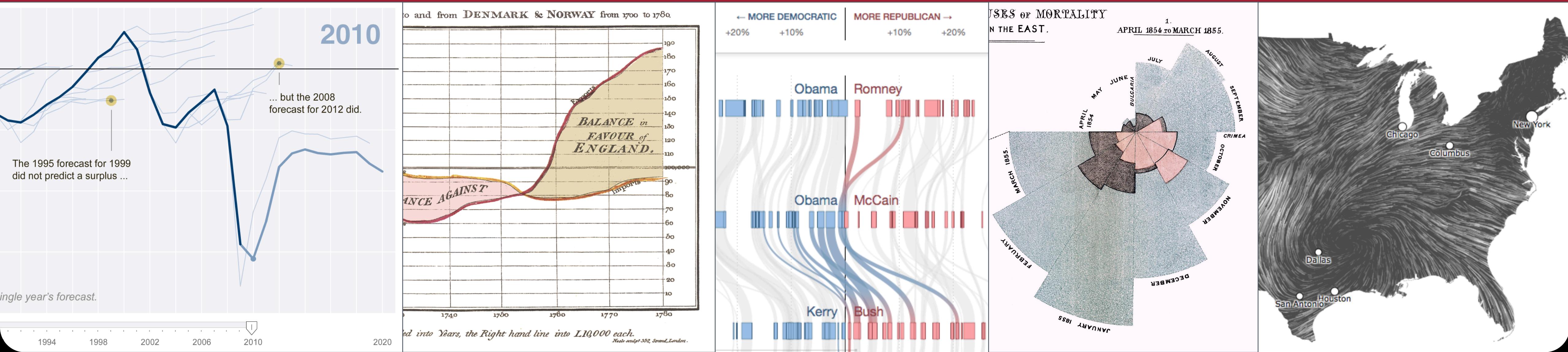


# 6.894: Interactive Data Visualization

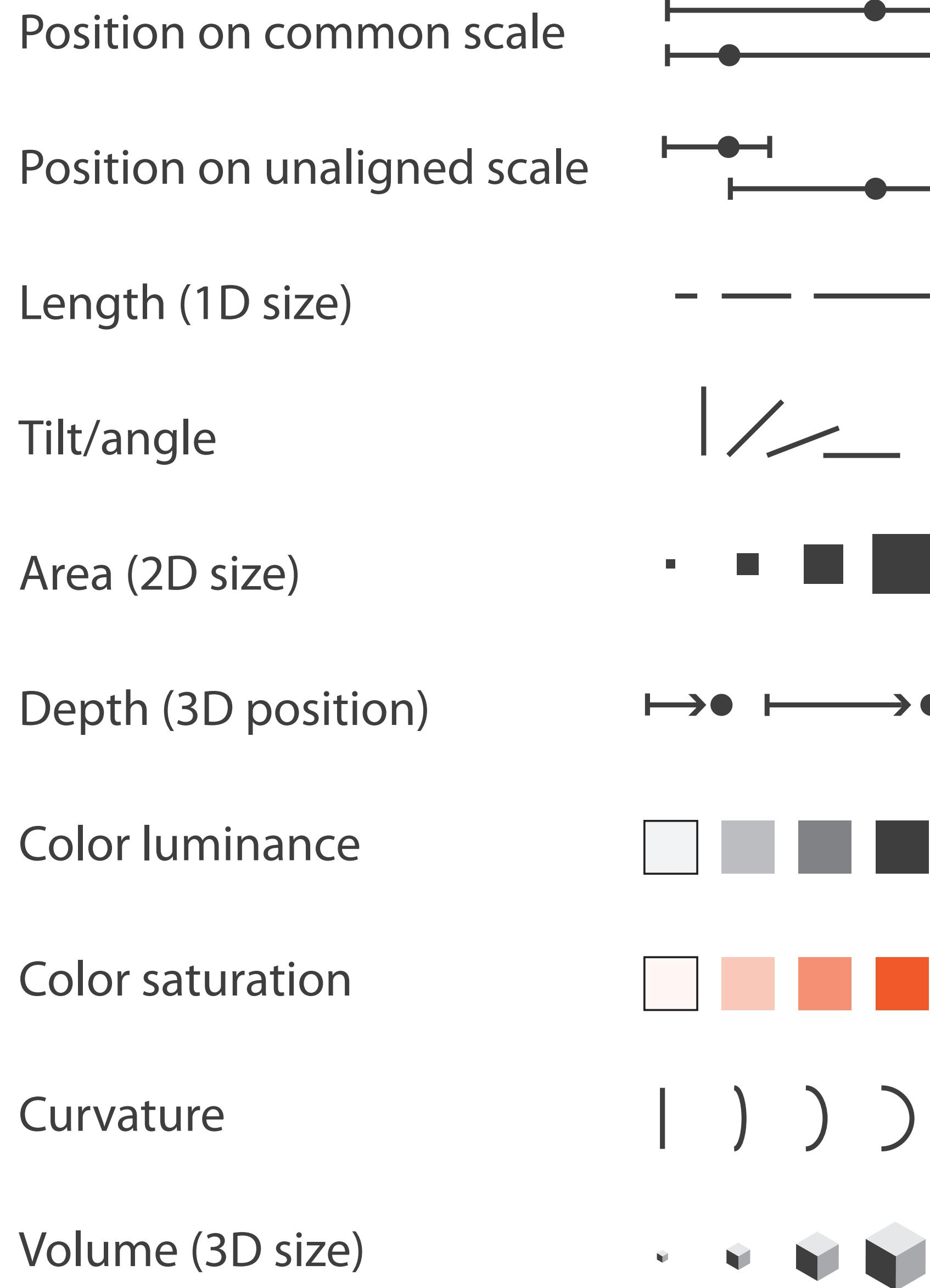
# Graphical Perception

Arvind Satyanarayan



# Channels: Expressiveness Types and Effectiveness Ranks

## → Magnitude Channels: O or Q attributes



## → Identity Channels: N attributes



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

**Signal Detection**

**Magnitude Detection**

**Pre-Attentive Processing**

**Selective Attention**

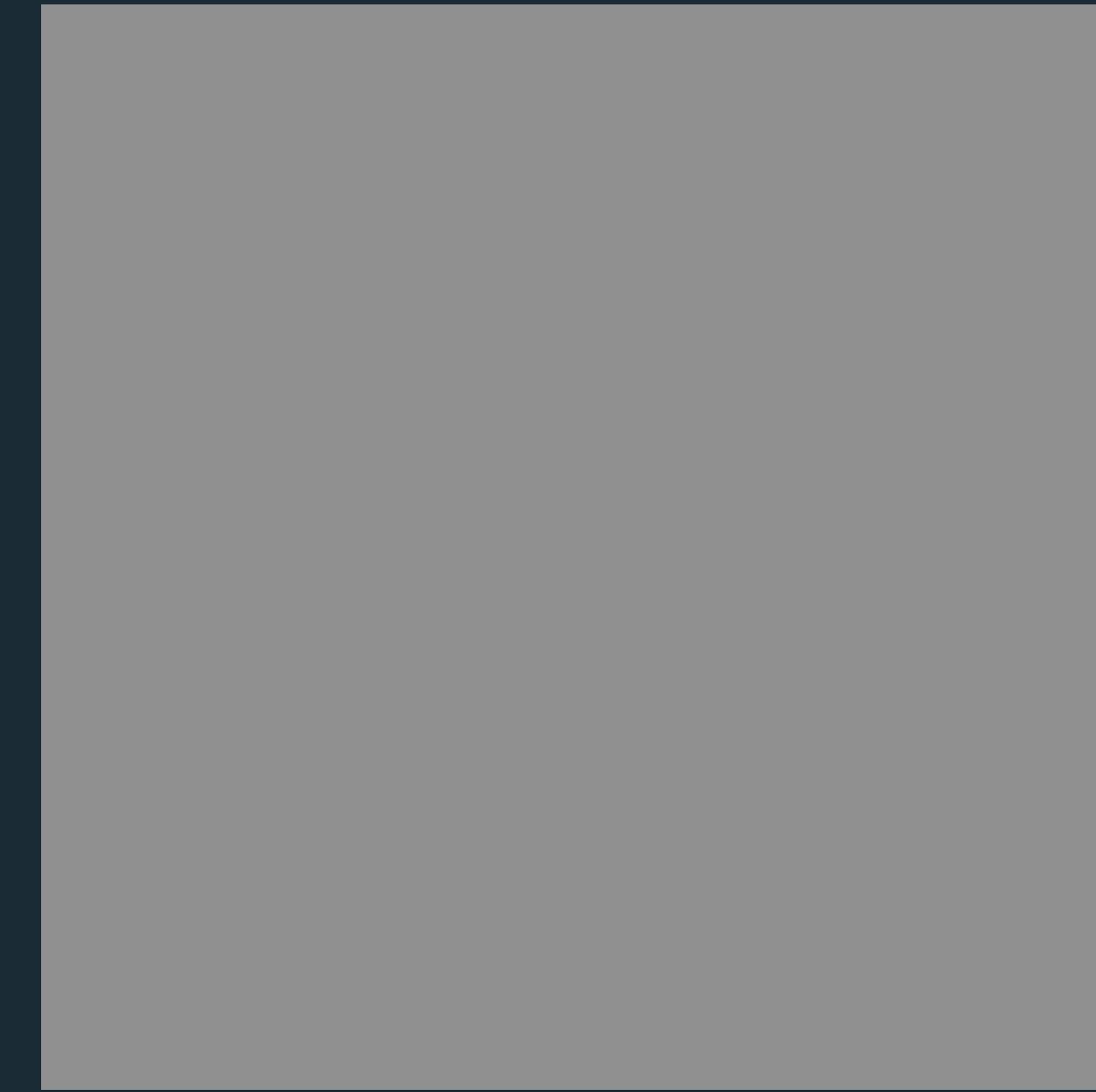
**Change Blindness**

**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)

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

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



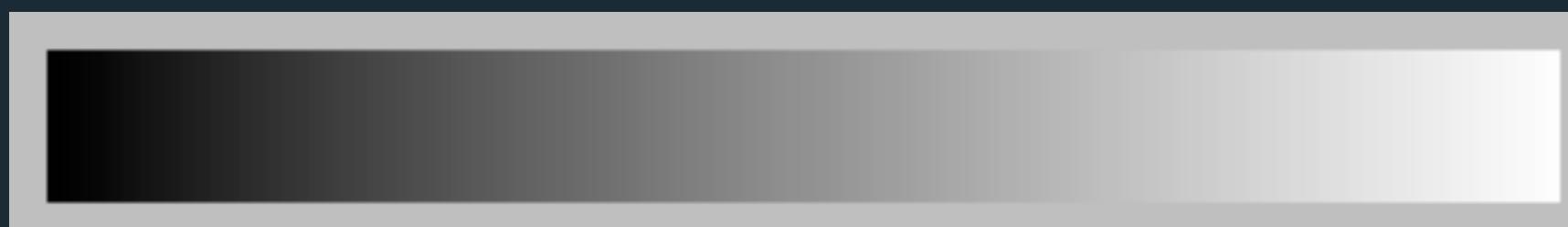
Ernst Weber

(1795–1878)

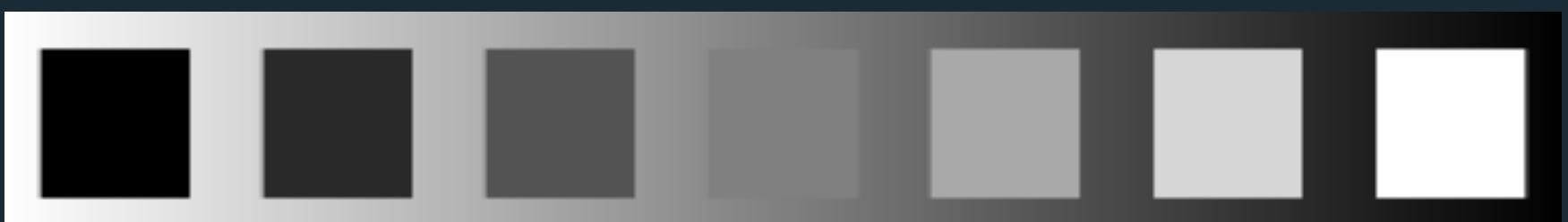
German physician  
and a founder of  
experimental  
psychology.

Ratios more important than magnitude.

Most continuous variation in stimuli are perceived in discrete steps.



vs.



**Signal Detection**

**Magnitude Detection**

**Pre-Attentive Processing**

**Selective Attention**

**Change Blindness**

**Gestalt Grouping**

Signal Detection

Magnitude Detection

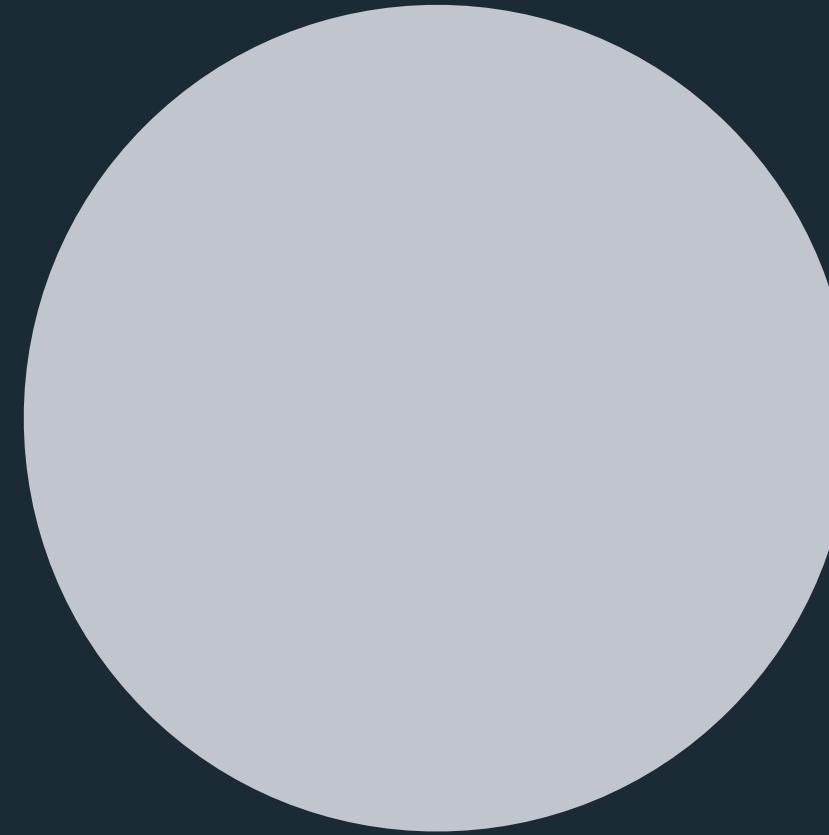
Pre-Attentive Processing

Selective Attention

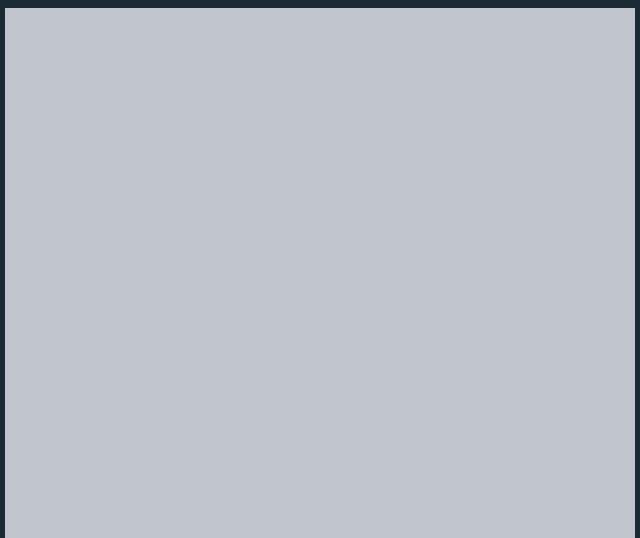
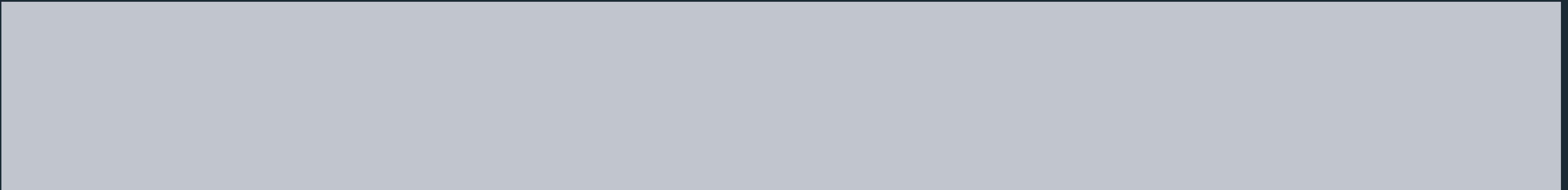
Change Blindness

Gestalt Grouping

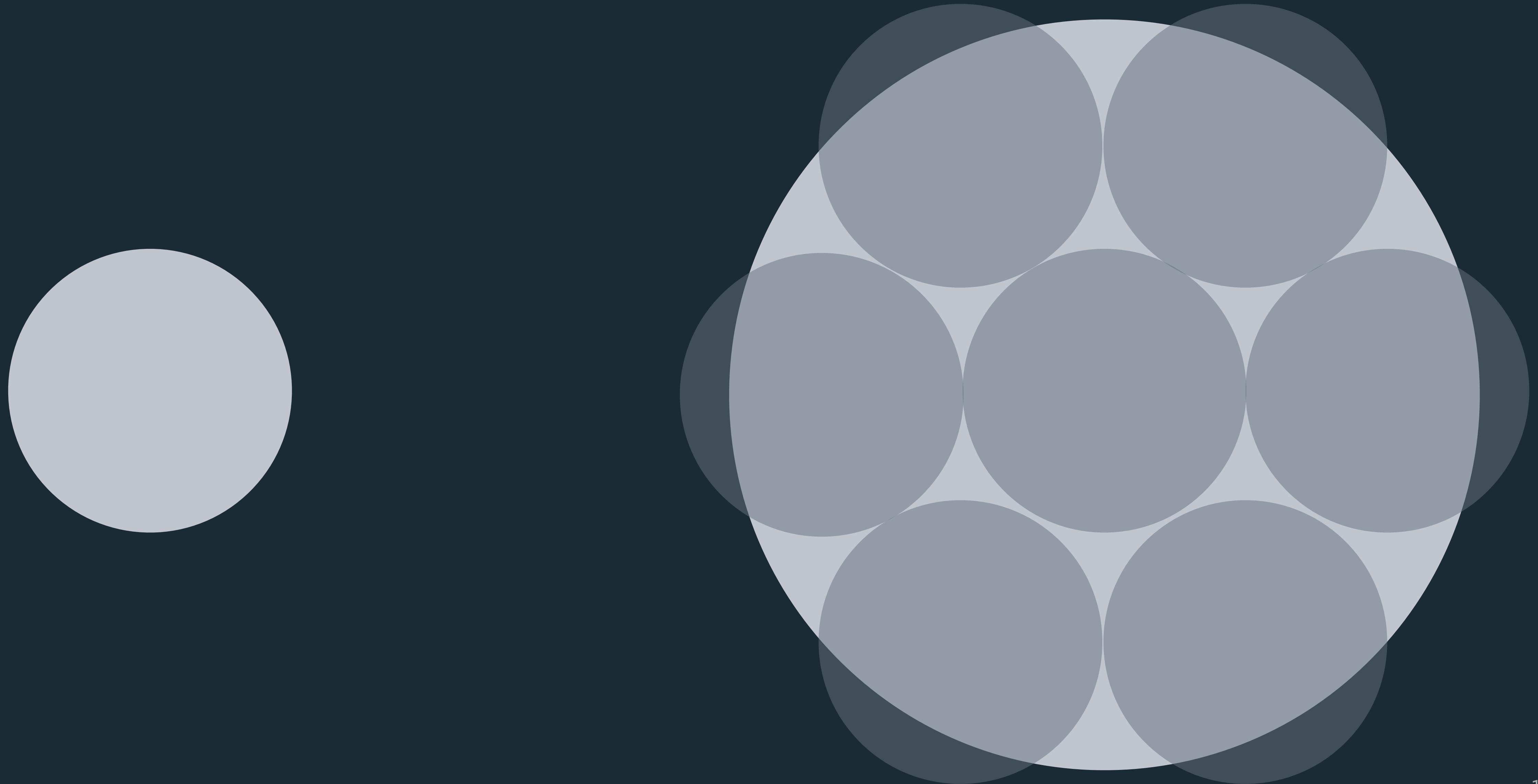
# How much larger is the area of the big circle?



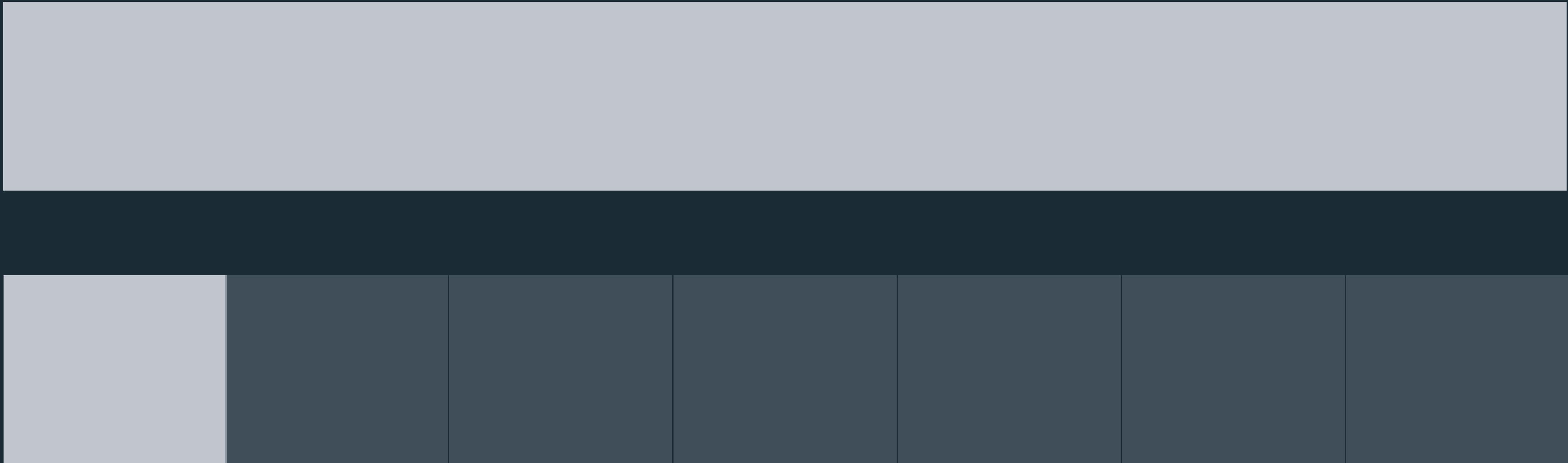
# How much longer is the big bar?



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



# How much longer is the big bar?



# Stevens' Power Law



$$S = IP^p$$

Physical Intensity

Perceived Sensation

Exponent  
(Determined Empirically)

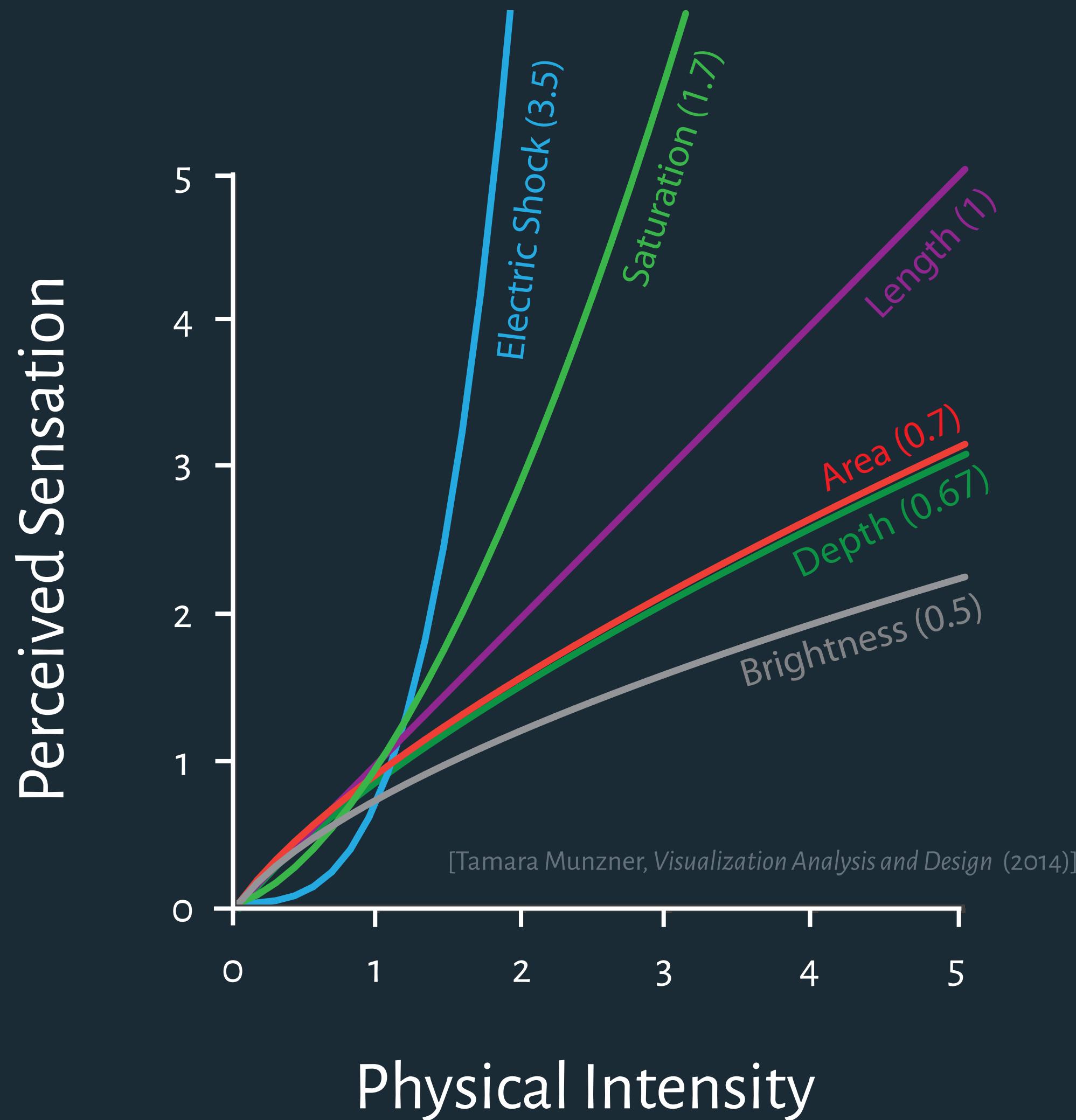
$p < 1$  = underestimation

$p > 1$  = overestimation

Predicts bias, not necessarily accuracy!

**S. S. Stevens** (1906–1972)

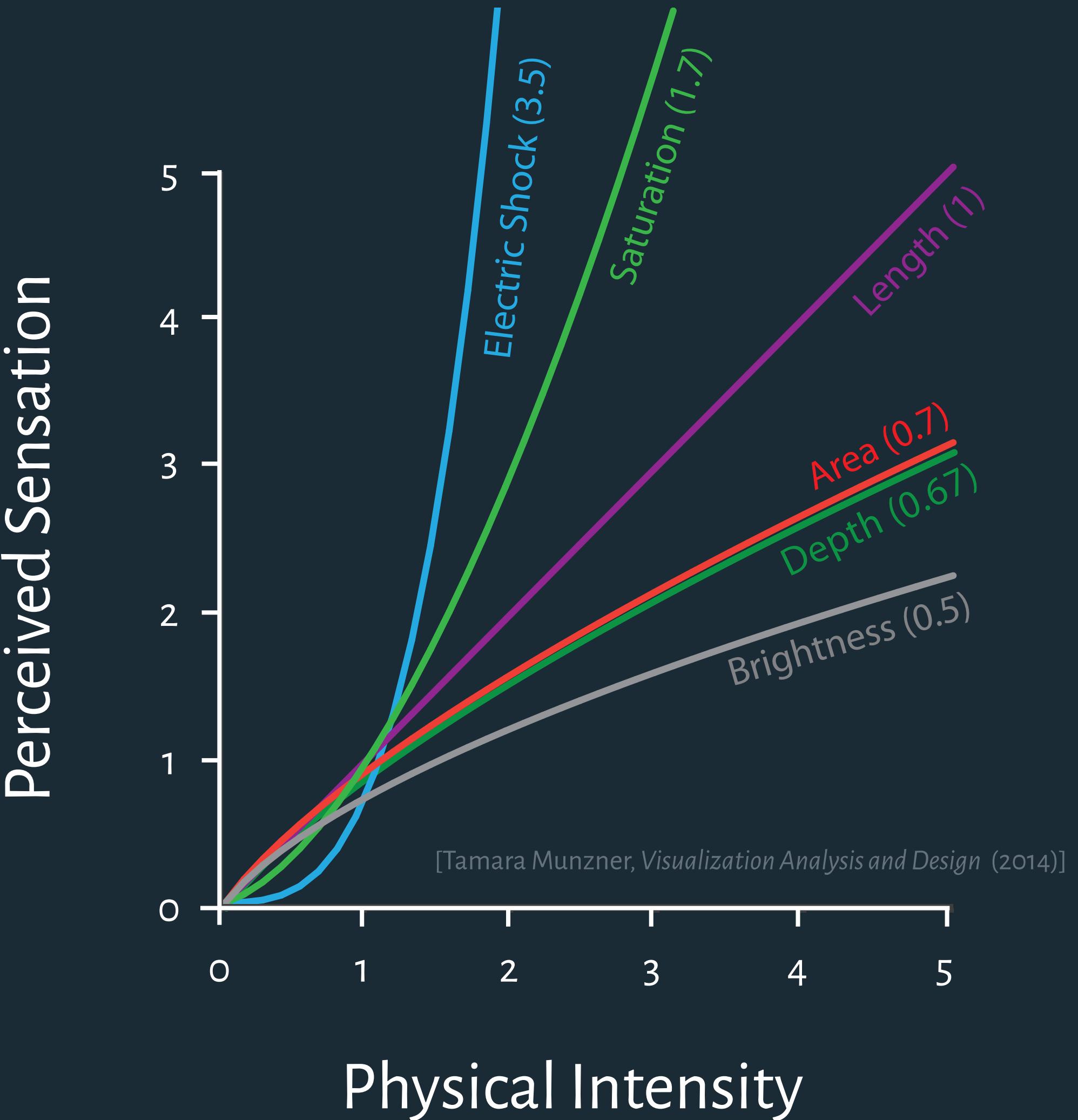
American psychologist, founded Harvard's Psychoacoustics Lab.



# Stevens' Power Law

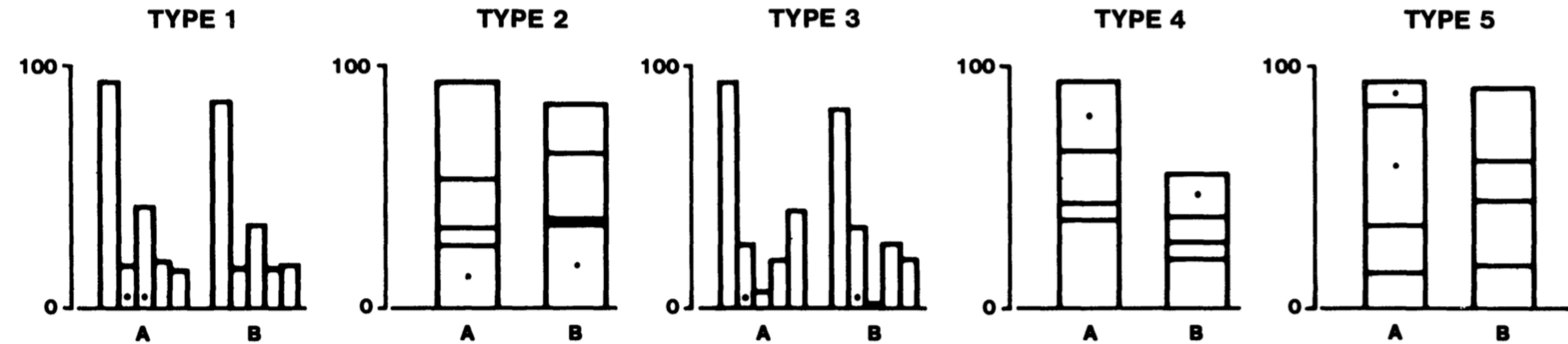
$$S = I^p$$

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



# Graphical Perception Studies

[Cleveland & McGill 1984]

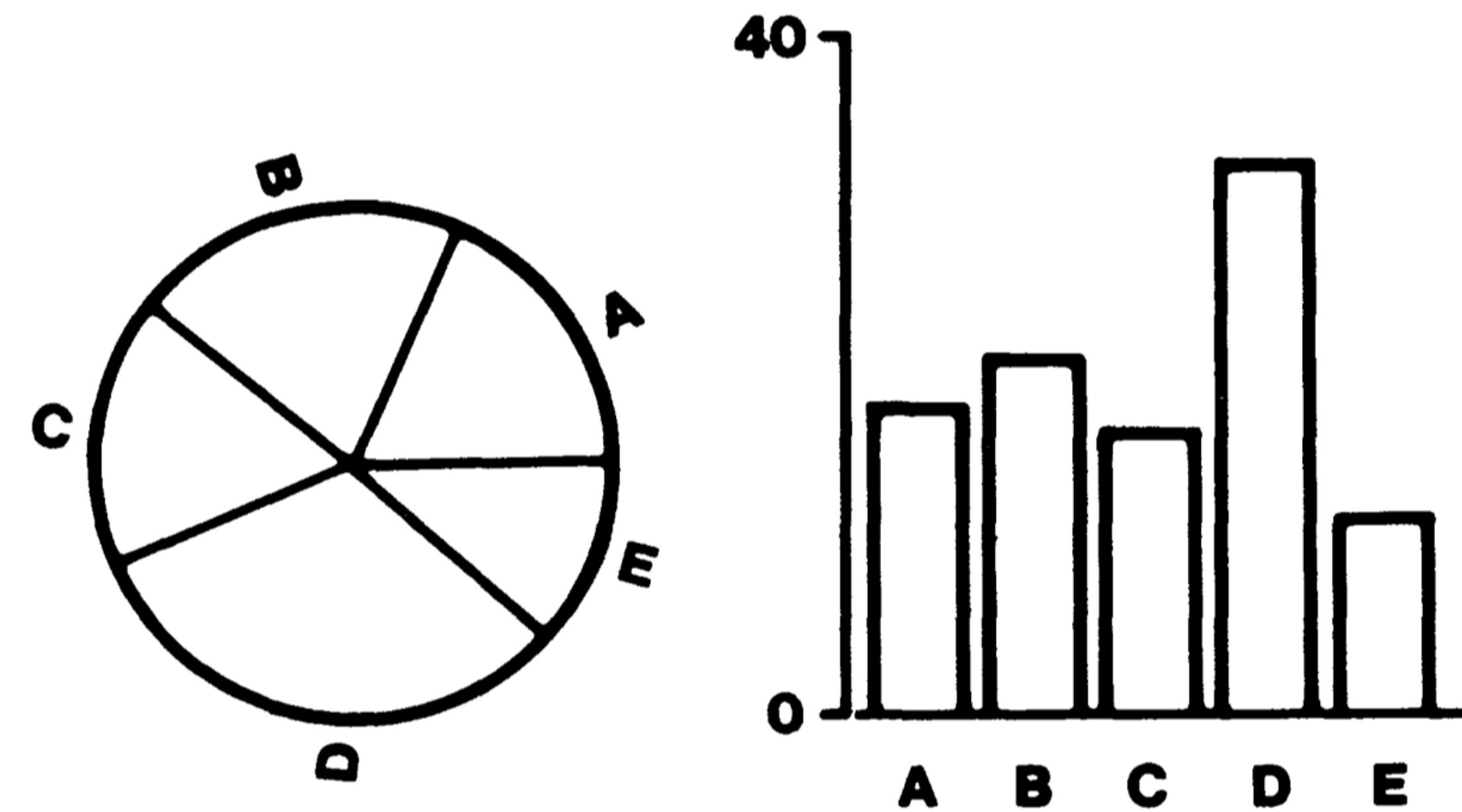


*Figure 4. Graphs from position-length experiment.*

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

# Graphical Perception Studies

[Cleveland & McGill 1984]



*Figure 3. Graphs from position–angle experiment.*

*What proportion is largest segment of the whole?*

# Graphical Perception Studies

[Cleveland & McGill 1984]

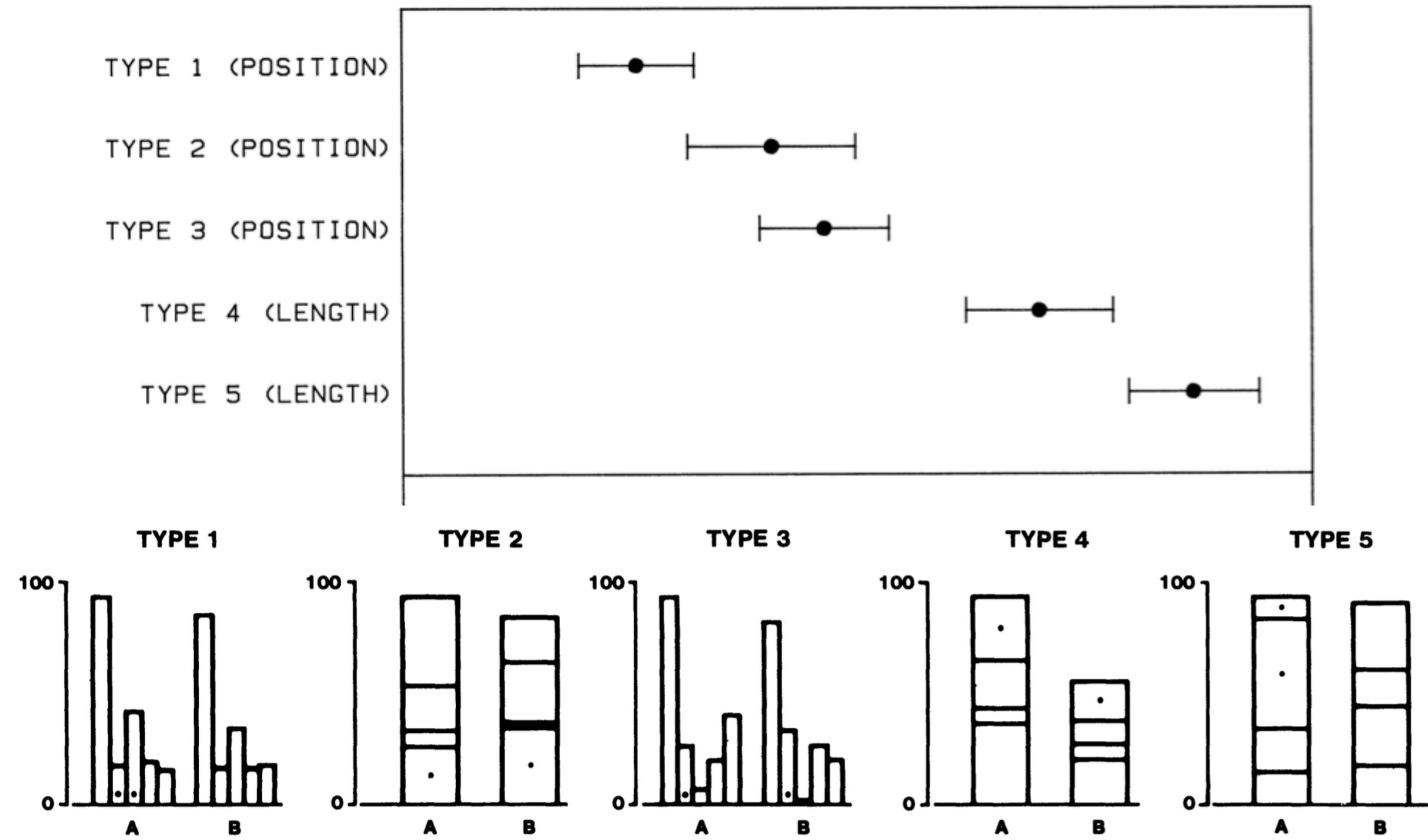
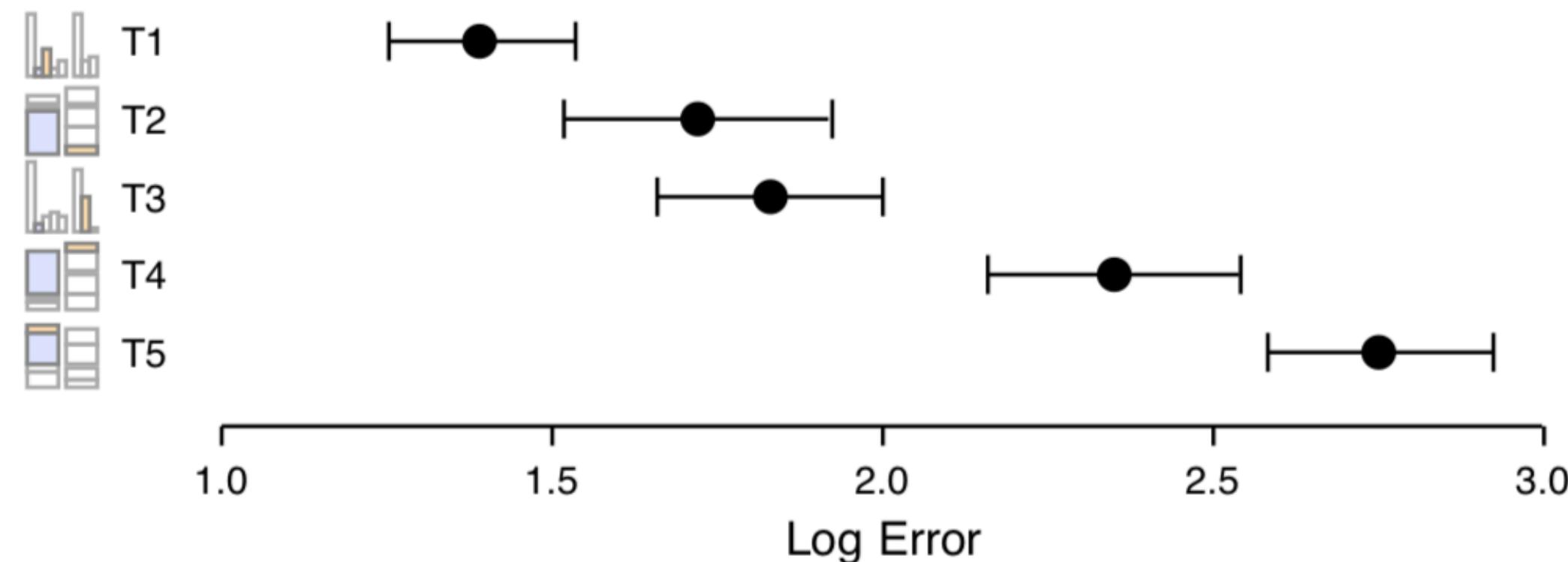


Figure 4. Graphs from position-length experiment.

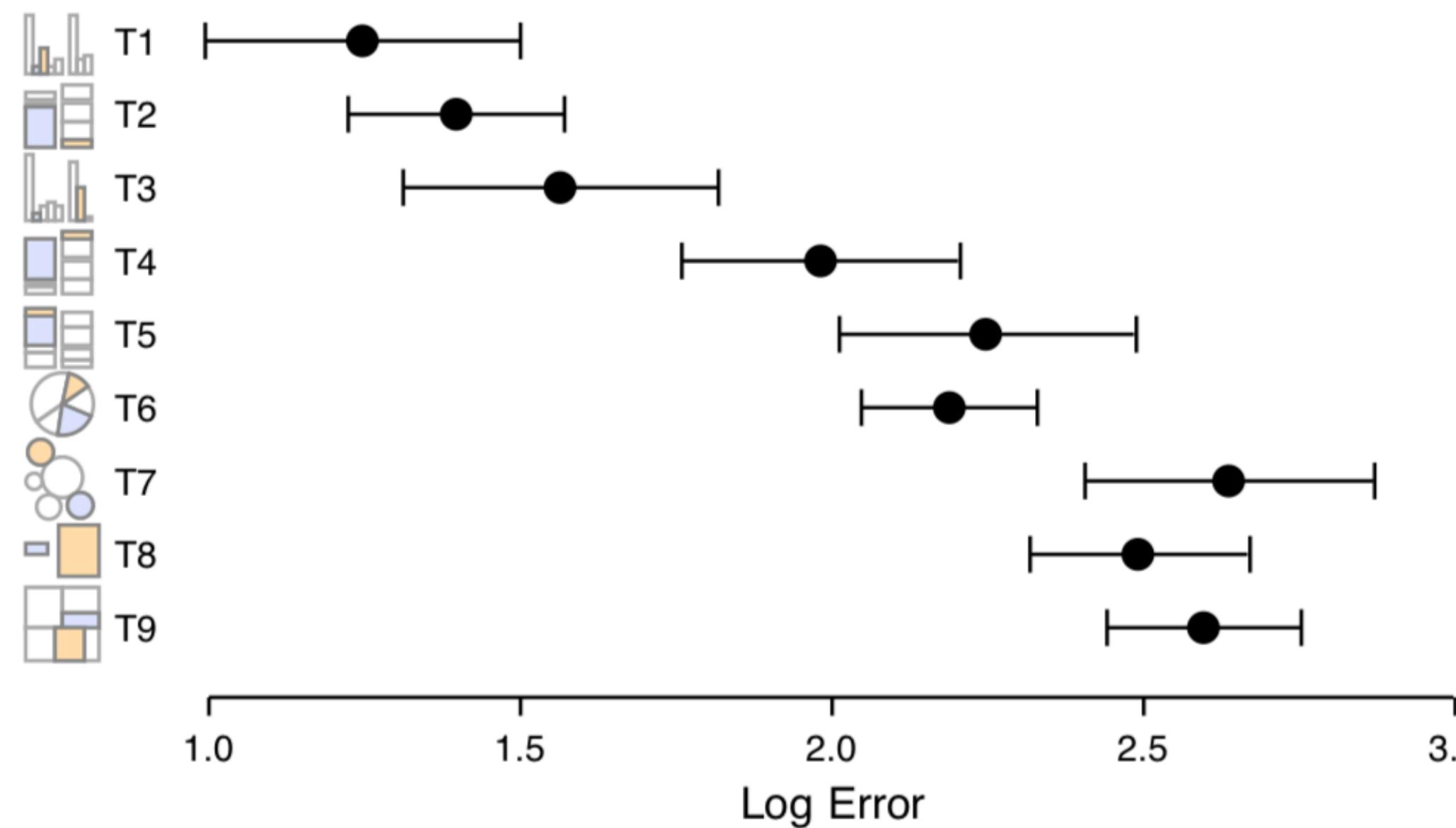
# Graphical Perception Studies

[Bostock & Heer 2010]

Cleveland & McGill's Results



Crowdsourced Results



Signal Detection

Magnitude Detection

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

Signal Detection

Magnitude Detection

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

# How many 3's?

1281768756138976546984506985604982826762  
9809858458224509856458945098450980943585  
90910302099059595772564675050678904567  
8845789809821677654876364908560912949686

# How many 3's?

1281768756138976546984506985604982826762  
9809858458224509856458945098450980943585  
90910302099059595772564675050678904567  
8845789809821677654876364908560912949686

# 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).

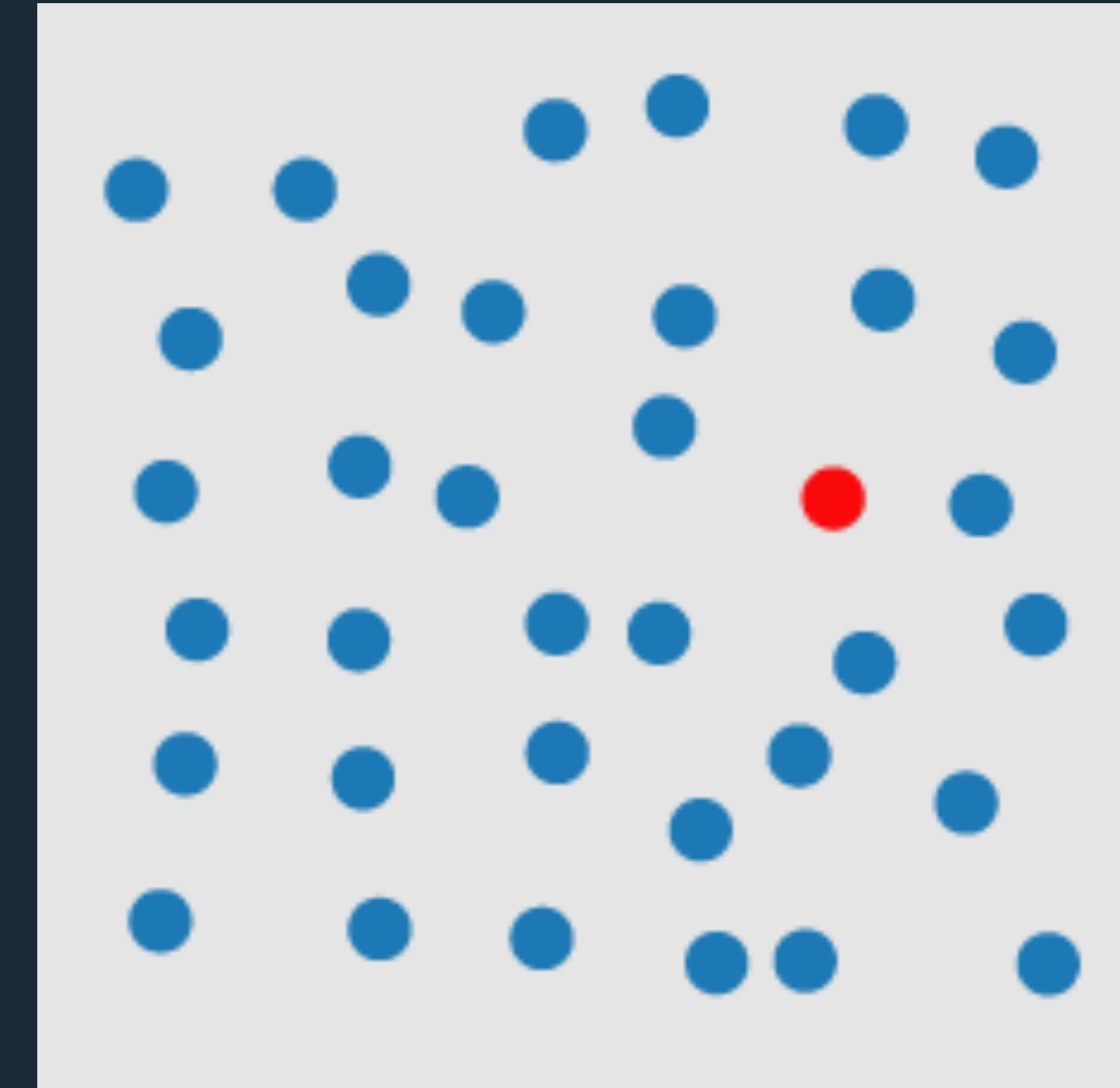
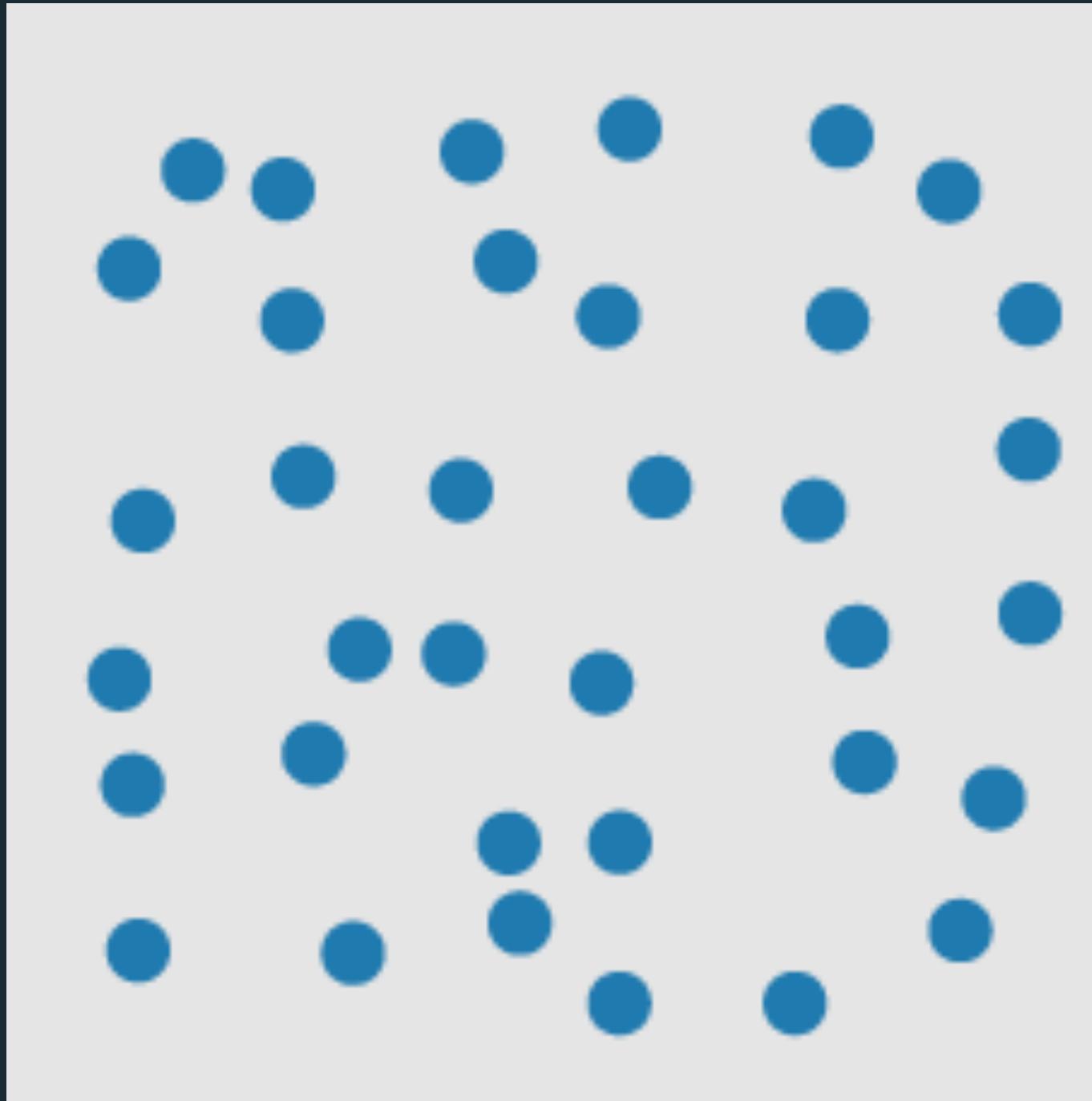
**Attentive:** Takes some deliberate effort to perceive differences.

# 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]

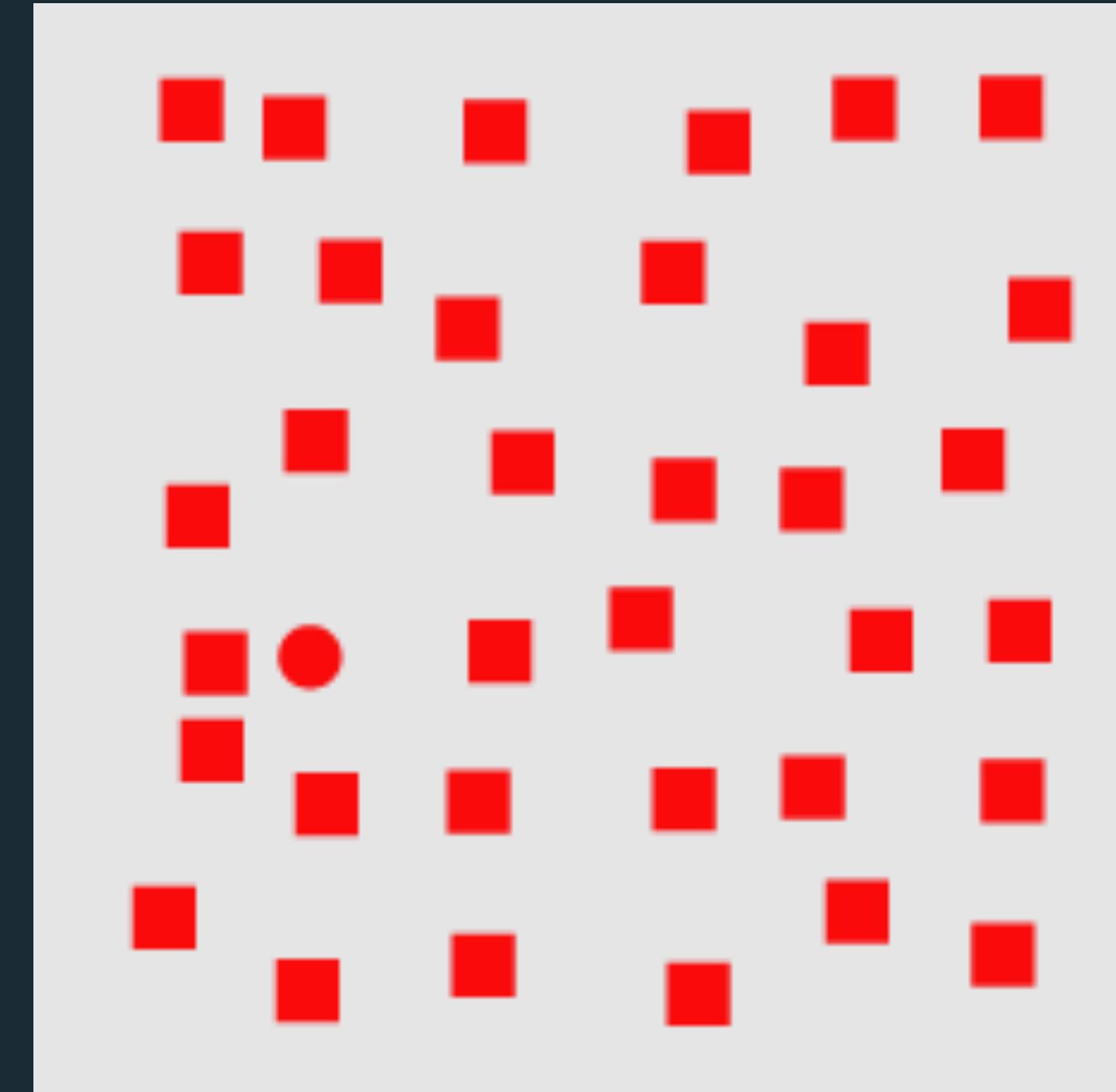
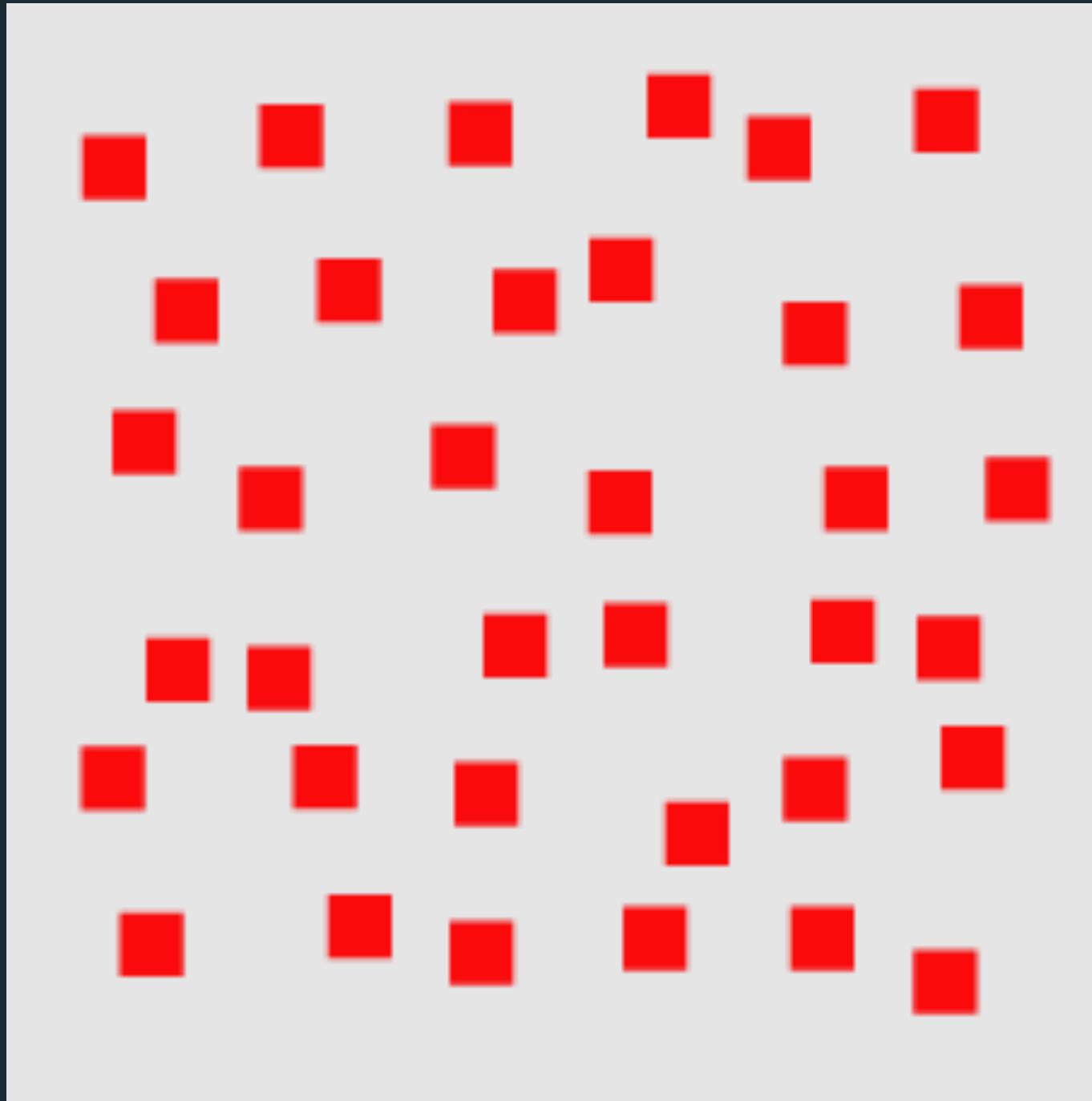
# Pre-Attentive Processing

## Visual Pop-Out: Color

**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: Shape



[Healey & Enns 2012]

# Pre-Attentive Processing

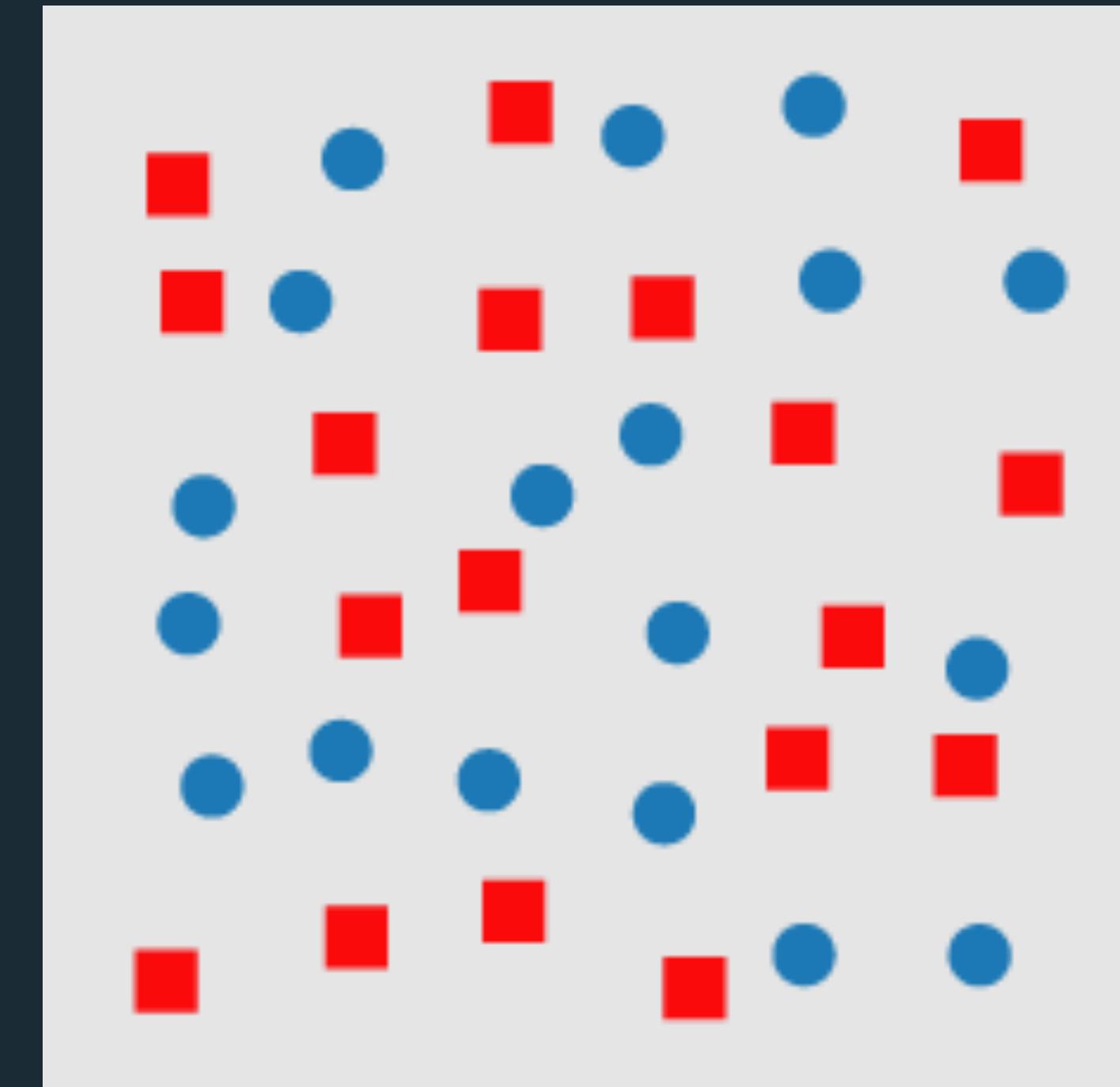
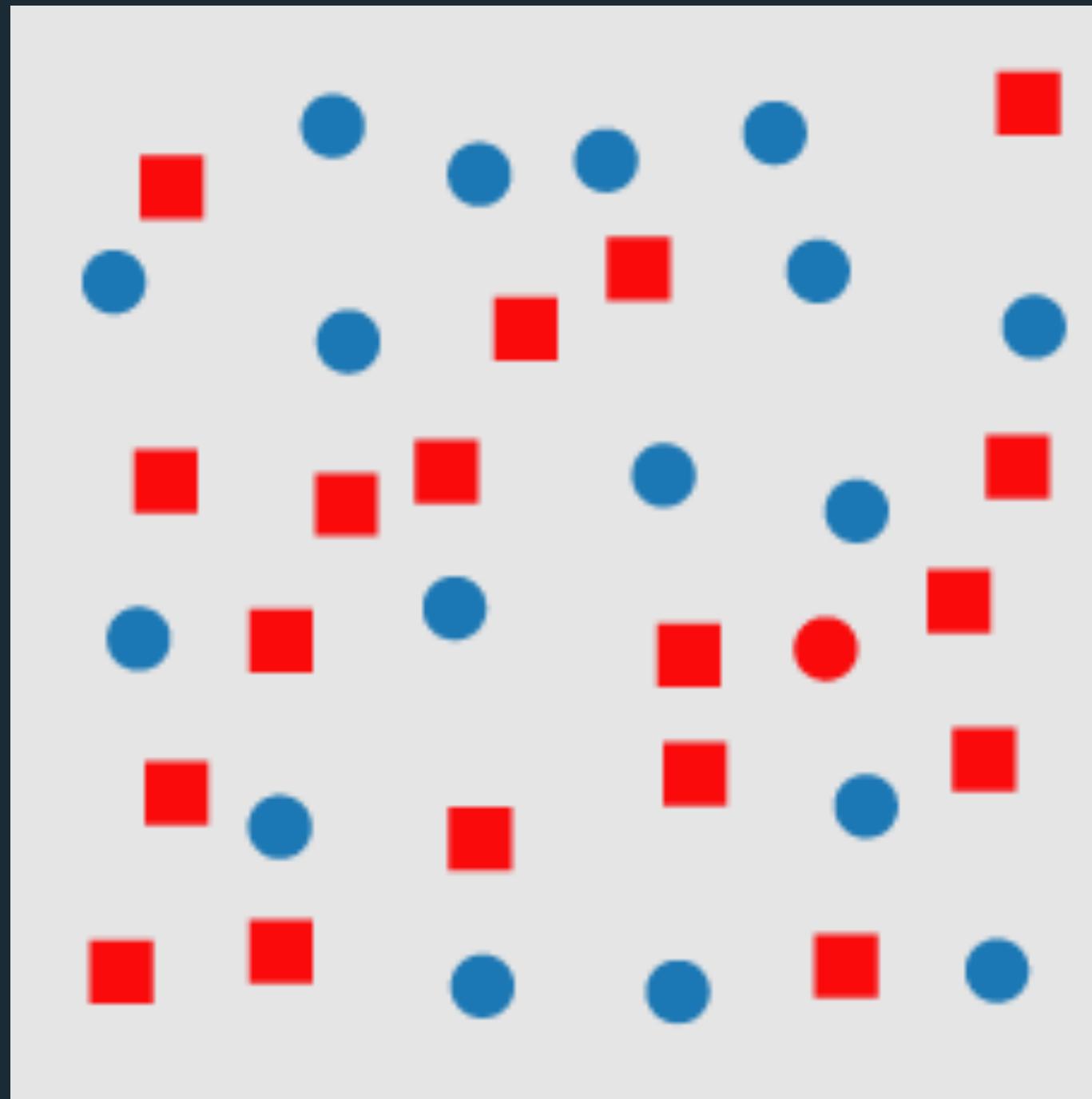
Visual Pop-Out: Color

Visual Pop-Out: Shape

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

**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:

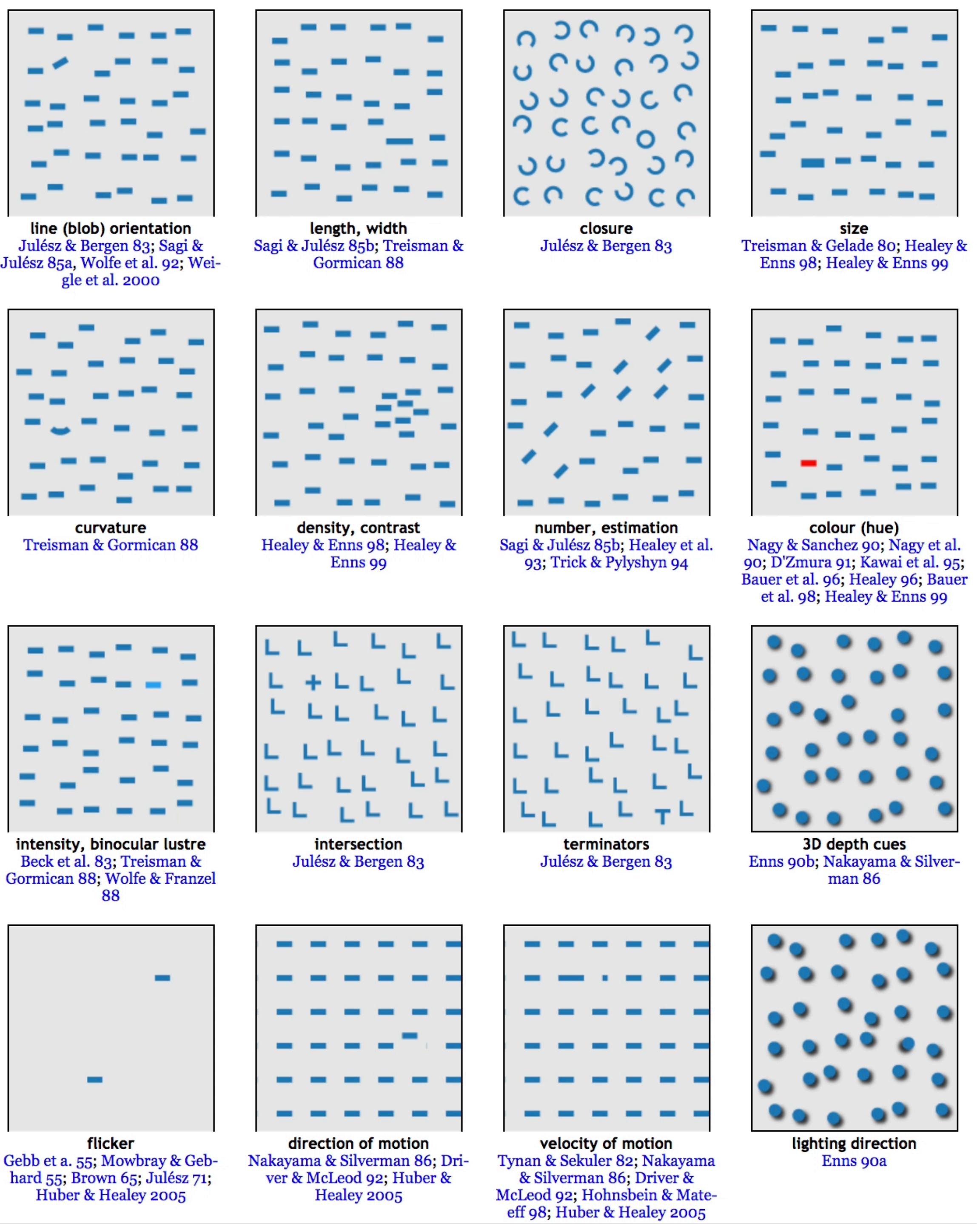
Motion & 3D disparity

Motion & color

Motion & shape

3D disparity & color

3D disparity & shape



# Pre-Attentive Processing

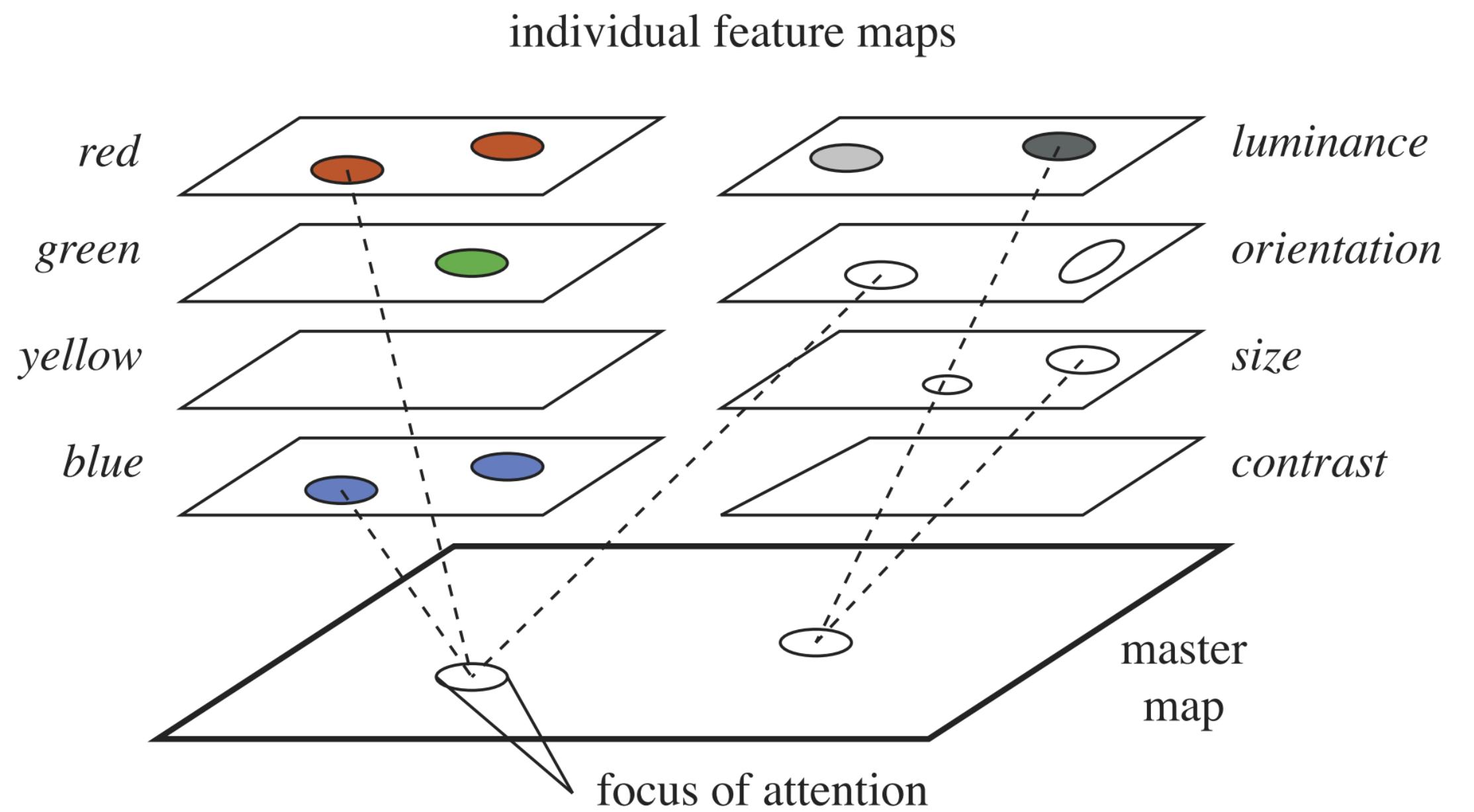
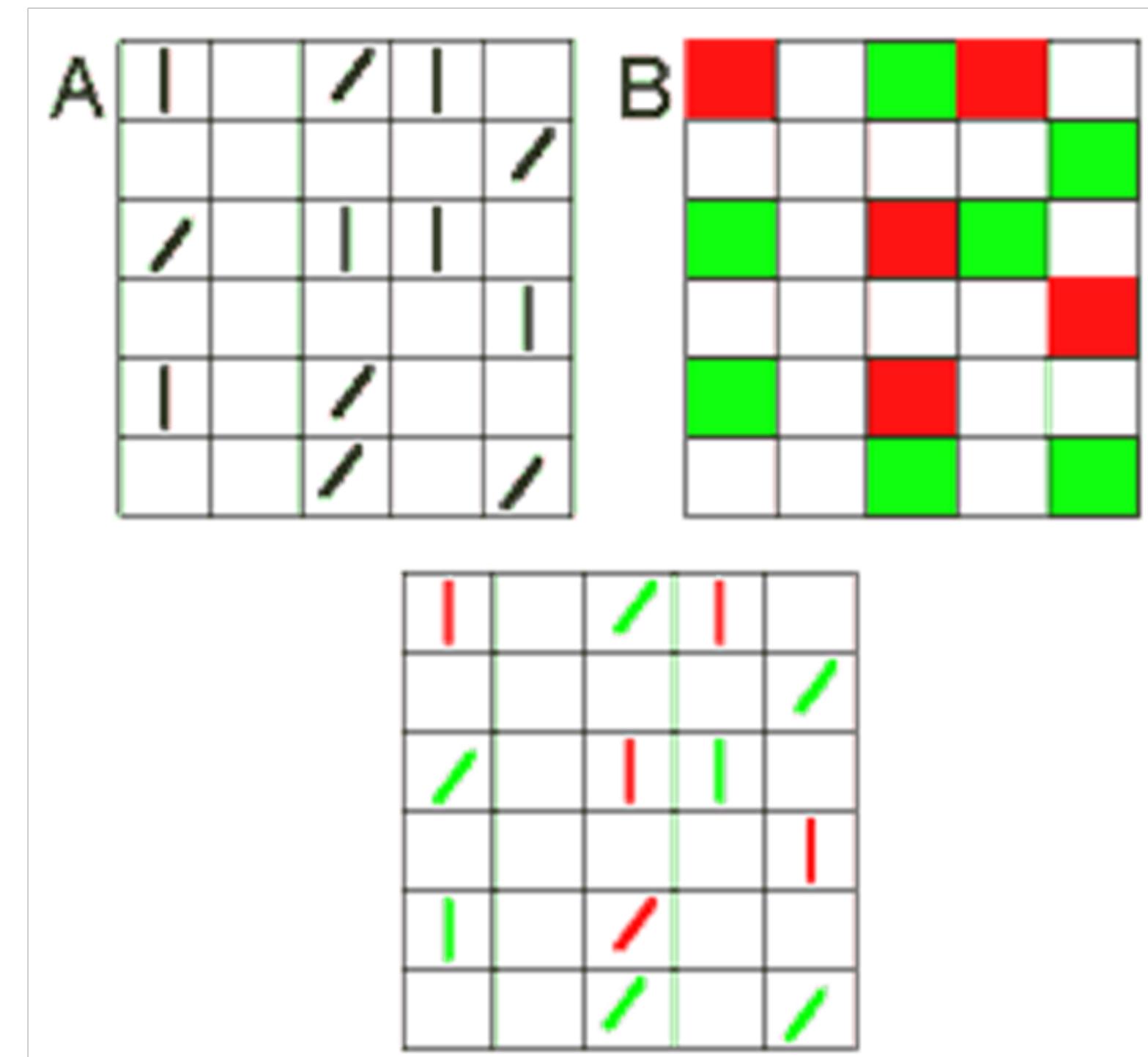


Fig. 3. Treisman's feature integration model of early vision—individual maps can be accessed in parallel to detect feature activity, but focused attention is required to combine features at a common spatial location [22].

[Healey & Enns 2012]

# Feature-Integration Theory



Feature maps for orientation & color

Signal Detection

Magnitude Detection

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

Signal Detection

Magnitude Detection

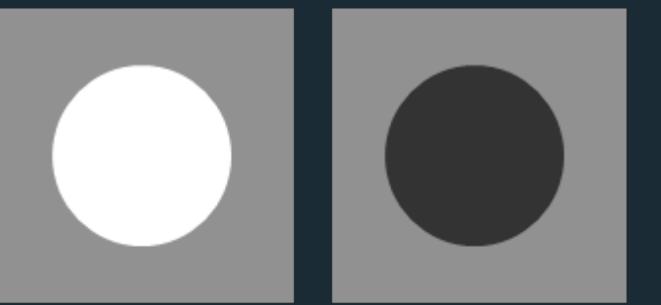
Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

# One-Dimensional: Lightness



White



White



Black



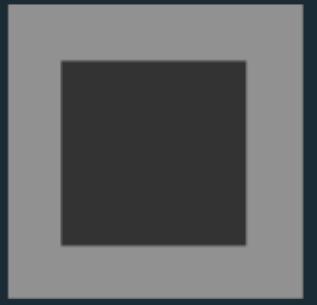
White



Black



White



Black



Black



White



White

# One-Dimensional: Shape



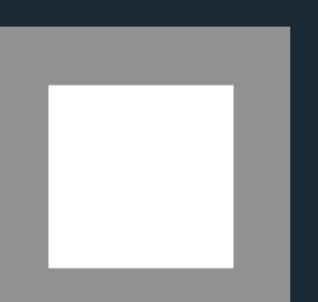
Square



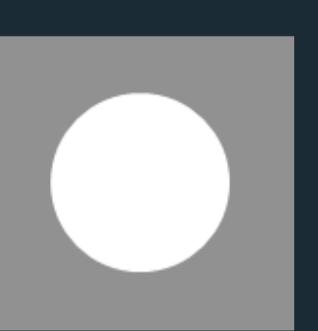
Circle



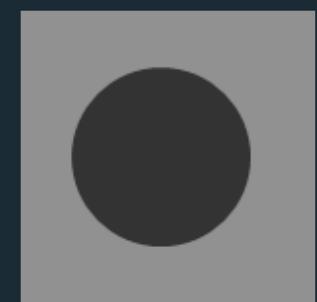
Circle



Square



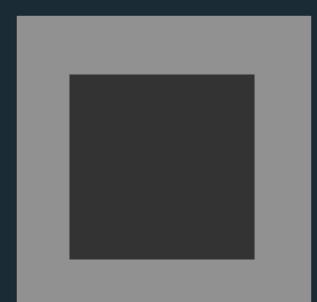
Circle



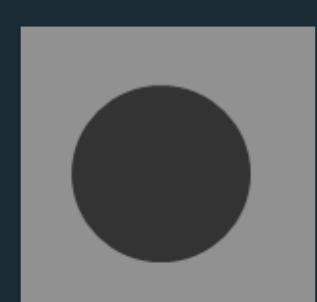
Circle



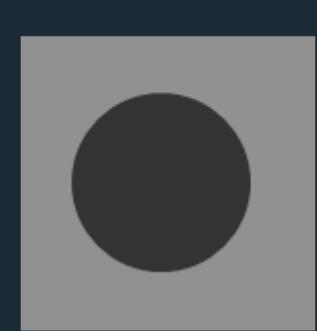
Circle



Square

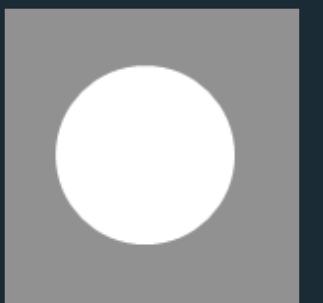


Circle



Circle

# Redundant: Shape & Lightness



White



Black



Black



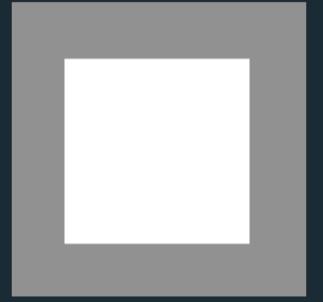
White



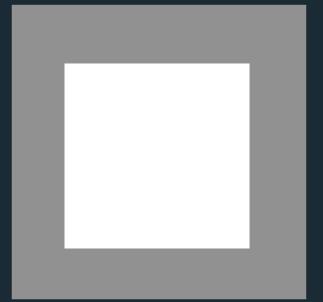
Black



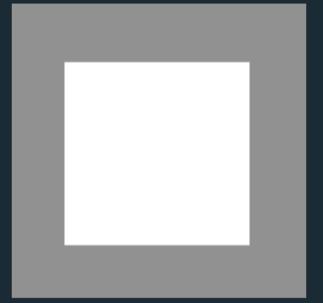
Circle



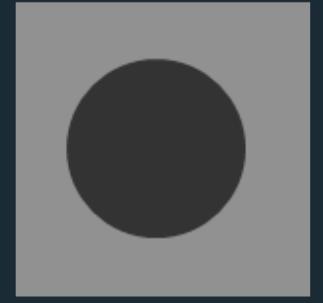
Square



Square



Square



Circle

# Orthogonal: Shape & Lightness



White



Circle

Black



Square

White



Square

Black



Circle

White



Square

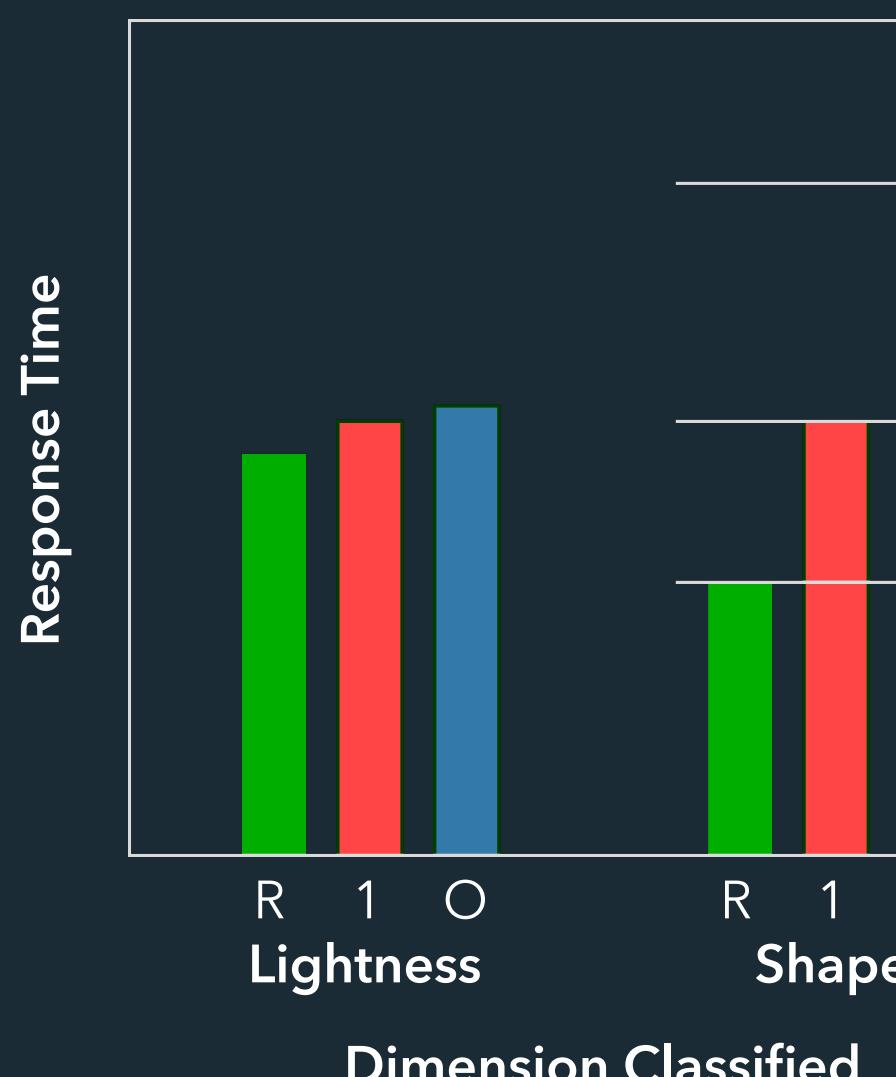
# Principles

## Redundancy Gain

Improved performance when both dimensions provide the same information.

## Filtering Interference

Difficulty in ignoring one dimension while attending to another.



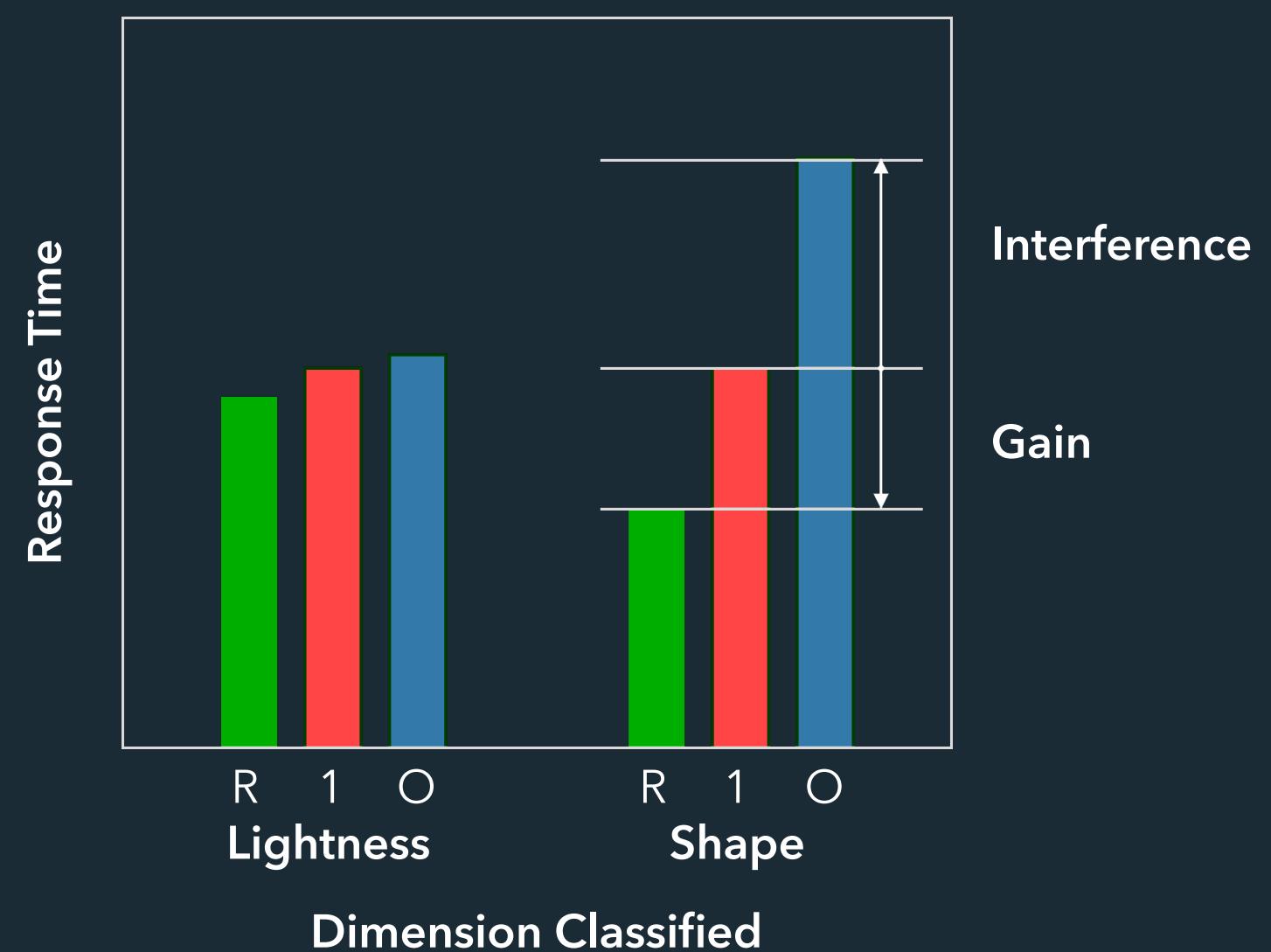
# Principles

## 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

## Integral

Filtering interference and redundancy gain.

## Separable

No interference or redundancy gain.

## Asymmetric

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

# Types of Dimensions

## Integral

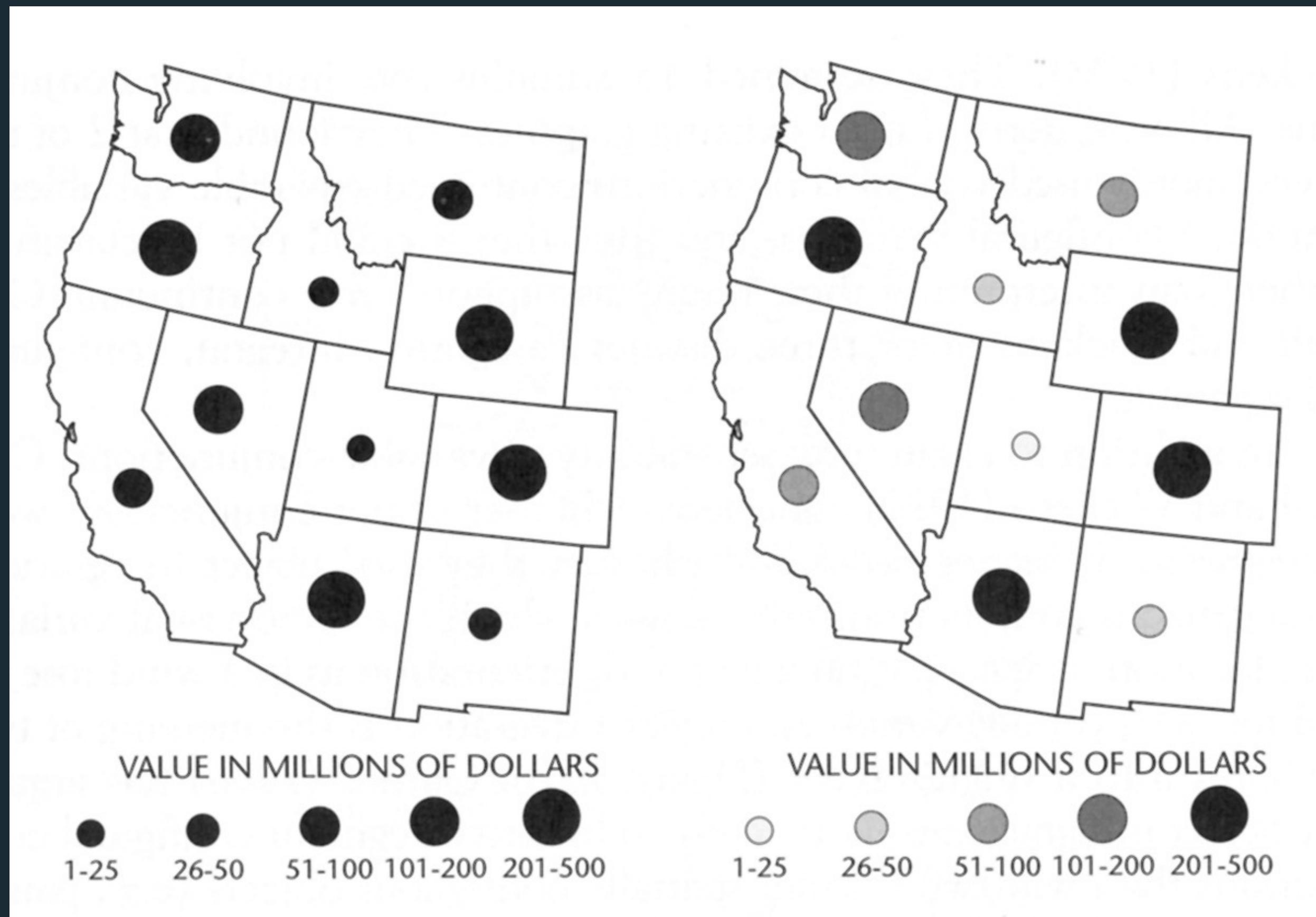
Filtering interference and redundancy gain.

## Separable

No interference or redundancy gain.

## Asymmetric

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



[MacEachren 1995]

# Types of Dimensions

## Integral

Filtering interference and redundancy gain.

## Separable

No interference or redundancy gain.

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

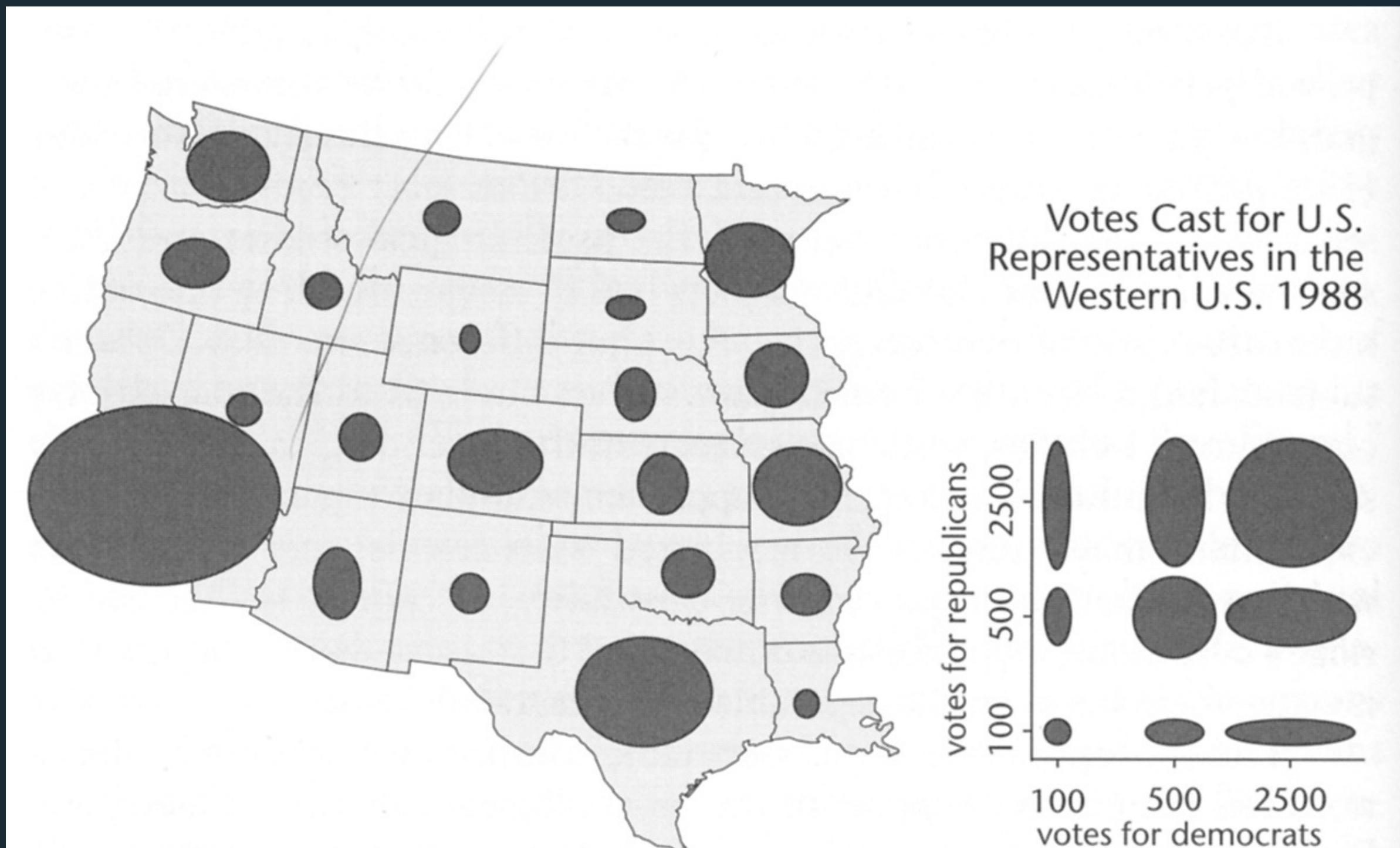


FIGURE 3.38. An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

[MacEachren 1995]

# Types of Dimensions

## Integral

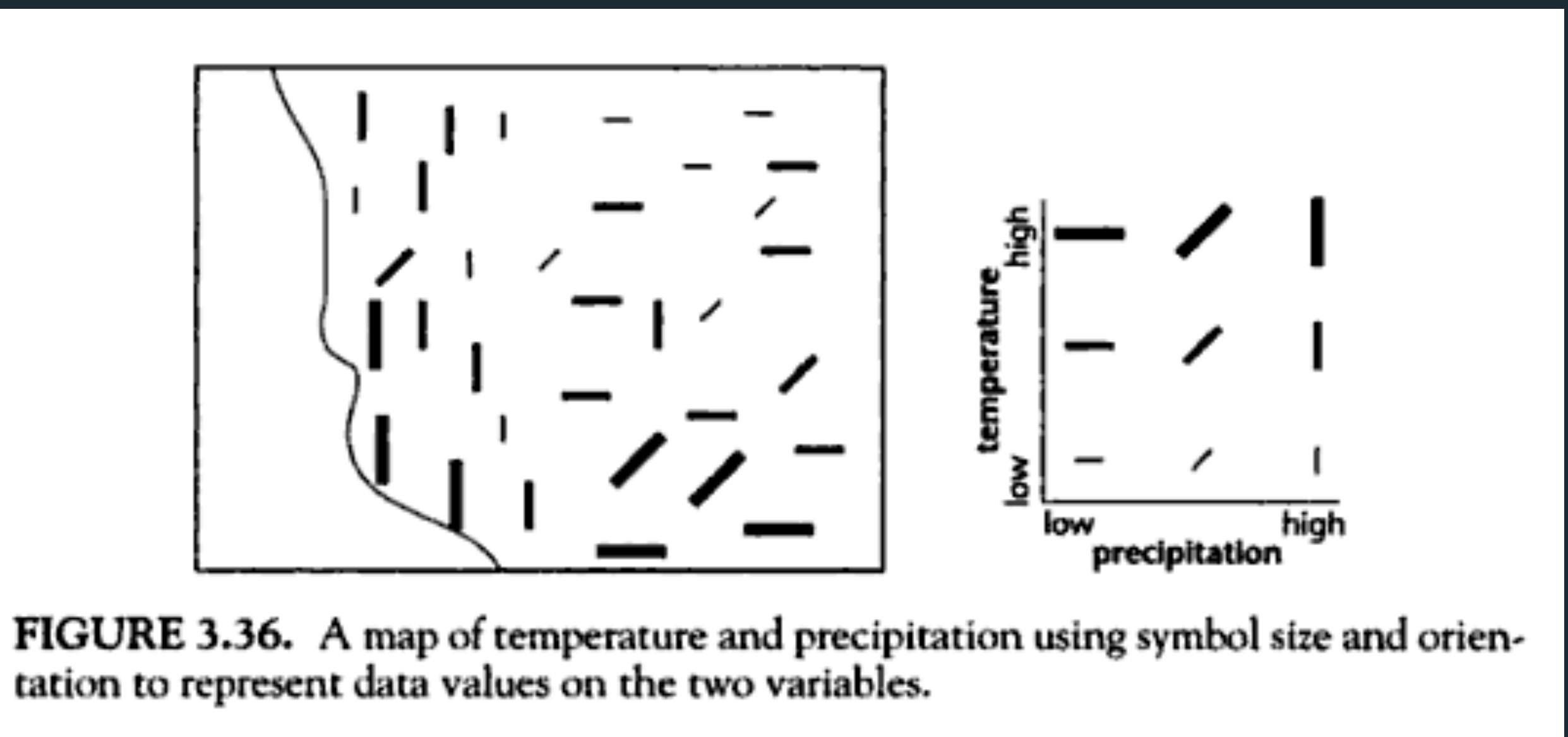
Filtering interference and redundancy gain.

## Separable

No interference or redundancy gain.

## Asymmetric

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



[MacEachren 1995]

# Types of Dimensions

## Integral

Filtering interference and redundancy gain.

## Separable

No interference or redundancy gain.

## Asymmetric

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

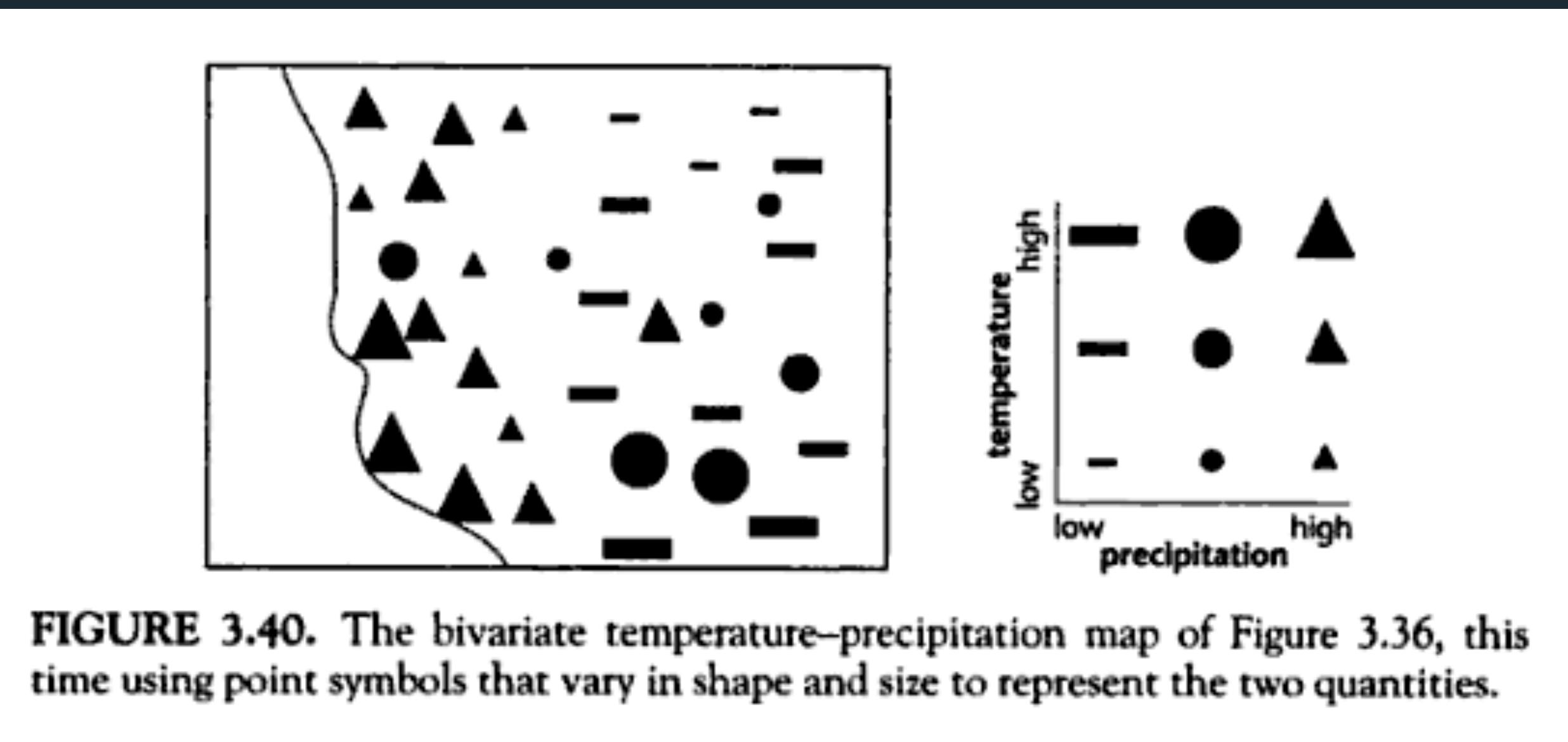


FIGURE 3.40. The bivariate temperature-precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

[MacEachren 1995]

# Types of Dimensions

## Integral

Filtering interference and redundancy gain.

blue

## Separable

No interference or redundancy gain.

yellow

## Asymmetric

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

red

green

orange

purple

# Types of Dimensions

## Integral

Filtering interference and redundancy gain.

blue

## Separable

No interference or redundancy gain.

yellow

## Asymmetric

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

red

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purple

# Types of Dimensions

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orange

purple

Signal Detection

Magnitude Detection

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping

Signal Detection

Magnitude Detection

Pre-Attentive Processing

Selective Attention

Change Blindness

Gestalt Grouping



[Resnick 2017]



[Resnick 2017]



[Resnick 2017]



[Resnick 2017]



[Resnick 2017]



[Resnick 2017]

Signal Detection

Magnitude Detection

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# Gestalt Principles

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

Figure / Ground

Proximity

Similarity

Symmetry

Connectedness

Continuity

Closure

Common Fate

# Gestalt Principles

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

## Figure / Ground

Proximity

Similarity

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Connectedness

Continuity

Closure

Common Fate



Ambiguous – vase or faces?



Unambiguous (?)

# Gestalt Principles

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

Figure / Ground

Proximity

Similarity

Symmetry

Connectedness

Continuity

Closure

Common Fate



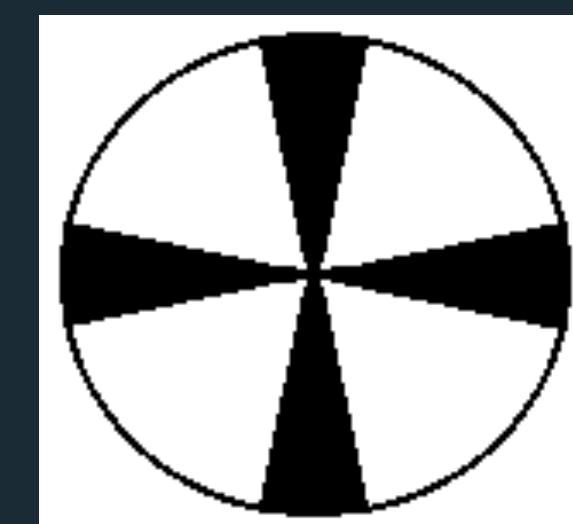
Ambiguous – vase or faces?



Unambiguous (?)



Principle of *surroundedness*.



Principle of *relative size*.

# Gestalt Principles

Figure / Ground

Proximity

Similarity

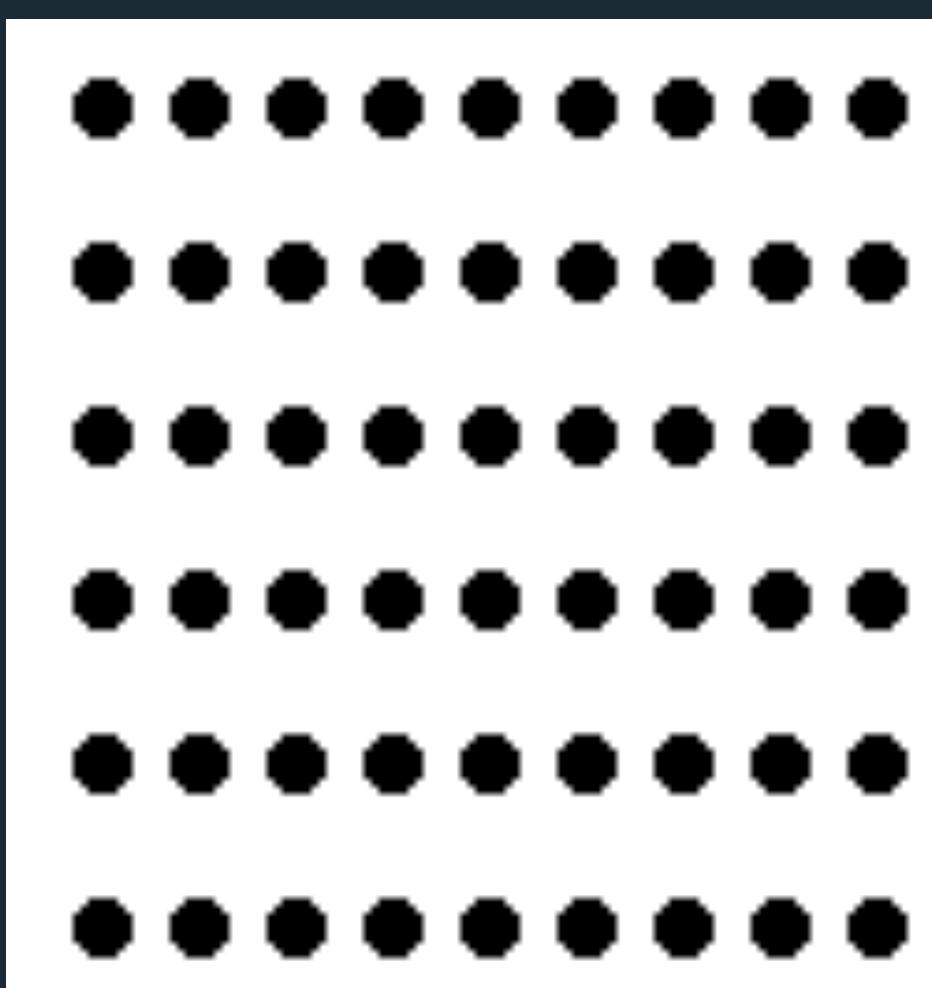
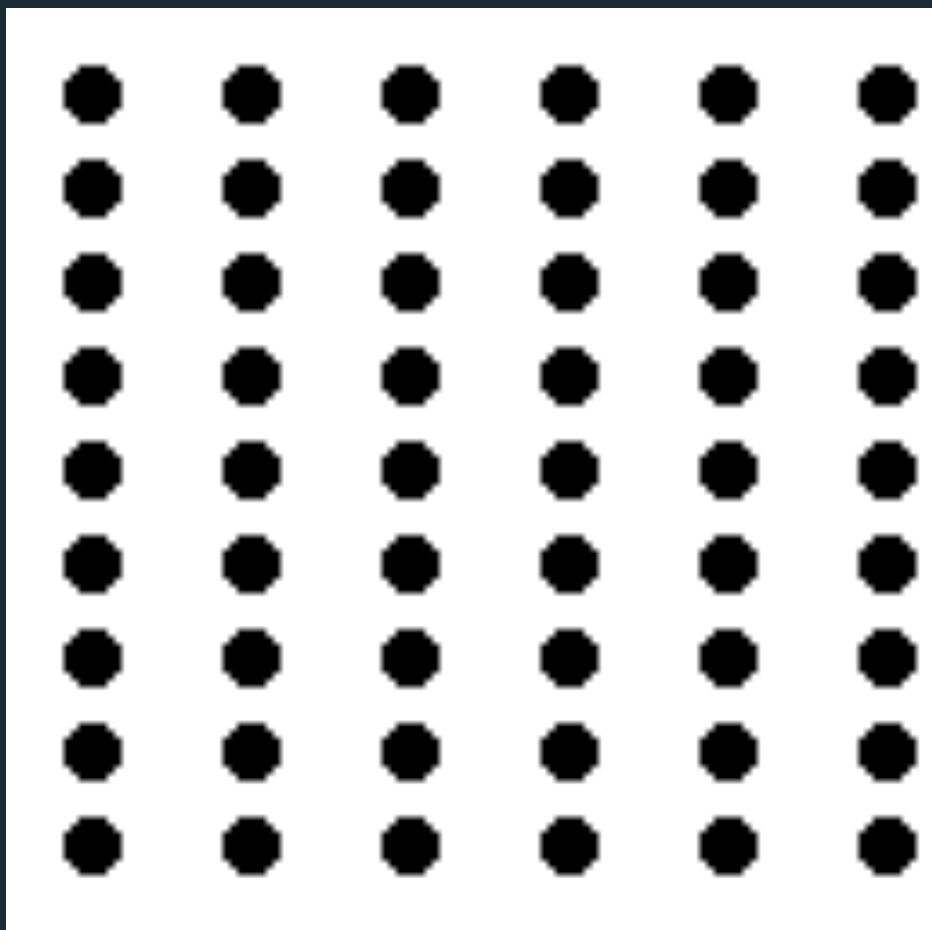
Symmetry

Connectedness

Continuity

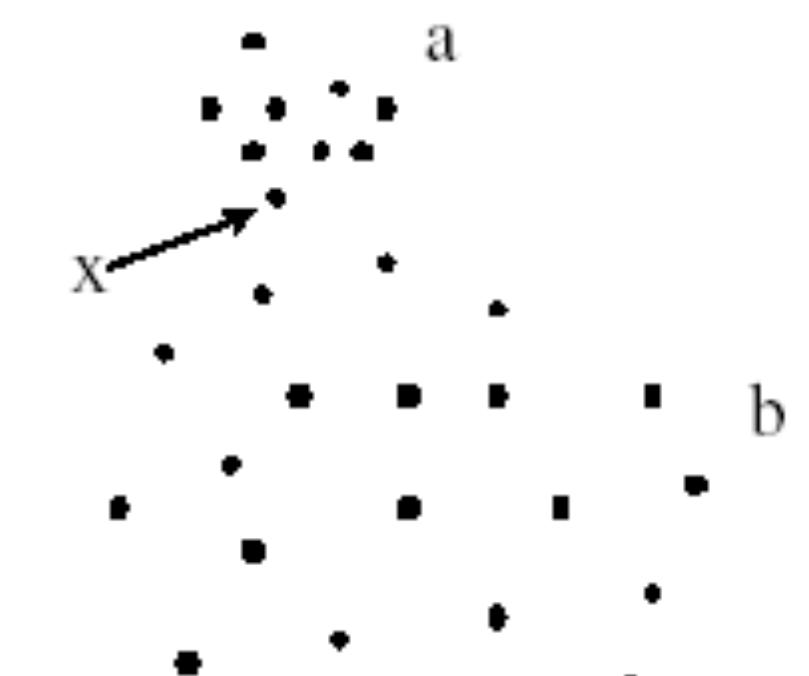
Closure

Common Fate



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

[Ware 2000]



Principle of *concentration*.

# Gestalt Principles

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

## Figure / Ground

Proximity

Similarity

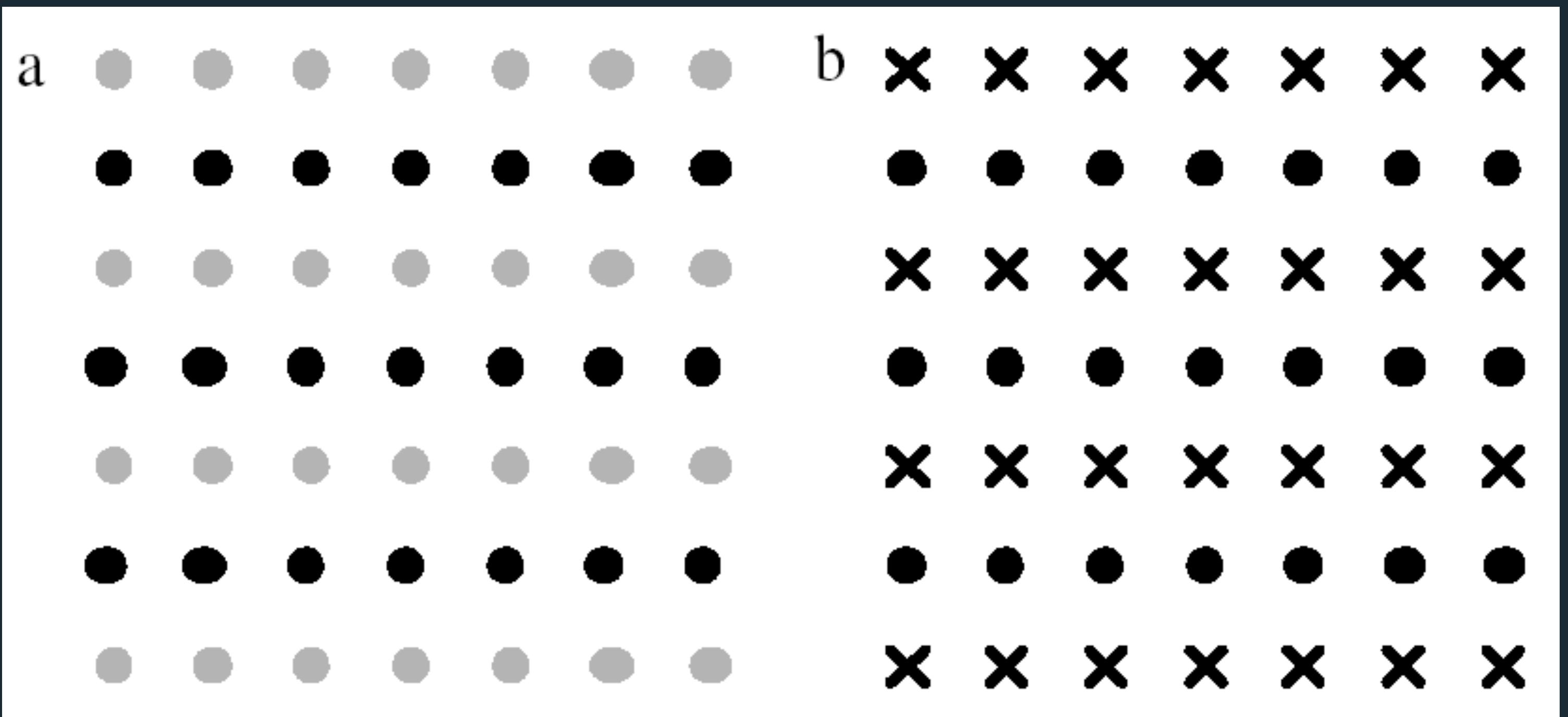
Symmetry

Connectedness

Continuity

Closure

Common Fate



Rows dominate due to similarity.

[Ware 2004]

# Gestalt Principles

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

## Figure / Ground

Proximity

Similarity

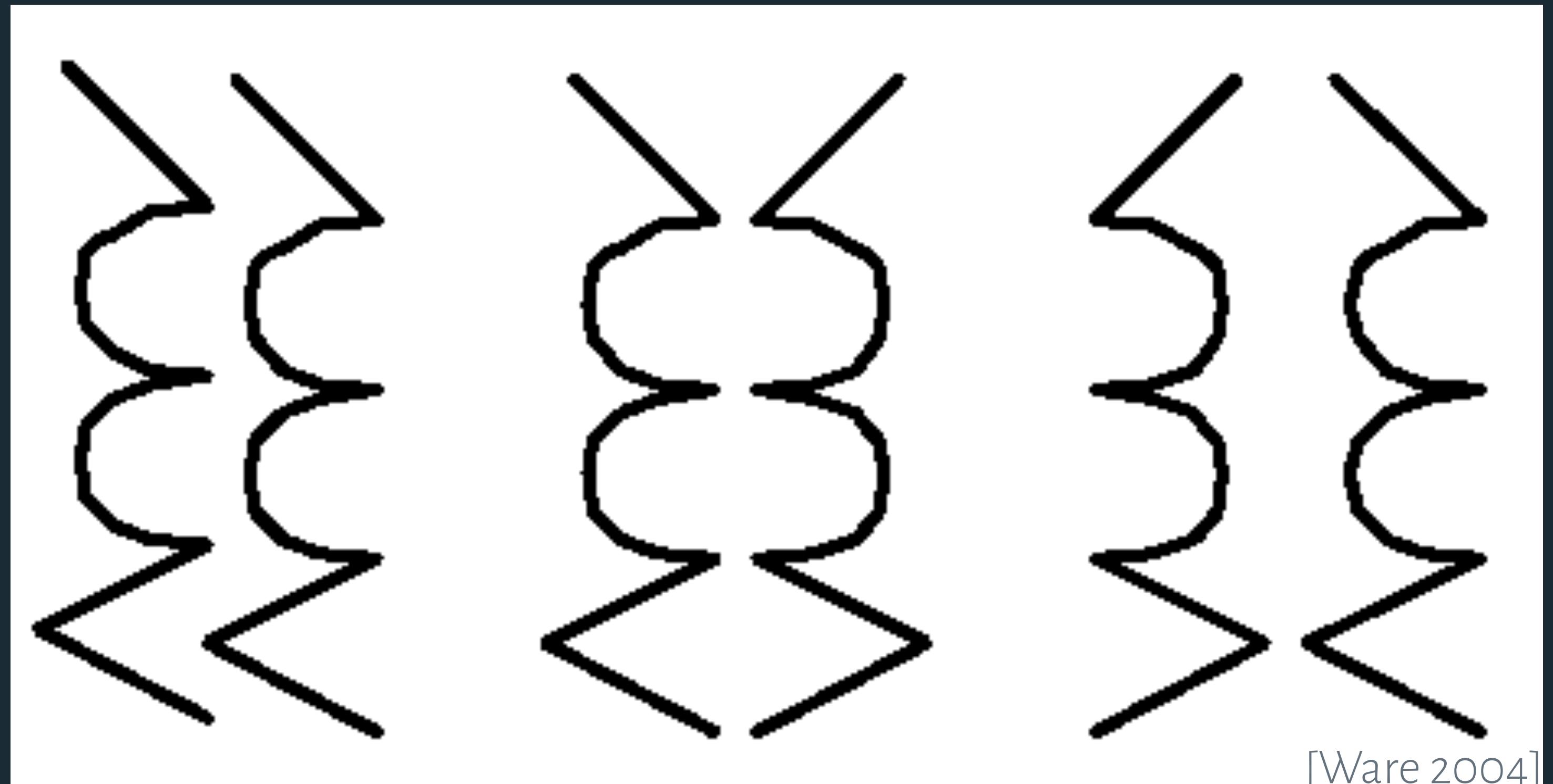
Symmetry

Connectedness

Continuity

Closure

Common Fate



[Ware 2004]

Bilateral symmetry gives the strong sense of a figure.

# Gestalt Principles

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

Figure / Ground

Proximity

Similarity

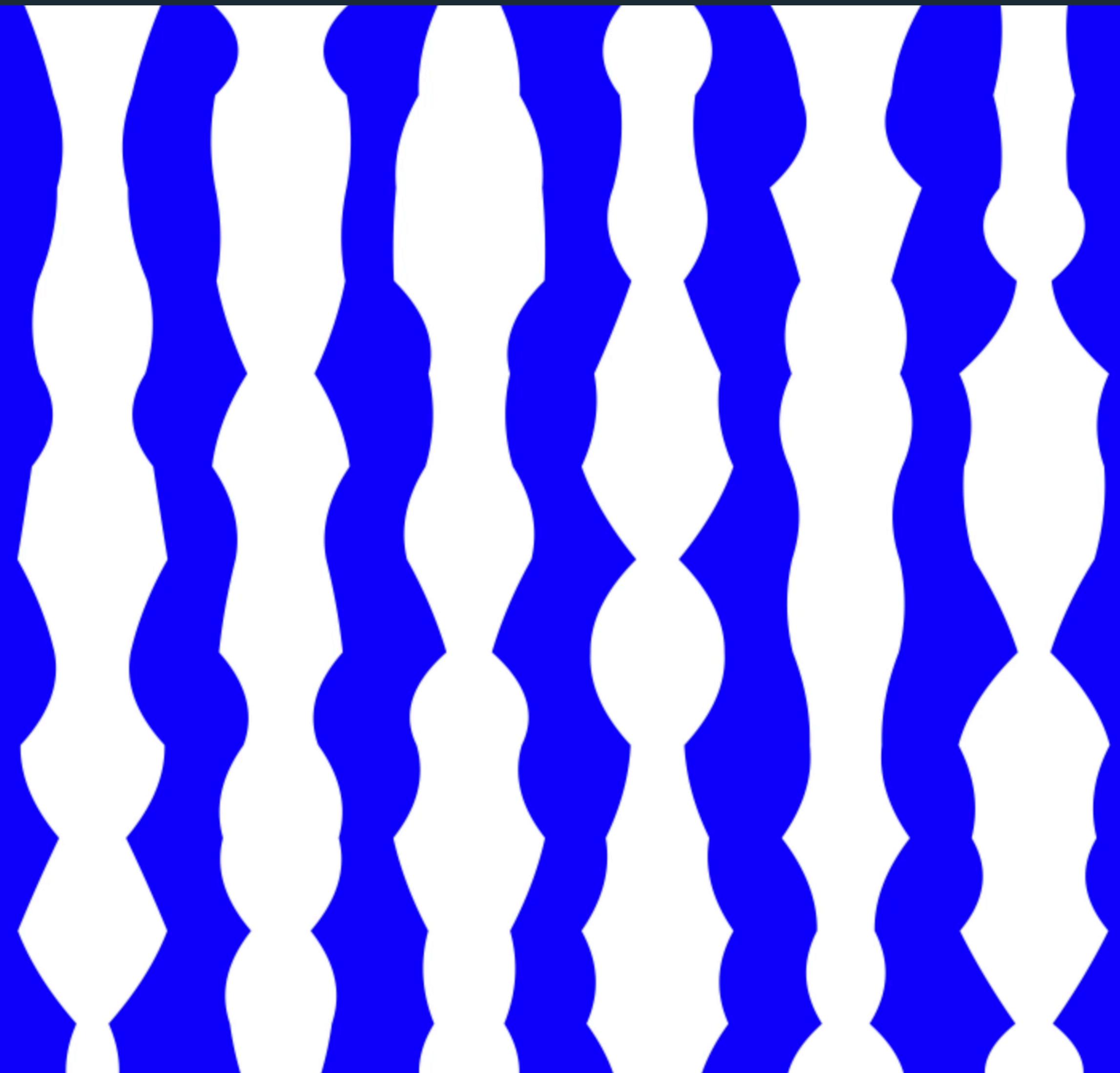
Symmetry

Connectedness

Continuity

Closure

Common Fate



# Gestalt Principles

Figure / Ground

Proximity

Similarity

Symmetry

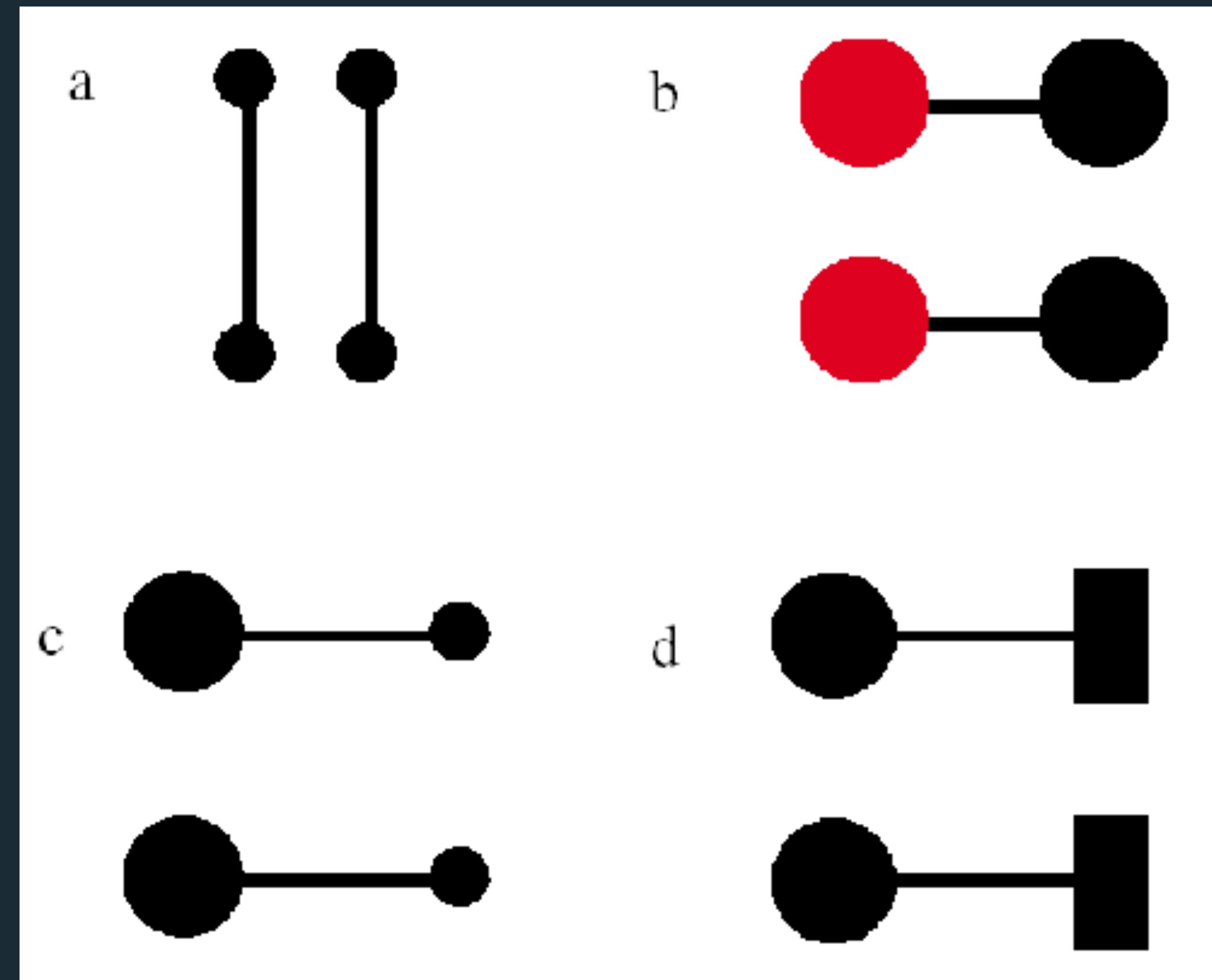
Connectedness

Continuity

Closure

Common Fate

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



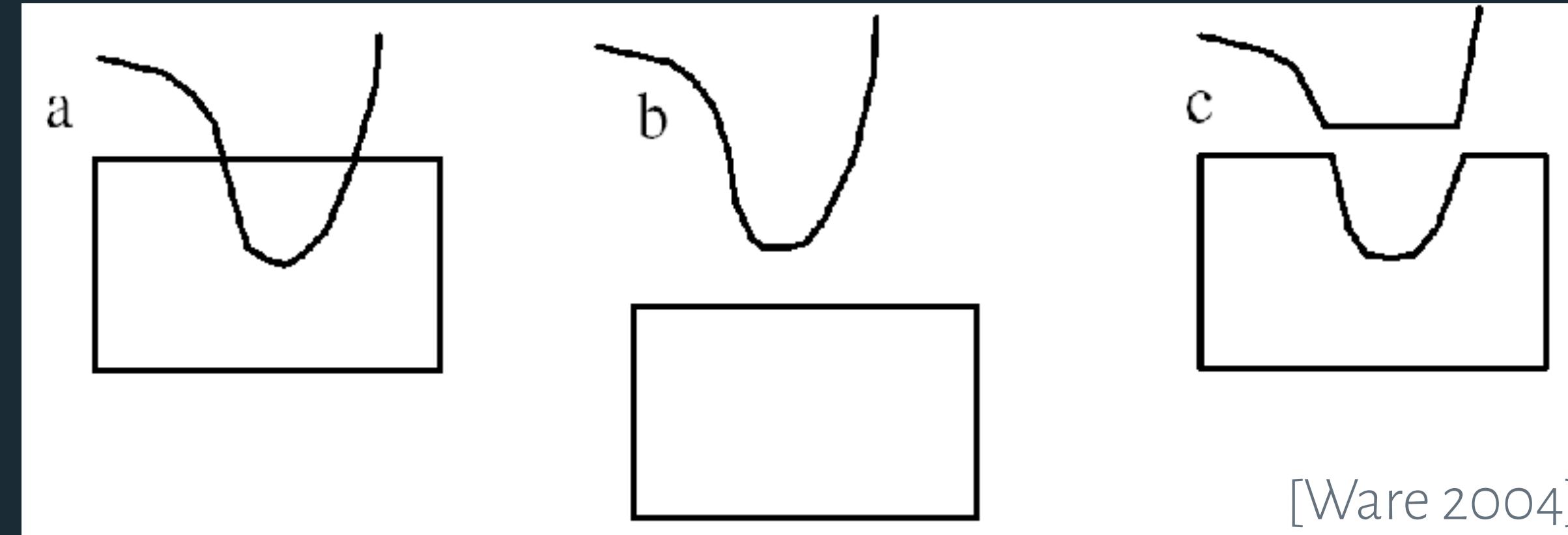
[Ware 2004]

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

# Gestalt Principles

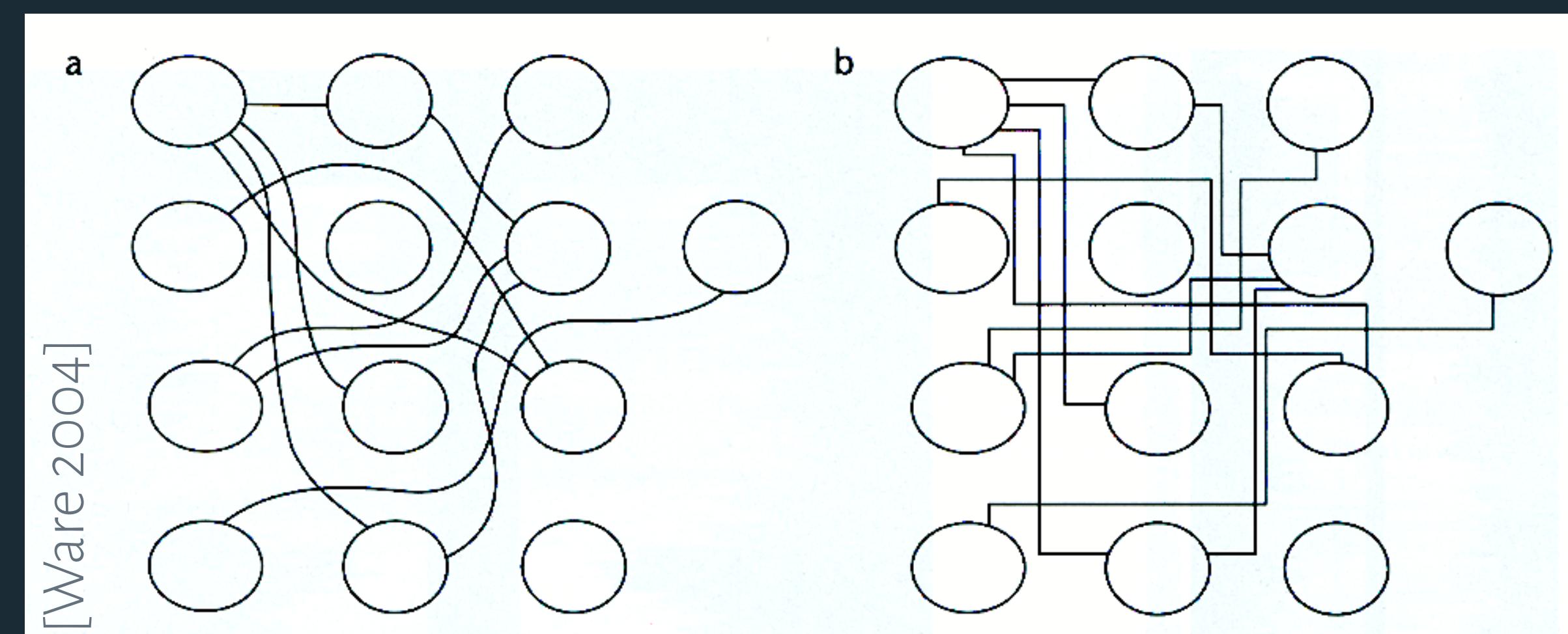
- Figure / Ground
- Proximity
- Similarity
- Symmetry
- Connectedness
- Continuity
- Closure
- Common Fate

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



[Ware 2004]

We prefer smooth, not abrupt, changes.



[Ware 2004]

Connections are clearer with smooth contours.

# Gestalt Principles

Figure / Ground

Proximity

Similarity

Symmetry

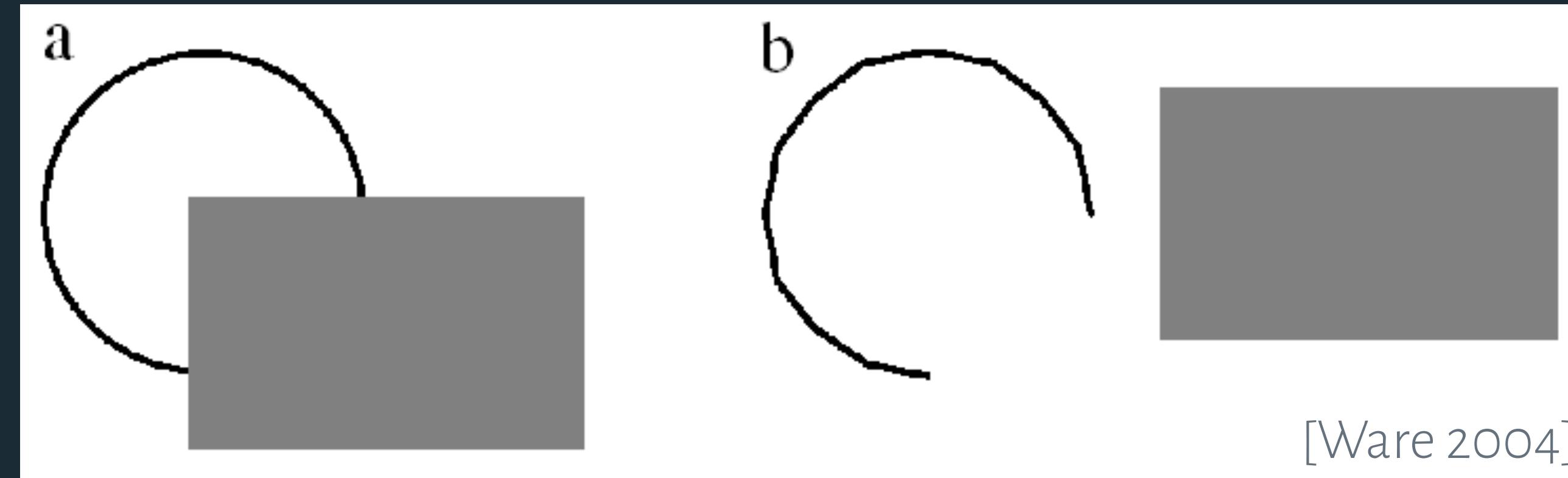
Connectedness

Continuity

Closure

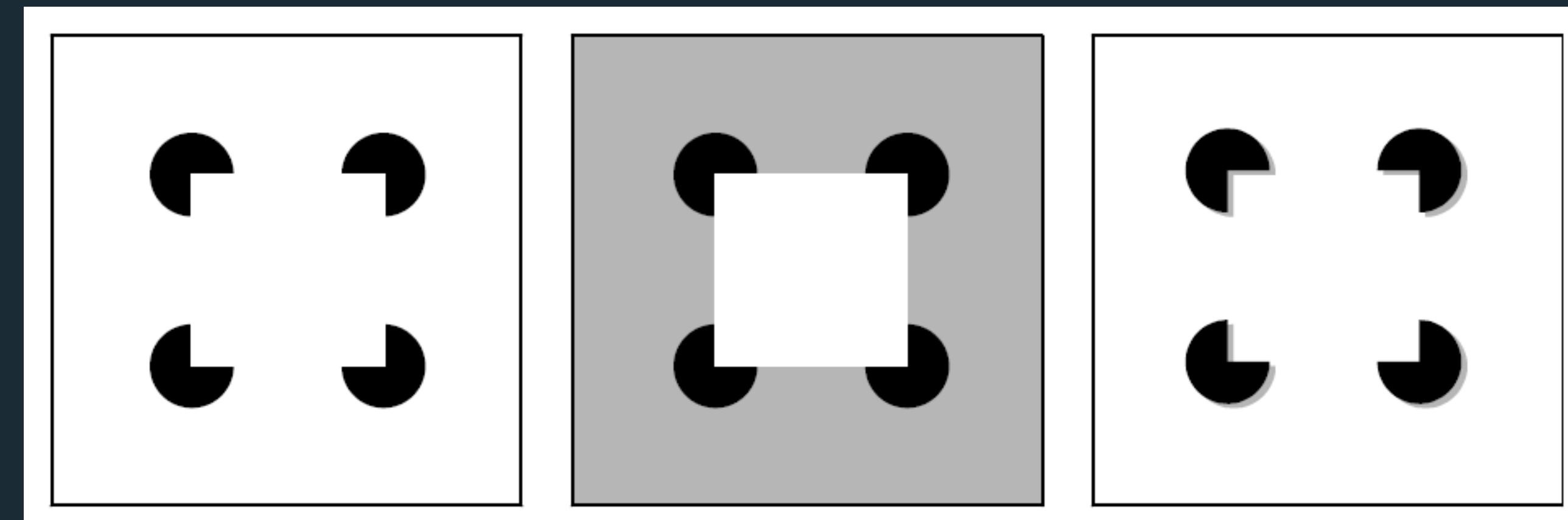
Common Fate

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



[Ware 2004]

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



[Durand 02]

Illusory contours

# Gestalt Principles

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

Figure / Ground

Proximity

Similarity

Symmetry

Connectedness

Continuity

Closure

Common Fate



Dots moving together are grouped.