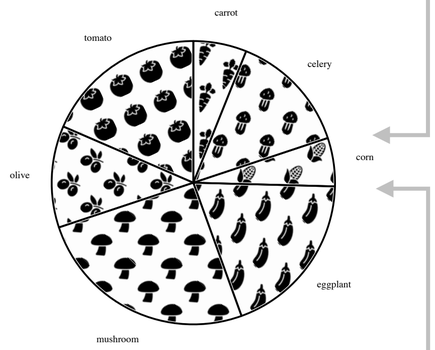
4.2



Mean

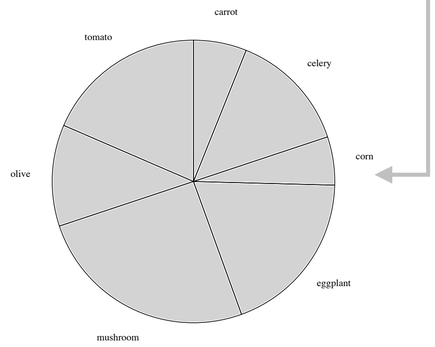
4.9

No difference



4.7

No difference

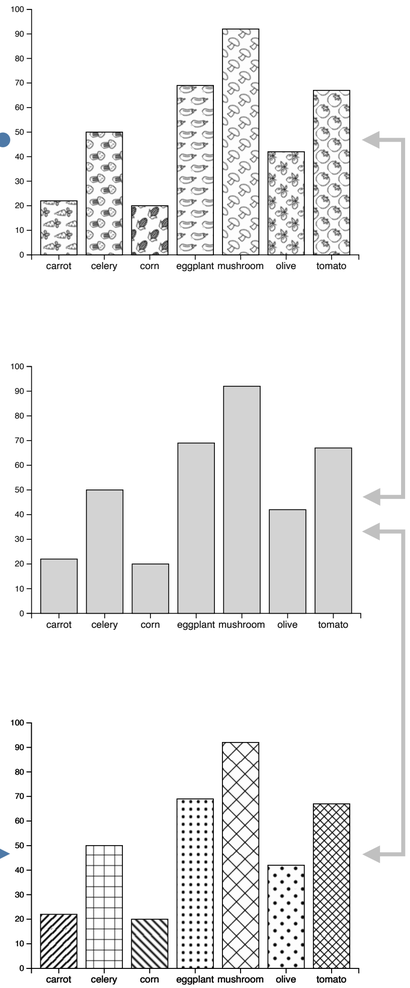


4.3

Experiment 3: Results

Aesthetics

More aesthetic



Mean

5.1

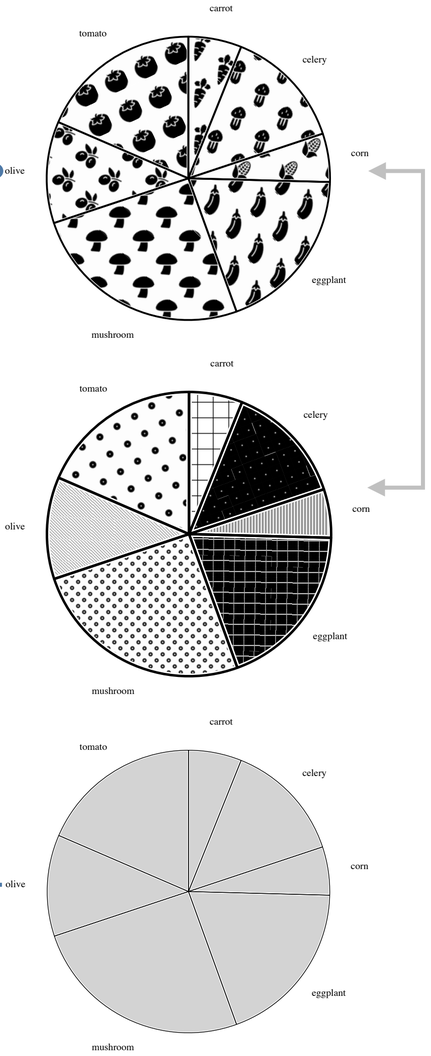
No difference

4.6

No difference

3.7

More aesthetic



Mean

5.0

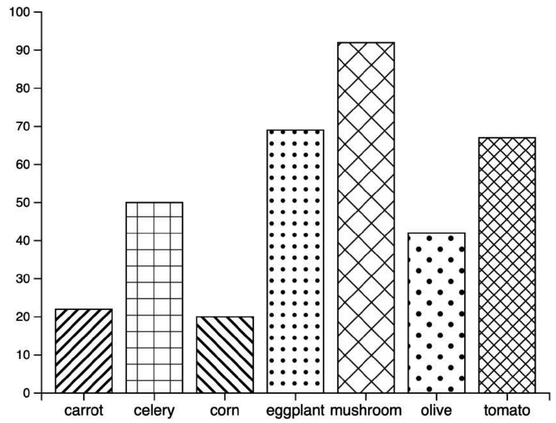
No difference

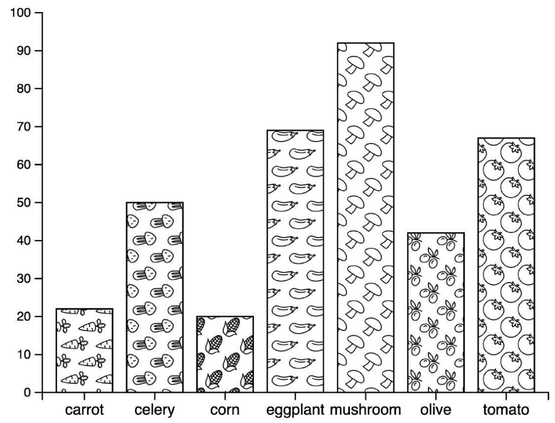
4.3

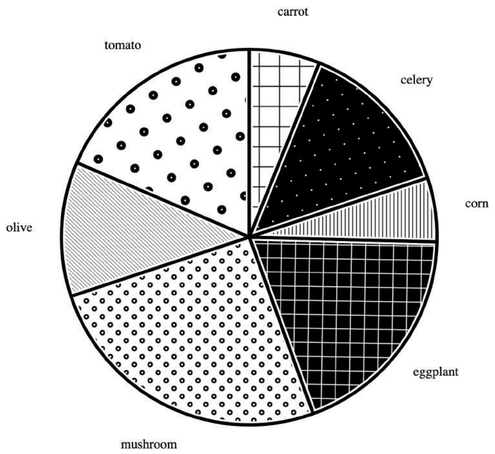
3.2

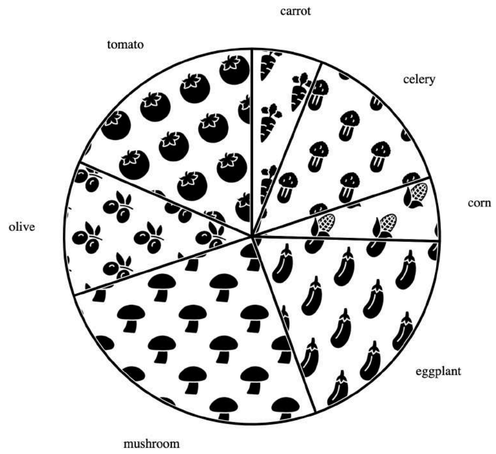
Conclusion

- Differences exist, but they are minor: Pattern is a viable option
- The appeal of patterns in visualization may be subjective: Recommend using patterns for specific aesthetic preferences or particular requirements





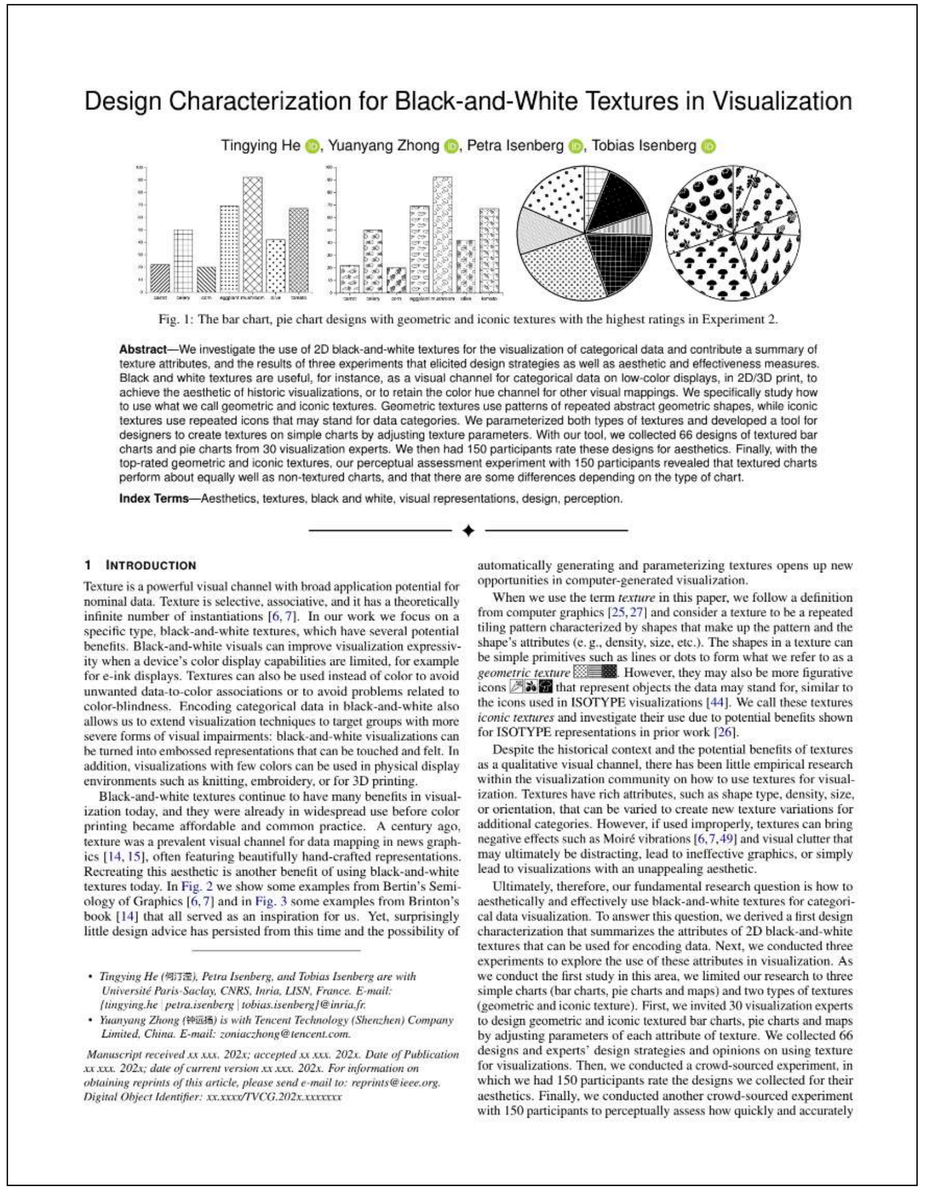




VIS 2023




Tingying He, Yuanyang Zhong, Petra Isenberg, and Tobias Isenberg. Design Characterization for Black-and-White Textures in Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 30(1):1019–1029, January 2024. DOI: 10.1109/TVCG.2023.3326941.



Design Characterization for Black-and-White Textures in Visualization

Tingying He, Yuanyang Zhong, Petra Isenberg, Tobias Isenberg

Fig. 1: The bar chart, pie chart designs with geometric and iconic textures with the highest ratings in Experiment 2.

Abstract—We investigate the use of 2D black-and-white textures for the visualization of categorical data and contribute a summary of texture attributes, and the results of three experiments that elicited design strategies as well as aesthetic and effectiveness measures. Black and white textures are useful, for instance, as a visual channel for categorical data on low-color displays, in 2D/3D print, to achieve the aesthetic of historic visualizations, or to retain the color hue channel for other visual mappings. We specifically study how to use what we call geometric and iconic textures. Geometric textures use patterns of repeated abstract geometric shapes, while iconic textures use repeated icons that may stand for data categories. We parameterized both types of textures and developed a tool for designers to create textures on simple charts by adjusting texture parameters. With our tool, we collected 66 designs of textured bar charts and pie charts from 30 visualization experts. We then had 150 participants rate these designs for aesthetics. Finally, with the top-rated geometric and iconic textures, our perceptual assessment experiment with 150 participants revealed that textured charts perform about equally well as non-textured charts, and that there are some differences depending on the type of chart.

Index Terms—Aesthetics, textures, black and white, visual representations, design, perception.

1 Introduction

Texture is a powerful visual channel with broad application potential for nominal data. Texture is selective, associative, and it has a theoretically infinite number of instantiations [6, 7]. In our work we focus on a specific type, black-and-white textures, which have several potential benefits. Black-and-white visuals can improve visualization expressivity when a device's color display capabilities are limited, for example for e-ink displays. Textures can also be used instead of color to avoid unwanted data-to-color associations or to avoid problems related to color-blindness. Encoding categorical data in black-and-white also allows us to extend visualization techniques to target groups with more severe forms of visual impairments: black-and-white visualizations can be turned into embossed representations that can be touched and felt. In addition, visualizations with few colors can be used in physical display environments such as knitting, embroidery, or for 3D printing.

Black-and-white textures continue to have many benefits in visualization today, and they were already in widespread use before color printing became affordable and common practice. A century ago, texture was a prevalent visual channel for data mapping in news graphics [14, 15], often featuring beautifully hand-crafted representations. Recreating this aesthetic is another benefit of using black-and-white textures today. In Fig. 2 we show some examples from Bertin's Semiology of Graphics [6, 7] and in Fig. 3 some examples from Brinton's book [14] that all served as an inspiration for us. Yet, surprisingly little design advice has persisted from this time and the possibility of automatically generating and parameterizing textures opens up new opportunities in computer-generated visualization.

When we use the term *texture* in this paper, we follow a definition from computer graphics [25, 27] and consider a texture to be a repeated tiling pattern characterized by shapes that make up the pattern and the shape's attributes (e. g., density, size, etc.). The shapes in a texture can be simple primitives such as lines or dots to form what we refer to as a *geometric texture*. However, they may also be more figurative icons that represent objects the data may stand for, similar to the icons used in ISOTYPE visualizations [44]. We call these textures *iconic textures* and investigate their use due to potential benefits shown for ISOTYPE representations in prior work [26].

Despite the historical context and the potential benefits of textures as a qualitative visual channel, there has been little empirical research within the visualization community on how to use textures for visualization. Textures have rich attributes, such as shape type, density, size, or orientation, that can be varied to create new texture variations for additional categories. However, if used improperly, textures can bring negative effects such as Moiré vibrations [6, 7, 49] and visual clutter that may ultimately be distracting, lead to ineffective graphics, or simply lead to visualizations with an unappealing aesthetic.

Ultimately, therefore, our fundamental research question is how to aesthetically and effectively use black-and-white textures for categorical data visualization. To answer this question, we derived a first design characterization that summarizes the attributes of 2D black-and-white textures that can be used for encoding data. Next, we conducted three experiments to explore the use of these attributes in visualization. As we conduct the first study in this area, we limited our research to three simple charts (bar charts, pie charts and maps) and two types of textures (geometric and iconic texture). First, we invited 30 visualization experts to design geometric and iconic textured bar charts, pie charts and maps by adjusting parameters of each attribute of texture. We collected 66 designs and experts' design strategies and opinions on using texture for visualizations. Then, we conducted a crowd-sourced experiment, in which we had 150 participants rate the designs we collected for their aesthetics. Finally, we conducted another crowd-sourced experiment with 150 participants to perceptually assess how quickly and accurately

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Scale Development

How can we measure the aesthetic pleasure of visual data representations?

aesthetics

aesthetic pleasure

aesthetics pleasure

a pleasurable subjective experience that is directed toward an object and not mediated by intervening reasoning. [Reber et al., 2004]

aesthetics pleasure

a pleasurable subjective experience that is directed toward an object and not mediated by intervening reasoning. [Reber et al., 2004]

- focuses on a visualization's visual appeal or beauty
- not related to how understandable, informative, or memorable it is

aesthetic pleasure

an important aspect of visualization

- affects usability and effectiveness
  [Cawthon & Vande Moere, 2007; Healey & Enns, 2022]
- has the potential to communicate
  [Brath et al., 2005]
- and to engage viewers
  [Bach et al., 2013; Tateosian et al., 2007]
- has been identified as one of the heuristics of some subfields, e.g., ambient visualization
  [Mankoff et al., 2003]

How to **measure** aesthetic pleasure?

Rating scales

A **Rating scale** measuring the aesthetic pleasure of websites [Lavie & Tractinsky, 2003]

Construct

Factor(s)

To what extent do you agree or disagree or disagree with the following statements: The website has a/an ____ .

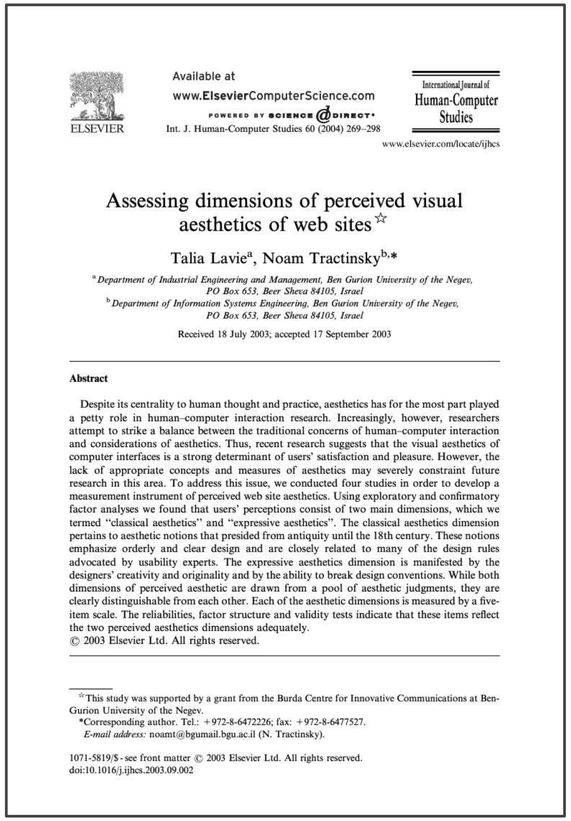
Strongly disagree — Strongly agree

Rating items

Factor 1: Classic aesthetics	**aesthetic design**
	pleasant design
	clear design
	clean design
	symmetric design
Factor 2: Expressive aesthetics	**creative design**
	fascinating design
	use of special effects
	original design
	sophisticated design

Scales for measuring the aesthetic pleasure of …

websites



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International Journal of Human-Computer Studies
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Assessing dimensions of perceived visual aesthetics of web sites ☆

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Abstract

Despite its centrality to human thought and practice, aesthetics has for the most part played a petty role in human–computer interaction research. Increasingly, however, researchers attempt to strike a balance between the traditional concerns of human–computer interaction and considerations of aesthetics. Thus, recent research suggests that the visual aesthetics of computer interfaces is a strong determinant of users' satisfaction and pleasure. However, the lack of appropriate concepts and measures of aesthetics may severely constraint future research in this area. To address this issue, we conducted four studies in order to develop a measurement instrument of perceived web site aesthetics. Using exploratory and confirmatory factor analyses we found that users' perceptions consist of two main dimensions, which we termed "classical aesthetics" and "expressive aesthetics". The classical aesthetics dimension pertains to aesthetic notions that presided from antiquity until the 18th century. These notions emphasize orderly and clear design and are closely related to many of the design rules advocated by usability experts. The expressive aesthetics dimension is manifested by the designers' creativity and originality and by the ability to break design conventions. While both dimensions of perceived aesthetic are drawn from a pool of aesthetic judgments, they are clearly distinguishable from each other. Each of the aesthetic dimensions is measured by a five-item scale. The reliabilities, factor structure and validity tests indicate that these items reflect the two perceived aesthetics dimensions adequately.

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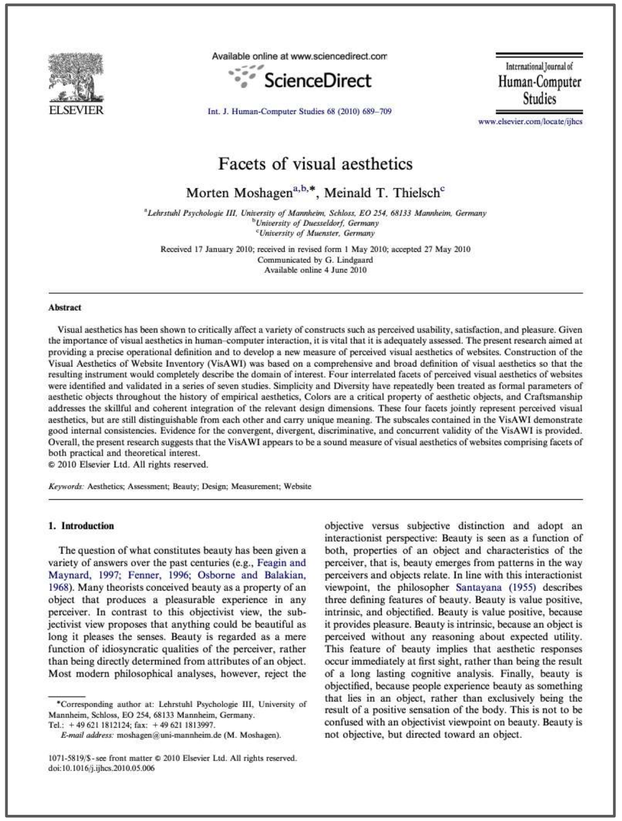
doi:10.1016/j.ijhcs.2003.09.002

[Lavie & Tractinsky, 2003]

websites



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Facets of visual aesthetics

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Abstract

Visual aesthetics has been shown to critically affect a variety of constructs such as perceived usability, satisfaction, and pleasure. Given the importance of visual aesthetics in human–computer interaction, it is vital that it is adequately assessed. The present research aimed at providing a precise operational definition and to develop a new measure of perceived visual aesthetics of websites. Construction of the Visual Aesthetics of Website Inventory (VisAWI) was based on a comprehensive and broad definition of visual aesthetics so that the resulting instrument would completely describe the domain of interest. Four interrelated facets of perceived visual aesthetics of websites were identified and validated in a series of seven studies. Simplicity and Diversity have repeatedly been treated as formal parameters of aesthetic objects throughout the history of empirical aesthetics, Colors are a critical property of aesthetic objects, and Craftsmanship addresses the skillful and coherent integration of the relevant design dimensions. These four facets jointly represent perceived visual aesthetics, but are still distinguishable from each other and carry unique meaning. The subscales contained in the VisAWI demonstrate good internal consistencies. Evidence for the convergent, divergent, discriminative, and concurrent validity of the VisAWI is provided. Overall, the present research suggests that the VisAWI appears to be a sound measure of visual aesthetics of websites comprising facets of both practical and theoretical interest.

Keywords: Aesthetics; Assessment; Beauty; Design; Measurement; Website

1. Introduction

The question of what constitutes beauty has been given a variety of answers over the past centuries (e.g., Feagin and Maynard, 1997; Fenner, 1996; Osborne and Balakian, 1968). Many theorists conceived beauty as a property of an object that produces a pleasurable experience in any perceiver. In contrast to this objectivist view, the subjectivist view proposes that anything could be beautiful as long it pleases the senses. Beauty is regarded as a mere function of idiosyncratic qualities of the perceiver, rather than being directly determined from attributes of an object. Most modern philosophical analyses, however, reject the objective versus subjective distinction and adopt an interactionist perspective: Beauty is seen as a function of both, properties of an object and characteristics of the perceiver, that is, beauty emerges from patterns in the way perceivers and objects relate. In line with this interactionist viewpoint, the philosopher Santayana (1955) describes three defining features of beauty. Beauty is value positive, intrinsic, and objectified. Beauty is value positive, because it provides pleasure. Beauty is intrinsic, because an object is perceived without any reasoning about expected utility. This feature of beauty implies that aesthetic responses occur immediately at first sight, rather than being the result of a long lasting cognitive analysis. Finally, beauty is objectified, because people experience beauty as something that lies in an object, rather than exclusively being the result of a positive sensation of the body. This is not to be confused with an objectivist viewpoint on beauty. Beauty is not objective, but directed toward an object.

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doi:10.1016/j.ijhcs.2010.05.006

[Moshagen & Thielsch, 2010]

designed artifacts

Psychology of Aesthetics, Creativity, and the Arts
2017, Vol. 11, No. 1, 86–98

1931-3896/17/$12.00 http://dx.doi.org/10.1037/aca0000098

The Aesthetic Pleasure in Design Scale: The Development of a Scale to Measure Aesthetic Pleasure for Designed Artifacts

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There is a lack of consistency regarding the scales used to measure aesthetic pleasure within design. They are often chosen ad hoc or adopted from other research fields without being validated for designed artifacts. Moreover, many scales do not measure aesthetic pleasure in isolation, but instead include its determinants (e.g., novelty). Therefore, we developed a new scale to measure aesthetic pleasure and included scales to measure its known determinants for discriminant validity purposes, which automatically led to validating these determinants as well. In the exploratory phase, we identified highly reliable items representative of aesthetic pleasure and its determinants across product categories. In the validation phase, we confirmed these findings across different countries (Australia, the Netherlands, and Taiwan). The final scale consists of 5 items, "beautiful," "attractive," "pleasing to see," "nice to see," and "like to look at," that together reliably capture the construct of aesthetic pleasure. Several recommendations are formulated regarding the application of this scale in design studies and beyond.

Keywords: aesthetic pleasure, design, scale development, determinants of aesthetic pleasure

Research into aesthetic pleasure or appreciation is often confined to art perception and appreciation (Hekkert, 2014b). Although works of art are—or should we say "were"—often created to delight the perceiver, for beauty purposes, they are clearly not the only "objects" that can be pleasant to look at, listen to, or touch. We can aesthetically appreciate a landscape or a photograph of that same landscape; we find beauty in faces, buildings, and other man-made things; we can even be aesthetically pleased by, and therefore ascribe beauty to, an idea, a chess move, or a scientific proof (Da Silva, Crilly, & Hekkert, 2015). Any object can be aesthetically appreciated, and objects are often deliberately designed to induce aesthetic pleasure (Postrel, 2003). Accordingly, we see an increasing interest in researching aesthetic pleasure derived from everyday objects such as products and websites in design research, consumer research, and human-computer interaction (HCI) research (e.g., Blijlevens, Carbon, Mugge, & Schoormans, 2012; Hassenzahl & Monk, 2010; Hekkert, Snelders, & Van Wieringen, 2003).

While ample research into what people find aesthetically pleasing exists in design, marketing, arts, and psychology literature (e.g., Blijlevens et al., 2012; Bloch, 1995; Hekkert, 2006, 2014a, 2014b; Hekkert et al., 2003; Hoyer & Stokburger-Sauer, 2012; Leder, Belke, Oeberst, & Augustin, 2004; Leder, Ring, & Dressler, 2013; Schoormans & Robben, 1997; Swami, 2013; Veryzer & Hutchinson, 1998) research into how aesthetic pleasure for designed artifacts should actually be defined and subsequently be measured has received little attention. More specifically, in the design field, most research focuses on how certain determinants

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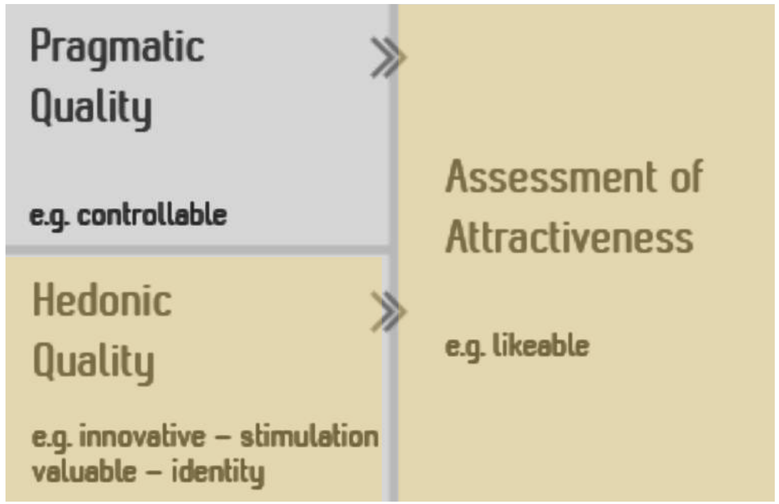
Correspondence concerning this article should be addressed to Janneke Blijlevens, Behavioural Business Lab, School of Economics, Finance and Marketing, Royal Melbourne Institute of Technology University, Building 80, 445 Swanston Street, Melbourne, 3000, Victoria, Australia. E-mail: janneke.blijlevens@rmit.edu.au

[Blijlevens et al., 2017]

AttrakDiff Questionnaire

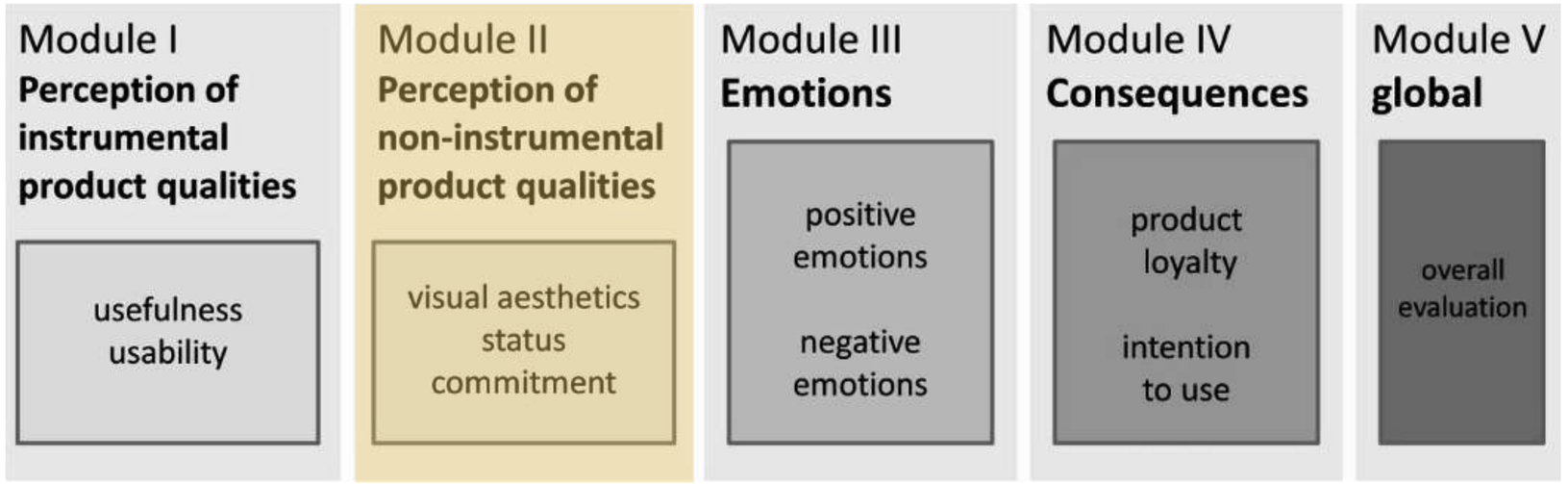


[Hassenzahl et al., 2003]

User Experience Questionnaire (UEQ)

[Schrepp et al., 2017]

meCUE Questionnaire

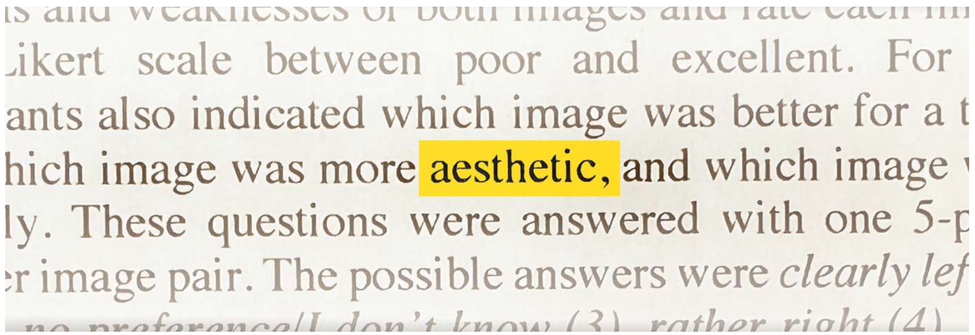


[Minge et al., 2017]

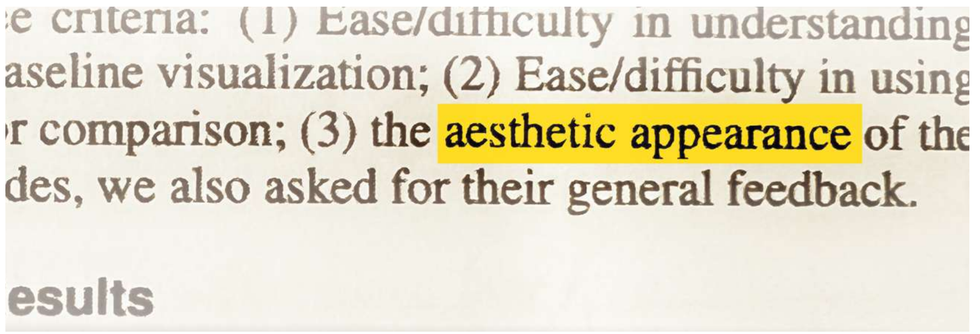
AttrakDiff Questionnaire
[Hassenzahl et al., 2003]

User Experience Questionnaire (UEQ)
[Schrepp et al., 2017]

no validated scale targeted for
measuring aesthetic pleasure of visualizations

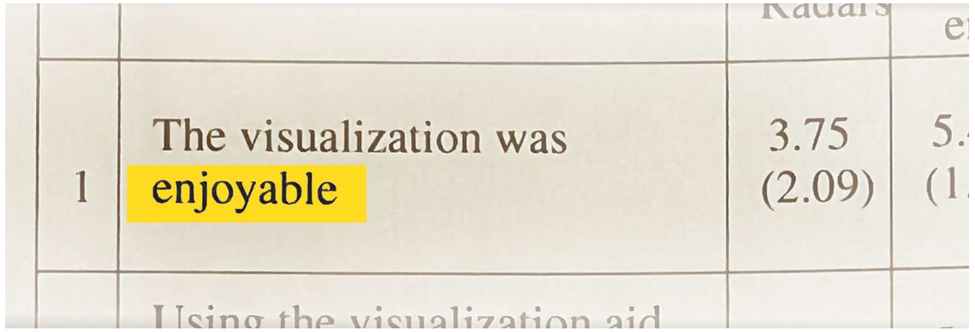

Likert scale between poor and excellent. For
ants also indicated which image was better for a t
hich image was more aesthetic, and which image
ly. These questions were answered with one 5-p
r image pair. The possible answers were *clearly lef*

[Jenny et al., 2021]

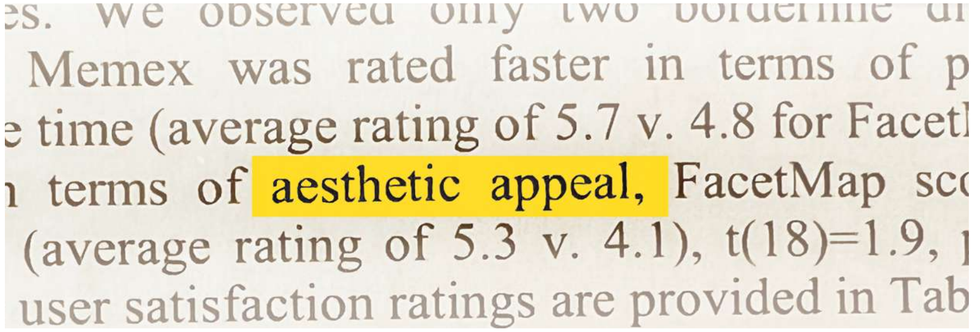

criteria: (1) Ease/difficulty in understanding
aseline visualization; (2) Ease/difficulty in using
r comparison; (3) the aesthetic appearance of the
des, we also asked for their general feedback.

esults

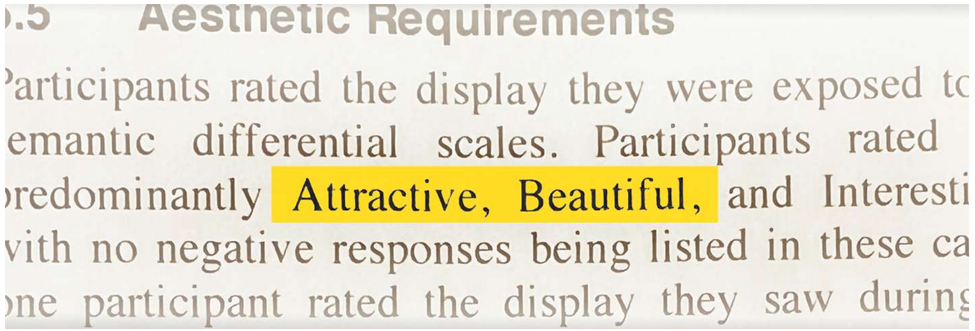
[Chen et al., 2021]


1	The visualization was enjoyable	3.75 (2.09)	5. (1.
	Using the visualization aid		

[Albo et al., 2016]

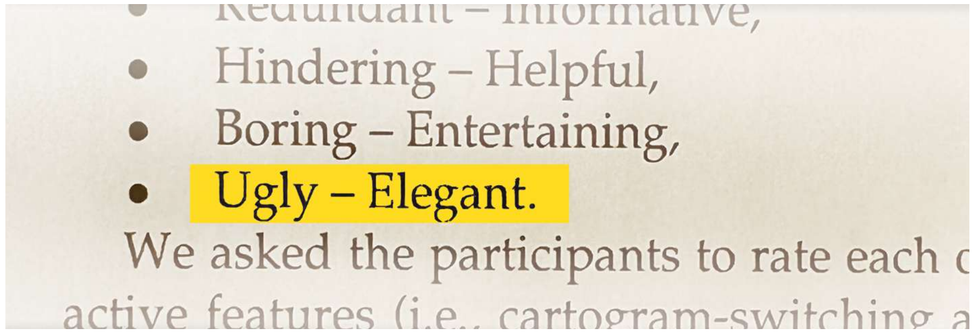

es. We observed only two borderline di
Memex was rated faster in terms of p
e time (average rating of 5.7 v. 4.8 for Facetl
n terms of aesthetic appeal, FacetMap sc
(average rating of 5.3 v. 4.1), t(18)=1.9,
user satisfaction ratings are provided in Tab

[Smith et al., 2006]


.5 Aesthetic Requirements

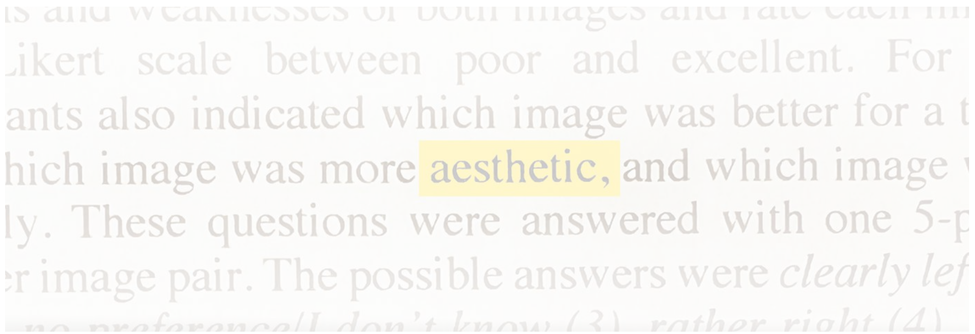
Participants rated the display they were exposed to
emantic differential scales. Participants rated
predominantly Attractive, Beautiful, and Interesti
vith no negative responses being listed in these ca
ne participant rated the display they saw during

[Rodgers and Bartram, 2011]

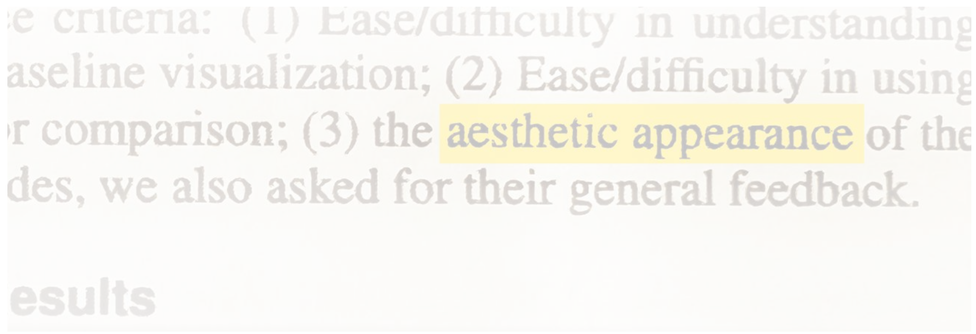

- Redundant – Informative,
- Hindering – Helpful,
- Boring – Entertaining,
- Ugly – Elegant.

We asked the participants to rate each
active features (i.e., cartogram-switching a

[Duncan et al., 2021]


Likert scale between poor and excellent. For
ants also indicated which image was better for a t
hich image was more aesthetic, and which image
ly. These questions were answered with one 5-p
r image pair. The possible answers were *clearly lef*

[Jenny et al., 2021]


e criteria: (1) Ease/difficulty in understanding
aseline visualization; (2) Ease/difficulty in using
r comparison; (3) the aesthetic appearance of the
des, we also asked for their general feedback.

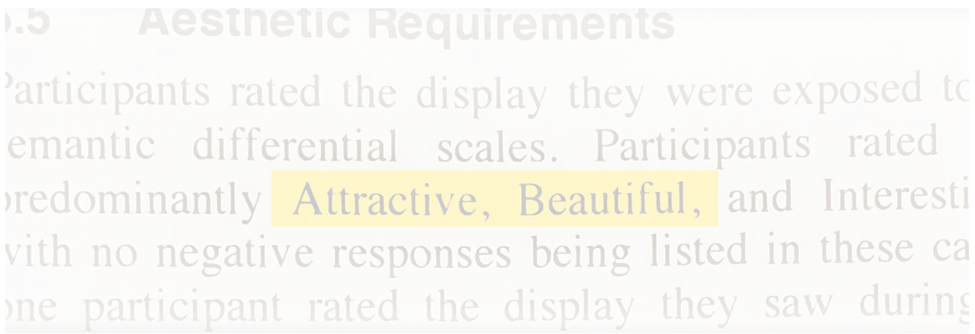
esults

[Chen et al., 2021]

Without validation, not sure about reliability or validity of the scale

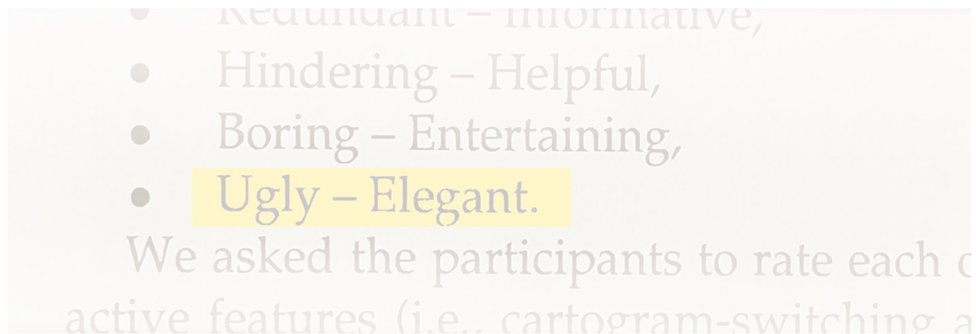
[Albo et al., 2016]

[Smith et al., 2006]


.5 Aesthetic Requirements

Participants rated the display they were exposed to
emantic differential scales. Participants rated
predominantly Attractive, Beautiful, and Interesti
vith no negative responses being listed in these ca
ne participant rated the display they saw during

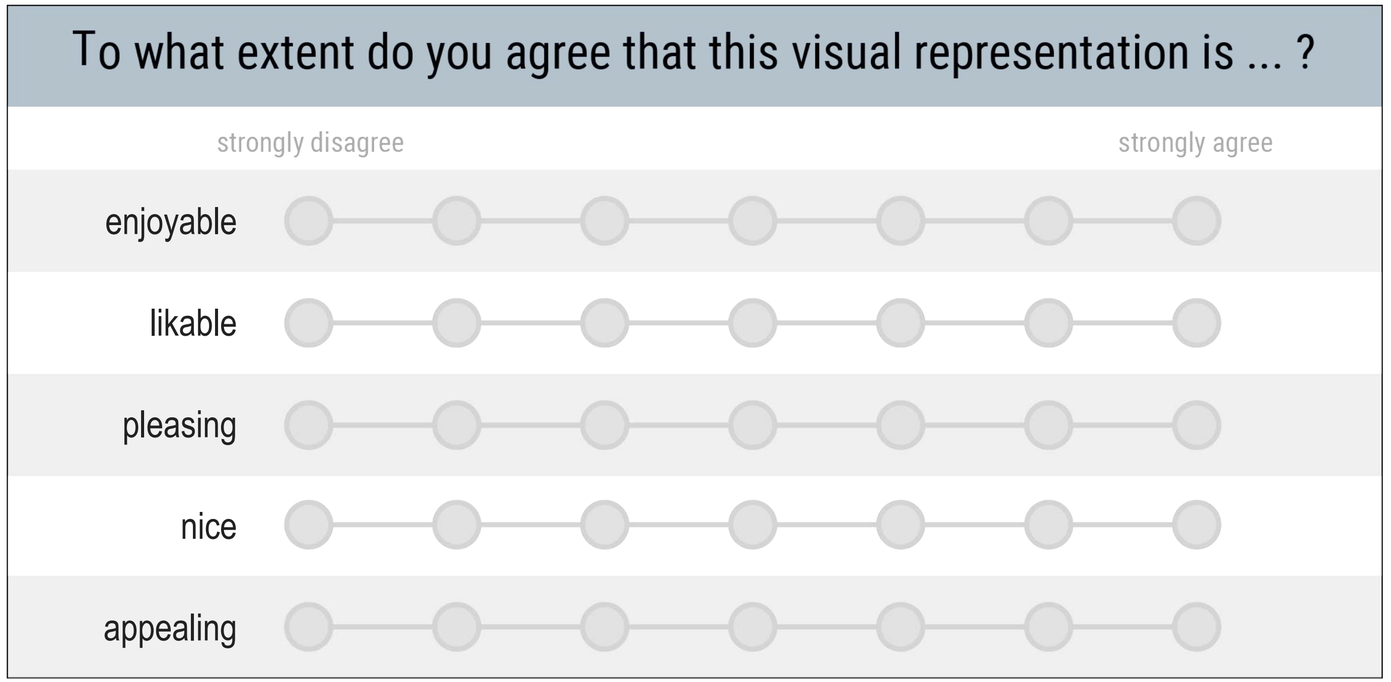
[Rodgers and Bartram, 2011]


- Redundant – Informative,
- Hindering – Helpful,
- Boring – Entertaining,
- Ugly – Elegant.

We asked the participants to rate each
active features (i.e., cartogram-switching a

[Duncan et al., 2021]

BeauVis scale



BeauVis scale in its recommended version

Methods

scale development

Step 1: Term generation → 209 terms

- literature review
- expert suggestion

Step 2: Term filtering → 31 Terms

- filtering on occurrence and semantics
- expert review

Step 3: Exploratory phase → Final Scale

- crowdsourced experiment
- exploratory factor analysis
- reliability evaluation
  - Cronbach's alpha

scale validation

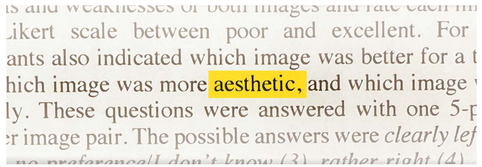
Step 4: Validation phase

- crowdsourced experiment
- confirmatory factor analysis
- reliability evaluation
  - Cronbach's Alpha
- validity evaluation
  - convergent validity
  - discriminant validity
  - differentiation by known groups

Step 1: Term generation

Literature review: VIS literature

terms from
68 out of 3189 IEEE VIS, TVCG and CG&A papers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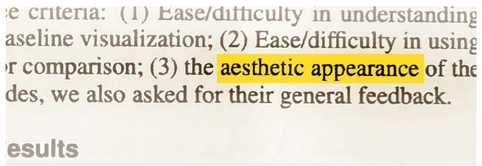
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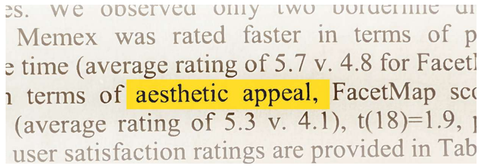
esults

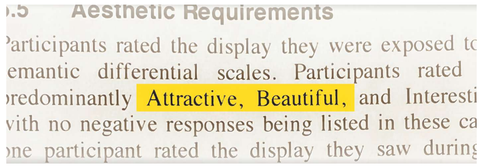
[Chen et al., 2021]


1	The visualization was enjoyable	3.75 (2.09)	5. (1

[Albo et al., 2016]


es. We observed only two borderline di
Memex was rated faster in terms of p
e time (average rating of 5.7 v. 4.8 for Facetl
n terms of aesthetic appeal, FacetMap sc
(average rating of 5.3 v. 4.1), t(18)=1.9,
user satisfaction ratings are provided in Tab

[Smith et al., 2006]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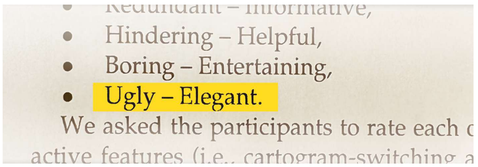
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- Boring – Entertaining,
- Ugly – Elegant.

We asked the participants to rate each
active features (i.e., cartogram-switching a

[Duncan et al., 2021]

...

spreadsheet for collecting terms

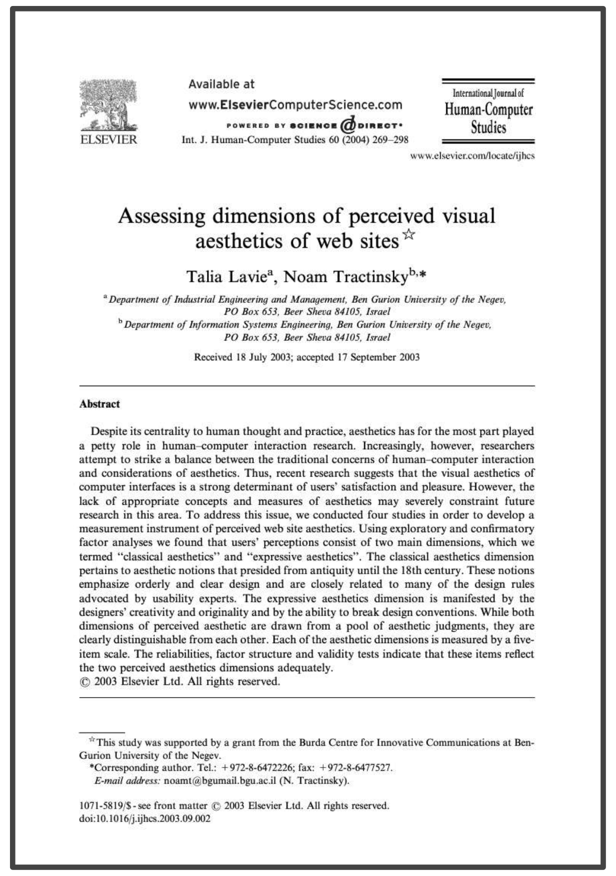
journal	title	doi link	filename	searchterm	likert term	adjective: To what extent do you agree that this visualization is ...	likert term context	whether I saw the whole questionnaire(source code) only papers I found relevent now.	excluded term	participant feedback	participant feedback context	path
TVCG	Evaluating Cartogram Effectiveness	https://doi.org/10.1109/TVCG.2016.2642109	07792176.pdf	likert;aesthetic;	??? (5-point: entertaining ... boring); ??? (5-point: elegant ... drab); ??? (5-point: innovative ... conventional);???(5-point;easy to understand);???(5-point;showing magnitude clearly...poorly)	entertaining;boring;elegant;drab;innovative;conventional;understandable;clear;	cartograms;		helpful/hindering;interested to use later;			
VIS	Chartem: Reviving Chart Images with Data Embedding	http://dx.doi.org/10.1109/TVCG.2020.3030351	111100a337	likert;aesthetic;	aesthetic (5-point: high impact on a ... no impact at all on a.);	aesthetic;	how much the embedding patterns on background impact the overall aesthetic of the chart;					../vis-all_full_paper_pdfs-text-extraction-results/InfoVis-2020/111100a337.tei.xml
VIS	FacetMap: A Scalable Search and Browse Visualization	http://dx.doi.org/10.1109/TVCG.2006.142	06_infovis_smith	questionnaire;aesthetic;	aesthetic appeal (7-point?);	aesthetic;	score the three streamgraphs based on their aesthetic preference and perceived readability;	no	satisfication	like(the bridge metaphor);		../vis-all_full_paper_pdfs-text-extraction-results/InfoVis-2006/06_infovis_smith.tei.xml
VIS	Co-Bridges: Pair-wise Visual Connection and Comparison for Multi-item Data Streams	http://dx.doi.org/10.1109/TVCG.2020.3030411	111100b612	likert;questionnaire;interview;aesthetic;	aesthetic appearance (5-point: nice, more or less nice, neutral, somwhat ugly, ugly);	aesthetic;nice;ugly;	For the aesthetic appearance, the users preferred Co-Bridges more.	no				../vis-all_full_paper_pdfs-text-extraction-results/Vast-2020/111100b612.tei.xml
VIS	SineStream: Improving the Readability of Streamgraphs by Minimizing Sine Illusion Effects	http://dx.doi.org/10.1109/TVCG.2020.3030404	111100b634	likert;questionnaire;aesthetic;	aesthetic preference (7-point: totally disagree ... neutral ... totally agree);readability (7-point: totally disagree ... neutral ... totally agree);	aesthetic;readable;	streamgraph;					../vis-all_full_paper_pdfs-text-extraction-results/InfoVis-2020/111100b634.tei.xml
VIS	The Influence of Contour on Similarity Perception of Star Glyphs	http://dx.doi.org/10.1109/TVCG.2014.2346426	2251_20tvcg12-fuchs-2346426	likert;questionnaire;aesthetic;	aesthetic preferences(7-point: strongly prefered ...);	aesthetic;						../vis-all_full_paper_pdfs-text-extraction-results/InfoVis-2014/2251_20tvcg12-fuchs-2346426.tei.xml
VIS	Vis4Heritage: Visual Analytics Approach on Grotto Wall Painting Degradations	http://dx.doi.org/10.1109/TVCG.2013.219	13_vast_zhang	questionnaire;aesthetic;	aesthetic;visual design;	aesthetic;well-designed;	tool;					../vis-all_full_paper_pdfs-text-extraction-results/Vast-2013/13_vast_zhang.tei.xml
VIS	Callicipe: Automatic Visual Data Story Generation from a Spreadsheet	http://dx.doi.org/10.1109/TVCG.2020.3030403	111100a453	likert;questionnaire;interview;	aestheticness (5-point: worst ... best);expressiveness (5-point: worst ... best);understandability (5-point: worst ... best);	aesthetic;expressive;understandable;	visualization;			satisfied;nice design;thoughtful design;		../vis-all_full_paper_pdfs-text-extraction-results/InfoVis-2020/111100a453.tei.xml
VIS	Vismate: Interactive Visual Analysis of Station-Based Observation Data on Climate Changes	http://dx.doi.org/10.1109/VAST.2014.7042489	li	questionnaire;aesthetic;	aesthetics (11-point: 0 ... 10);visual design (11-point: 0 ... 10);	aesthetic;well-designed;	aesthetics - design of graphical user interface and visualization;visual design - of three views were suitable for analyzing domain tasks;	no				../vis-all_full_paper_pdfs-text-extraction-results/Vast-2014/li.tei.xml
	Augmented Reality Graph	https://doi.org/10.1109/M		questionnaire;a	aesthetics (5-point:	aesthetic;						

Step 1: Term generation

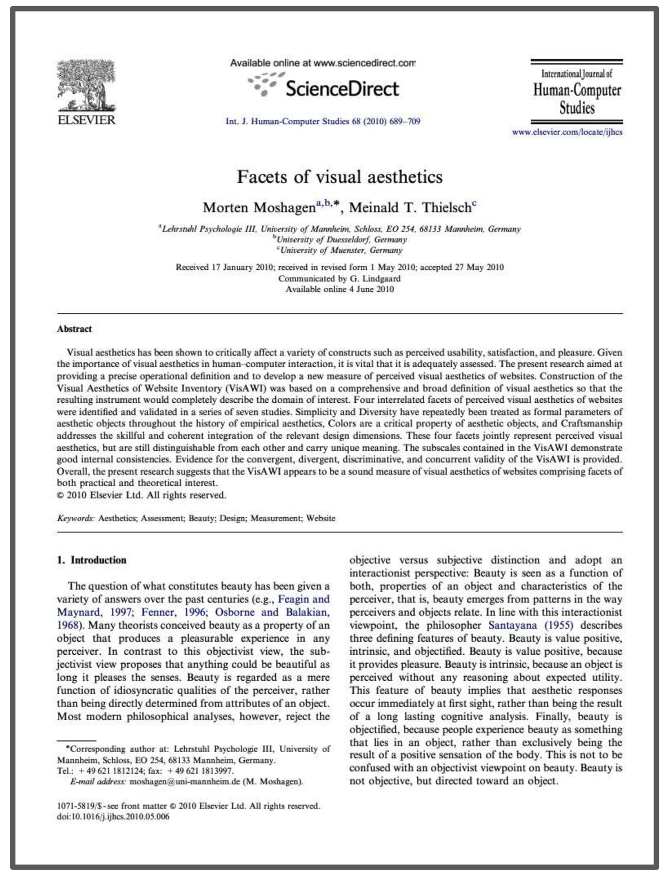
Literature review: Literature from related field

Terms from
4 aesthetics-related scales development papers

Spreadsheet for collecting terms


Assessing dimensions of perceived visual aesthetics of web sites
Talia Lavie, Noam Tractinsky
International Journal of Human-Computer Studies

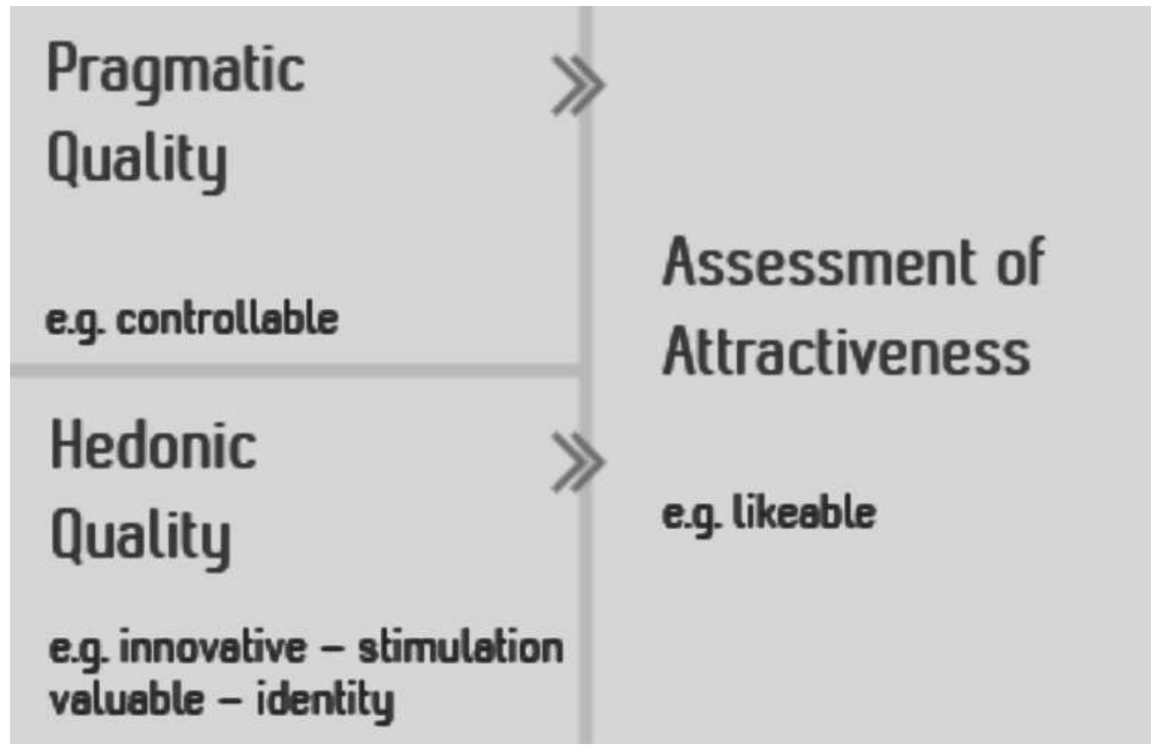
[Lavie & Tractinsky, 2003]


Facets of visual aesthetics
Morten Moshagen, Meinald T. Thielsch
International Journal of Human-Computer Studies

[Moshagen & Thielsch, 2010]


The Aesthetic Pleasure in Design Scale: The Development of a Scale to Measure Aesthetic Pleasure for Designed Artifacts

[Blijlevens et al., 2017]



[Hassenzahl et al., 2003]

	AttrakDiff	Blijlevens, 2017	Lavie, 2003	Moshagen, 2010
aesthetic		aesthetic	aesthetic	
appealing	repelling/appealing	appealing		appealing
attractive	attractive	attractive		attractively positioned;attractive;
balanced				balanced;there are too many elements in o
beautiful		beautiful	beautiful	
clean		clean	clean	
cluttered				
creative	creative	creative	creative	creative
elegant				
harmonious			harmonic	
inviting	inviting	inviting		
modern			modern	modern;contemporary
nice		nice		
organized			organized	pleasantly organized
overloaded			overloaded	overloaded
pretty		pretty		
tasteful			applies good taste	
well-designed		designed	skilfully designed	
artistic			artistic	
boring	dull		dull	boring
delightful		delightful		
engaging				
enjoyable			enjoyable	
entertaining				
exciting		exciting	exciting	
fascinating		fascinating	fascinating	
good	good	good		
color-harmonious				
interesting		interesting		interesting;lacks interesting design details
likable	likable	like		
motivating	motivating	motivating		
pleasing	pleasant	pleasant;pleasurable	pleasing;pleasant	a pleasant effect
professional	professional/unprofessional	professional	professional	professional
provoking				
satisfying				
sophisticated		sophisticated	sophisticated	
lovely				
dynamic		dynamic		dynamic
crowded		density		crowded;too many elements
drab			monotonous	monotonous
high-quality		confers quality		
stylish	stylish			
well-proportioned				well proportioned
informative				
colorful			colorful	colorful;too few colors
eye-catching				

Step 1: Term generation

Expert suggestion

invitation email sent to 57 visualization experts

Subject: Survey Invitation - How to Judge the Aesthetics of Visualizations?

To: [email of an expert in visualization]

Dear [expert's name],

We are currently working on a research project about generating a validated scale for rating the aesthetics of a visualization. An important step in the generation of a scale is to elicit terms from experts. Given your expert status in our domain we would much appreciate it if you could spend 2-3 minutes of your time and fill out our short survey.

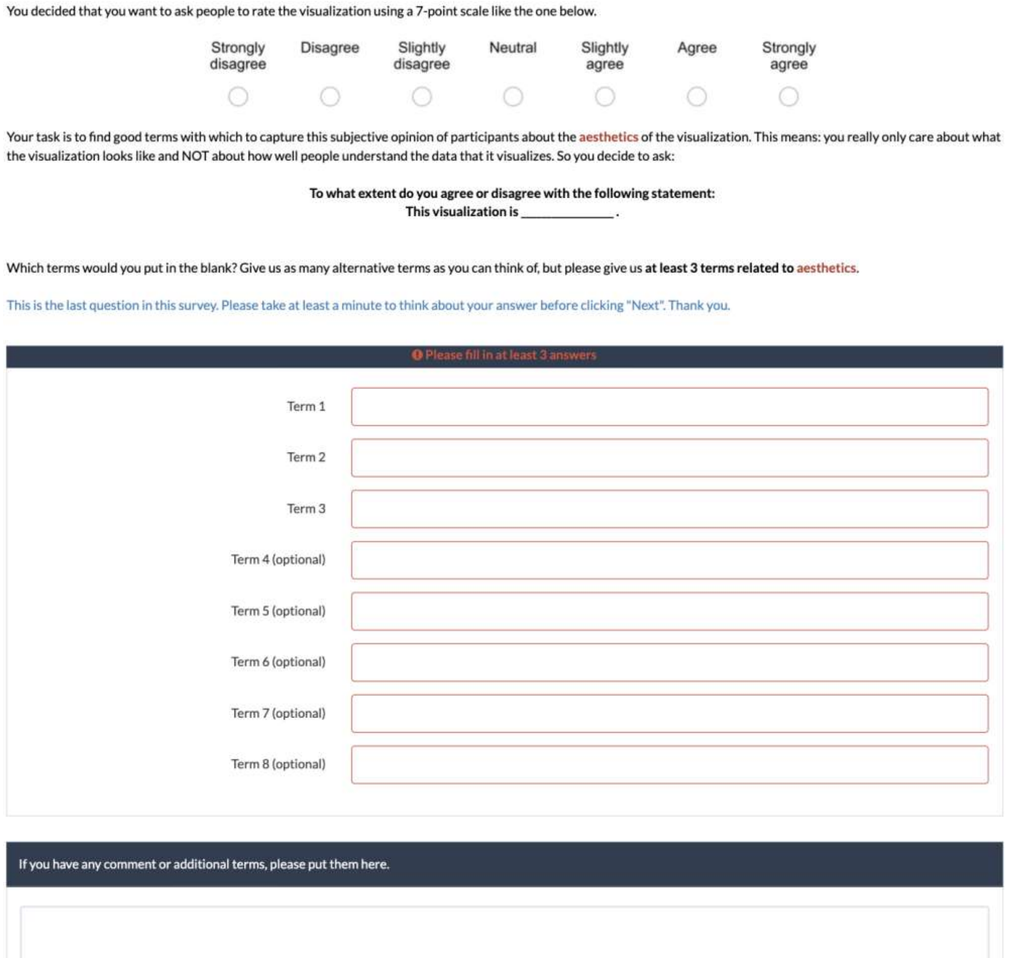
To participate, please access the survey here:[survey link]

Please notice that this study has a two-stage evaluation process. After this survey, we would like to contact you again for a second very short survey.

We thank you a lot in advance and would be happy to share the results of our work with you if you are interested! Just let us know.

Best regards,
Tingying He, Petra Isenberg, Raimund Dachselt, and Tobias Isenberg

survey for collecting terms (31 responses)



You decided that you want to ask people to rate the visualization using a 7-point scale like the one below.

Strongly disagree | Disagree | Slightly disagree | Neutral | Slightly agree | Agree | Strongly agree

Your task is to find good terms with which to capture this subjective opinion of participants about the aesthetics of the visualization. This means: you really only care about what the visualization looks like and NOT about how well people understand the data that it visualizes. So you decide to ask:

To what extent do you agree or disagree with the following statement:
This visualization is _____.

Which terms would you put in the blank? Give us as many alternative terms as you can think of, but please give us **at least 3 terms related to** aesthetics.

This is the last question in this survey. Please take at least a minute to think about your answer before clicking "Next". Thank you.

Please fill in at least 3 answers

Term 1
Term 2
Term 3
Term 4 (optional)
Term 5 (optional)
Term 6 (optional)
Term 7 (optional)
Term 8 (optional)

If you have any comment or additional terms, please put them here.

Step 1: Term generation

209 terms

aesthetic	emotion	cognitive	data-aesthetic
a poor visual focus	alienating	*a poor visual focus*	*expressive*
aesthetic	*appealing*	appropriate	*informative*
appealing	appreciating	attention-catching	suitable
artistic	averageness	categorizable	
asymmetrical	awe	challenging	
attractive	boring	clear	**other**
awesome	bring me closer to people/separates me from people	*cluttered*	a printing effect
balanced	*calm*	compelling	admirable
beautiful	comfortable	comprehensible	alive
bold	connective	conceptless	amateurish
calm	cool	confusing	bad
captivating	delightful	contemplative	botched
cautious	desirable	cumbersome	cheap
clean	disgreeable	easy to grasp	colorblind-safe
cluttered	disturbing	elicits associations	consistent
color-harmonious	dynamic	*informative*	convenient
colorful	elation	inspiring	convenient
complex	emotive	interpretable	*conventional*
conservative	energetic	intuitive	easy on eyes
contrastful	engaging	meaningful	easy orientation
conventional	enjoyable	memorable	easy to navigate
creative	entertaining	practical	easy to use
crisp	evocative	readable	fauvist
crowded	evoking feelings	slick	fit together
discouraging	exciting	stimulating creativity	flowing
distinctive	fascinating	stimulating curiosity	fluent to process
drab	favorable	straightforward	good
elegant	fun	structured	hectic
expressive	gratifying	undemanding	*high-quality*
eye-catching	happy	understandable	human
familiar	hideous	*use of color is successful*	*innovative*
geometric	integrating		it is possible to discover new things even when looking at the page for a longer time.
harmonious	intense		manageable
has enough free space	interesting		noisy
high-quality	intriguing		one-sided
illuminating	intrusive		pleasantly animated
innovative	isolating		premium
inventive	likable		professional
inviting	motivating		restless
just eye-candy	moved		romantic
lack imagination	perfection		shows complete ignorance of human visual perception
looks great, but does not enable to get insight	pleasing		some elements seem out of place
lovely	positive		sophisticated
made with care	powerful		static
modern	predictable		stucco
nice	preferable		technology
novel	provoking		the control instructions are too static
old-fashioned	relaxed		the number of images is adequate
orderly	satisfying		the page contains too much text
ordinary	stimulating		too little happens on the page
organized	striking		unique
original	sublime		unruly
overloaded	the page changes too little due to user actions		uses special effects
painterly	thrills or chills		varied
patchy	touched		versatile
presentable	warm feeling		well-combined
pretty			well-finished
realistic appearance			wretched
rejecting			
simple			
streamlined			
stunning			
stylish			
symmetrical			
tacky			
tasteful			
thoughtful			
thrown together			
ugly			
unimaginative			
unique			
up-to-date			
use of color is successful			
vulgar			
well-crafted			
well-designed			
well-proportioned			

Step 2: Term filtering

Filtering on occurrence and semantics

6 objective criteria by authors

1. The terms needed to be **related to *aesthetic pleasure*** rather than *understanding* or *comprehension* of a visual representation or its data (e. g., we excluded "informative," "clear," or "confusing").
2. The terms had to have **appeared at least twice** in one of the three resources we used for our item generation: visualization papers, other relevant aesthetics scale papers, or expert suggestions.
3. The terms should be **usable in a rating scale** and have a **clearly good or bad connotation** (e. g., we excluded "complex" because a complex aesthetic could be seen as positive or as negative).
4. The terms should be **easy to understand** (e. g., we excluded "consistent" because it would be unclear according to what aspect a visual appearance would be consistent) and their **interpretation should be clear** (e. g., we excluded "novel" because it would require people to know what "old" visualizations look like; we also excluded "drab" as a rare term that is not easily understood by many non-native speakers of English).
5. The terms had to **clearly apply to an assessment of a visual representation** (e. g., we excluded "dynamic" because, within visualization, the term may be read as referring to the property of being animated or interactive, rather than a dynamic aesthetic).
6. The terms should **not be pairs of opposite adjectives**. We only retained negative terms that did not have a clear positive opposite (e. g., we excluded "ugly" as the opposite of "beautiful").

Step 2: Term filtering

Expert review

Invitation email sent to 56 visualization experts

Subject: Invitation for new short 4min survey - Terms to judge the aesthetics of a visualization

To: [email of an expert in visualization]

Dear [expert's name],

You have previously received an email from us about a first quick survey regarding how to judge the aesthetics of a visualization. If you had a chance to participate, thank you very much! We received a lot of useful input and comments that we will address! If not - don't worry - you still have a chance to participate in this second survey.

To clarify, our project is about developing a simple instrument to gauge the aesthetic pleasure of a visualization – meant to provide a few simple rating questions that can accompany other types of experiments (quantitative or qualitative).

In the first phase of our work we asked you to provide a few terms that you consider to be usable in an aesthetic rating. In addition to terms provided by experts like you, we have also assessed the literature and come up with a final list of 37 terms; narrowed down from a list of > 200 terms. An important second phase in scale development is to ask experts to rate the appropriateness of the terms we collected. As such, we would much appreciate it if you could spend around 3-4 minutes of your time to fill out our second survey. We hope that at least as a small reward seeing the list of terms may already be useful or inspiring to you.

To participate, please access the survey here: [survey link]

We thank you a lot in advance and would be happy to share the results of our work with you if you are interested! Just let us know.

Best regards,
Tingying He, Petra Isenberg, Raimund Dachselt, and Tobias Isenberg

Survey for reviewing terms (25 responses)

The **aesthetic pleasure of visualization** is the pleasure people derive from looking at a visualization for its own sake, as a source of immediate experiential pleasure in itself, and not essentially for its utility in producing insight or knowledge gain or something else that is either useful or pleasurable.

The table below includes terms that have been suggested or used in the literature by visualization experts like you for studying the **aesthetic pleasure of a visualization**. Imagine that these terms would later be used in a rating scale that asks participants to select to what extent a visualization is ...[term].

Below we would like you to rate these different terms according to how relevant you consider them for actually judging the aesthetic pleasure of a visualization. Please note that **we only care about aesthetic pleasure in terms of what a visualization looks like** and not how well people can comprehend the data that it shows.

* How relevant do you think the following terms are for judging or describing the aesthetic pleasure of a visualization?

	1 = not at all relevant	2	3	4	5 = very relevant
sophisticated					
beautiful					
appealing					
likable					
cluttered					
enjoyable					
tasteful					
modern					
aesthetic					
clean					
color-harmonious					
boring					
satisfying					
delightful					
entertaining					
exciting					
attractive					
good					
interesting					

Step 2: Term filtering

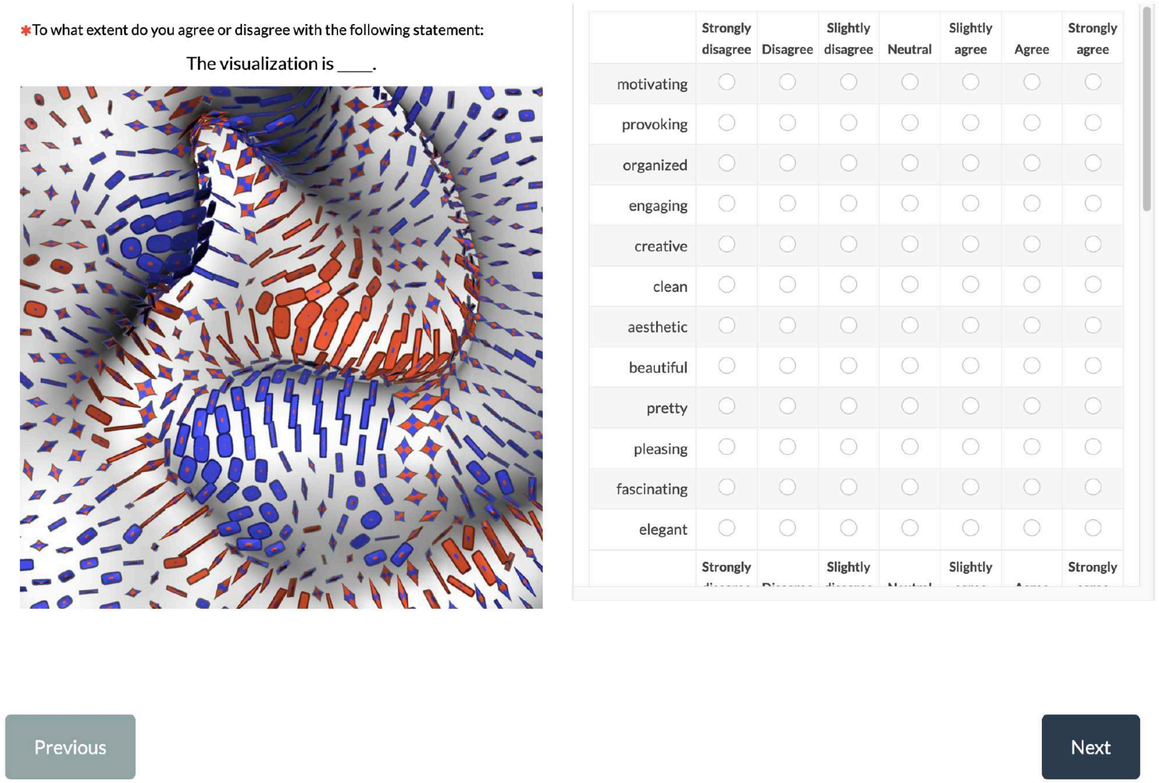
31 terms

aesthetic	emotion	cognitive	other
appealing	*appealing*	*cluttered*	professional
artistic	delightful		sophisticated
attractive	engaging		
balanced	enjoyable		
beautiful	exciting		
clean	fascinating		
cluttered	interesting		
color-harmonious	likable		
creative	motivating		
elegant	pleasing		
harmonious	provoking		
inviting	satisfying		
lovely			
nice			
organized			
pretty			
tasteful			
well-designed			

Step 3: Exploratory phase

Crowdsourced experiment

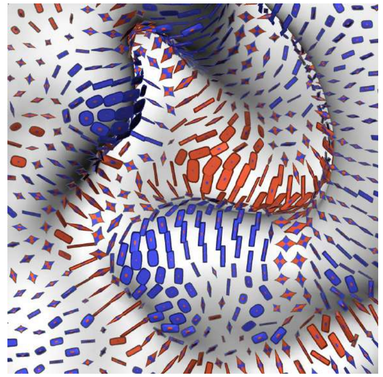
- 1001 participants
- 15 data representations
- 3 representations / participant

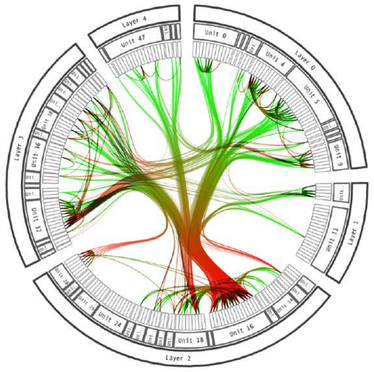


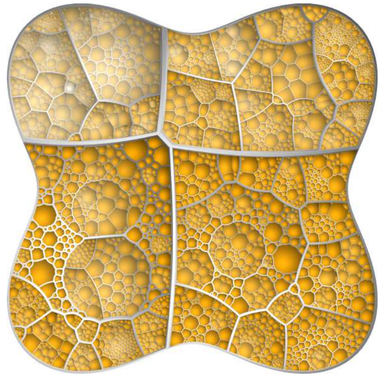
Exploratory experiment screenshot

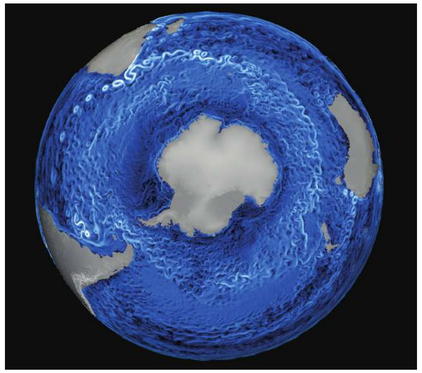
Step 3: Exploratory phase

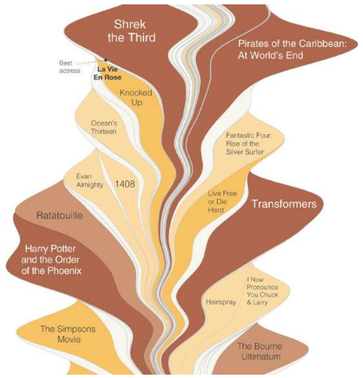
Stimuli: 15 diverse data representations

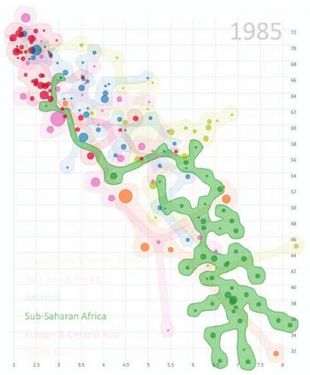


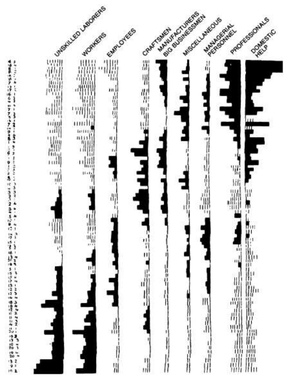


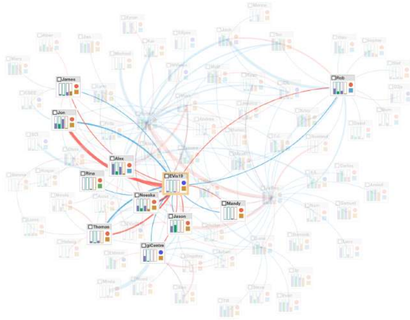


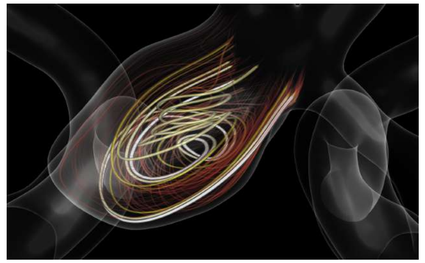


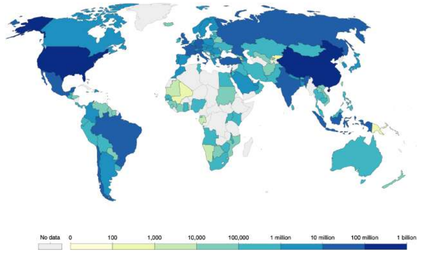


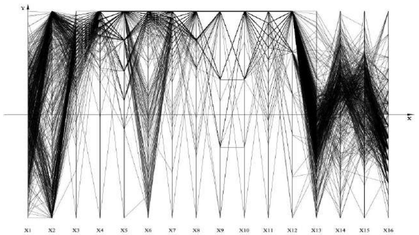


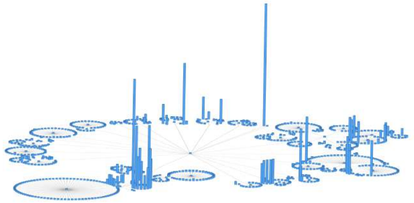


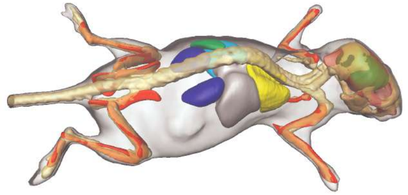


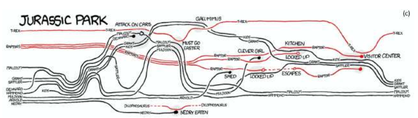








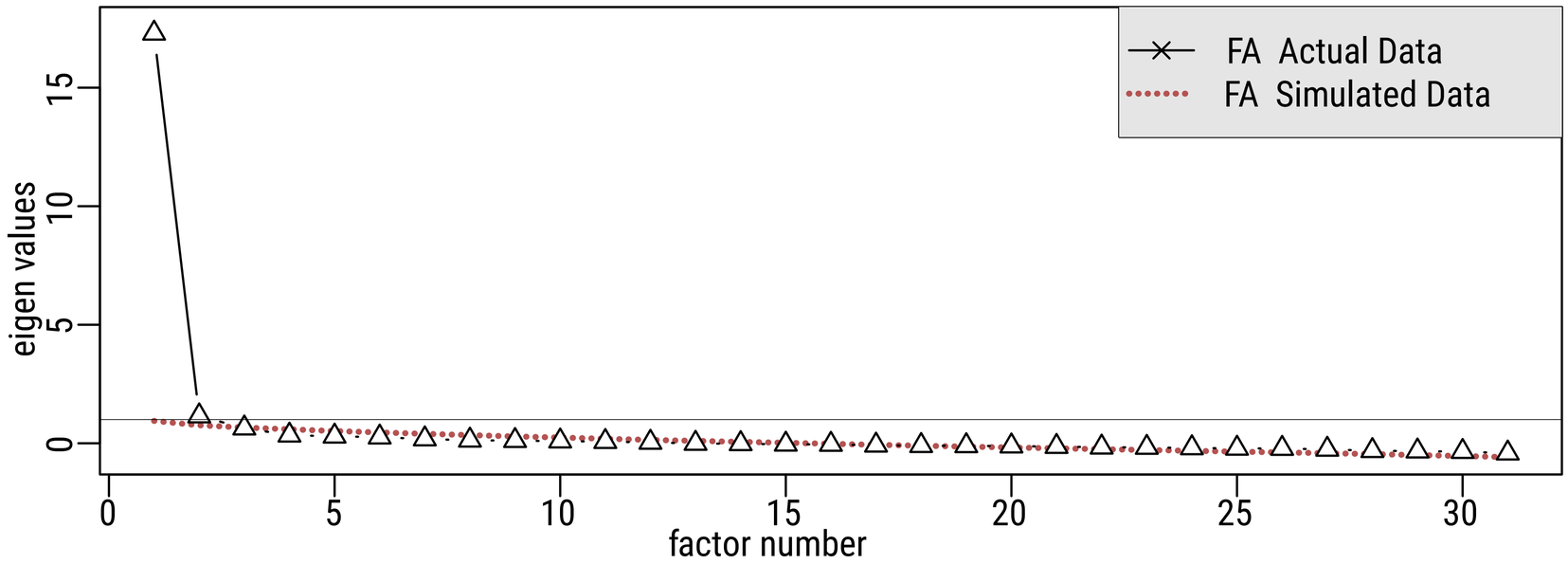




Images from other people's papers, used with permission, see our paper for details.

Exploratory factor analysis

potential factor structure of our scale: 1 factor



Scree plot for Image 1 (3D surface glyphs), see our paper for details

Reducing terms based on factor loadings

terms / image	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average
likable	0.91	0.79	0.88	0.87	0.86	0.84	0.90	0.88	0.84	0.86	0.85	0.89	0.87	0.87	0.89	0.87
pleasing	0.85	0.80	0.84	0.88	0.89	0.87	0.90	0.84	0.80	0.88	0.87	0.88	0.87	0.84	0.88	0.86
enjoyable	0.87	0.78	0.83	0.86	0.86	0.84	0.88	0.87	0.84	0.87	0.85	0.88	0.83	0.85	0.89	0.86
appealing	0.85	0.80	0.80	0.84	0.87	0.83	0.88	0.85	0.85	0.88	0.85	0.88	0.88	0.83	0.90	0.85
nice	0.90	0.81	0.81	0.82	0.87	0.83	0.87	0.87	0.81	0.85	0.84	0.82	0.89	0.82	0.89	0.85
attractive	0.84	0.78	0.81	0.81	0.86	0.87	0.89	0.84	0.84	0.86	0.85	0.87	0.86	0.84	0.85	0.84
delightful	0.86	0.74	0.78	0.85	0.83	0.81	0.89	0.82	0.79	0.82	0.86	0.88	0.89	0.84	0.88	0.83
satisfying	0.77	0.73	0.77	0.83	0.85	0.80	0.90	0.80	0.82	0.85	0.86	0.87	0.85	0.81	0.84	0.83
pretty	0.85	0.76	0.77	0.78	0.81	0.81	0.88	0.79	0.76	0.80	0.84	0.85	0.83	0.86	0.85	0.82
beautiful	0.84	0.77	0.76	0.79	0.84	0.78	0.87	0.81	0.76	0.82	0.85	0.85	0.78	0.82	0.84	0.81
lovely	0.85	0.75	0.78	0.82	0.80	0.77	0.83	0.81	0.74	0.81	0.86	0.86	0.83	0.79	0.83	0.81
inviting	0.83	0.74	0.71	0.73	0.82	0.80	0.84	0.85	0.78	0.78	0.83	0.78	0.84	0.76	0.83	0.79
engaging	0.79	0.70	0.76	0.74	0.78	0.78	0.82	0.83	0.74	0.76	0.79	0.77	0.80	0.73	0.80	0.77
tasteful	0.78	0.64	0.68	0.72	0.77	0.78	0.80	0.81	0.81	0.80	0.82	0.76	0.81	0.77	0.83	0.77
exciting	0.79	0.66	0.72	0.76	0.81	0.76	0.81	0.77	0.70	0.77	0.82	0.77	0.79	0.75	0.79	0.77
motivating	0.74	0.65	0.71	0.77	0.83	0.78	0.84	0.75	0.75	0.77	0.78	0.71	0.83	0.76	0.77	0.76
elegant	0.83	0.76	0.71	0.78	0.74	0.68	0.83	0.69	0.71	0.84	0.76	0.80	0.78	0.74	0.80	0.76
harmonious	0.79	0.69	0.76	0.75	0.82	0.74	0.74	0.74	0.69	0.80	0.77	0.80	0.76	0.75	0.81	0.76
well designed	0.76	0.71	0.67	0.77	0.81	0.73	0.69	0.71	0.73	0.74	0.76	0.81	0.81	0.66	0.76	0.74
fascinating	0.68	0.64	0.73	0.77	0.70	0.72	0.80	0.71	0.72	0.66	0.73	0.77	0.76	0.70	0.71	0.72
interesting	0.70	0.70	0.71	0.74	0.76	0.71	0.73	0.74	0.61	0.64	0.70	0.73	0.74	0.59	0.74	0.70
balanced	0.69	0.63	0.61	0.73	0.71	0.69	0.59	0.70	0.65	0.77	0.74	0.66	0.68	0.71	0.74	0.69
clean	0.73	0.70	0.71	0.64	0.70	0.60	0.66	0.70	0.60	0.68	0.71	0.71	0.63	0.73	0.67	0.68
sophisticated	0.68	0.63	0.62	0.63	0.61	0.62	0.73	0.65	0.66	0.63	0.63	0.75	0.71	0.71	0.71	0.66
organized	0.59	0.61	0.62	0.74	0.67	0.59	0.55	0.60	0.59	0.66	0.64	0.66	0.65	0.62	0.65	0.63
creative	0.53	0.49	0.55	0.60	0.67	0.62	0.66	0.70	0.62	0.68	0.65	0.64	0.58	0.54	0.65	0.61
artistic	0.52	0.49	0.51	0.59	0.66	0.63	0.69	0.61	0.56	0.66	0.64	0.69	0.55	0.58	0.67	0.60
professional	0.63	0.67	0.52	0.61	0.62	0.53	0.60	0.46	0.50	0.61	0.52	0.67	0.67	0.62	0.60	0.59
color harmonious	0.65	0.59	0.63	0.63	0.64	0.63	0.48	0.55	0.43	0.62	0.51	0.62	0.43	0.64	0.64	0.58
provoking	0.17	0.20	0.22	0.28	0.28	0.33	0.19	0.37	0.32	0.27	0.40	0.32	0.22	0.22	0.35	0.28
cluttered	0.30	-0.33	0.03	0.15	0.39	0.18	0.27	0.34	0.41	0.45	0.21	-0.05	0.12	0.05	0.24	0.18

Factor loadings for all 31 terms and 15 images

The higher the **factor loading** a term has, the better this term is able to describe the construct.

Reducing terms based on factor loadings

terms / image	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average
likable	0.91	0.79	0.88	0.87	0.86	0.84	0.90	0.88	0.84	0.86	0.85	0.89	0.87	0.87	0.89	0.87
pleasing	0.85	0.80	0.84	0.88	0.89	0.87	0.90	0.84	0.80	0.88	0.87	0.88	0.87	0.84	0.88	0.86
enjoyable	0.87	0.78	0.83	0.86	0.86	0.84	0.88	0.87	0.84	0.87	0.85	0.88	0.83	0.85	0.89	0.86
appealing	0.85	0.80	0.80	0.84	0.87	0.83	0.88	0.85	0.85	0.88	0.85	0.88	0.88	0.83	0.90	0.85
nice	0.90	0.81	0.81	0.82	0.87	0.83	0.87	0.87	0.81	0.85	0.84	0.82	0.89	0.82	0.89	0.85
attractive	0.84	0.78	0.81	0.81	0.86	0.87	0.89	0.84	0.84	0.86	0.85	0.87	0.86	0.84	0.85	0.84
delightful	0.86	0.74	0.78	0.85	0.83	0.81	0.89	0.82	0.79	0.82	0.86	0.88	0.89	0.84	0.88	0.83
satisfying	0.77	0.73	0.77	0.83	0.85	0.80	0.90	0.80	0.82	0.85	0.86	0.87	0.85	0.81	0.84	0.83
pretty	0.85	0.76	0.77	0.78	0.81	0.81	0.88	0.79	0.76	0.80	0.84	0.85	0.83	0.86	0.85	0.82
beautiful	0.84	0.77	0.76	0.79	0.84	0.78	0.87	0.81	0.76	0.82	0.85	0.85	0.78	0.82	0.84	0.81
lovely	0.85	0.75	0.78	0.82	0.80	0.77	0.83	0.81	0.74	0.81	0.86	0.86	0.83	0.79	0.83	0.81
inviting	0.83	0.74	0.71	0.73	0.82	0.80	0.84	0.85	0.78	0.78	0.83	0.78	0.84	0.76	0.83	0.79
engaging	0.79	0.70	0.76	0.74	0.78	0.78	0.82	0.83	0.74	0.76	0.79	0.77	0.80	0.73	0.80	0.77
tasteful	0.78	0.64	0.68	0.72	0.77	0.78	0.80	0.81	0.81	0.80	0.82	0.76	0.81	0.77	0.83	0.77
exciting	0.79	0.66	0.72	0.76	0.81	0.76	0.81	0.77	0.70	0.77	0.82	0.77	0.79	0.75	0.79	0.77
motivating	0.74	0.65	0.71	0.77	0.83	0.78	0.84	0.75	0.75	0.77	0.78	0.71	0.83	0.76	0.77	0.76
elegant	0.83	0.76	0.71	0.78	0.74	0.68	0.83	0.69	0.71	0.84	0.76	0.80	0.78	0.74	0.80	0.76
harmonious	0.79	0.69	0.76	0.75	0.82	0.74	0.74	0.74	0.69	0.80	0.77	0.80	0.76	0.75	0.81	0.76
well designed	0.76	0.71	0.67	0.77	0.81	0.73	0.69	0.71	0.73	0.74	0.76	0.81	0.81	0.66	0.76	0.74
fascinating	0.68	0.64	0.73	0.77	0.70	0.72	0.80	0.71	0.72	0.66	0.73	0.77	0.76	0.70	0.71	0.72
interesting	0.70	0.70	0.71	0.74	0.76	0.71	0.73	0.74	0.61	0.64	0.70	0.73	0.74	0.59	0.74	0.70
balanced	0.69	0.63	0.61	0.73	0.71	0.69	0.59	0.70	0.65	0.77	0.74	0.66	0.68	0.71	0.74	0.69
clean	0.73	0.70	0.71	0.64	0.70	0.60	0.66	0.70	0.60	0.68	0.71	0.71	0.63	0.73	0.67	0.68
sophisticated	0.68	0.63	0.62	0.63	0.61	0.62	0.73	0.65	0.66	0.63	0.63	0.75	0.71	0.71	0.71	0.66
organized	0.59	0.61	0.62	0.74	0.67	0.59	0.55	0.60	0.59	0.66	0.64	0.66	0.65	0.62	0.65	0.63
creative	0.53	0.49	0.55	0.60	0.67	0.62	0.66	0.70	0.62	0.68	0.65	0.64	0.58	0.54	0.65	0.61
artistic	0.52	0.49	0.51	0.59	0.66	0.63	0.69	0.61	0.56	0.66	0.64	0.69	0.55	0.58	0.67	0.60
professional	0.63	0.67	0.52	0.61	0.62	0.53	0.60	0.46	0.50	0.61	0.52	0.67	0.67	0.62	0.60	0.59
color harmonious	0.65	0.59	0.63	0.63	0.64	0.63	0.48	0.55	0.43	0.62	0.51	0.62	0.43	0.64	0.64	0.58
provoking	0.17	0.20	0.22	0.28	0.28	0.33	0.19	0.37	0.32	0.27	0.40	0.32	0.22	0.22	0.35	0.28
cluttered	0.30	-0.33	0.03	0.15	0.39	0.18	0.27	0.34	0.41	0.45	0.21	-0.05	0.12	0.05	0.24	0.18

Factor loadings for all 31 terms and 15 images

Factor Loading > 0.7 : High

[Hair, 2009]

Retained **12 terms** with a factor loading > 0.7 for all 15 images

Step 3: Exploratory phase

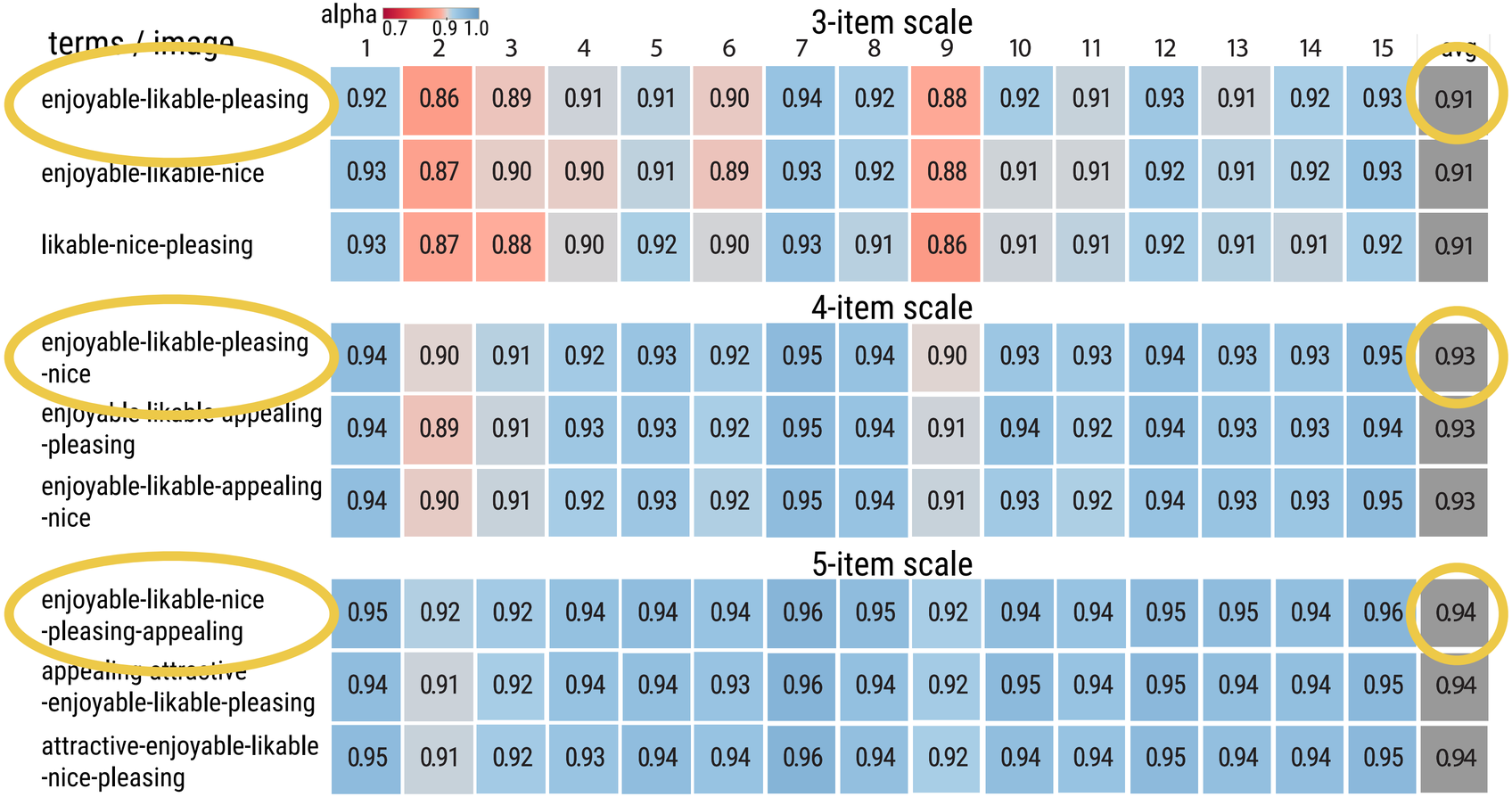
Reliability: Cronbach's Alpha

> 0.7 : Reliable
[Boateng et al., 2018]

Enjoyable Likable Pleasing

Enjoyable Likable Pleasing Nice

Enjoyable Likable Pleasing Nice Appealing



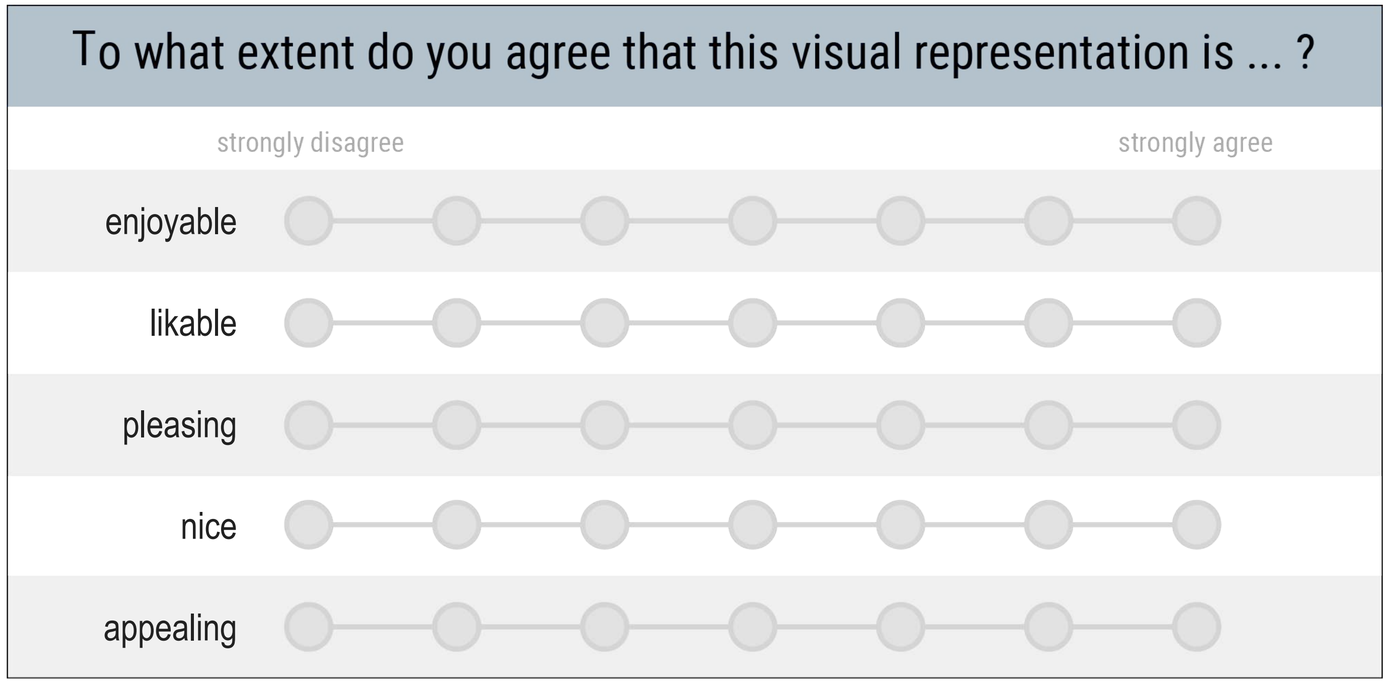
0.91

0.93

0.94

Cronbach's alpha for each image on the most reliable 3-, 4-, and 5-item subsets of the remaining 12 terms with factor loading > 0.7.

BeauVis scale

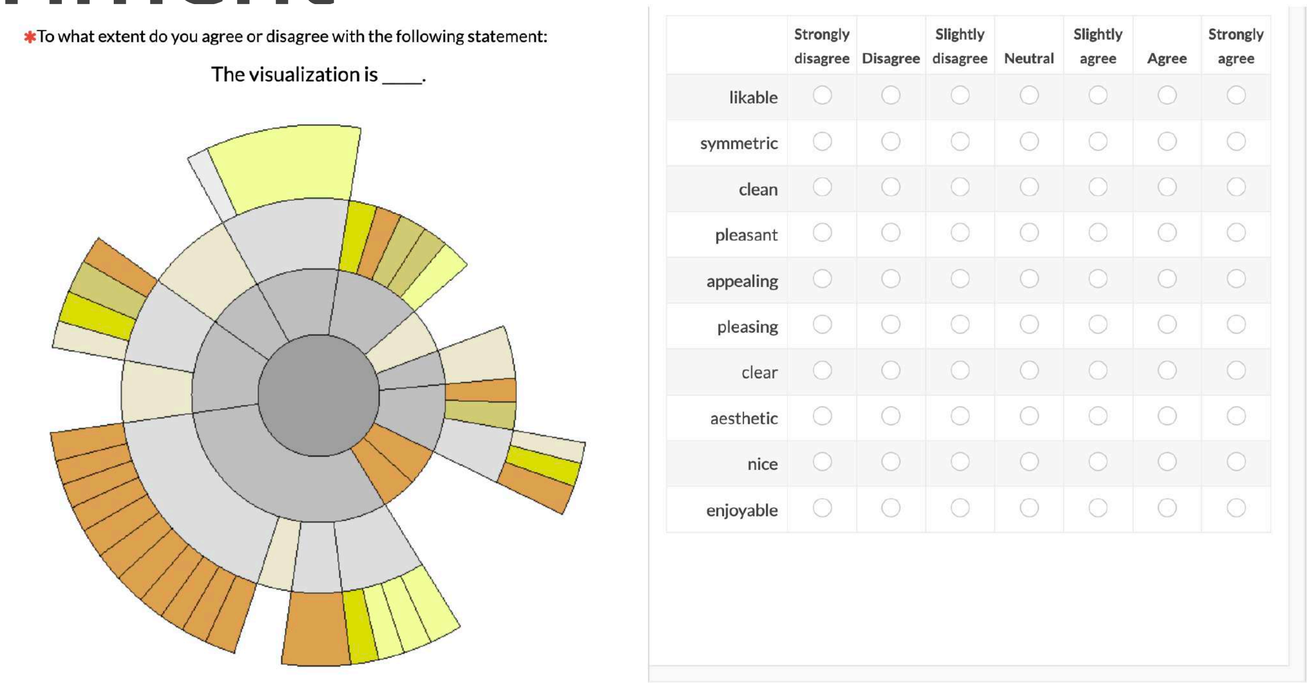


BeauVis scale in its recommended version

Step 4: Validation phase

Crowdsourced experiment

- 201 participants
- 3 data representations



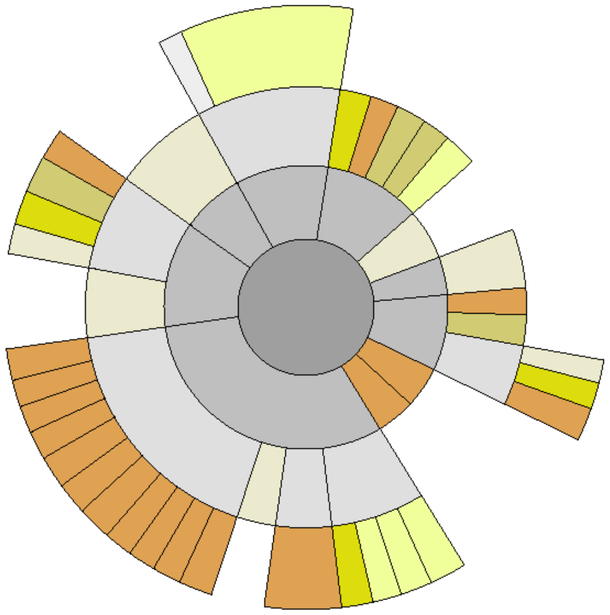
Confirmatory experiment screenshot
Terms from the BeauVis scale and [Lavie & Tractinsky, 2003]

Image from Cawthon and Vande Moere, 2007 (https://doi.org/10.1109/IV.2007.147); © IEEE, used with permission.

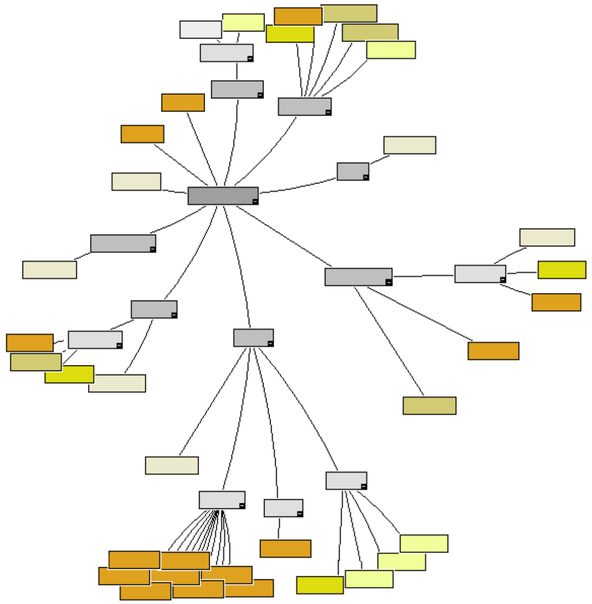
Step 4: Validation phase

Stimuli

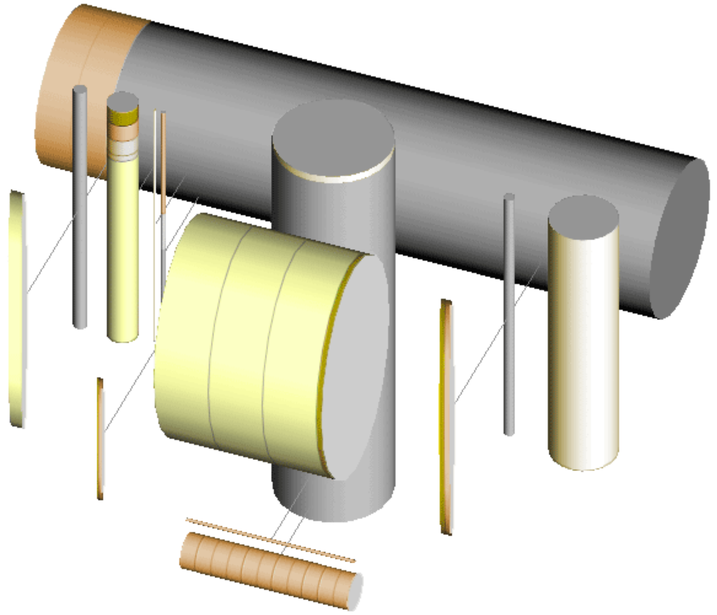
Ranking for aesthetic pleasure in the previous study [Cawthon and Vande Moere, 2007]



SunBurst



StarTree



BeamTree

“most beautiful”

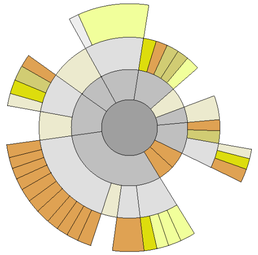
“most ugly”

Step 4: Validation phase

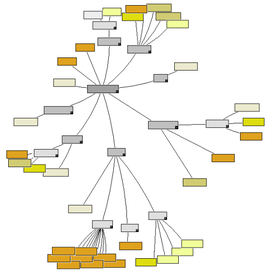
BeauVis replicated the aesthetic ranking [Cawthon and Vande Moere, 2007]

Ranking in previous study
(“Known groups”)

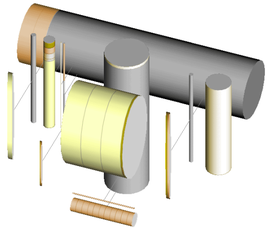
Results with BeauVis scale
(Differentiation by known groups)



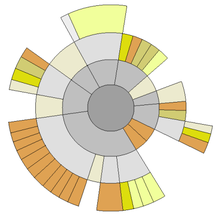
SunBurst
“most beautiful”

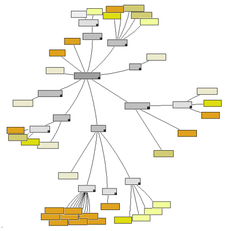


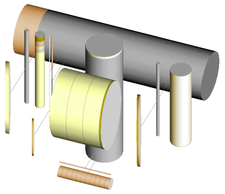
StarTree

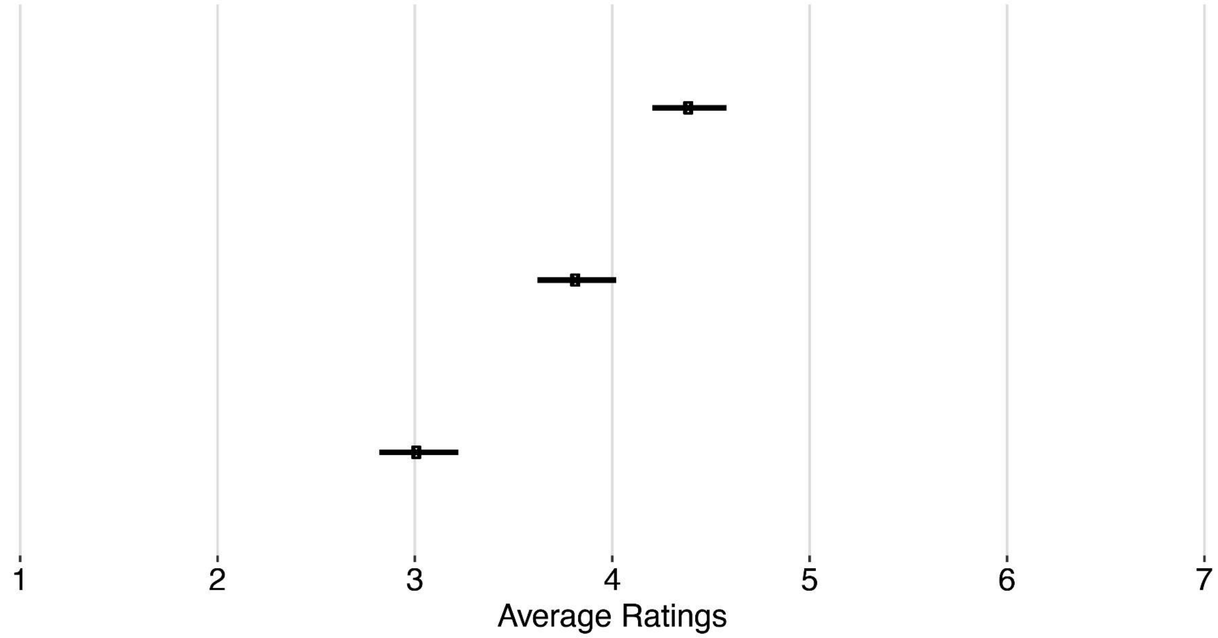


BeamTree
“most ugly”









Step 4: Validation phase

Confirmation of structure, reliability, validity

Confirmatory factor analysis

	SunBurst	StarTree	BeamTree
p-value (χ^2)	0.290	0.222	0.016
TLI	0.998	0.996	0.982
CFI	0.999	0.998	0.991
SRMR	0.009	0.011	0.014
RMSEA	0.034	0.045	0.095

Goodness of fit indices

Item	Factor Loading		
	SunBurst	StarTree	BeamTree
enjoyable	0.893	0.878	0.911
likable	0.914	0.925	0.874
pleasing	0.889	0.895	0.893
nice	0.845	0.877	0.888
appealing	0.910	0.842	0.889

Standardized factor loading for 5 items

Reliability

	SunBurst	StarTree	BeamTree
Cronbach's Alpha	0.95	0.946	0.95

Cronbach's alpha for each visualization

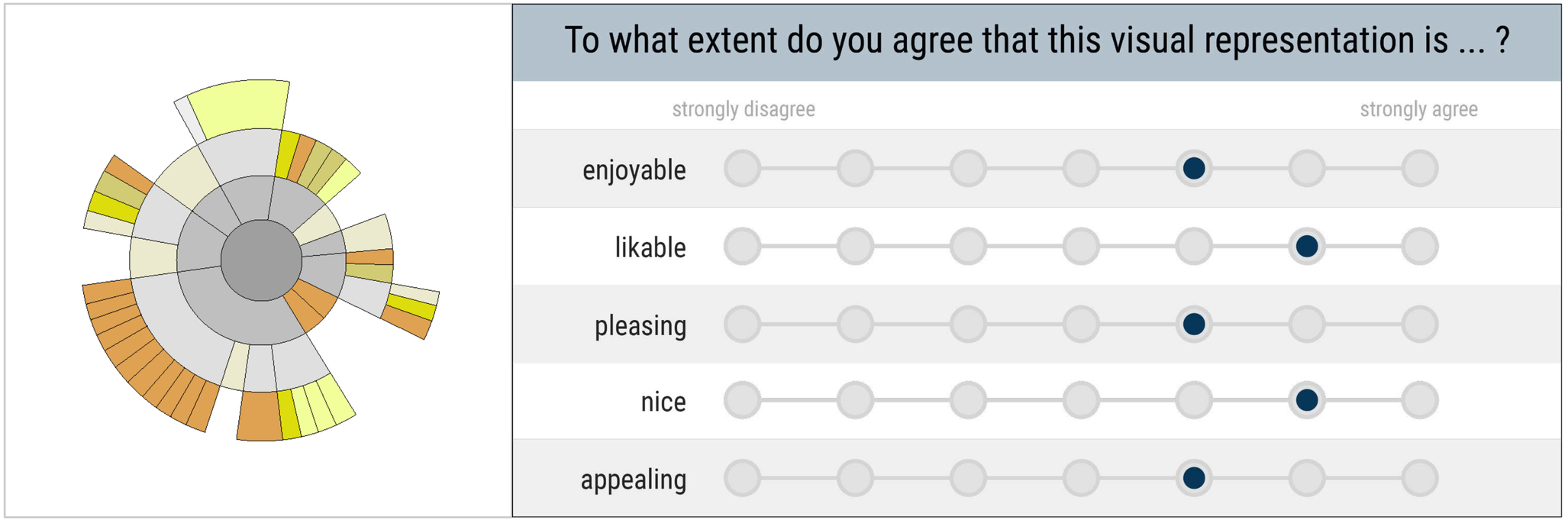
Validity

	SunBurst	StarTree	BeamTree
Classic Aesthetic	0.84	0.88	0.87
Age	0.07	0.12	0.14

Pearson correlation

Usage of the BeauVis Scale

rapidly **compare** the aesthetic pleasure of different visual data representations

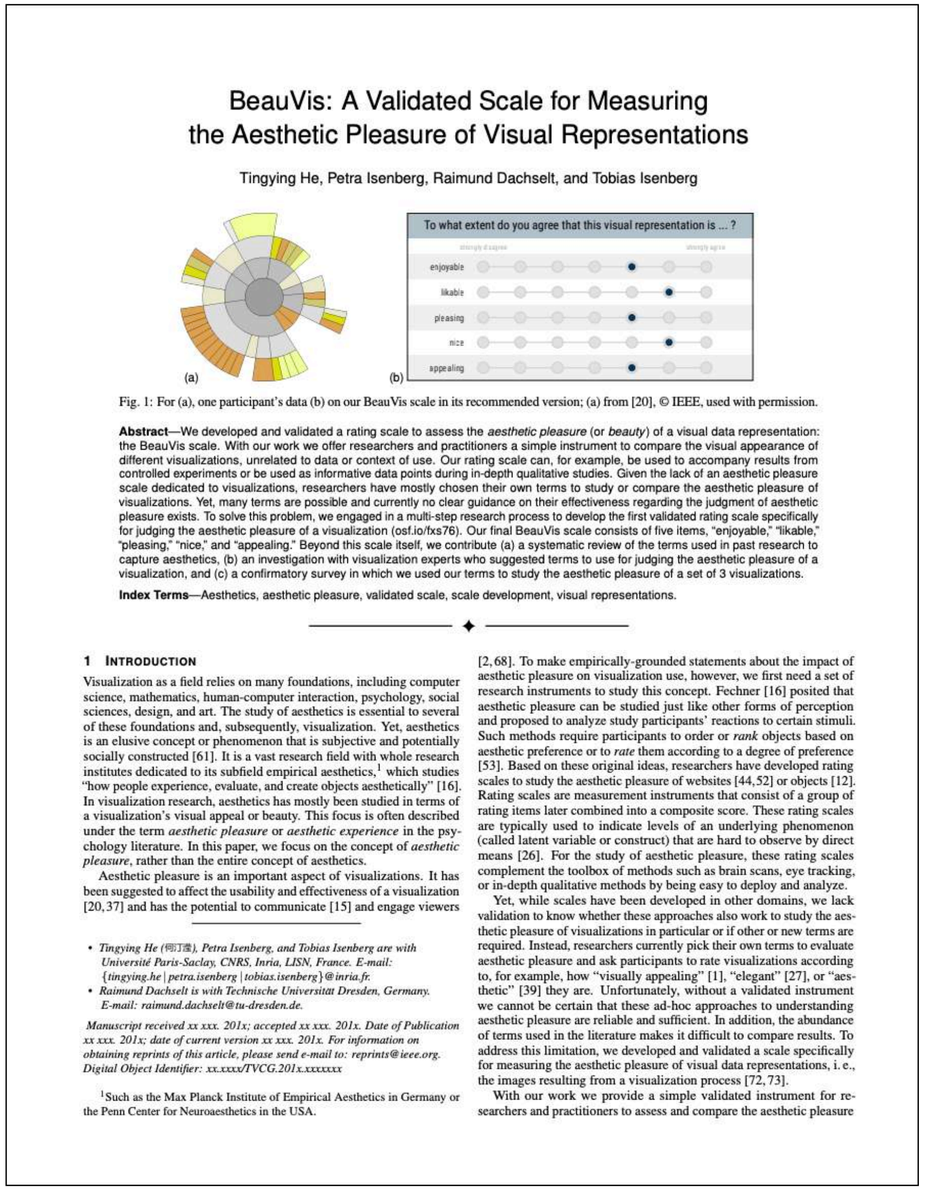


Recommended form of using the BeauVis scale

VIS 2022




Tingying He, Petra Isenberg, Raimund Dachselt, and Tobias Isenberg. BeauVis: A Validated Scale for Measuring the Aesthetic Pleasure of Visual Representations. *IEEE Transactions on Visualization and Computer Graphics*, 29(1):363–373, January 2023.
DOI: 10.1109TVCG.2022.3209390.



BeauVis: A Validated Scale for Measuring the Aesthetic Pleasure of Visual Representations

Tingying He, Petra Isenberg, Raimund Dachselt, and Tobias Isenberg

Fig. 1: For (a), one participant's data (b) on our BeauVis scale in its recommended version; (a) from [20], © IEEE, used with permission.

Abstract—We developed and validated a rating scale to assess the *aesthetic pleasure* (or *beauty*) of a visual data representation: the BeauVis scale. With our work we offer researchers and practitioners a simple instrument to compare the visual appearance of different visualizations, unrelated to data or context of use. Our rating scale can, for example, be used to accompany results from controlled experiments or be used as informative data points during in-depth qualitative studies. Given the lack of an aesthetic pleasure scale dedicated to visualizations, researchers have mostly chosen their own terms to study or compare the aesthetic pleasure of visualizations. Yet, many terms are possible and currently no clear guidance on their effectiveness regarding the judgment of aesthetic pleasure exists. To solve this problem, we engaged in a multi-step research process to develop the first validated rating scale specifically for judging the aesthetic pleasure of a visualization (osf.io/fxs76). Our final BeauVis scale consists of five items, "enjoyable," "likable," "pleasing," "nice," and "appealing." Beyond this scale itself, we contribute (a) a systematic review of the terms used in past research to capture aesthetics, (b) an investigation with visualization experts who suggested terms to use for judging the aesthetic pleasure of a visualization, and (c) a confirmatory survey in which we used our terms to study the aesthetic pleasure of a set of 3 visualizations.

Index Terms—Aesthetics, aesthetic pleasure, validated scale, scale development, visual representations.

1 Introduction

Visualization as a field relies on many foundations, including computer science, mathematics, human-computer interaction, psychology, social sciences, design, and art. The study of aesthetics is essential to several of these foundations and, subsequently, visualization. Yet, aesthetics is an elusive concept or phenomenon that is subjective and potentially socially constructed [61]. It is a vast research field with whole research institutes dedicated to its subfield empirical aesthetics,[1] which studies "how people experience, evaluate, and create objects aesthetically" [16]. In visualization research, aesthetics has mostly been studied in terms of a visualization's visual appeal or beauty. This focus is often described under the term *aesthetic pleasure* or *aesthetic experience* in the psychology literature. In this paper, we focus on the concept of *aesthetic pleasure*, rather than the entire concept of aesthetics.

Aesthetic pleasure is an important aspect of visualizations. It has been suggested to affect the usability and effectiveness of a visualization [20, 37] and has the potential to communicate [15] and engage viewers [2, 68]. To make empirically-grounded statements about the impact of aesthetic pleasure on visualization use, however, we first need a set of research instruments to study this concept. Fechner [16] posited that aesthetic pleasure can be studied just like other forms of perception and proposed to analyze study participants' reactions to certain stimuli. Such methods require participants to order or *rank* objects based on aesthetic preference or to *rate* them according to a degree of preference [53]. Based on these original ideas, researchers have developed rating scales to study the aesthetic pleasure of websites [44, 52] or objects [12]. Rating scales are measurement instruments that consist of a group of rating items later combined into a composite score. These rating scales are typically used to indicate levels of an underlying phenomenon (called latent variable or construct) that are hard to observe by direct means [26]. For the study of aesthetic pleasure, these rating scales complement the toolbox of methods such as brain scans, eye tracking, or in-depth qualitative methods by being easy to deploy and analyze.

Yet, while scales have been developed in other domains, we lack validation to know whether these approaches also work to study the aesthetic pleasure of visualizations in particular or if other or new terms are required. Instead, researchers currently pick their own terms to evaluate aesthetic pleasure and ask participants to rate visualizations according to, for example, how "visually appealing" [1], "elegant" [27], or "aesthetic" [39] they are. Unfortunately, without a validated instrument we cannot be certain that these ad-hoc approaches to understanding aesthetic pleasure are reliable and sufficient. In addition, the abundance of terms used in the literature makes it difficult to compare results. To address this limitation, we developed and validated a scale specifically for measuring the aesthetic pleasure of visual data representations, i. e., the images resulting from a visualization process [72, 73].

With our work we provide a simple validated instrument for researchers and practitioners to assess and compare the aesthetic pleasure

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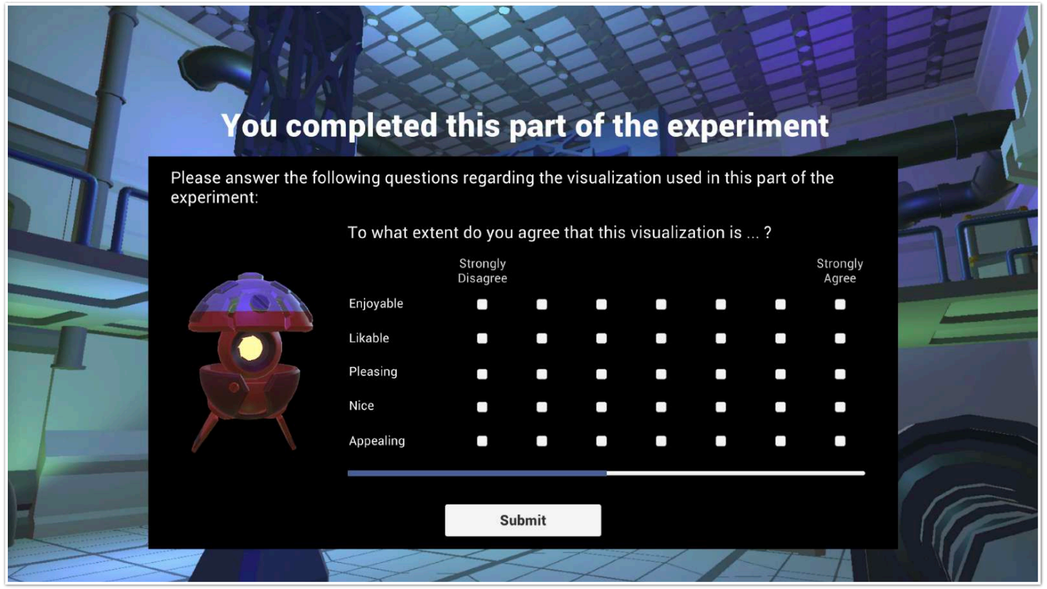
Manuscript received xx xxx. 201x; accepted xx xxx. 201x. Date of Publication xx xxx. 201x; date of current version xx xxx. 201x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org. Digital Object Identifier: xx.xxxx/TVCG.201x.xxxxxxx

[1] Such as the Max Planck Institute of Empirical Aesthetics in Germany or the Penn Center for Neuroaesthetics in the USA.

Researchers are using the BeauVis scale



[Yao et al., 2025]

To what extent do you agree that this visual representation is:

	1	2	3	4	5
Enjoyable	○	○	○	○	○
Likeable	○	○	○	○	○
Pleasing	○	○	○	○	○
Nice	○	○	○	○	○
Appealing	○	○	○	○	○

[Arunkumar et al., 2024]

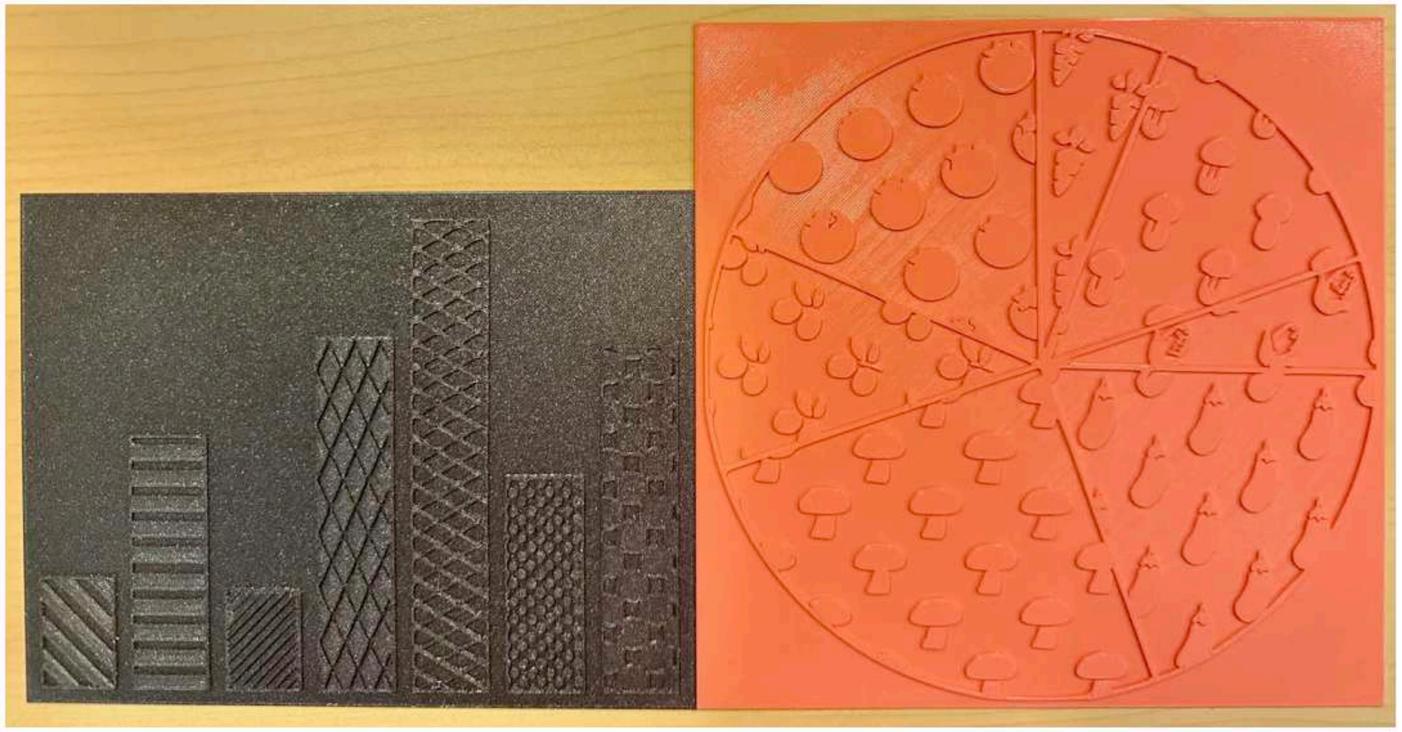
Discussion

Other contributions and future work

Data physicalization with b/w patterns

monochromatic nature makes them suitable for physical creation

data embroidery with b/w patterns [He et al., 2023]



3D-printed charts with b/w patterns [He et al., 2023]



Tingying He, Petra Isenberg, Tobias Isenberg. Data Embroidery with Black-and-White Textures. *In Proceedings of the alt.VIS Workshop (at IEEE VIS, 23 October, Melbourne, Australia)*, IEEE, Los Alamitos, CA, USA, 2023.

Data Embroidery with Black-and-White Textures

Tingying He, Petra Isenberg, Tobias Isenberg

Fig. 1: (a): An embroidered chart with black-and-white textures displaying the results of a survey within a family. (b): A canvas bag featuring the embroidered chart on the left. (c) and (d): the bag being used within the family.

Abstract—We investigated data embroidery with black-and-white textures, identifying challenges in the use of textures for machine embroidery based on our own experience. Data embroidery, as a method of physically representing data, offers a unique way to integrate personal data into one's everyday fabric-based objects. Owing to their monochromatic characteristics, black-and-white textures promise to be easy to employ in machine embroidery. We experimented with different textured visualizations designed by experts and, in this paper, we detail our workflow and evaluate the performance and suitability of different textures. We then conducted a survey on vegetable preferences within a family and created a canvas bag as a case study, featuring the embroidered family data to show how embroidered data can be used in practice.

Index Terms—Textures, black-and-white, design, data physicalization, personal data visualization.

1 Introduction

Data embroidery [13] is an innovative technique for data physicalization [7]. Machine embroidery as a computer-numerically controlled (CNC) technology makes it possible to produce complex data embroideries (relatively) quickly and integrate them into fabric-based personal belongings [13]. Data embroidery of personal data has potential because a less conventional approach to visualization may stimulate people to explore their own data more intensively [12]. It can also serve as an ambient visualization within a home setting, thereby initiating dialogues with curious visitors [9]. Data embroidery can, like in our case, be accessible to a broad set of the population through local Fablabs.

A promising yet so far unexplored avenue within data embroidery involves the use of black-and-white textures. Before the ubiquity of color printing, these monochromatic textures served as a powerful visual channel for data visualization (e. g., see the OldVisOnline collection [15]). Their inherent simplicity facilitates the conversion of images to embroidery files, overcoming challenges associated with the lower color resolution of embroidery machines compared to color screens. Moreover, they eliminate the need for multiple color changes during the embroidery process, enhancing efficiency.

In our work we explore data embroidery with black-and-white textures and contribute the following: (1) a detailed and hands-on workflow for creating data embroidery from an existing black-and-white textured chart image, (2) preliminary evaluations of which textures can be most effectively translated into data embroidery, and (3) a showcase of data embroidery of personal data with black-and-white textures—a canvas bag with an embroidered chart visualizing a within-family survey.

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2 Related Work

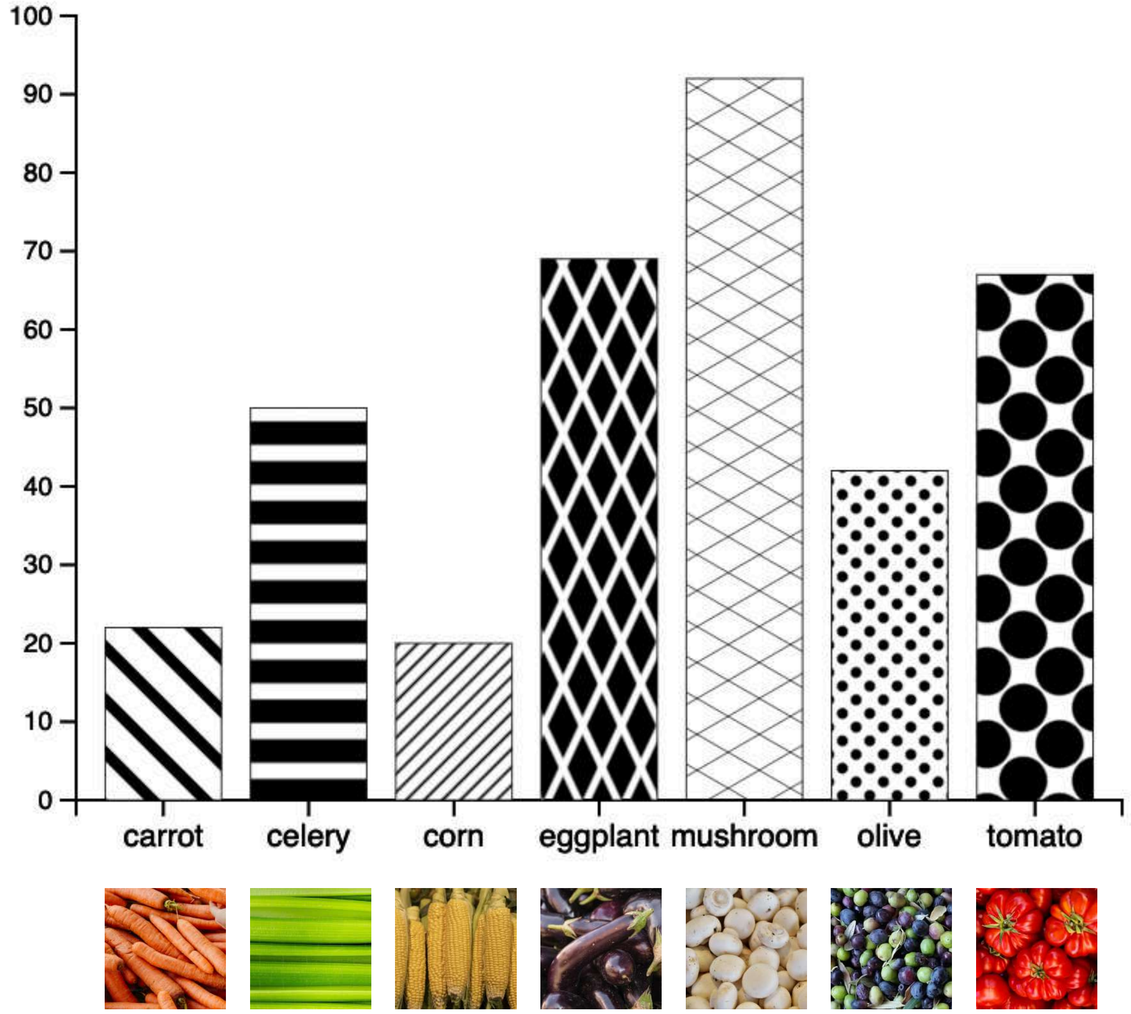
Many researchers and artists have experimented with embroidery as a means to create visualization artwork. For instance, Liz Bravo [2] manually embroidered charts of the distribution of U.S. cotton from 1942 to 1948, a visualization originally created by Mary Eleanor Spear, a pioneer in data visualization. Olivia Johnson [3] used cross-stitch techniques to create charts about gender inequality and discrimination at workplaces [4]. Hand embroidery has also been used to explore personal data. For example, Jane Zhang [14] logged her anxiety over 21 days and created an embroidered chart to visualize it—akin to other efforts in personal data visualization [8]. In the visualization research literature, Smit [11] has expanded the fabric-based data visualization landscape by exploring hand knitting as a potential medium for data physicalization, resulting in several *data knitualization* works. All these efforts, however, have employed manual methods to represent data on fabric, while we explore a more automated process.

Machine embroidery has gradually started to draw researchers' attention as well. Wannamaker et al. [13] explored the use of CNC embroidery machines for expressing personal data and embroidered a personal data physicalization representing text message data on a blanket. Schneider [10] provided a tutorial on data visualization with machine embroidery using Ink/Stitch [1], in which he outlined a general workflow of computerized embroidery. This workflow notably includes an essential step of reducing colors of the drawing to adapt it to the embroidery constraints, which underscores the suitability of monochromatic charts for machine embroidery. We used this process as an inspiration but specifically focused on textured visualizations.

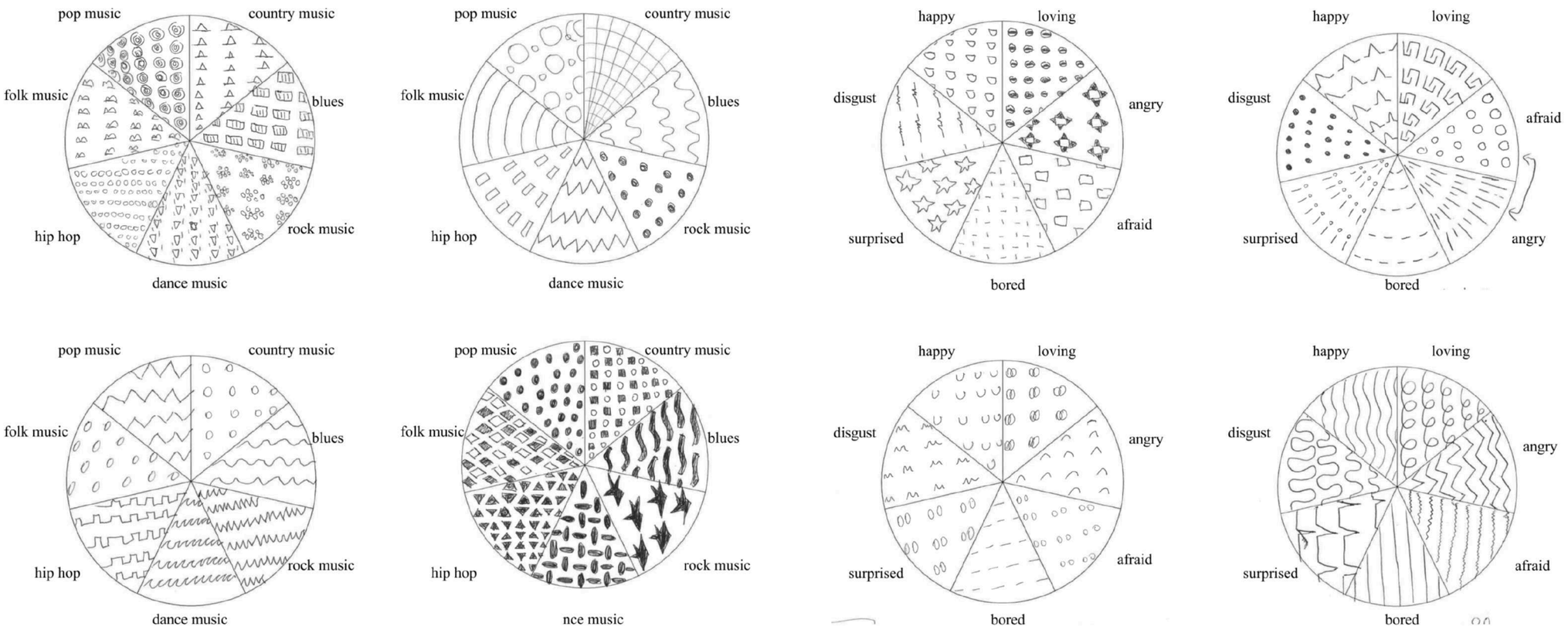
3 Machine Embroidery for Visualization

We first detail the workflow we followed for creating data embroidery from a chart image, as well as the choices we made during this process. We then discuss the common issues we encountered during our data embroidery process and possible troubleshooting methods.

Semantically-resonant patterns



How to design semantically-resonant patterns?



Examples of semantically-remnant patterns collected in our design workshop [Lu, 2025]

université PARIS-SACLAY master thesis



Zihan Lu. A design space of semantically-resonant patterns. *Master's thesis*, supervised by **Tingying He** and Tobias Isenberg.

Master Thesis

université PARIS-SACLAY

Master 2 in Computer Science
Human-Computer Interaction Program

A design space of semantically-resonant patterns

Author:
Zihan Lu

Supervisor:
Tobias Isenberg
Tingying He

Hosting lab/enterprise:
Aviz-Centre Inria de Saclay

04/03/2024 – 06/09/2024

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Email: Murielle.Benard@u-psud.fr

PREVis Scale

understandability

layout clarity

readability of data patterns

readability of data value

Understand subscale

understand1	It is **obvious** for me how to read this visualization
understand2	I can easily understand **how the data is represented** in this visualization
understand3	I can **easily understand** this visualization

Layout subscale

layout1	I **don't** find this visualization **messy**
layout2	I **don't** find this visualization **crowded**
layout3	I **don't** find **distracting parts** in this visualization

DataFeat subscale

dataFeat1	I find data features (for example, a minimum, or an outlier, or a trend) **visible** in this visualization
dataFeat2	I can **clearly see** data features (for example, a minimum, or an outlier, or a trend) in this visualization

DataRead subscale

dataRead1	I can easily **find specific elements** in this visualization
dataRead2	I can easily **identify relevant information** in this visualization
dataRead3	I can easily **retrieve information** from this visualization

[Cabouat et al., 2025]




Anne-Flore Cabouat, **Tingying He**, Petra Isenberg, and Tobias Isenberg. PREVis: Perceived Readability Evaluation for Visualizations. *IEEE Transactions on Visualization and Computer Graphics*, 31, 2025. To appear.

Best Paper Honorable Mention Award

PREVis: Perceived Readability Evaluation for Visualizations

Anne-Flore Cabouat, Tingying He, Petra Isenberg, Tobias Isenberg

Understand subscale

obvious	It is **obvious** for me how to read this visualization
represent	I can easily understand **how the data is represented** in this visualization
understand	I can **easily understand** this visualization

Layout subscale

messy	I **don't** find this visualization **messy**
crowded	I **don't** find this visualization **crowded**
distracting	I **don't** find **distracting parts** in this visualization

DataRead subscale

find	I can easily **find specific elements** in this visualization
identify	I can easily **identify relevant information** in this visualization
inform	I can easily **retrieve information** from this visualization

DataFeat subscale

visible	I find data features (for example, a minimum, or an outlier, or a trend) **visible** in this visualization
clear	I can **clearly see** data features (for example, a minimum, or an outlier, or a trend) in this visualization

Strongly disagree | Disagree | Slightly disagree | Neutral | Slightly agree | Agree | Strongly agree

I don't know / Not applicable (if you wish, feel free to elaborate below)

Fig. 1: PREVis subscales, items, and recommended presentation of answer options for a computer-supported questionnaire.

Abstract—We developed and validated an instrument to measure the perceived readability in data visualization: PREVis. Researchers and practitioners can easily use this instrument as part of their evaluations to compare the perceived readability of different visual data representations. Our instrument can complement results from controlled experiments on user task performance or provide additional data during in-depth qualitative work such as design iterations when developing a new technique. Although readability is recognized as an essential quality of data visualizations, so far there has not been a unified definition of the construct in the context of visual representations. As a result, researchers often lack guidance for determining how to ask people to rate their perceived readability of a visualization. To address this issue, we engaged in a rigorous process to develop the first *validated* instrument targeted at the subjective readability of visual data representations. Our final instrument consists of 11 items across 4 dimensions: understandability, layout clarity, readability of data values, and readability of data patterns. We provide the questionnaire as a document with implementation guidelines on osf.io/9cg8j. Beyond this instrument, we contribute a discussion of how researchers have previously assessed visualization readability, and an analysis of the factors underlying perceived readability in visual data representations.

Index Terms—Visualization, readability, validated instrument, perception, user experiments, empirical methods, methodology.

1 Introduction

When looking at examples of data visualizations, it is intuitively clear that some are easier to read than others. For many data analysis use cases, poor readability will drastically reduce the usefulness of a visual representation of data for the viewer. As such, readability is a basic quality criterion in data visualization [53]. One of the fundamental challenges in studying the readability of data visualizations, however, is that the concepts of *reading* and *readability* are held as tacit knowledge. The terms are often used in scientific writing without clear definitions of what they specifically mean in the context of data visualization—recalling Kosara's "empire built on sand" [54].

Readability of text is broadly defined as "the quality of being easy and enjoyable to read" [19]. It applies to letters and words as well as entire books. Linguists have developed hundreds of formulas to analyze the readability of texts [8], but this approach fails to take into account characteristics of readers. Since readability is better explained as a function of the interaction between the properties of texts and the characteristics of readers [5], researchers now seek to analyze text difficulty based on cognitive theories. Such an approach may also be suitable to explore the readability of visual representations of data.

As we discuss in more detail below, a few definitions of "readability" exist in the visualization domain, yet they do not fully overlap. As a result, it is unclear to what extent different approaches to measuring readability can thoroughly capture the concept. In addition, we do not have a definition of what "reading" a data visualization is as a cognitive activity. Cognitive processes in visualization range from low-level visual perception [83] to high-level activities such as data exploration [111], insight and knowledge generation [86, 97], sense-making of unfamiliar visualizations [58], or decision-making [74]. Current cognitive models of visualization comprehension [37, 48, 74] provide important theoretical grounding to explain how people process information from visual data representations; the models, however, do not specify the boundaries of "reading" within the cognition continuum.

Our work is based on the fundamental premise that readability is a crucially important quality criterion in data visualization. As such, it requires formal definition and ***empirically verified*** methods to study it. In this paper we present the development and validation of our PREVis questionnaire. PREVis is a reliable instrument that allows respondents to rate how readable they find a static data visualization across 4 dimensions: layout clarity, ease of understanding, ease of reading data features, and ease of reading data values. During the development process, we also had to take first steps in clarifying what readability means in data visualization. This clarification is important because discrepancies in the use of terminology pose issues of comparability and reliability of empirical findings. In particular, we observed that researchers who asked participants to rate the readability of visualization did so using a wide variety of terms and answer options. Our PREVis tool addresses this problem because we followed well-established methodologies in scale development [12, 30]. Developing a valid scale

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Manuscript received xx xxx. 202x; accepted xx xxx. 202x. Date of Publication xx xxx. 202x; date of current version xx xxx. 202x. For information on obtaining reprints of this article, please send e-mail to: reprints@ieee.org. Digital Object Identifier: xx.xxxx/TVCG.202x.xxxxxxx

Summary

Contribution of my thesis

Theory

- clarification of terminology
- a design space of pattern

Empirical studies

- on aesthetics
- on effectiveness

Scale development

- introduce the methodology of scale development into community
- a validated scale for measuring aesthetic pleasure of visualization

Publication list

Peer-Reviewed Journal Articles

Tingying He, Yuanyang Zhong, Petra Isenberg, and Tobias Isenberg. Design Characterization for Black-and-White Textures in Visualization. *IEEE Transactions on Visualization and Computer Graphics*, 30(1):1019–1029, January 2024. DOI: 10.1109/TVCG.2023.3326941. HAL: hal-04167900

Tingying He, Petra Isenberg, Raimund Dachselt, and Tobias Isenberg. BeauVis: A Validated Scale for Measuring the Aesthetic Pleasure of Visual Representations. *IEEE Transactions on Visualization and Computer Graphics*, 29(1):363–373, January 2023. DOI: 10.1109/TVCG.2022.3209390. HAL: hal-03763559

Anne-Flore Cabouat, Tingying He, Petra Isenberg, and Tobias Isenberg. PREVis: Perceived Readability Evaluation for Visualizations. Submitted to *IEEE Visualization 2024*.

In Preparation

Tingying He, Jason Dykes, Petra Isenberg, Tobias Isenberg. Toward an Understanding of 'Pattern' as a Visual Variable.

Peer-Reviewed Workshop Papers

Anne-Flore Cabouat, Tingying He, Florent Cabric, Tobias Isenberg, and Petra Isenberg. Position Paper: A Case to Study the Relationship between Data Visualization Readability and Visualization Literacy. In *Proceedings of CHI Workshop "Toward a More Comprehensive Understanding of Visualization Literacy"*, 2024. HAL: hal-04523790

Tingying He, Petra Isenberg, and Tobias Isenberg. Data Embroidery with Black-and-White Textures. In Lonni Besançon, Derya Akbaba, Andrew McNutt, Sara Di Bartolomeo, and Victor Schetinger, editors, In *Proceedings of the alt.VIS Workshop (at IEEE VIS, 23 October, Melbourne, Australia)*, article no. 3, 5 pages, 2023. HAL: hal-04197527

Alaul Islam, Lijie Yao, Anastasia Bezerianos, Tanja Blascheck, Tingying He, Bongshin Lee, Romain Vuillemot, Petra Isenberg. Reflections on Visualization in Motion for Fitness Trackers. In *Proceedings of New Trends in HCI and Sports Workshop (at MobileHCI, September 2022, Vancouver, Canada)*, ACM Press, New York, NY, USA, 2022. HAL: hal-03775633

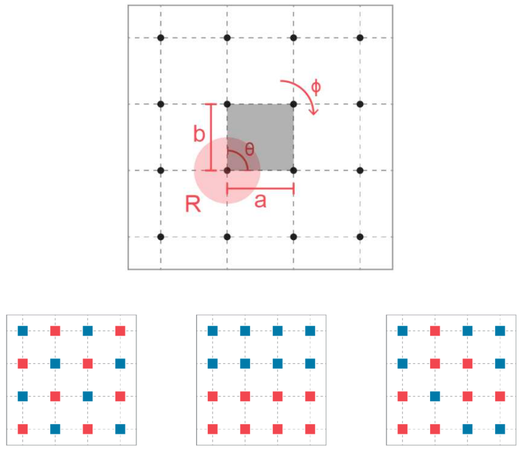
Under Review

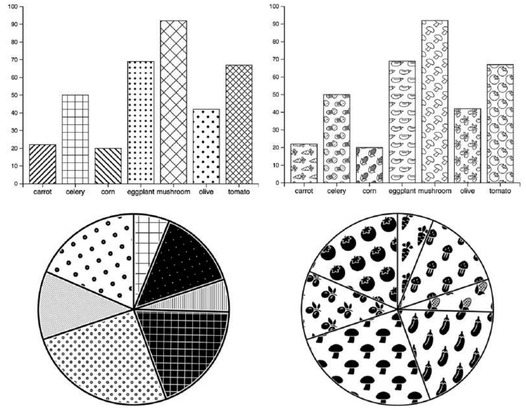
Alaul Islam, Tingying He, Anastasia Bezerianos, Bongshin Lee, Tanja Blascheck, Petra Isenberg. Submitted to *ACM Interactive Surfaces and Spaces Conference 2024*.

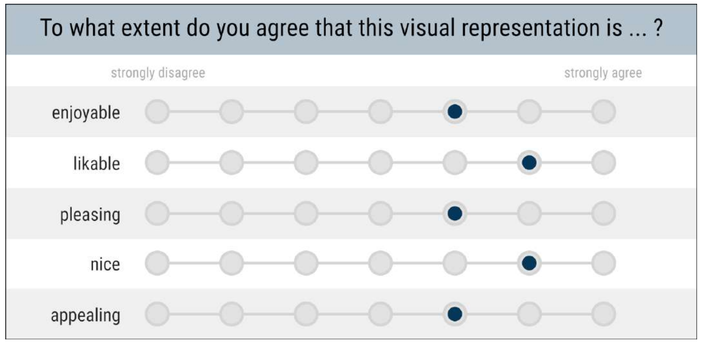
Thank you!

Encoding with Patterns

A Design Space and Evaluations







Aviz
Visual Analytics Project

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