

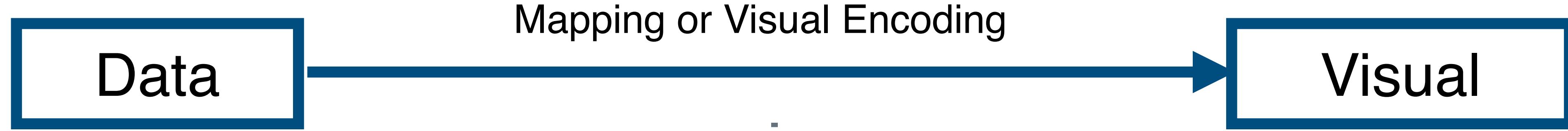
# Perception

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**DSC 106: Data Visualization**

Jared Wilber

UC San Diego



## Expressiveness

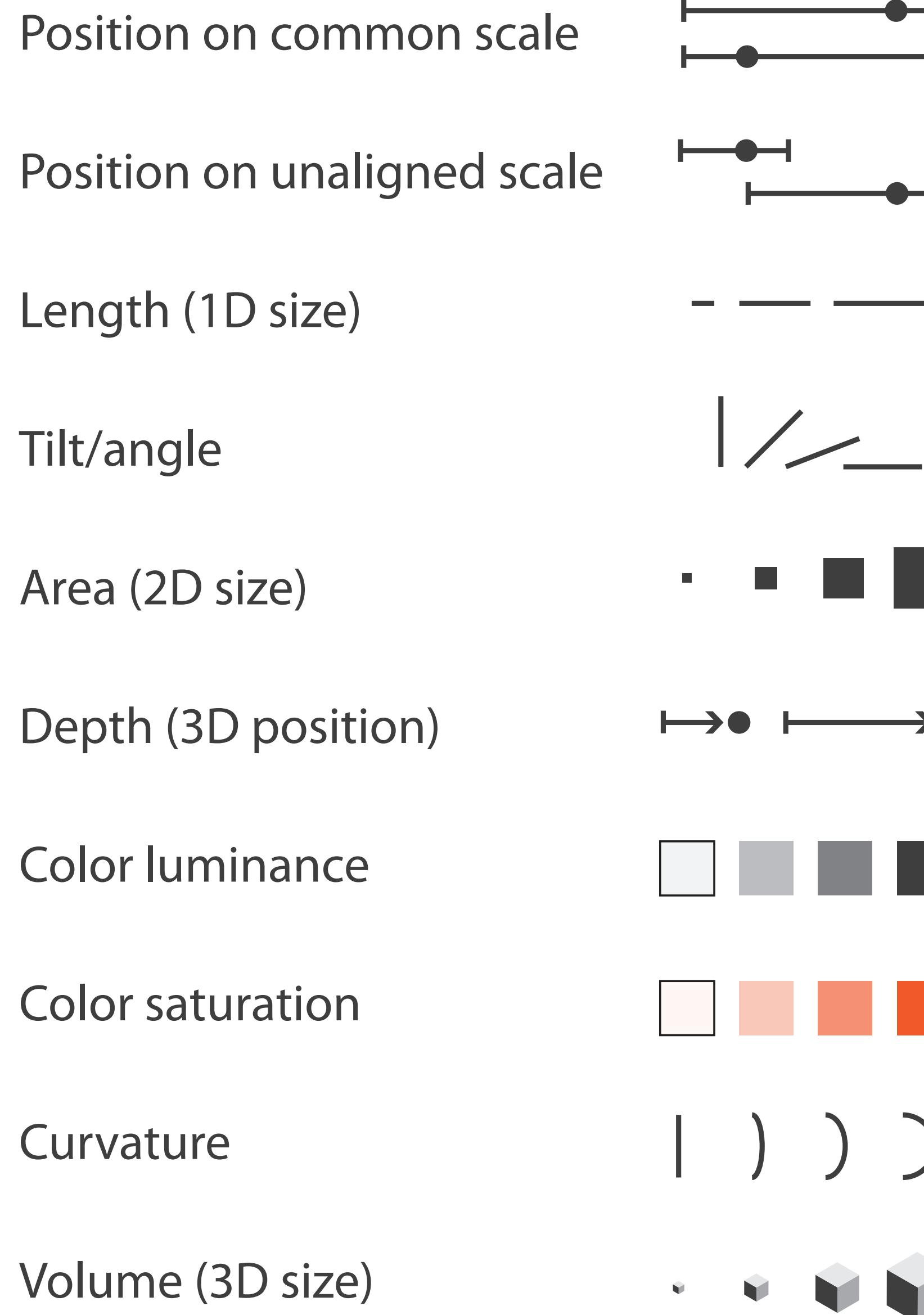
A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express *all the facts in the set of data, and only the facts in the data.*

## Effectiveness

A visualization is more *effective* than another if the information it conveys *is more readily perceived* than the information in the other visualization

## Channels: Expressiveness Types and Effectiveness Ranks

### → Magnitude Channels: Ordered Attributes



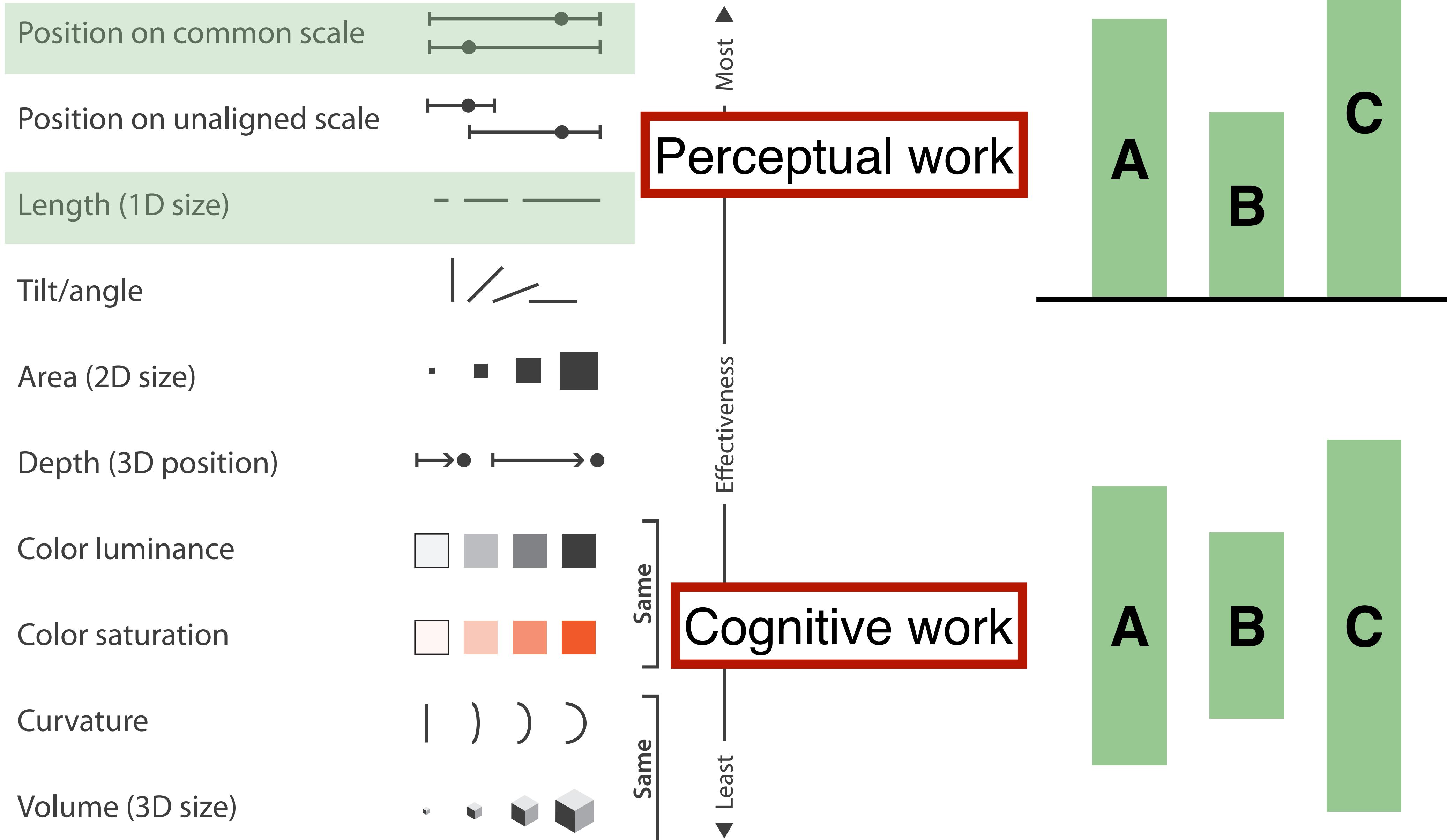
### → Identity Channels: Categorical Attributes



Tamara Munzner, *Visualization Analysis and Design* (2014).

# Channels: Expressiveness Types and Effectiveness Ranks

→ **Magnitude Channels:** O or Q attributes



# **Graphical Perception**

The ability of viewers to interpret visual (graphical) encodings of information and thereby decode information in graphs.

**Signal Detection**

**Magnitude Estimation**

**Pre-Attentive Processing**

**Selective Attention**

**Gestalt Grouping**

# **Signal Detection**

Discriminability: how easy is it  
to tell two things apart?

# Magnitude Estimation

# Pre-Attentive Processing

# Selective Attention

# Gestalt Grouping

# Which is brighter?



rgb(128, 128, 128)



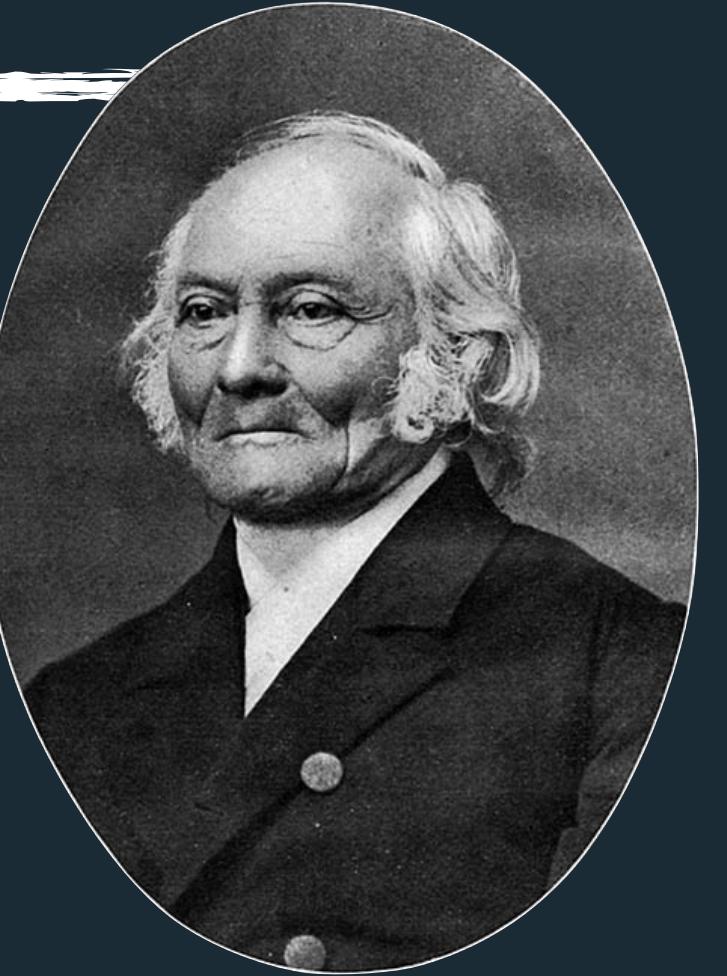
rgb(144, 144, 144)



# Which is brighter?



# Just Noticeable Difference (jnd)



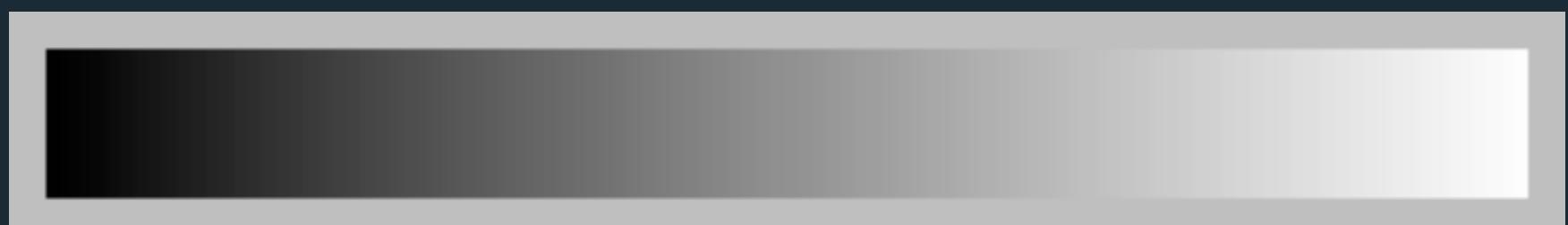
Ernst Weber  
(1795 – 1878)  
German  
physician  
and a founder  
of  
experimental  
psychology.

$$\Delta S = k \frac{\Delta I}{I}$$

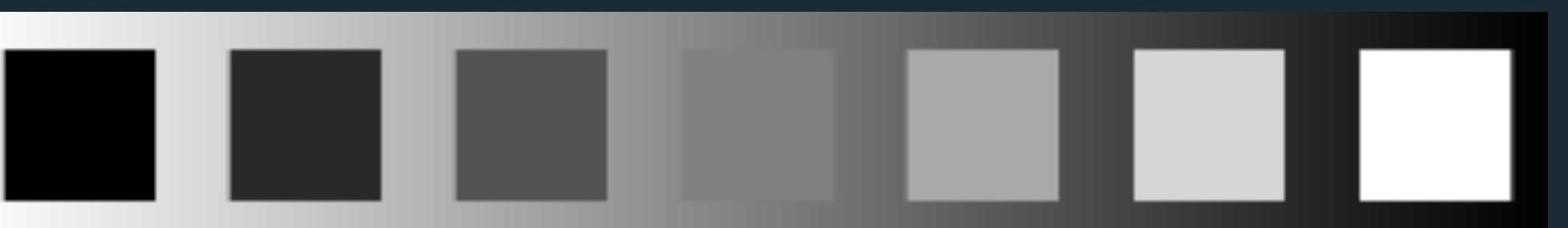
Perceived Change      Scale Factor (Determined Empirically)      Change of Intensity      Physical Intensity

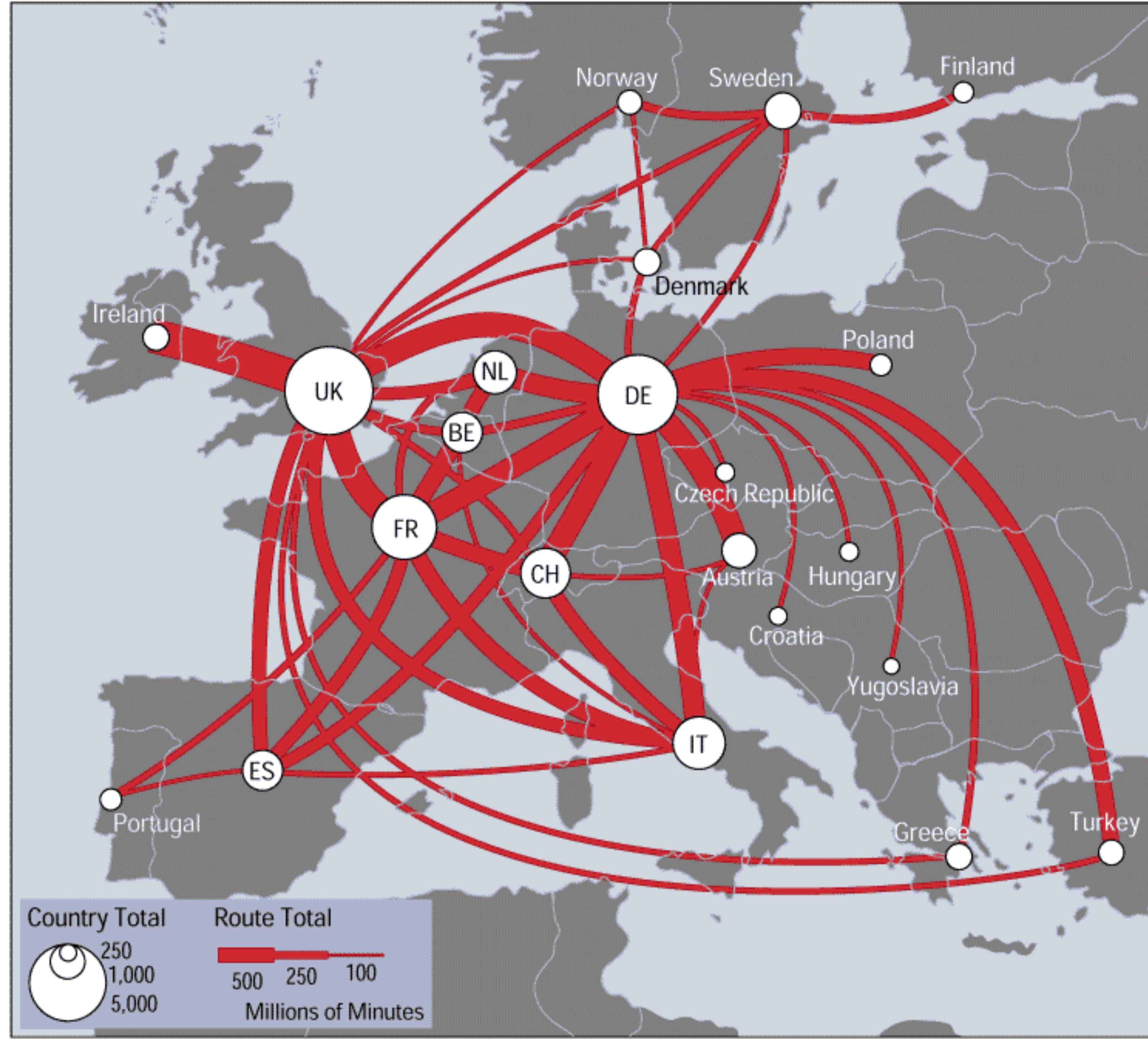
Ratios more important than magnitude.

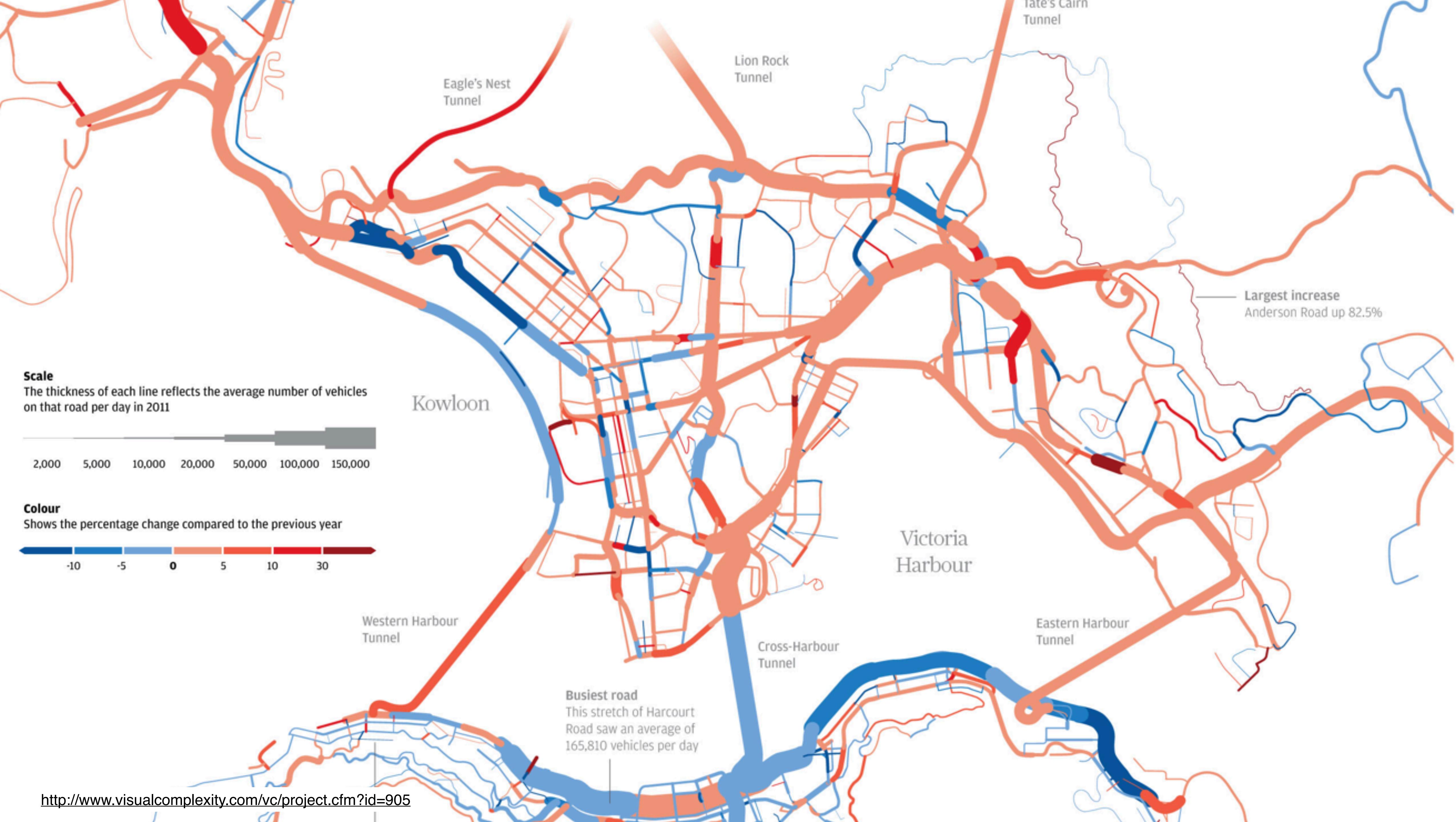
Most continuous variation in stimuli are perceived in discrete steps.



vs.







# **Signal Detection**

Discriminability: how easy is it  
to tell two things apart?

# Magnitude Estimation

# Pre-Attentive Processing

# Selective Attention

# Gestalt Grouping

## Signal Detection

## Magnitude Estimation

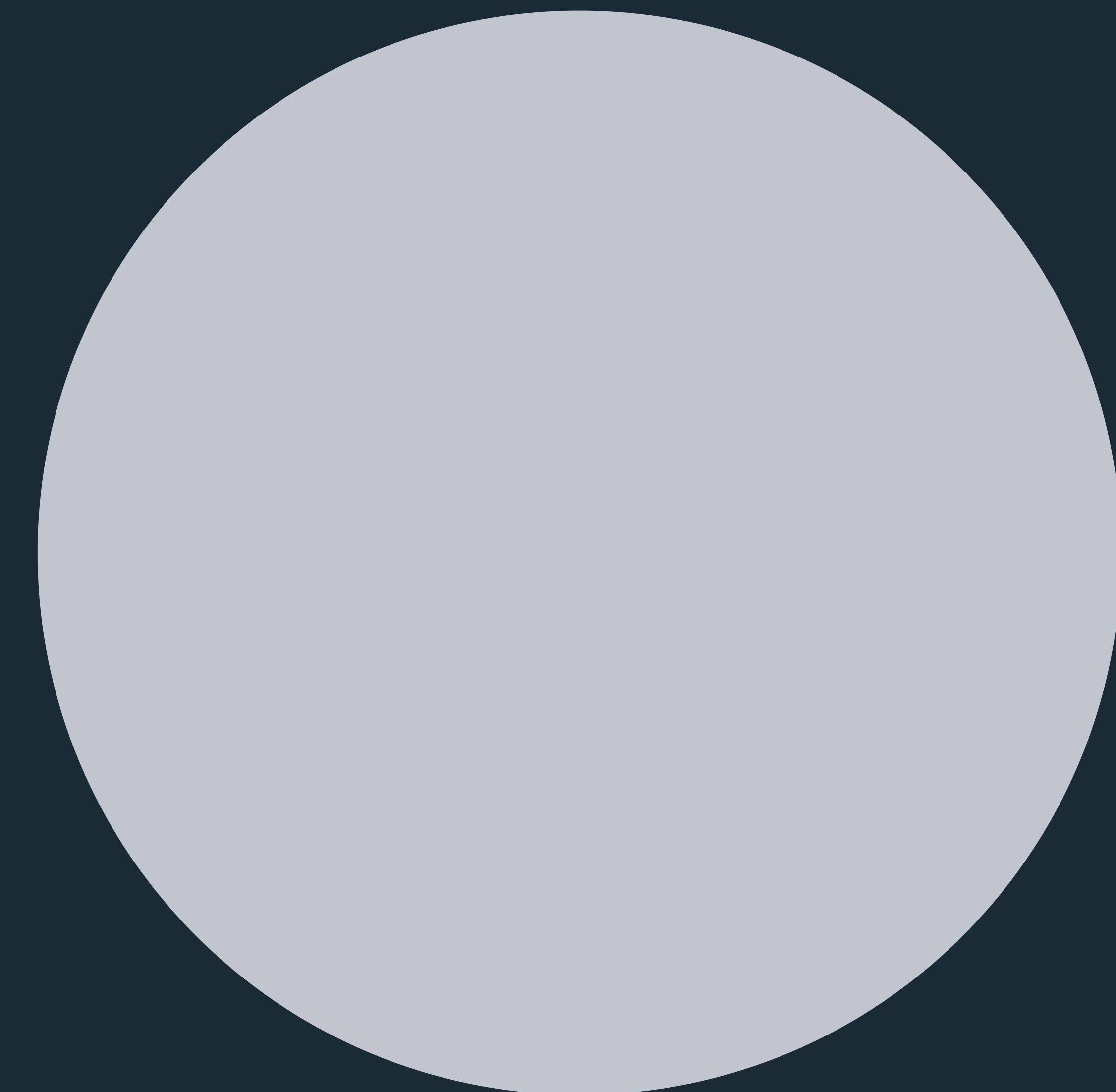
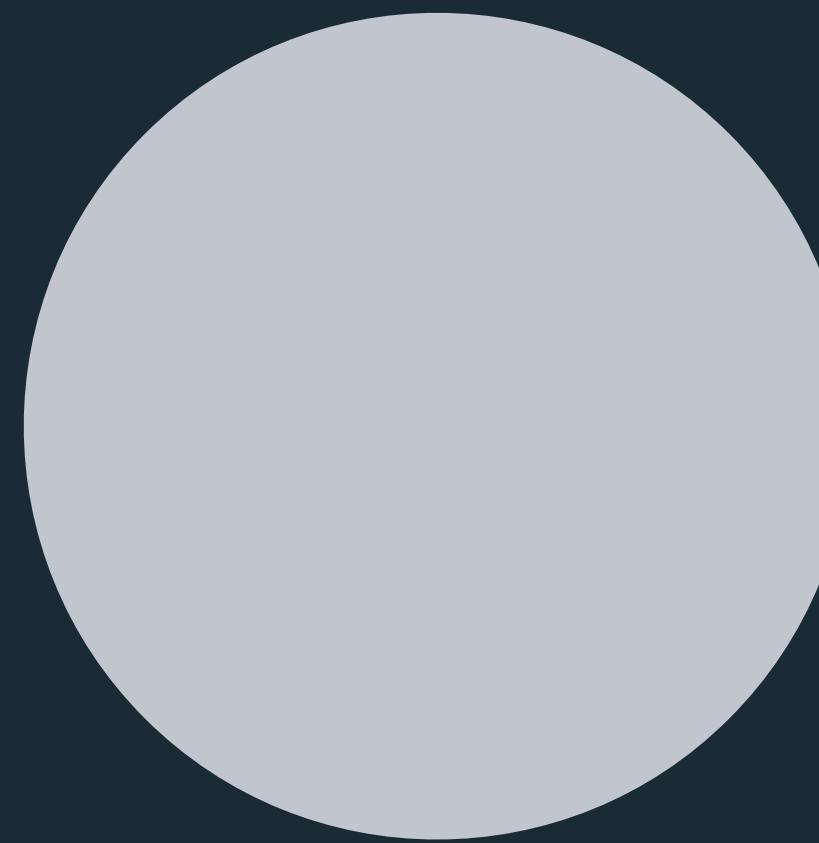
## Pre-Attentive Processing

## Selective Attention

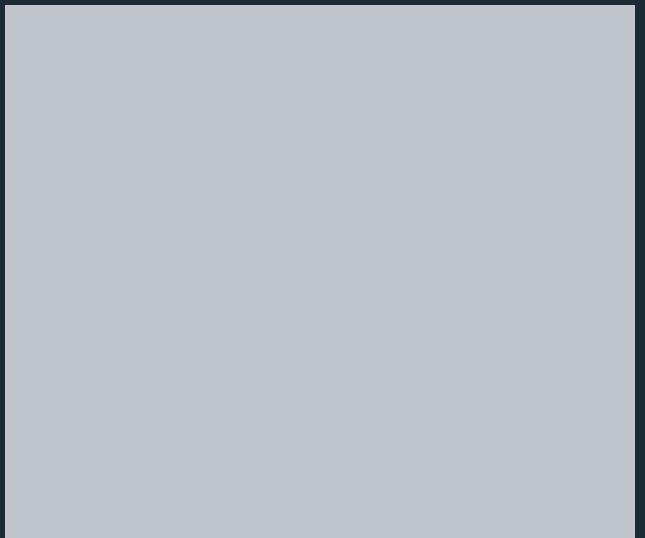
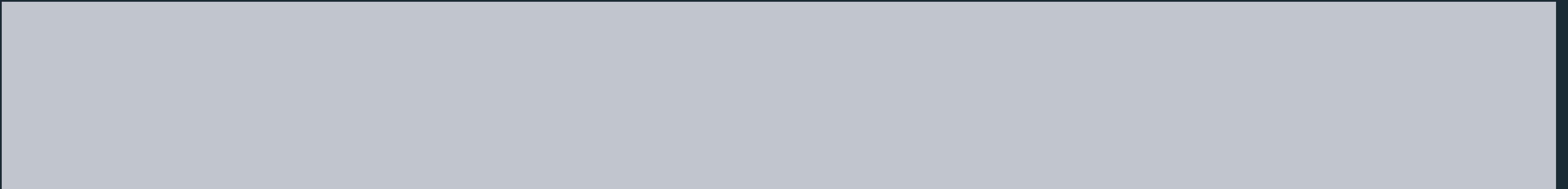
## Gestalt Grouping

Accuracy: how correctly can we  
read off values?

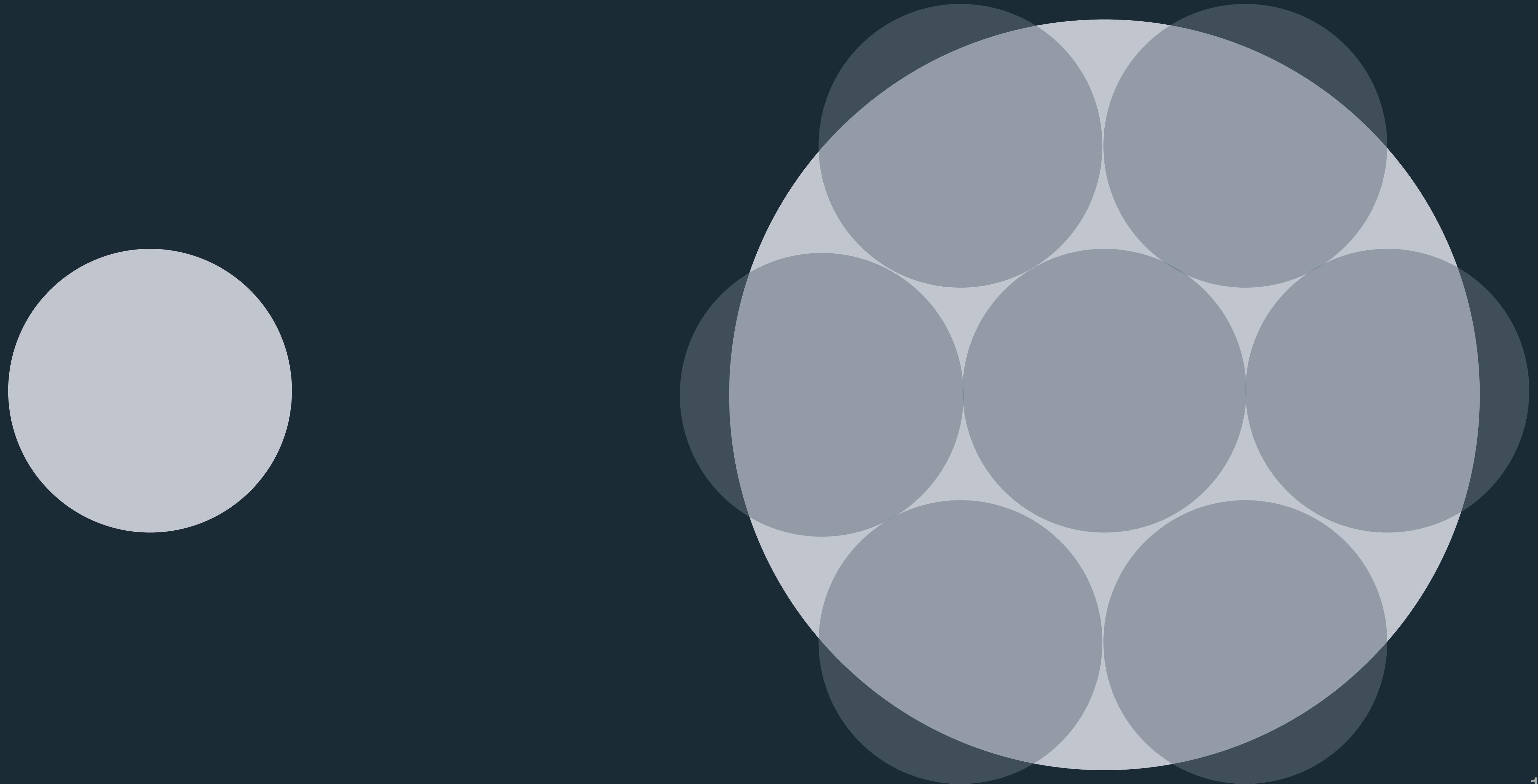
# How much larger is the area of the big circle?



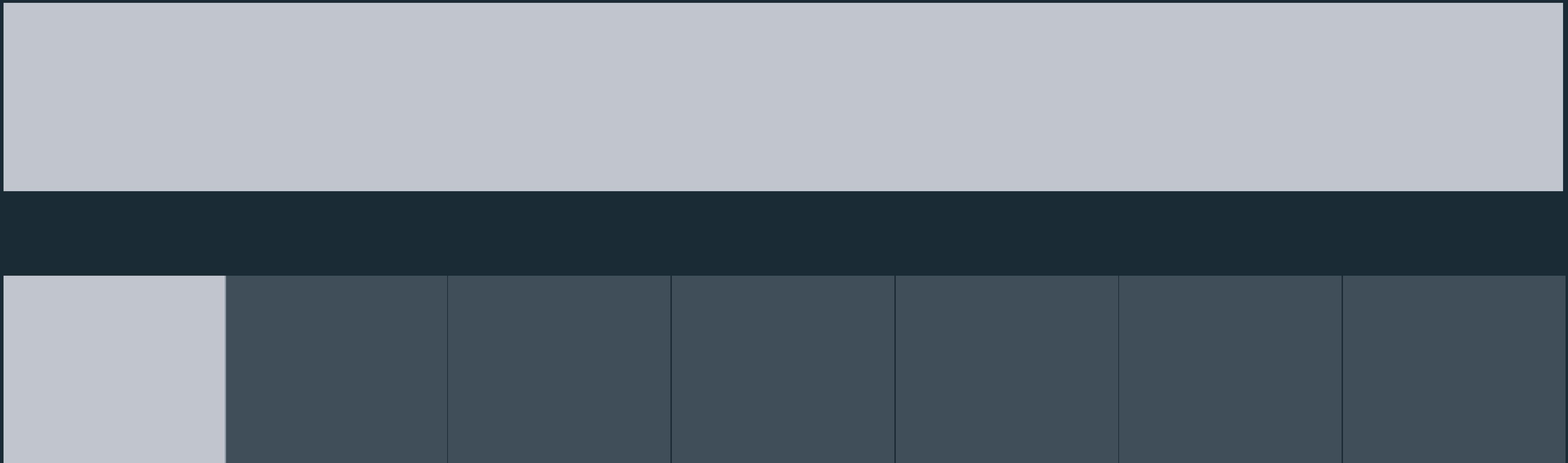
# How much longer is the big bar?



# How much larger is the area of the big circle?



# How much longer is the big bar?



# Stevens' Power Law



S. S. Stevens (1906 – 1972)

American psychologist, founded Harvard's Psychoacoustics Lab.

$$S = IP^p$$

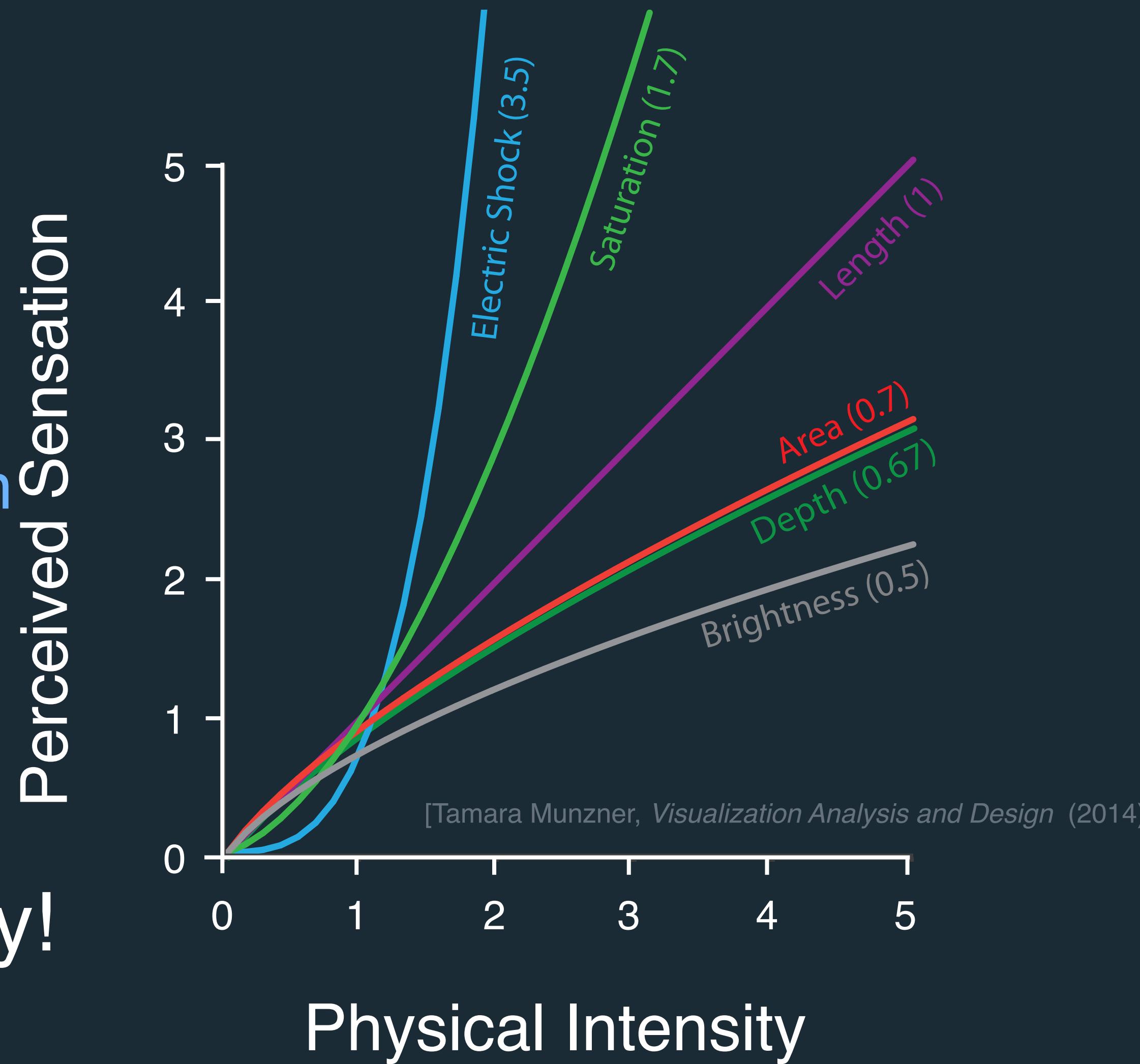
Physical Intensity

Perceived Sensation

Exponent  
(Determined Empirically)

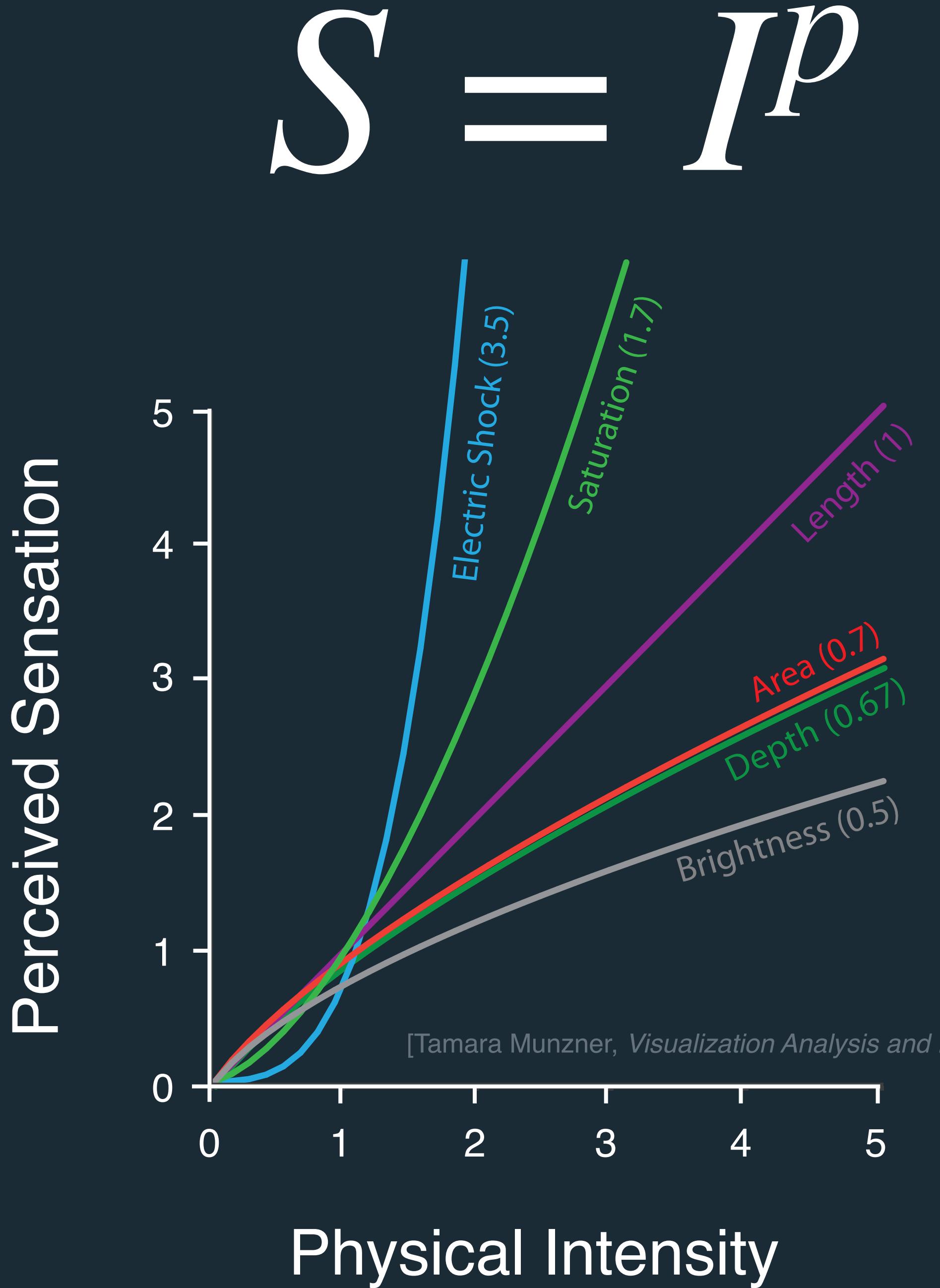
$p < 1$  = underestimation  
 $p > 1$  = overestimation

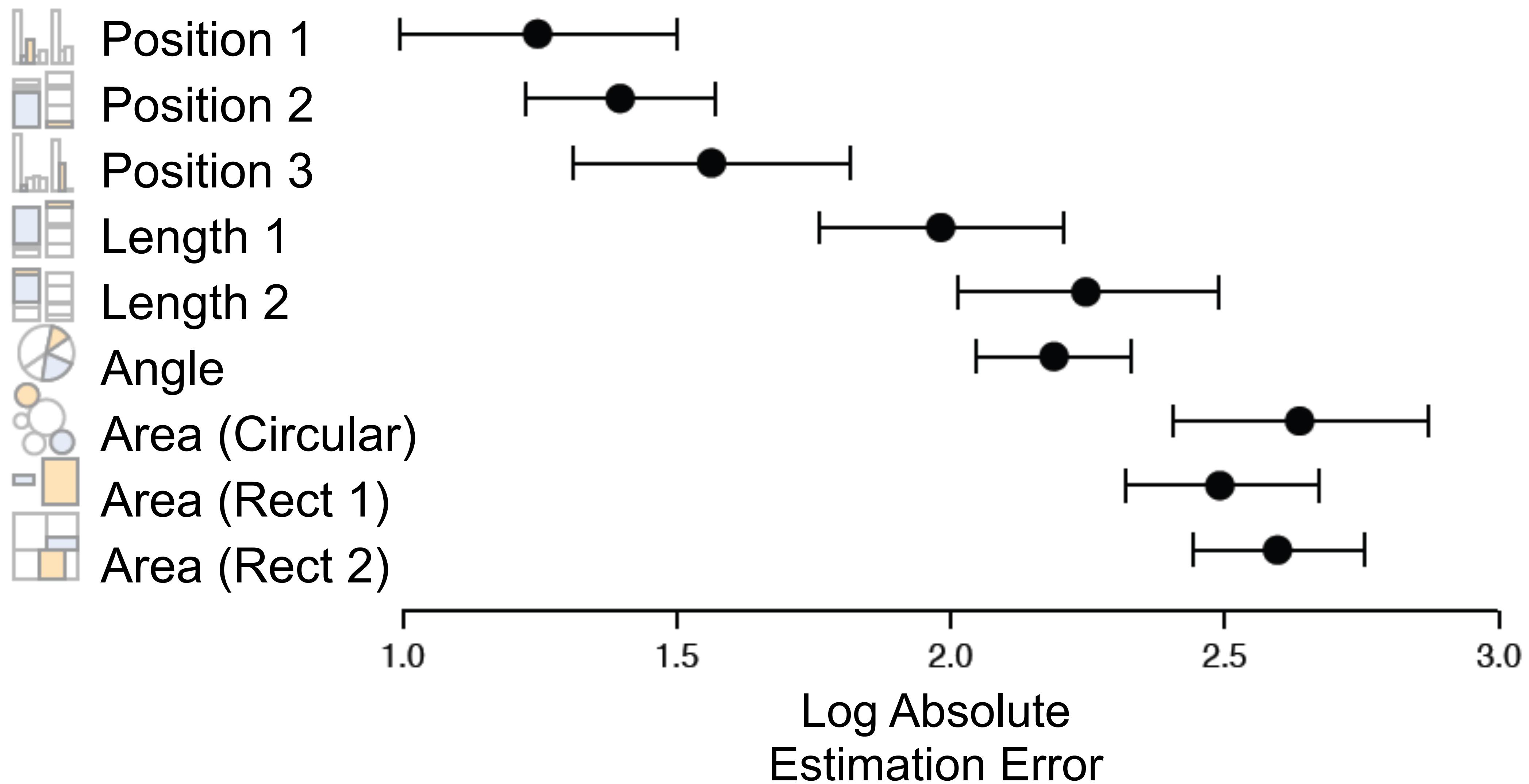
Predicts bias, not necessarily accuracy!



# Stevens' Power Law

Sensation	Exponent
Loudness	0.6
Brightness	0.33
Smell	0.55 (Coffee) – 0.6
Taste	0.6 (Saccharin) – 1.3
Temperature	1.0 (Cold) – 1.6 (Warm)
Vibration	0.6 (250 Hz) – 0.95 (60)
Duration	1.1
Pressure	1.1
Heaviness	1.45
Electric Shock	3.5





## Signal Detection

## Magnitude Estimation

## Pre-Attentive Processing

## Selective Attention

## Gestalt Grouping

Accuracy: how correctly can we  
read off values?

## Signal Detection

## Magnitude Estimation

## Pre-Attentive Processing

## Selective Attention

## Gestalt Grouping

Pop Out: how easy is it to spot some values from the rest?

# How many 3's?

128176875613897654698450698560498  
2826762  
980985845822450985645894509845098  
0943585

# How many 3's?

128176875613897654698450698560498  
2826762  
980985845822450985645894509845098  
0943585

# Pre-Attentive Processing

How immediately does our visual system perceive differences in a scene?

**Pre-Attentive:** immediately recognize variation with little or no conscious effort (<200–250 ms).

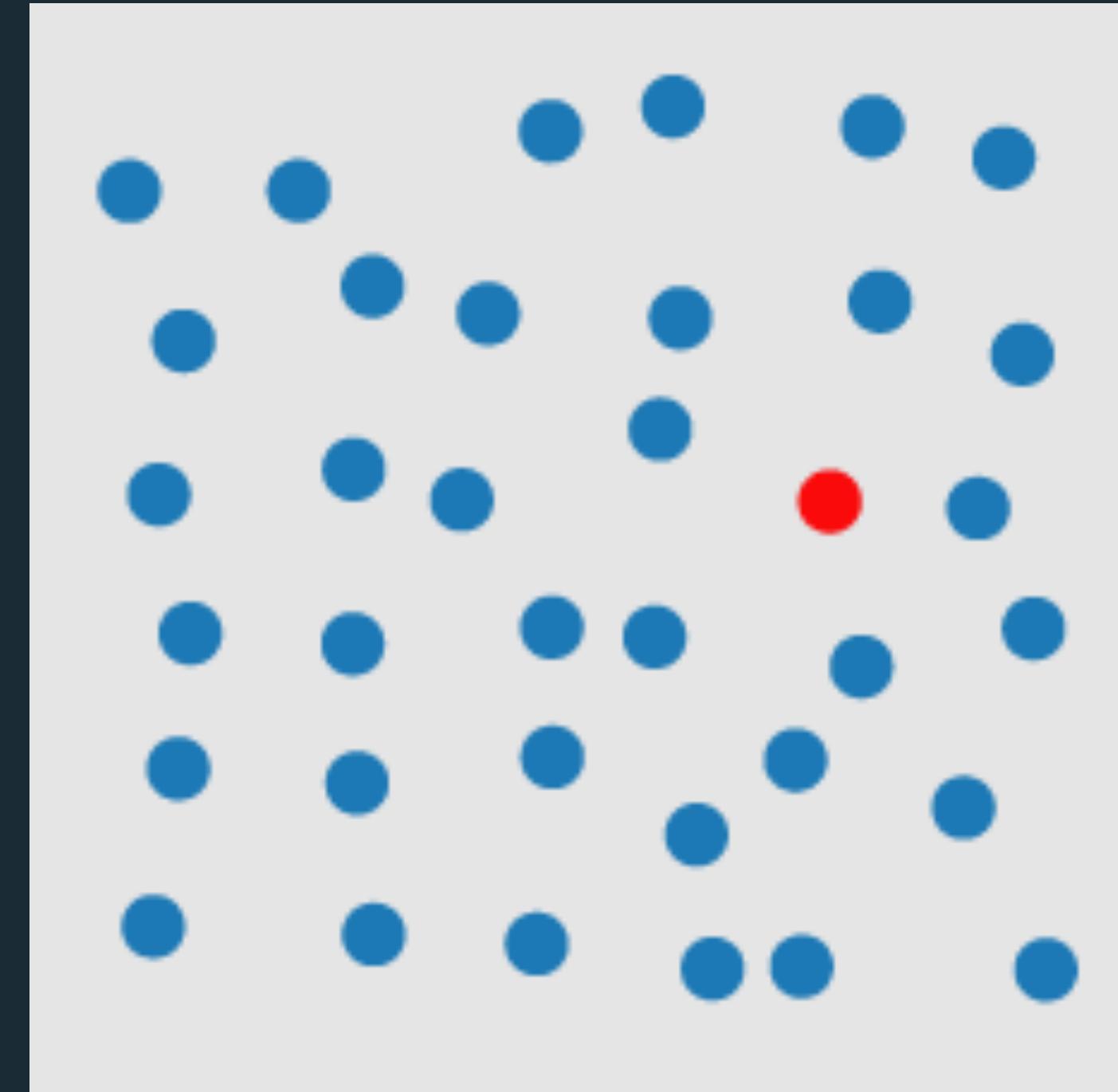
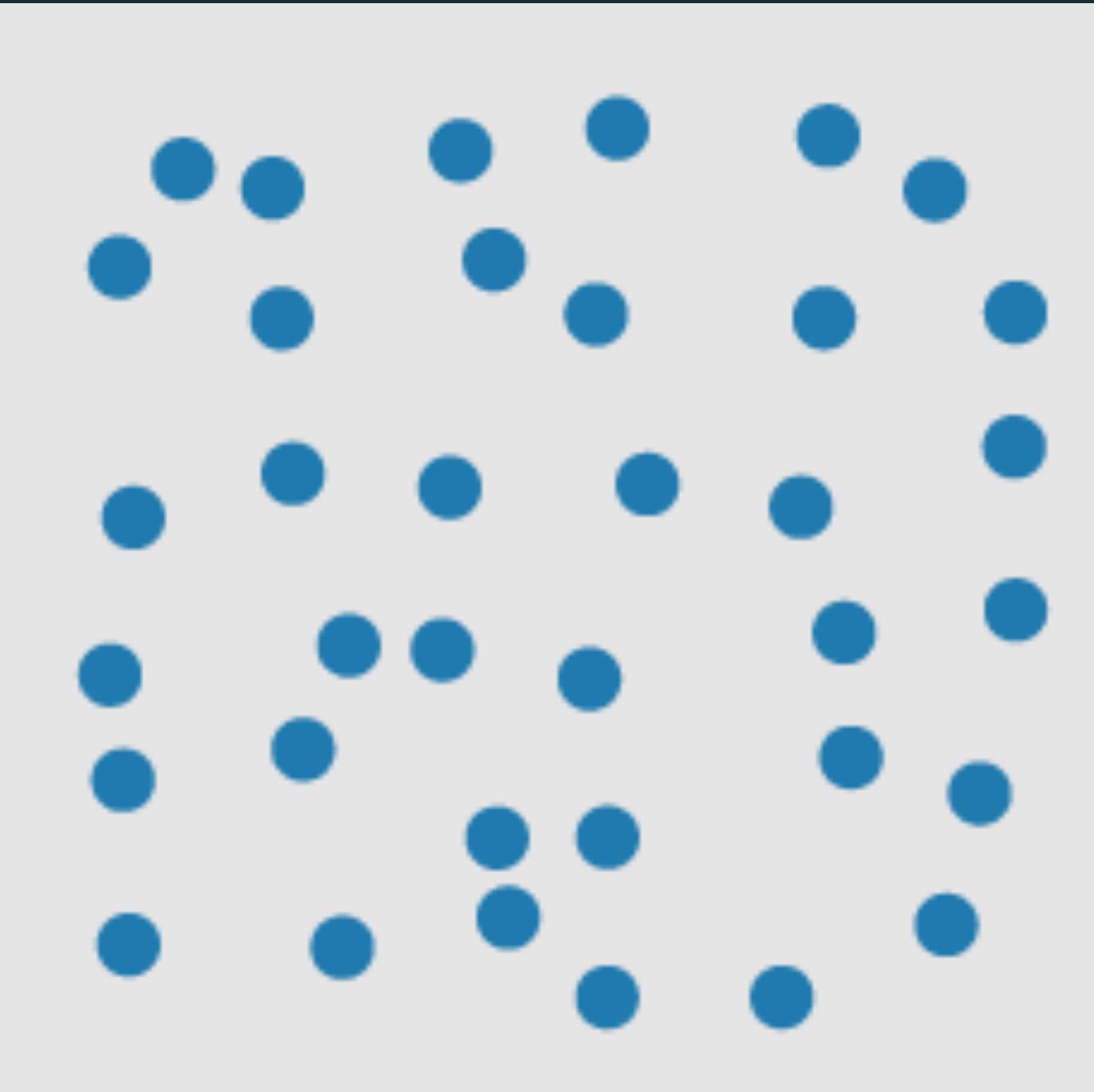
**Attentive:** Takes some deliberate effort to perceive differences.

# Pre-Attentive Processing

Pre-Attentive: immediately recognize variation with little or no conscious effort (<200–250 ms).

Attentive: Takes some deliberate effort to perceive differences.

## Visual Pop-Out: Color



[Healey & Enns 2012]

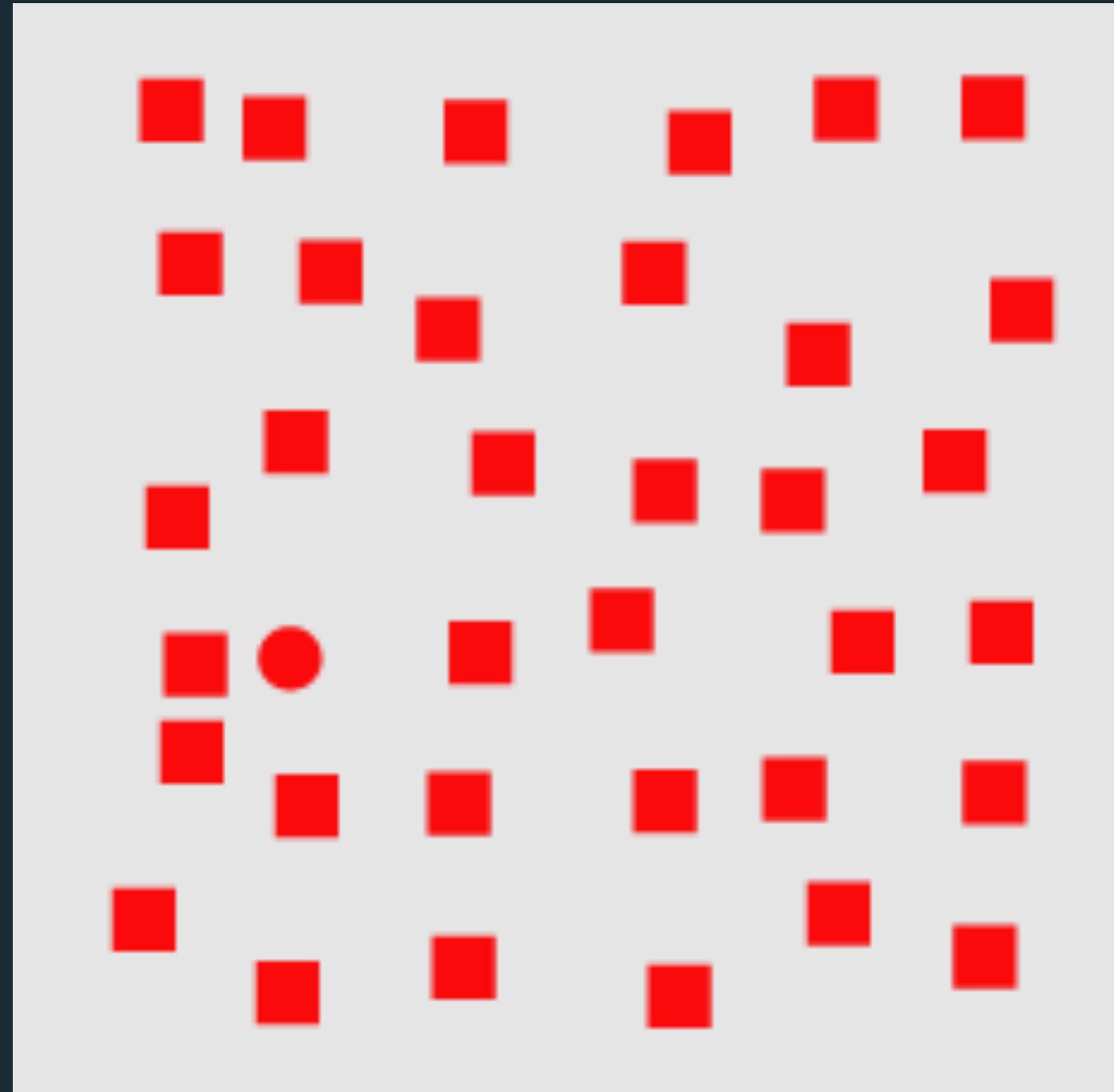
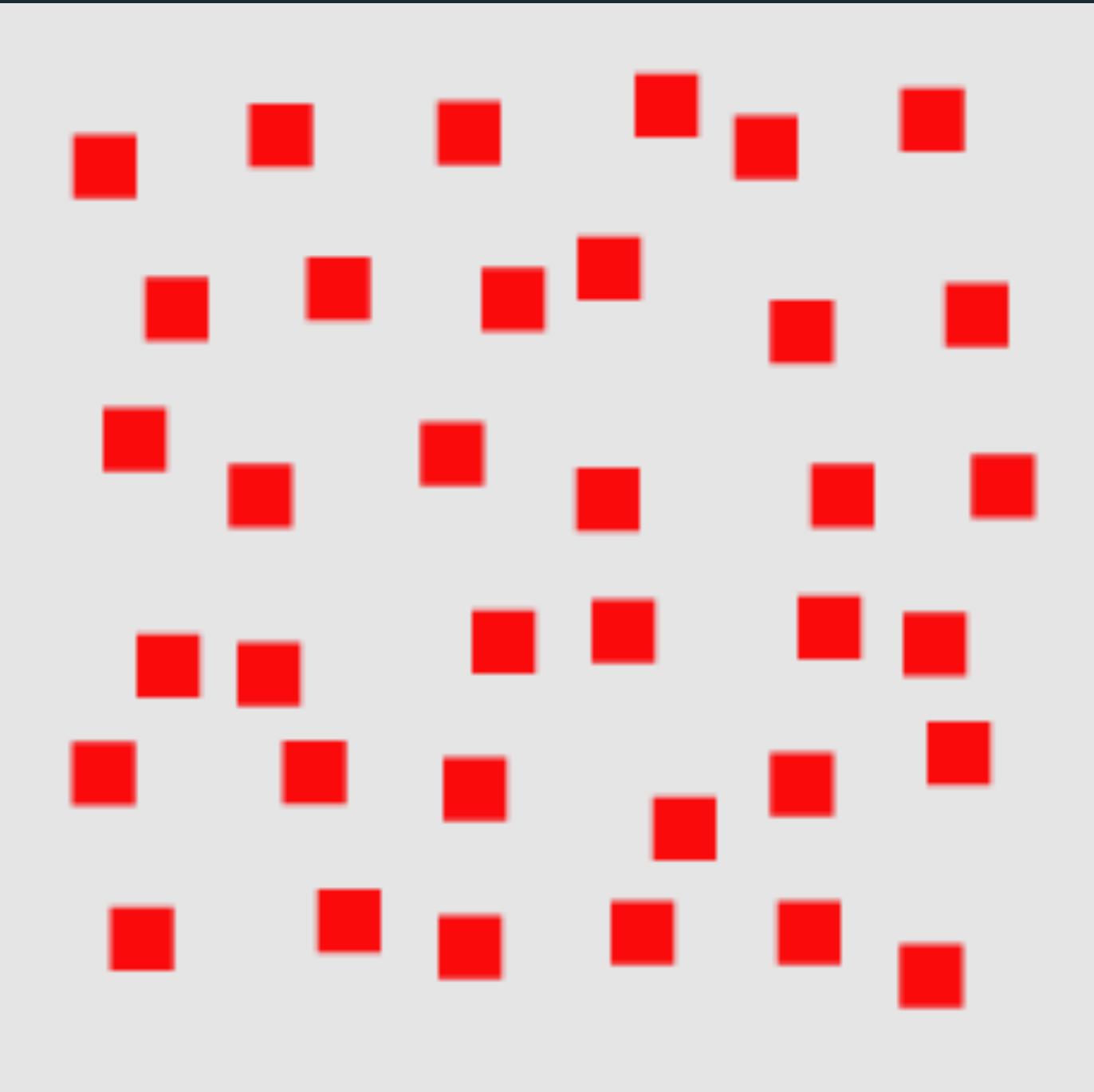
# Pre-Attentive Processing

Pre-Attentive: immediately recognize variation with little or no conscious effort (<200–250 ms).

## Visual Pop-Out: Color

Attentive: Takes some deliberate effort to perceive differences.

## Visual Pop-Out: Shape



[Healey & Enns 2012]

# Pre-Attentive Processing

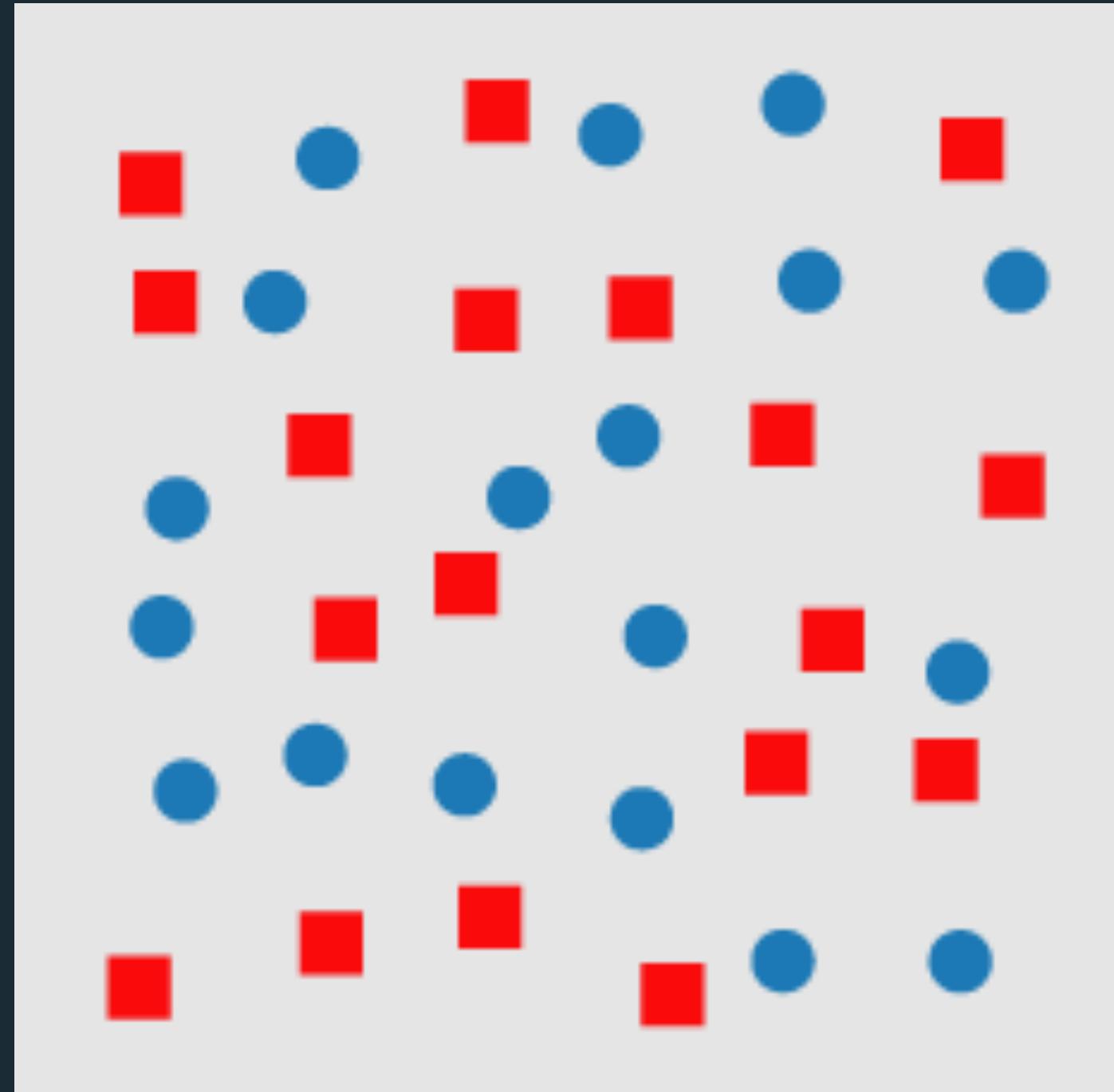
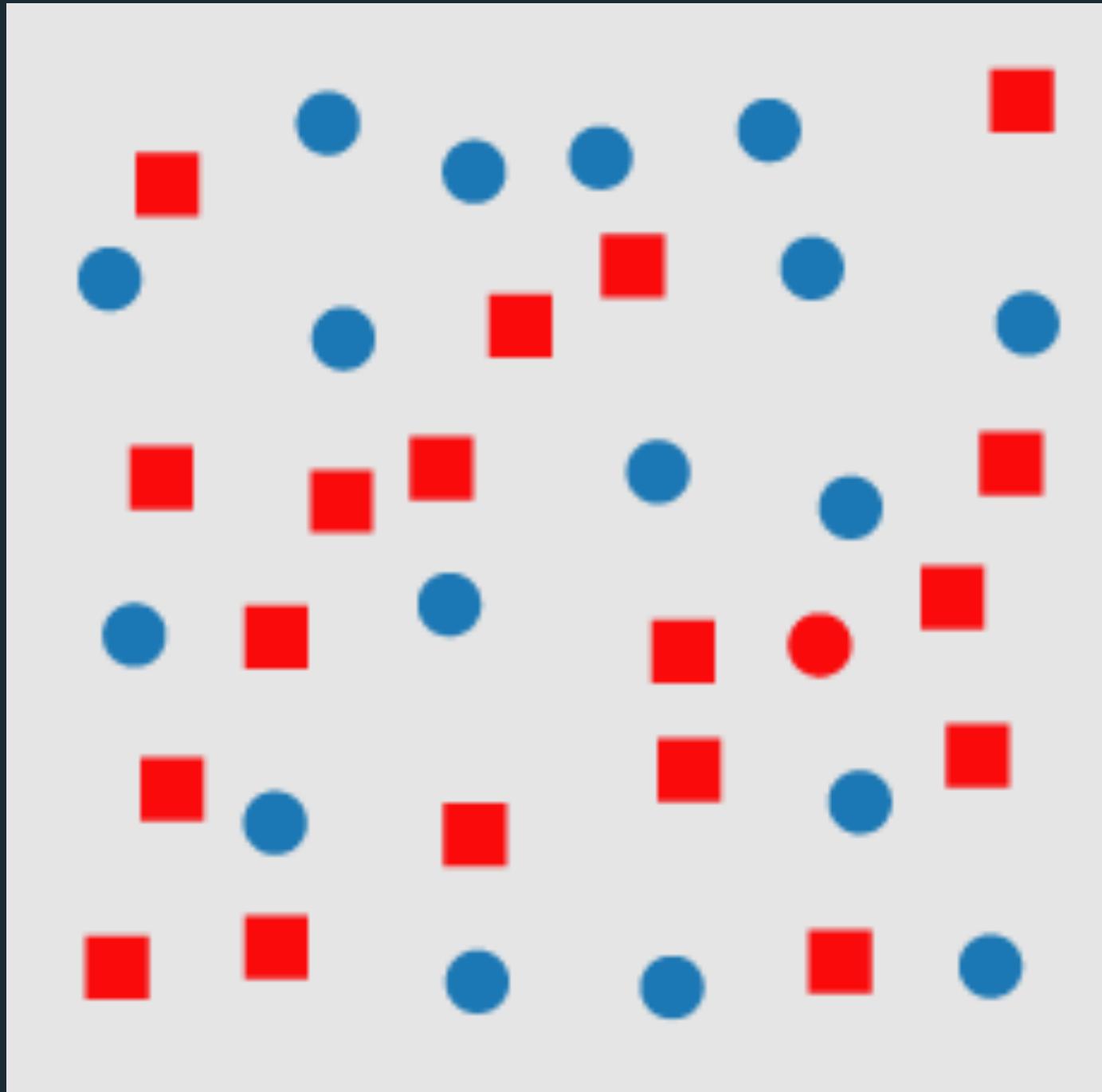
Pre-Attentive: immediately recognize variation with little or no conscious effort (<200–250 ms).

Visual Pop-Out: Color

Visual Pop-Out: Shape

Attentive: Takes some deliberate effort to perceive differences.

## Feature Conjunctions



[Healey & Enns 2012]

# Pre-Attentive Processing

## Visual Pop-Out: Color Visual Pop-Out: Shape Feature Conjunctions

Conjunctions are *not* pre-attentive except for spatial conjunctions:

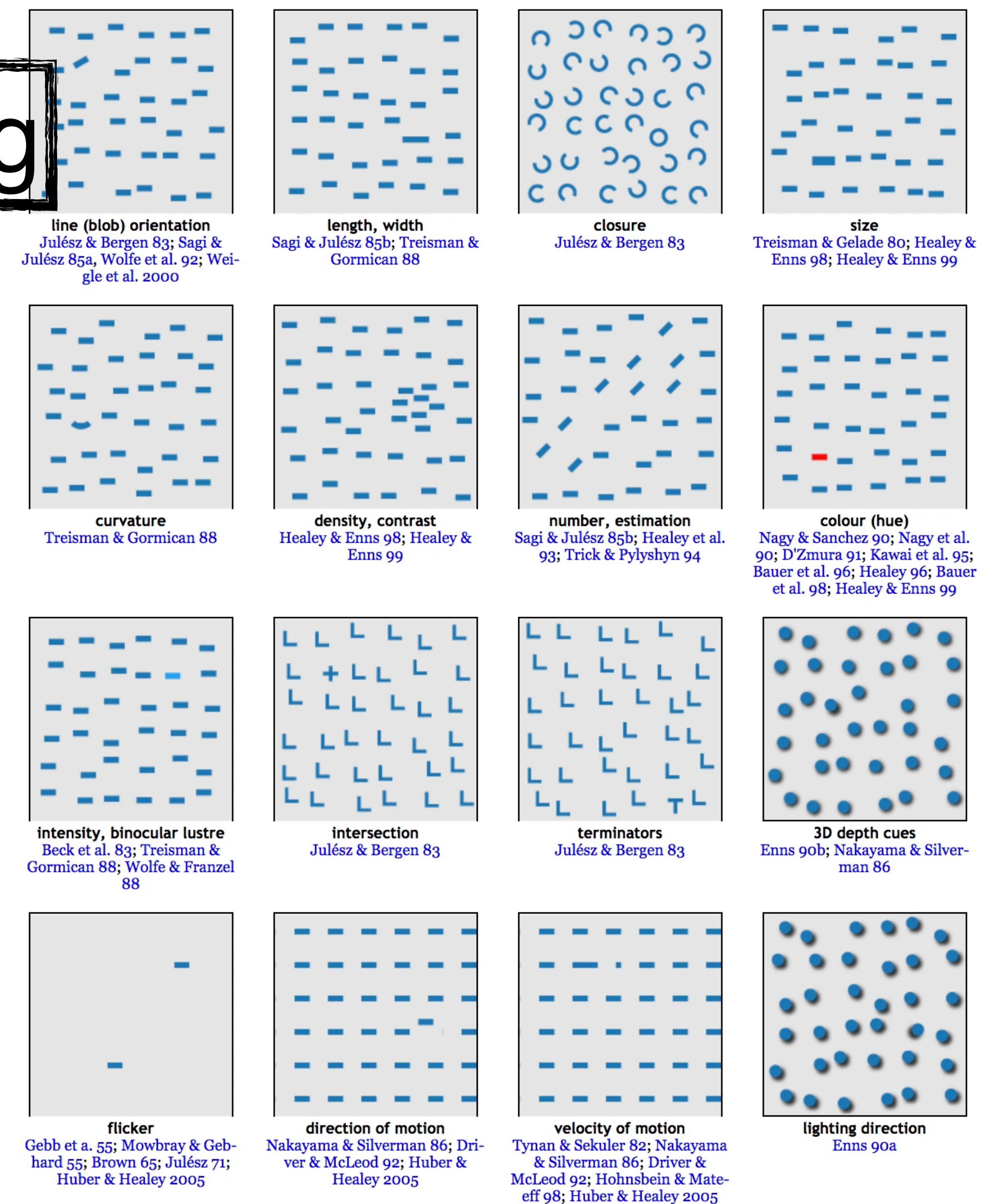
Motion & 3D disparity

Motion & color

Motion & shape

3D disparity & color

3D disparity & shape



## Signal Detection

## Magnitude Estimation

## Pre-Attentive Processing

## Selective Attention

## Gestalt Grouping

Pop Out: how easy is it to spot some values from the rest?

## Signal Detection

## Magnitude Estimation

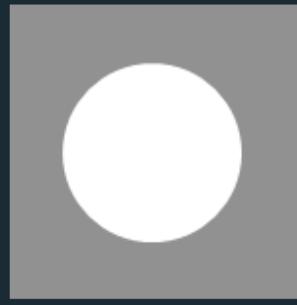
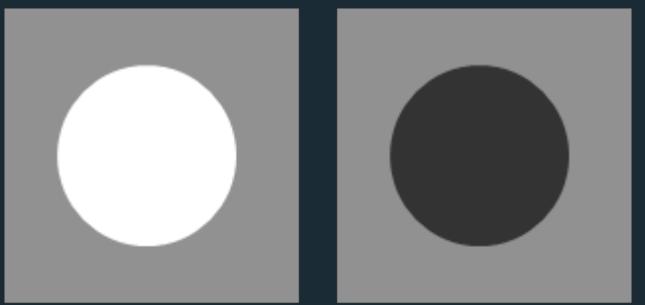
## Pre-Attentive Processing

## Selective Attention

## Gestalt Grouping

Separability: how much interaction occurs between attributes?

# One-Dimensional: Lightness



White



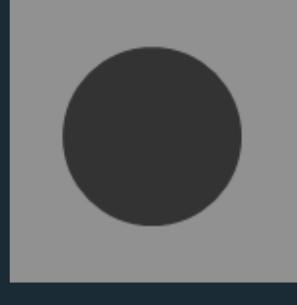
White



Black



White



Black



White



Black



Black



White



White

# One-Dimensional: Shape



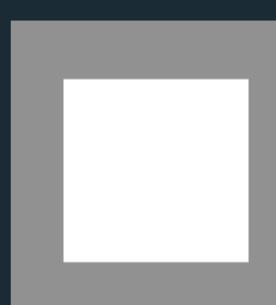
Square



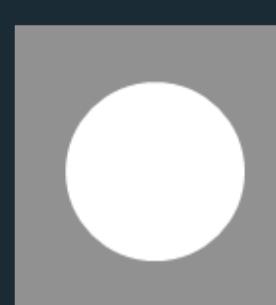
Circle



Circle



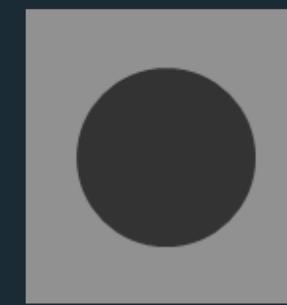
Square



Circle



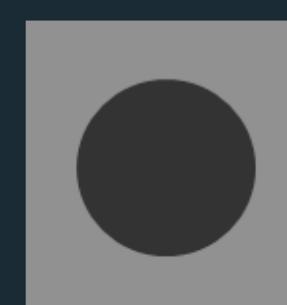
Circle



Circle



Square



Circle

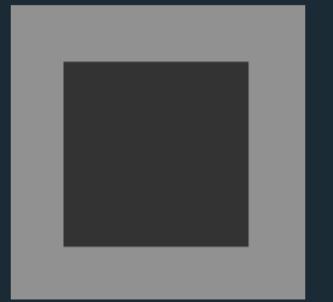


Circle

# Redundant: Shape & Lightness



White



Black



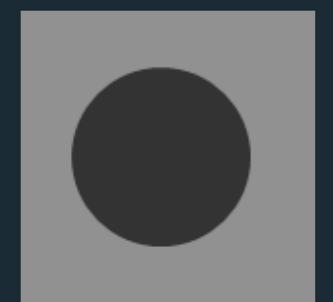
Black



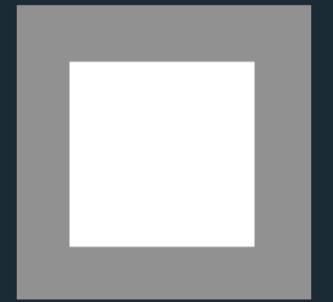
White



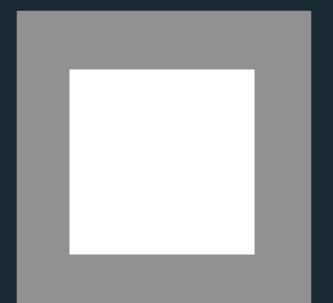
Black



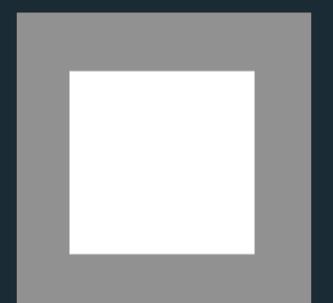
Circle



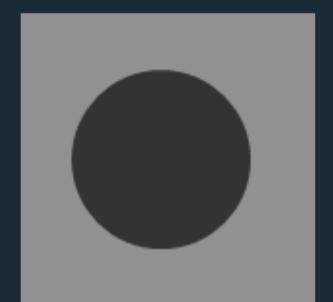
Square



Square



Square

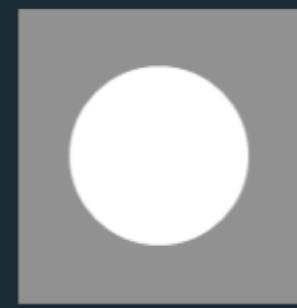


Circle

# Orthogonal: Shape & Lightness



White



Circle

Black



Square

White



Square

Black



Circle

White



Square

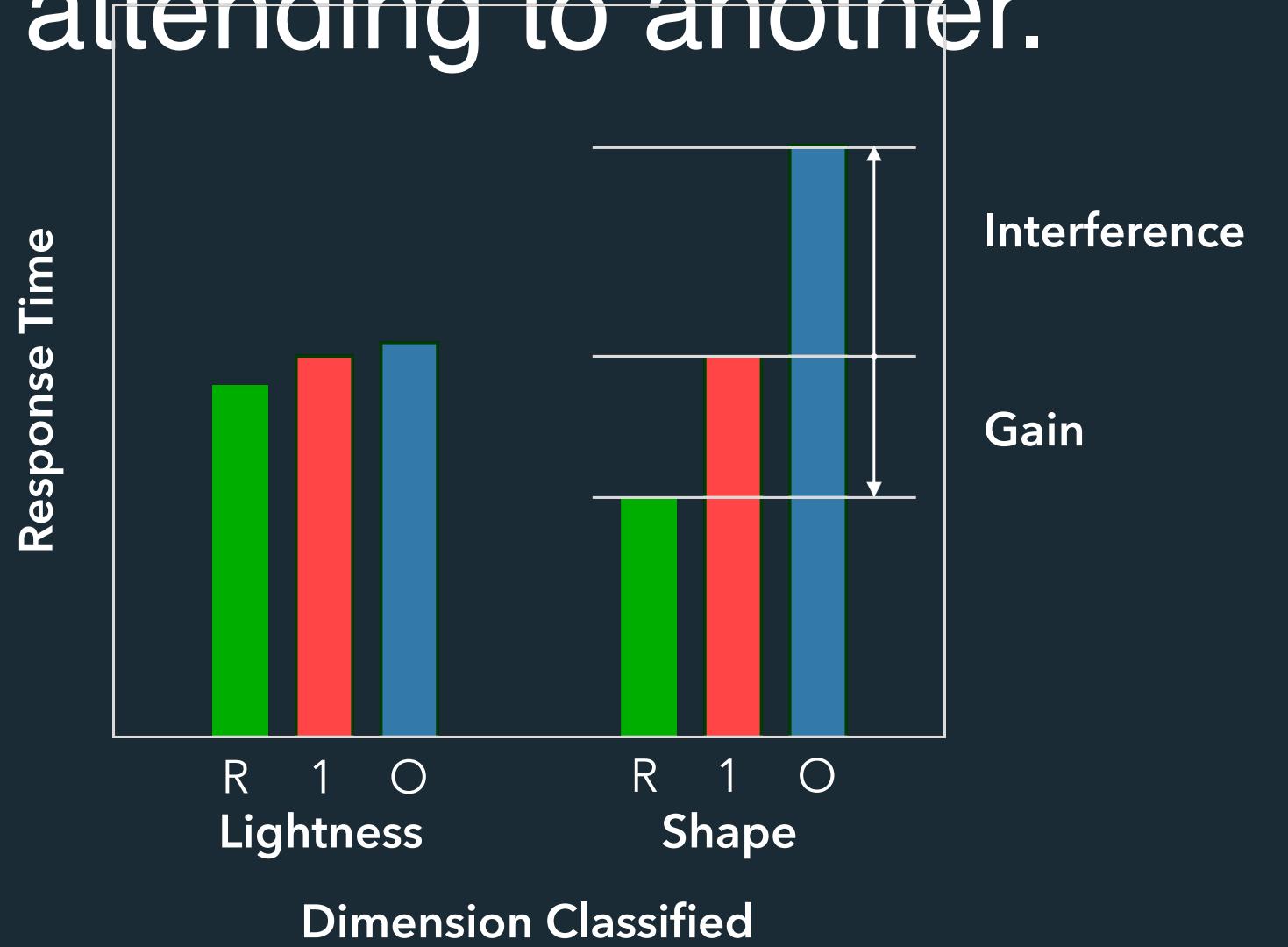
# Principles

## Redundancy Gain

Improved performance when both dimensions provide the same information.

## Filtering Interference

Difficulty in ignoring one dimension while attending to another.



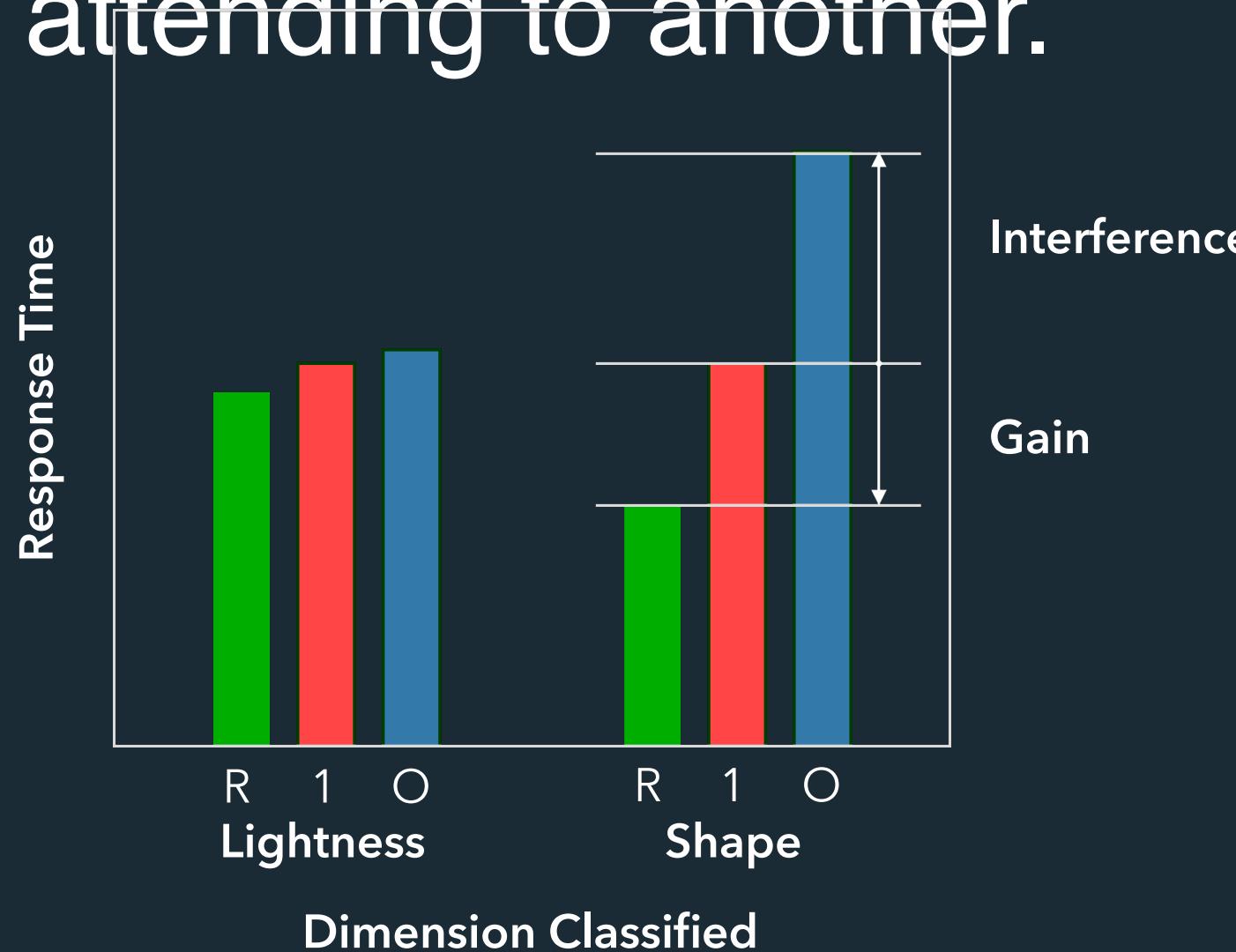
# Principles

## Redundancy Gain

Improved performance when both dimensions provide the same information.

## Filtering Interference

Difficulty in ignoring one dimension while attending to another.



# Types of Dimensions

## Separable

No interference or redundancy gain.

## Integral

Filtering interference and redundancy gain.

## Configural

Only interference. No redundancy gain.

## Asymmetric

One dimension is separable from the other, but not vice versa.

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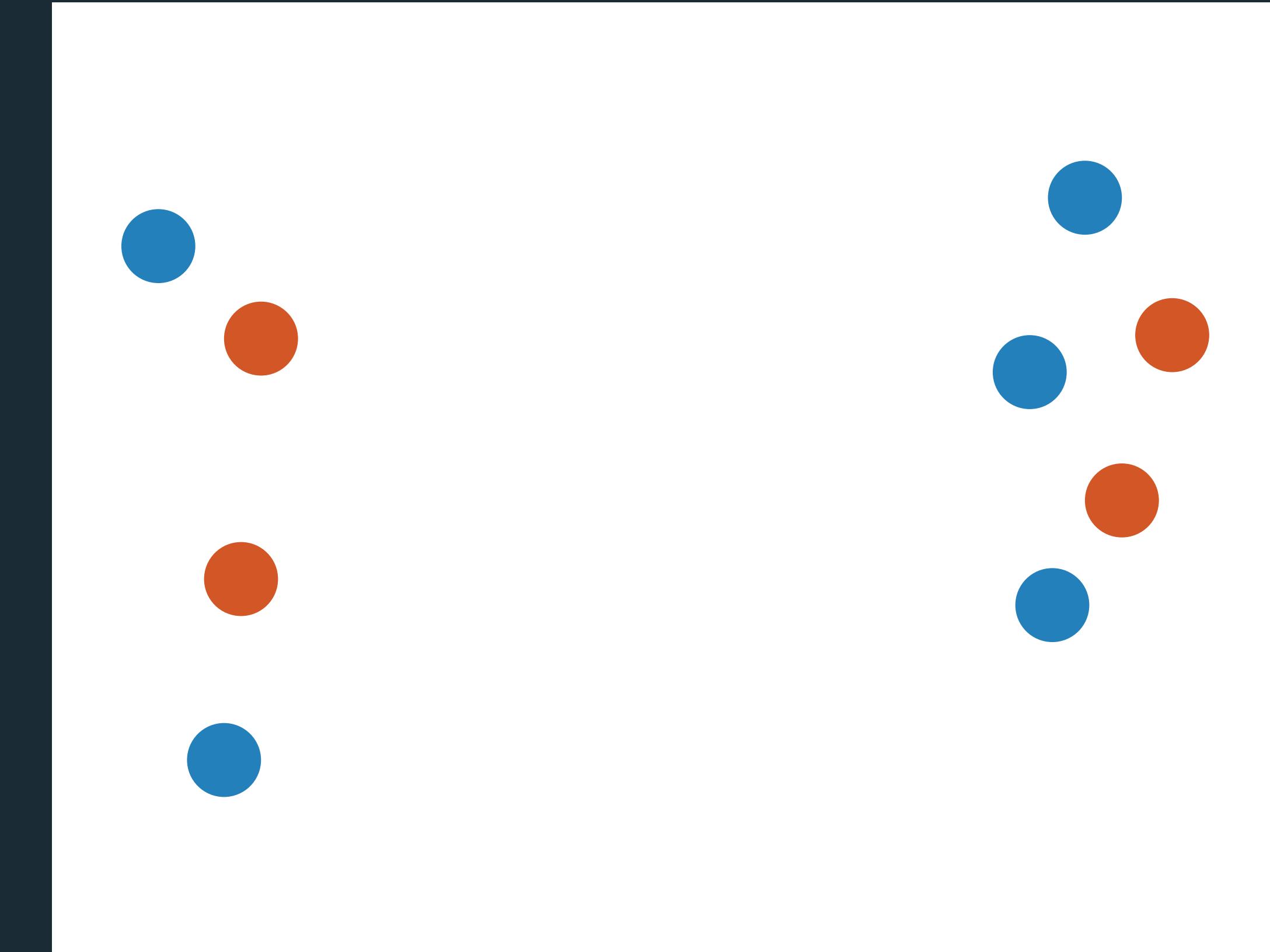
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Position & Hue (Color)?



[Tamara Munzner, *Visualization Analysis and Design* (2014)]

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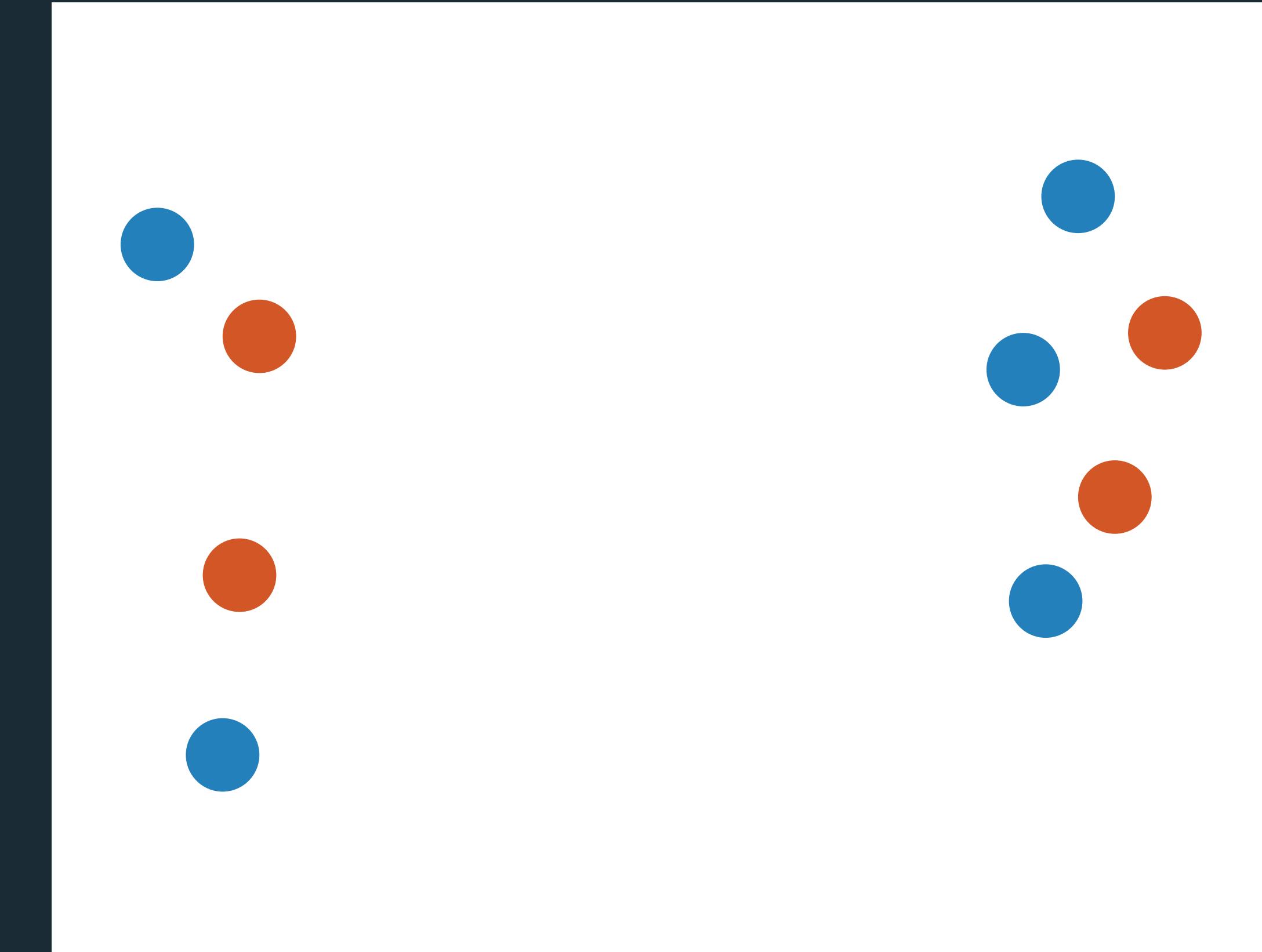
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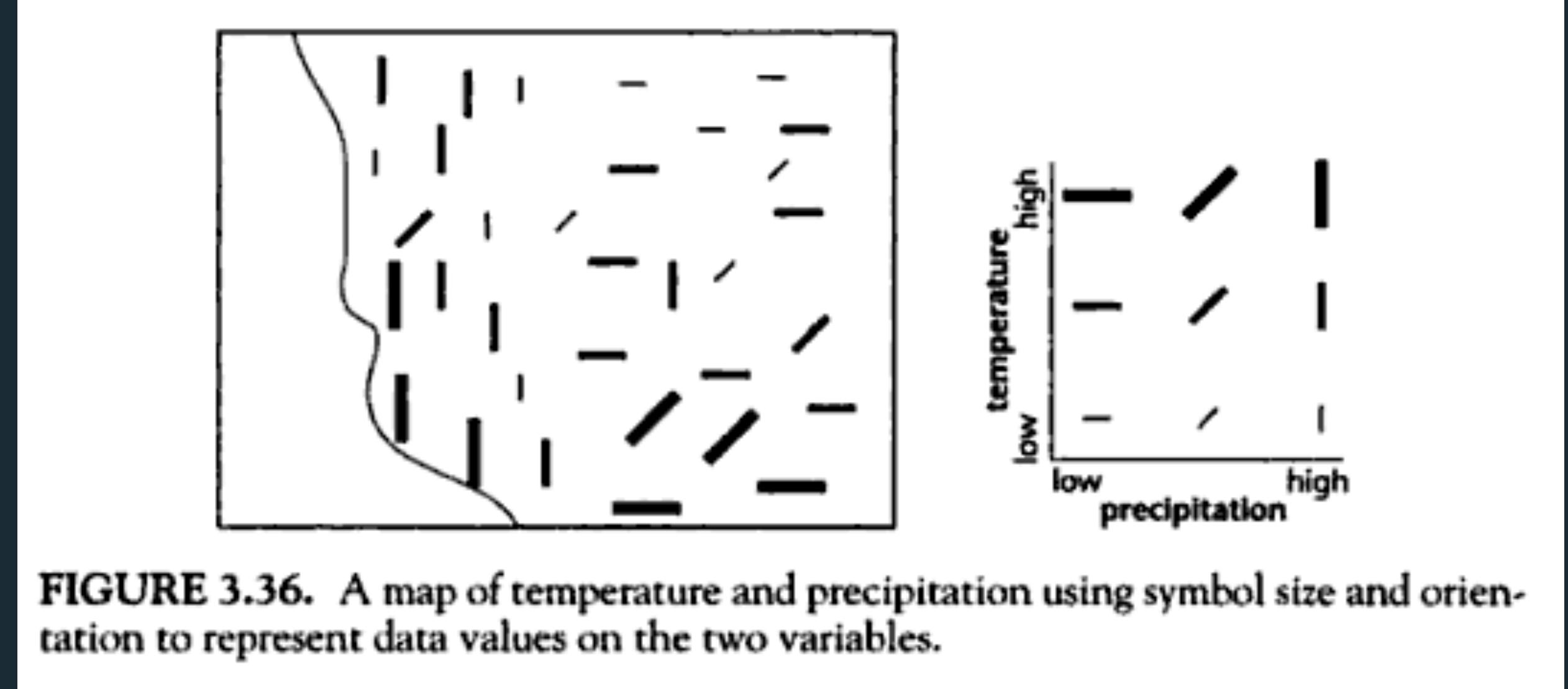
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Size & Orientation?



[MacEachren 1993]

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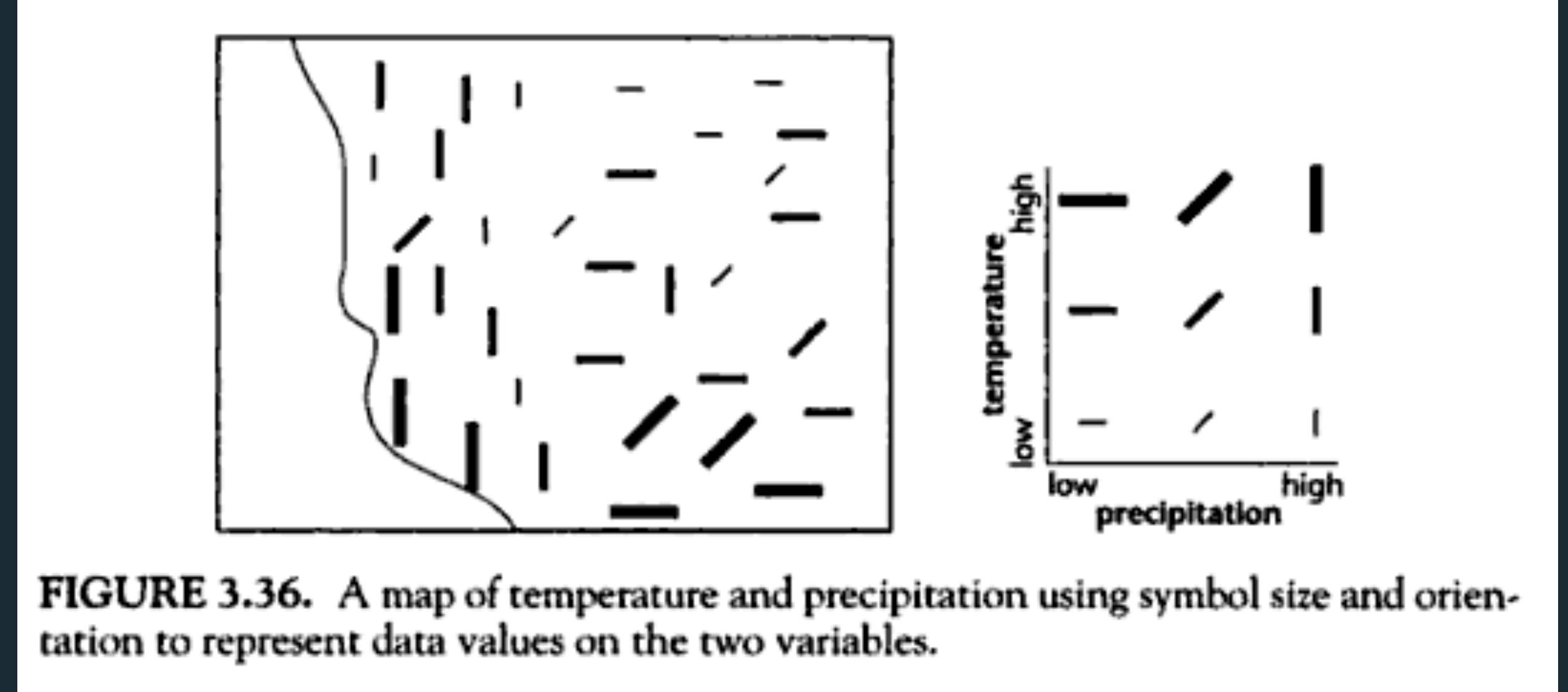
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One dimension is separable from the other, but not vice versa.

Size & Orientation?



[MacEachren 1993]

# Types of Dimensions

Size & Value?

## Separable

No interference or redundancy gain.

## Integral

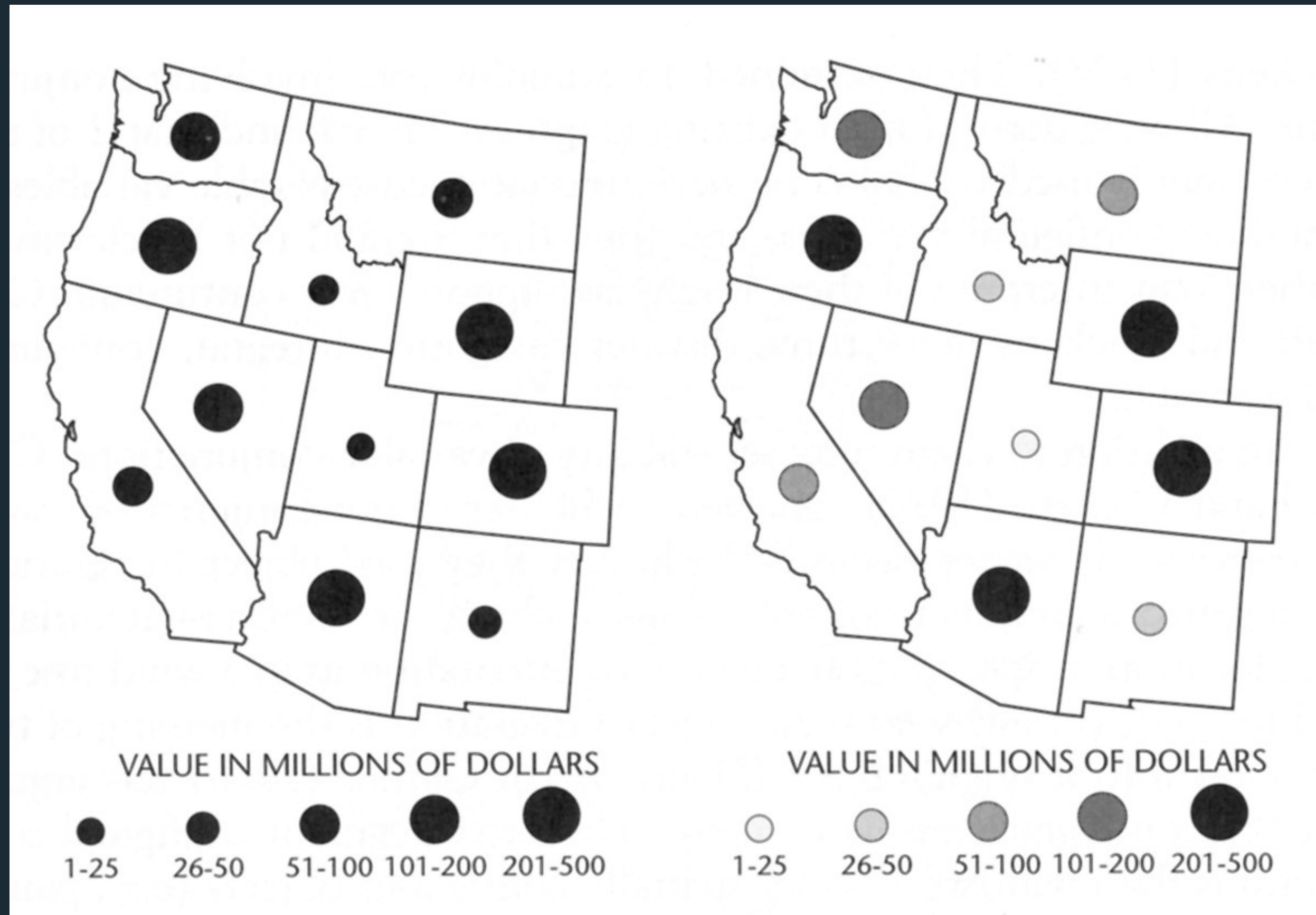
Filtering interference and redundancy gain.

## Configural

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[MacEachren 199]

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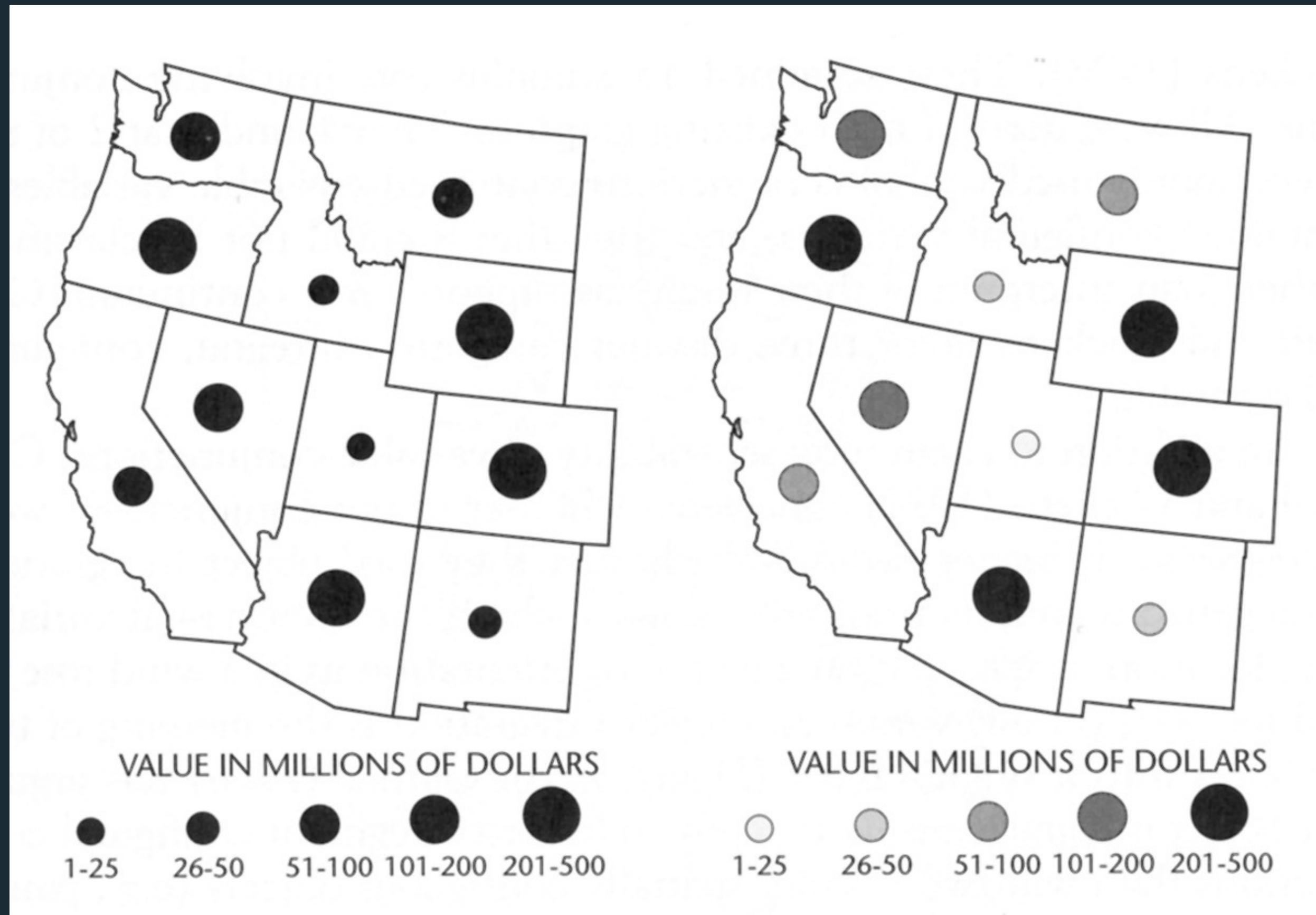
Filtering interference and redundancy gain.

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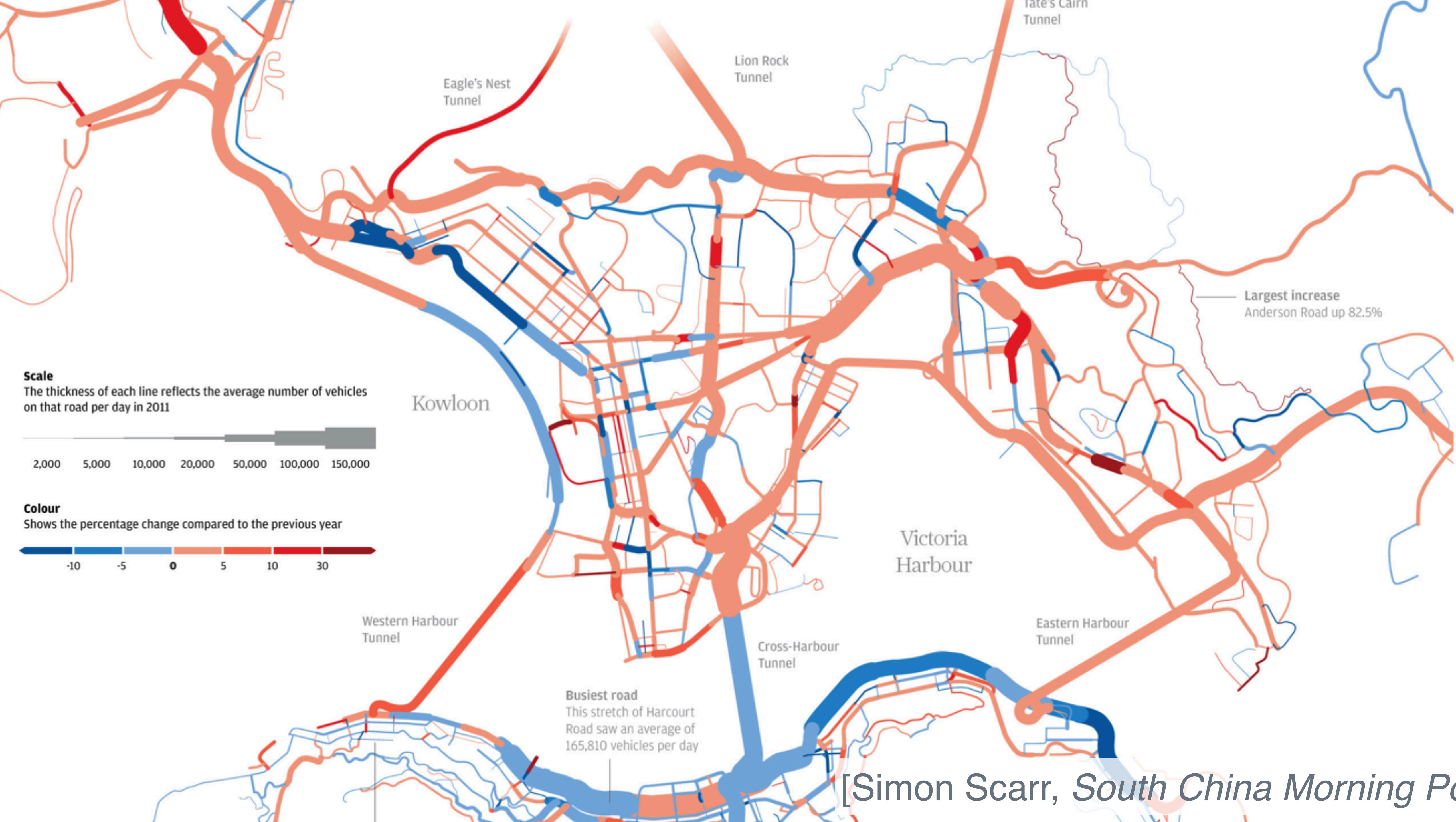
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Shape & Size?

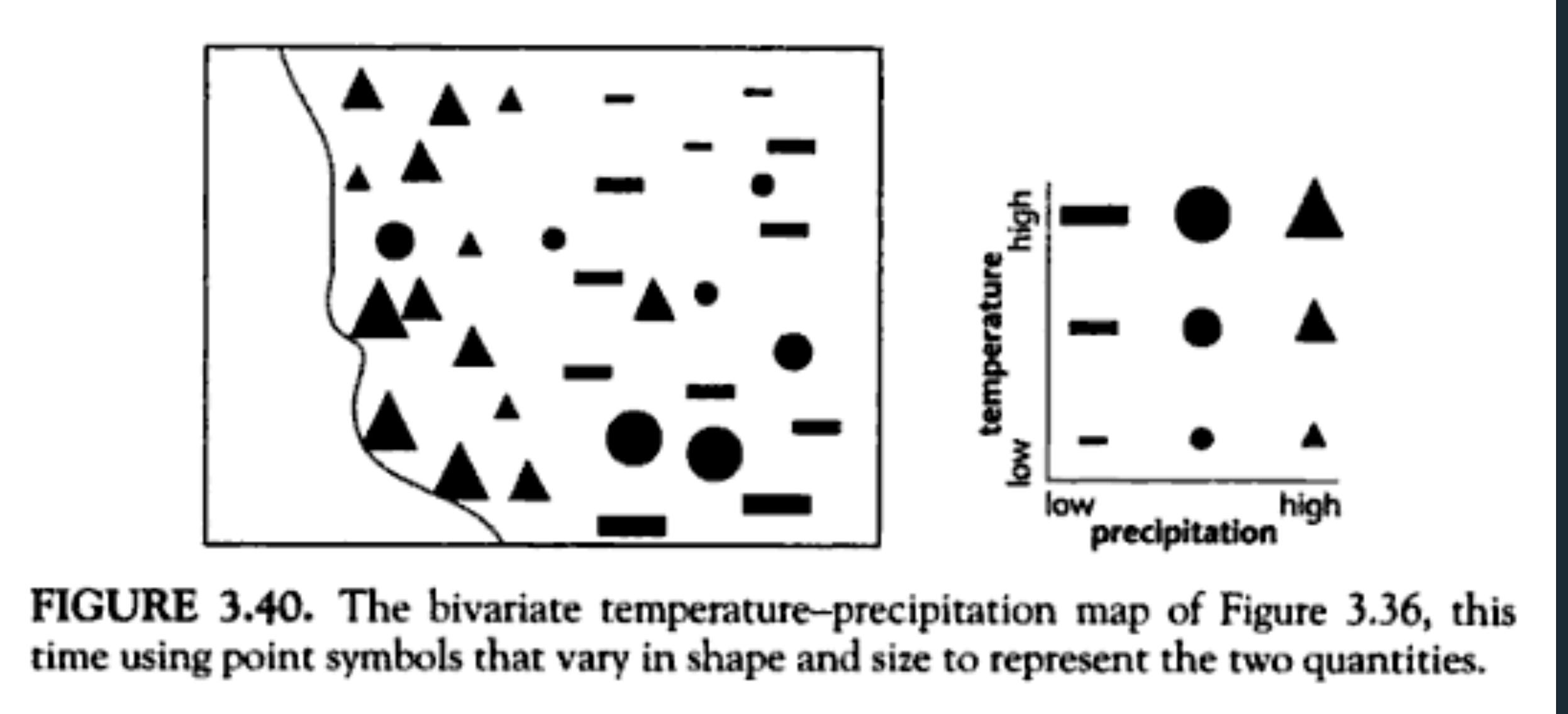


FIGURE 3.40. The bivariate temperature-precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

[MacEachren 1993]

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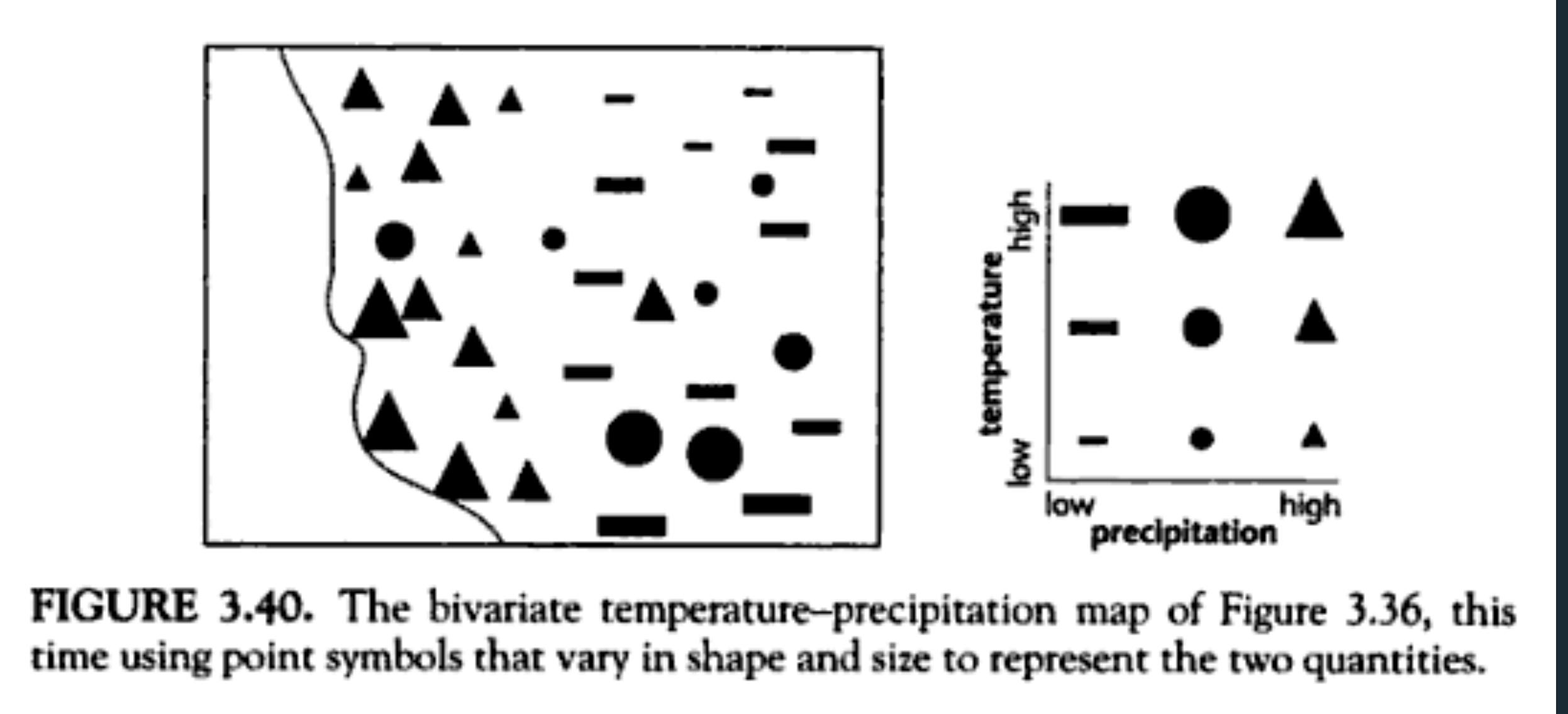


FIGURE 3.40. The bivariate temperature-precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

[MacEachren 1993]

# Types of Dimensions

Width & Height?

## Separable

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## Integral

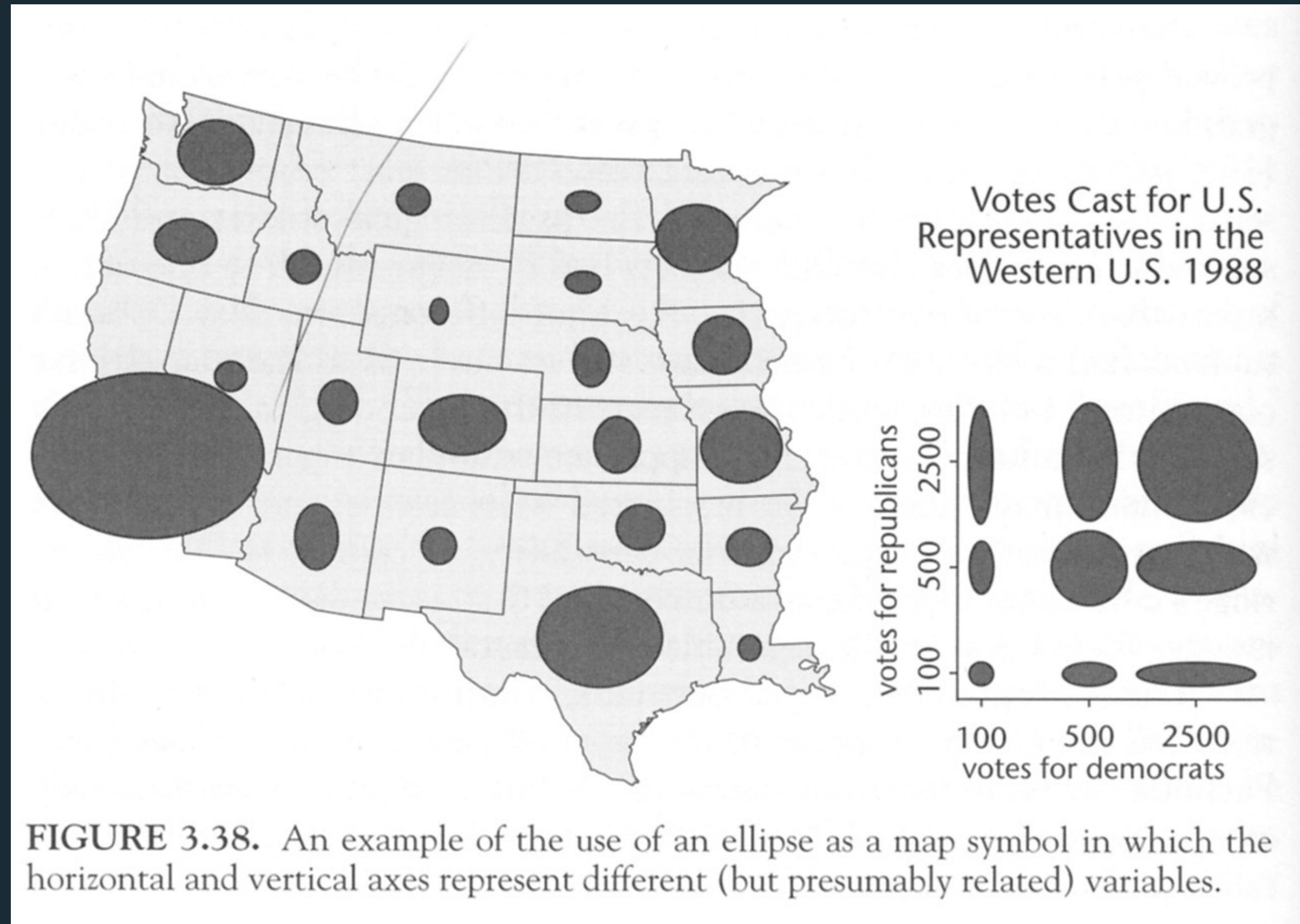
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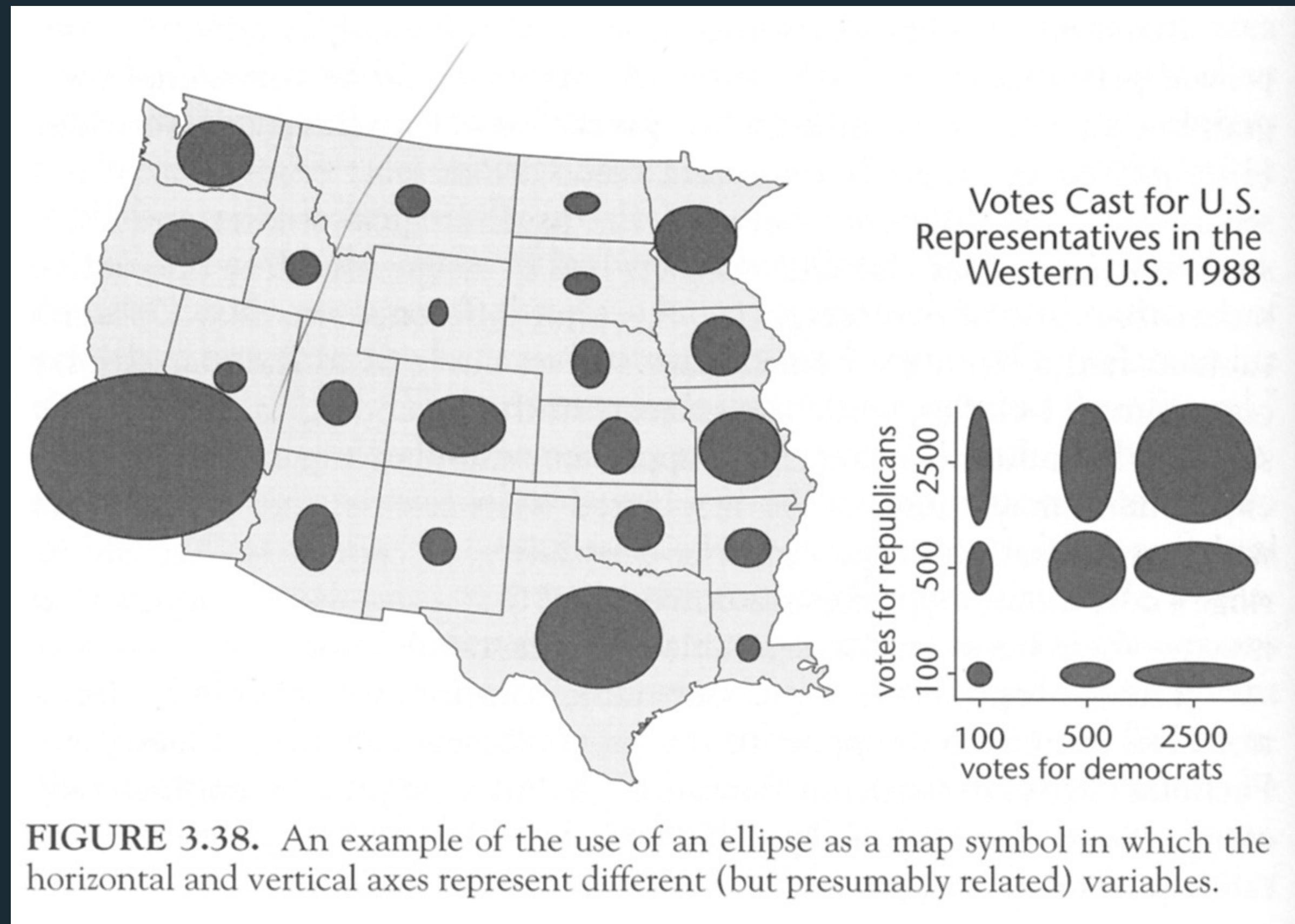
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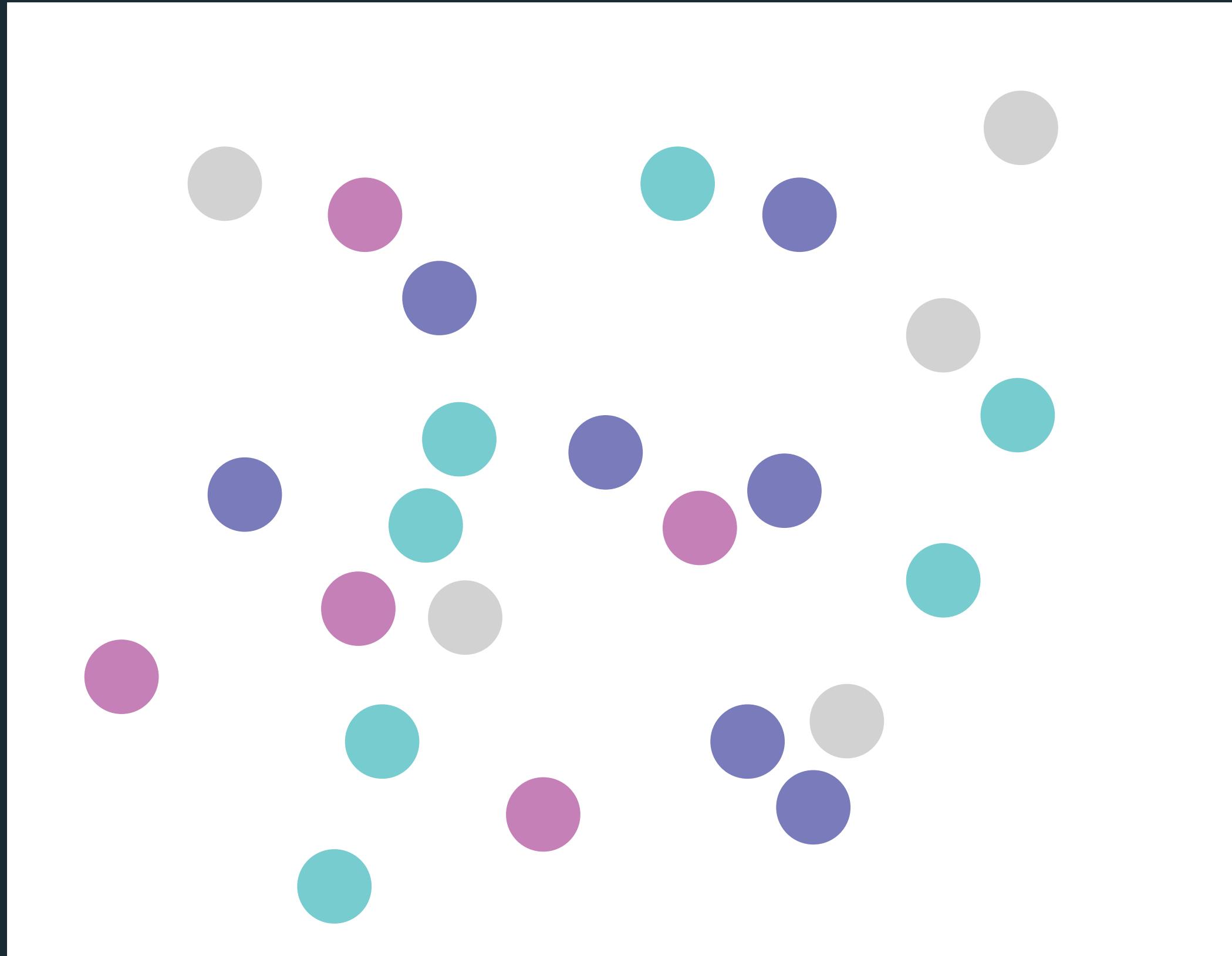
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Red & Green / Yellow & Blue?



[Tamara Munzner, *Visualization Analysis and Design* (2014)]

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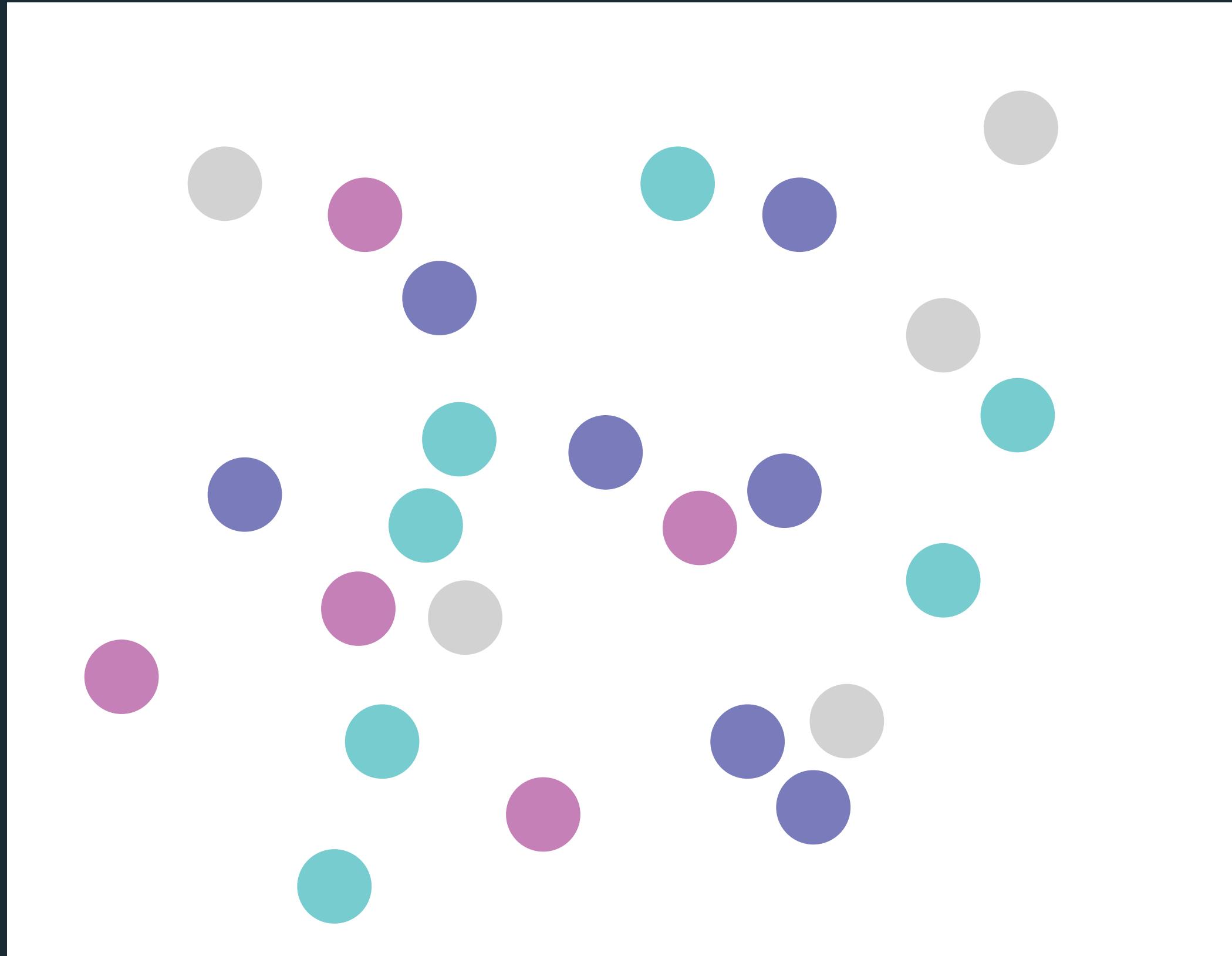
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## Asymmetric

One dimension is separable from the other, but not vice versa.

Red & Green / Yellow & Blue?



[Tamara Munzner, *Visualization Analysis and Design* (2014)]

# Types of Dimensions

## Separable

No interference or redundancy gain.

blue

## Integral

Filtering interference and redundancy gain.

yellow

## Configural

Only interference. No redundancy gain.

red

## Asymmetric

One dimension is separable from the other, but not vice versa.

green

orange

purple

# Types of Dimensions

## Separable

No interference or redundancy gain.

blue

## Integral

Filtering interference and redundancy gain.

yellow

## Configural

Only interference. No redundancy gain.

red

## Asymmetric

One dimension is separable from the other, but not vice versa.

green

orange

purple

# Types of Dimensions

## Separable

No interference or redundancy gain.

blue

## Integral

Filtering interference and redundancy gain.

yellow

## Configural

Only interference. No redundancy gain.

red

## Asymmetric

One dimension is separable from the other, but not vice versa.

green

orange

purple

## Signal Detection

## Magnitude Estimation

## Pre-Attentive Processing

## Selective Attention

## Gestalt Grouping

Separability: how much interaction occurs between attributes?

**Signal Detection**

**Magnitude Estimation**

**Pre-Attentive Processing**

**Selective Attention**

**Gestalt Grouping**

# Gestalt Principles

Figure / Ground

Proximity

Similarity

Symmetry

Connectedness

Continuity

Closure

Common Fate

# Gestalt Principles

*Pragnanz:* we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

Symmetry

Connectedness

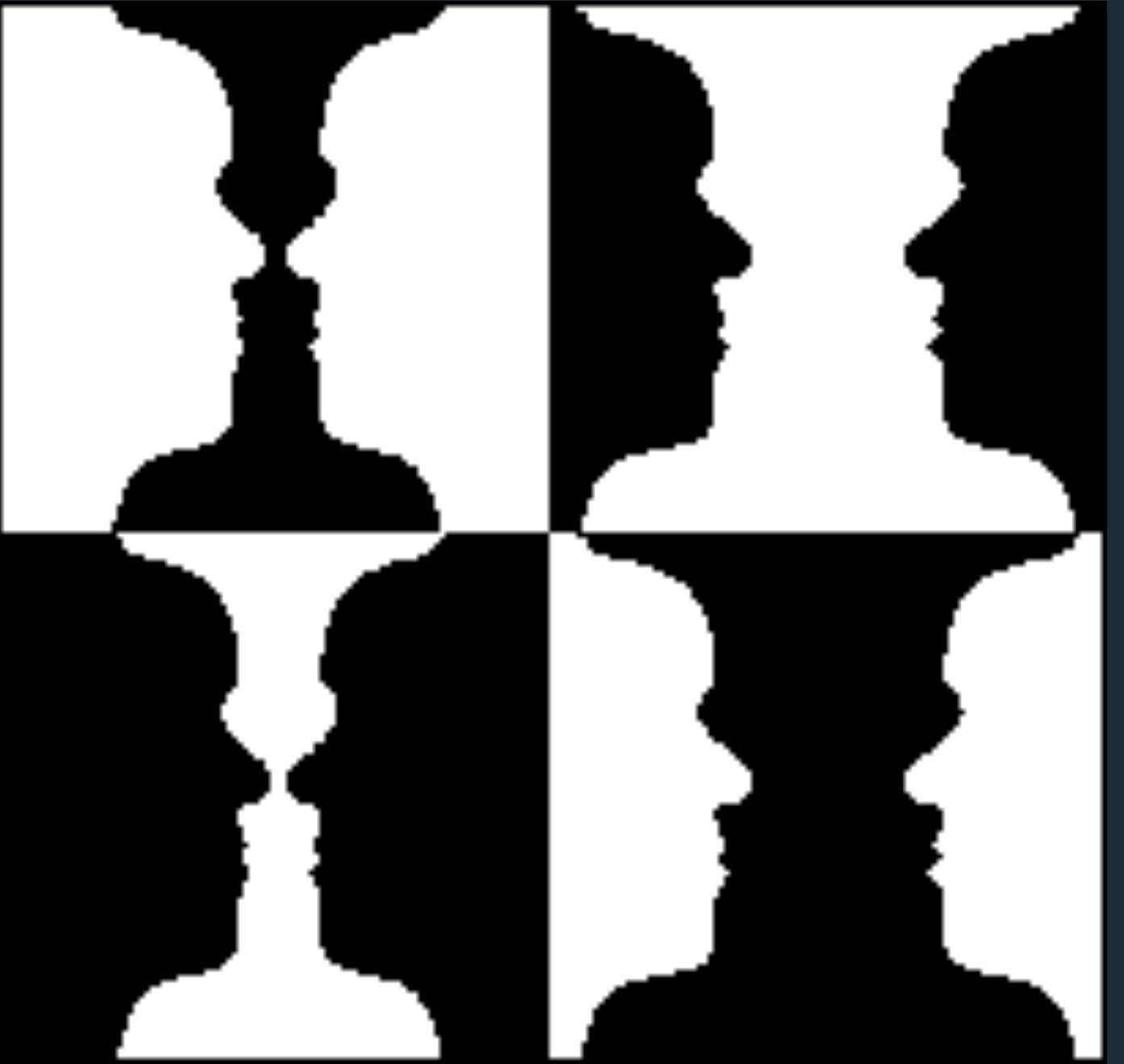
Continuity

Closure

Common Fate



Ambiguous – vase or faces?



Unambiguous (?)

# Gestalt Principles

*Pragnänz:* we favor the simplest and most stable interpretation

Figure / Ground



Ambiguous – vase or faces?

Proximity



Unambiguous (?)

Similarity

Symmetry

Connectedness

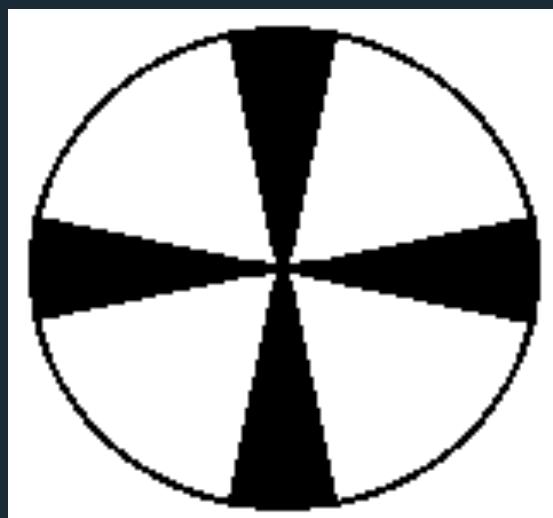
Continuity

Closure

Common Fate



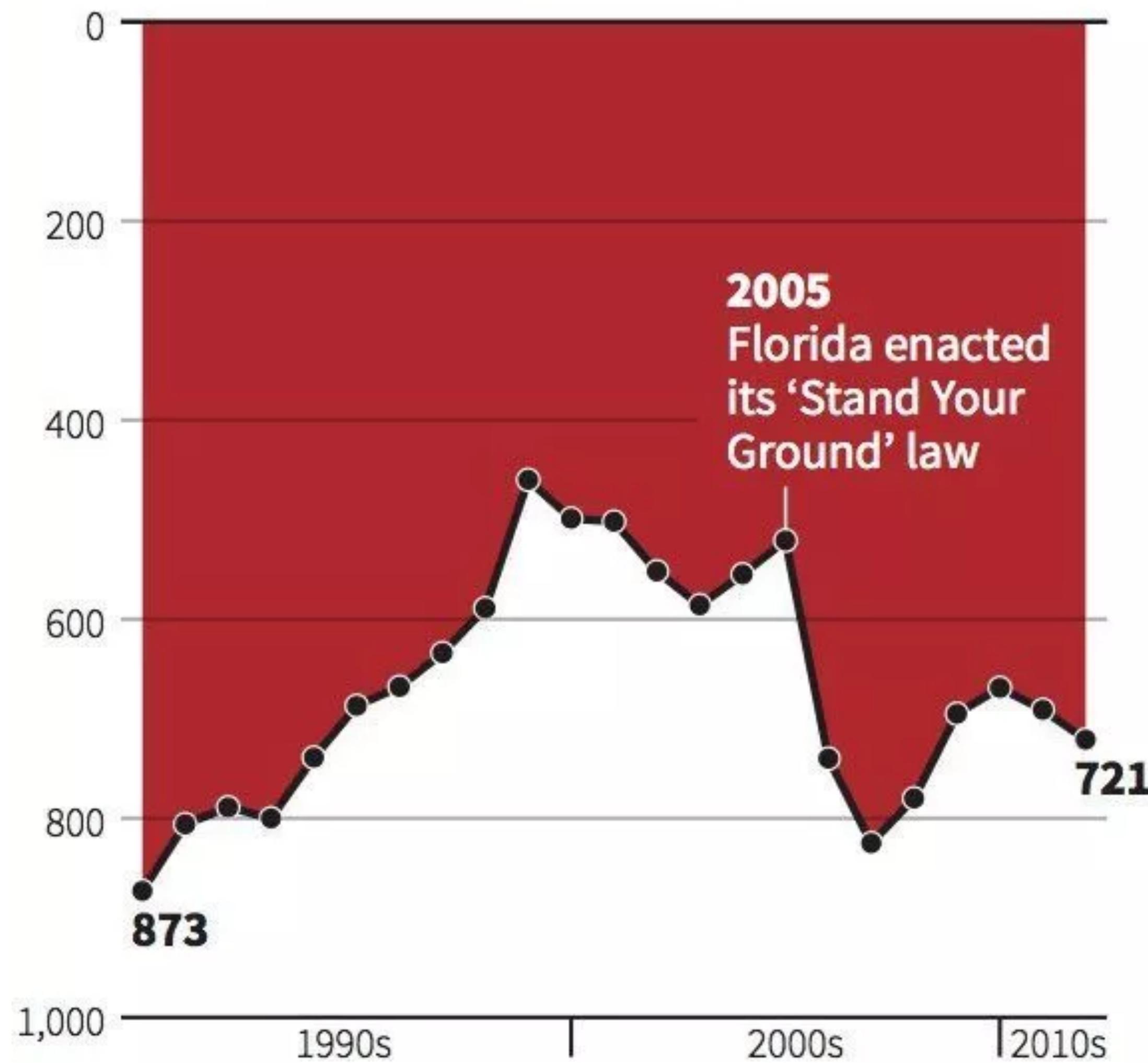
Principle of *surroundedness*.



Principle of *relative size*.

# Gun deaths in Florida

Number of murders committed using firearms



Source: Florida Department of Law Enforcement

# Gestalt Principles

*Pragnanz*: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

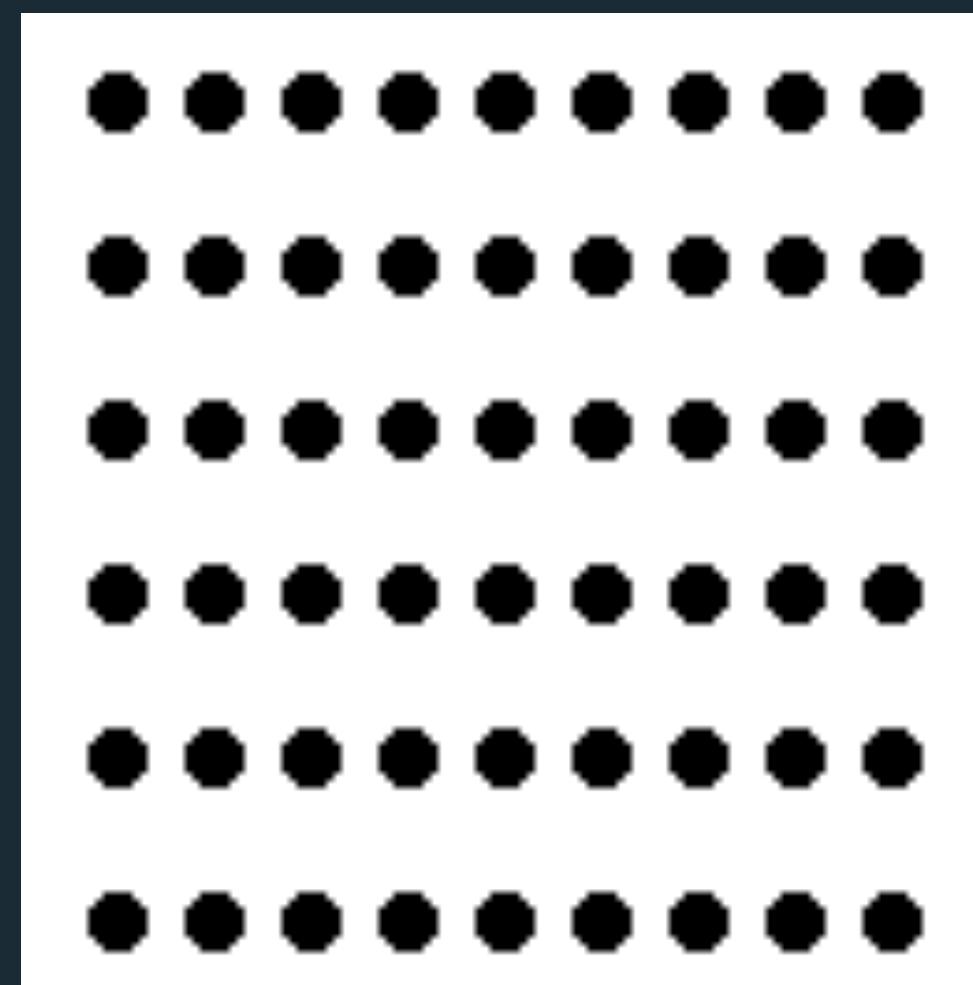
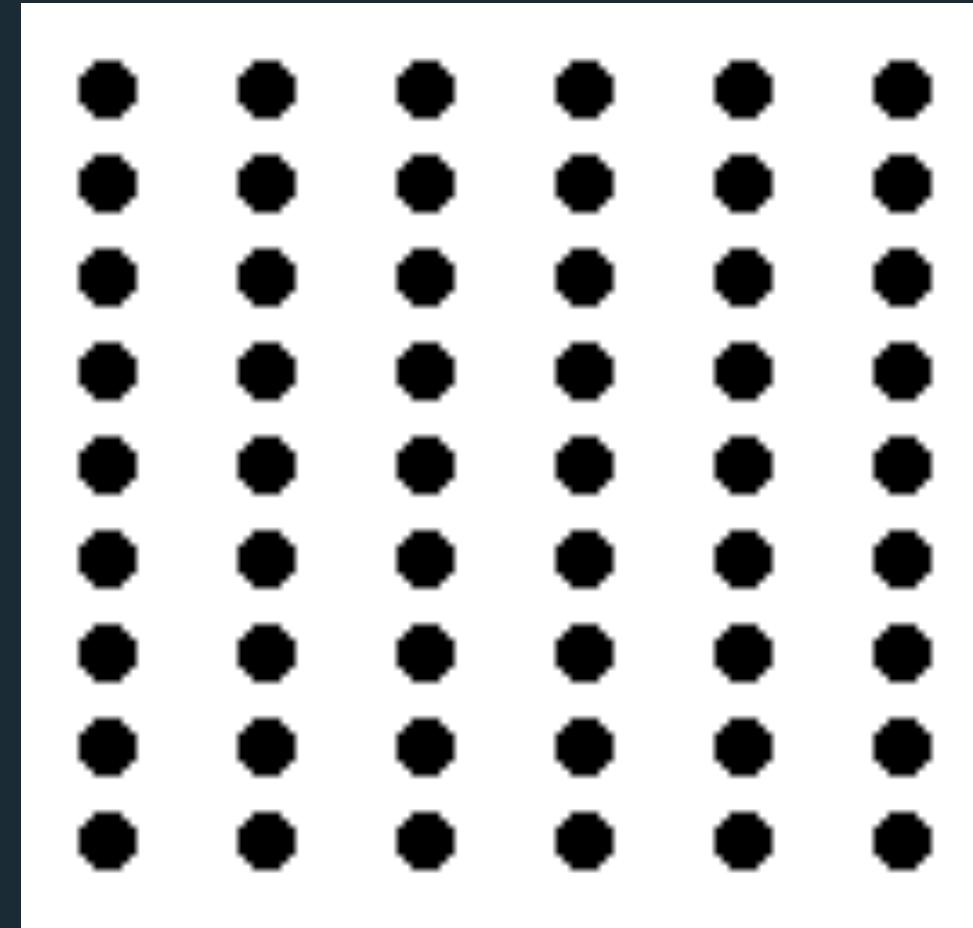
Symmetry

Connectedness

Continuity

Closure

Common Fate



# Gestalt Principles

*Pragnanz:* we favor the simplest and most stable interpretations

Figure / Ground

Proximity

Similarity

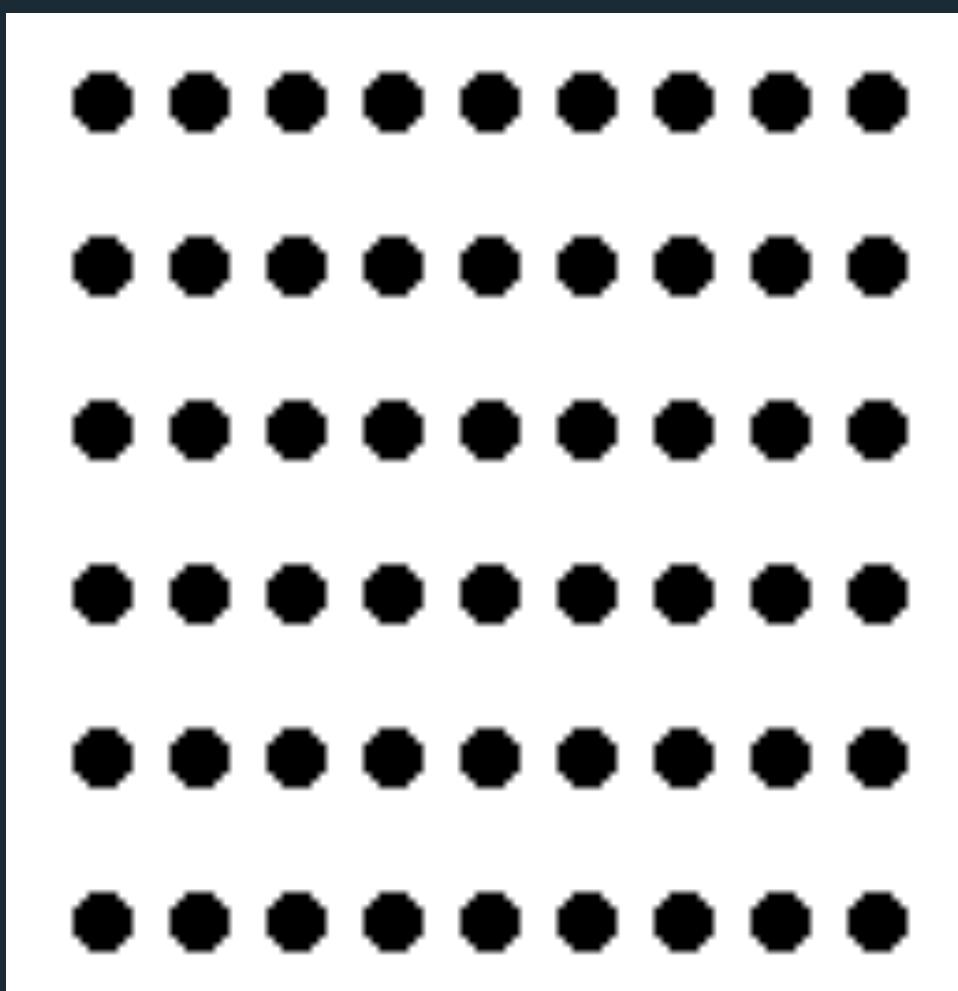
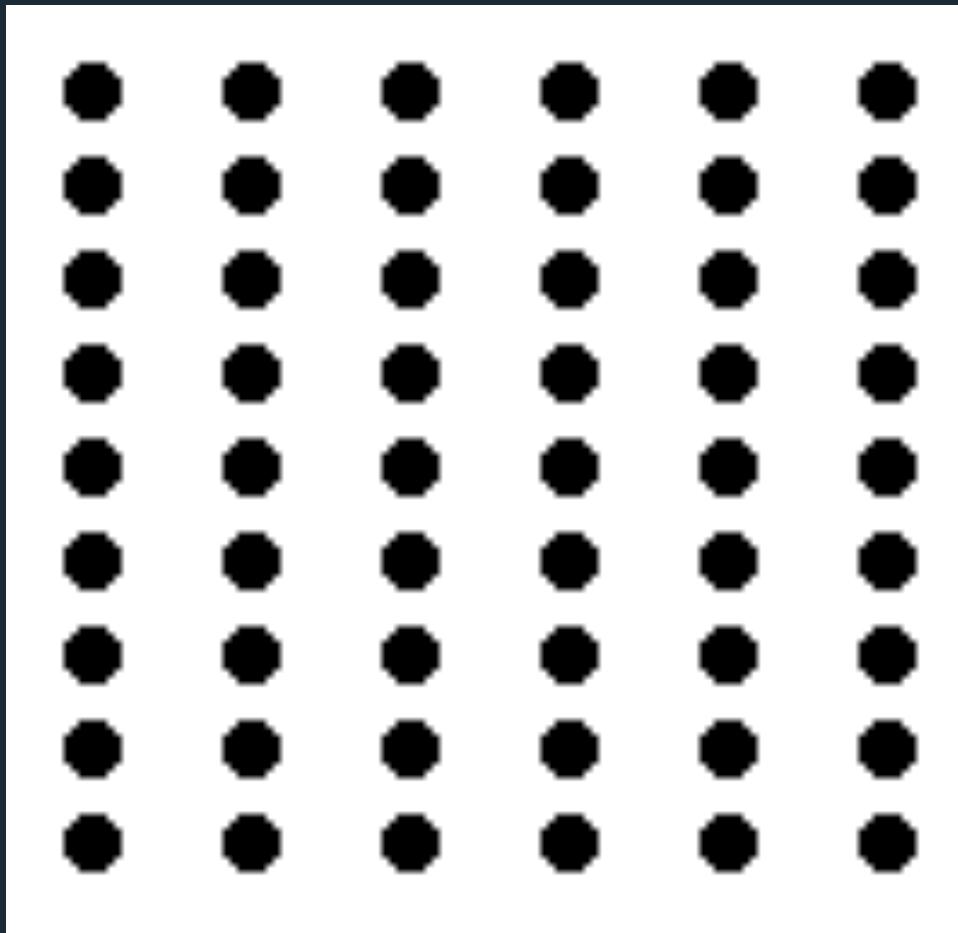
Symmetry

Connectedness

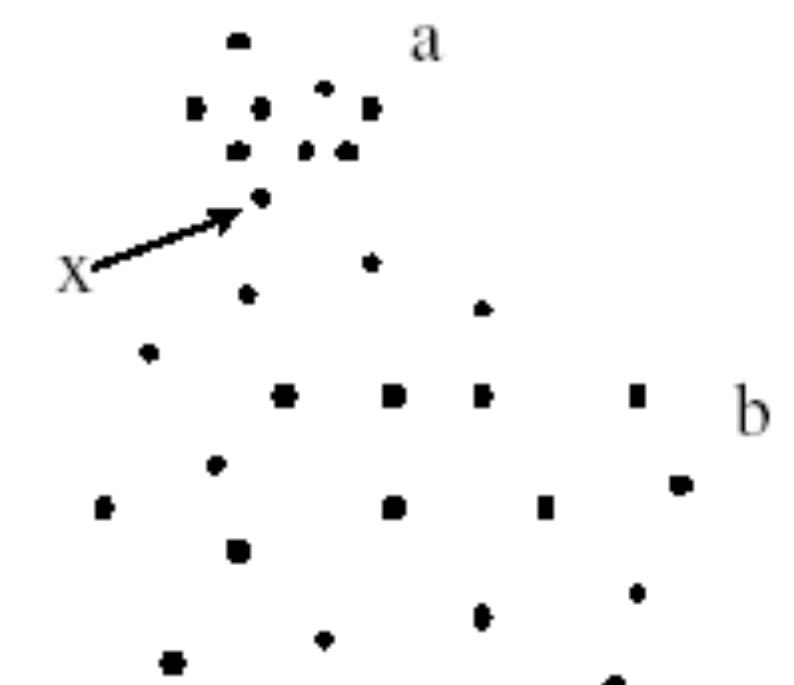
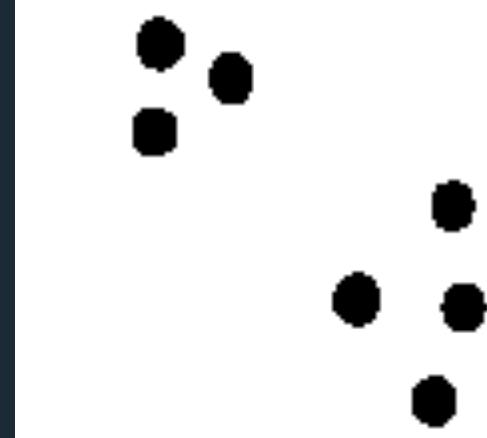
Continuity

Closure

Common Fate



[Ware 2000]



Principle of *concentration*.

# Gestalt Principles

*Pragnänz*: we favor the simplest and most stable interpretation

## Figure / Ground

Proximity

Similarity

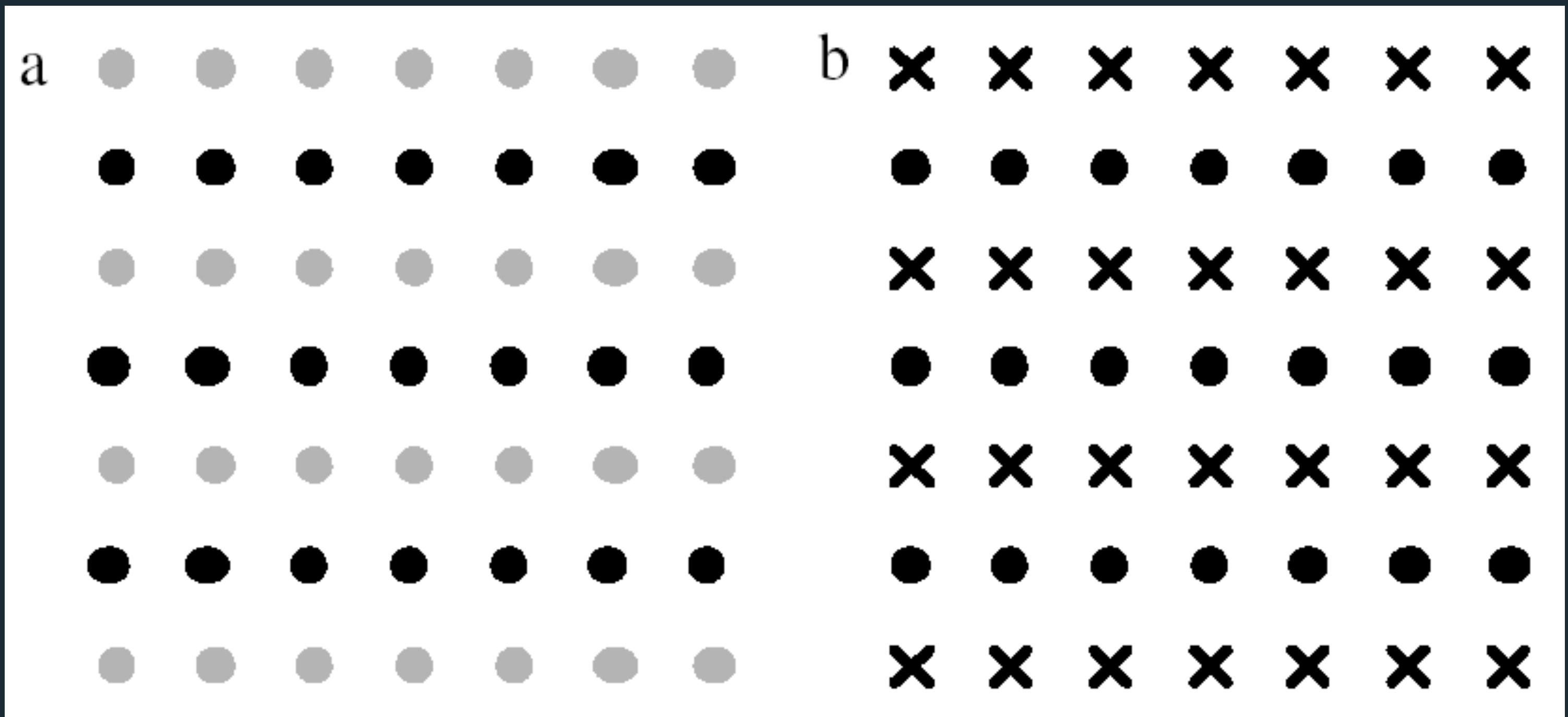
Symmetry

Connectedness

Continuity

Closure

Common Fate



Rows dominate due to similarity. [Ware 2004]

# Gestalt Principles

*Pragnänz*: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

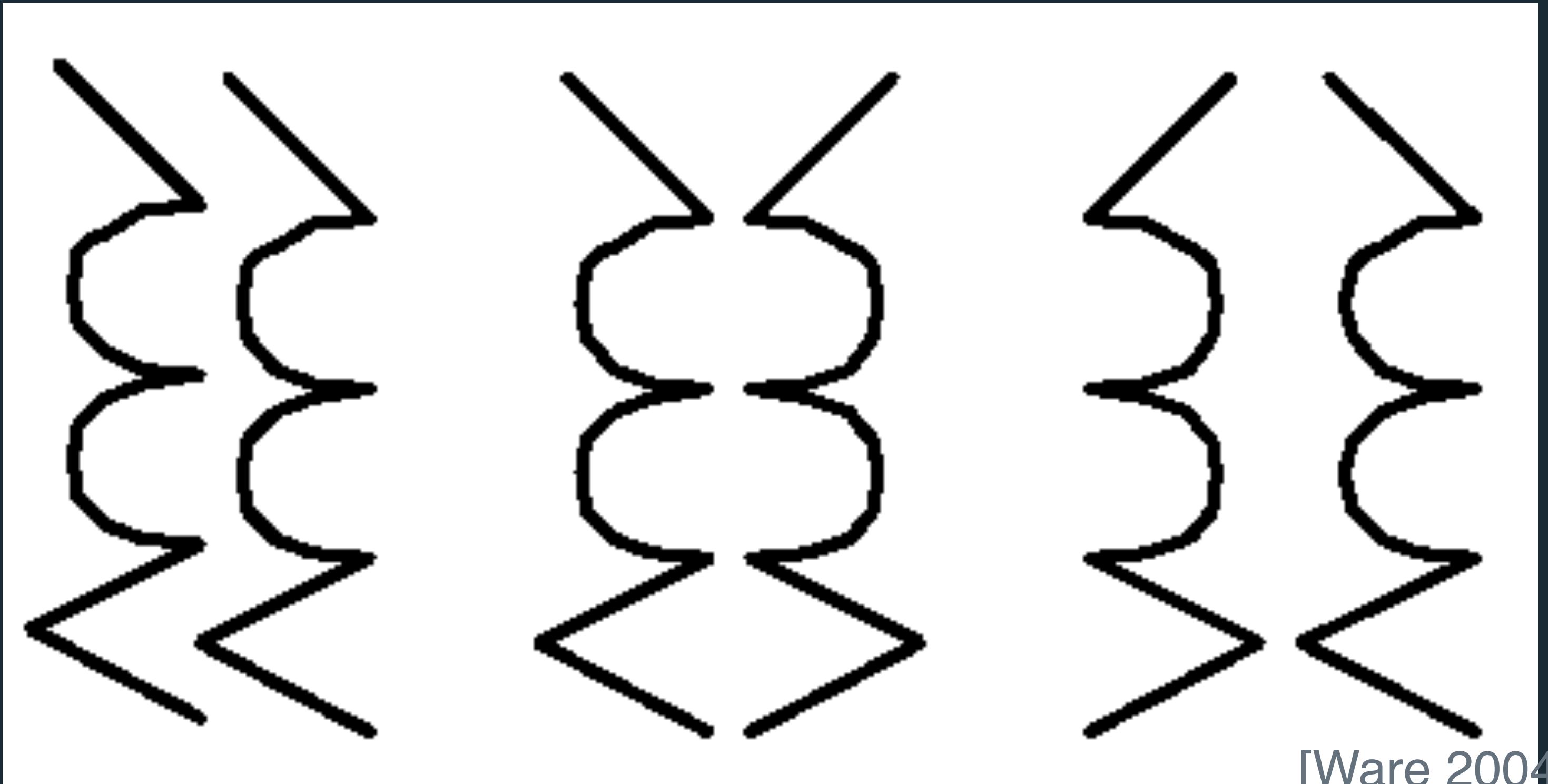
Symmetry

Connectedness

Continuity

Closure

Common Fate

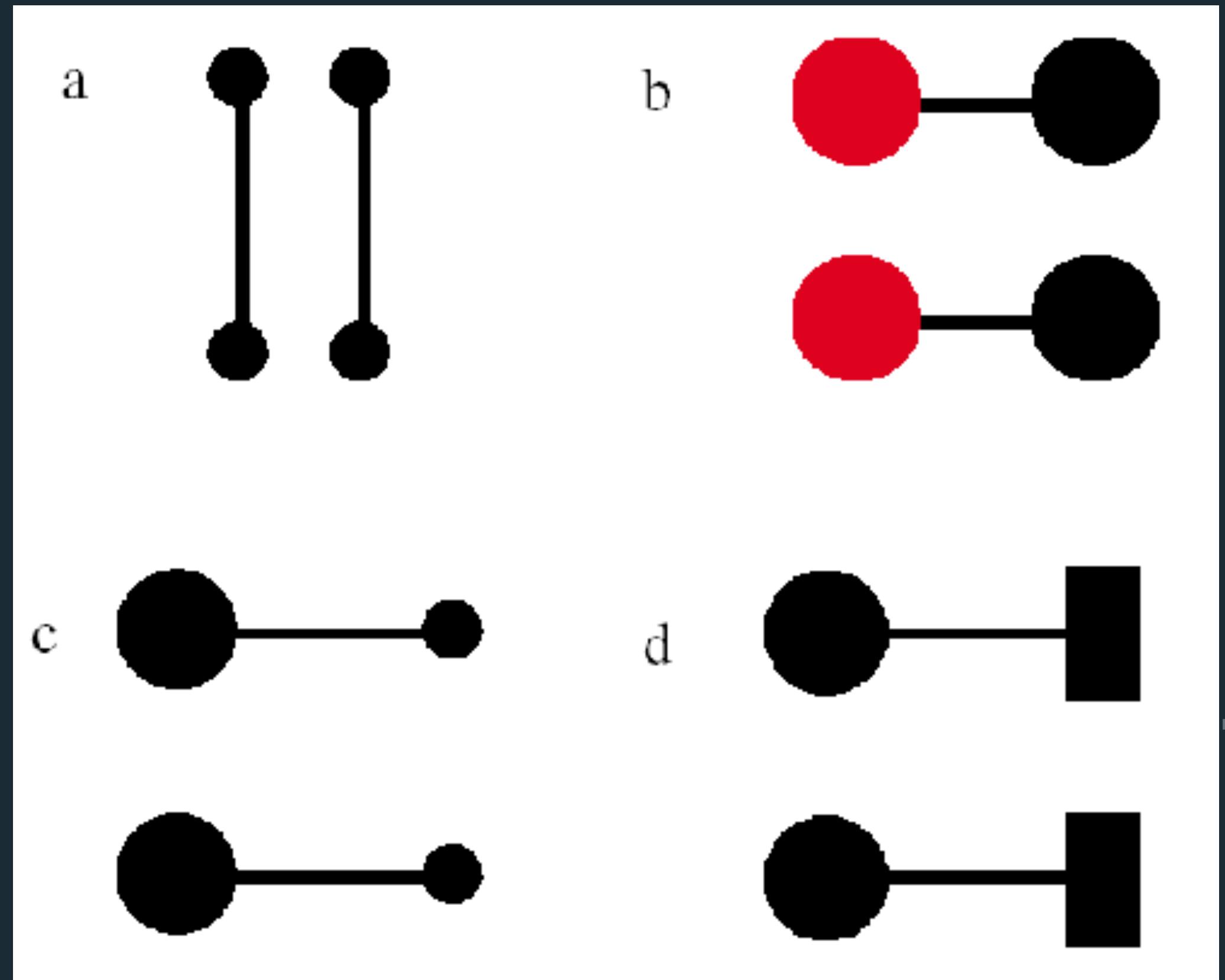


Bilateral symmetry gives the strong sense of a figure.

# Gestalt Principles

Figure / Ground  
Proximity  
Similarity  
Symmetry  
Connectedness  
Continuity  
Closure  
Common Fate

*Pragnänz*: we favor the simplest and most stable interpretation



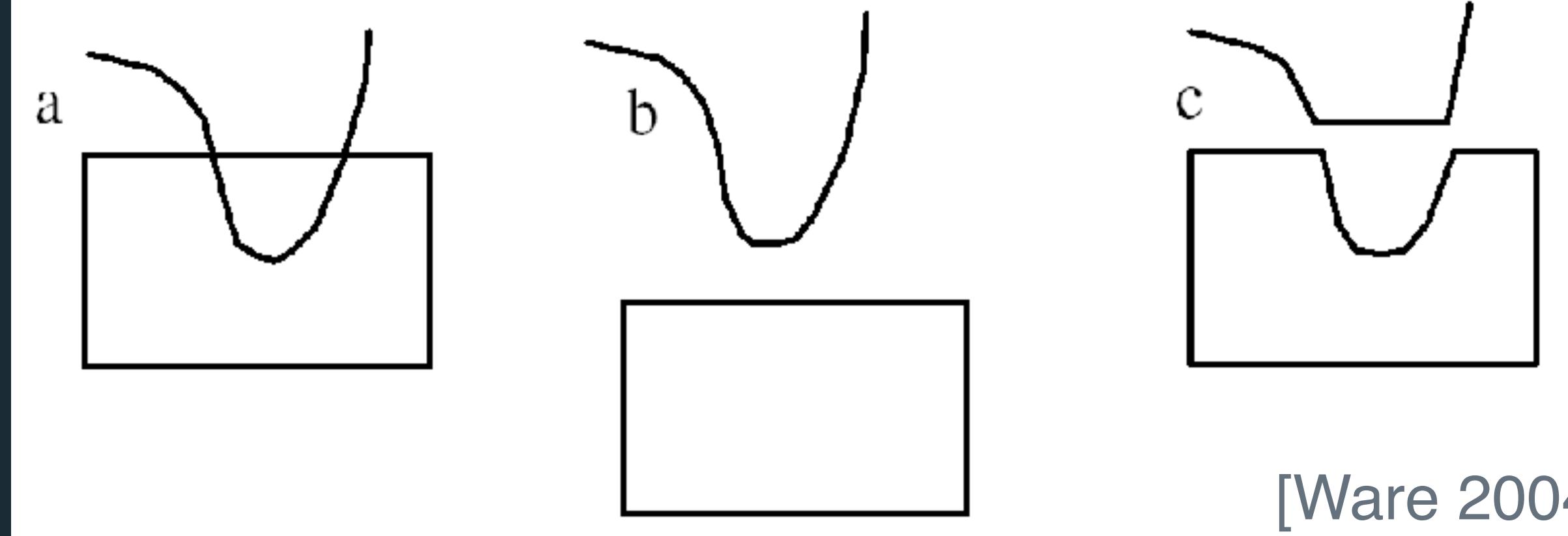
Connectedness overrules proximity, size, color, shape

[Ware 2004]

# Gestalt Principles

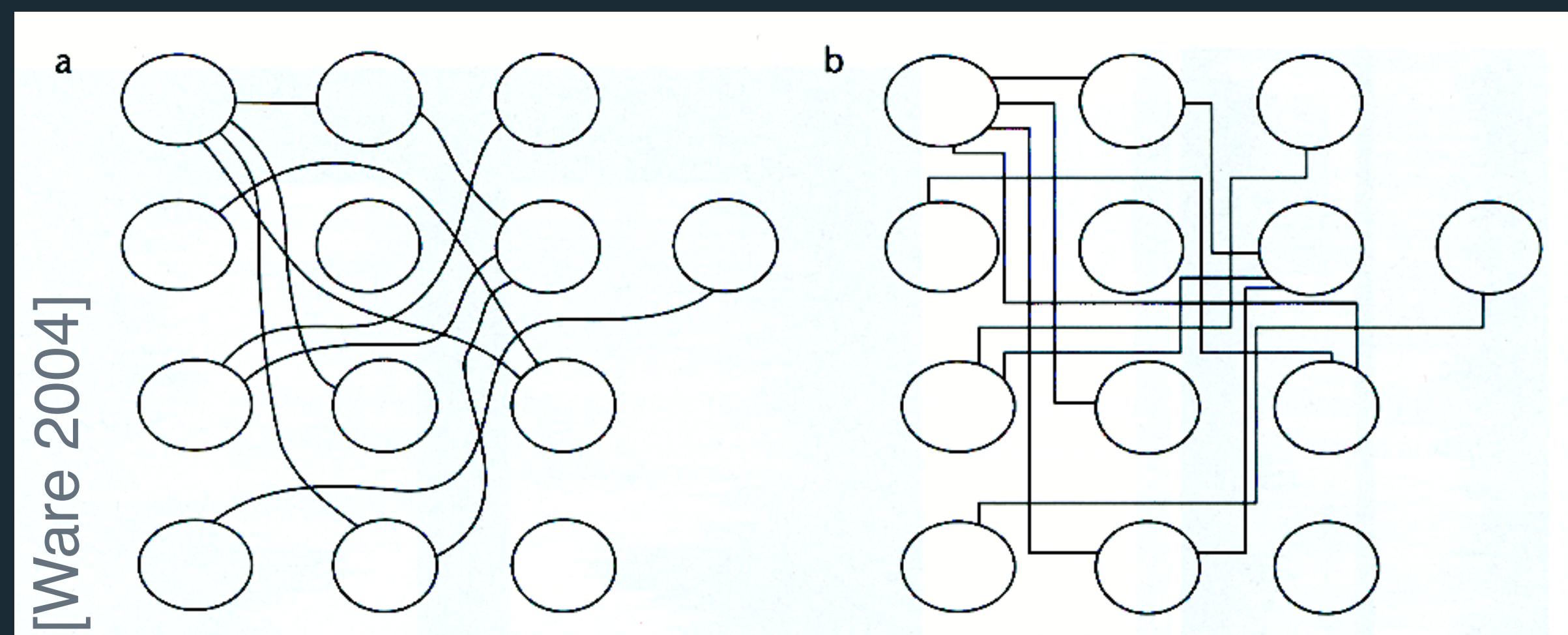
Figure / Ground  
Proximity  
Similarity  
Symmetry  
Connectedness  
**Continuity**  
Closure  
Common Fate

*Pragnänz*: we favor the simplest and most stable interpretation



[Ware 2004]

We prefer smooth, not abrupt, changes.



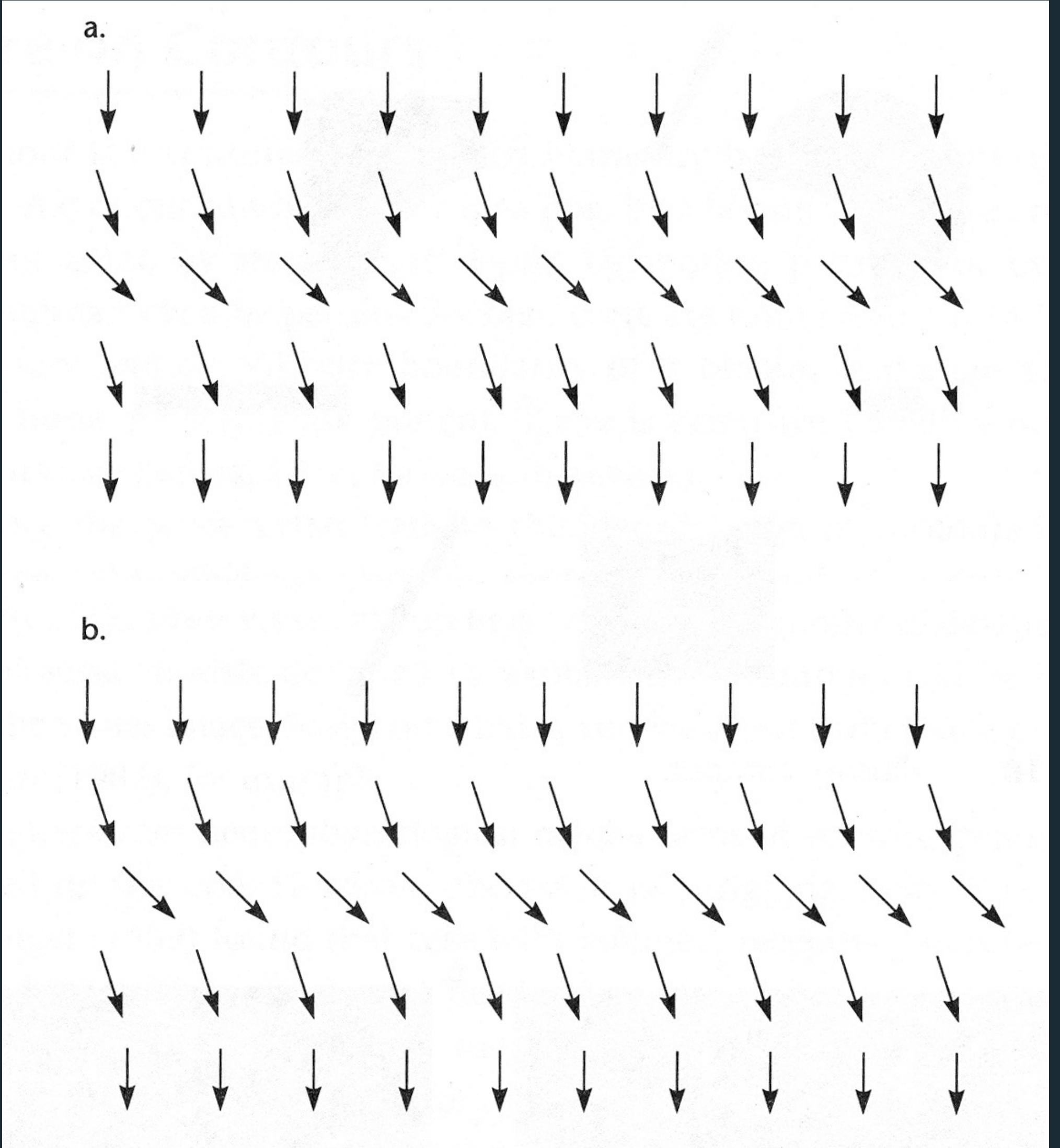
[Ware 2004]

Connections are clearer with smooth contours.

# Gestalt Principles

*Pragnänz*: we favor the simplest and most stable interpretation

- Figure / Ground
- Proximity
- Similarity
- Symmetry
- Connectedness
- Continuity
- Closure
- Common Fate

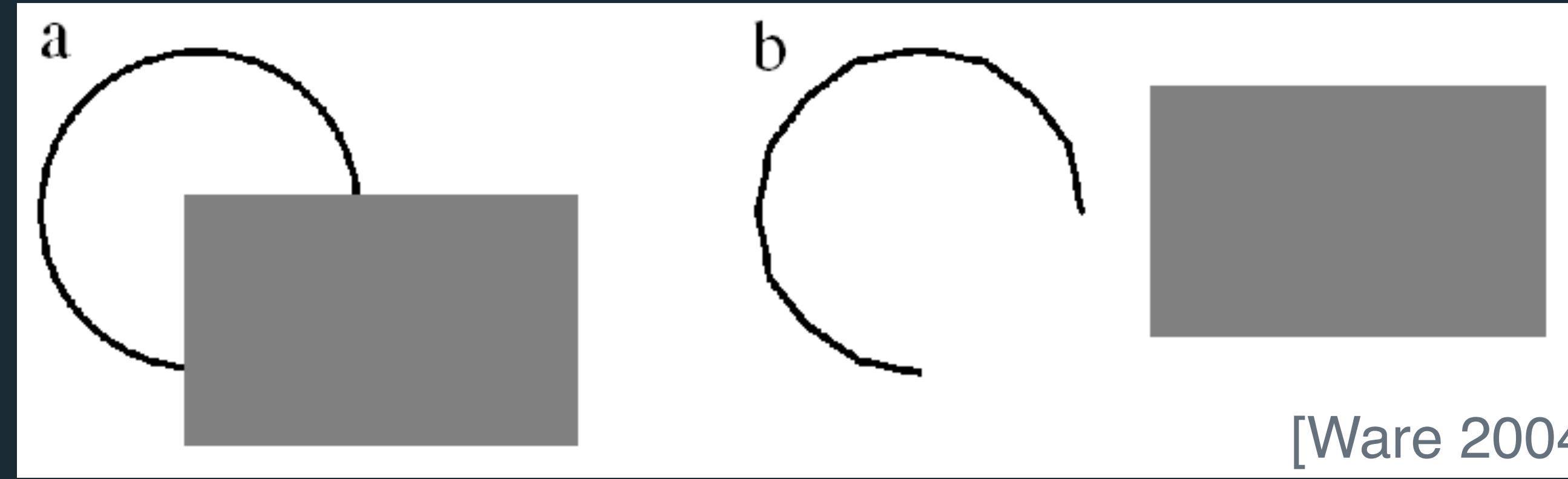


Prefer field  
that shows  
smooth  
continuous  
contours  
[Ware 2004]

# Gestalt Principles

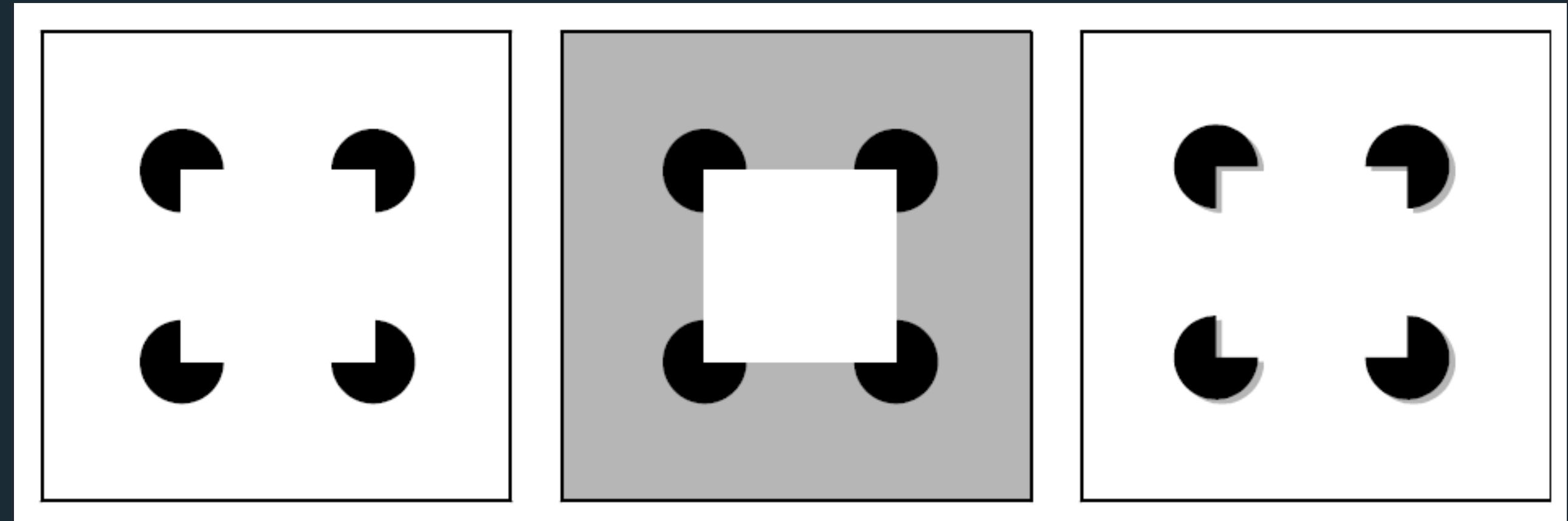
*Pragnänz:* we favor the simplest and most stable interpretations

- Figure / Ground
- Proximity
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- Symmetry
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- Continuity
- Closure
- Common Fate



[Ware 2004]

We see a circle behind a rectangle, not a broken circle



[Durand 02]

Illusory contours

# Gestalt Principles

*Pragnanz:* we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

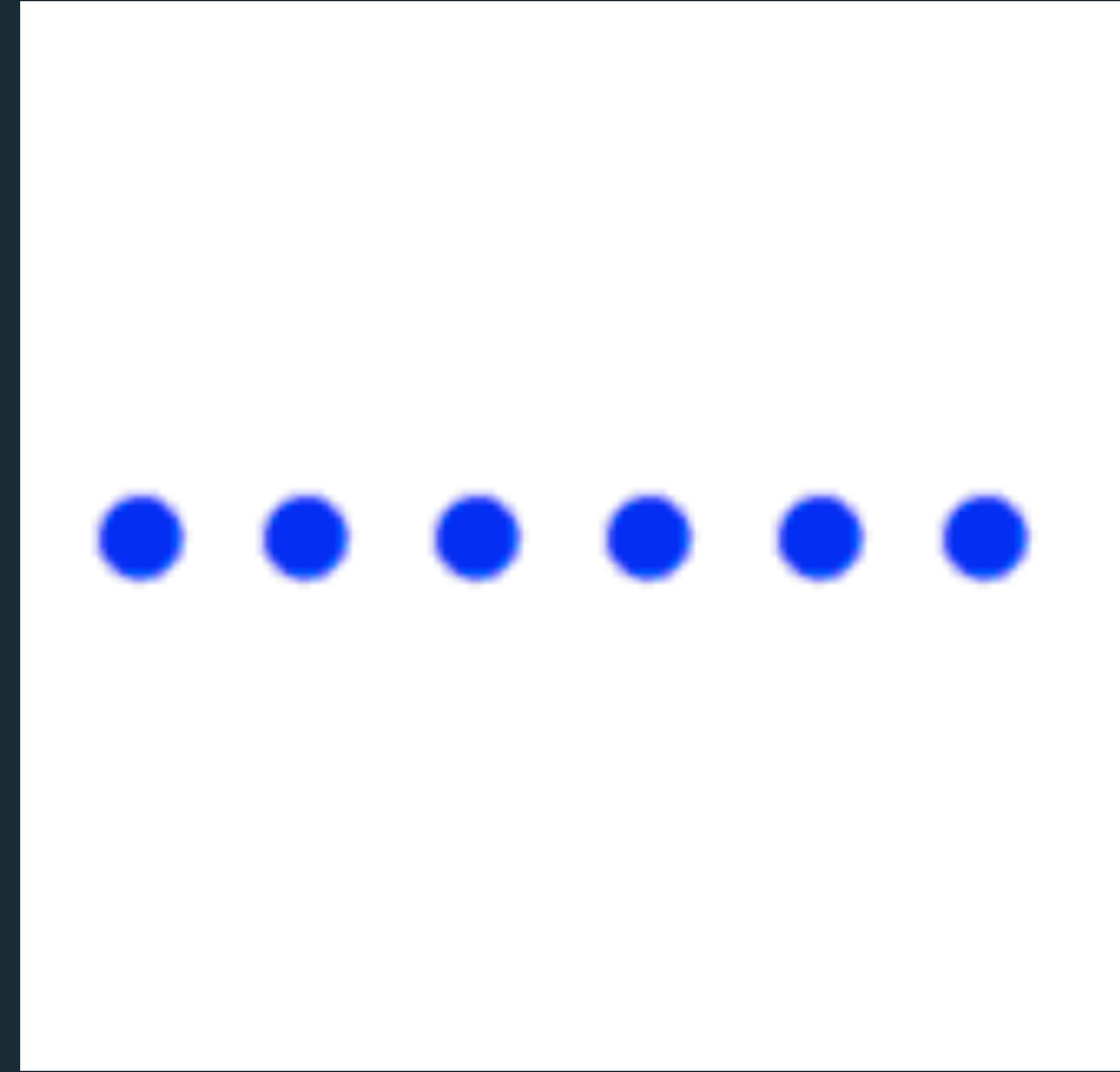
Symmetry

Connectedness

Continuity

Closure

Common Fate



Dots moving together are grouped.

## **Signal Detection**

Use 4-5 steps for most channels, hard for people to distinguish more

## **Magnitude Estimation**

Even a direct map to e.g. area or brightness won't always work.

## **Pre-Attentive Processing**

Use channels that are pre-attentive for callouts e.g. color, shape.

## **Selective Attention**

...but be careful with combinations of channels!

## **Gestalt Grouping**

Use these to improve annotations, coloring, animations.