



Visual Variables

Introduction

- Our usual way of communicating is with words. Written words consist of single symbols (letters), gaining meaning when arranged in certain combinations.
- The question is: If there are basic visual symbols arranged in a particular way, can they be used to convey information in a similar manner?
- Jaques Bertin^[3]described **marks** as these basic units and also developed a given number of methods through which these units can be modified, including position, size, shape, or color. Each of these variables can have certain **characteristics**.

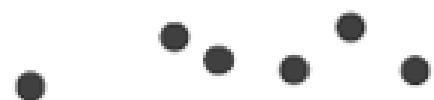
Marks are basic geometric elements that depict items or links, and channels control their appearance.

[anything used for visualization]

A **mark** is a basic graphical element in an image. Marks are geometric primitive objects classified according to the number of spatial dimensions they require.

Volume → 3D

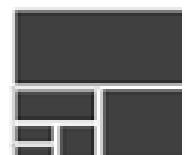
0D
→ Points



1D
→ Lines



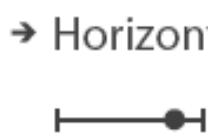
2D
→ Areas



Visual Channel

A visual **channel** is a way to control the appearance of marks, independent of the dimensionality of the geometric primitive

④ Position



④ Color



eg. Let's take `dot()` as marker

• ^{single}
 ↳ ^{color}
 ↑
 position

④ Shape



④ Tilt



④ Size

→ Length



→ Area

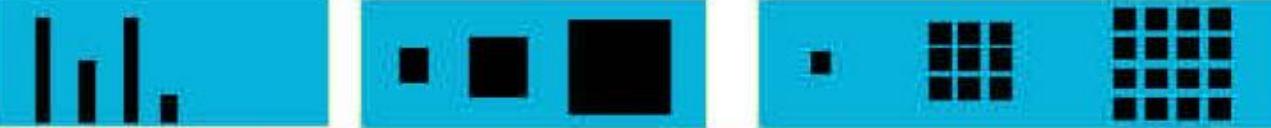
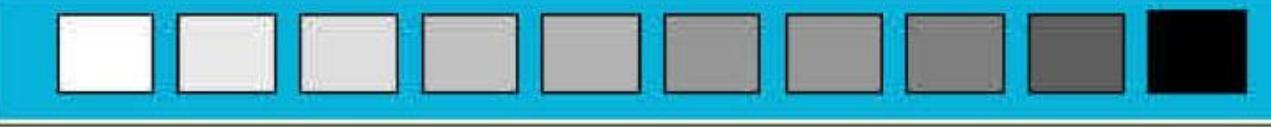
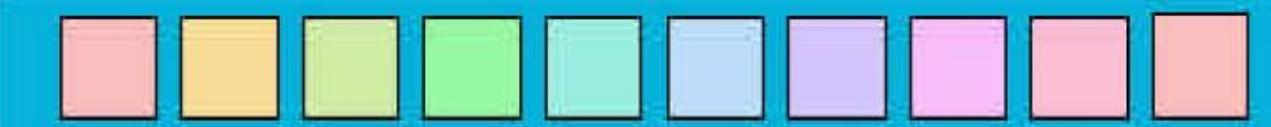
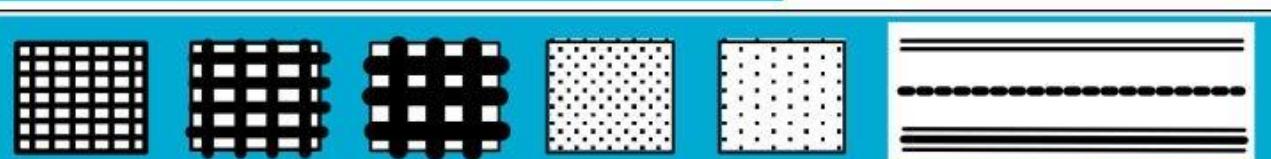


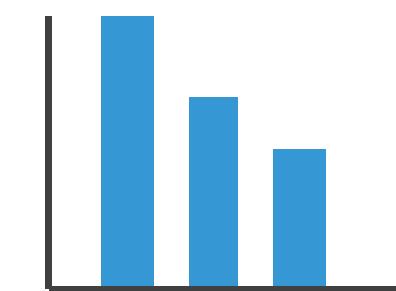
→ Volume



7 visual channels to
change the mark properties

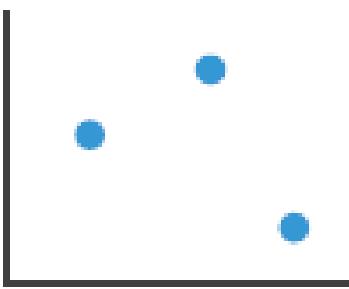
Visual variables - attributes

Bertin's Original Visual Variables	
1) Position changes in the x, y location	
2) Size change in length, area or repetition	
3) Shape infinite number of shapes	
4) Value (brightness) changes from light to dark	
5) Colour changes in hue at a given value	
6) Orientation (angles) changes in alignment	
7) Texture variation in 'grain'	



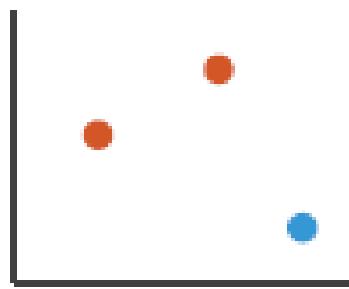
(a)

bar-charts
[size marks]



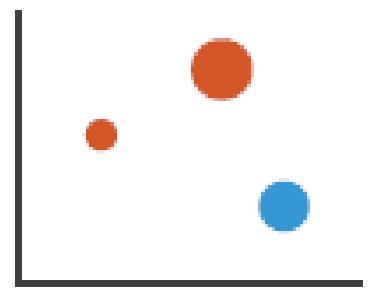
(b)

scatter



(c)

scatter
[color]

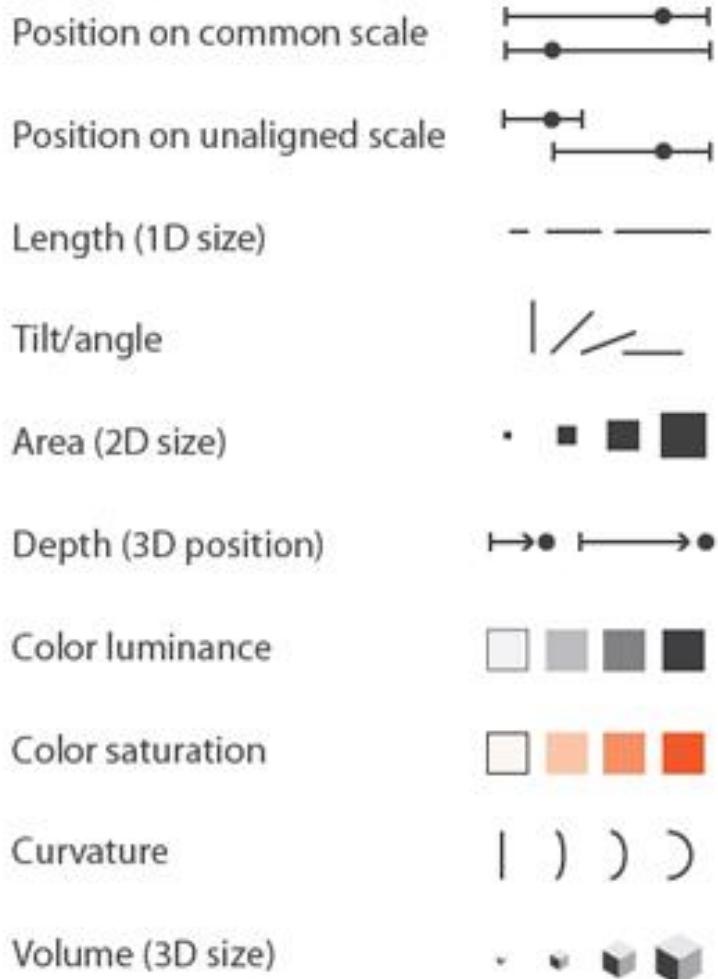


(d)

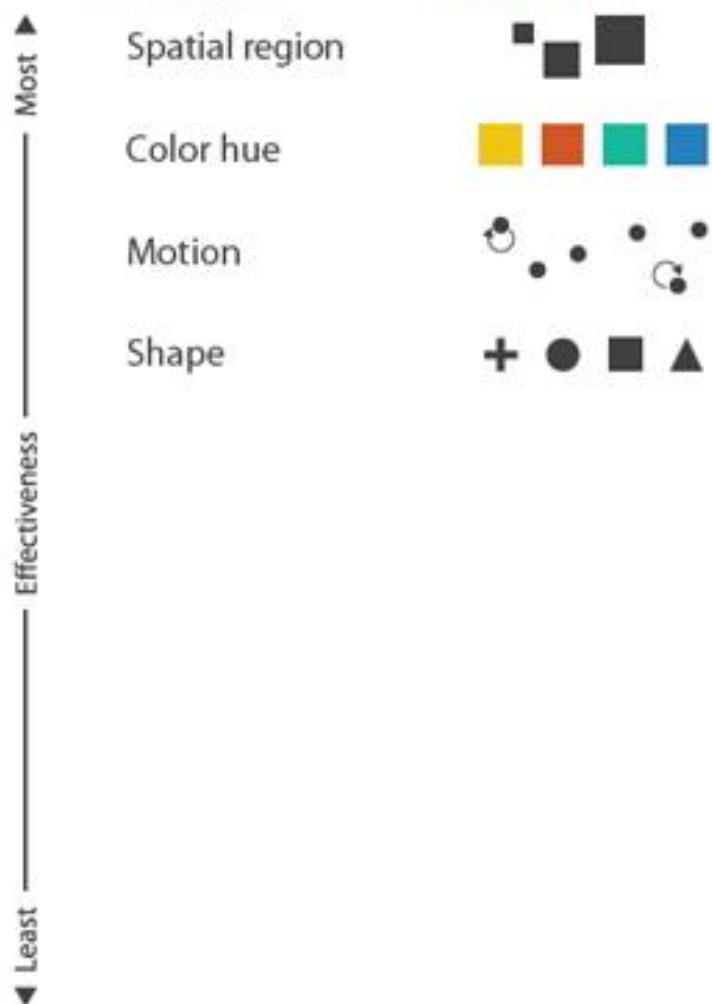
scatter
[color & size]

Channels: Expressiveness Types and Effectiveness Ranks

④ Magnitude Channels: Ordered Attributes



④ Identity Channels: Categorical Attributes



Visual variables – characteristics

- **selective** is a change enough to allow us to select it from a group?
- **associative** is a change enough to allow us to perceive them as a group?
- **quantitative** is there a numerical reading obtainable from changes in this variable?
- **order** are changes in this variable perceived as ordered?
- **length** across how many changes in this variable are distinctions perceptible?

Position

Select Associate Quantify Order Length



Position

Select Associate Quantify Order Length



Position

Select Associate Quantify Order Length



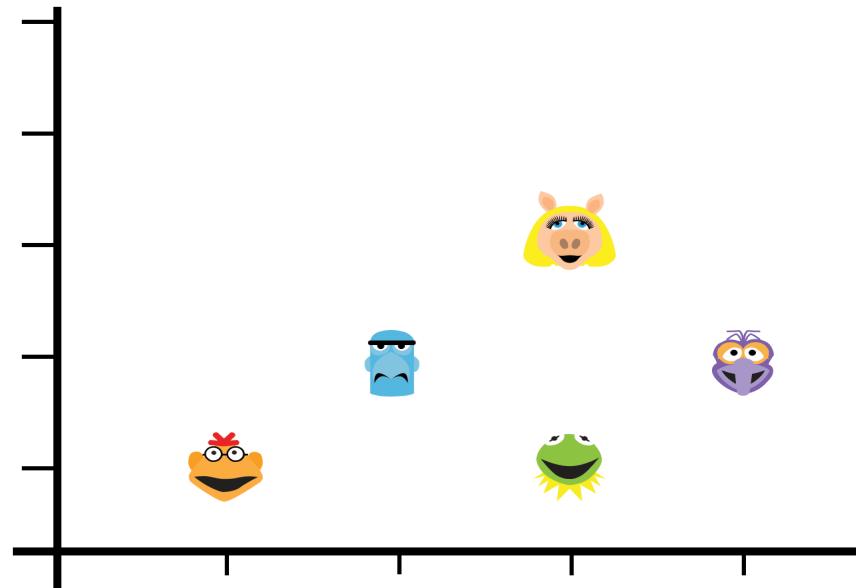
Position

Select Associate Quantify Order Length



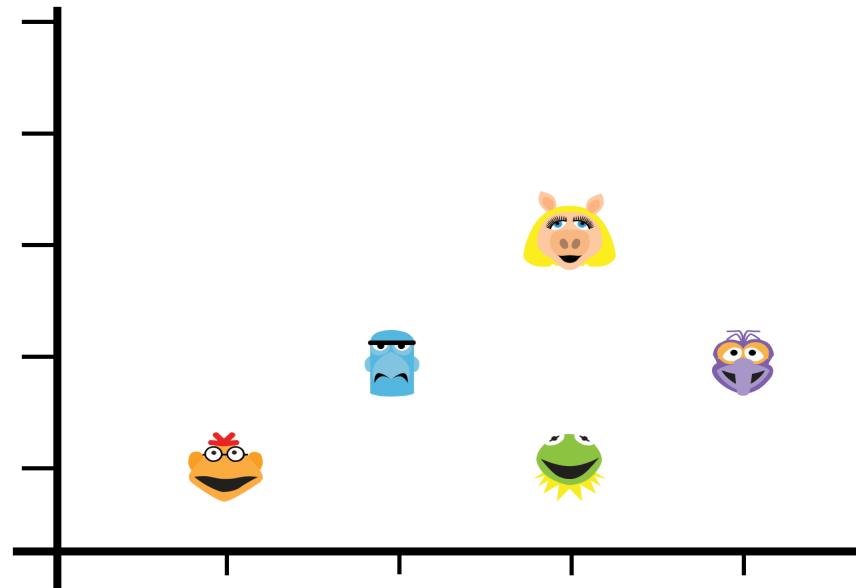
Position

Select Associate Quantify Order Length



Position

Select Associate Quantify Order Length



Position

Select Associate Quantify Order Length



✓

✓

✓



Position

Select Associate Quantify Order Length



✓

✓

✓

✓



Position

Select Associate Quantify Order Length



✓

✓

✓

✓



Position

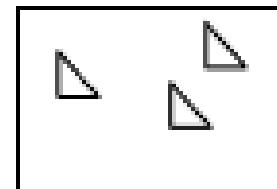
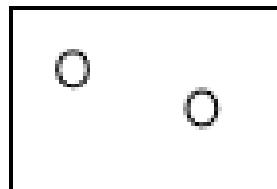
Select Associate Quantify Order Length



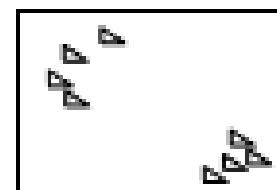
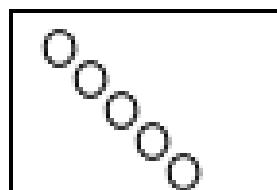
✓ ✓ ✓ ✓ ✓ ✓ (∞)

Position

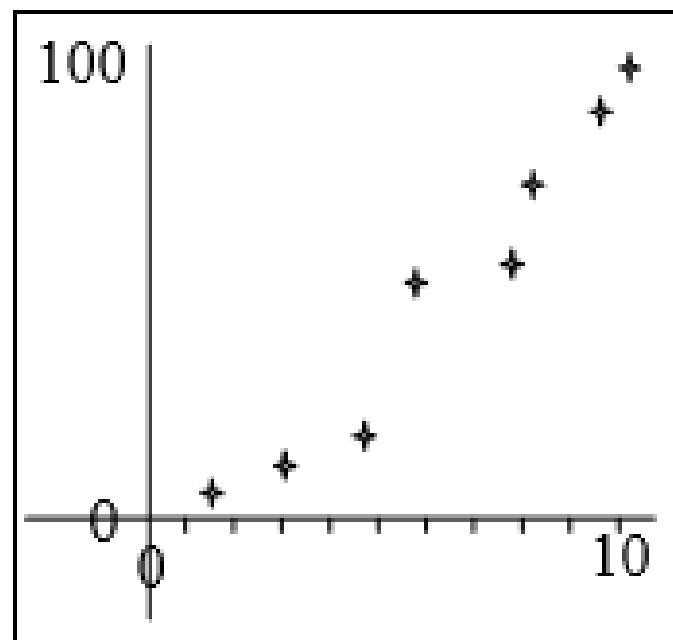
✓ selective



✓ associative



✓ quantitative



✓ order

✓ length

Is Size Selective?

find the big & small Muppets



Is Size Associative?

find all the small Muppets



Is Size Quantitative?

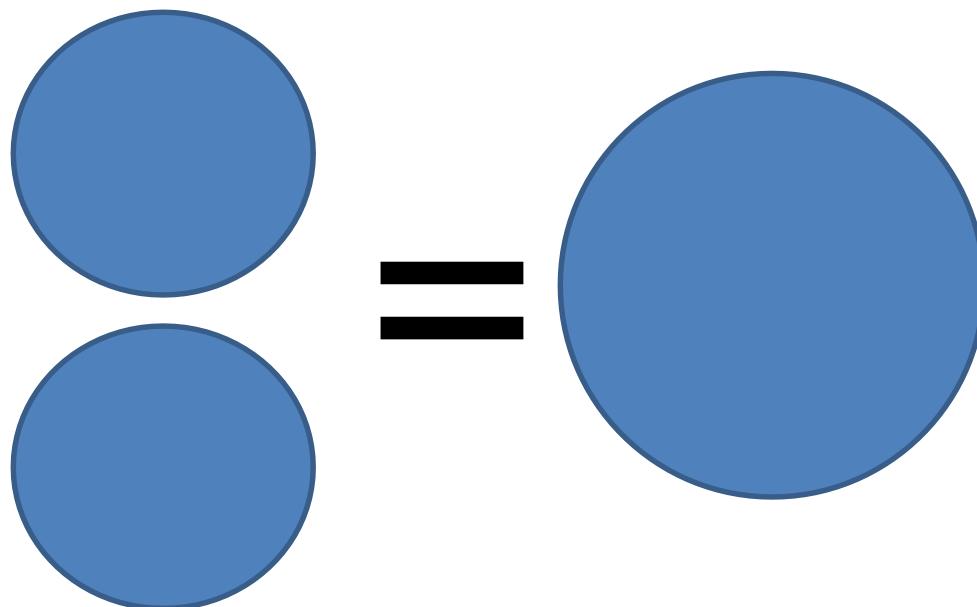
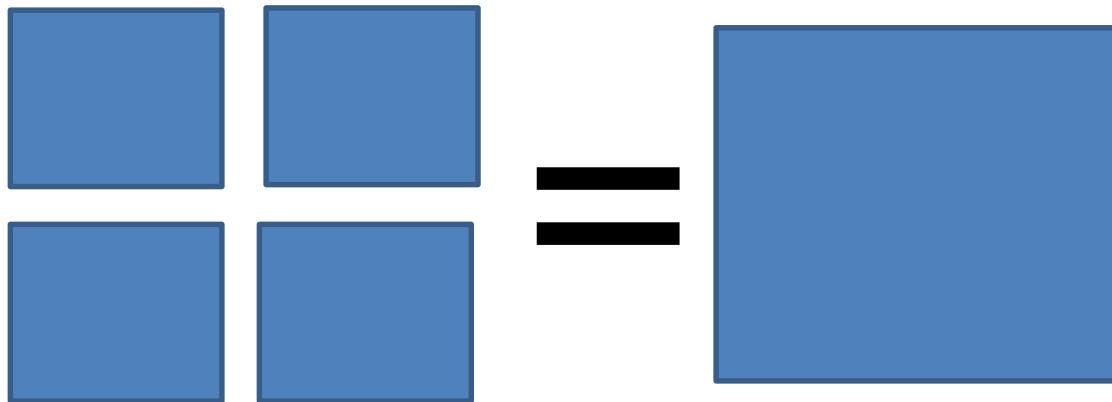
compare Kermit and
Fozzie



Is Size Quantitative?



Is Size Quantitative?



Is Size Ordered?

put the Muppets in order



Does Size Have Length?

how many different sizes can we
use/perceive?



Visual

Variable

Properties

- Selective - **can we pick it out of the crowd?**
- Associative - **can we identify groups?**
- Quantitative - **can we tell if one is 3X another?**
- Order - **can we tell order (smallest to largest)?**
- Length - **how many differences can we see?**

Size



Select Associate Quantify Order Length

e

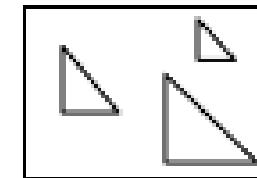
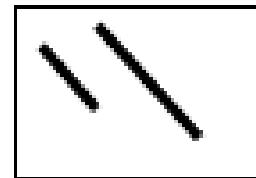
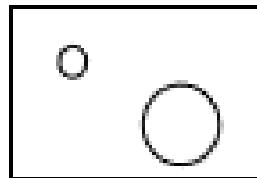
✓ ✓

✓ ~sort of ✓

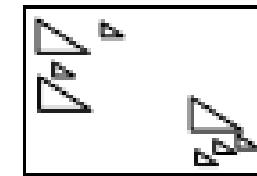
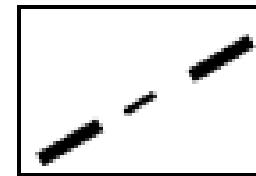
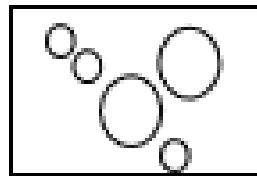
5/20

Size

✓ selective



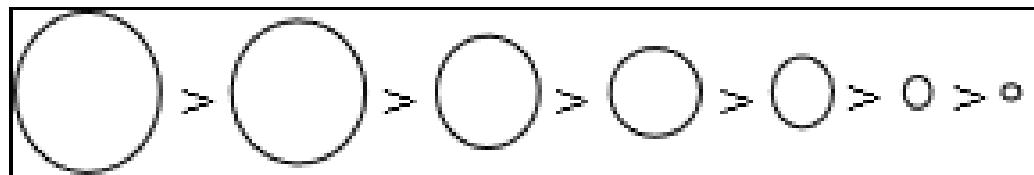
✓ associative



✗ quantitative

$$4 \times \square = \boxed{\square \square} ?$$

✓ order

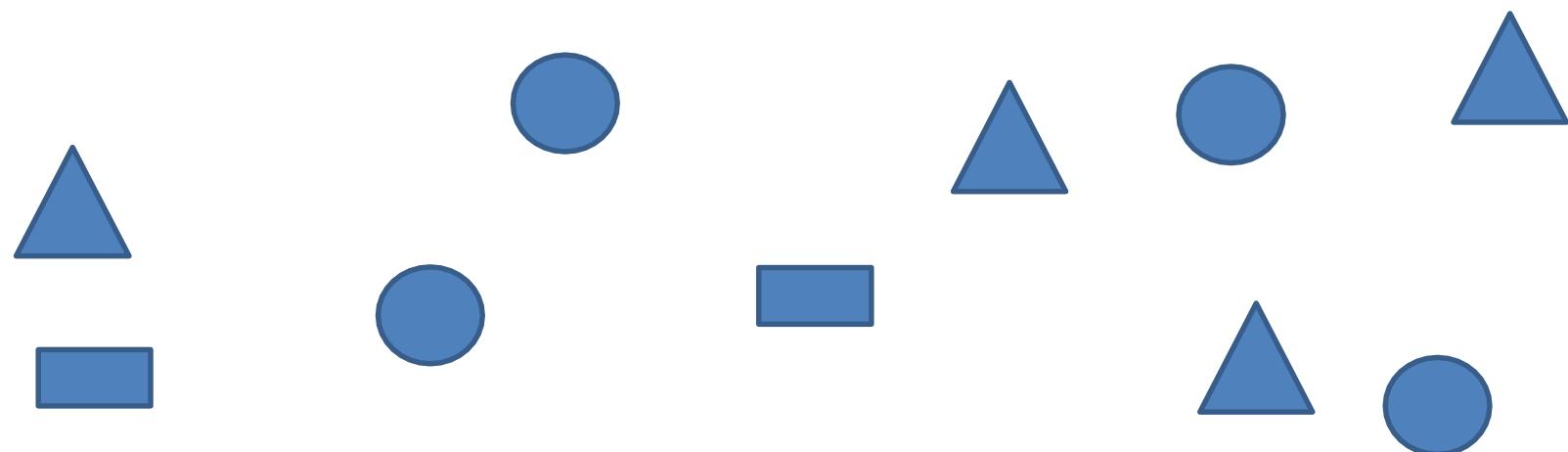


✓ length

- theoretically infinite but practically limited
- association and selection ~ 5 and distinction ~ 20

Shape

Select Associate Quantify Order Length

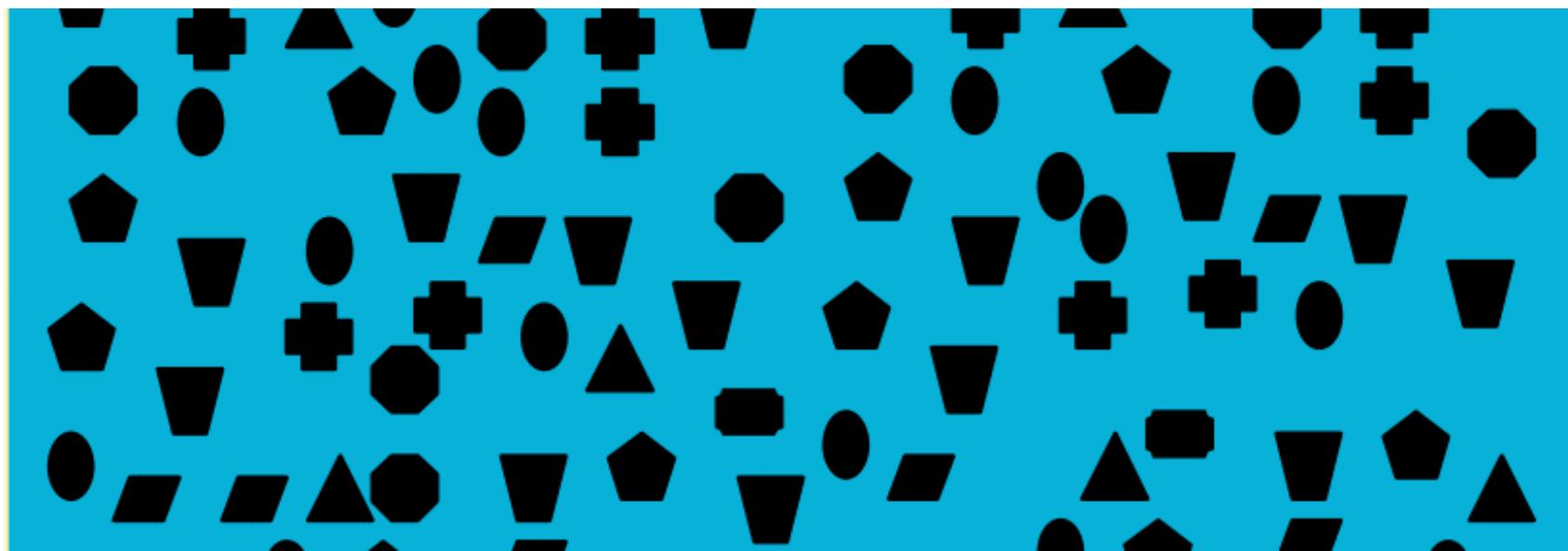


Shape

Select Associate Quantify Order Length



< 5

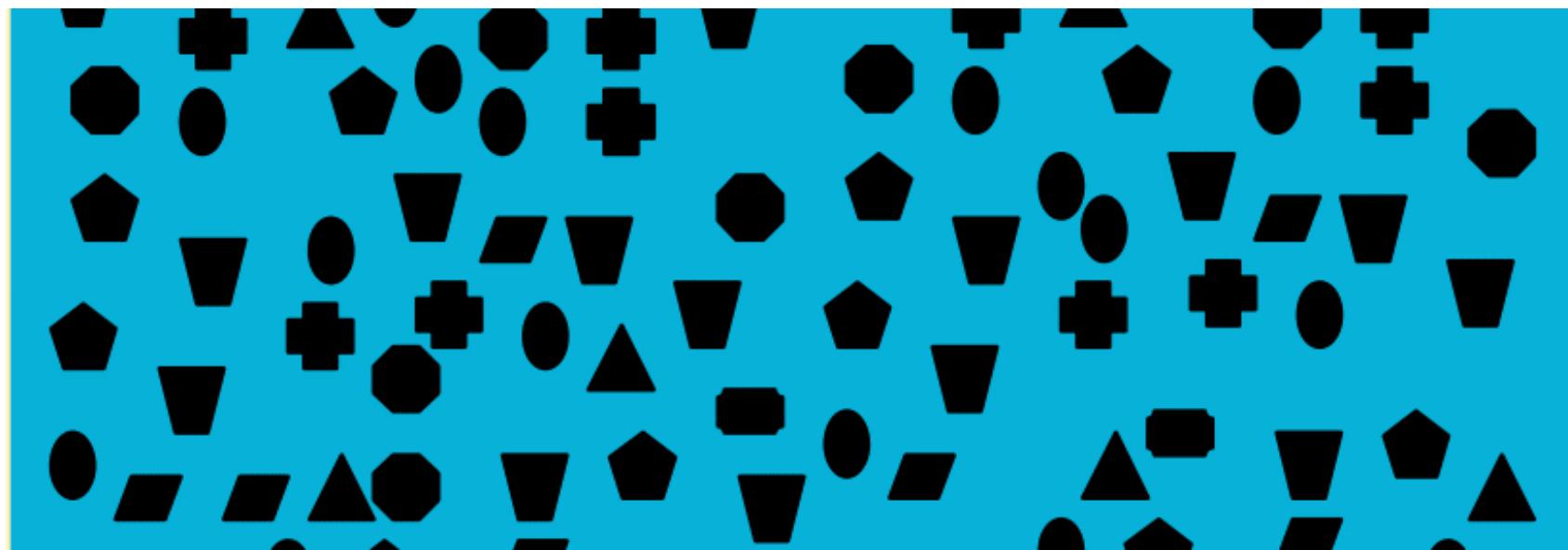


Shape

Select Associate Quantify Order Length



< 5 < 5



Shape

Select Associate Quantify Order Length

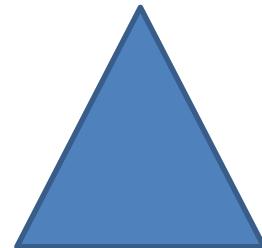
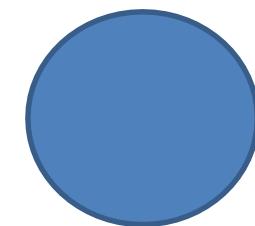


< 5

< 5

X

X

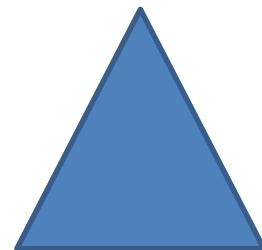
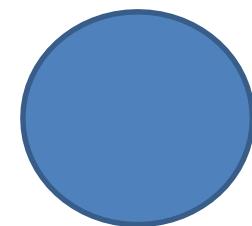


Shape

Select Associate Quantify Order Length

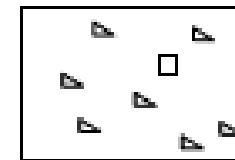
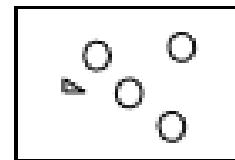
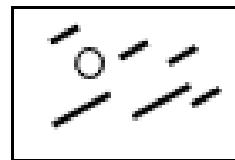


< 5 < 5 X X 5 /∞

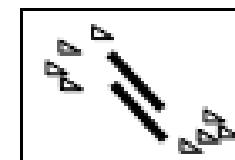
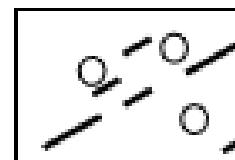
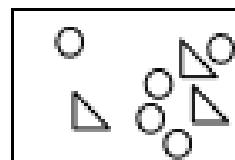


Shape

↳ selective



↳ associative

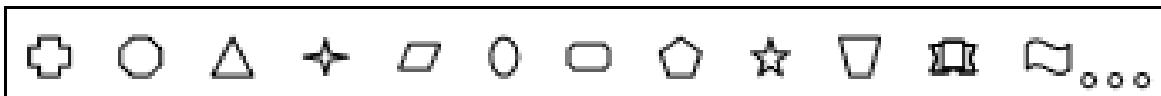


✗ quantitative



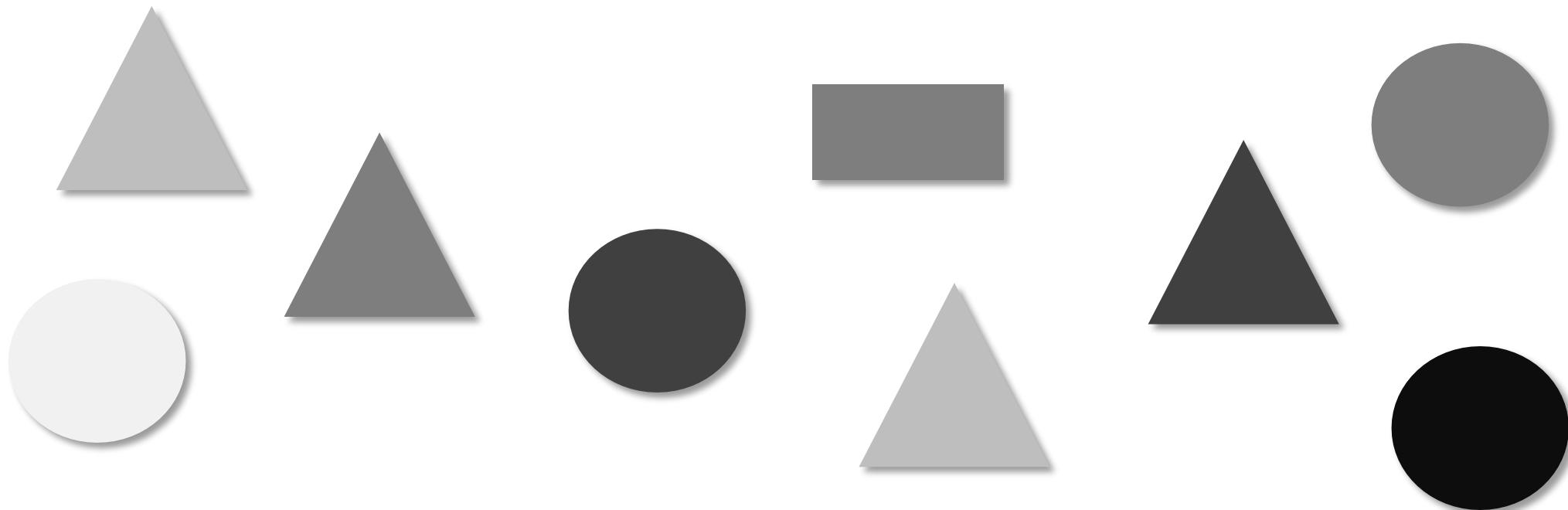
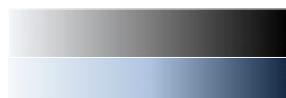
✗ order

✓ length - infinite variation



Saturation/Lightness

Select Associate Quantify Order Length

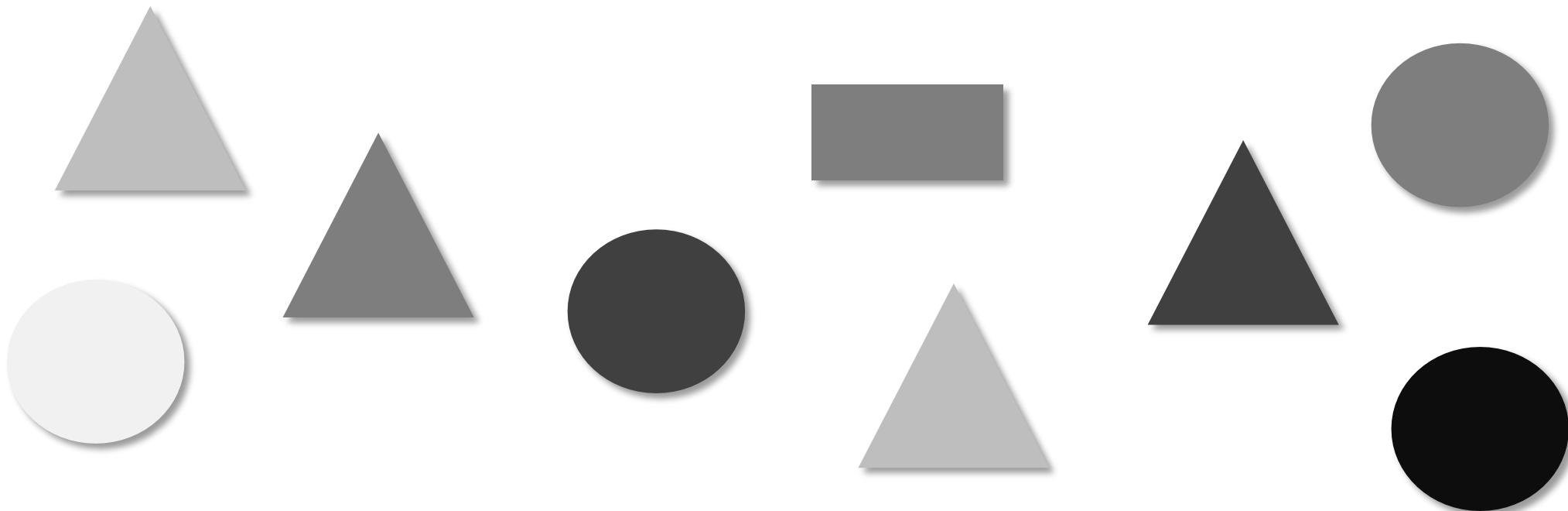


Saturation/Lightness

Select Associate Quantify Order Length

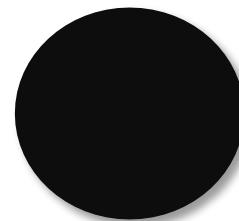
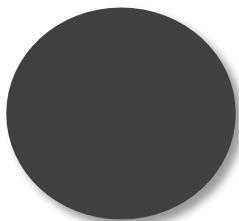
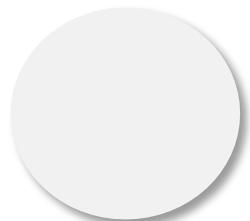


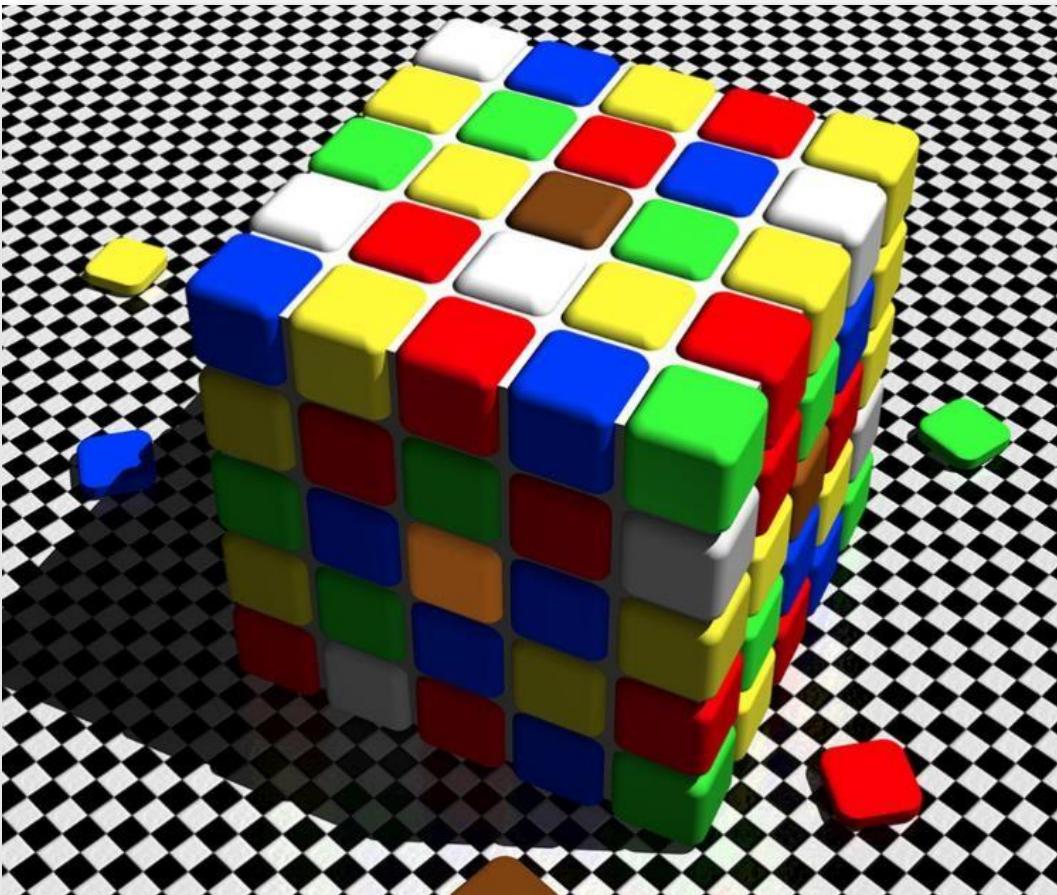
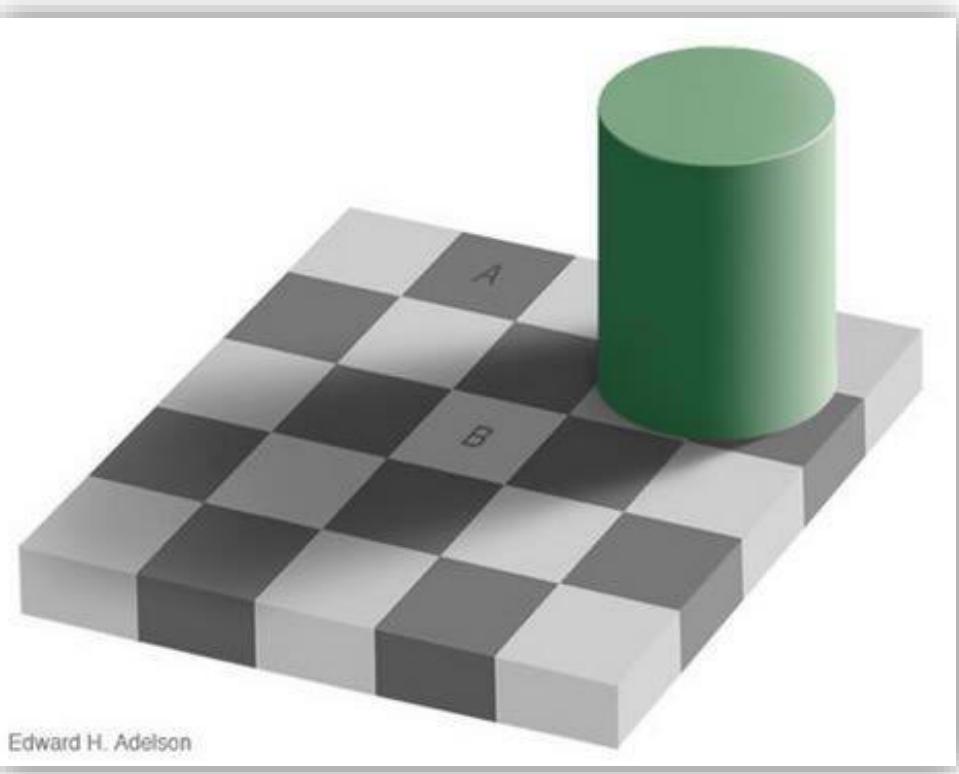
✓ ✓



Saturation/Lightness

Select Associate Quantify Order Length





Weber's Law: human perception is fundamentally based on relative judgments, not absolute values.

Saturation/Lightness

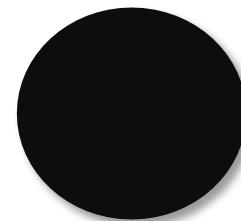
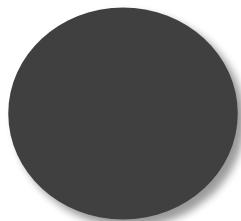
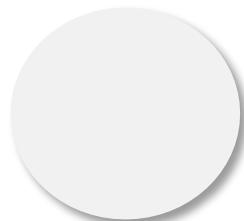
Select Associate Quantify Order Length



✓

✓

X



Saturation/Lightness

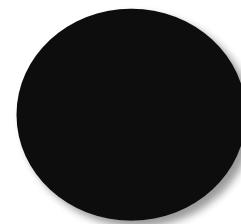
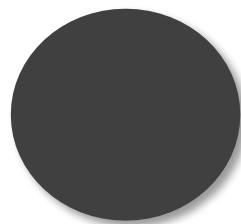
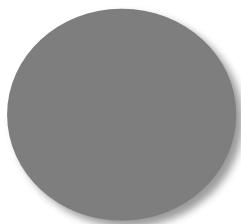
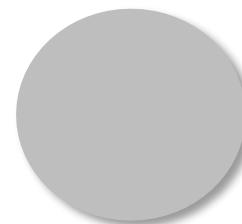
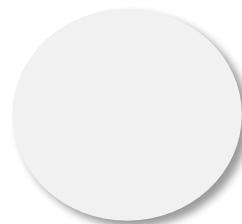
Select Associate Quantify Order Length



✓

✓

X



Saturation/Lightness

Select Associate Quantify Order Length

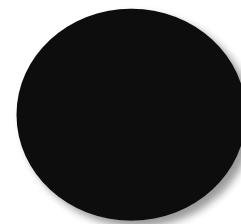
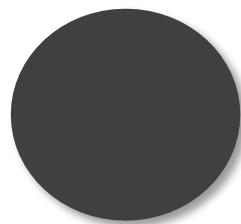
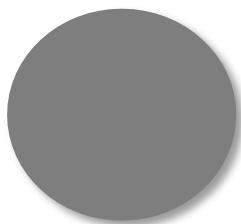
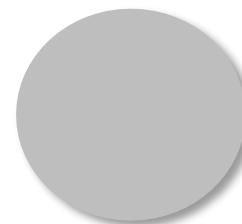
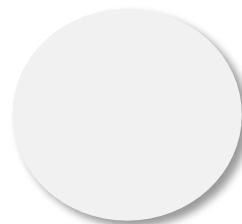


✓

✓

X

✓



Saturation/Lightness

Select Associate Quantify Order Length

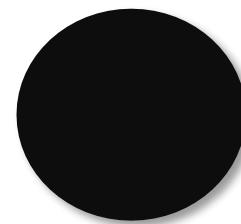
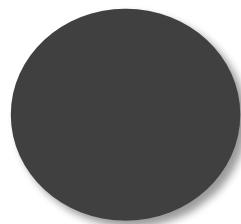
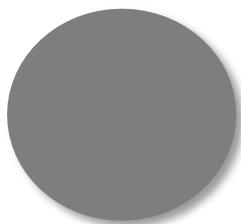
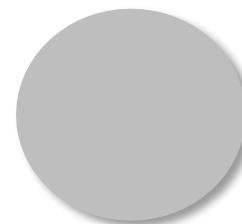
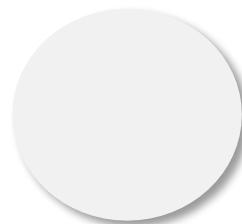


✓

✓

X

✓



Saturation/Lightness

Select Associate Quantify Order Length



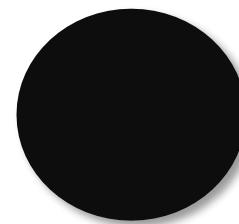
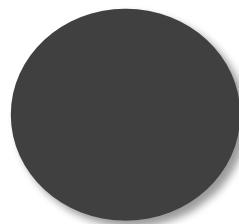
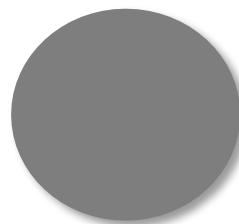
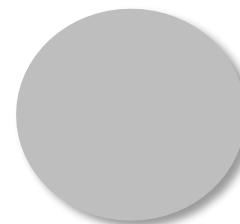
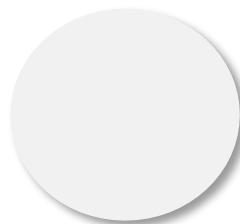
✓

✓

X

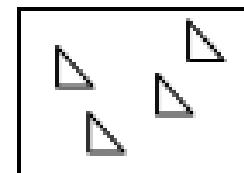
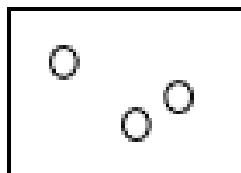
✓

7 / 10

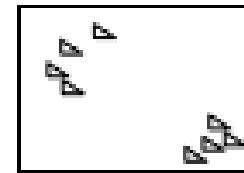
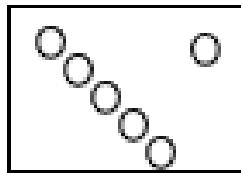


Value

✓ selective

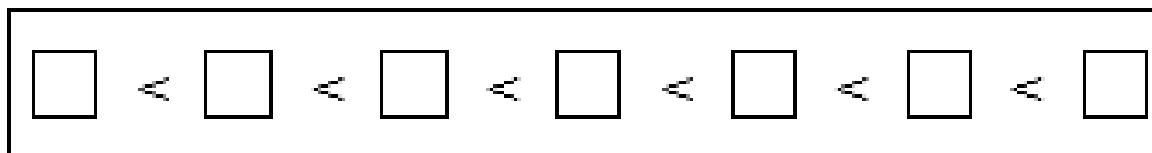


✓ associative



✗ quantitative

✓ order



✓ length

- theoretically infinite but practically limited
- association and selection ~ < 7 and distinction ~ 10

Hue

Select Associate Quantify Order Length



Hue

Select Associate Quantify Order Length



Hue

Select Associate Quantify Order Length



Hue

Select Associate Quantify Order Length

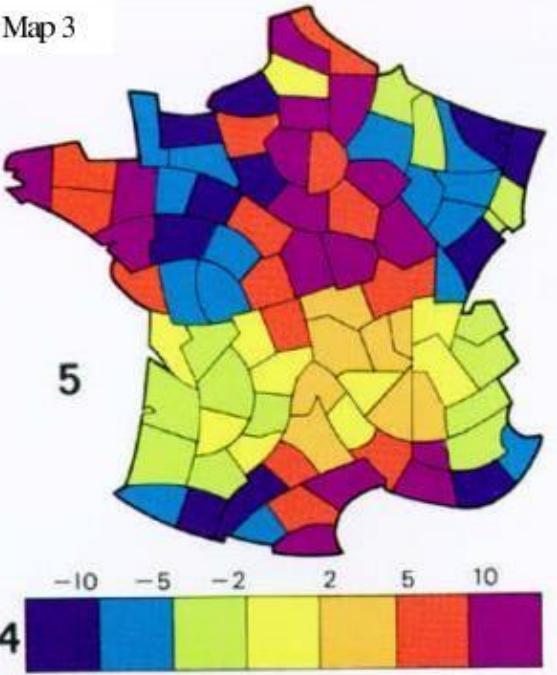


Rainbow Scale Considerations

Map 1



Map 3

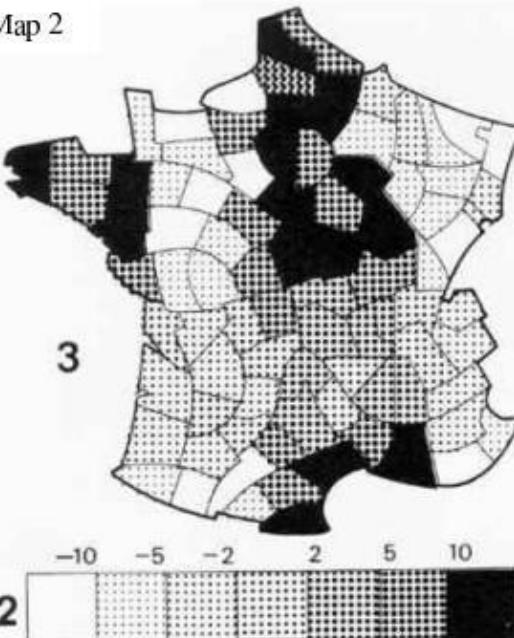


Rainbow Scale Considerations

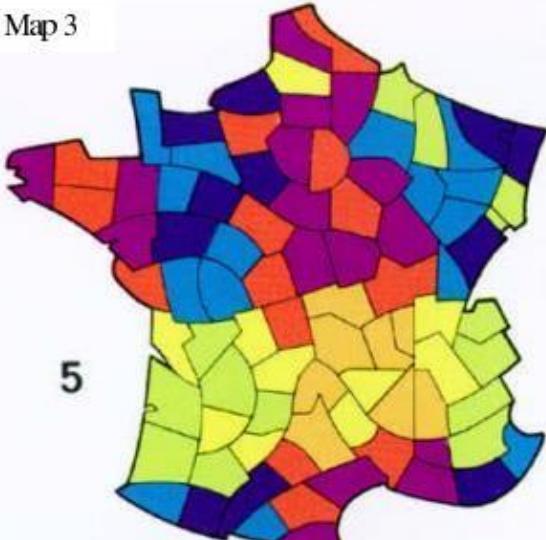
Map 1



Map 2

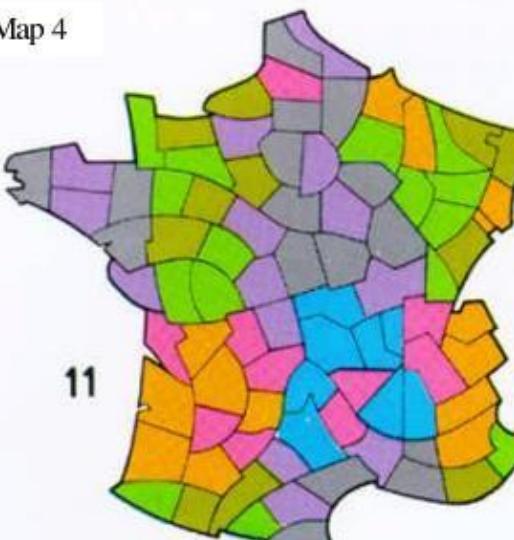


Map 3

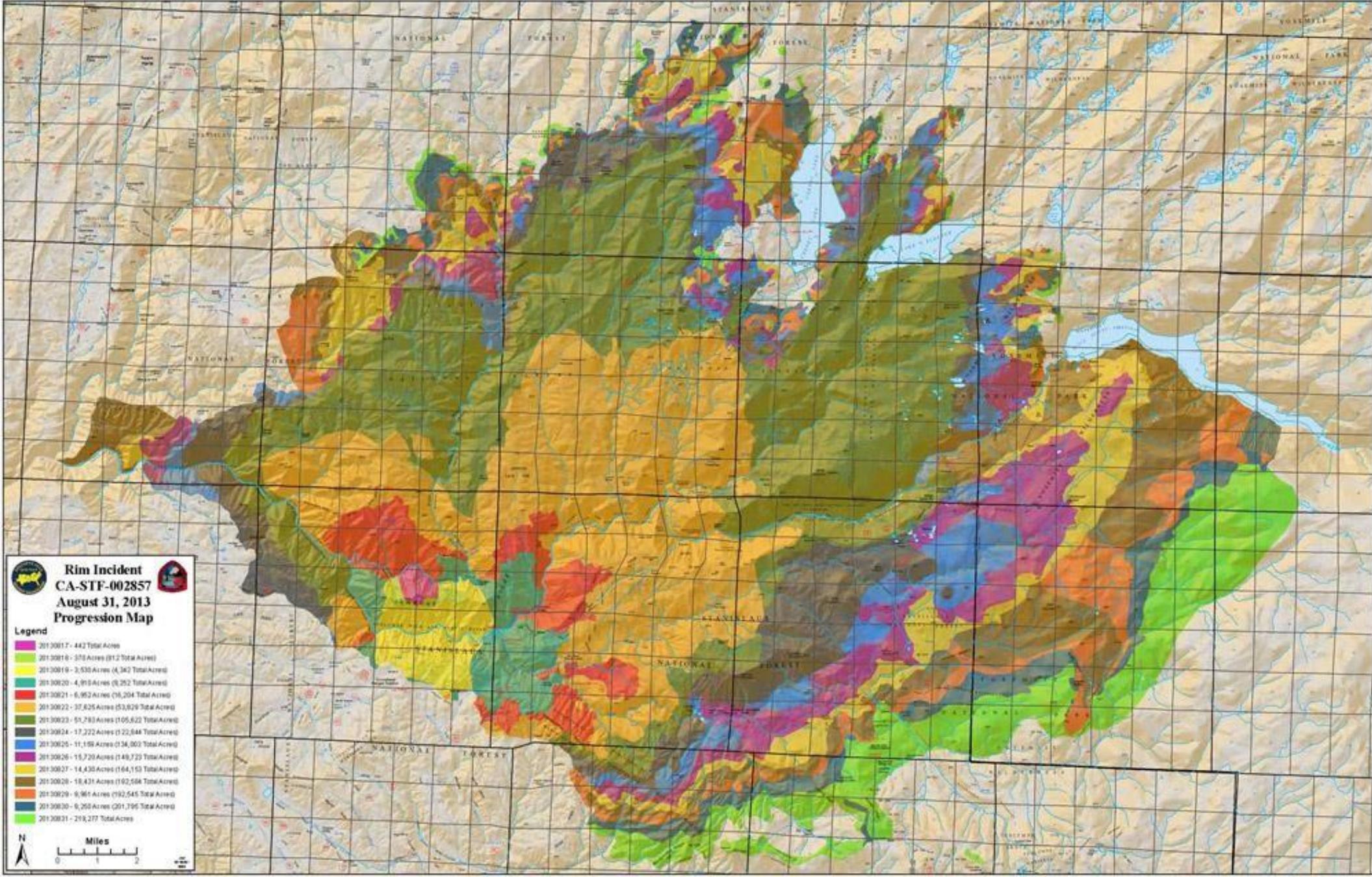


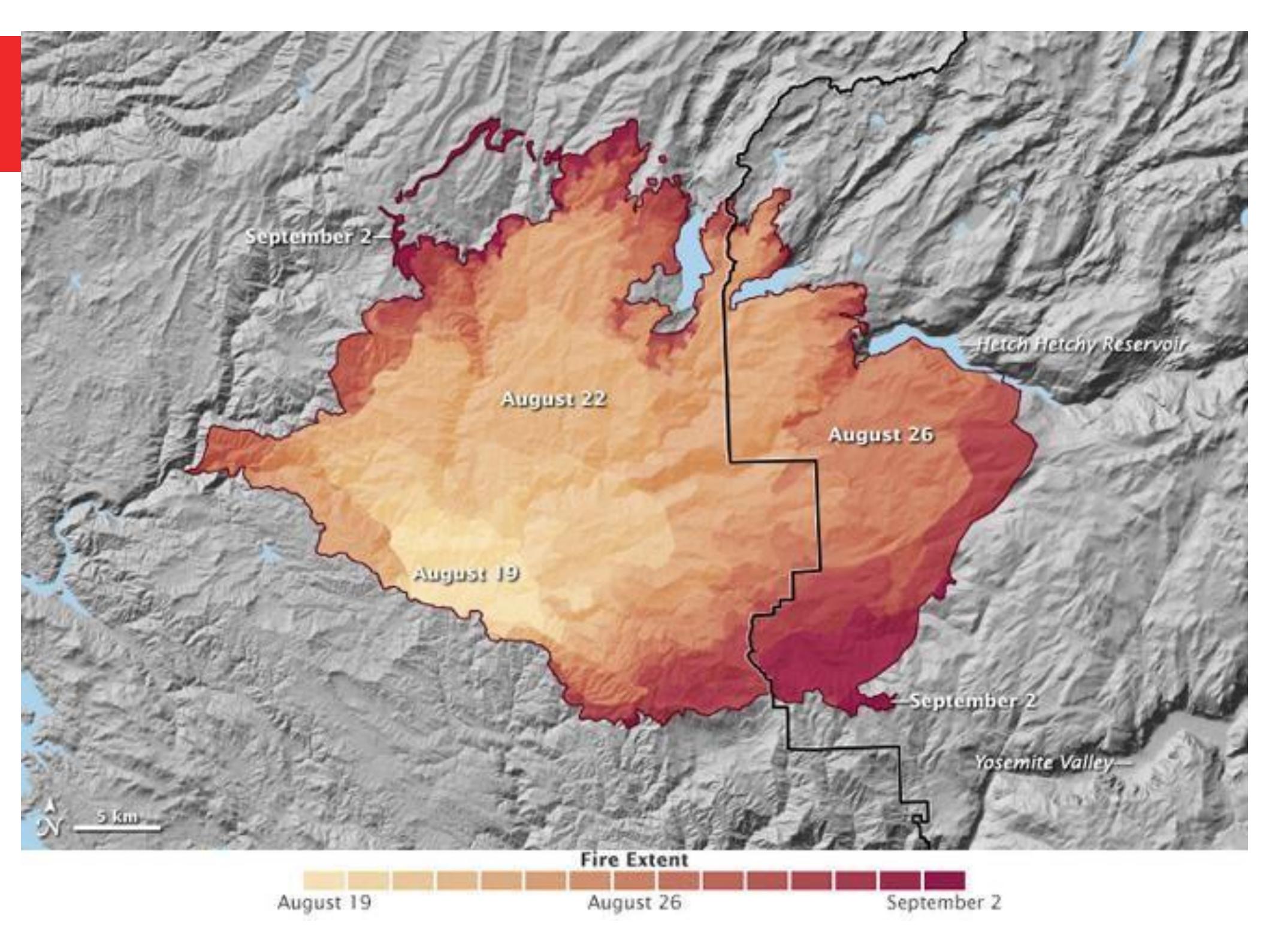
4

Map 4



10





September 2

August 22

August 19

August 26

September 2

Yosemite Valley

August 19

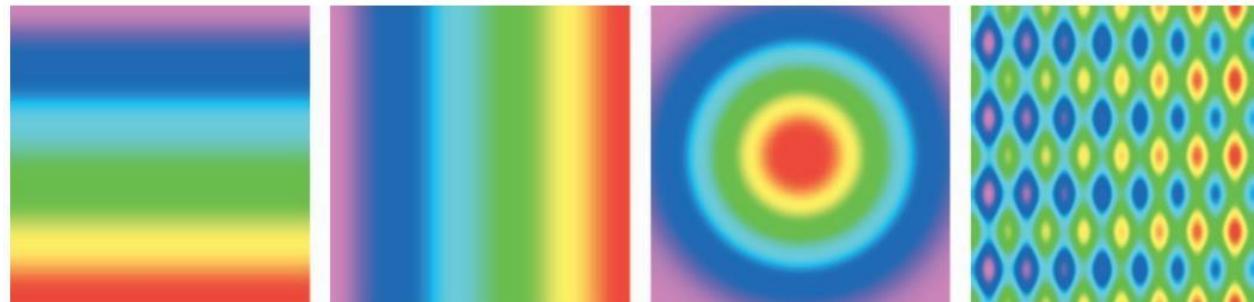
Fire Extent

September 2

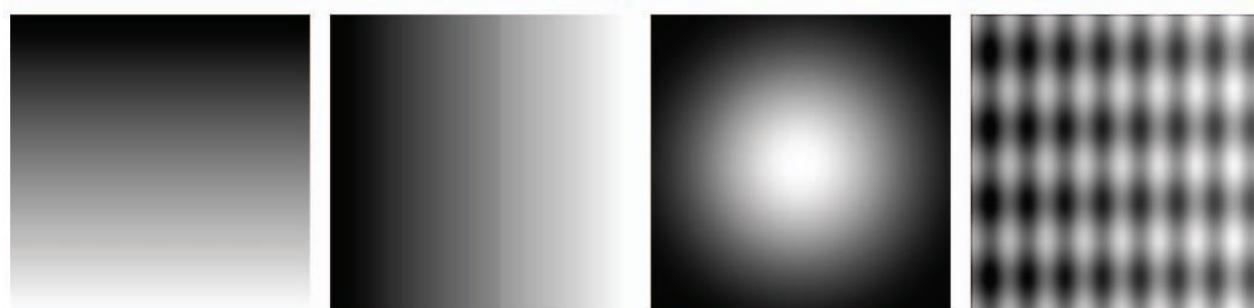




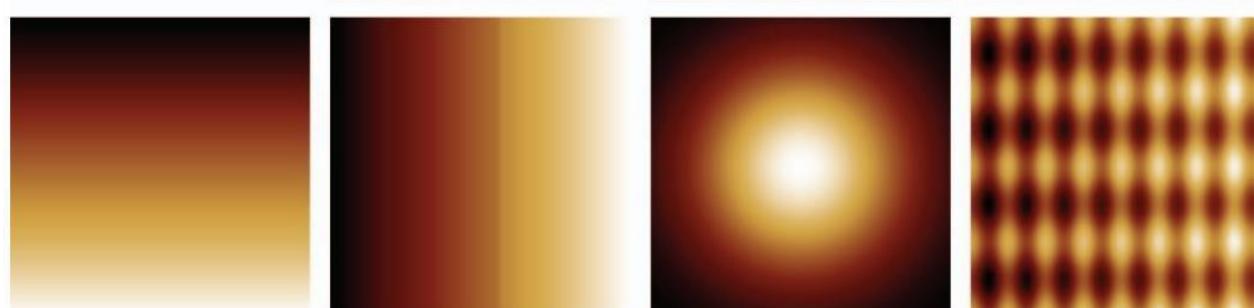
Rainbo
w



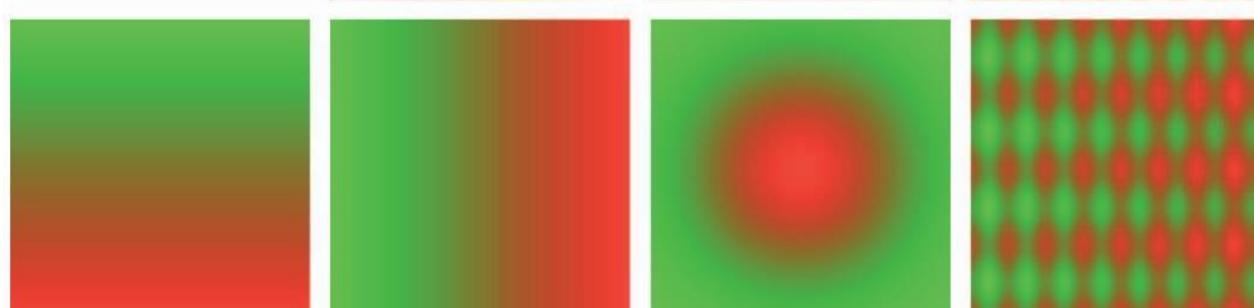
Gra
y



Black-
Body
Radiation



Red-
Green



Hue

Select Associate Quantify Order Length



Hue

Select Associate Quantify Order Length



✓

✓

✗

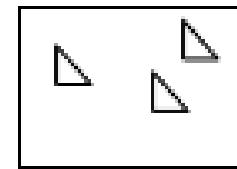
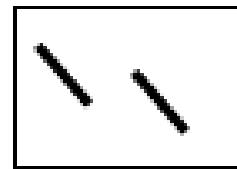
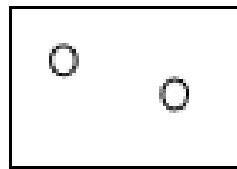
✓

7 / 10

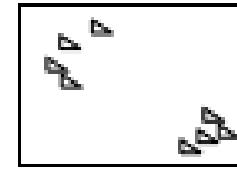
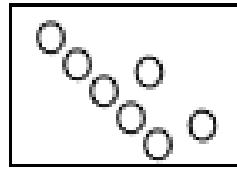


Color

✓ selective

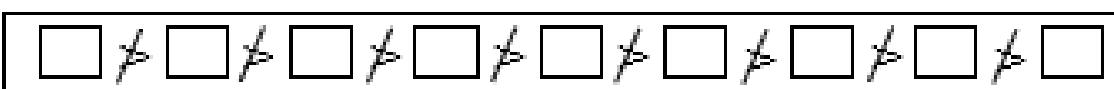


✓ associative



✗ quantitative

✗ order



✓ length

- theoretically infinite but practically limited
- association and selection $\sim < 7$ and distinction ~ 20

Angle

Select Associate Quantify Order Length
e

| / —



Angle

Select Associate Quantify Order Length
e

| / — ✓



✓



X



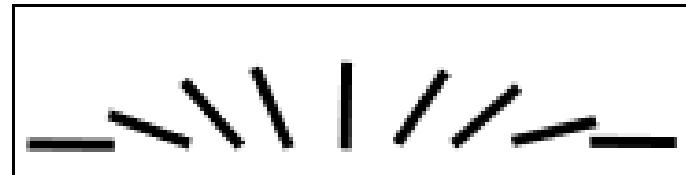
X



4 / 8

Orientation

✓ selective

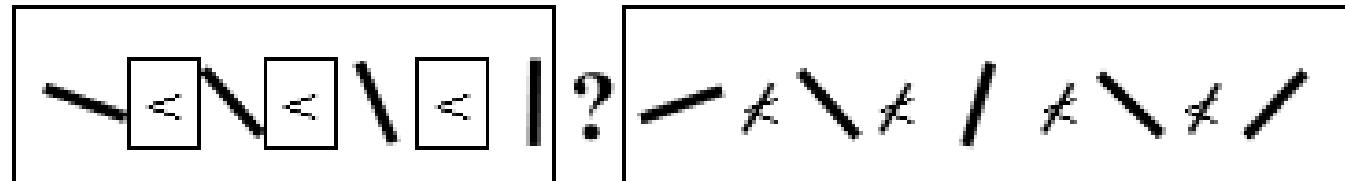


✓ associative



✗ quantitative

✗ order

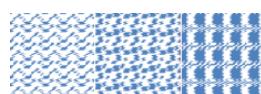


✓ length

- ~5 in 2D; ? in 3D

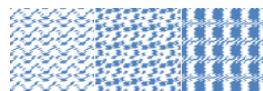
Texture

Select Associate Quantify Order Length



Texture

Select Associate Quantify Order Length



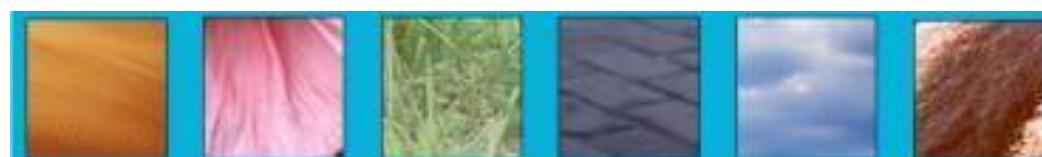
✓

✓

X

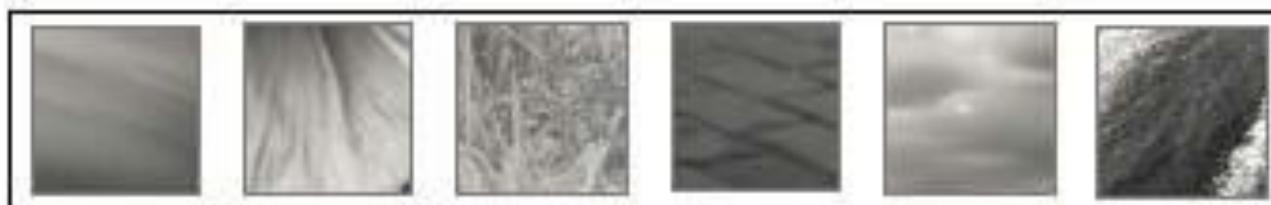
X

✓

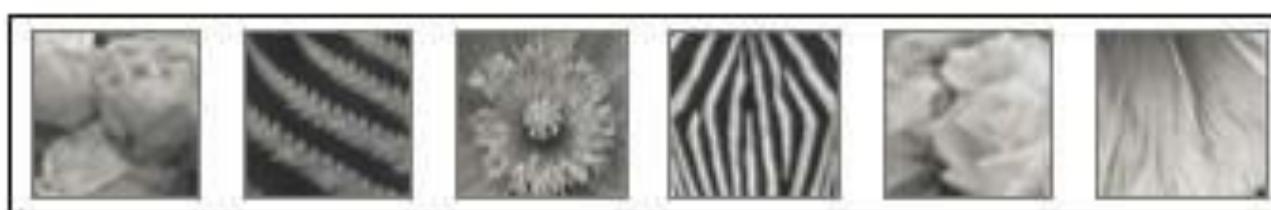


Texture

✓ selective

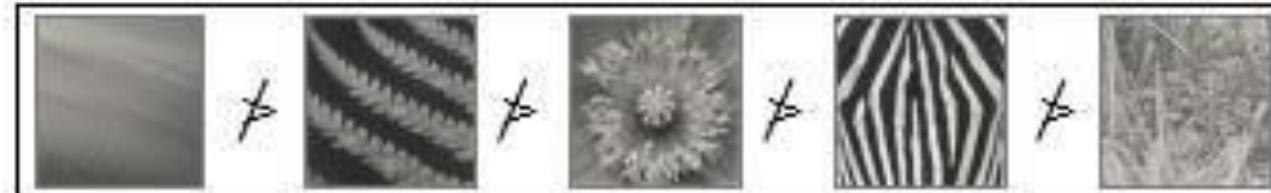


✓ associative



✗ quantitative

✗ order



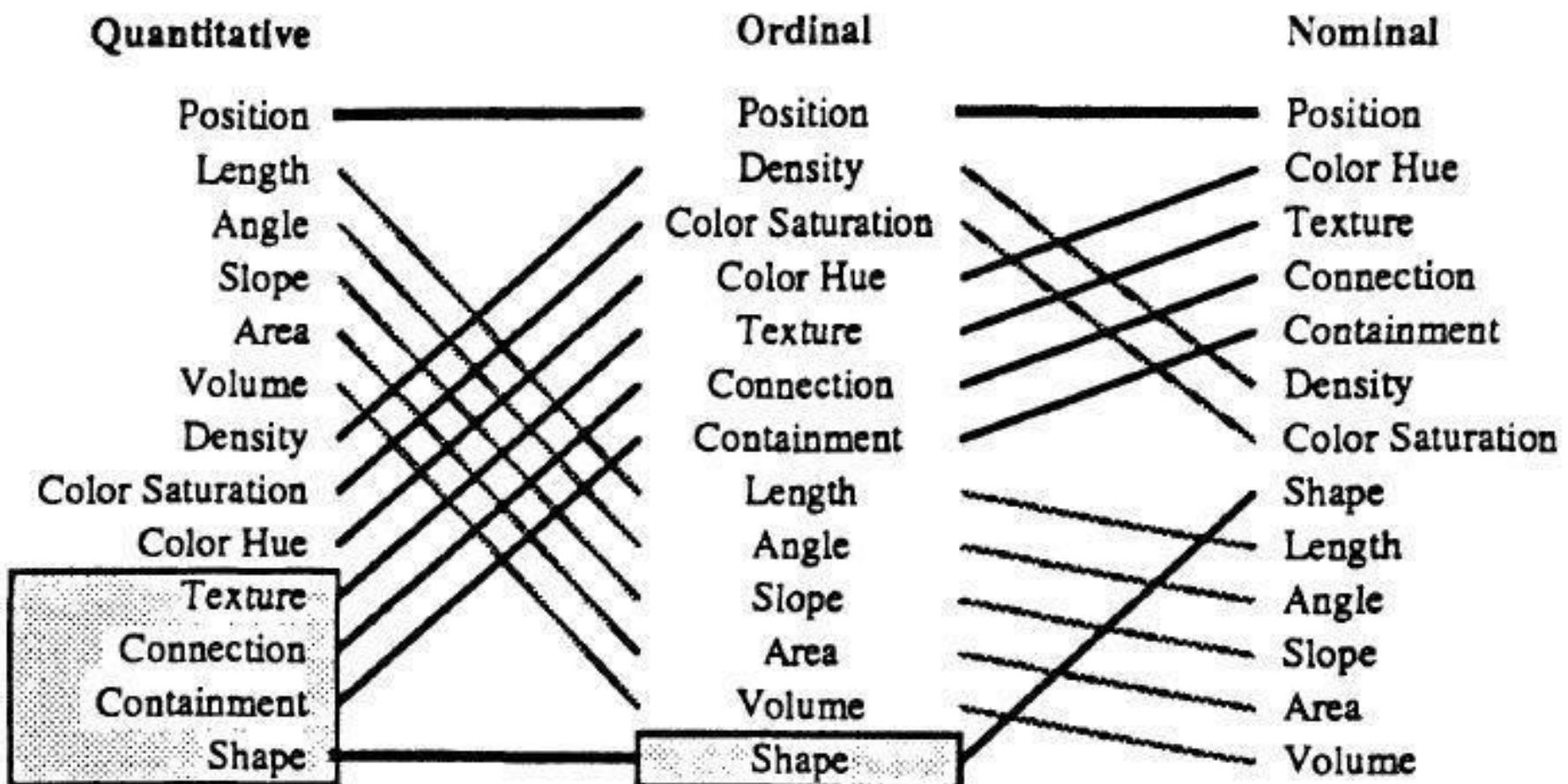
✓ length

– theoretically infinite

Conclusion

Visual Variables	Characteristics				
	Selective	Associative	Quantitative	Order	Length
Position	● ●	●● ●●	↑	↑	Theoretically Infinite
Size	● ●●	●●●●●		●●●●●	Selection: ~5 Distinction: ~20
Shape					Theoretically Infinite
Value	○●○○○○	●○○●○○●		○○○○○●	Selection: <7 Distinction: ~10
Color	● ○	○○●○○●			Selection: <7 Distinction: ~10
Orientation	\\ /				Theoretically Infinite
Texture	○○	○○○○○○			Theoretically Infinite

Ranking of perceptual tasks



Traffic accident victims France 1958

pedestrians 28,951

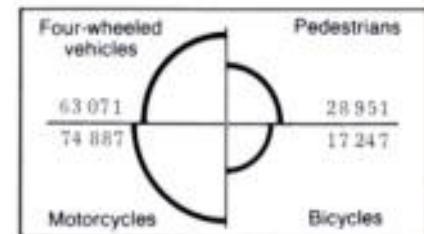
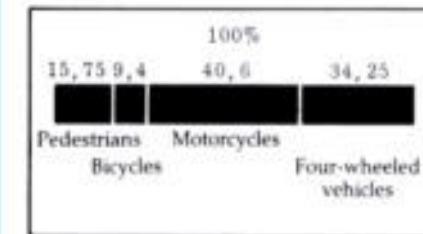
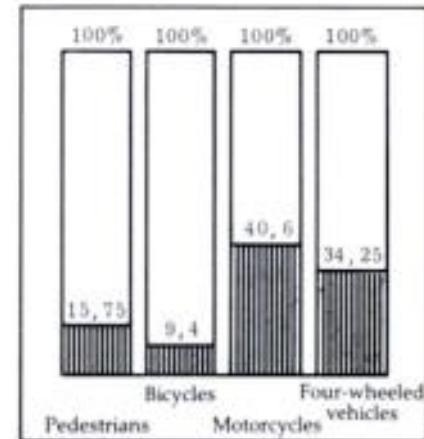
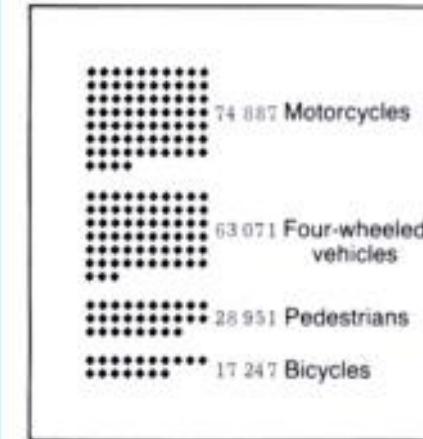
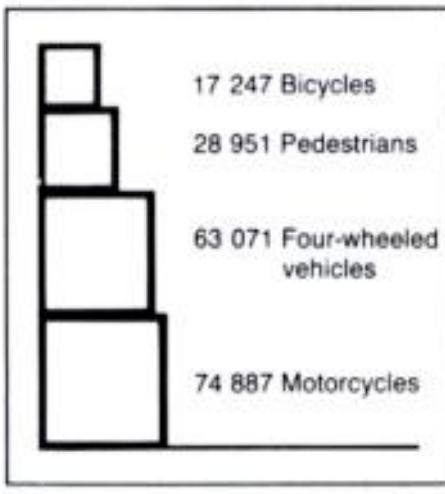
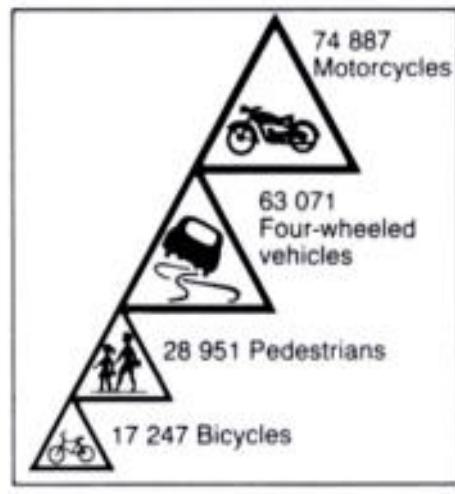
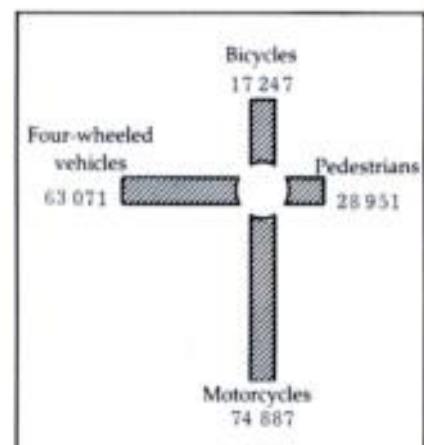
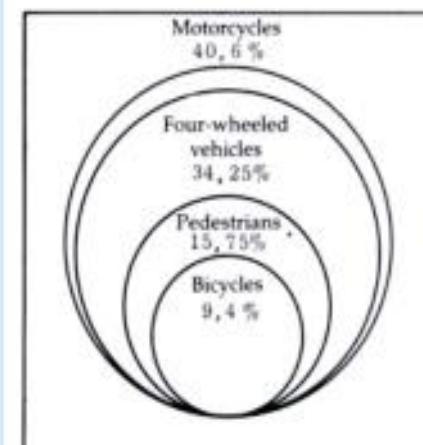
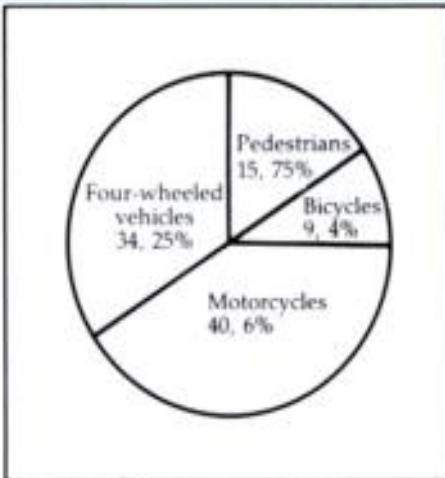
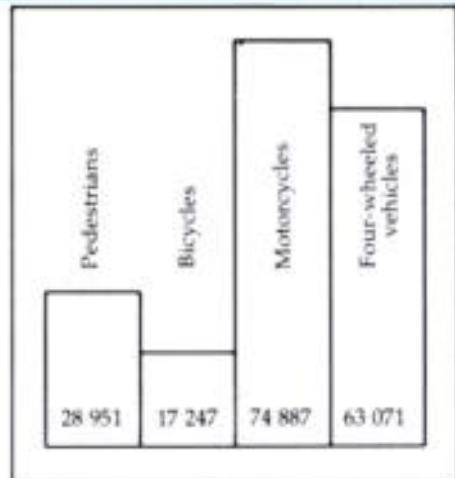
bicycles 17,247

motorcycles 74,887

4 wheel vehicles 63,071

Data
Quantitative ← → Qualitative/categorical
↳ Discrete
↳ Continuous
↳ Nominal
↳ Ordinal

Traffic accident victims France 1958



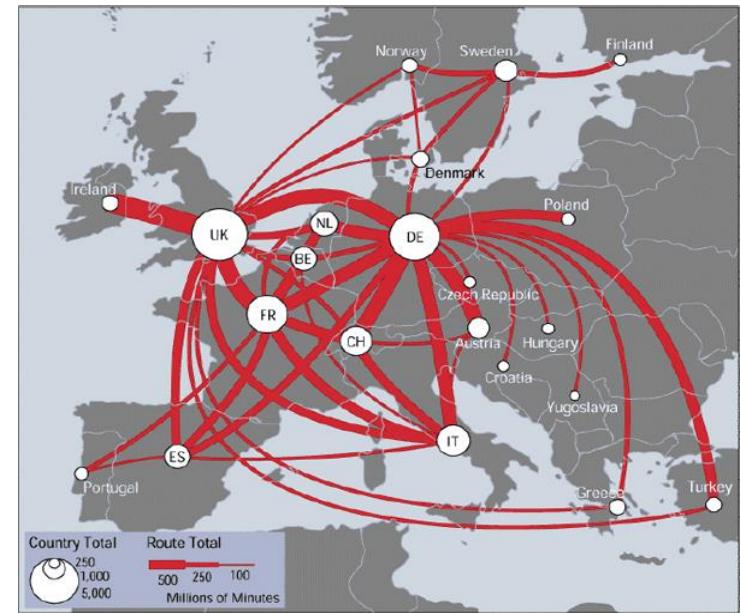
Expressiveness and Effectiveness

The **expressiveness principle** dictates that the visual encoding should express all of, and only, the information in the dataset attributes

The **effectiveness principle** dictates that the importance of the attribute should match the **salience** of the channel

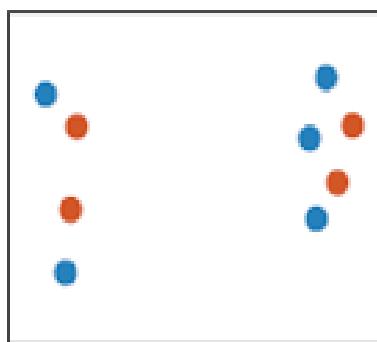
Channel Effectiveness

1. Accuracy
2. Discriminability
3. Separability
4. Popout
5. Grouping



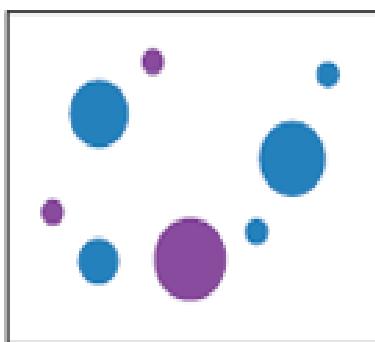
Separability

Position
+ Hue (Color)



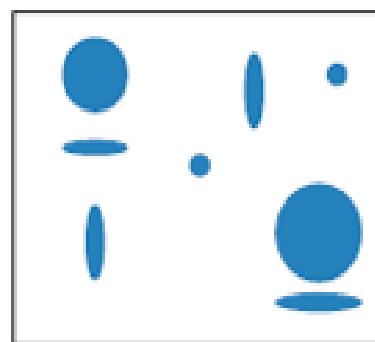
Fully separable

Size
+ Hue (Color)



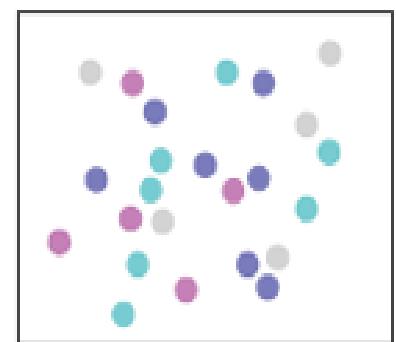
Some interference

Width
+ Height



Some/significant
interference

Red
+ Green



Major interference

People with color
blind-ness are
difficult to view

Popout

