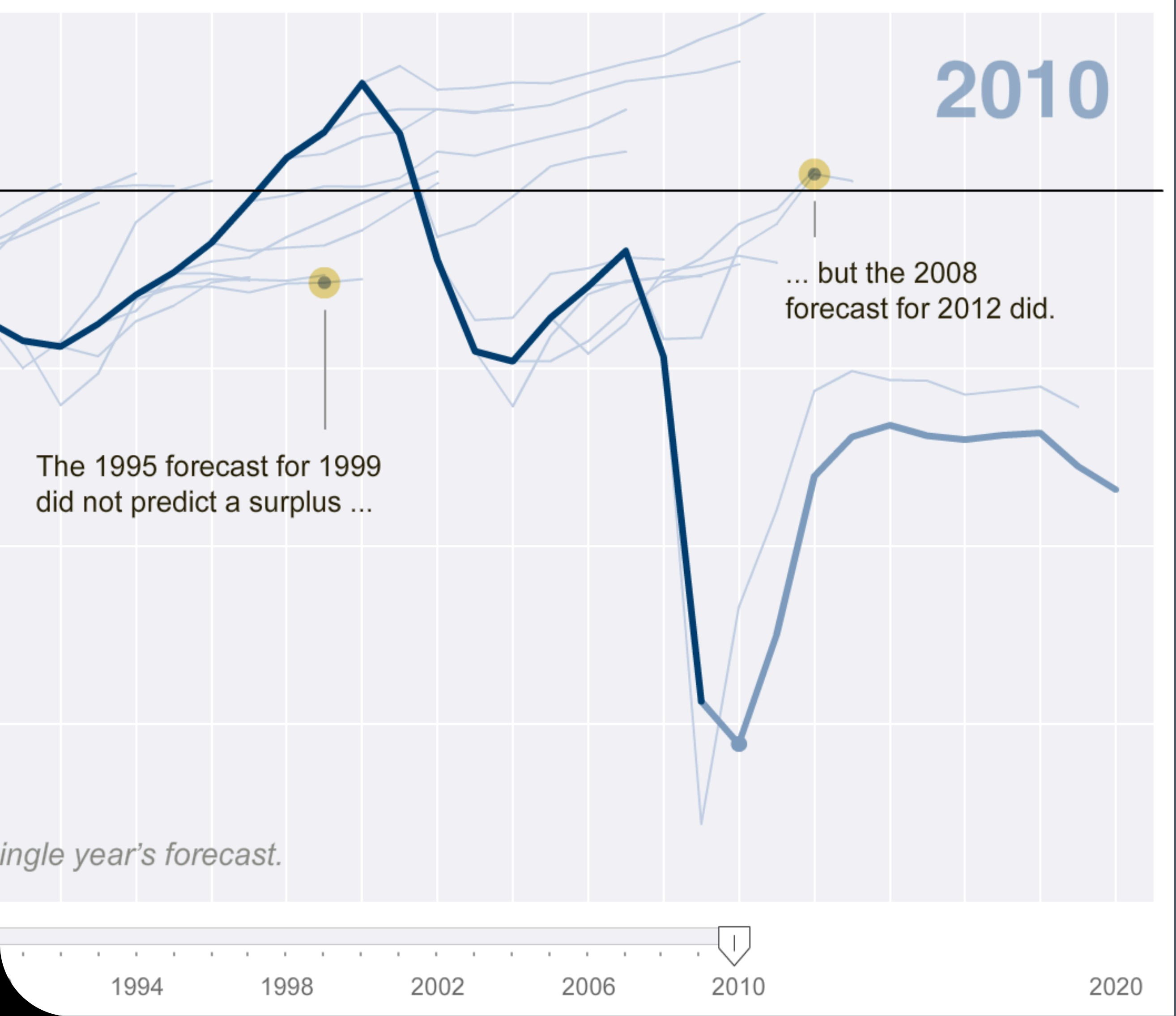
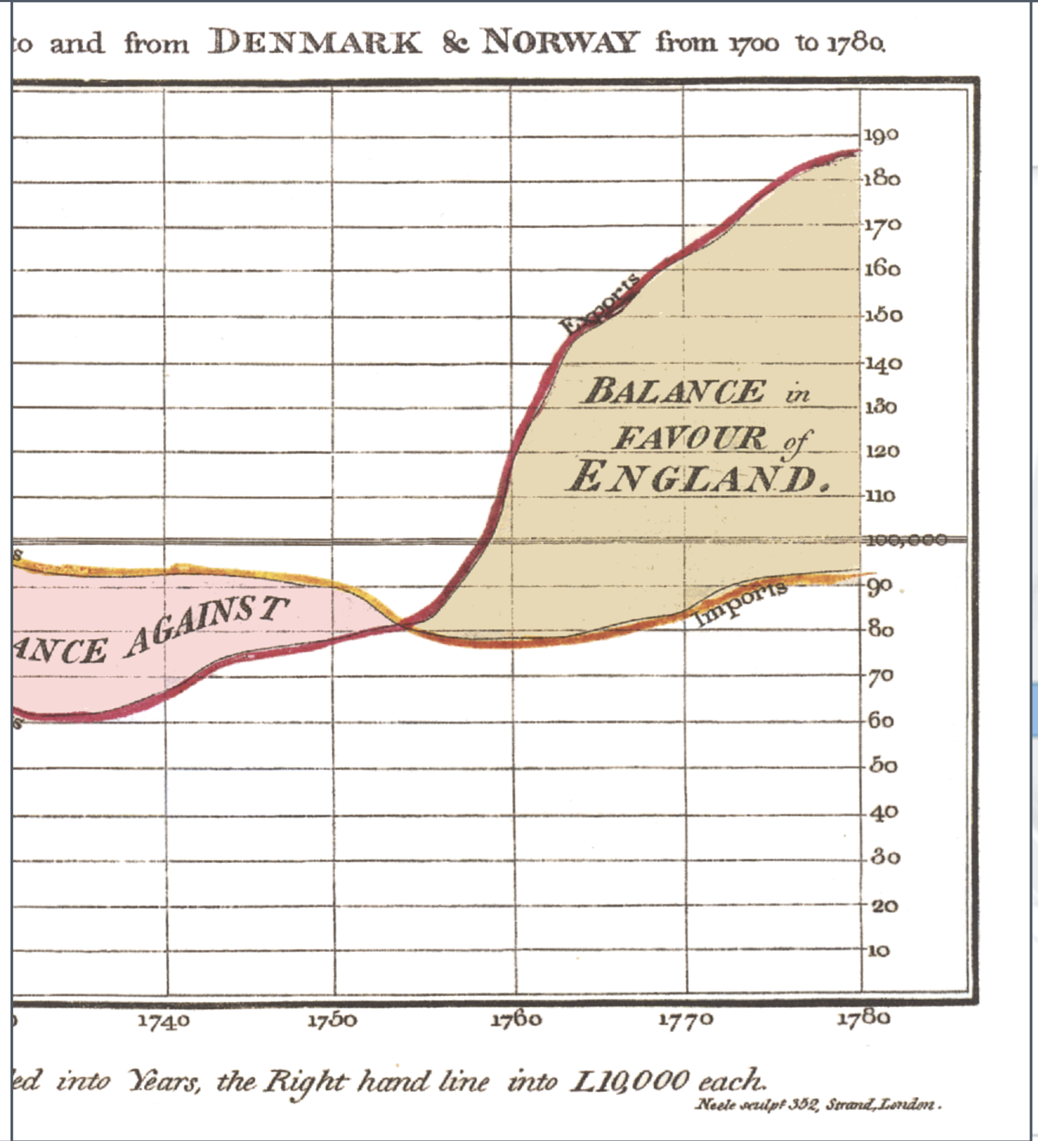
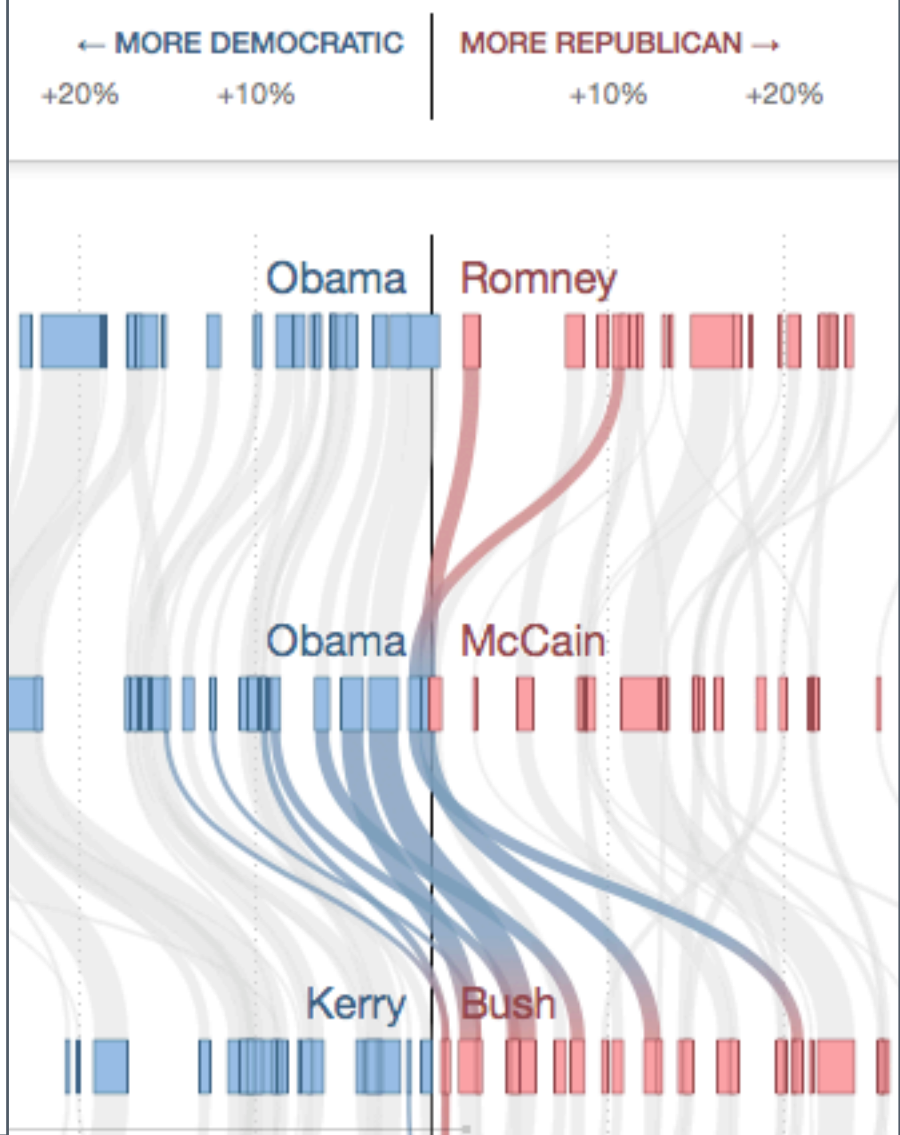
# 6.859: Interactive Data Visualization

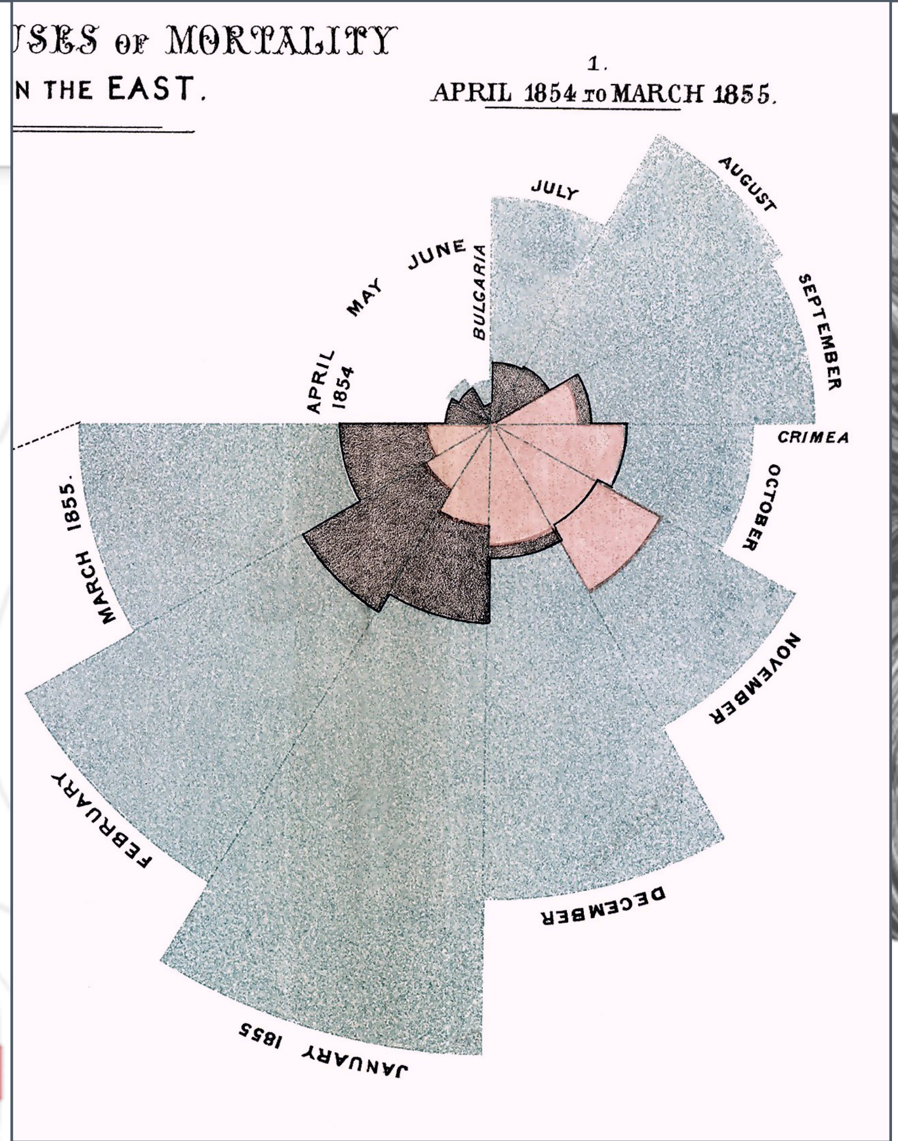
# **Graphical Perception**

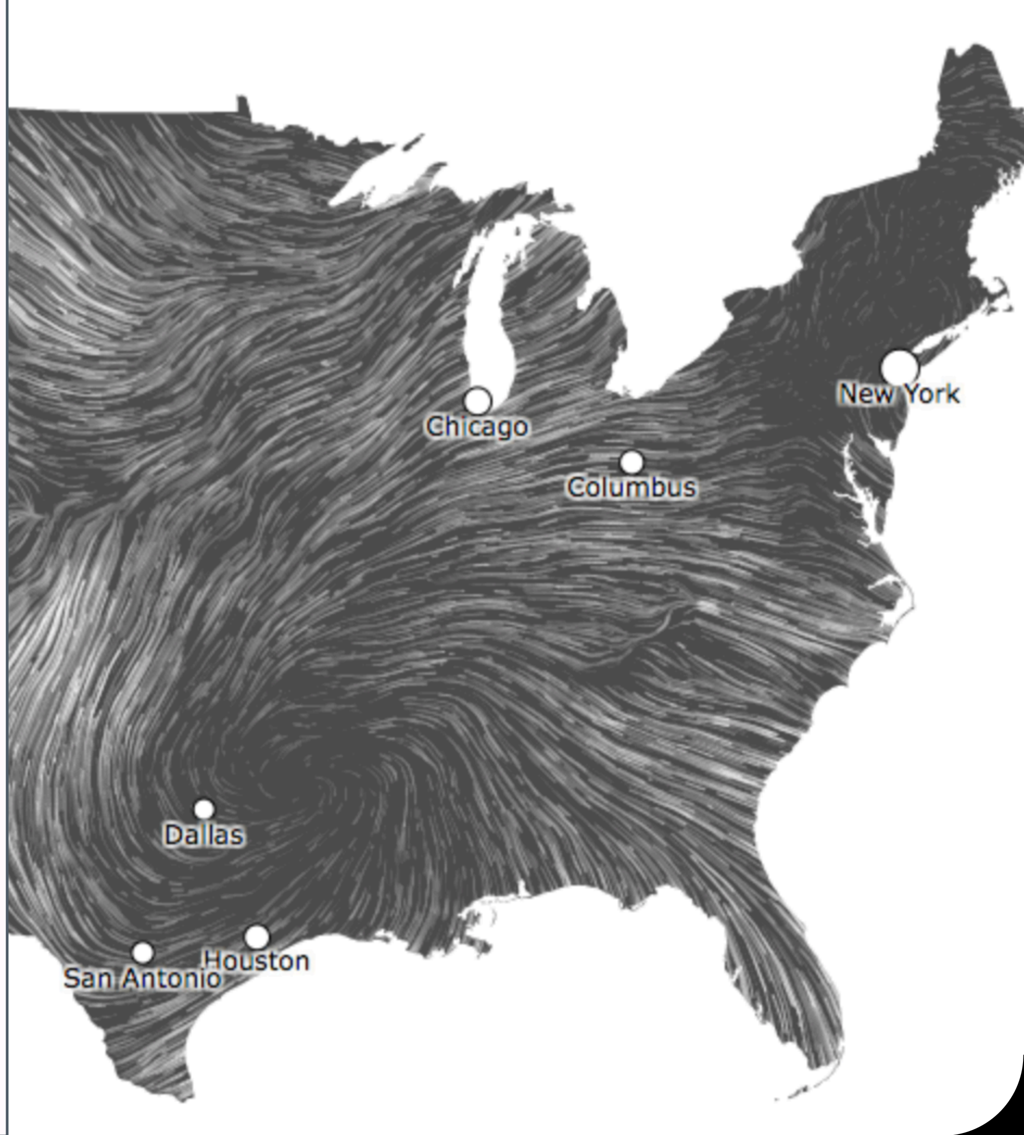
Arvind Satyanarayan



## **Channels:** Expressiveness Types and Effectiveness Ranks

### Magnitude Channels: O or Q attributes

- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

Same (Color luminance, Color saturation)

Same (Curvature, Volume (3D size))

Effectiveness: Most — Least

### Identity Channels: N attributes

- Spatial region
- Color hue
- Motion
- Shape

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

Signal Detection

Magnitude Estimation

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

**Signal Detection**

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

**Magnitude Estimation**

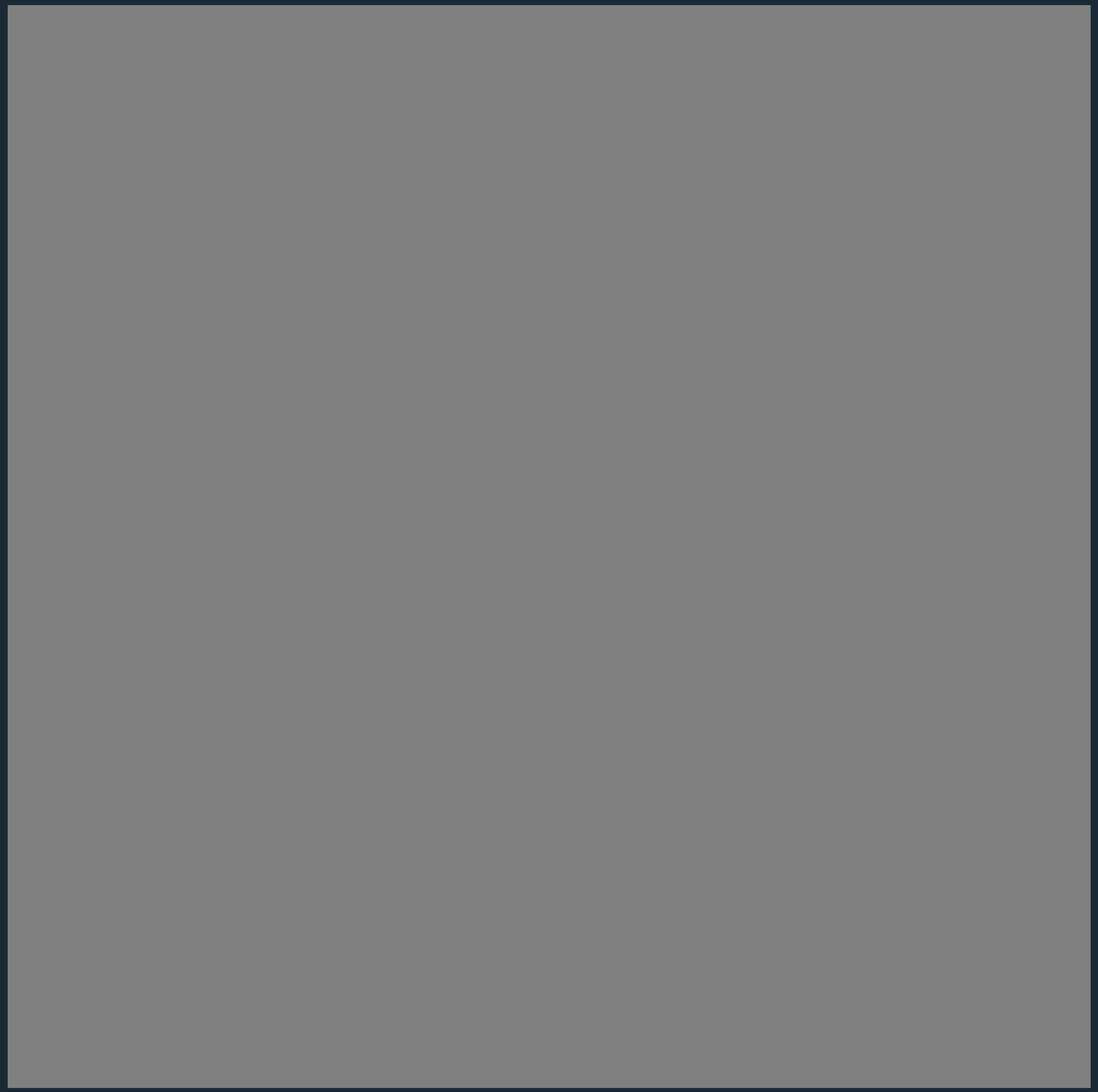
**Pre-Attentive Processing**

**Selective Attention**

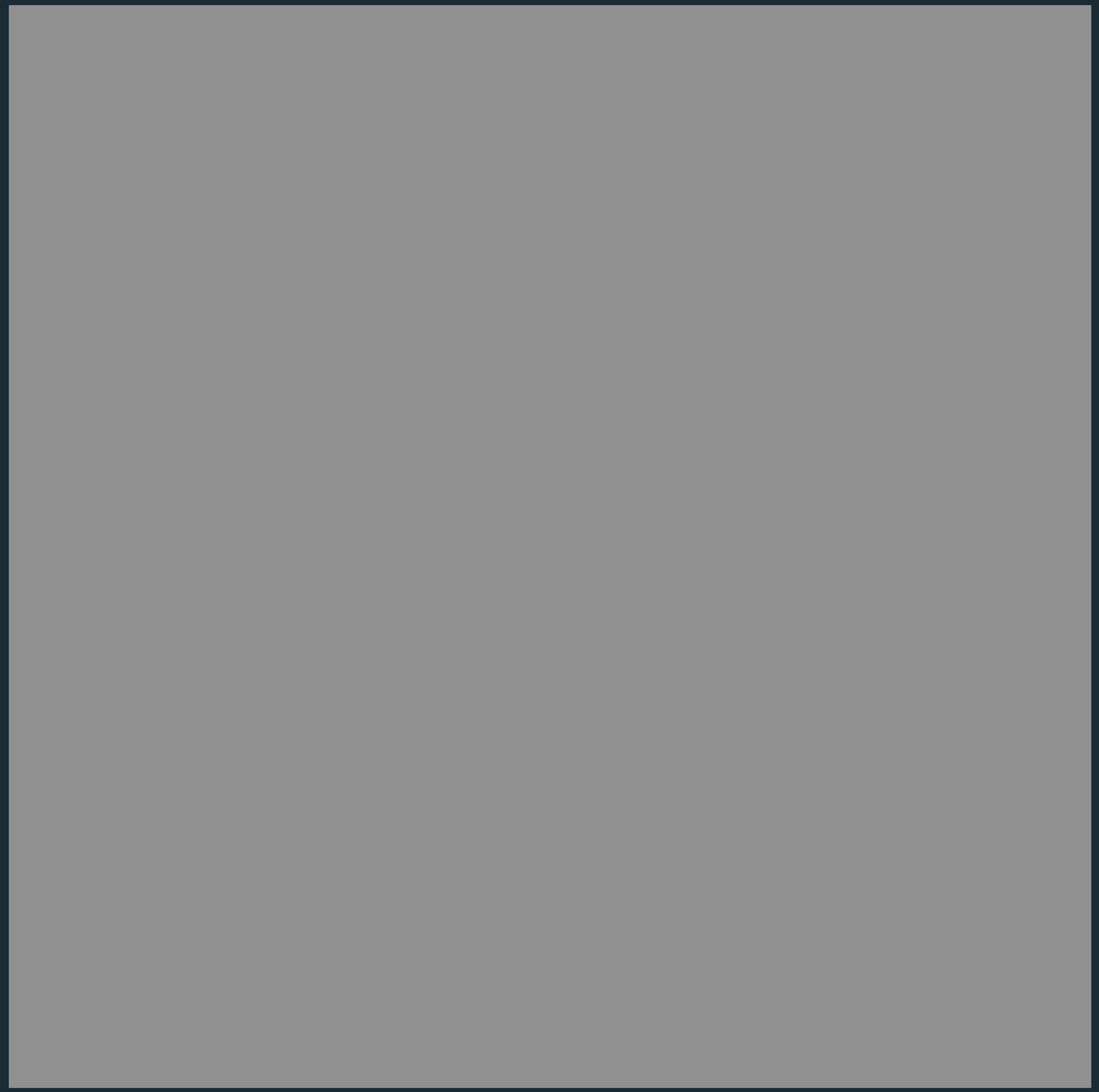
**Change Blindness**

**Gestalt Grouping**

# Which is brighter?



rgb(128, 128, 128)



rgb(144, 144, 144)

# Which is brighter?

rgb(134, 134, 134)

rgb(128, 128, 128)

# Just Noticeable Difference (jnd)

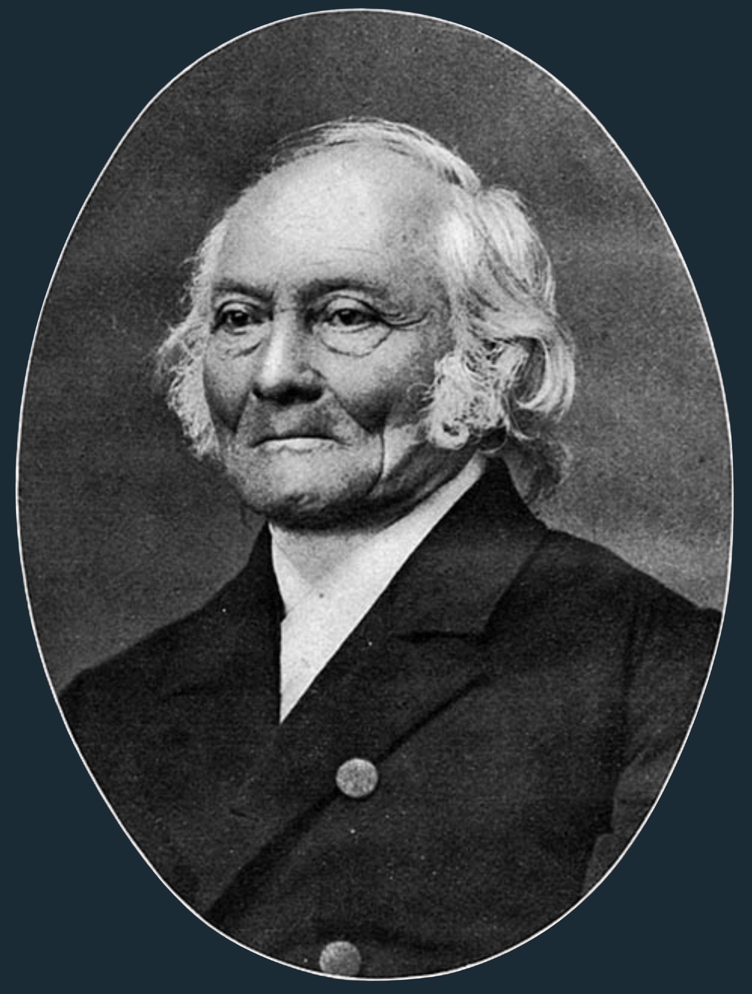
Scale Factor
(Determined Empirically)

Change of Intensity

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

Perceived Change

Physical Intensity

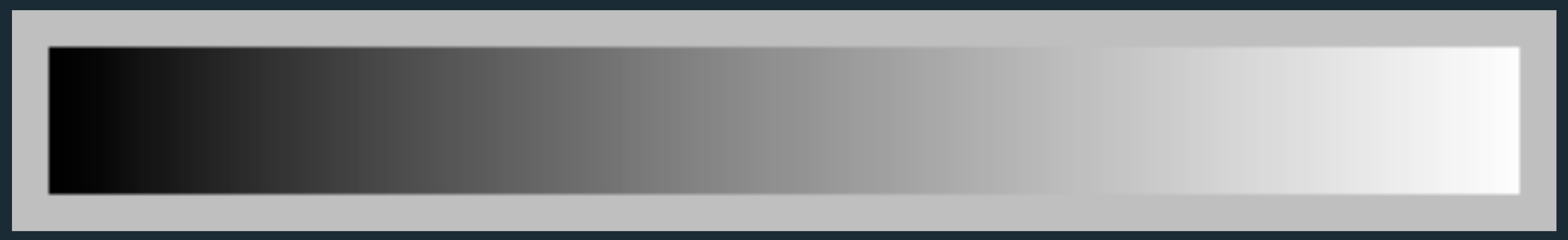


**Ernst Weber**
(1795–1878)

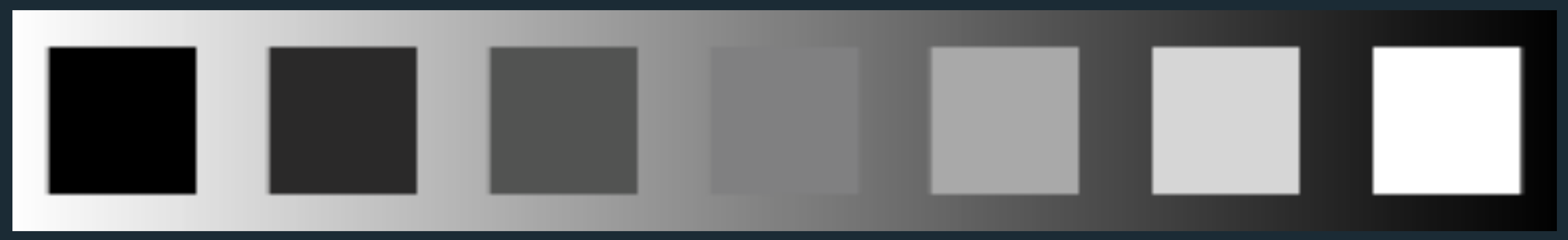
German physician and a founder of experimental psychology.

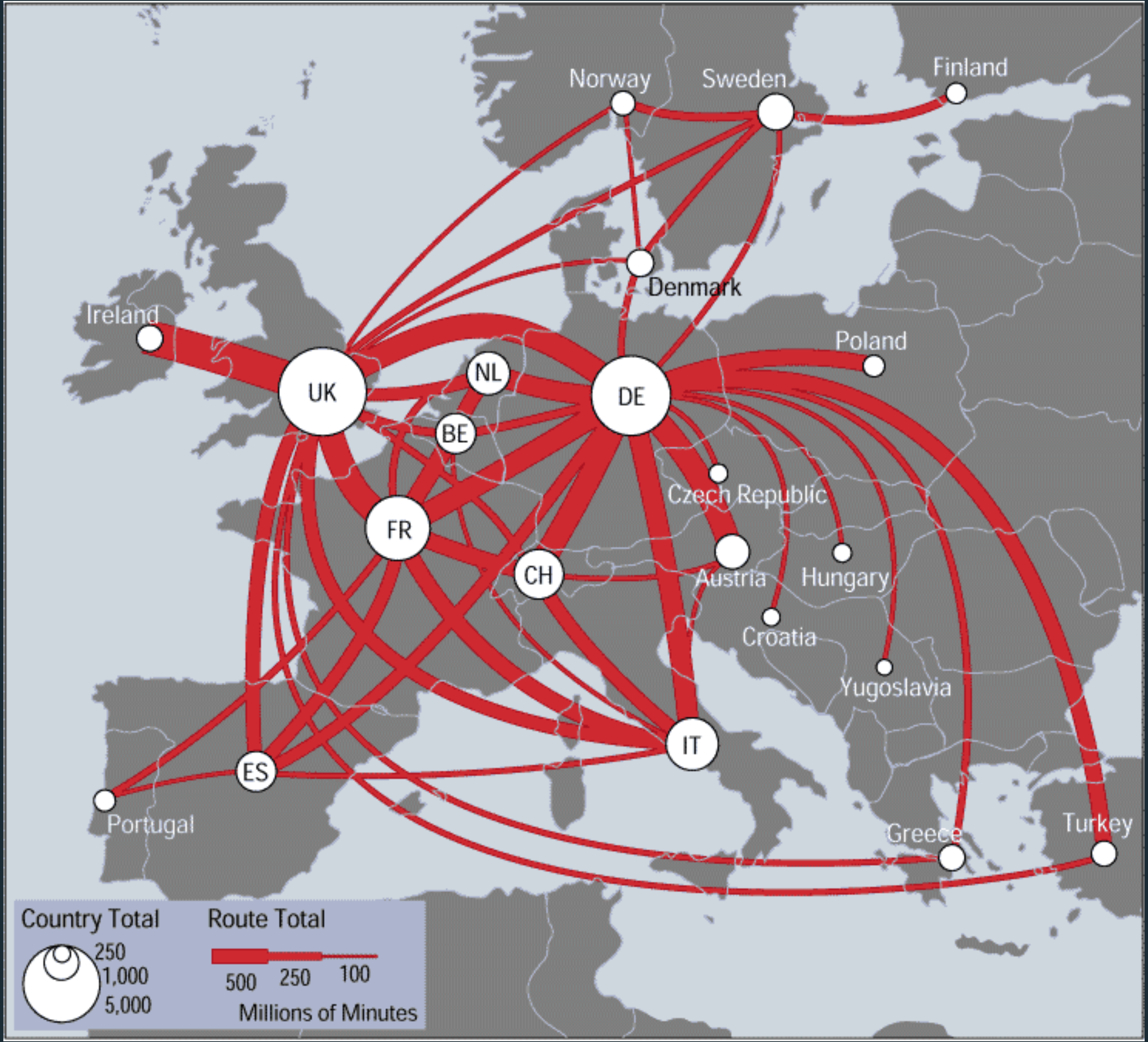
Ratios more important than magnitude.

Most continuous variation in stimuli are perceived in discrete steps.



vs.






[Telegeography, Inc. 2000]


[Simon Scarr, *South China Morning Post*. 2012]

**Signal Detection**

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

**Magnitude Estimation**

**Pre-Attentive Processing**

**Selective Attention**

**Change Blindness**

**Gestalt Grouping**

Signal Detection

**Magnitude Estimation**

*Accuracy: how correctly can we read off values?*

Pre-Attentive Processing

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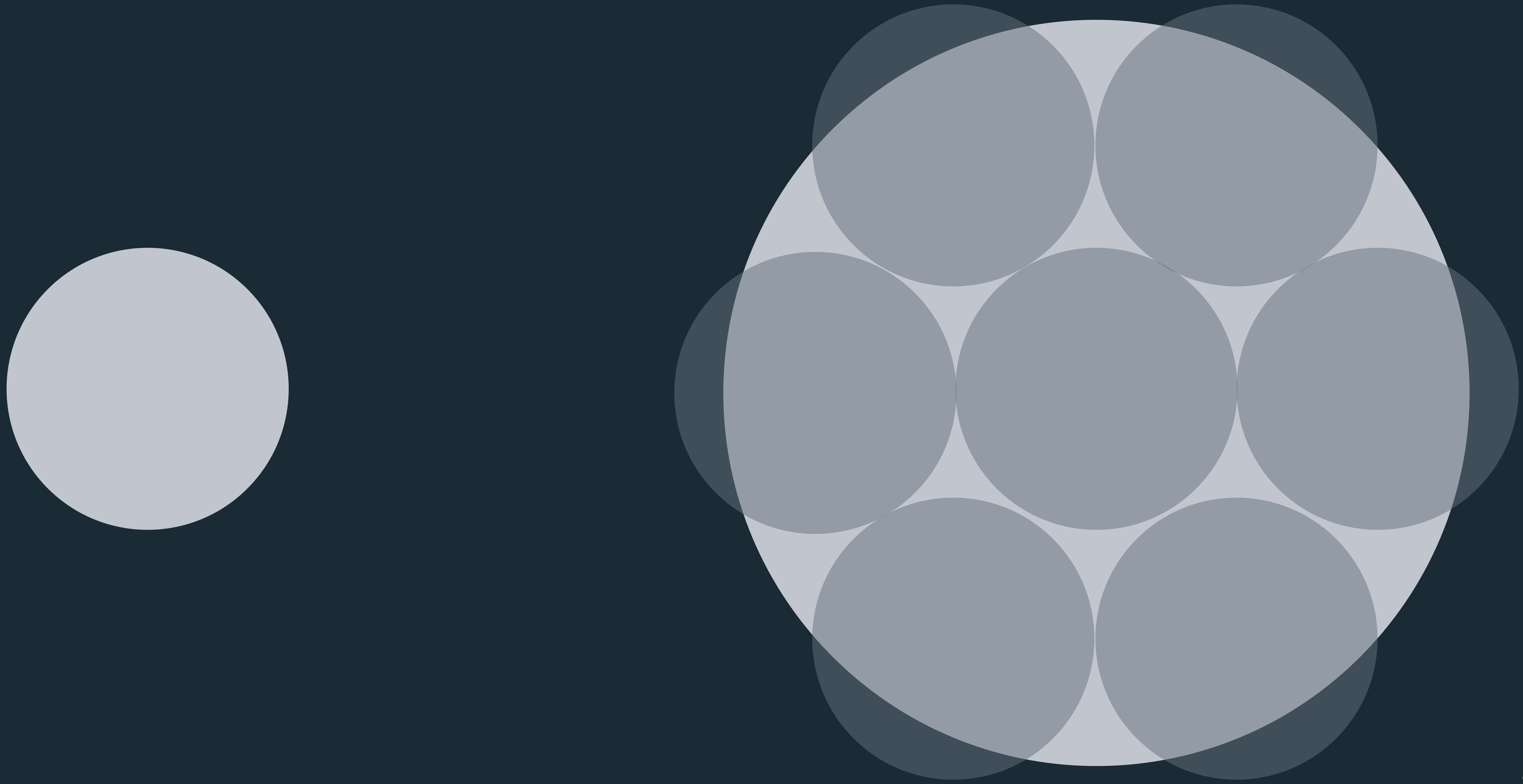
Change Blindness

Gestalt Grouping

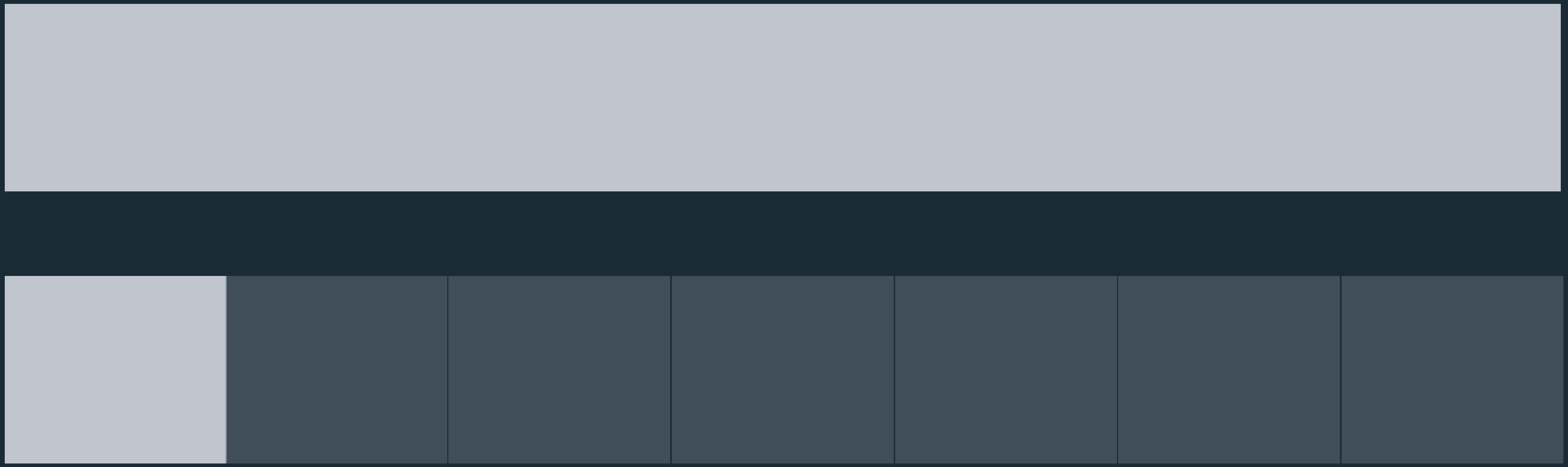
# How much larger is the area of the big circle?

# 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.

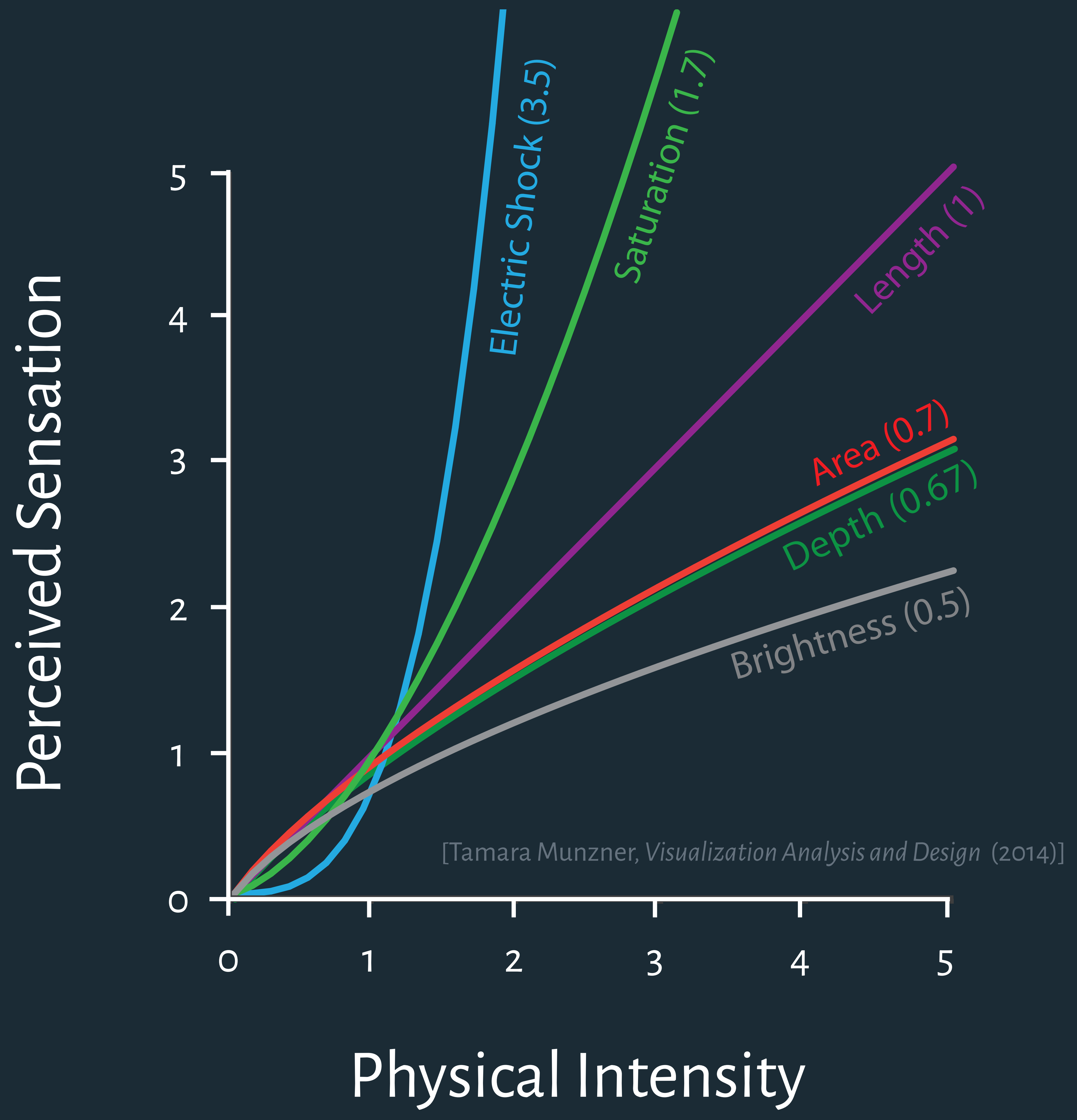
Physical Intensity

$$S = I^p$$

Perceived Sensation

Exponent
(Determined Empirically)

p < 1 = **under**estimation
p > 1 = **over**estimation

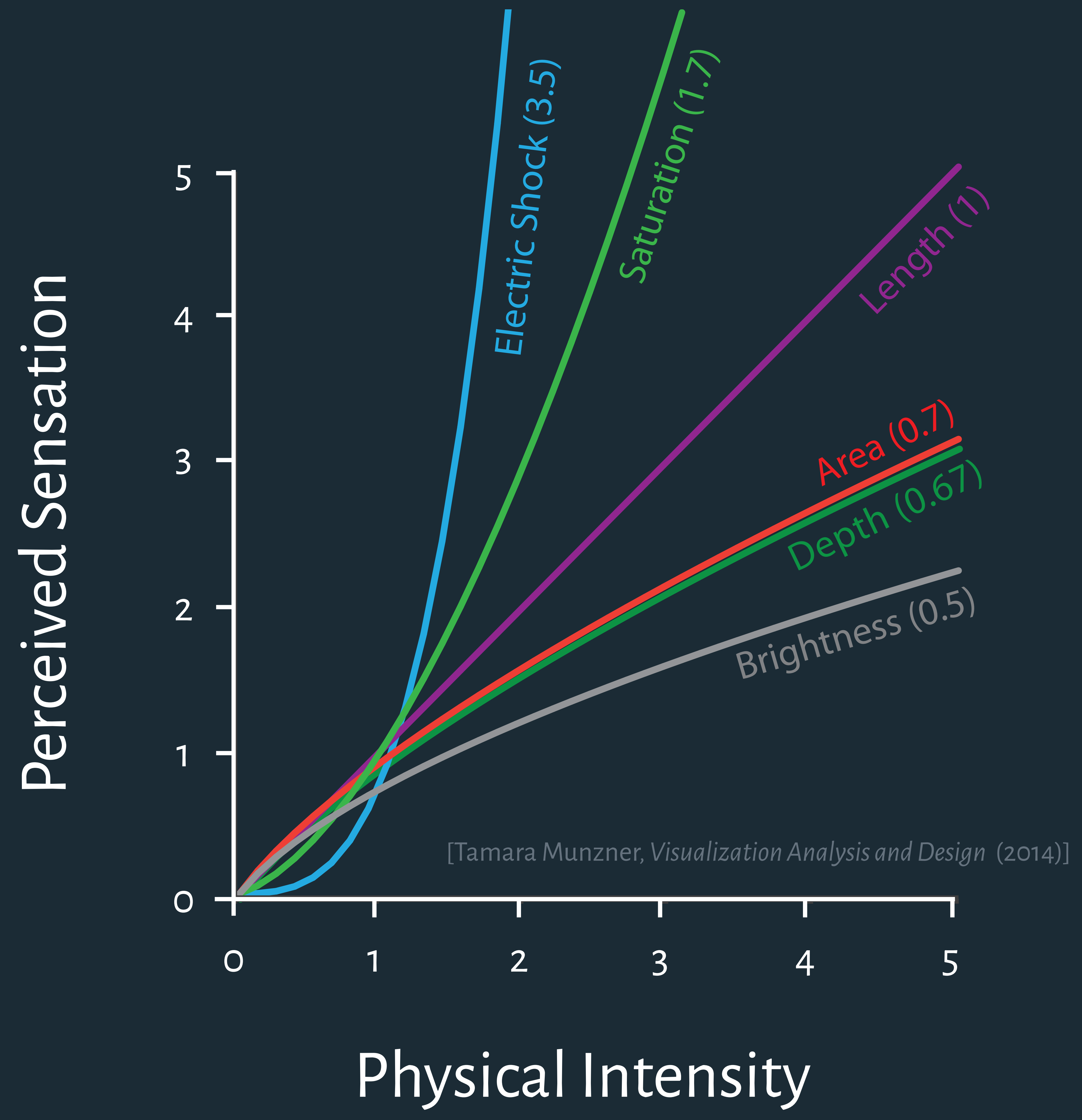



Predicts bias, not necessarily accuracy!

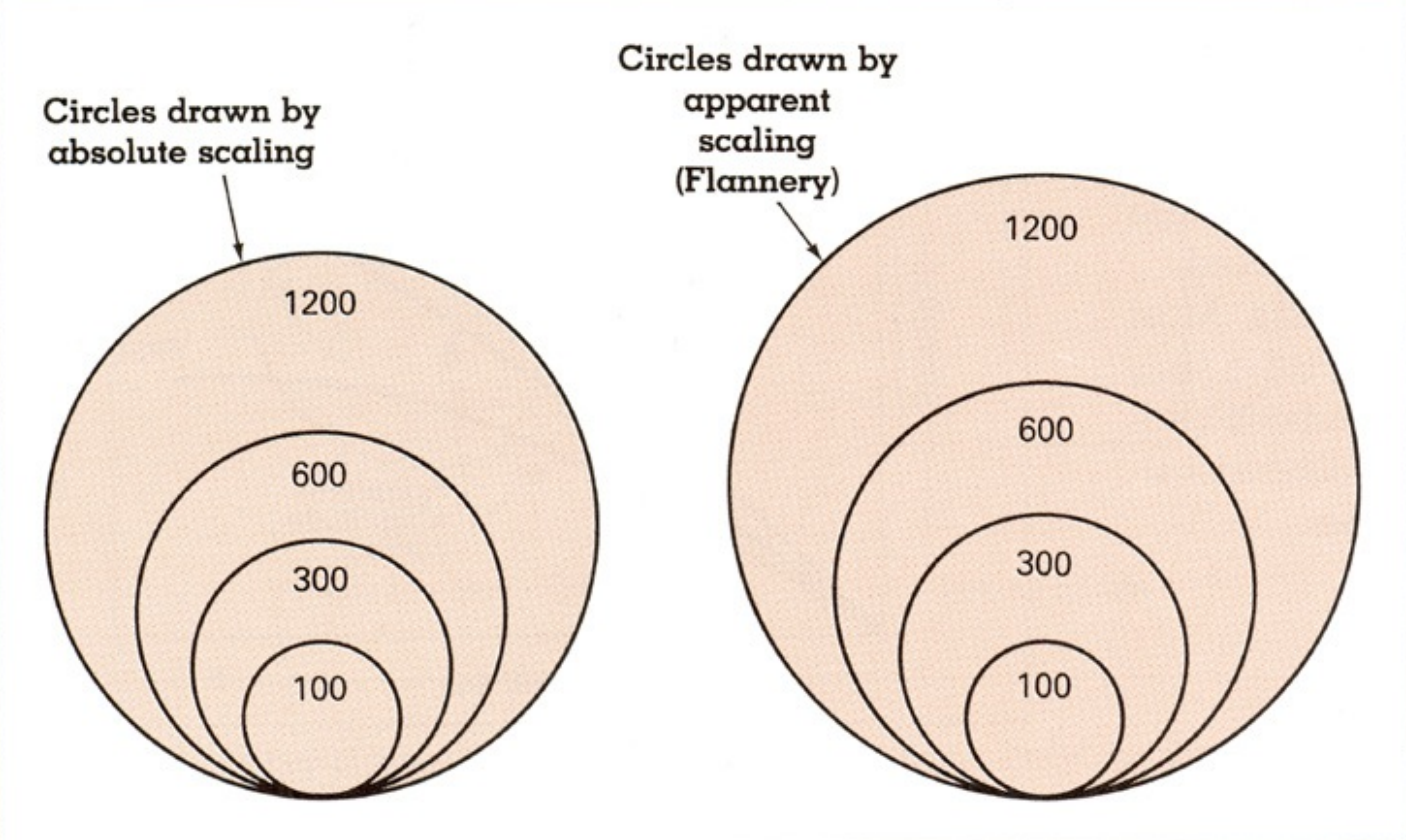
# Stevens' Power Law

$$S = I^p$$

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



# Stevens' Power Law




[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

$S = 0.98A^{0.87}$ [Flannery 71]

# Graphical Perception Studies

[Cleveland & McGill 1984]


Figure 4. Graphs from position–length experiment.

*What proportion is the smaller marked section of the larger?*

# Graphical Perception Studies

[Cleveland & McGill 1984]

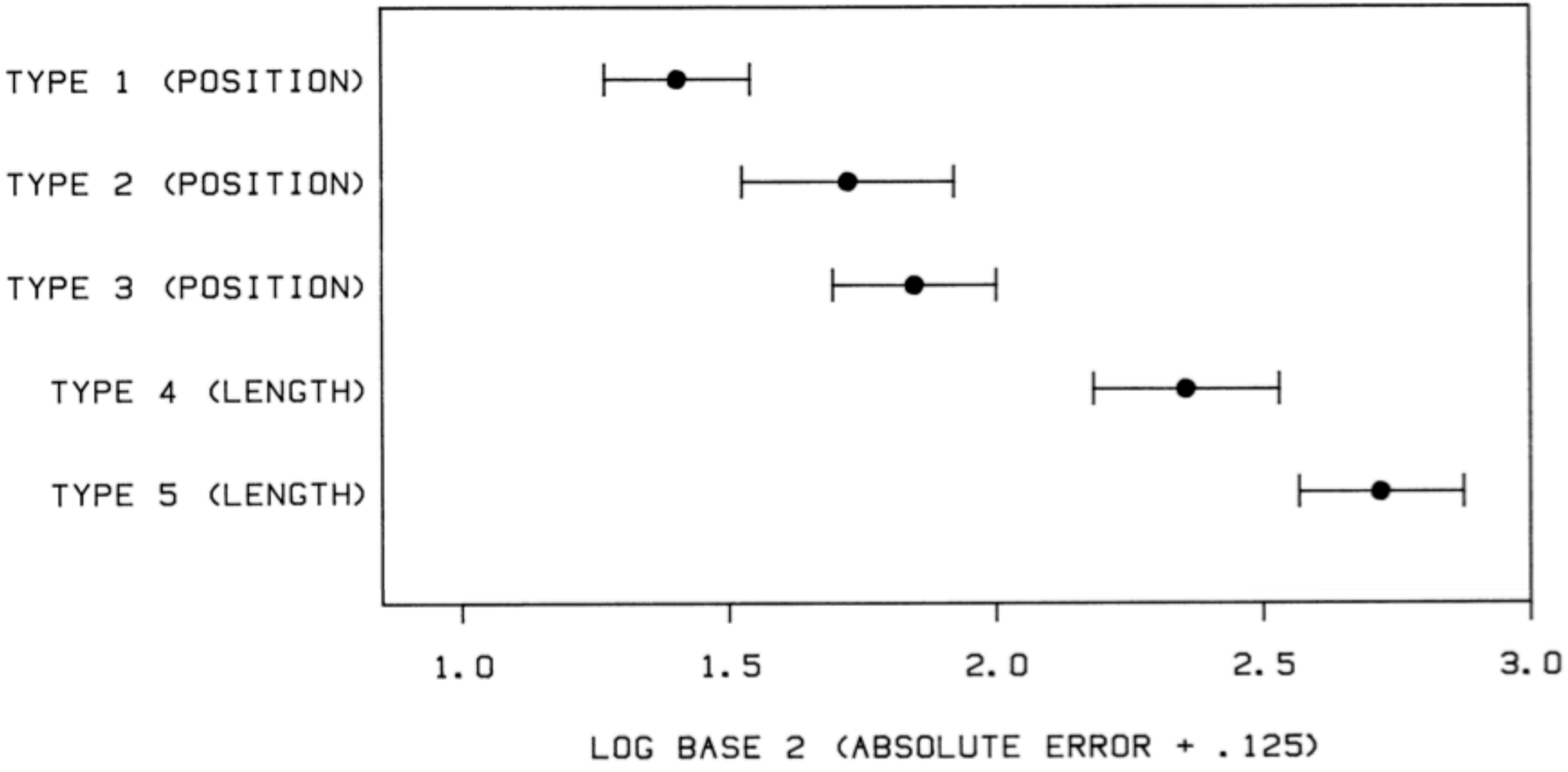
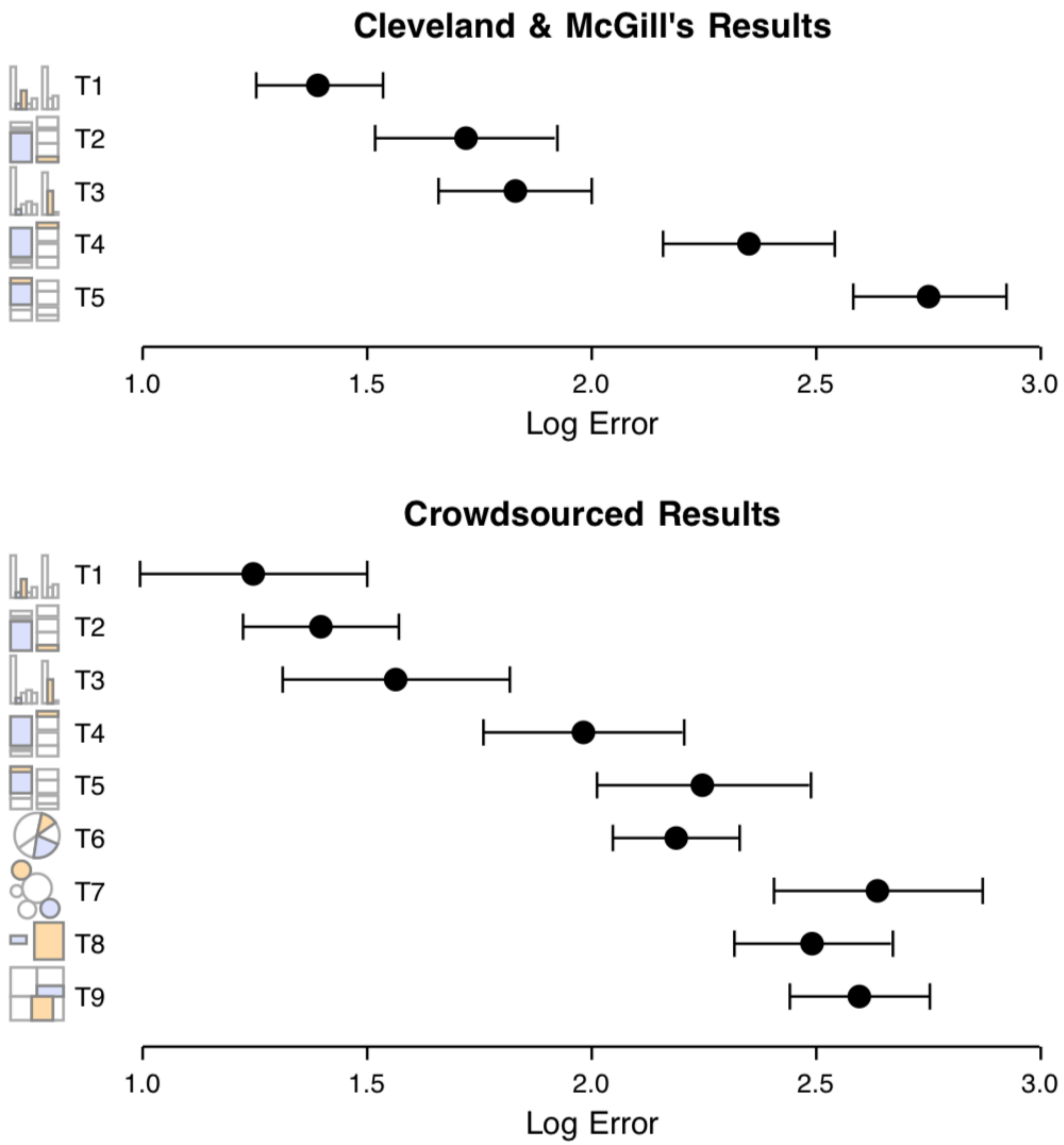



*Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position–length experiment (top) and position–angle experiment (bottom).*

# Graphical Perception Studies

[Bostock & Heer 2010]



Signal Detection

**Magnitude Estimation**

*Accuracy: how correctly can we read off values?*

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

Signal Detection

Magnitude Estimation

**Pre-Attentive Processing**

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

Selective Attention

Change Blindness

Gestalt Grouping

# How many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[Based on a slide from John Stasko]

# How many 3's?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[Based on a slide from John Stasko]

# 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).

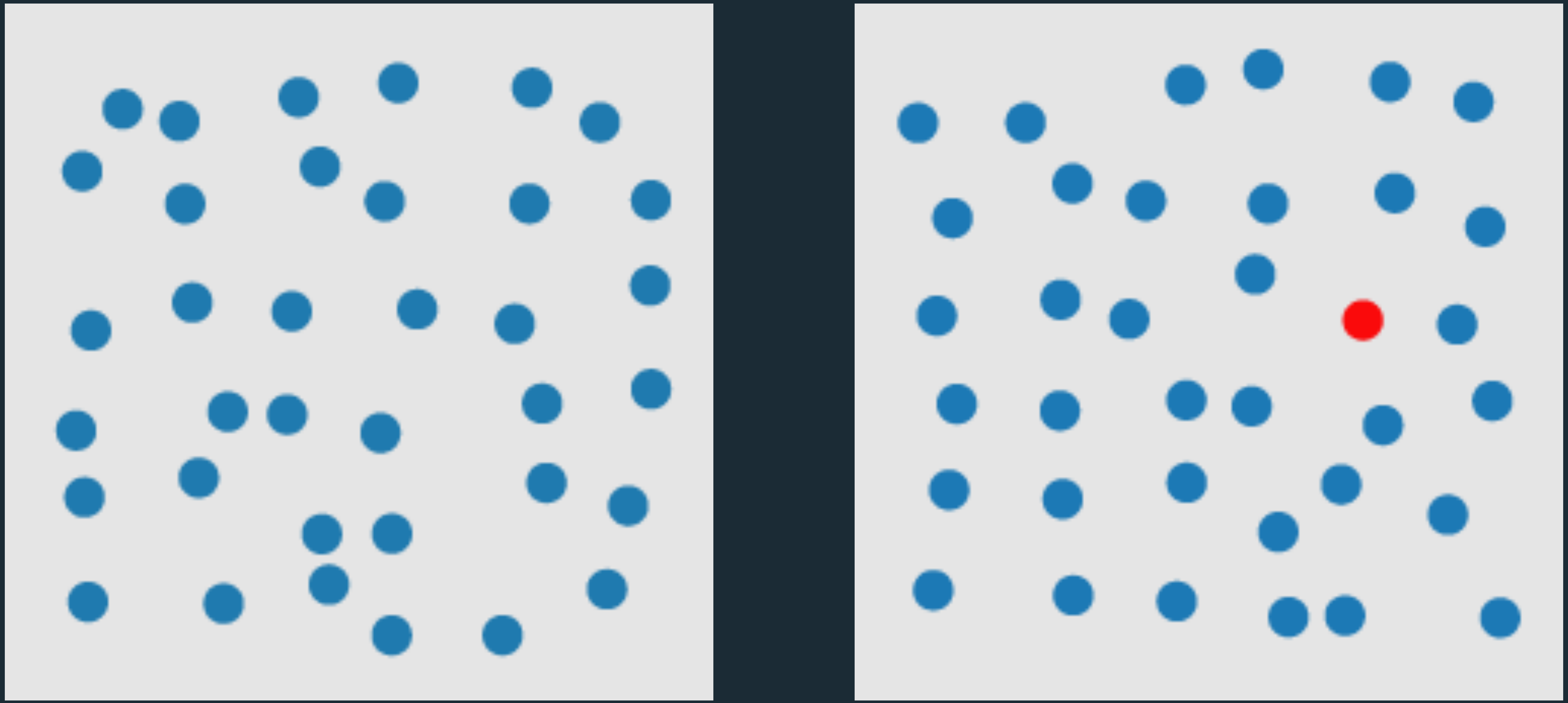
**Attentive:** Takes some deliberate effort to perceive differences.

# 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]

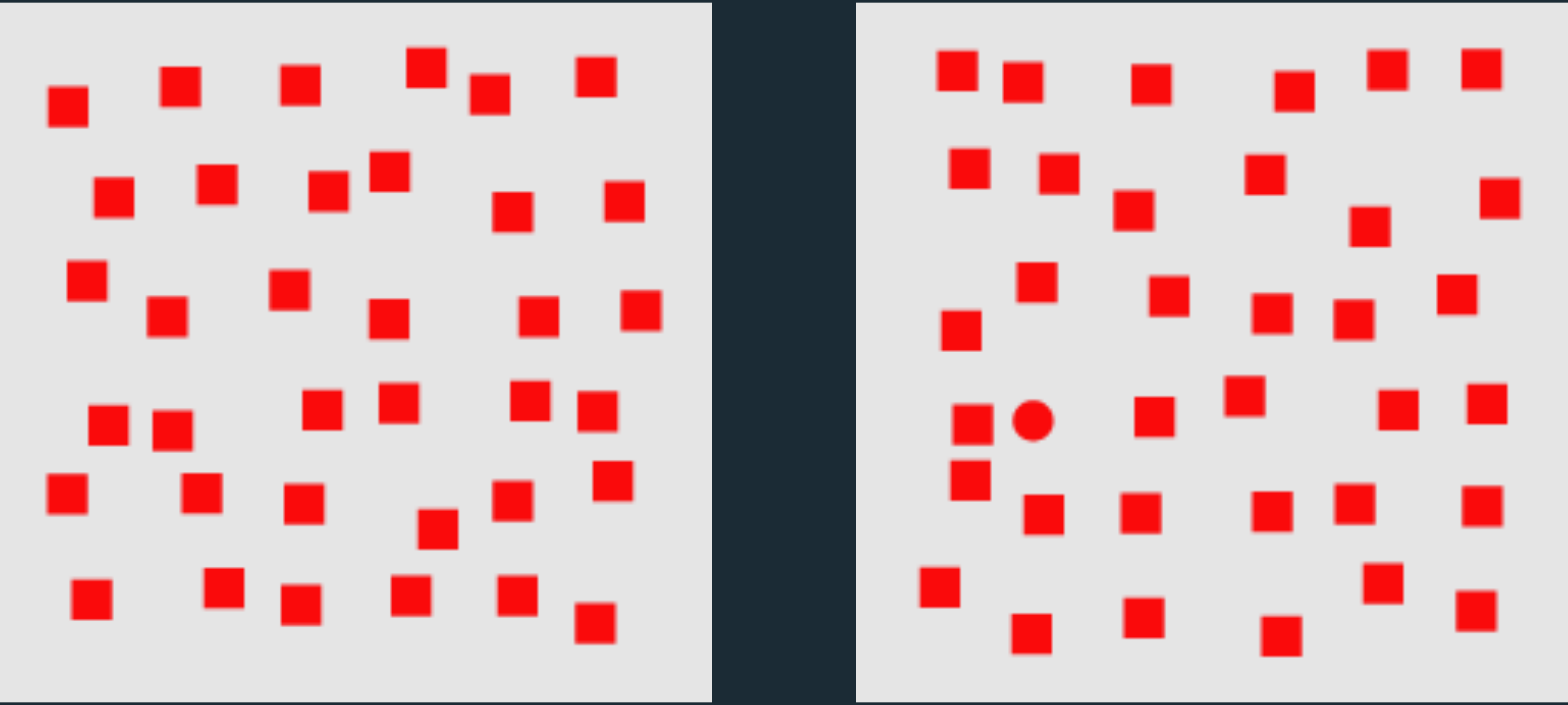
# Pre-Attentive Processing

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

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

## Visual Pop-Out: Color

## Visual Pop-Out: Shape



[Healey & Enns 2012]

# Pre-Attentive Processing

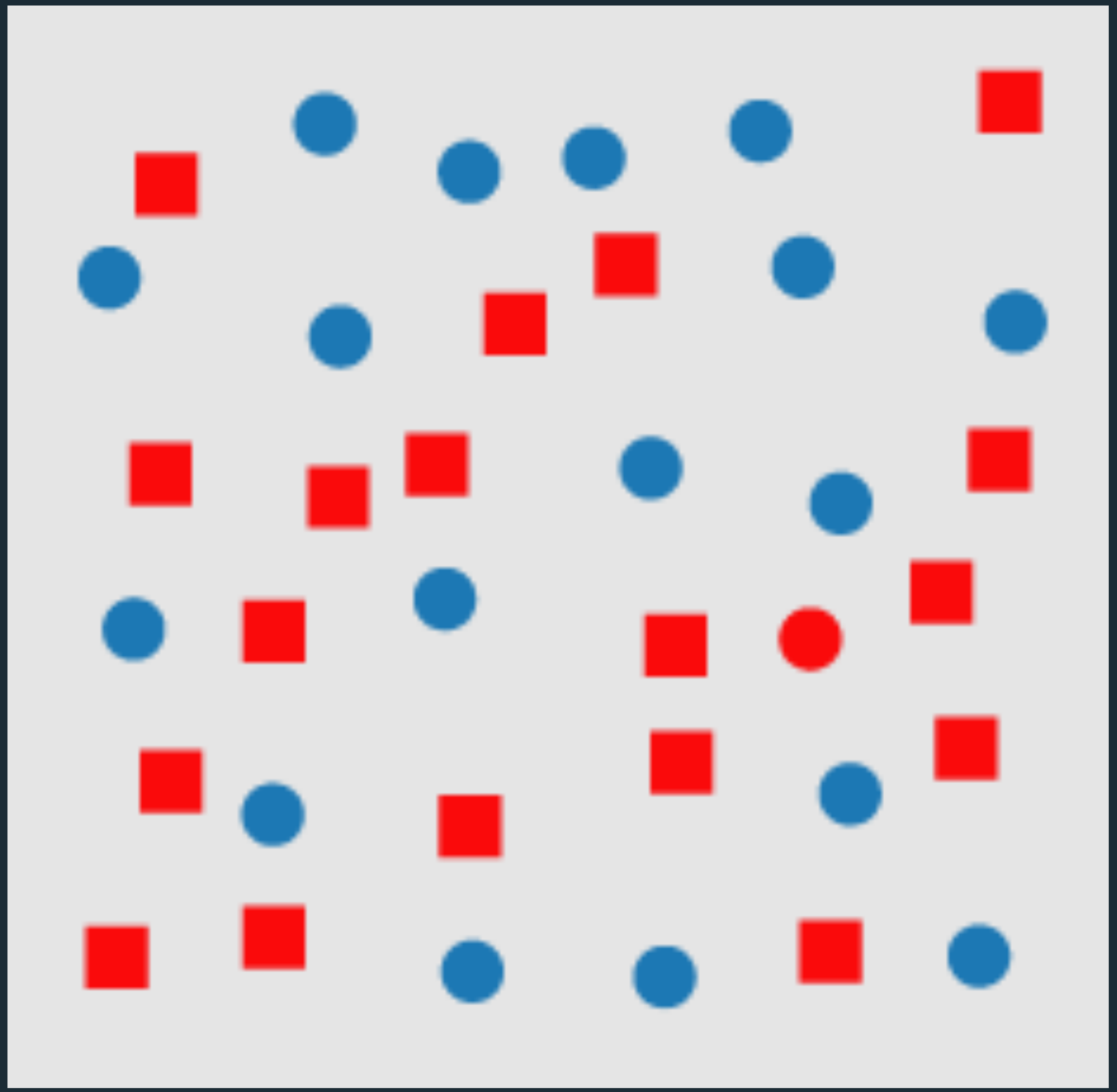
**Pre-Attentive:** immediately recognize variation with little or no conscious effort (<200–250 ms).

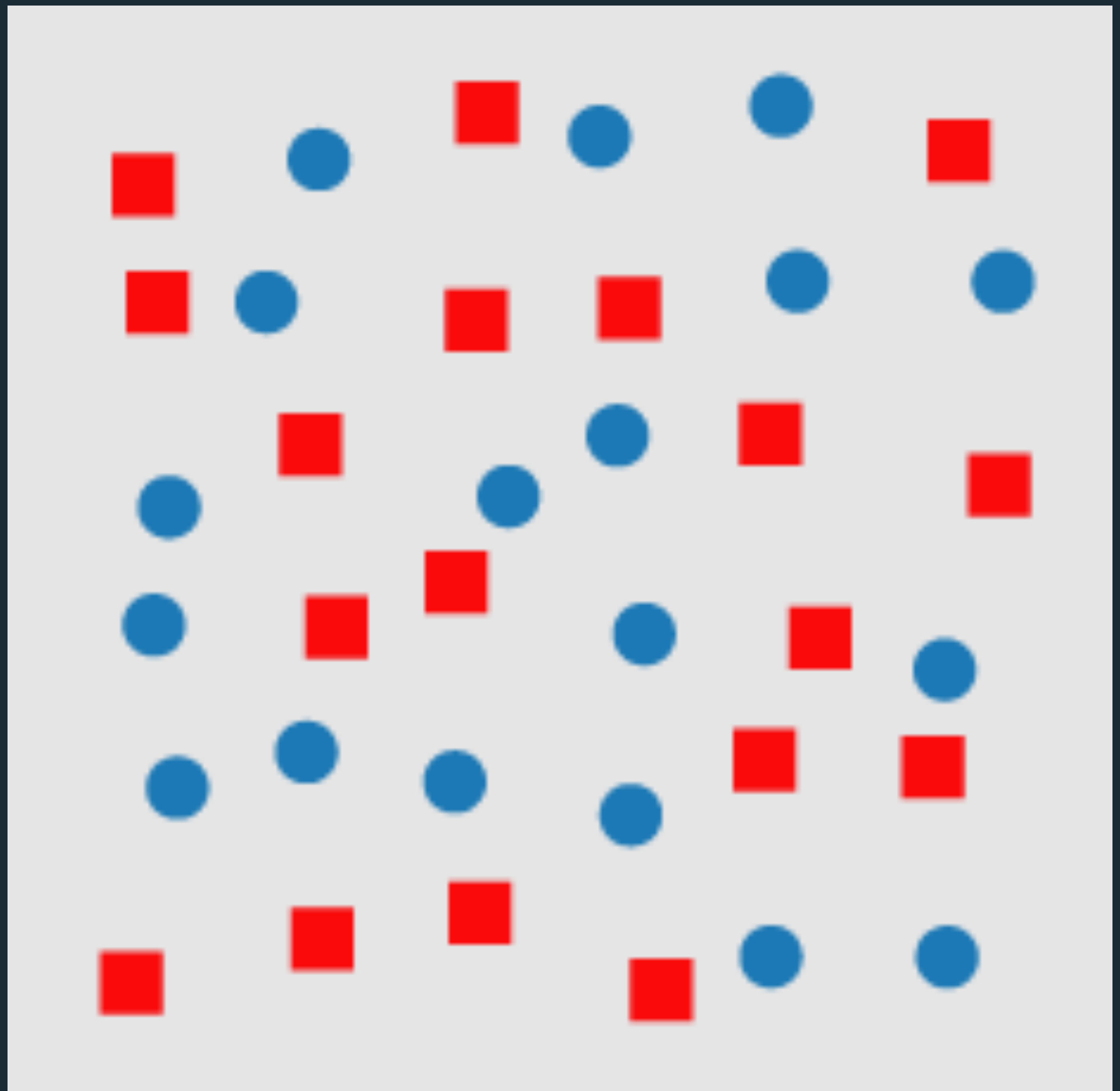
**Attentive:** Takes some deliberate effort to perceive differences.

## Visual Pop-Out: Color

## Visual Pop-Out: Shape

## Feature Conjunctions





[Healey & Enns 2012]

# Pre-Attentive Processing

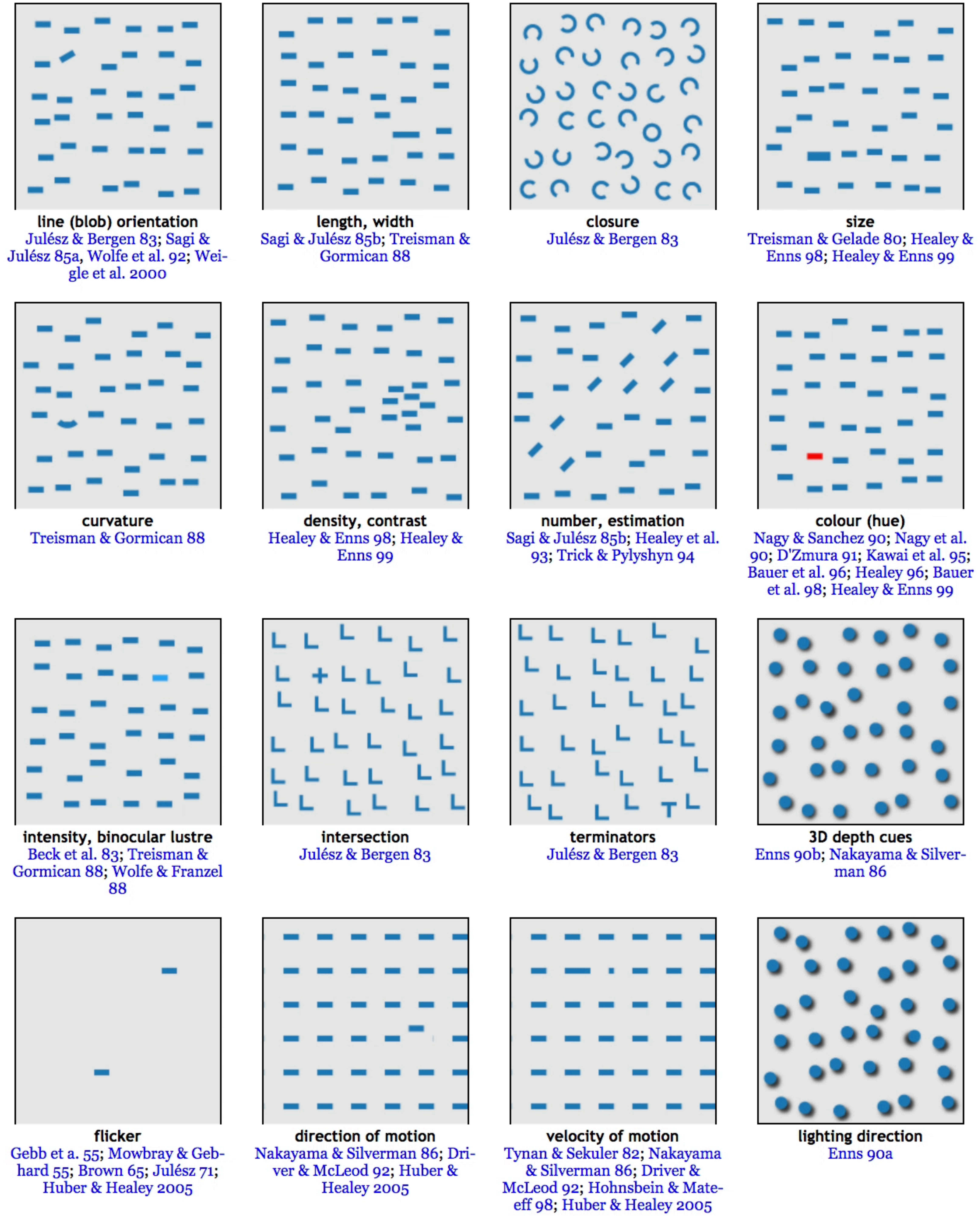
## Visual Pop-Out: Color

## 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




[Healey & Enns 2012]

Signal Detection

Magnitude Estimation

**Pre-Attentive Processing**

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

Selective Attention

Change Blindness

Gestalt Grouping

Signal Detection

Magnitude Estimation

Pre-Attentive Processing

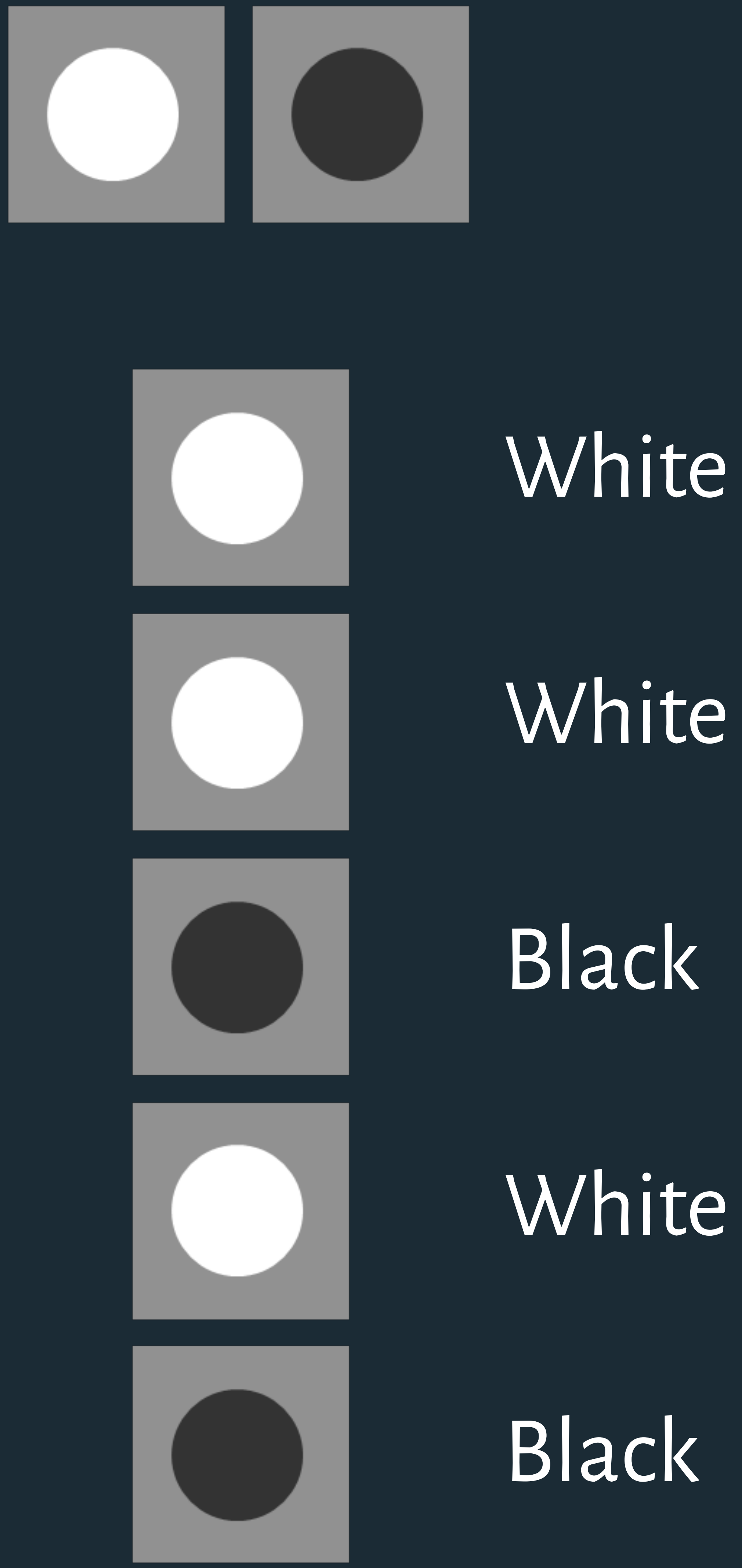
**Selective Attention**

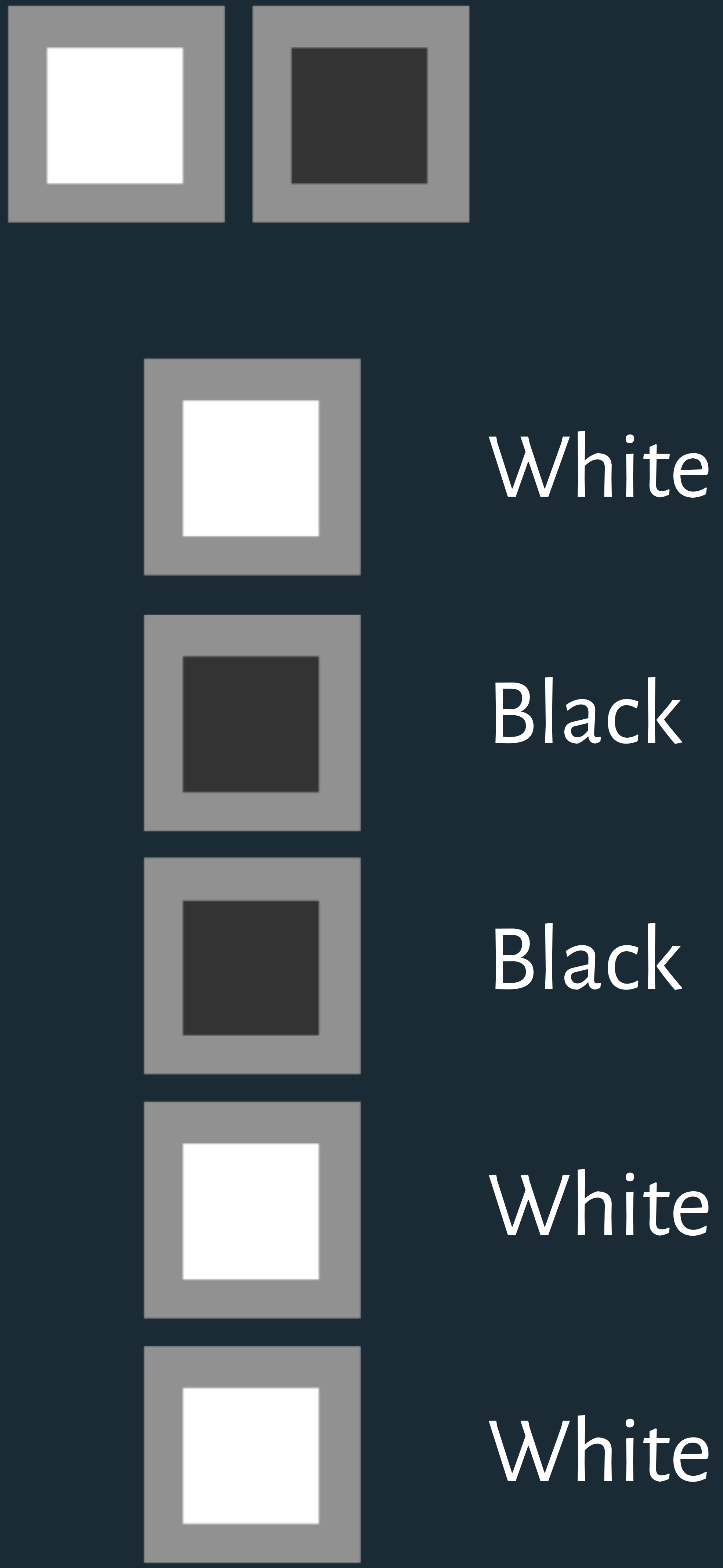
*Separability: how much interaction occurs between attributes?*

Change Blindness

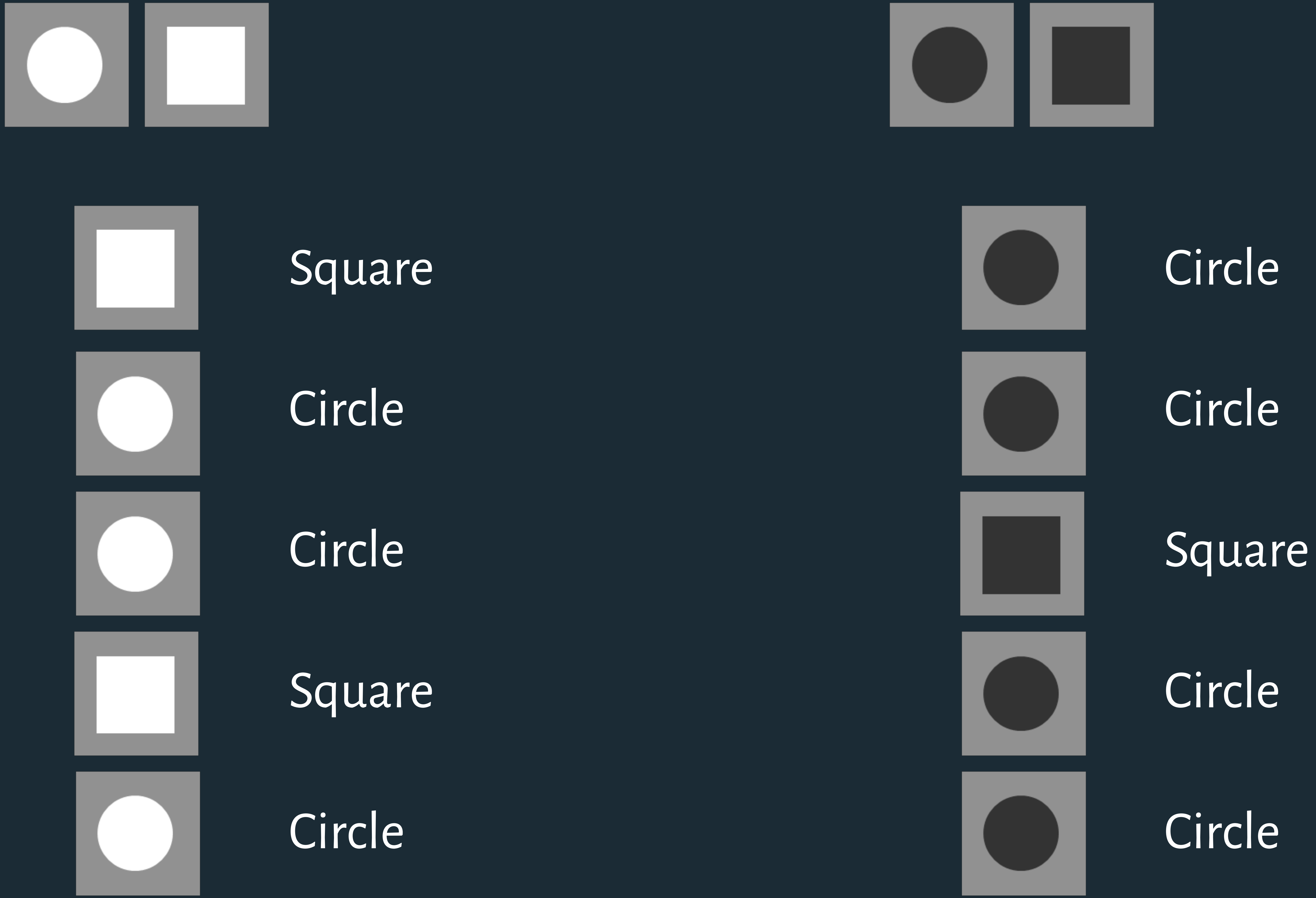
Gestalt Grouping

# One-Dimensional: Lightness

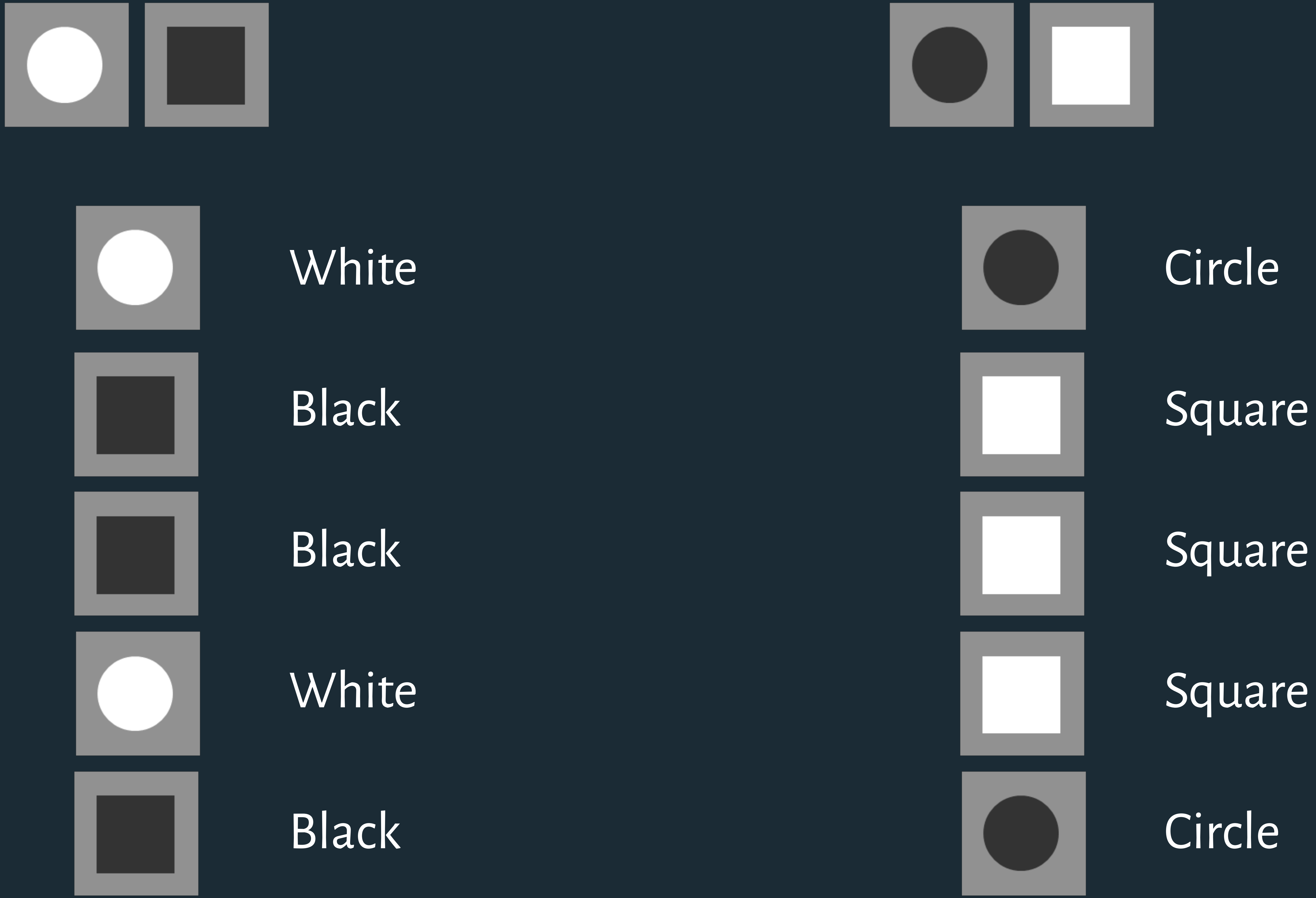


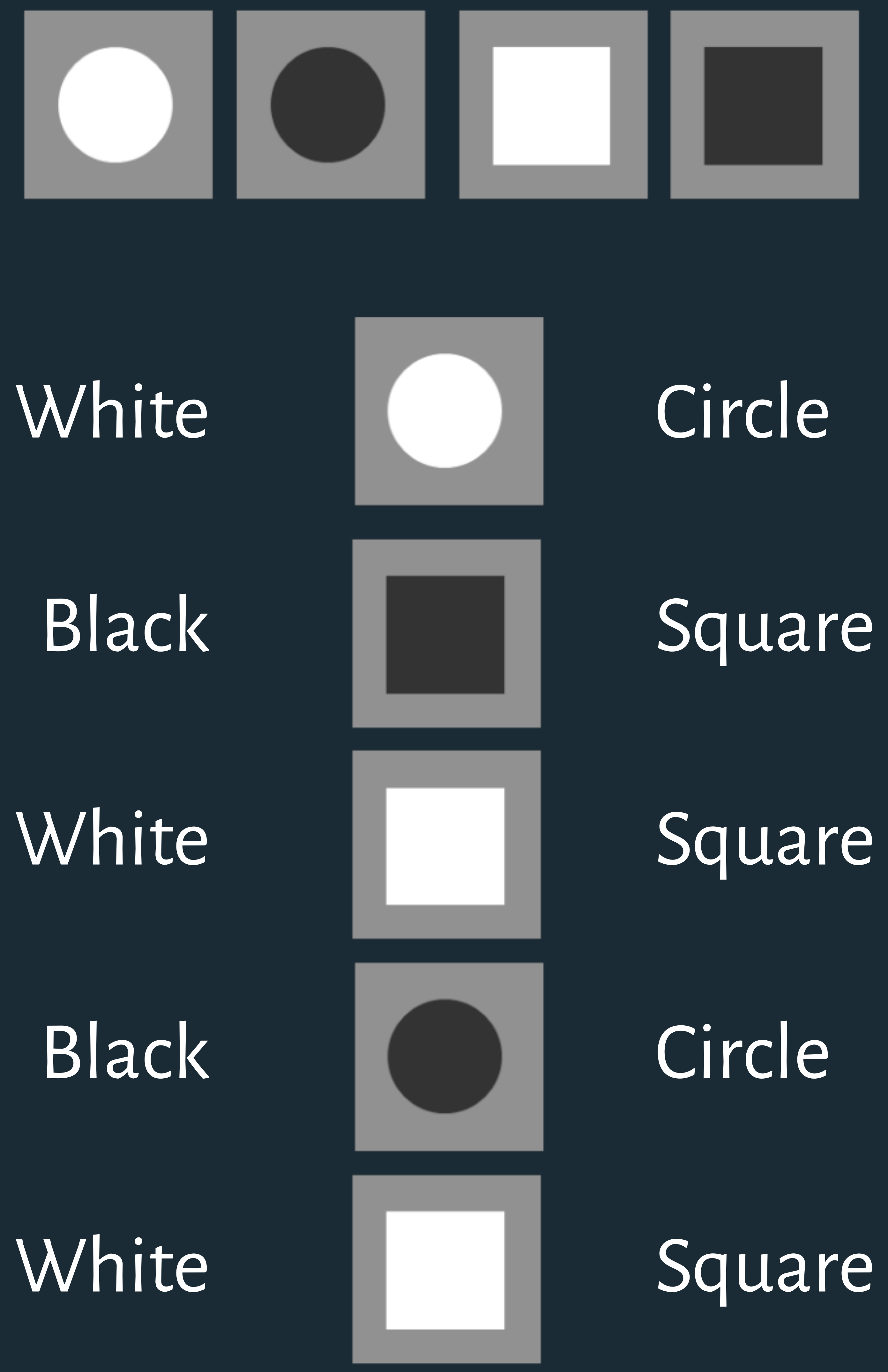
# One-Dimensional: Shape



# Redundant: Shape & Lightness



# Orthogonal: Shape & Lightness



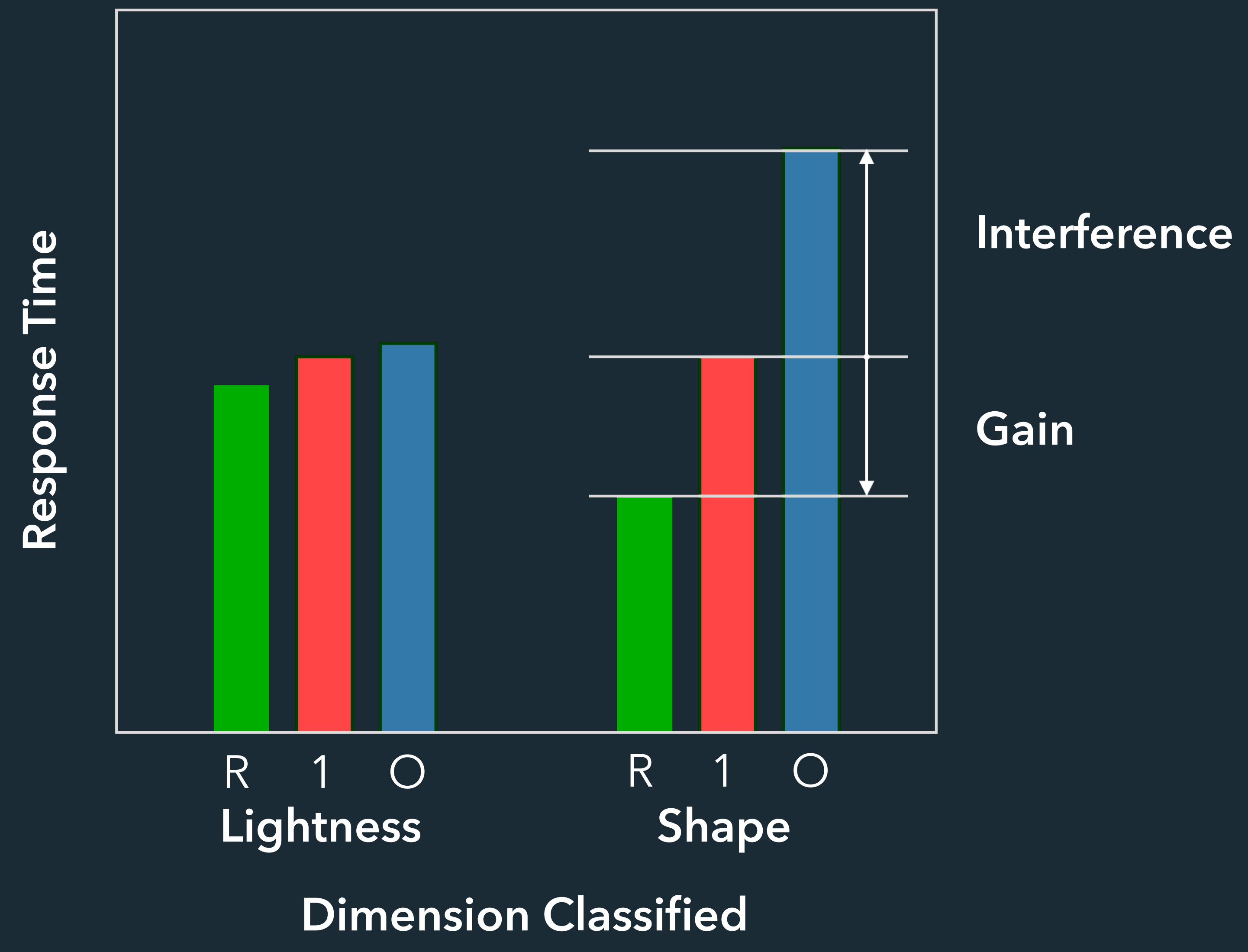
# Principles

## Redundancy Gain

Improved performance when both dimensions provide the same information.

## Filtering Interference

Difficulty in ignoring one dimension while attending to another.



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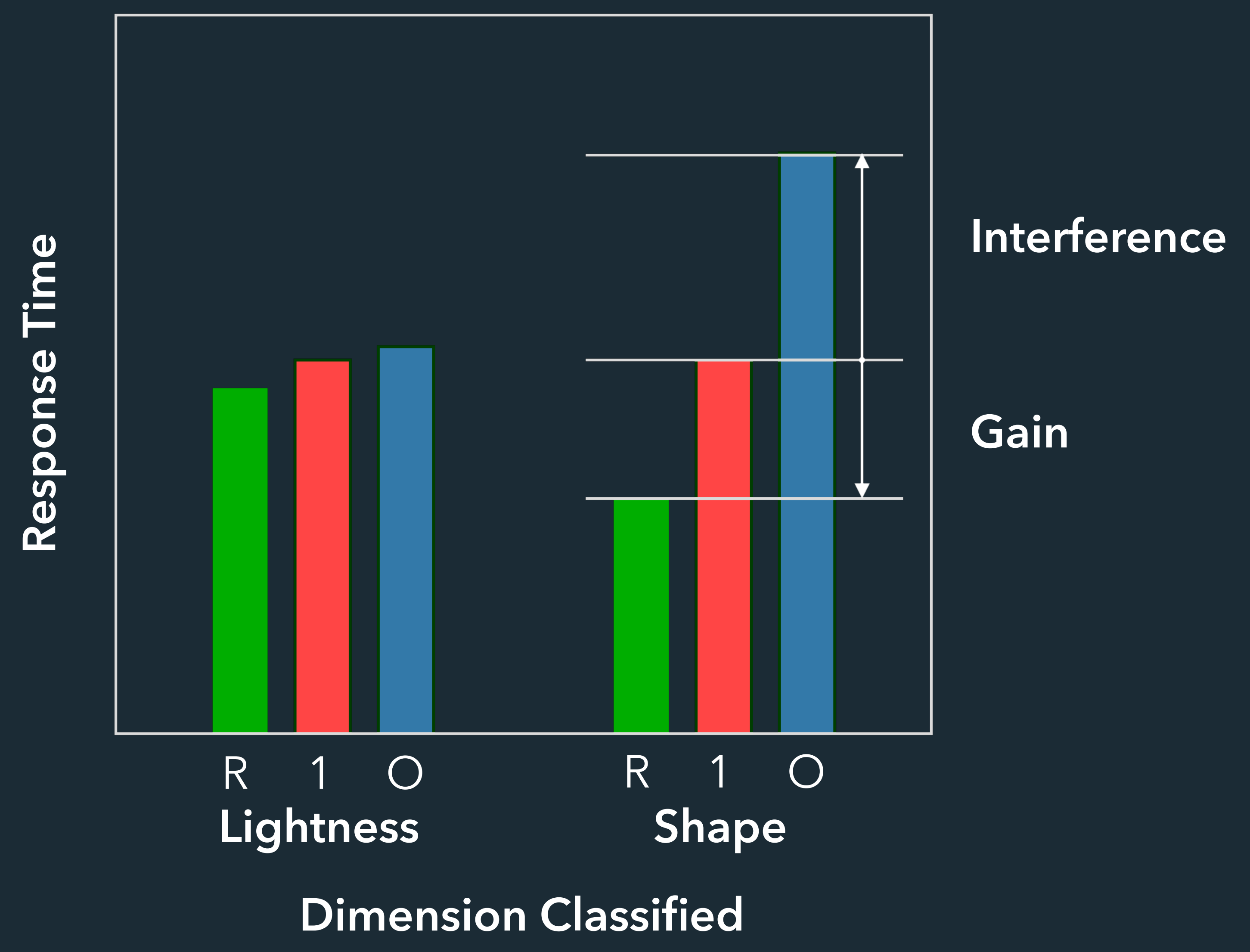


# Types of Dimensions

## 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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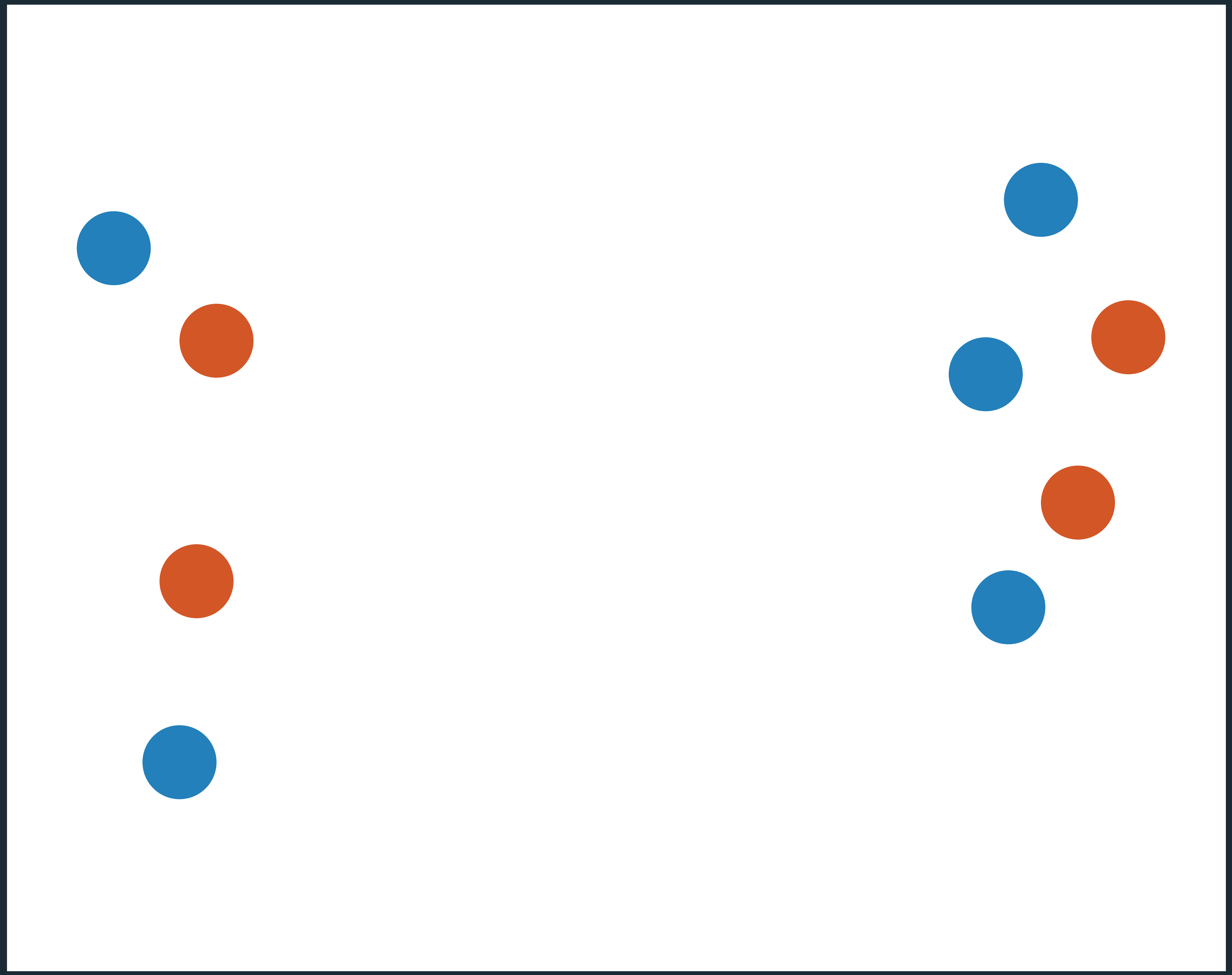
Position & Hue (Color)?



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

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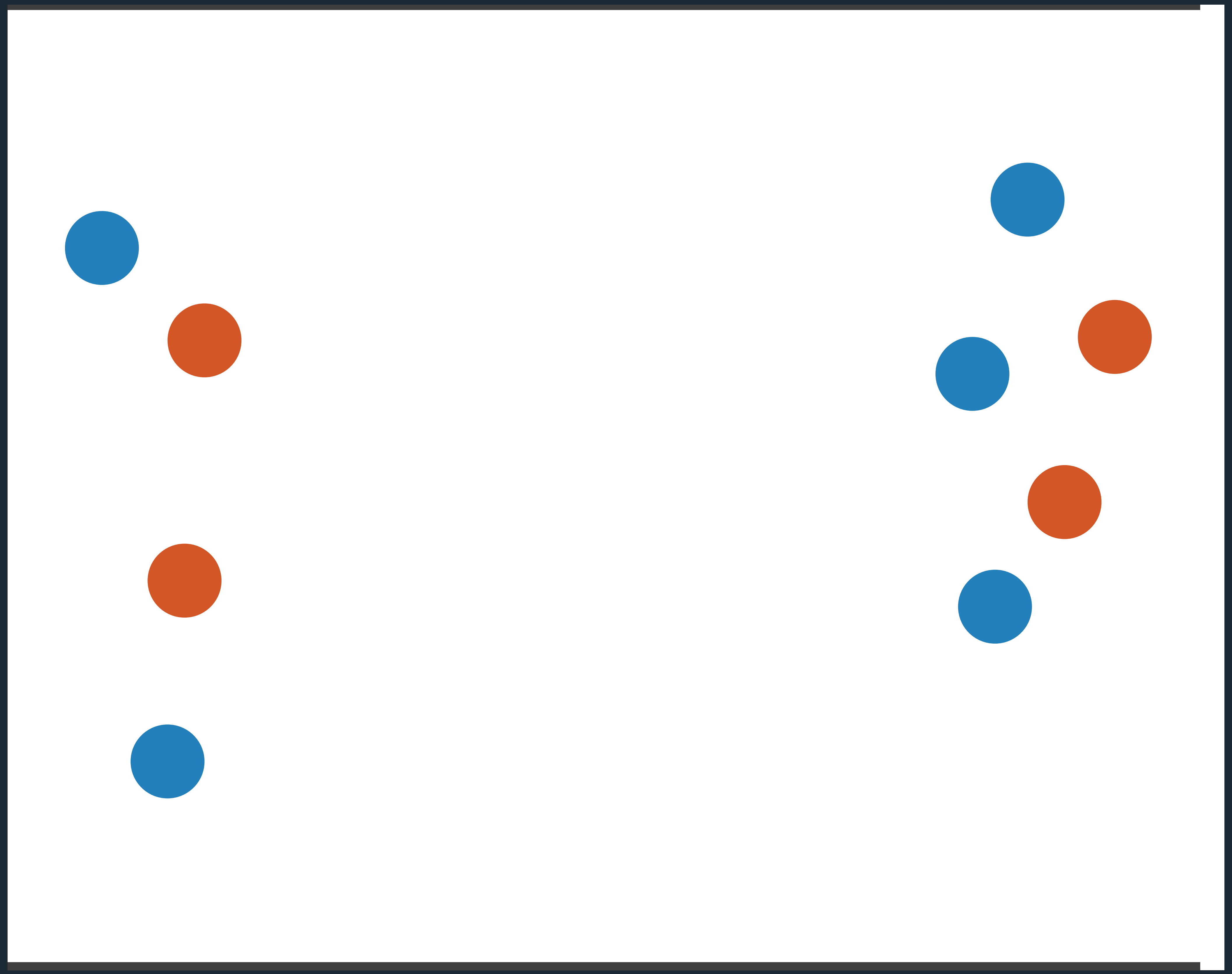

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Size & Orientation?

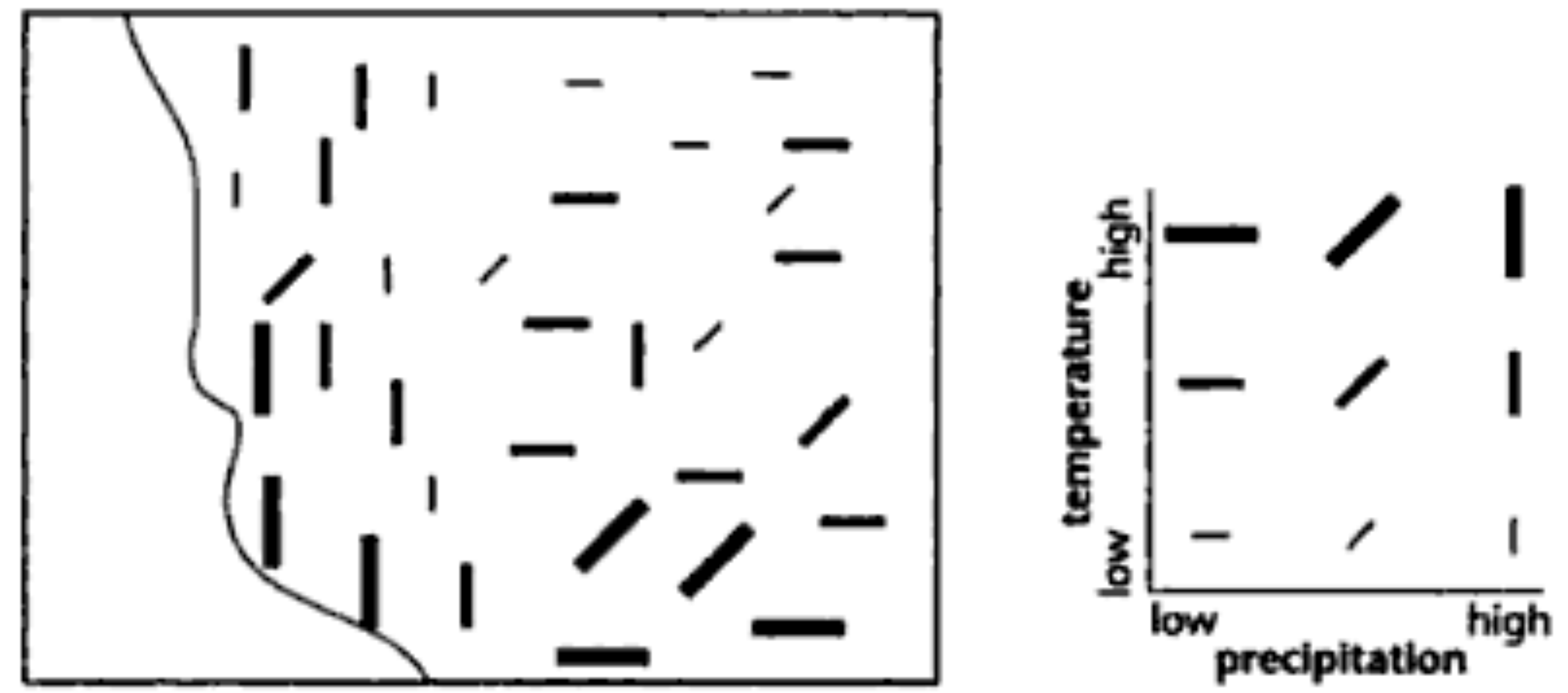


**FIGURE 3.36.** A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

[MacEachren 1995]

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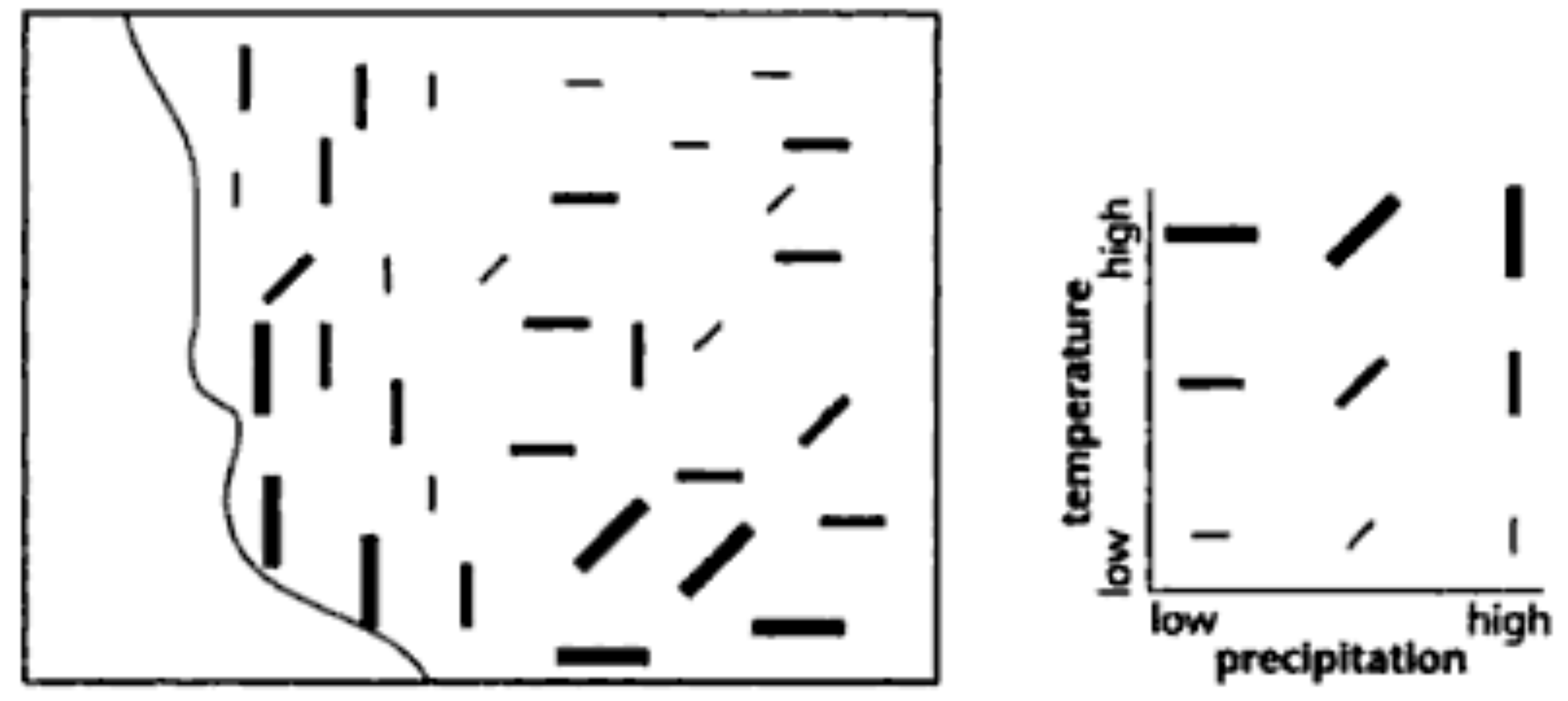


FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

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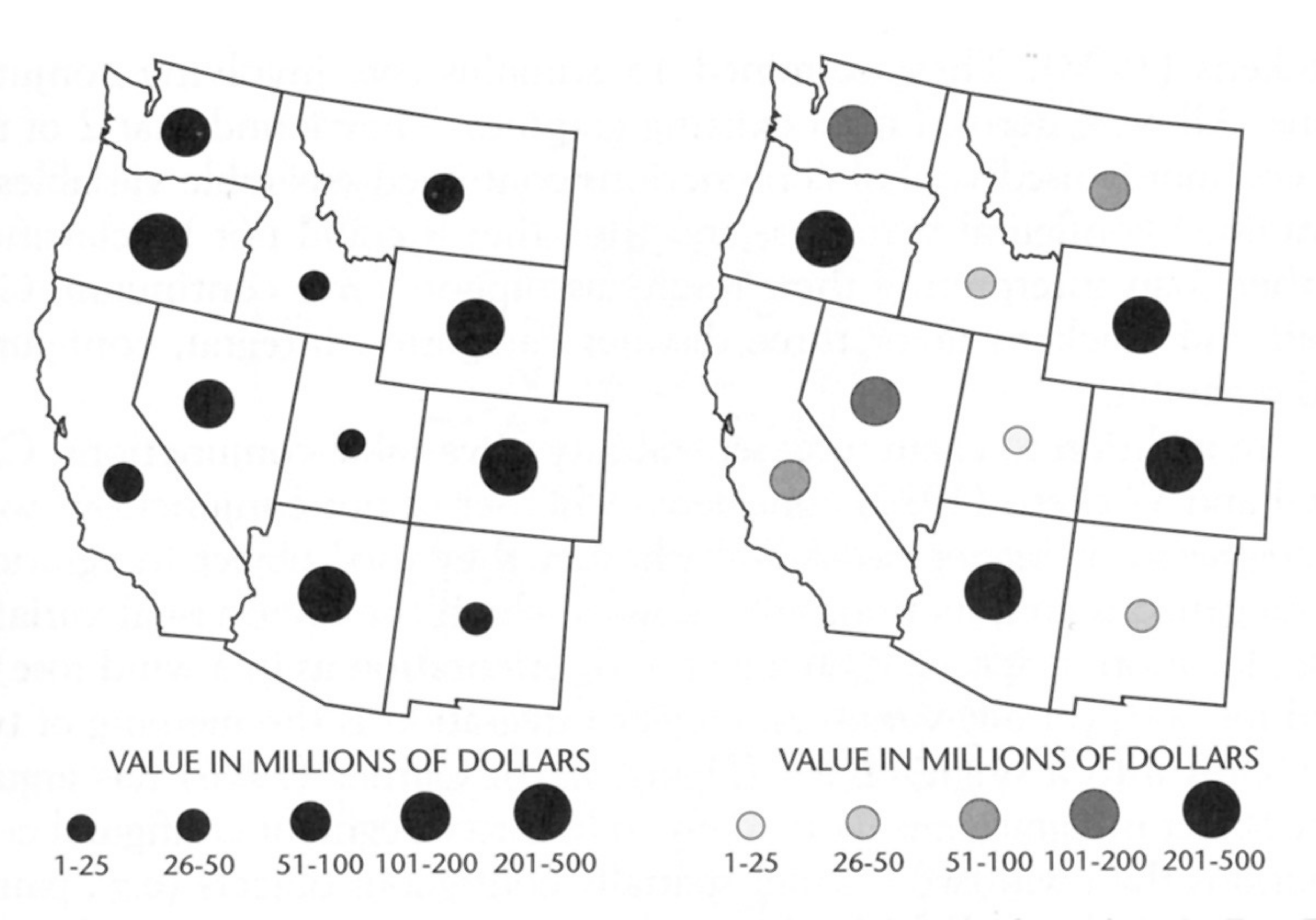
Size & Value?

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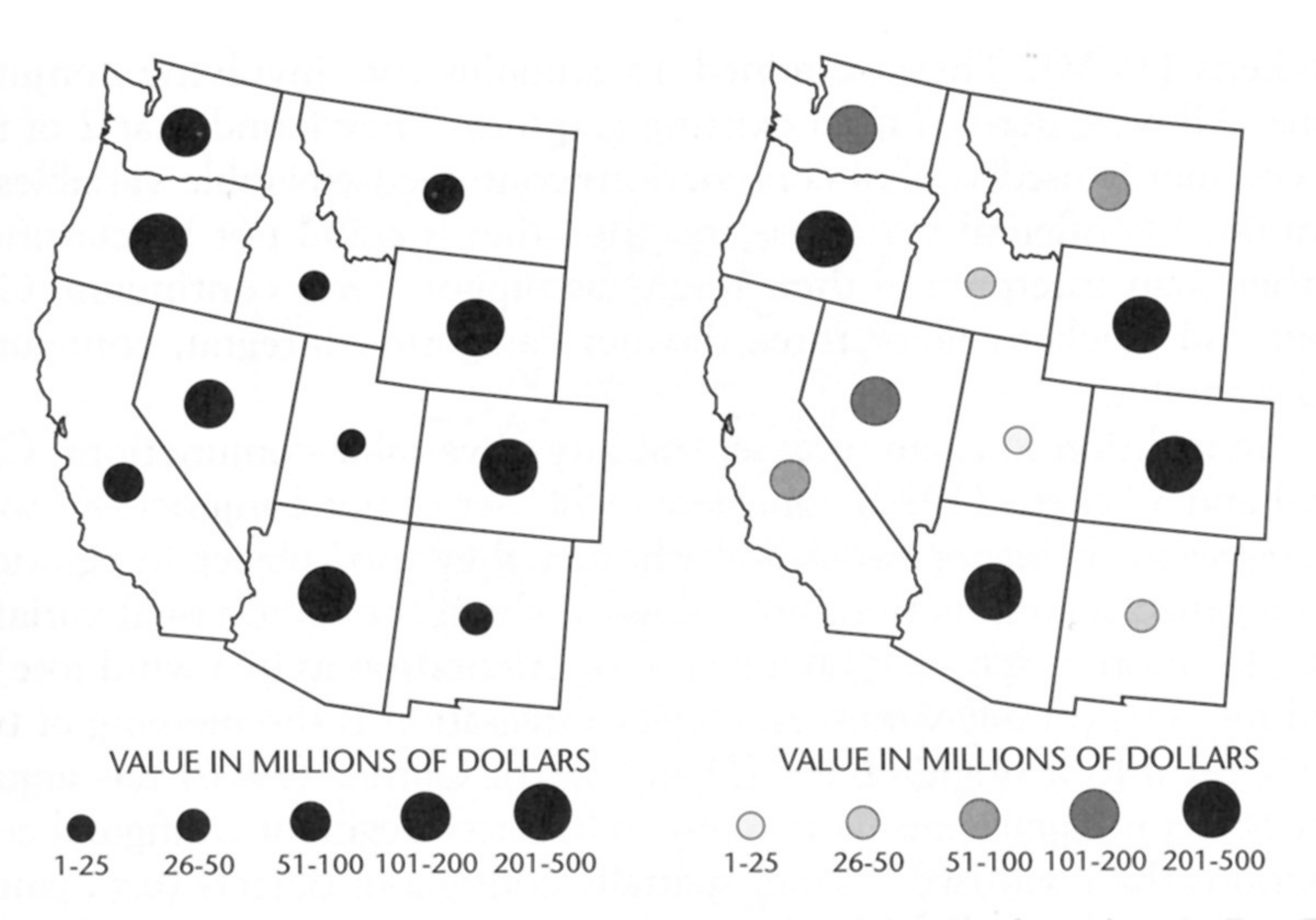


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Shape & Size?

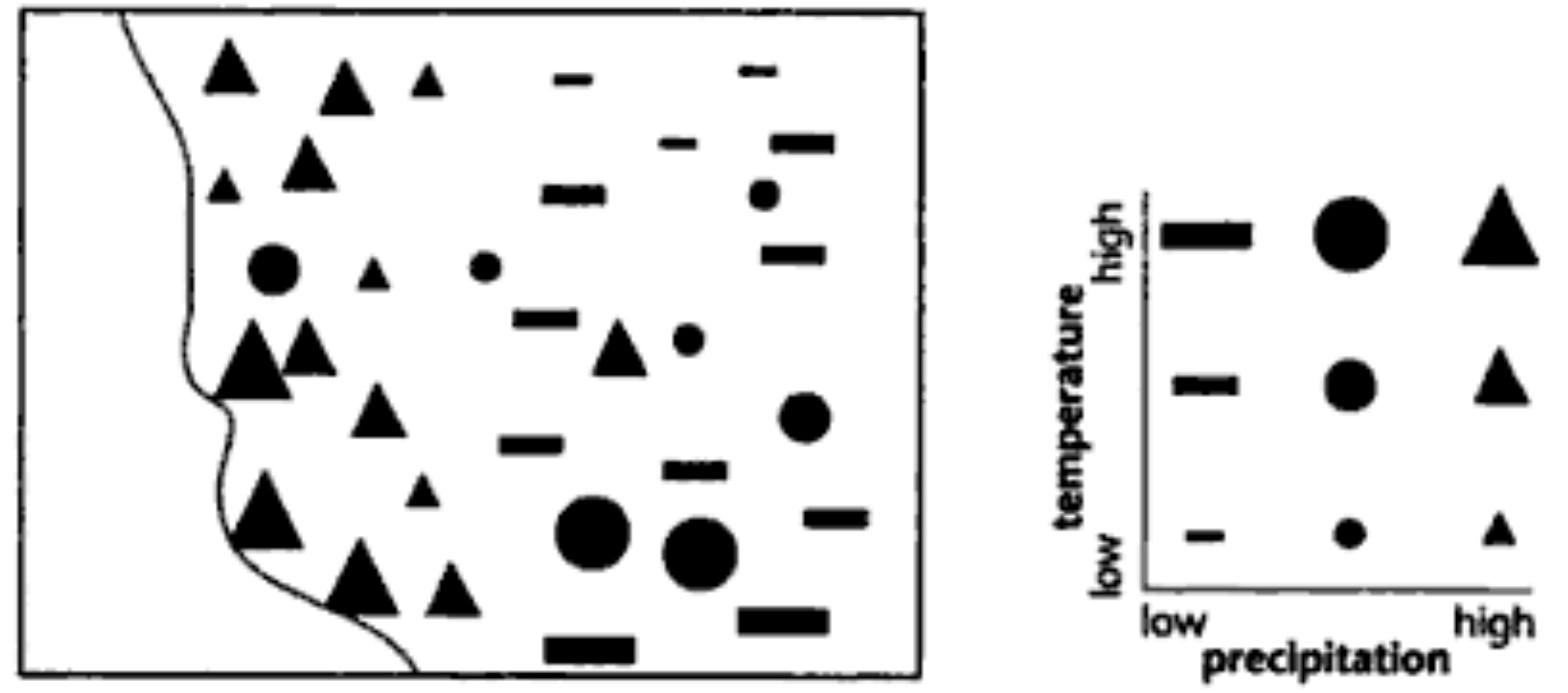


FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

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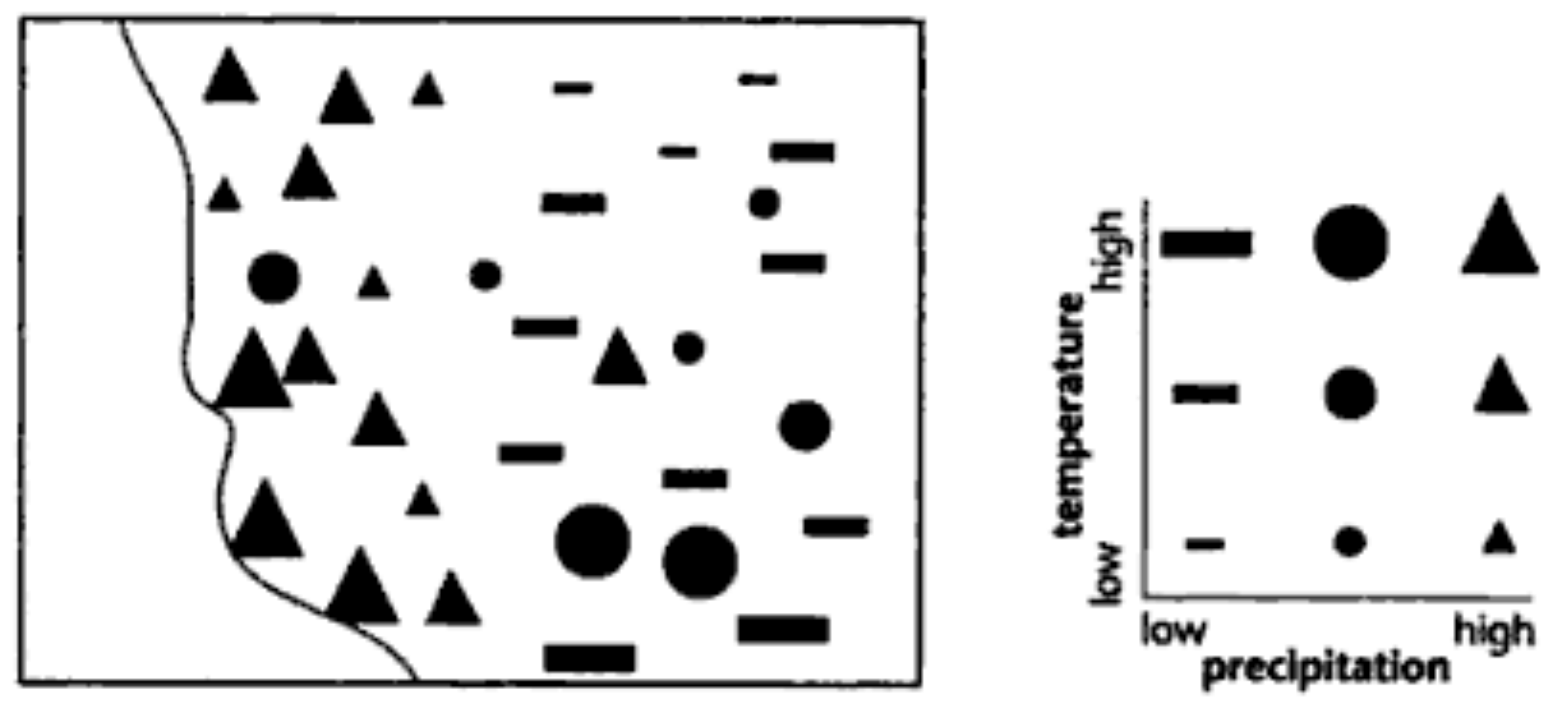


FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

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# Types of Dimensions

Width & Height?

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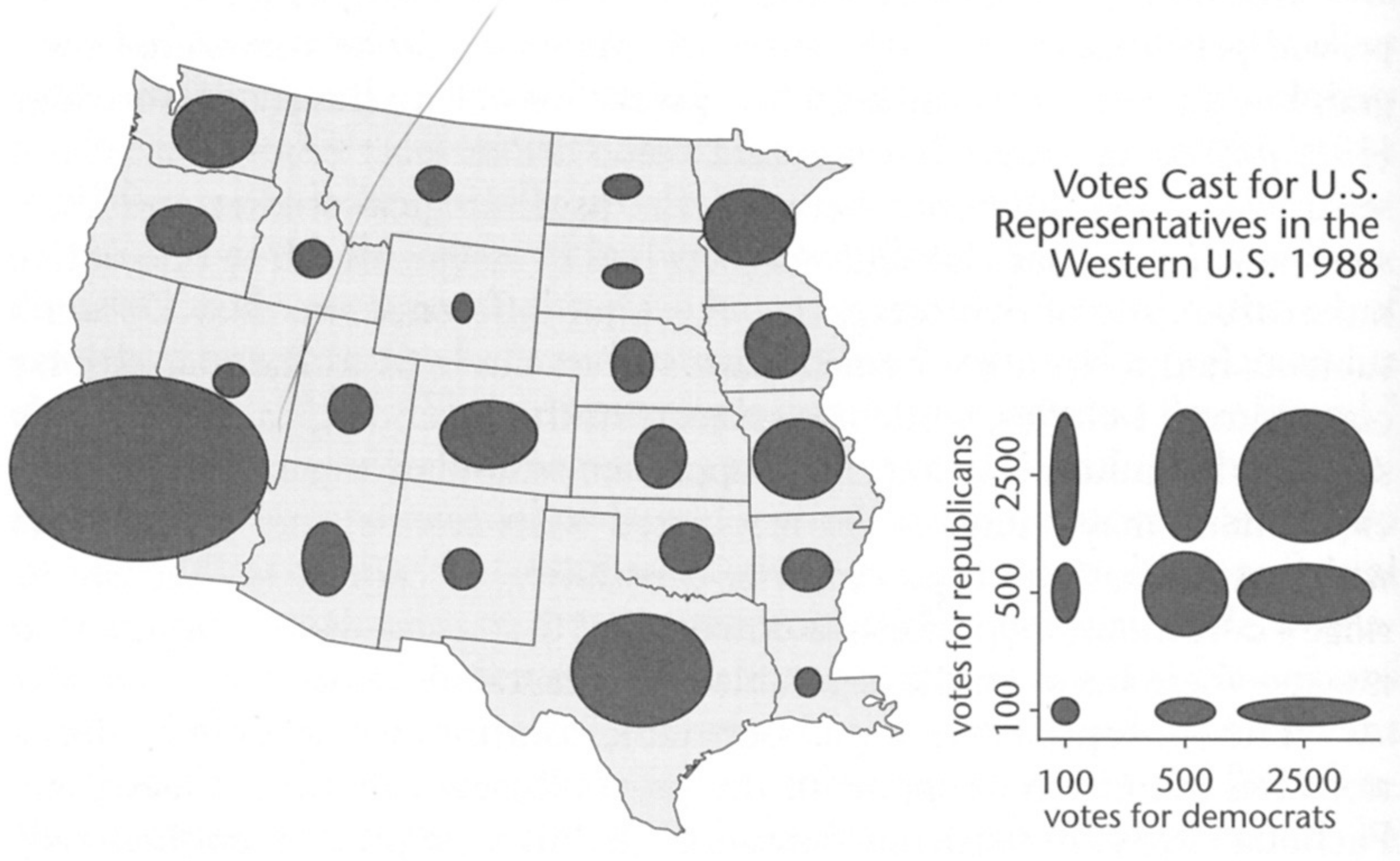


**FIGURE 3.38.** An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

[MacEachren 1995]

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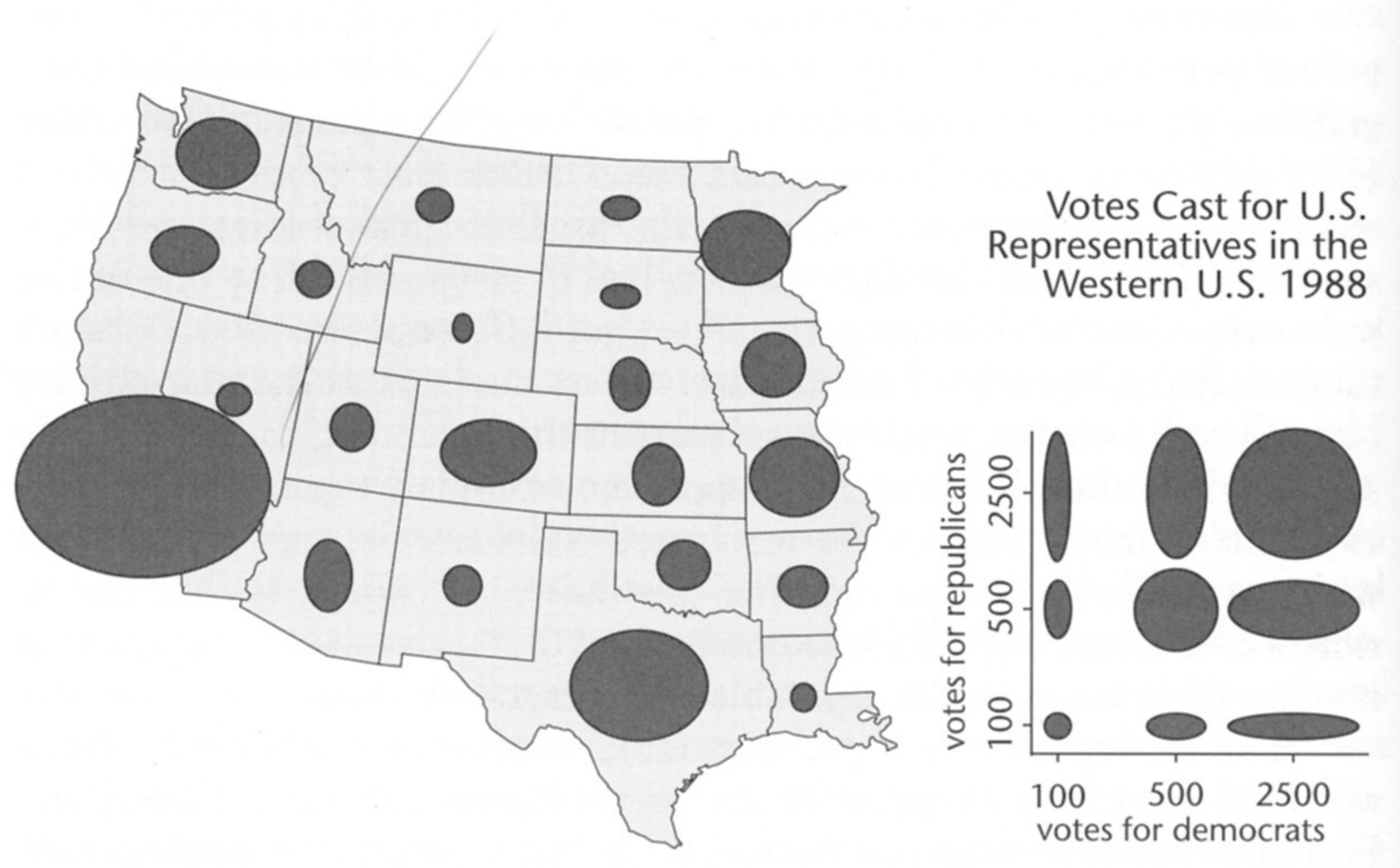


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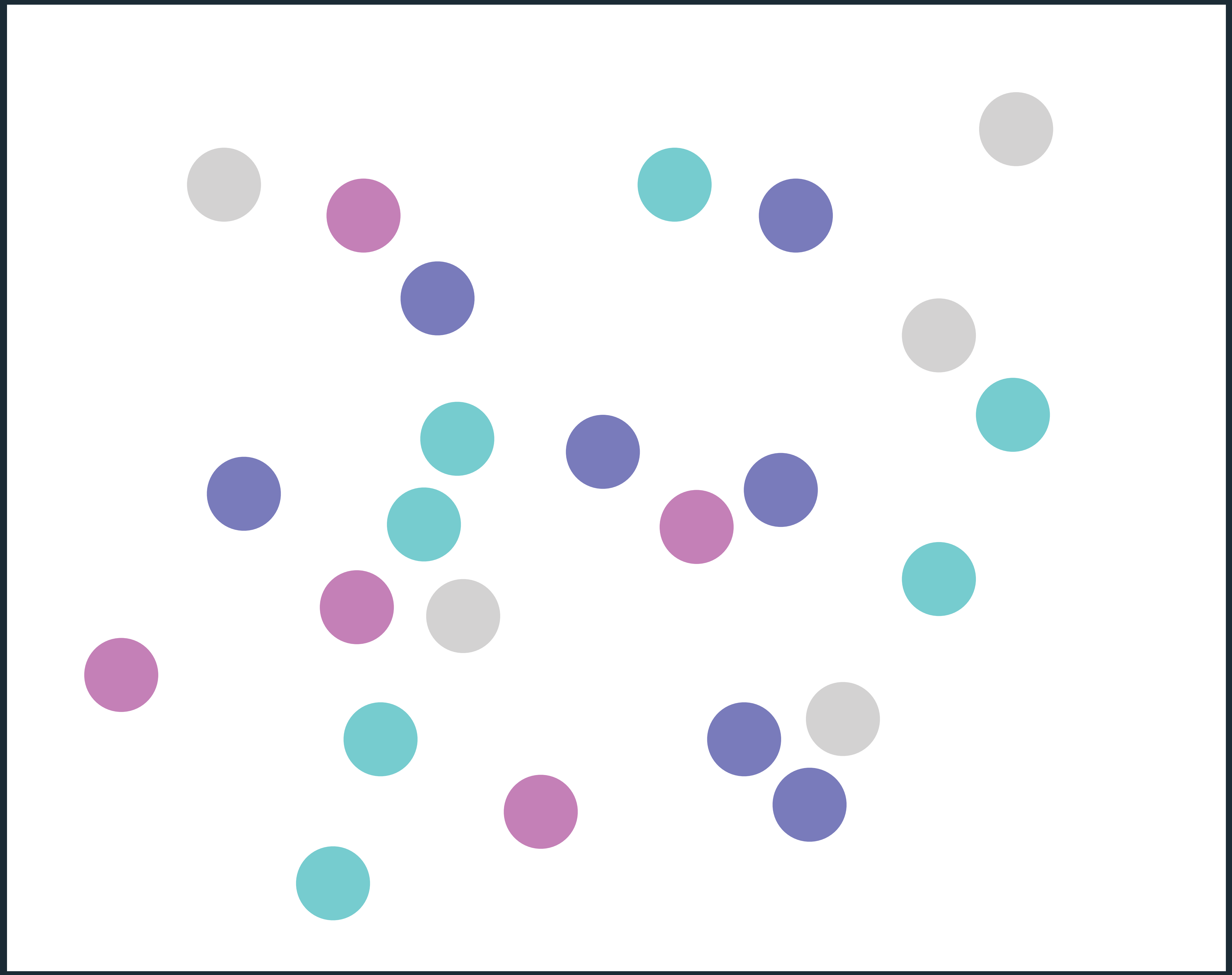
Red & Green?



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

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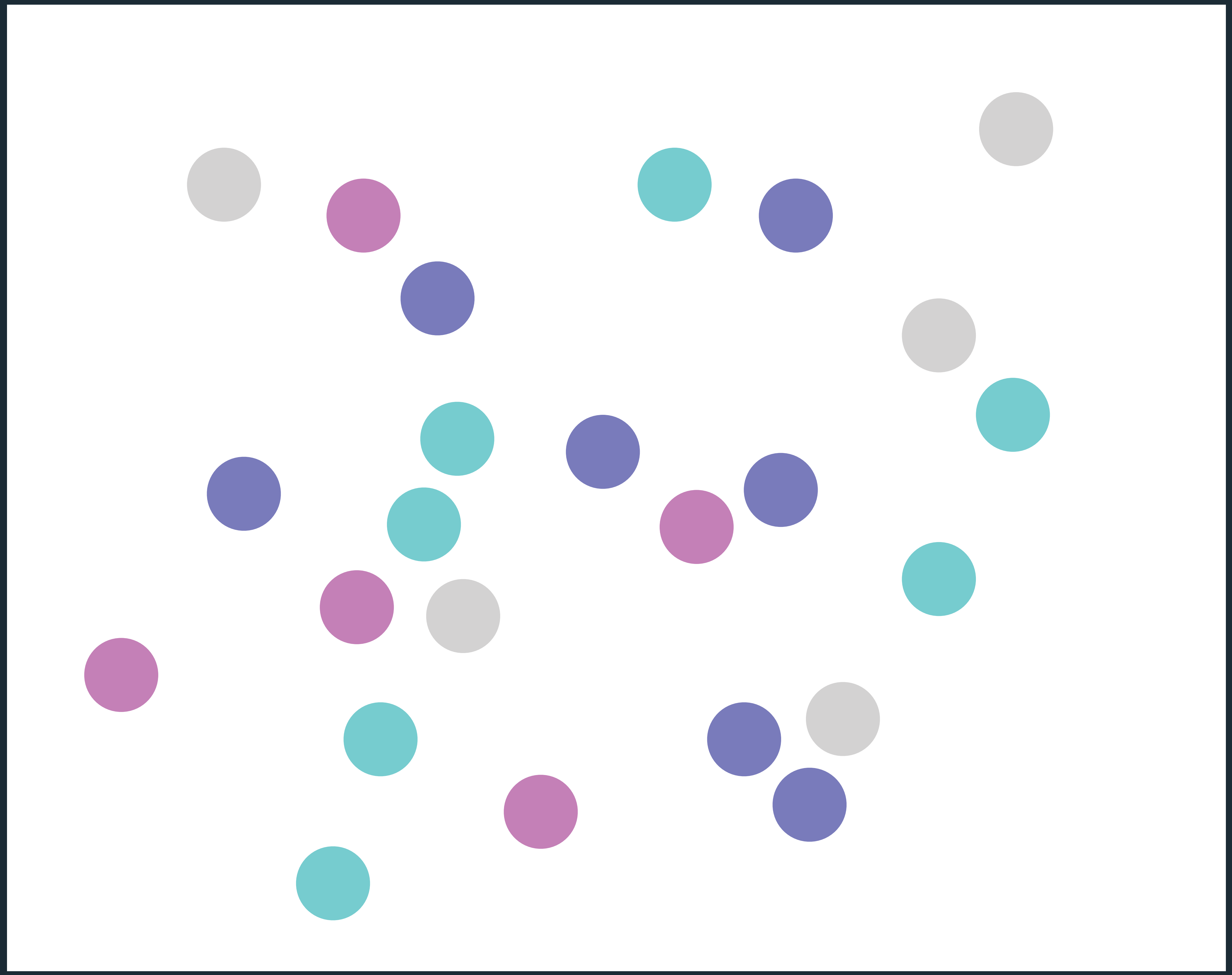

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blue

yellow

red

green

orange

purple

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[Resnick 2017]

[Resnick 2017]

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[Resnick 2017]

[Resnick 2017]

Signal Detection

Magnitude Estimation

Pre-Attentive Processing

Selective Attention

**Change Blindness**

Gestalt Grouping

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# Gestalt Principles

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

Figure / Ground

Proximity

Similarity

Symmetry

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Continuity

Closure

Common Fate

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Ambiguous – vase or faces?

Unambiguous (?)

http://visual-memory.co.uk/daniel/Modules/FM21820/visper07.html

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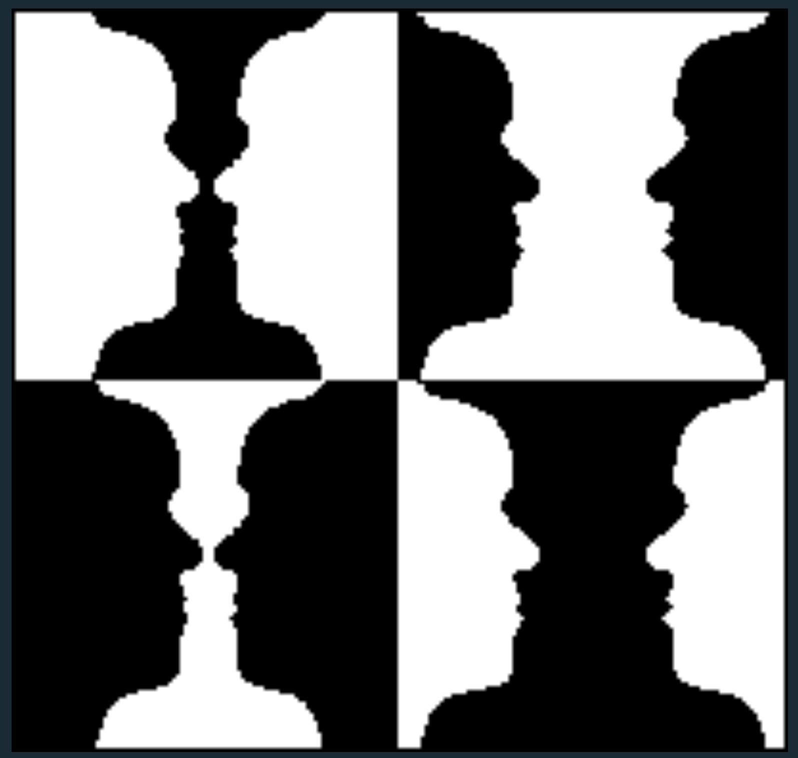
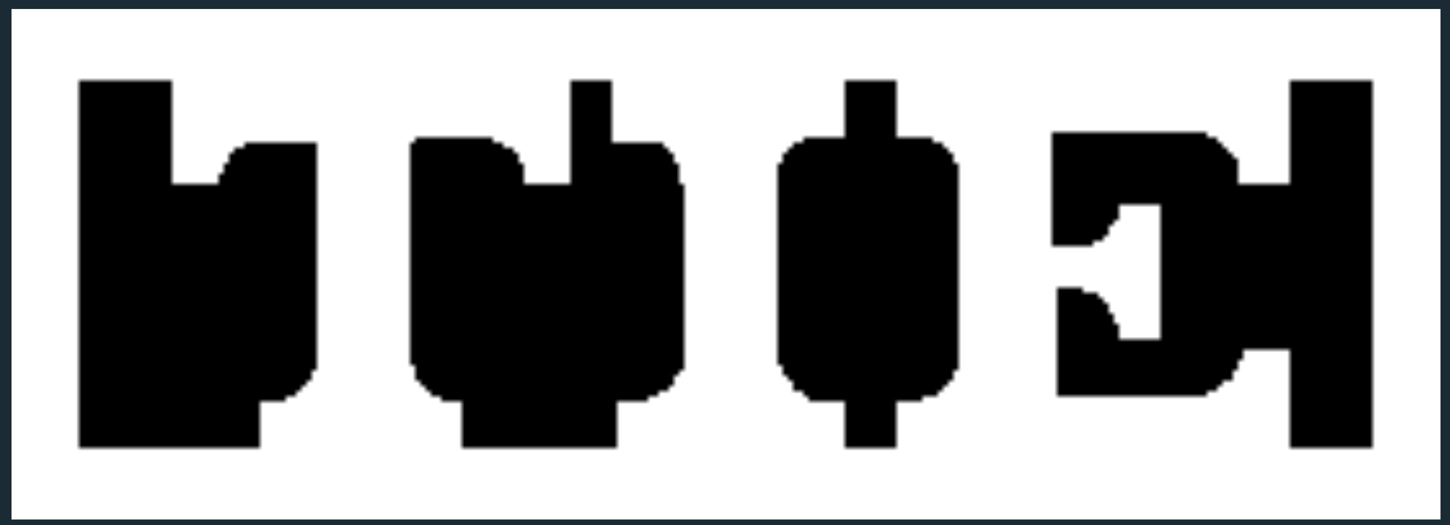
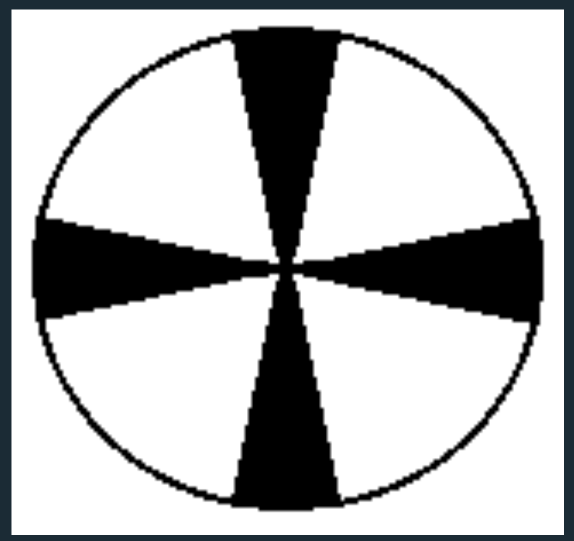


Unambiguous (?)



Principle of *surroundedness*.



Principle of *relative size*.

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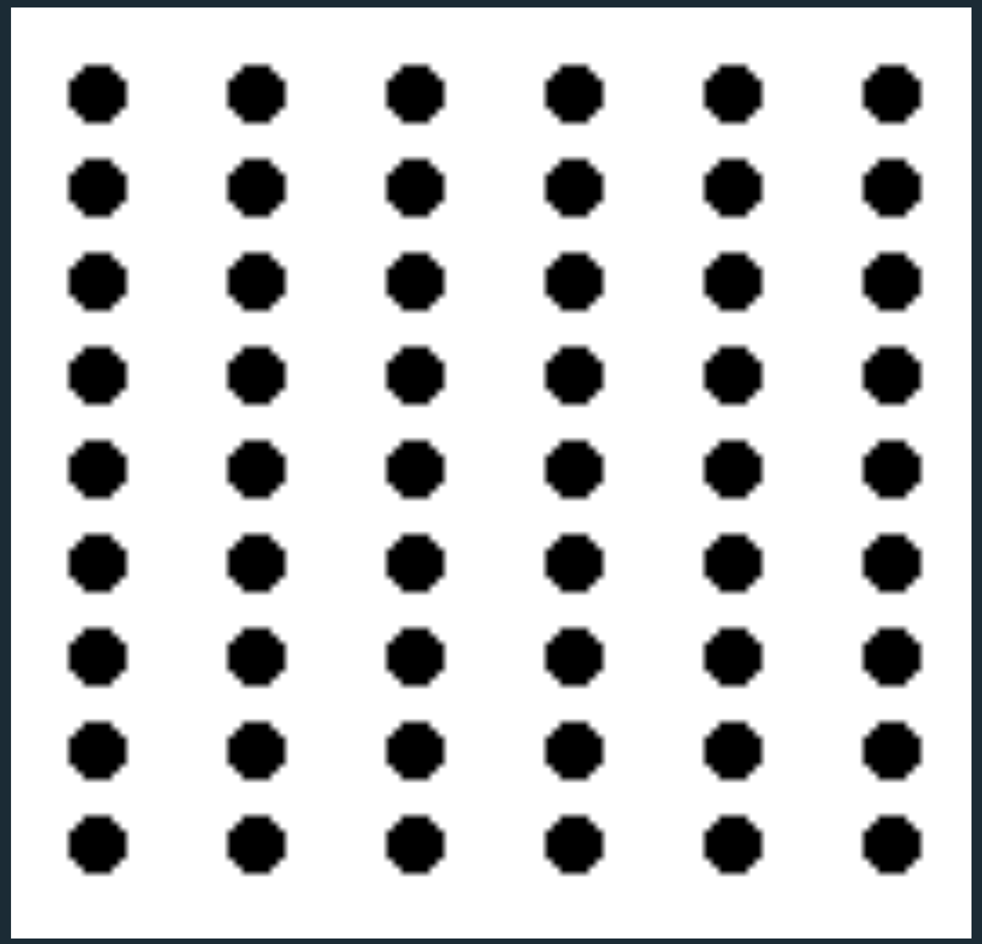

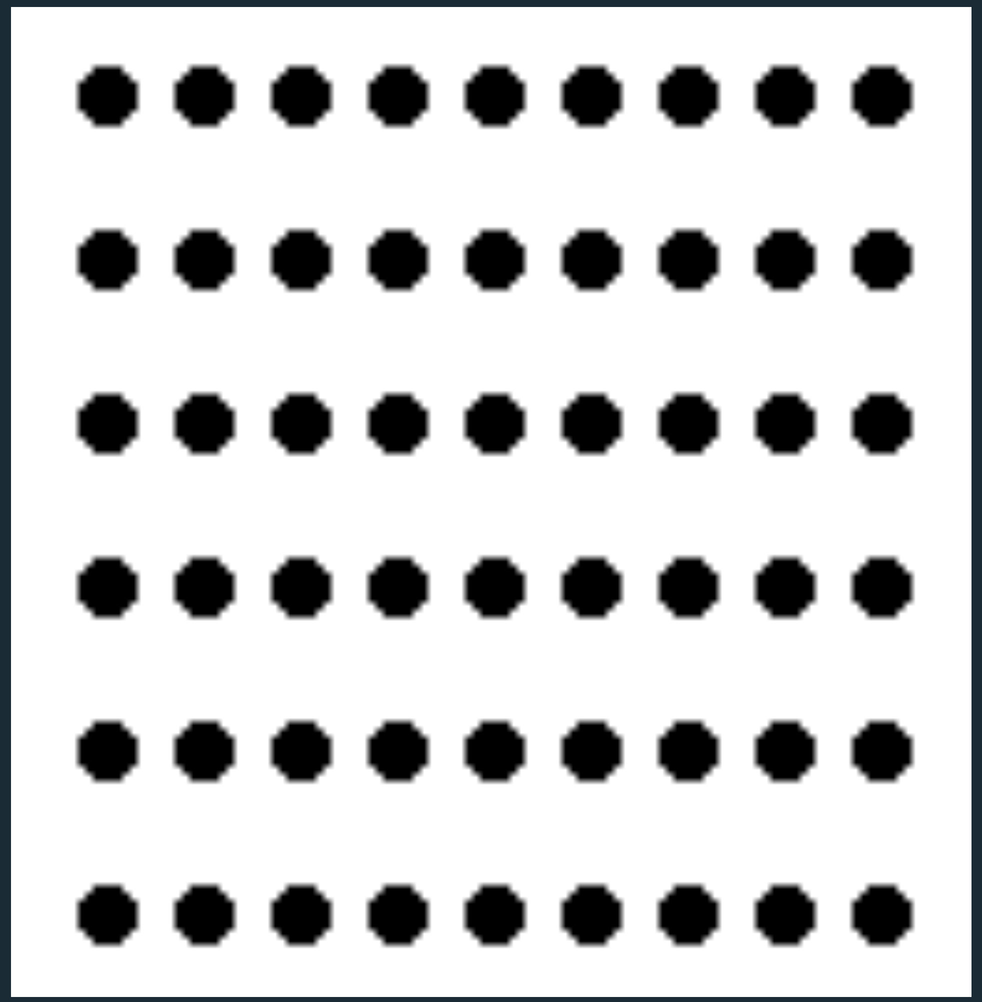

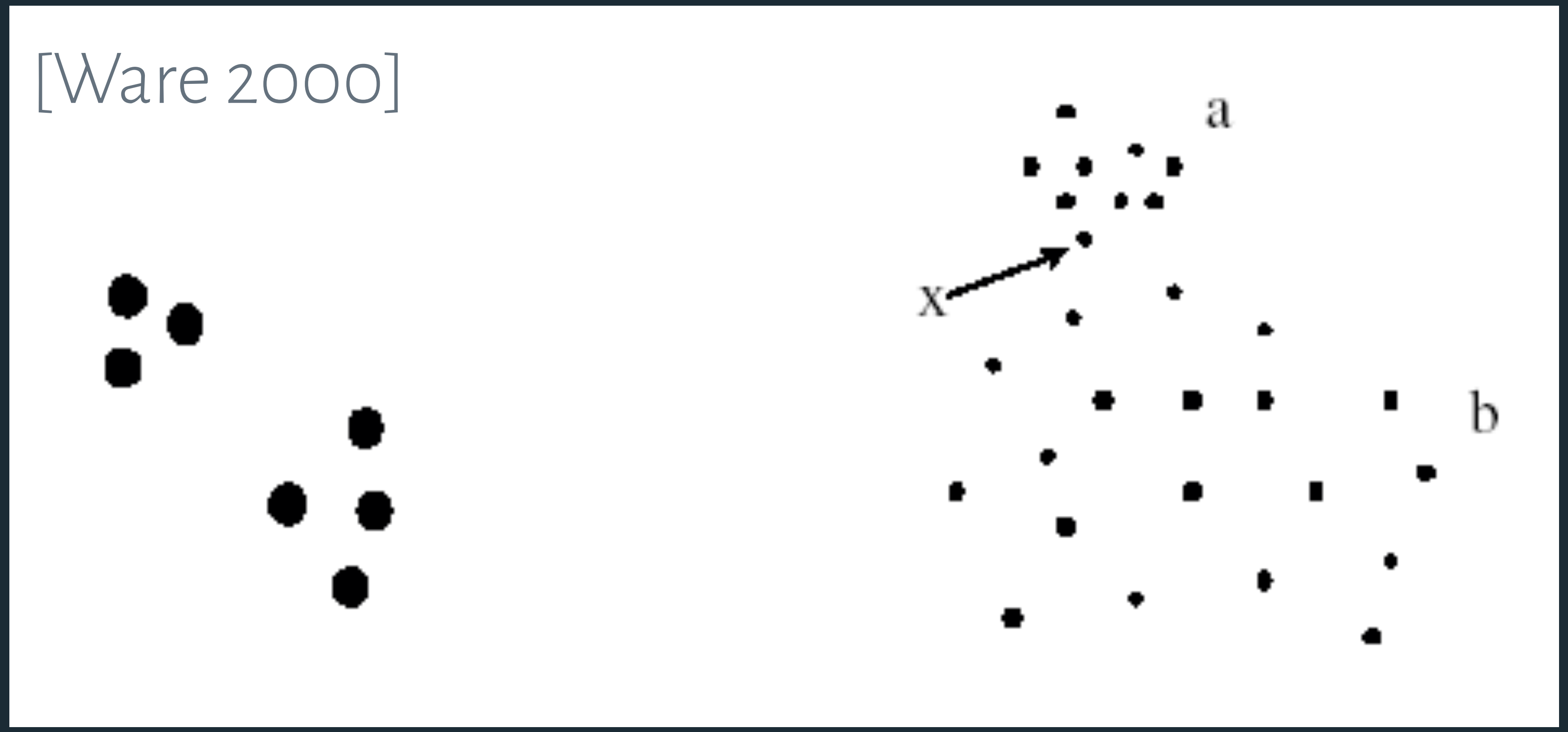


Principle of *concentration*.

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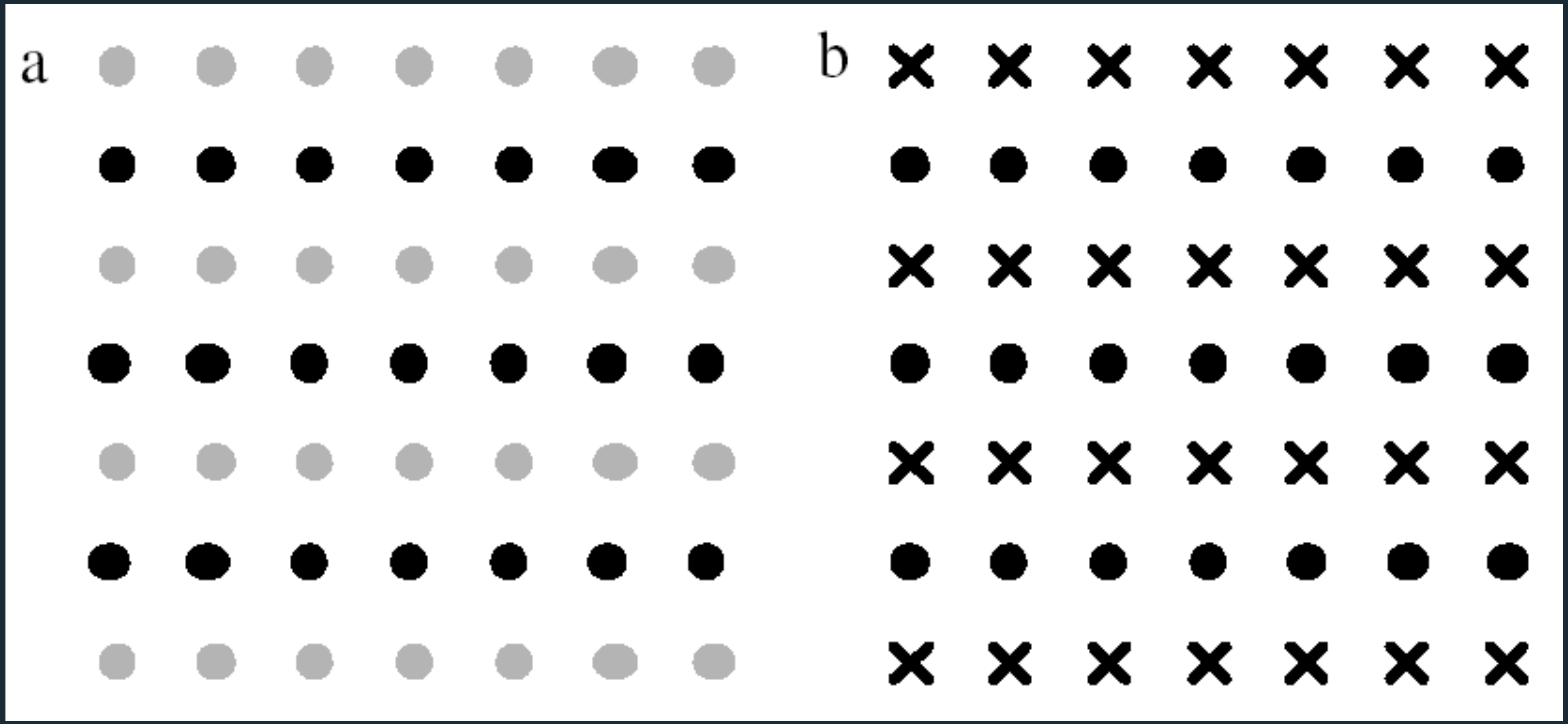


Rows dominate due to similarity. [Ware 2004]

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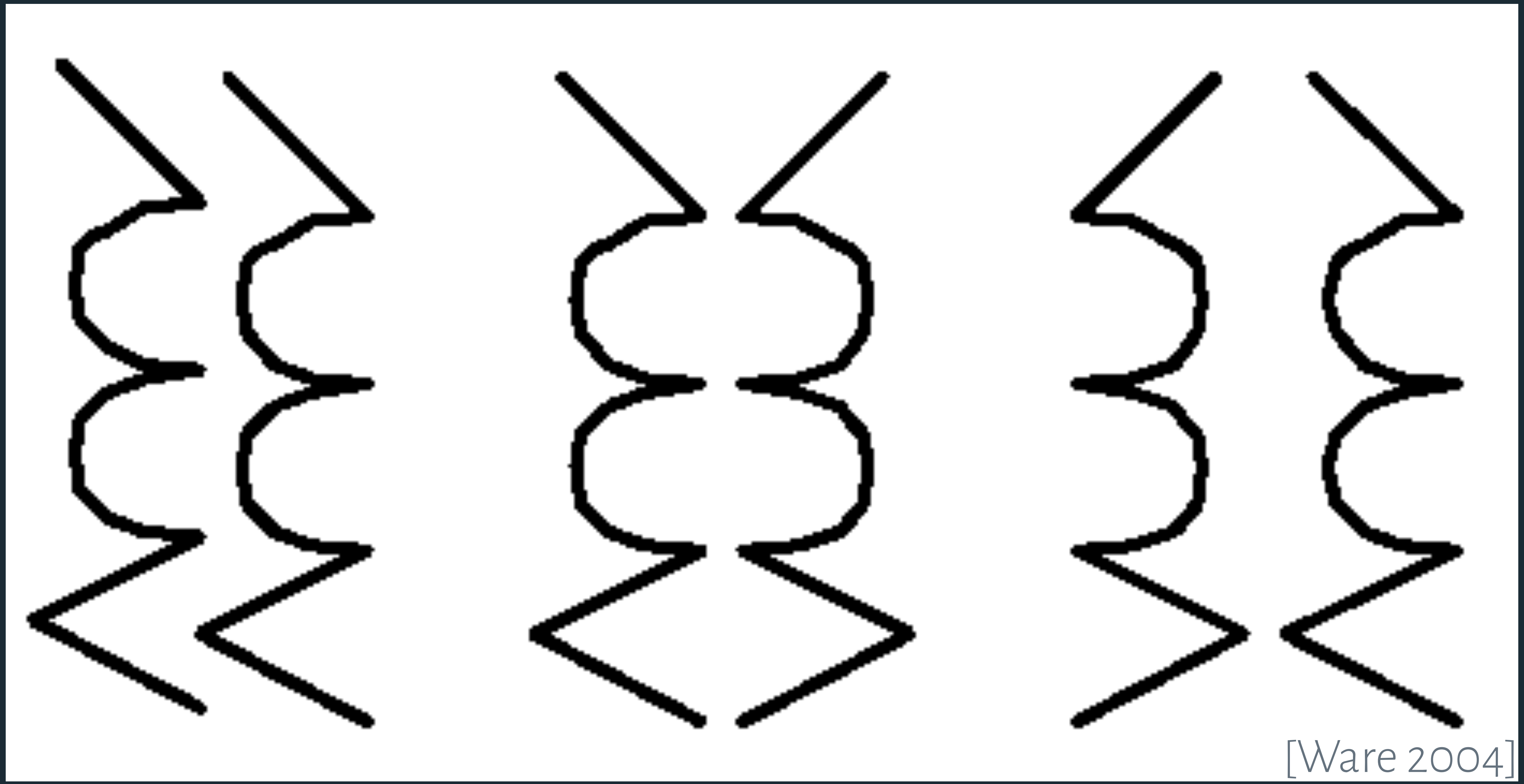


Bilateral symmetry gives the strong sense of a figure.

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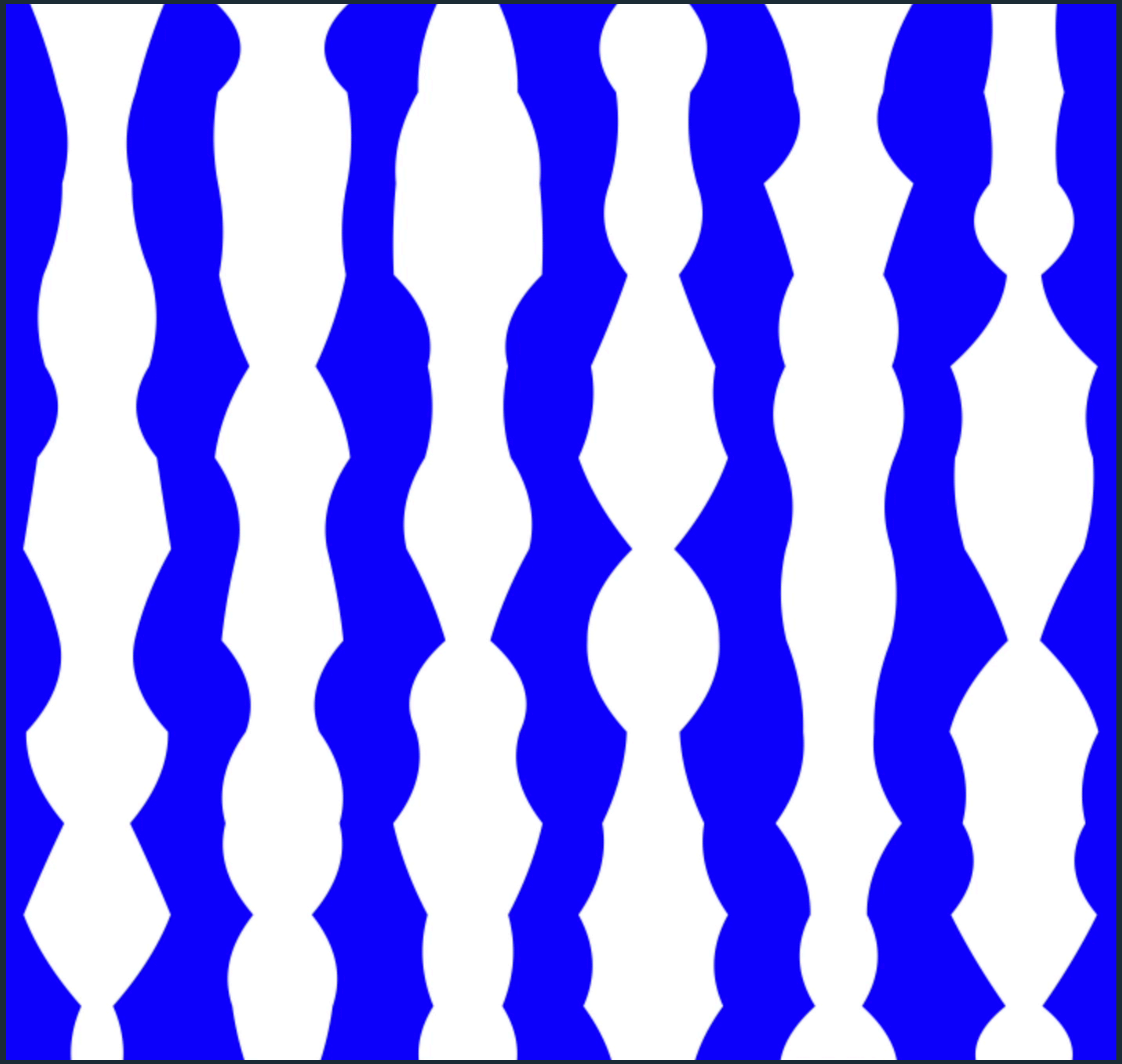

https://isle.hanover.edu/Ch05Object/Ch05SymmetryLaw_evt.html

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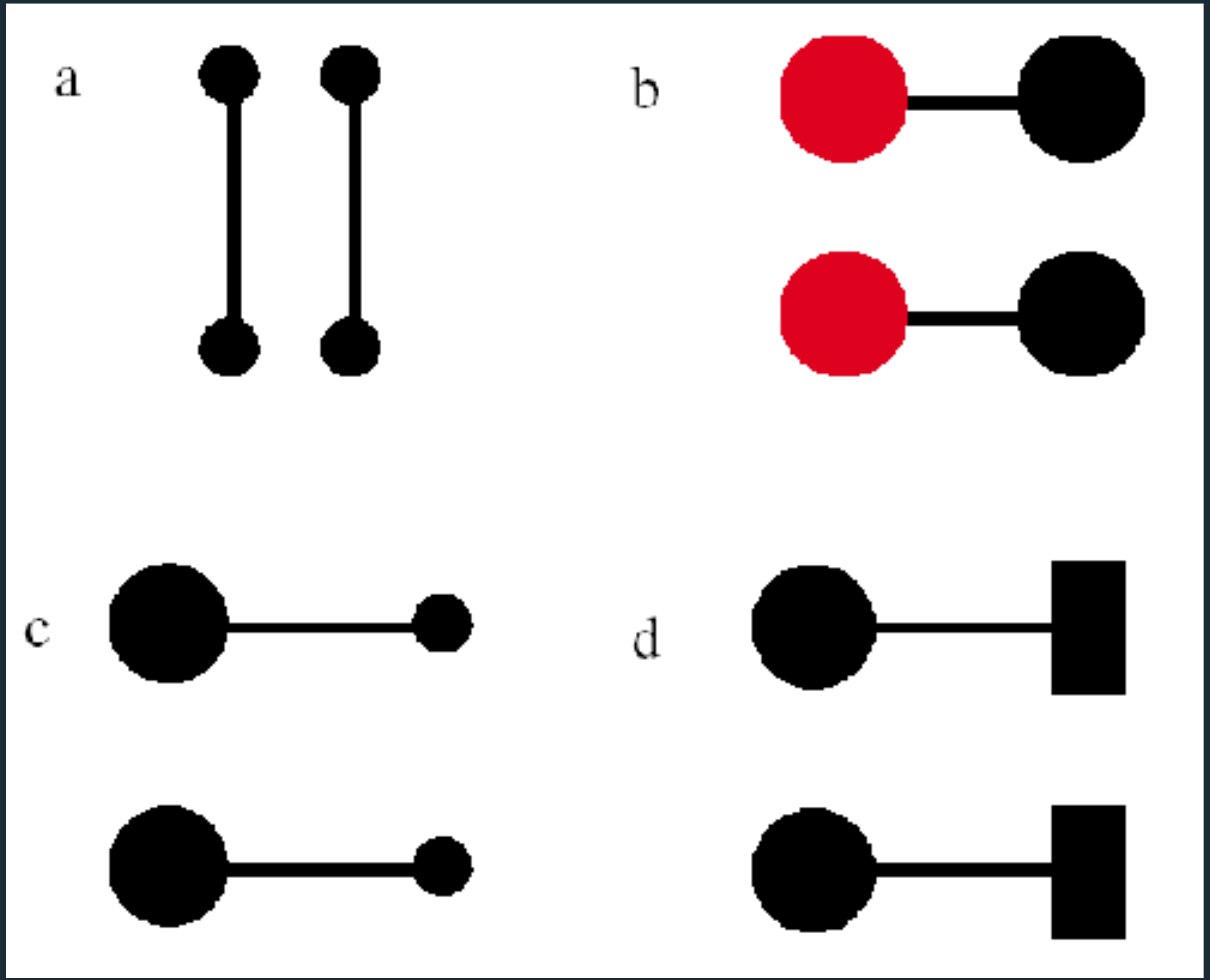


[Ware 2004]

Connectedness overrules proximity, size, color, shape, etc.

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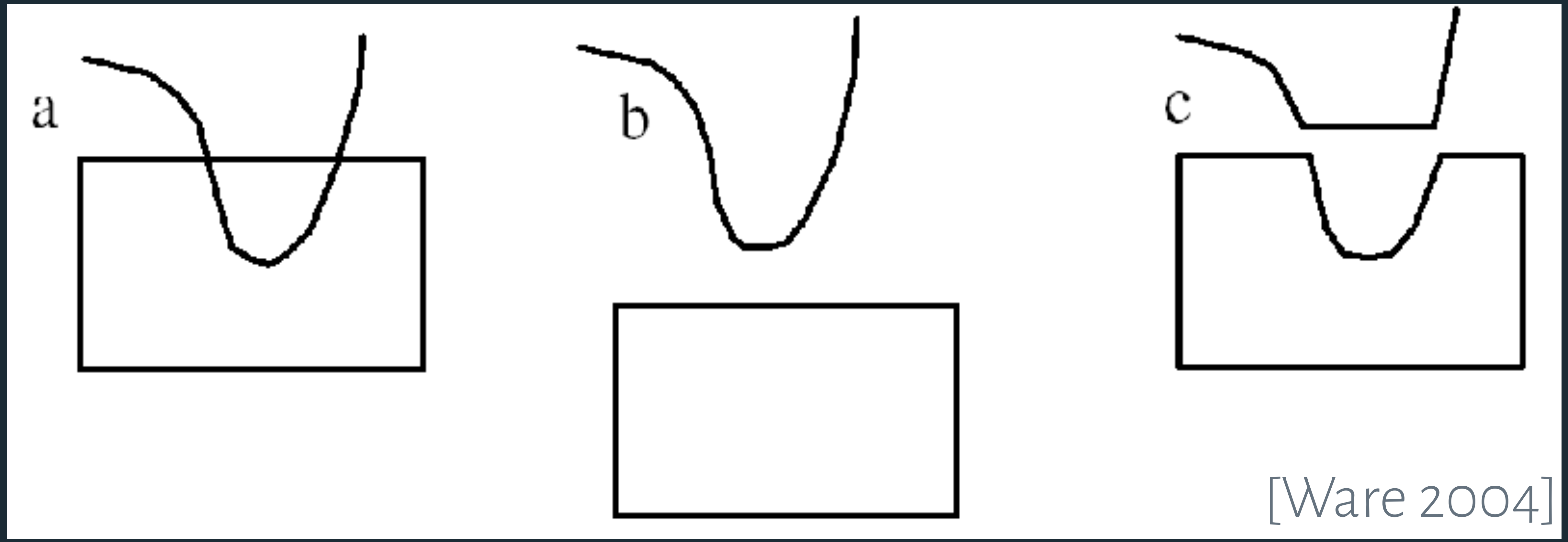
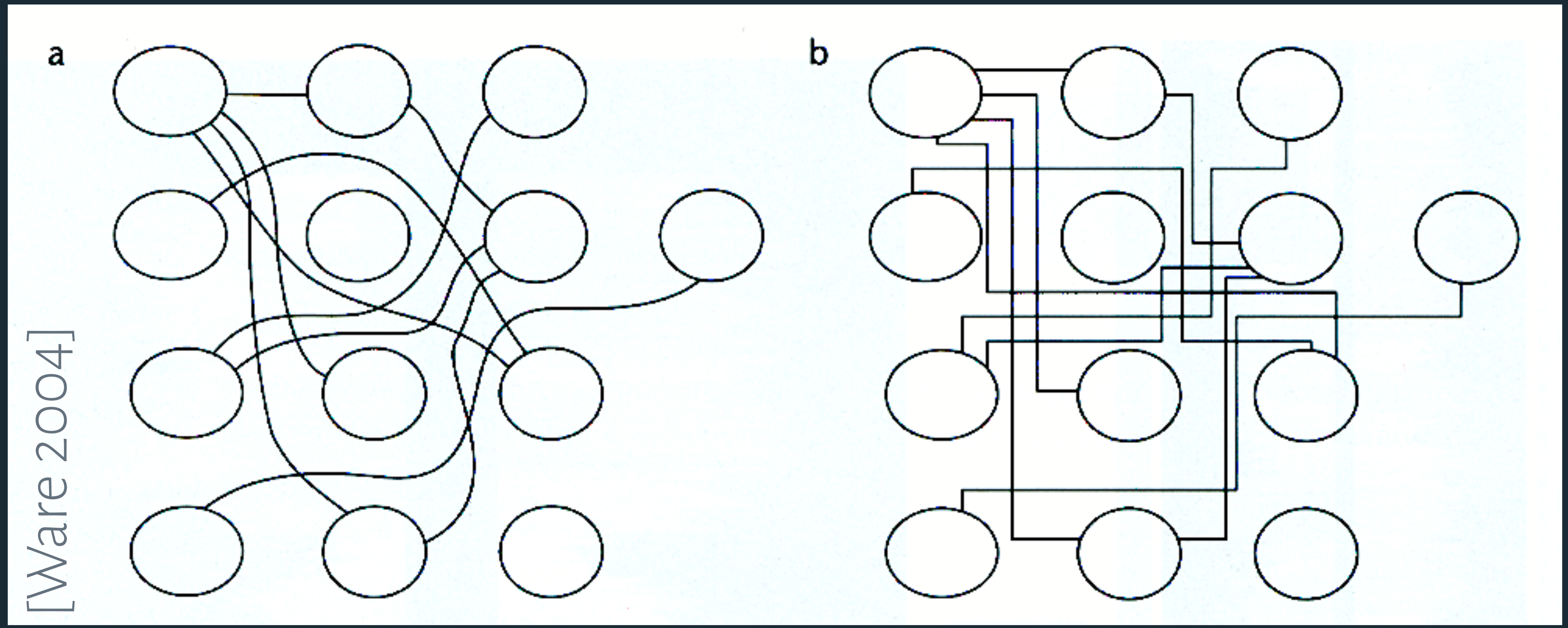



We prefer smooth, not abrupt, changes.




Connections are clearer with smooth contours.

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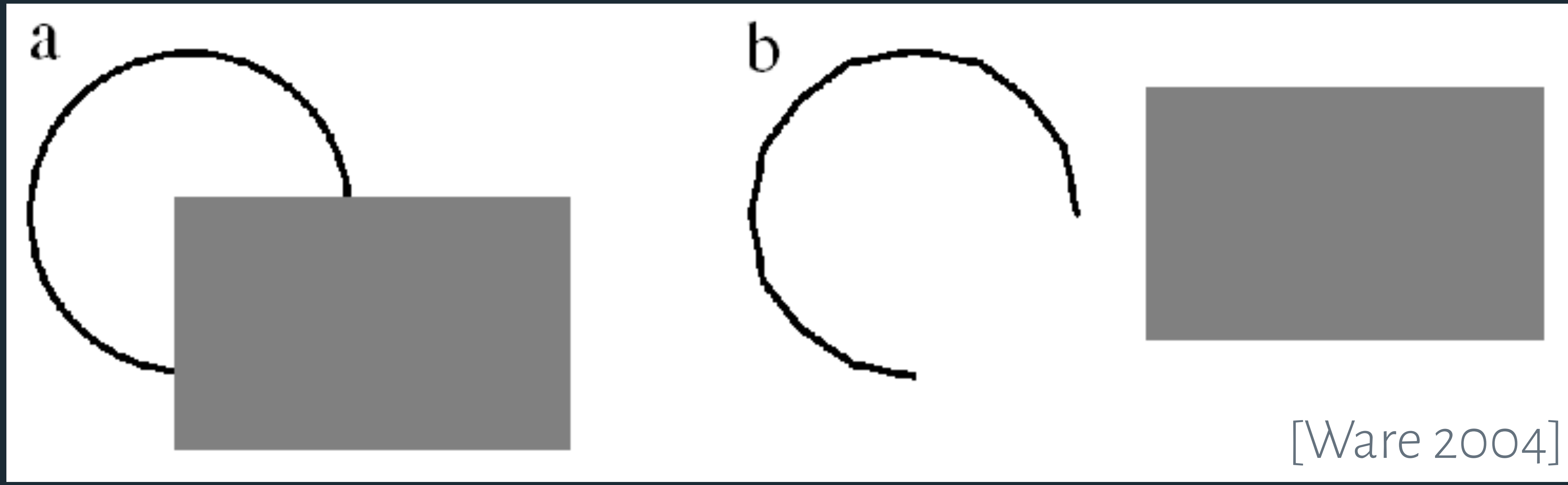
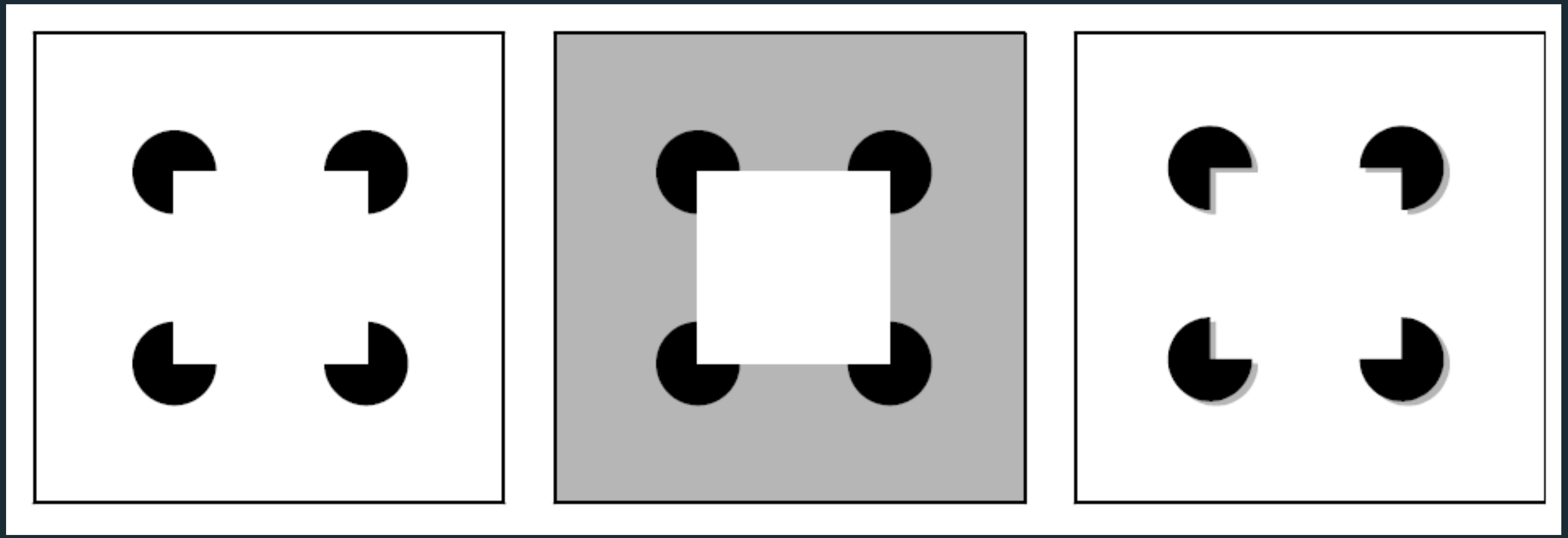



We see a circle behind a rectangle, not a broken circle.



[Durand 02]

Illusory contours

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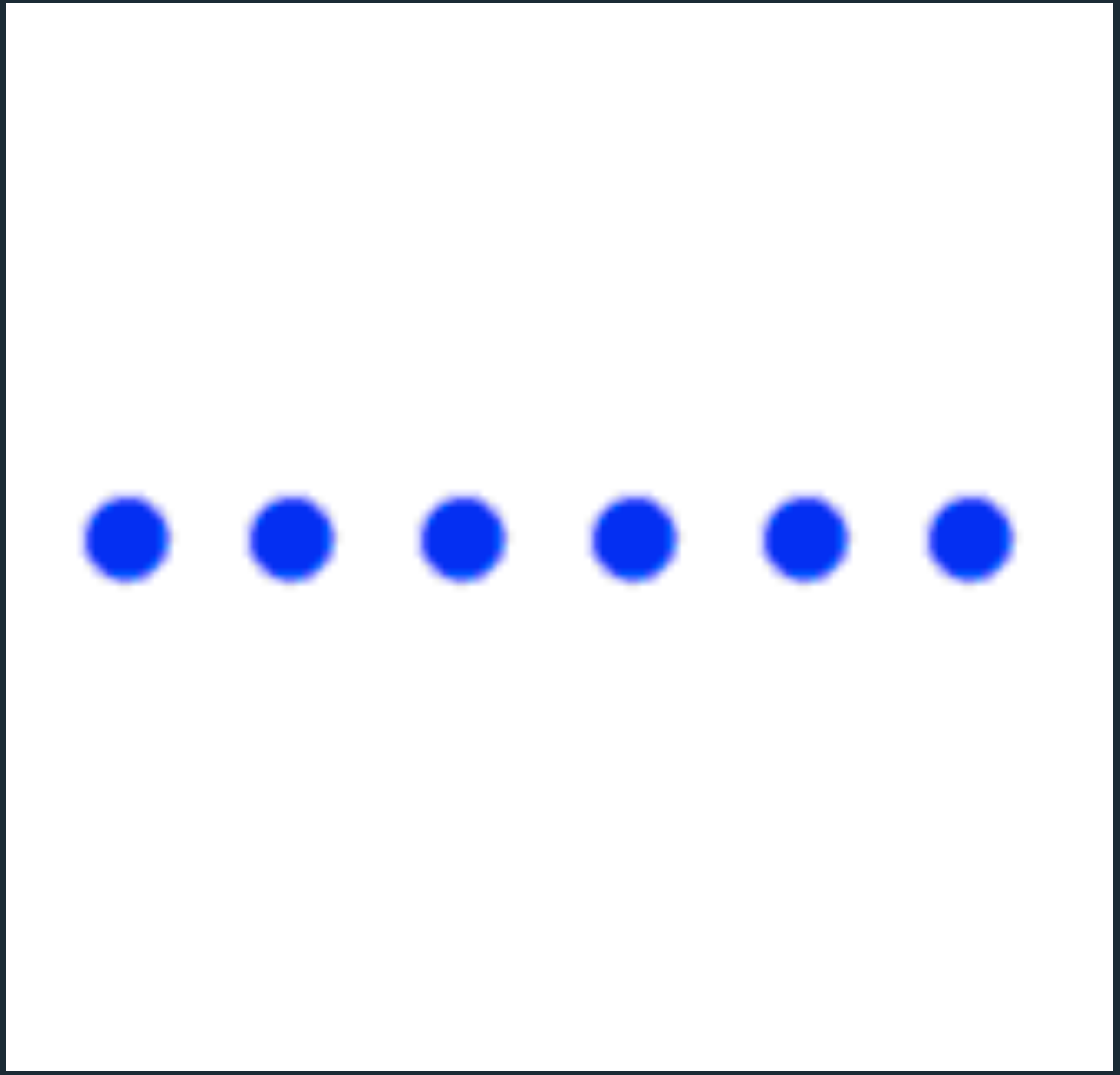

Dots moving together are grouped.