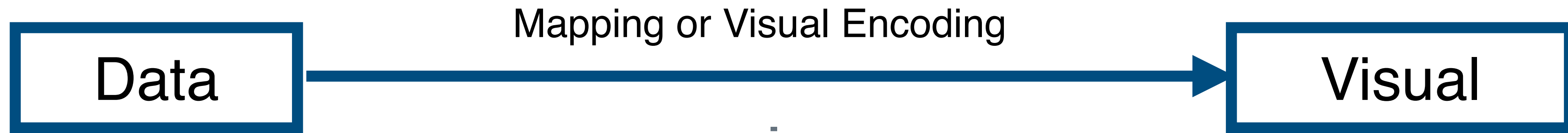


Perception

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

Position on common scale



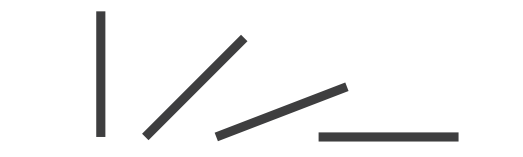
Position on unaligned scale



Length (1D size)



Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



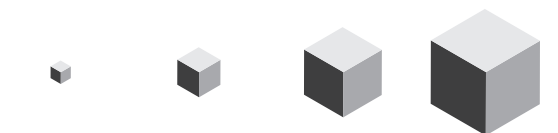
Color saturation



Curvature



Volume (3D size)



Same

Most Effectiveness Least

➔ Identity Channels: Categorical Attributes

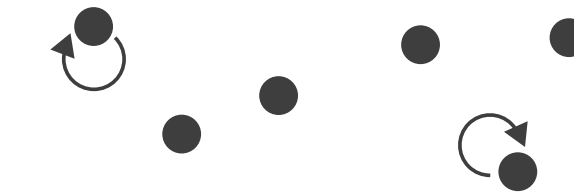
Spatial region



Color hue



Motion



Shape




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

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) 

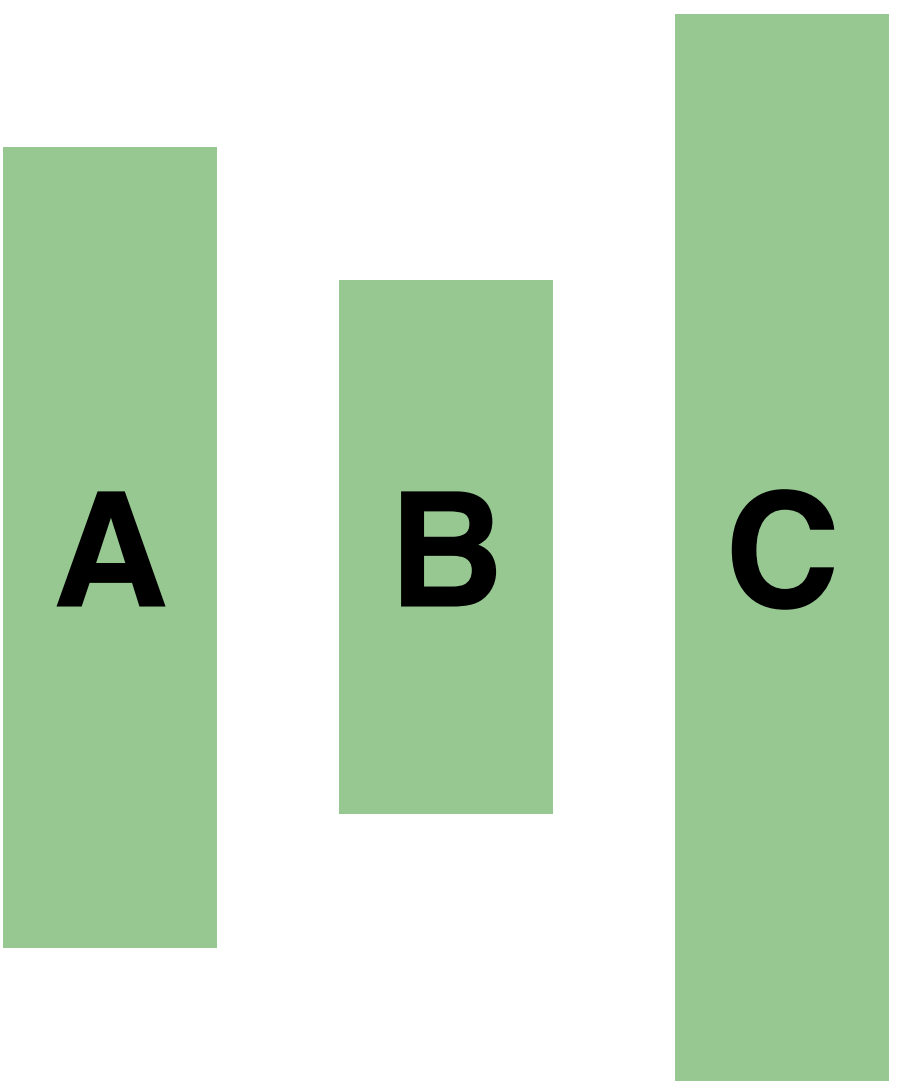
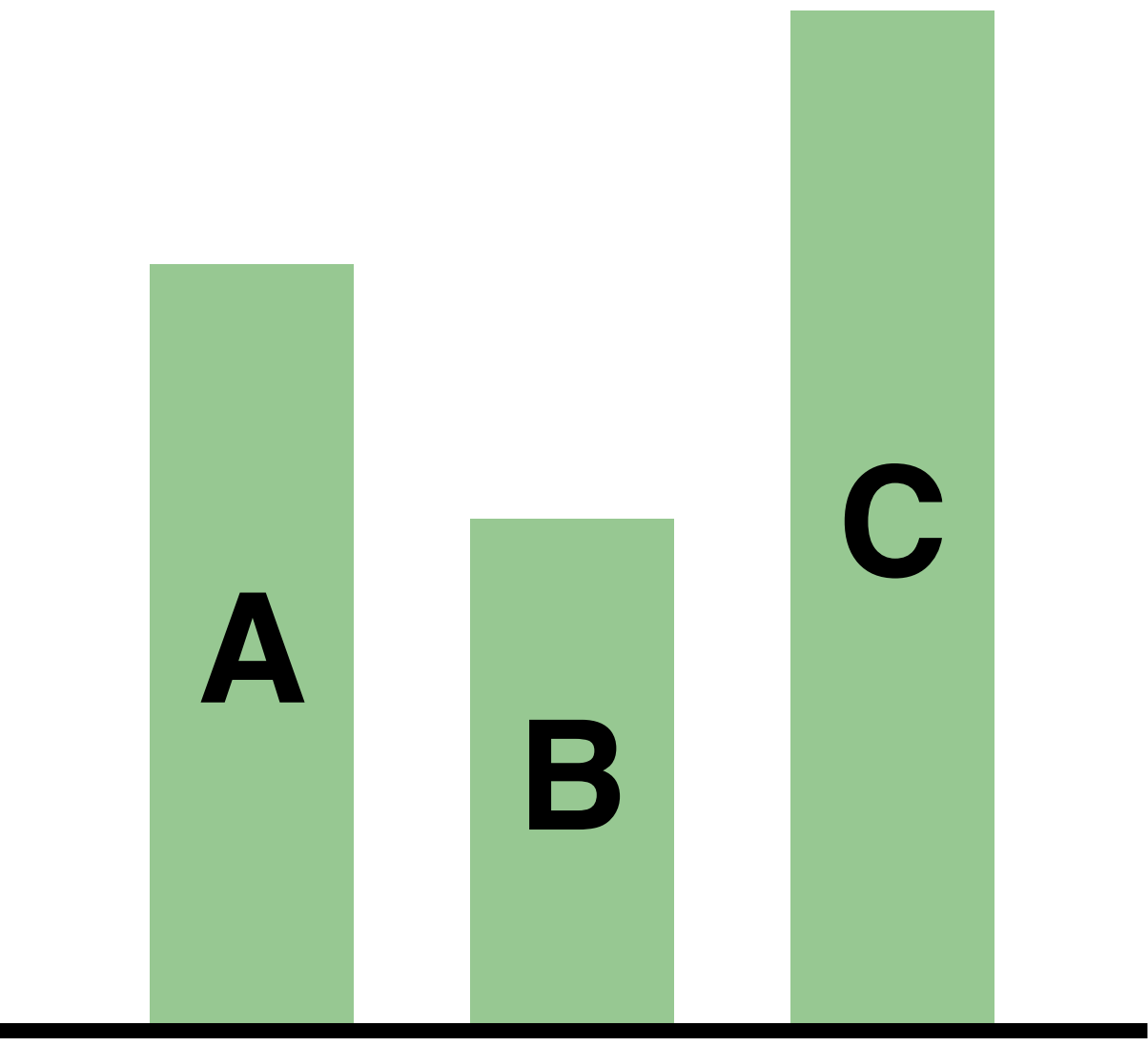
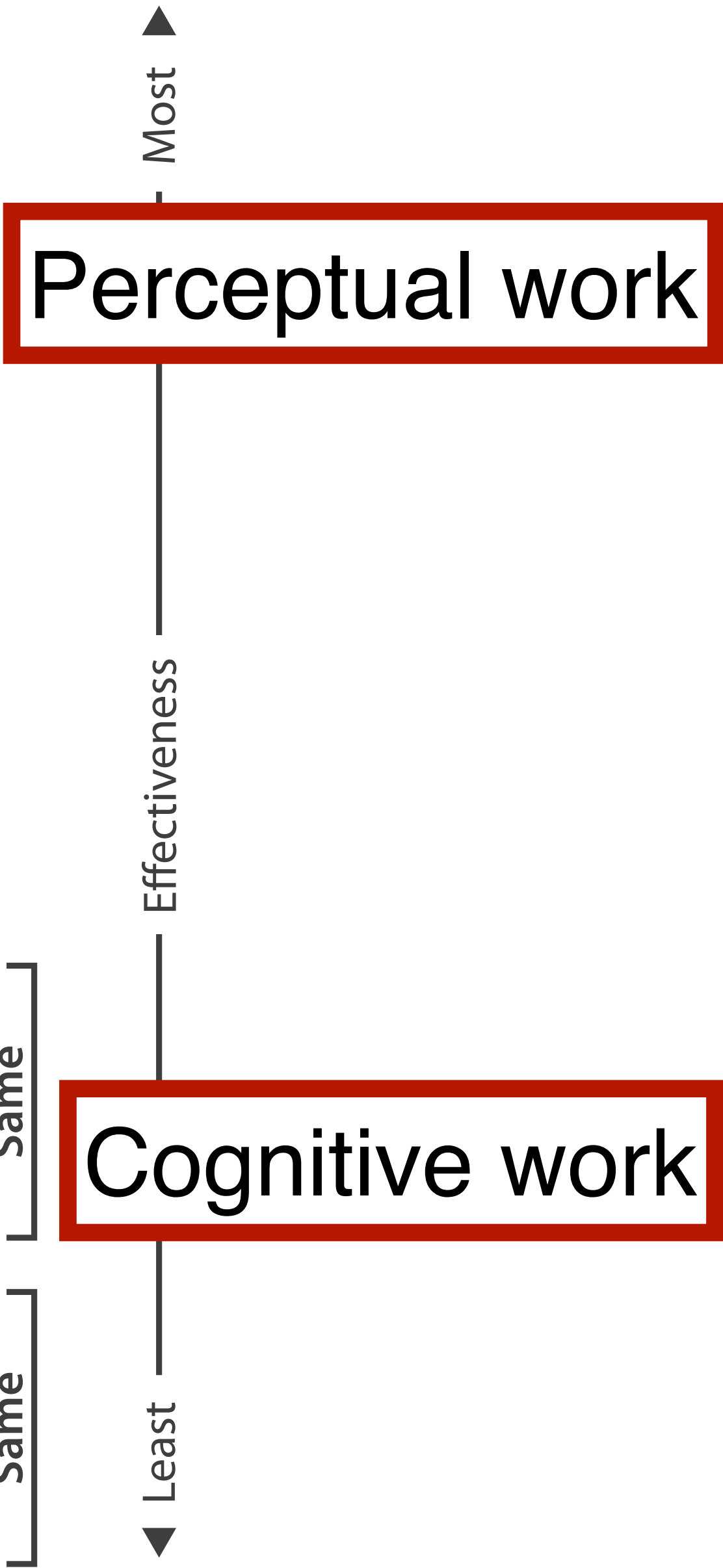
Depth (3D position) 

Color luminance 

Color saturation 

Curvature 

Volume (3D size) 



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

Magnitude Estimation

Pre-Attentive Processing

Selective Attention

Gestalt Grouping

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

Which is brighter?

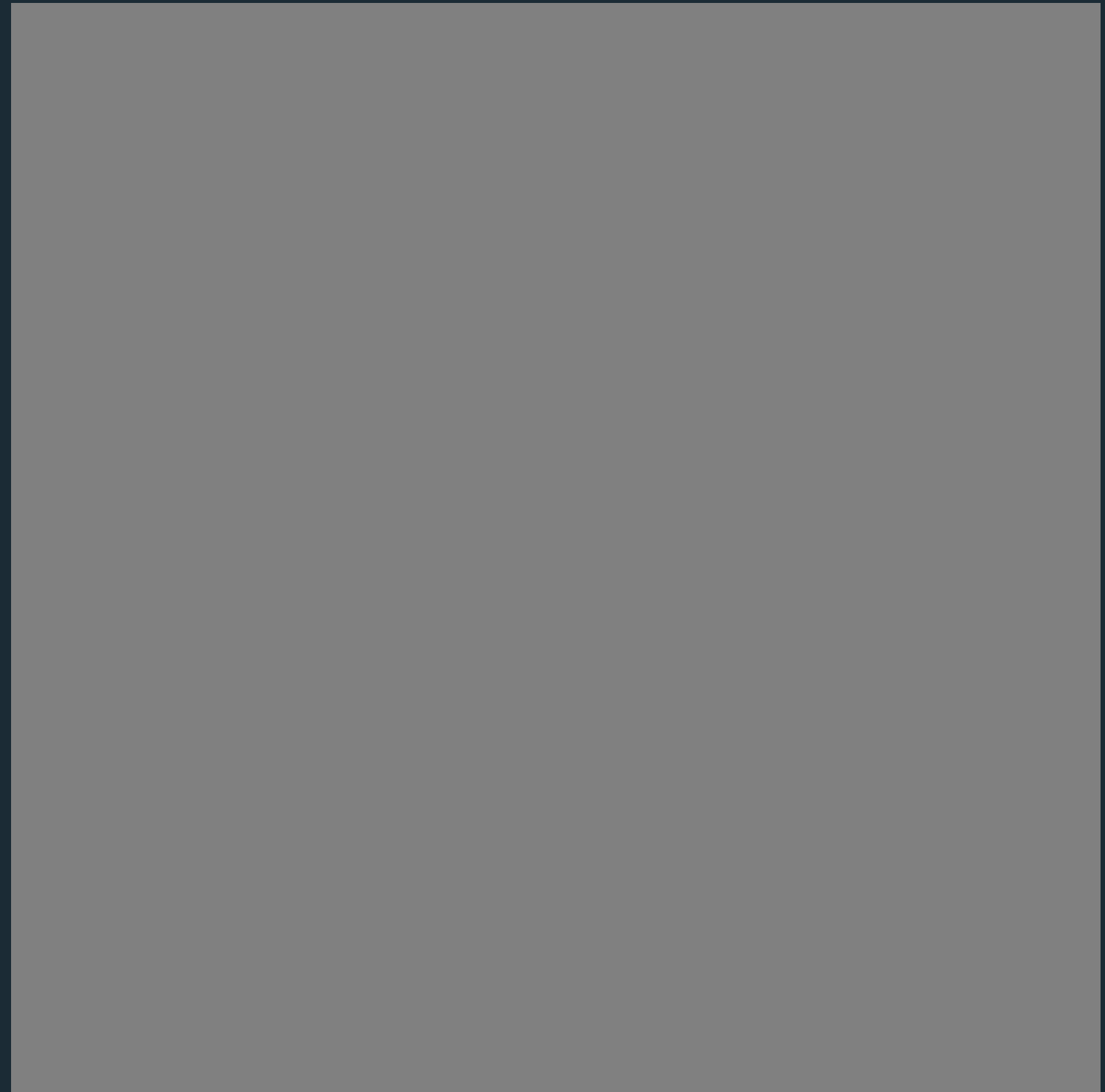


`rgb(128, 128, 128)`

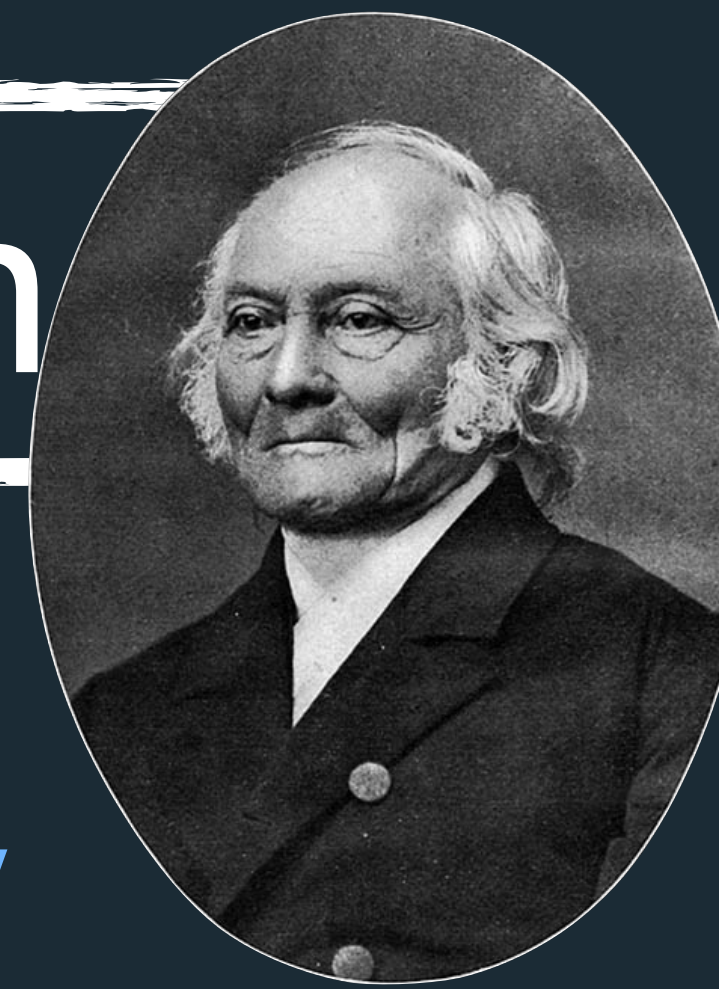


`rgb(144, 144, 144)`

Which is brighter?



Just Noticeable Difference (jn



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

Scale Factor
(Determined Empirically)

ΔI Change of Intensity

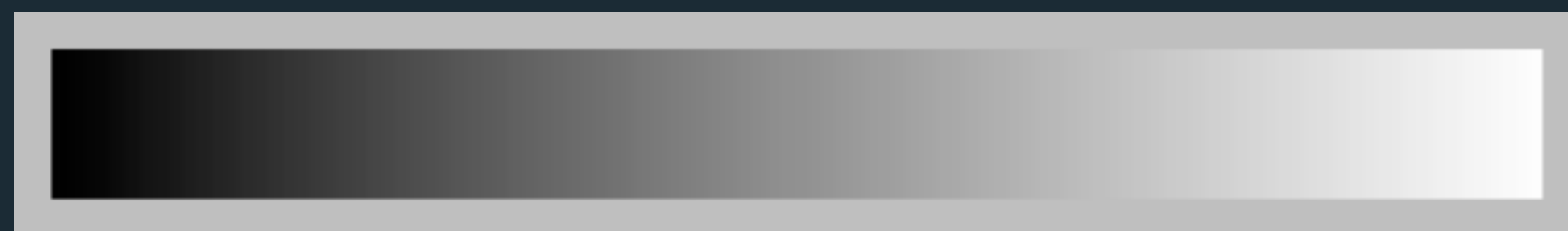
$$\Delta S = k \frac{\Delta I}{I}$$

I Physical Intensity

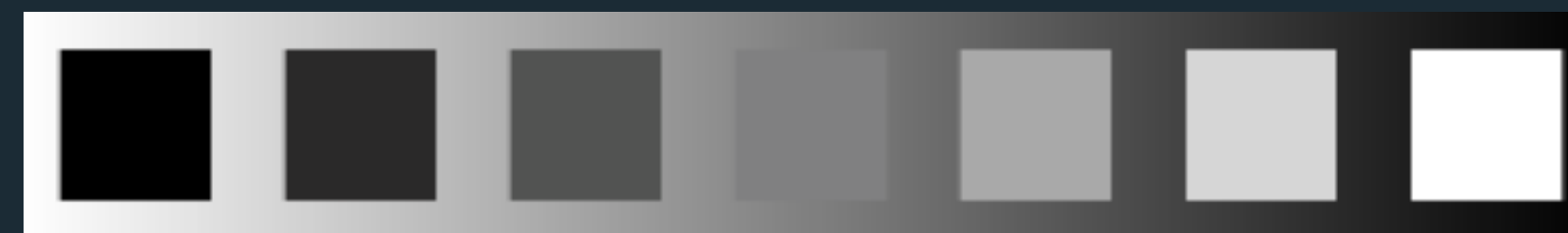
Perceived Change

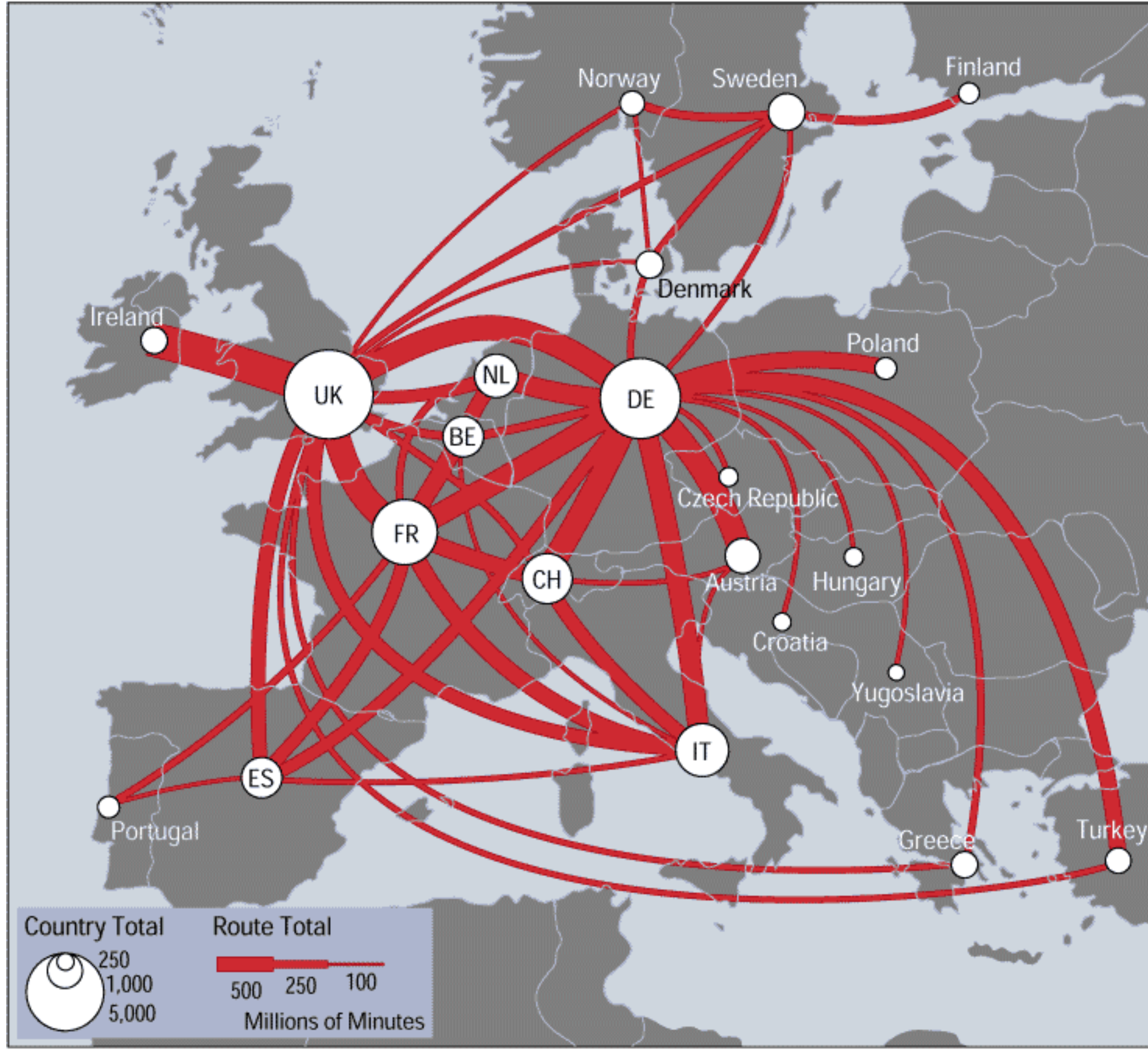
Ratios more important than magnitude.

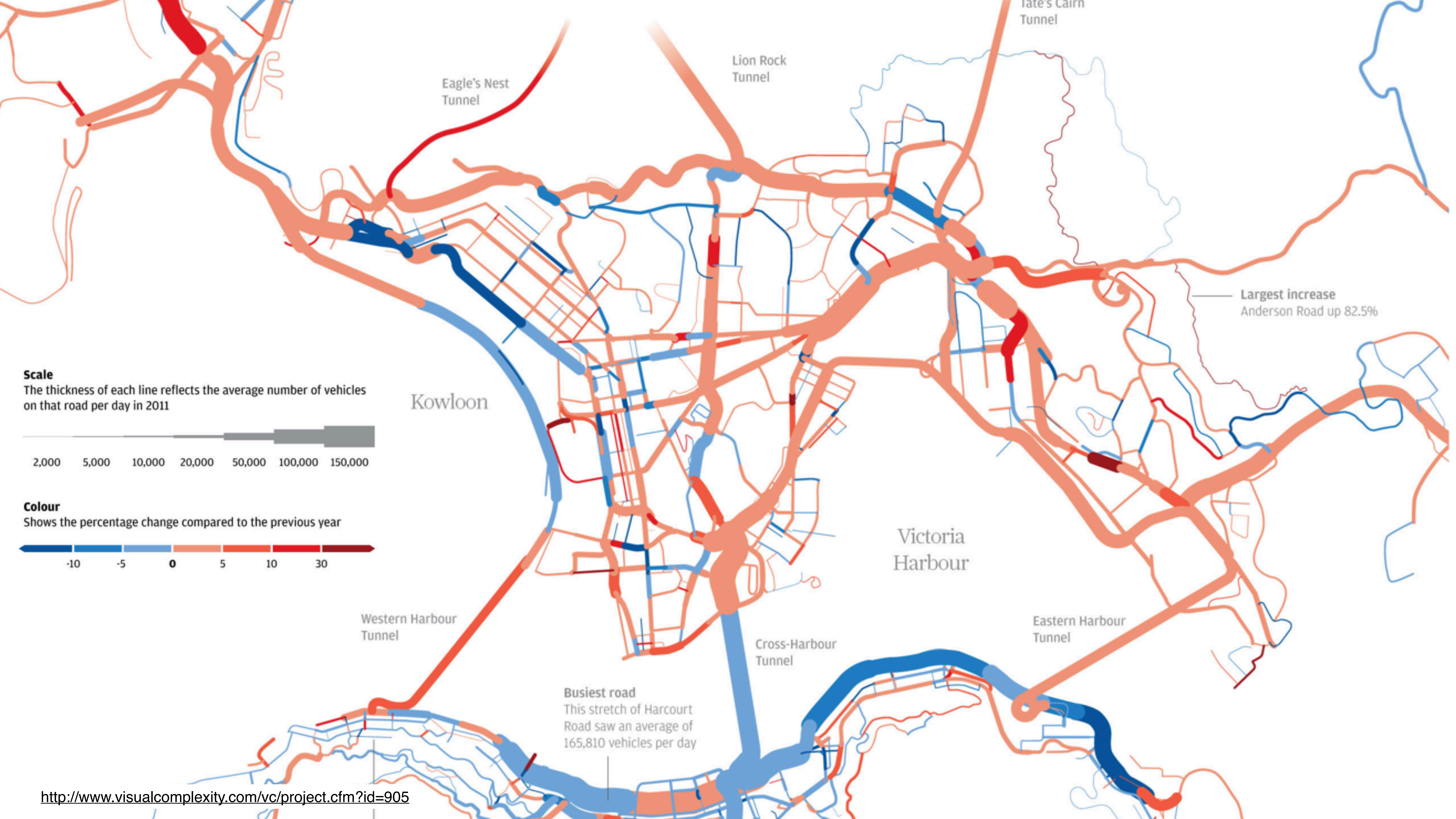
Most continuous variation in stimuli are perceived in discrete steps.



vs.







Signal Detection

Magnitude Estimation

Pre-Attentive Processing

Selective Attention

Gestalt Grouping

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

Signal Detection

Magnitude Estimation

Accuracy: how correctly can we read off values?

Pre-Attentive Processing

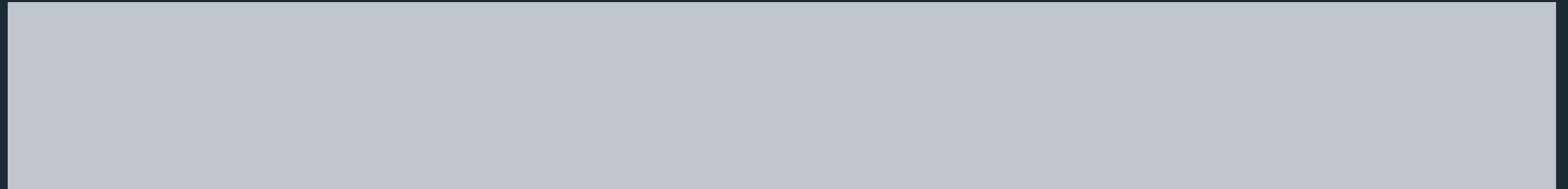
Selective Attention

Gestalt Grouping

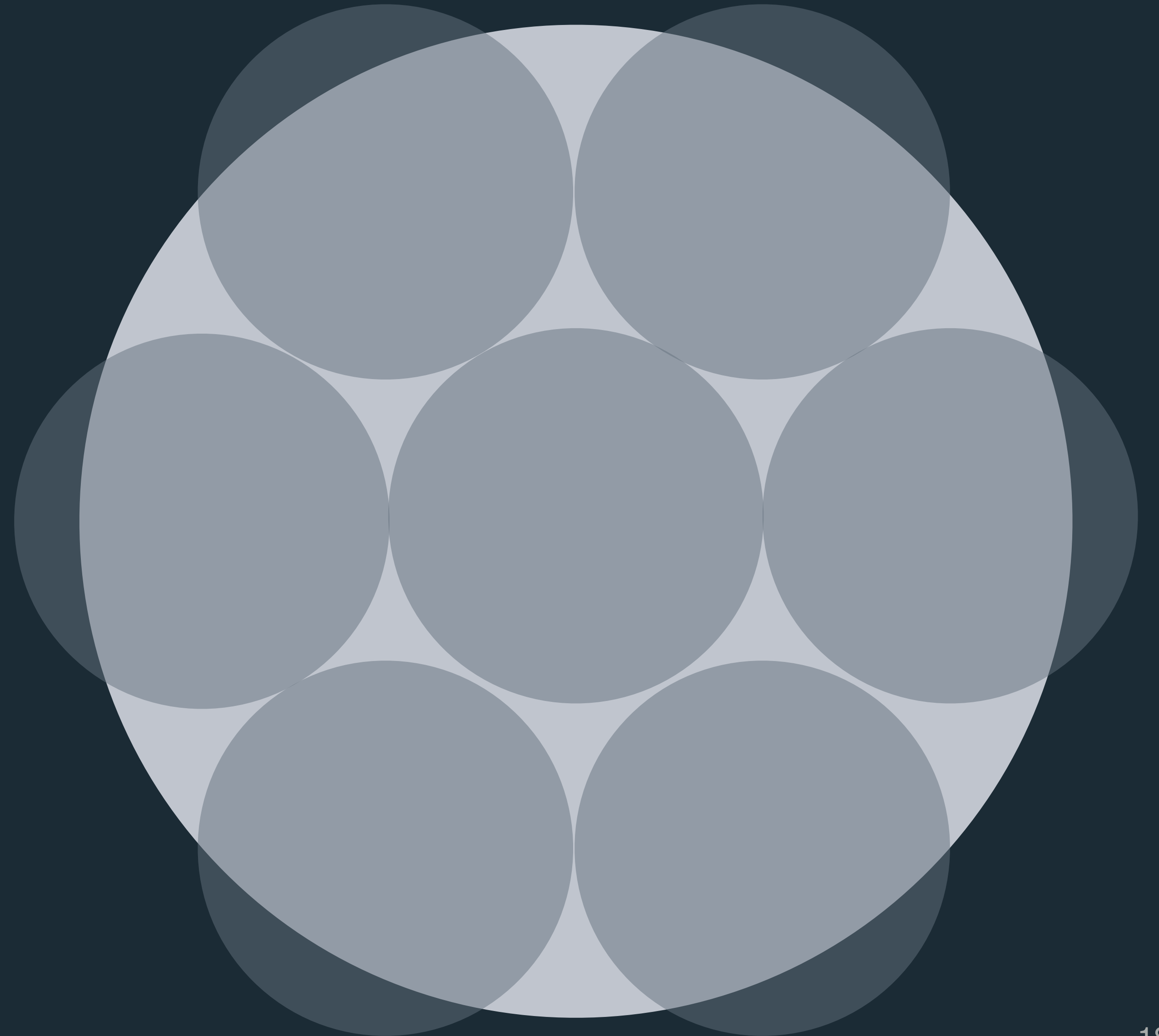
How much larger is the area of the big circle?



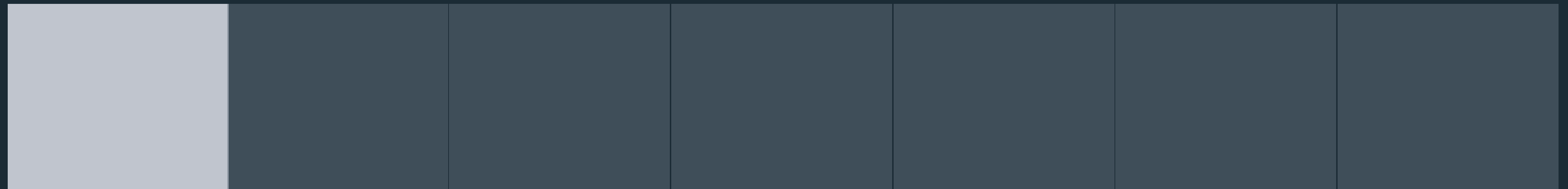
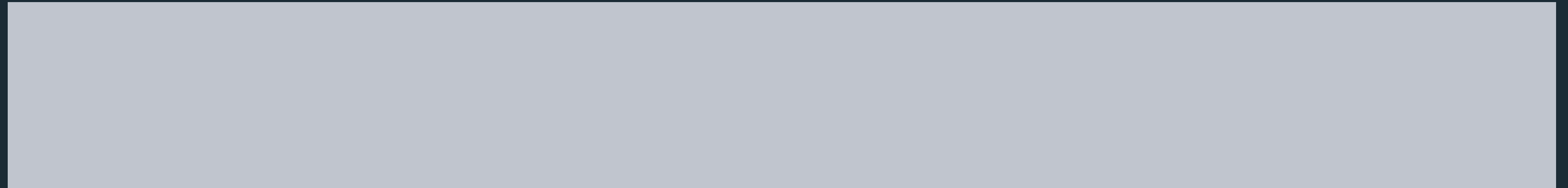
How much longer is the big bar?



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

$$S = I^p$$

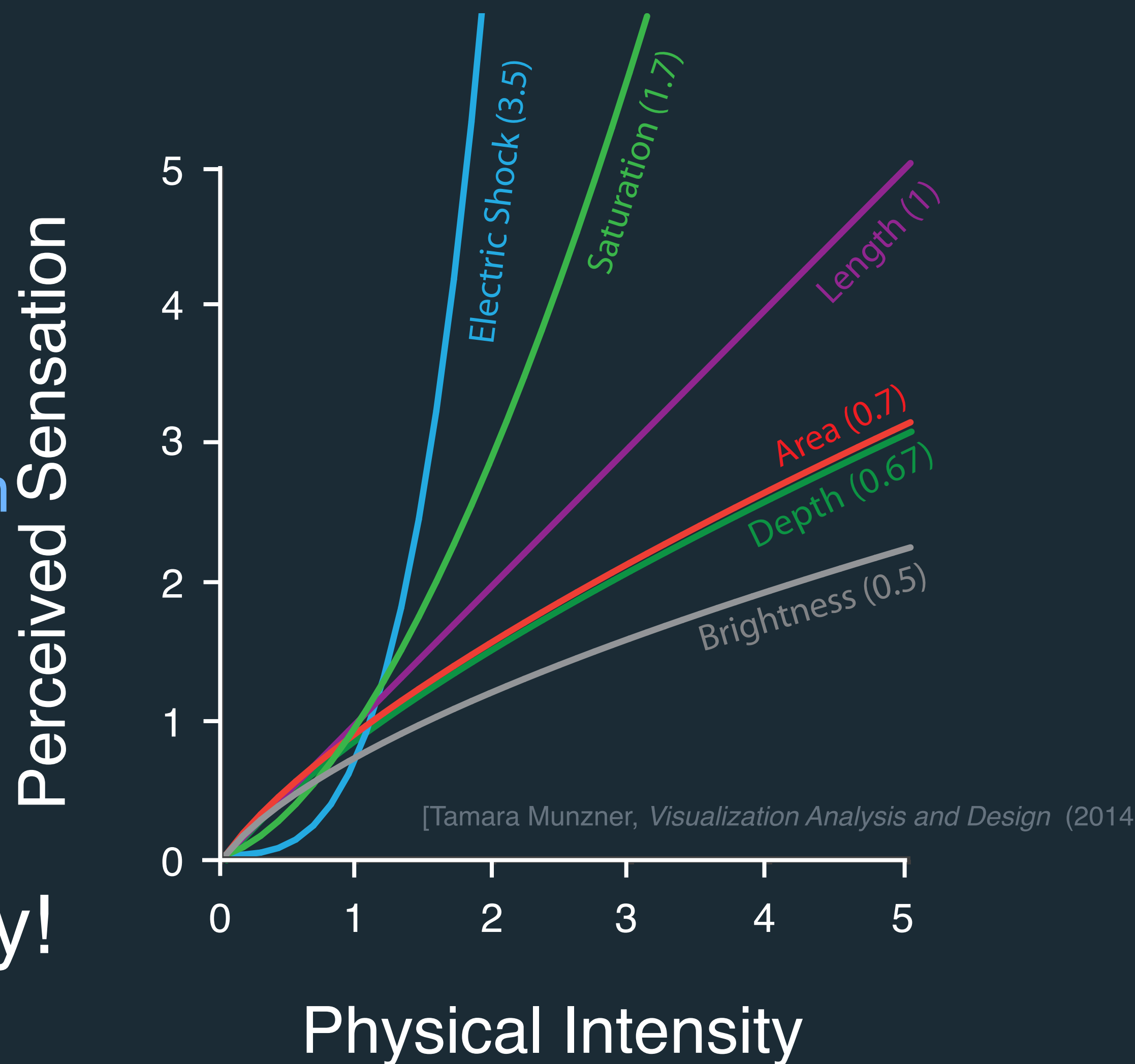
Perceived Sensation

Exponent
(Determined Empirically)

$p < 1$ = **underestimation**

$p > 1$ = **overestimation**

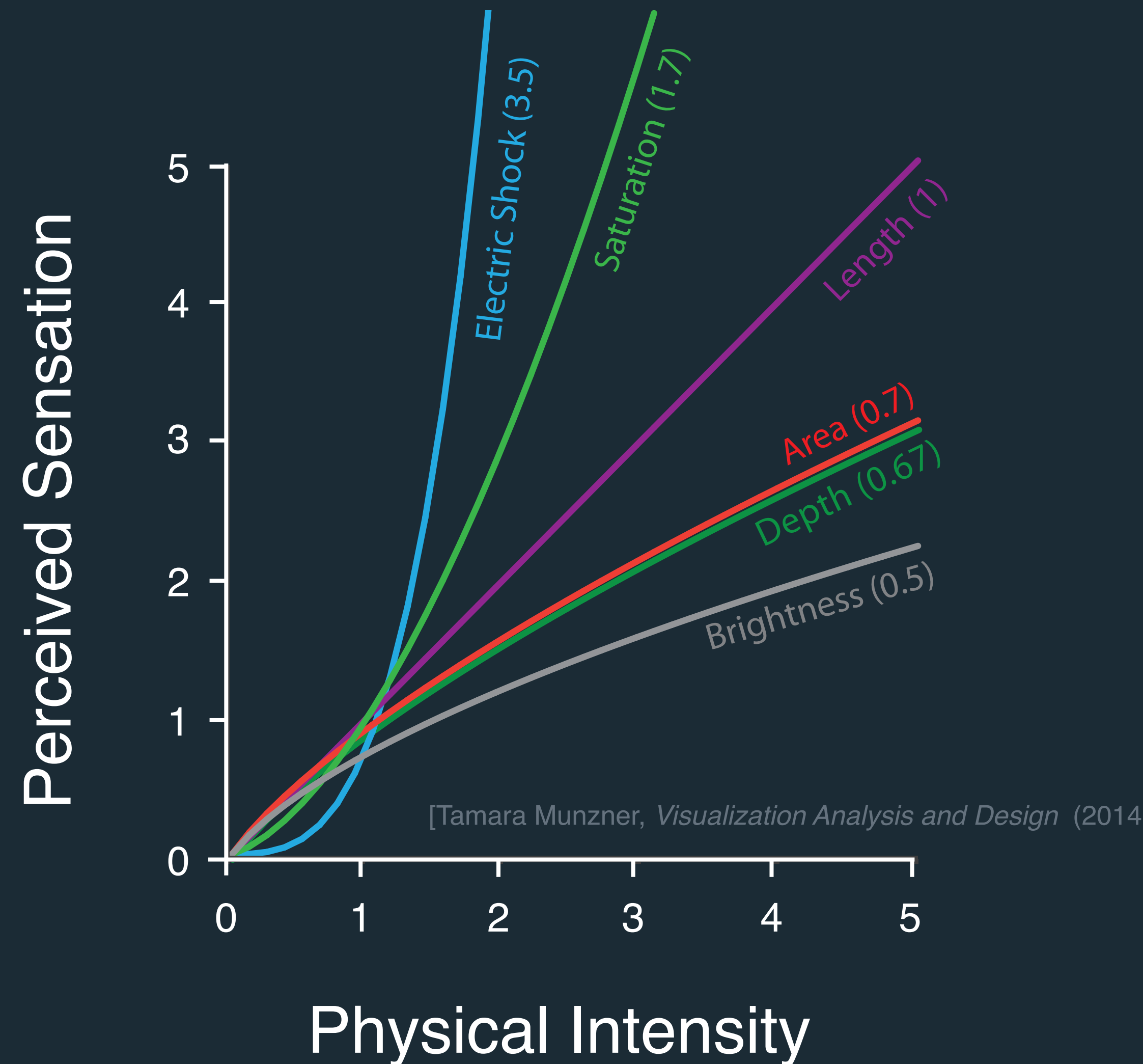
Predicts bias, not necessarily accuracy!

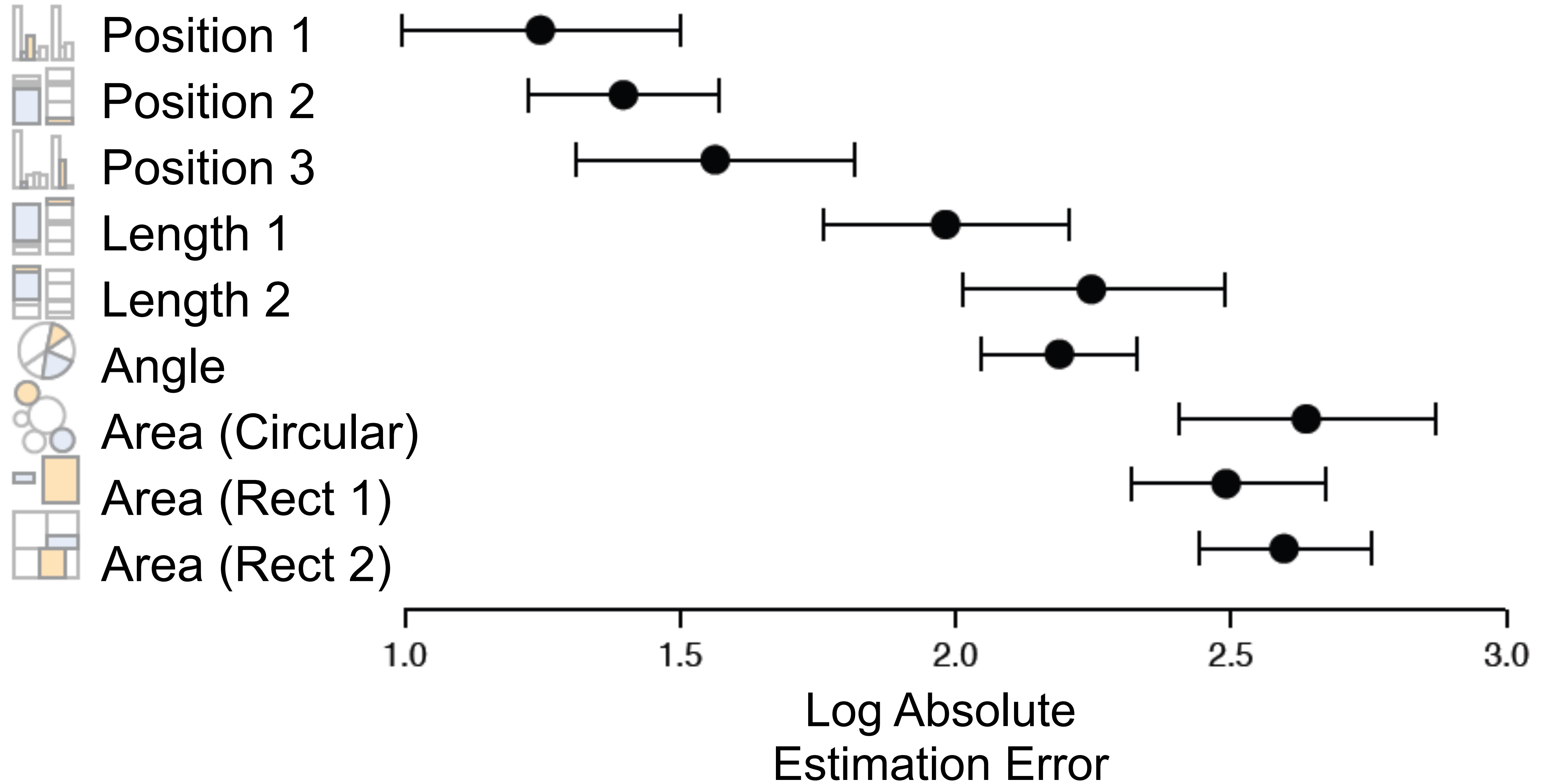


Stevens' Power Law

$$S = I^p$$

Sensation	Exponent
Loudness	0.6
Brightness	0.33
Smell	0.55 (Coffee) – 0.6
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

Accuracy: how correctly can we read off values?

Pre-Attentive Processing

Selective Attention

Gestalt Grouping

Signal Detection

Magnitude Estimation

Pre-Attentive Processing

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

Selective Attention

Gestalt Grouping

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).

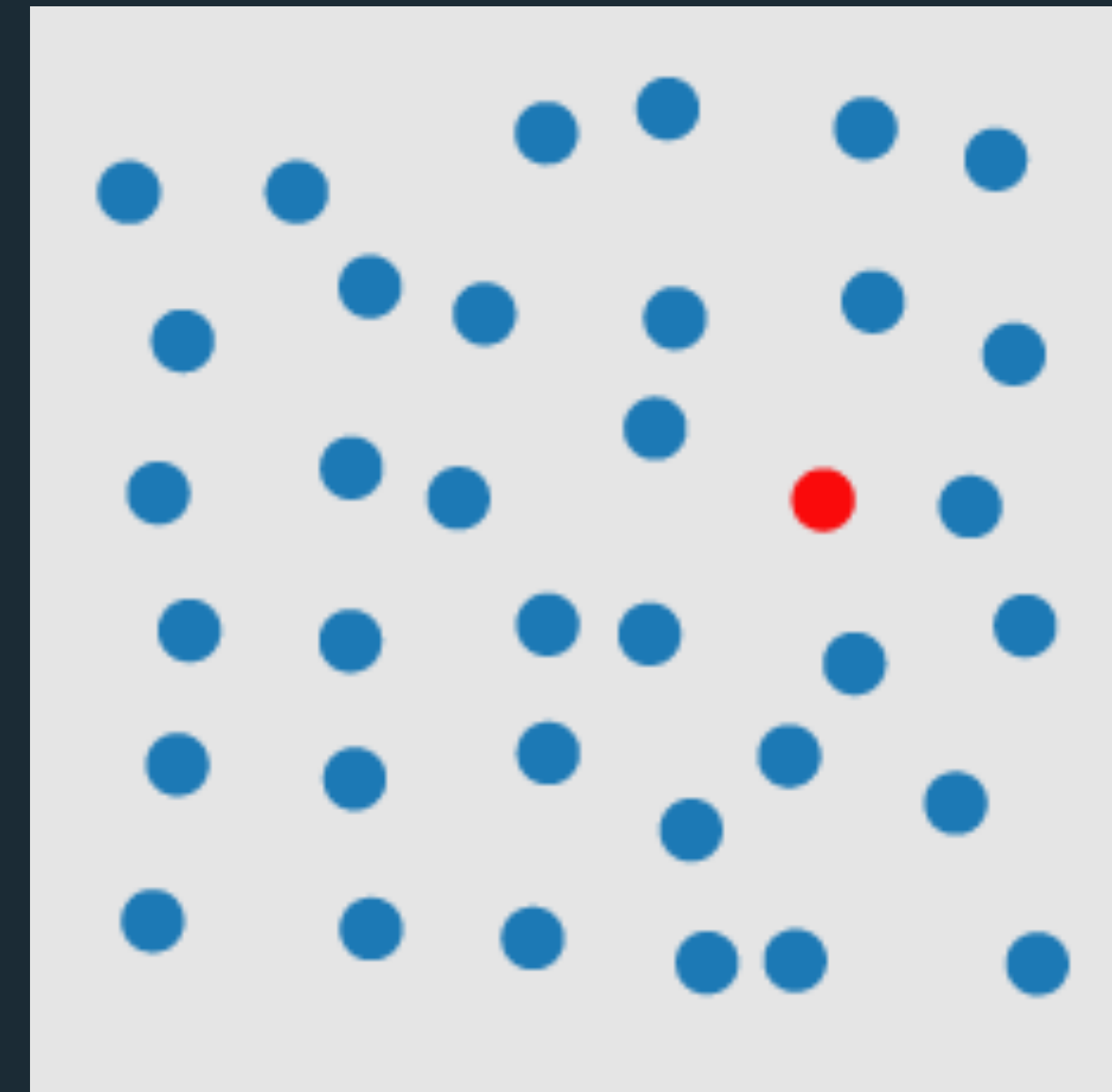
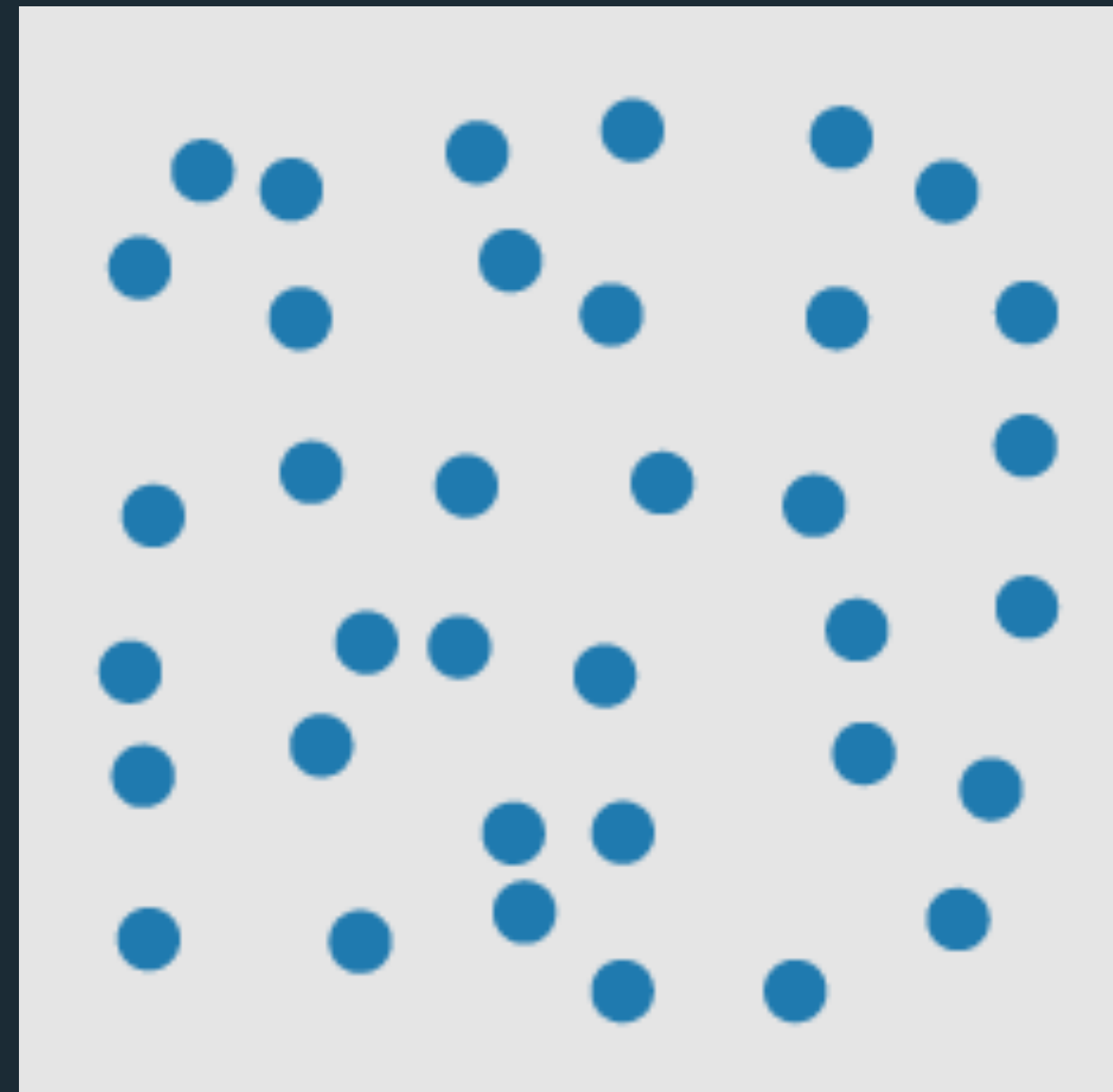
Attentive: Takes some deliberate effort to perceive differences.

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 & Emms 2012]

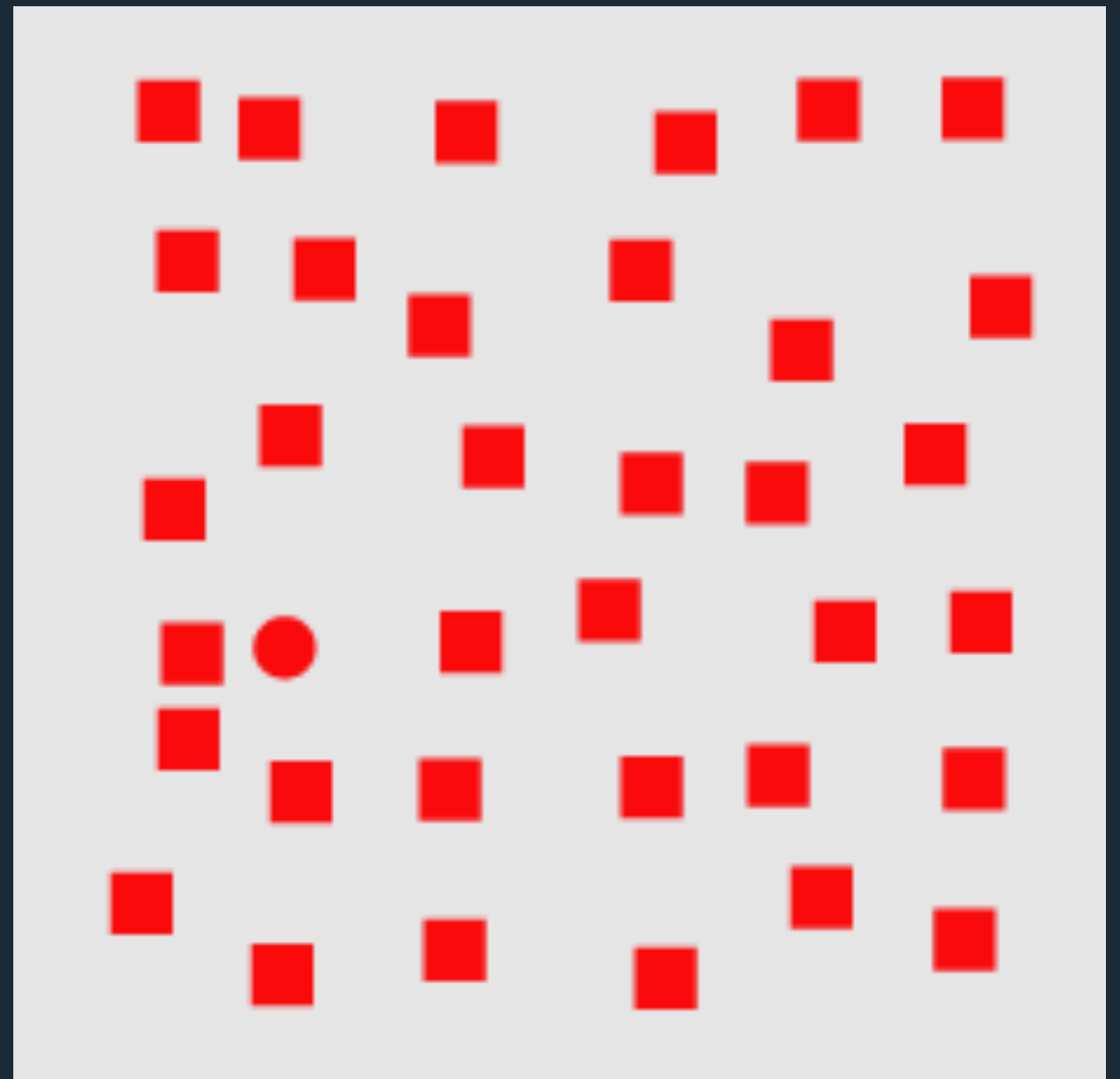
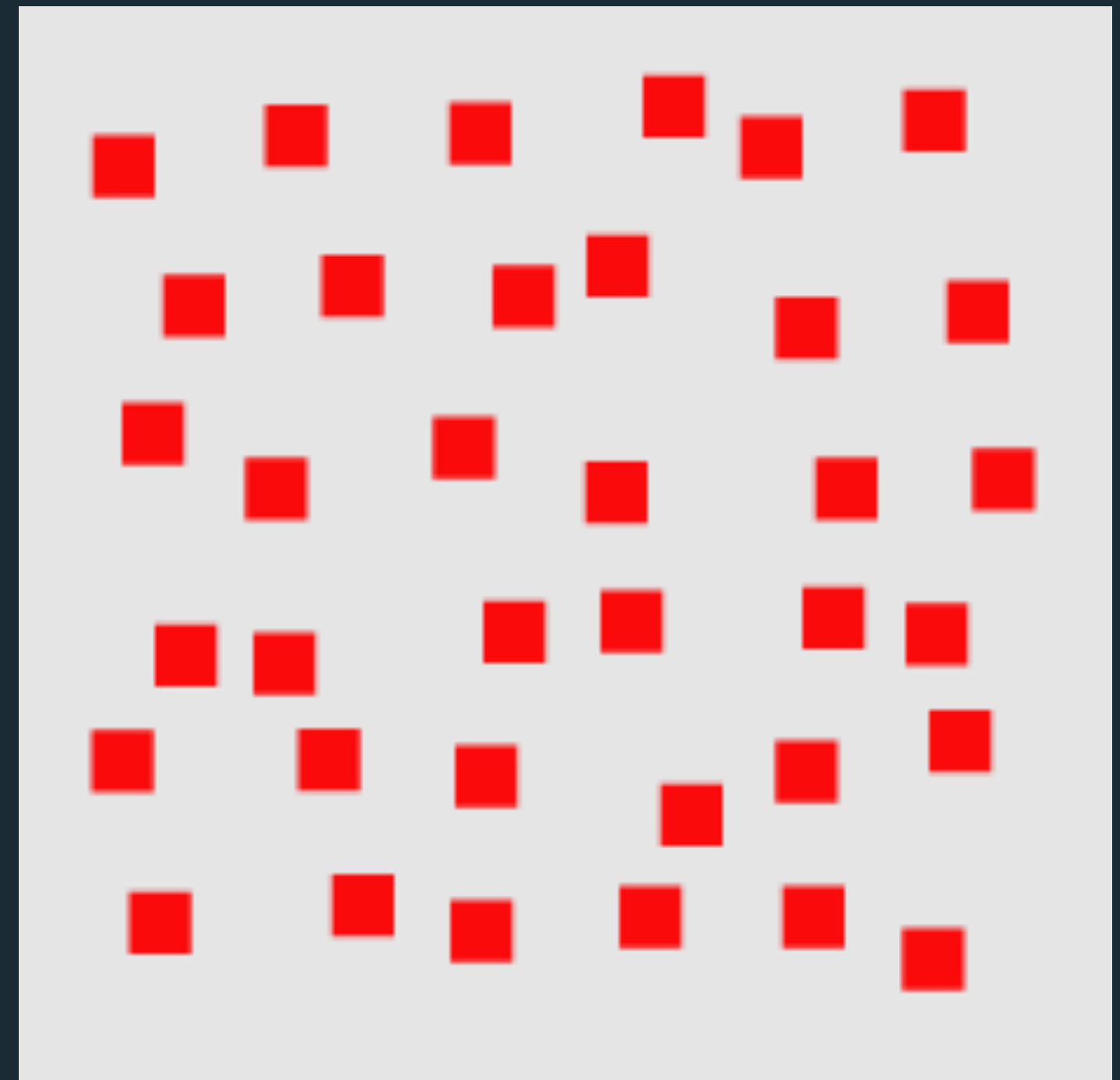
Pre-Attentive Processing

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

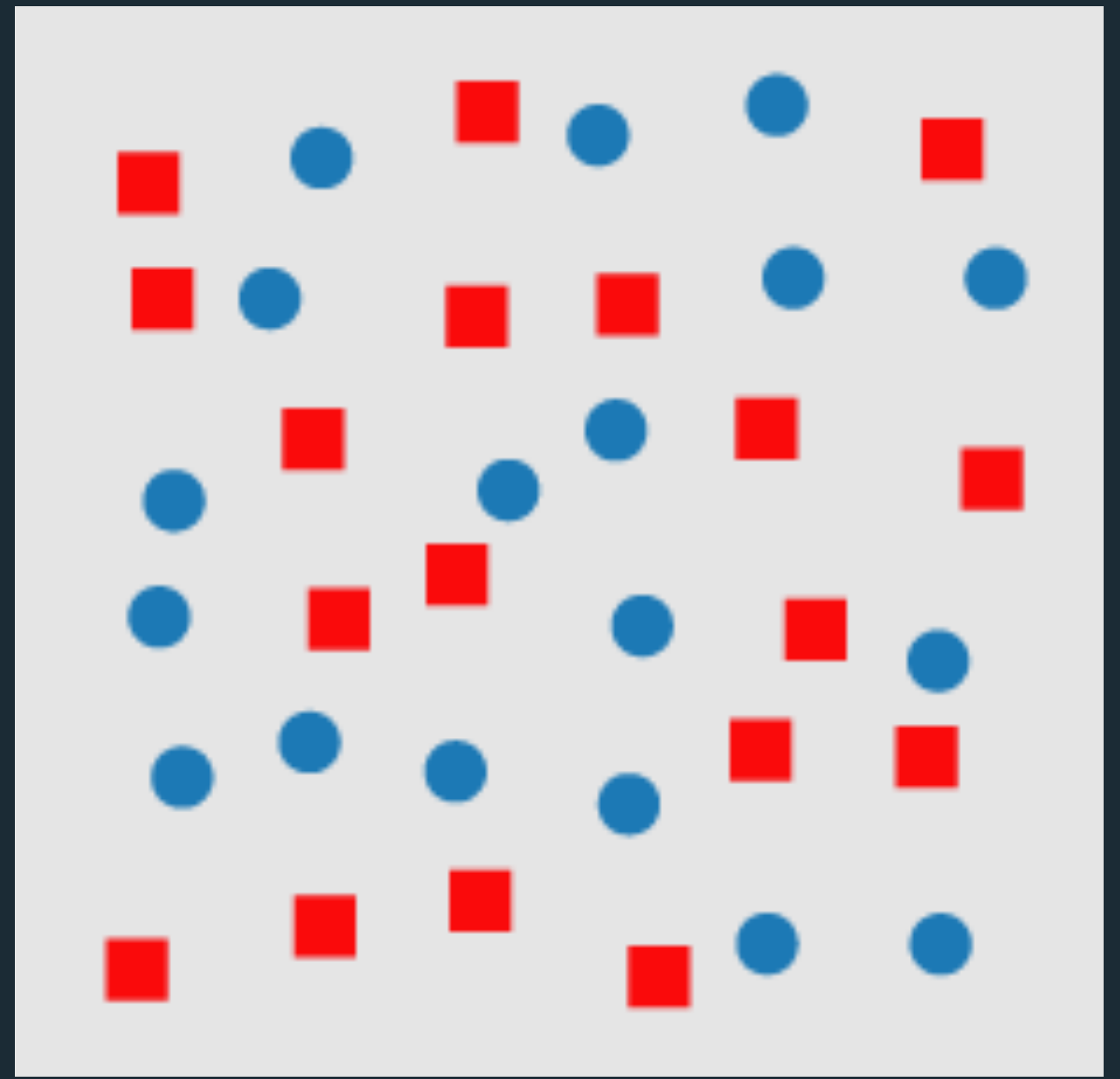
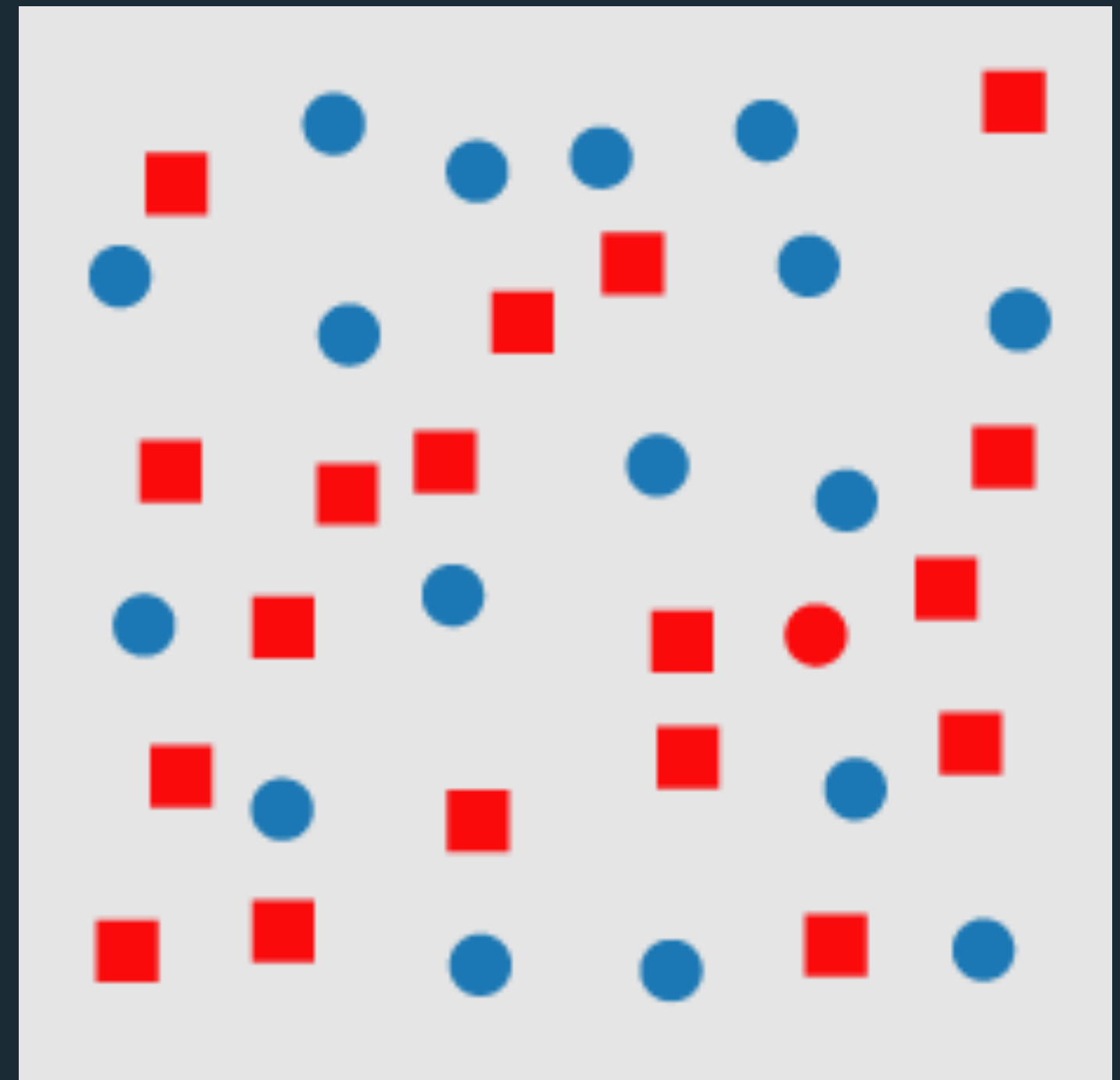
Pre-Attentive: immediately recognize variation with little or no conscious effort (<200–250 ms).

Visual Pop-Out: Color

Visual Pop-Out: Shape

Attentive: Takes some deliberate effort to perceive differences.

Feature Conjunctions



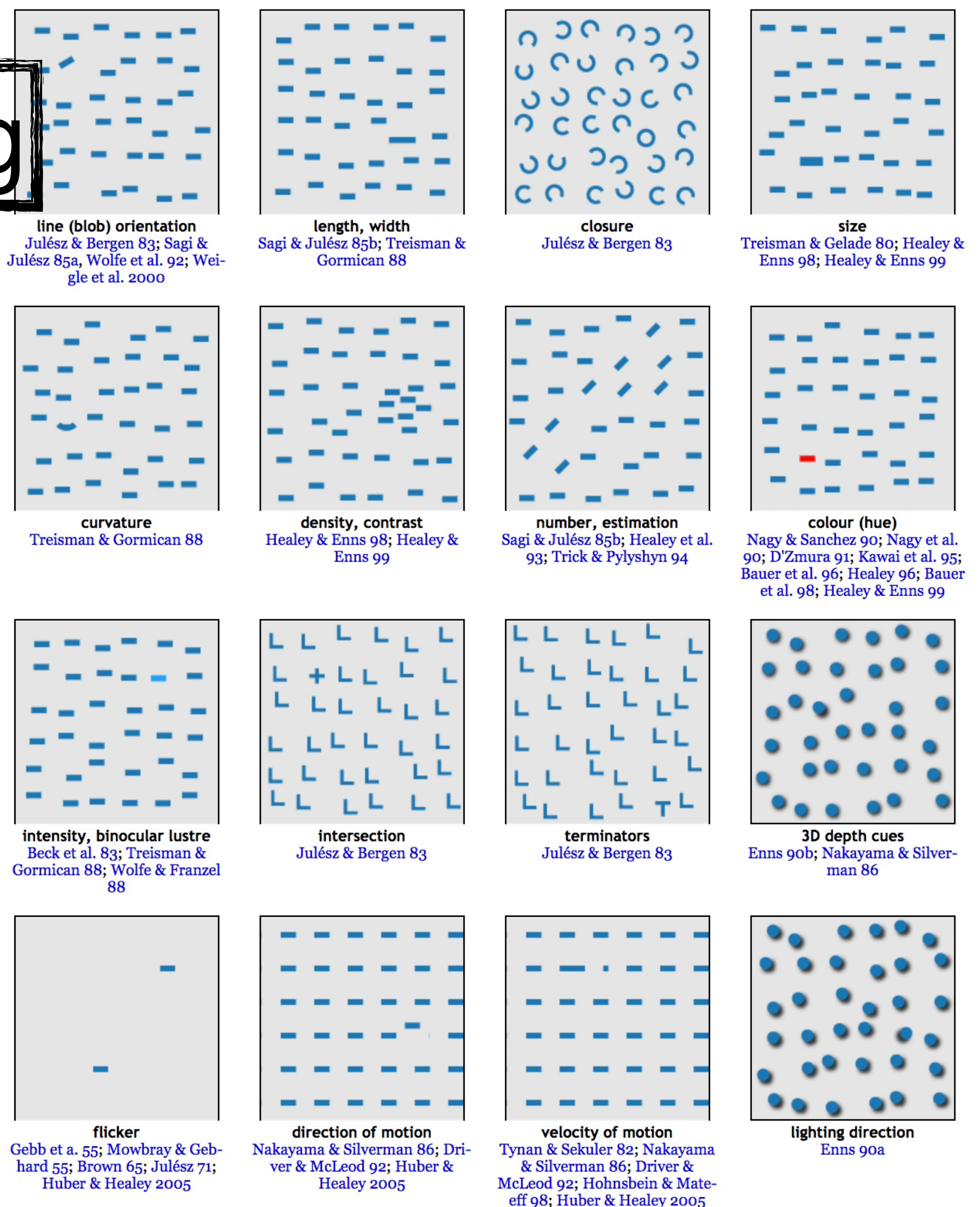
[Healey & Emms 2012]

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

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

Selective Attention

Gestalt Grouping

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



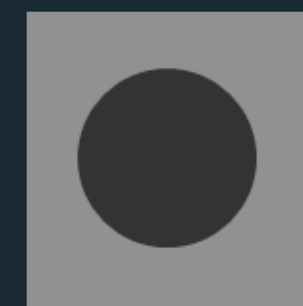
Circle



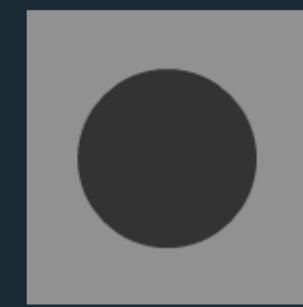
Square



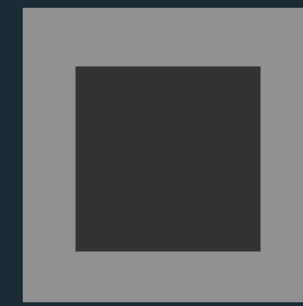
Circle



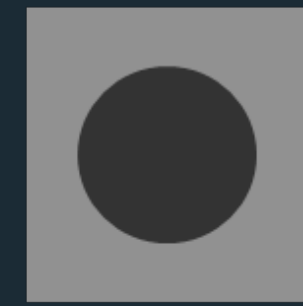
Circle



Circle



Square



Circle

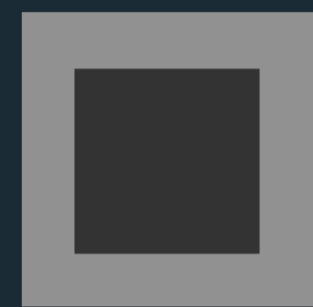


Circle

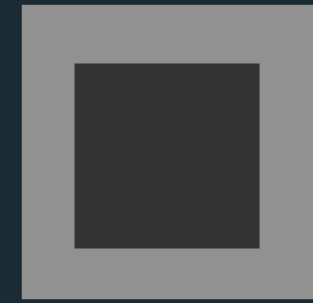
Redundant: Shape & Lightness



White



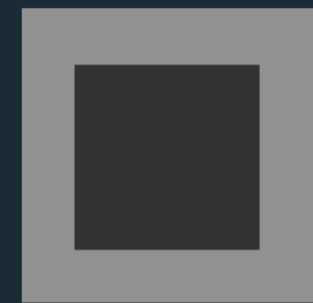
Black



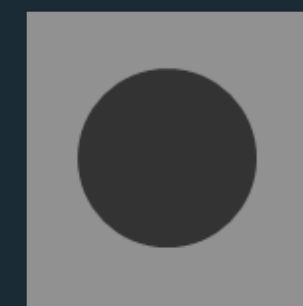
Black



White



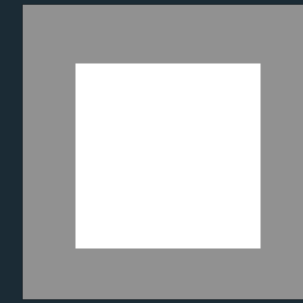
Black



Circle



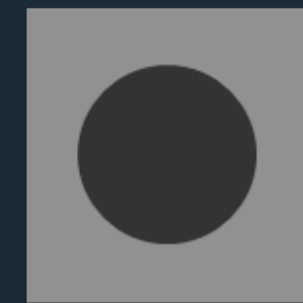
Square



Square








Square



Circle

Orthogonal: Shape & Lightness



White		Circle
Black		Square
White		Square
Black		Circle
White		Square

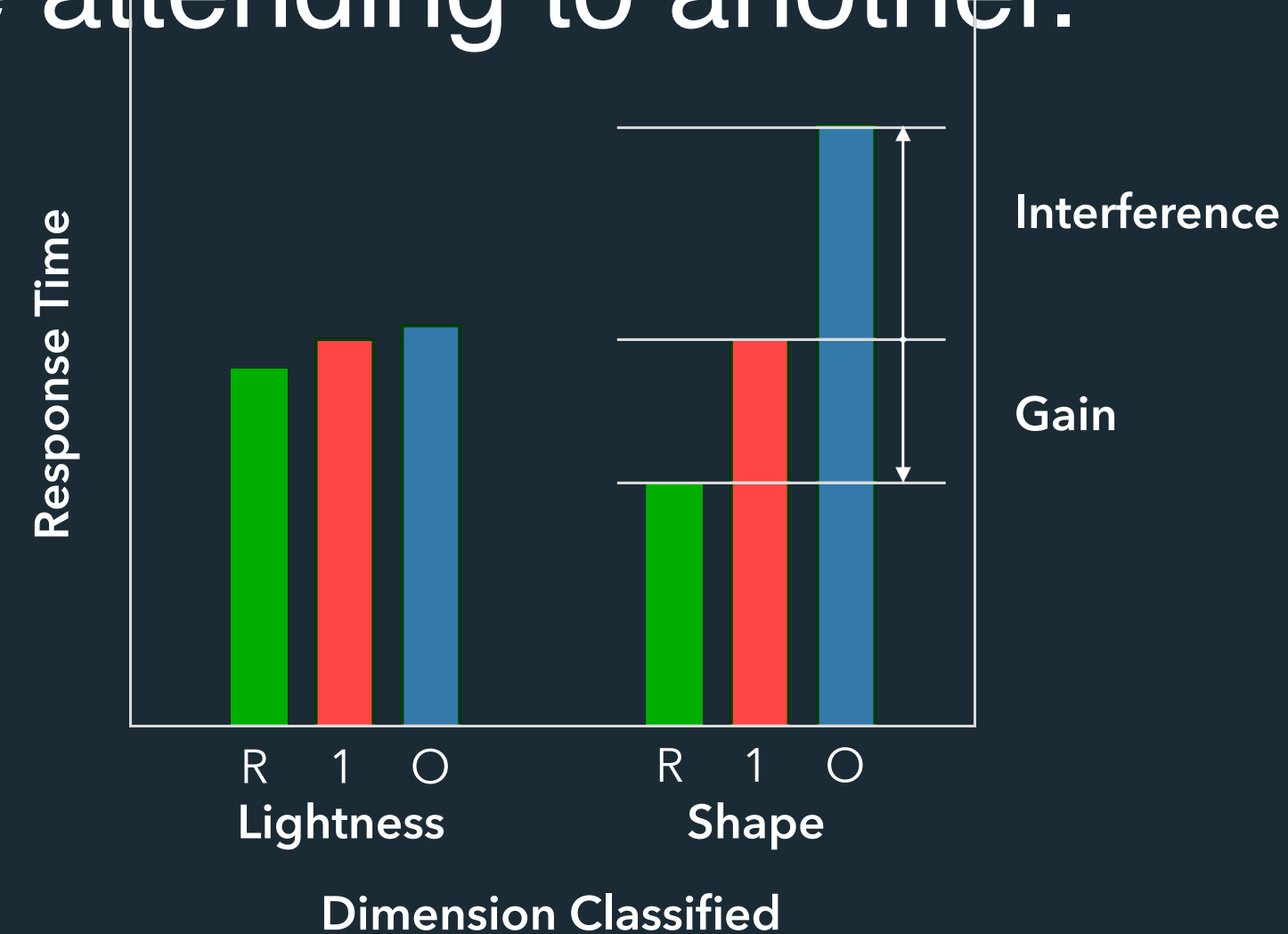
Principles

Redundancy Gain

Improved performance when both dimensions provide the same information.

Filtering Interference

Difficulty in ignoring one dimension while attending to another.



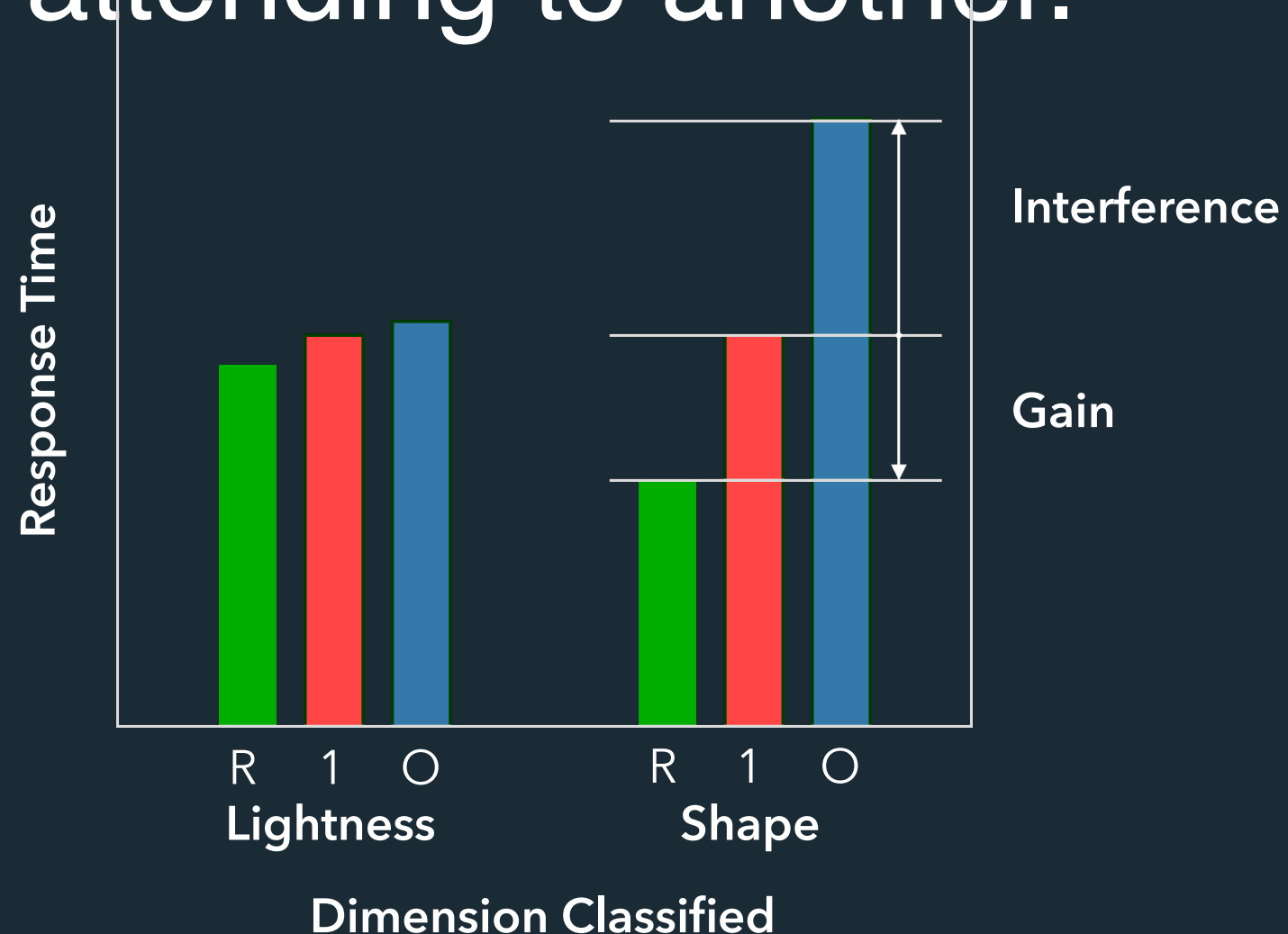
Principles

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.

Types of Dimensions

Separable

No interference or redundancy gain.

Integral

Filtering interference and redundancy gain.

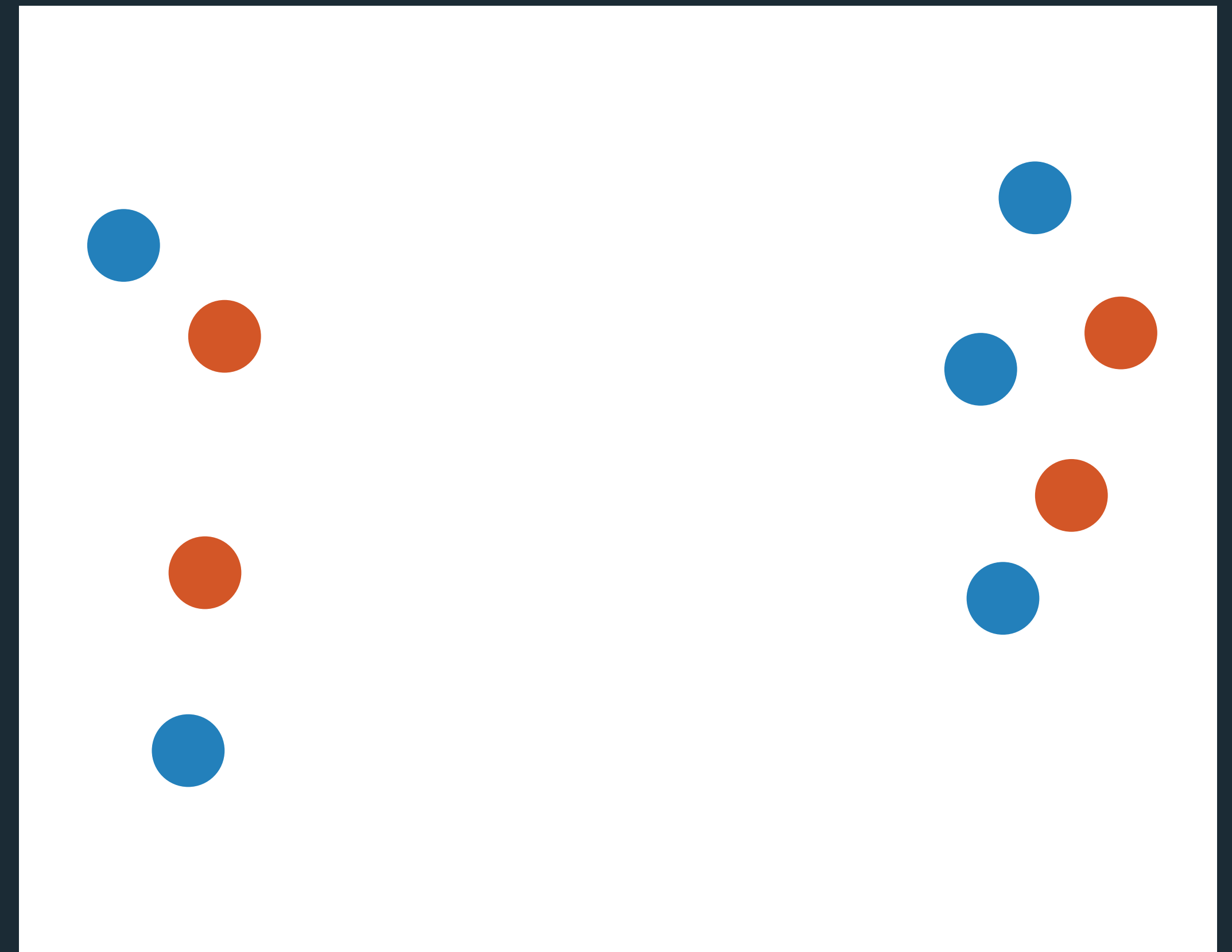
Configural

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Position & Hue (Color)?



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

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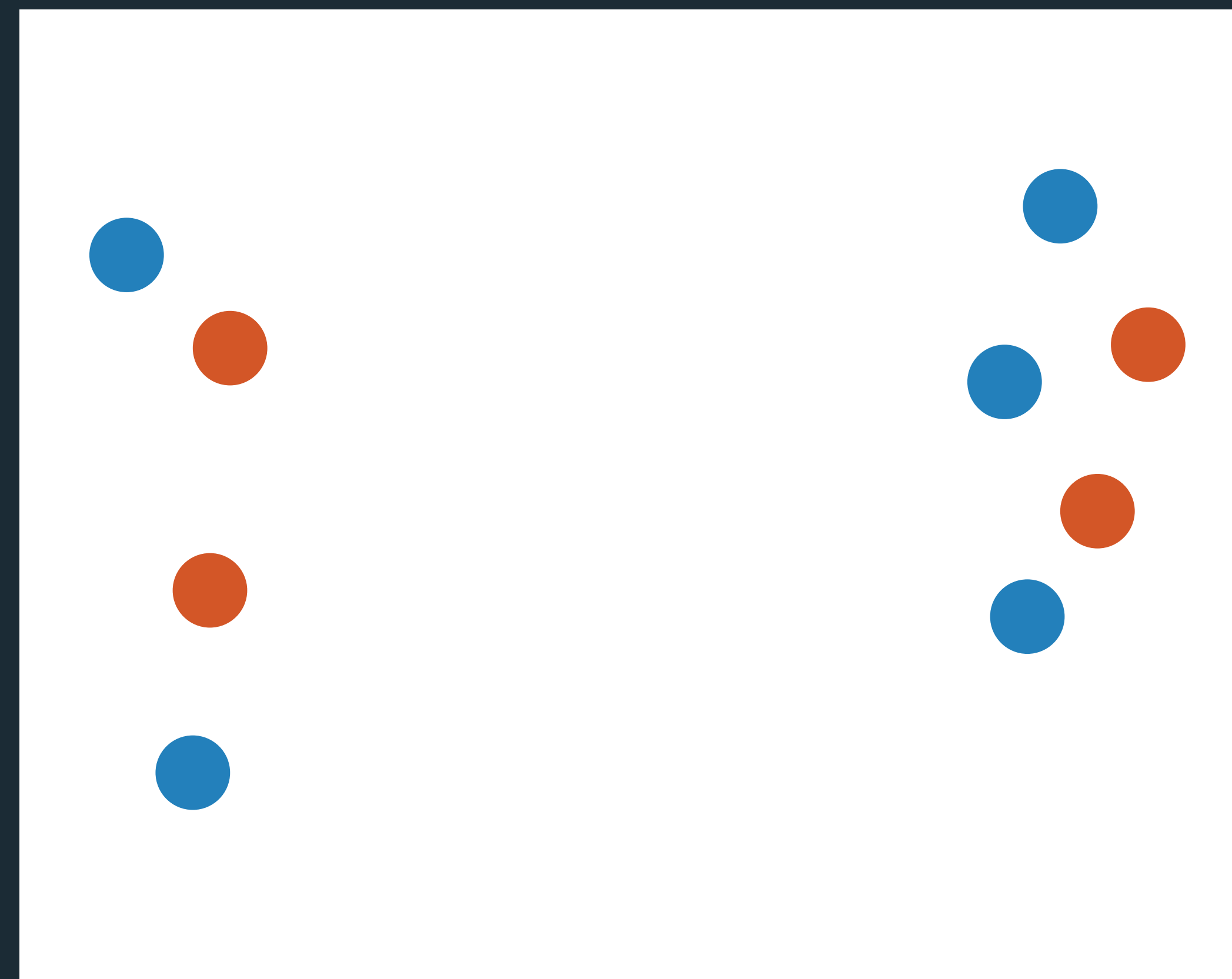
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Size & Orientation?

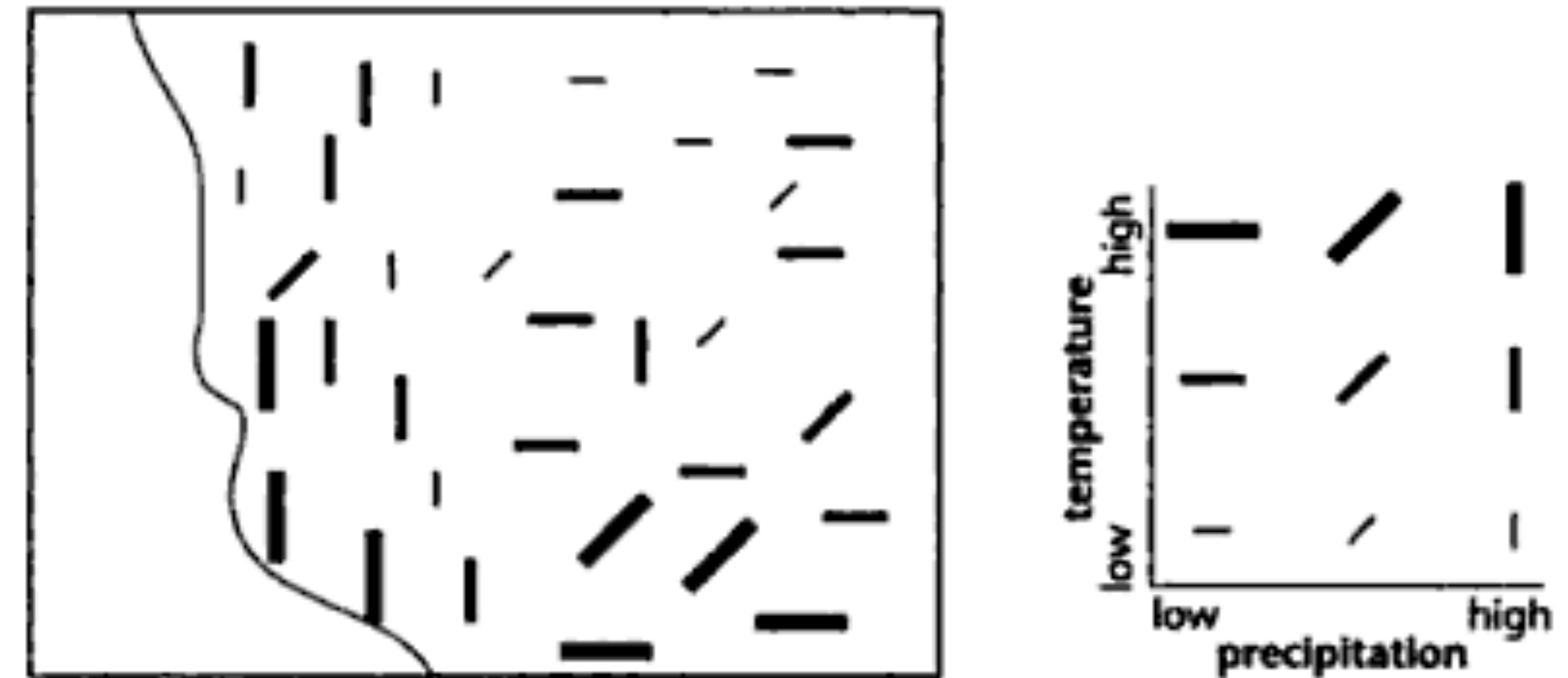


FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

[MacEachren 1999]

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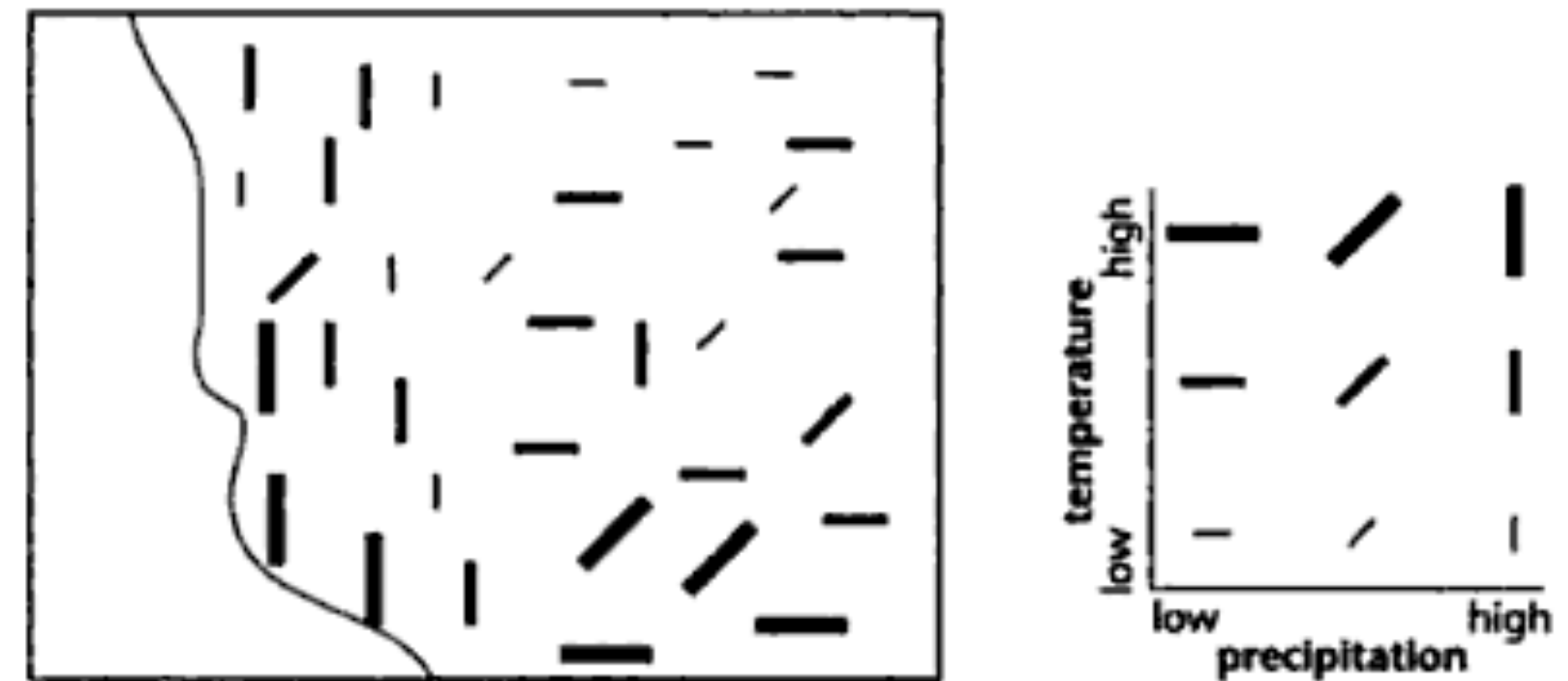


FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

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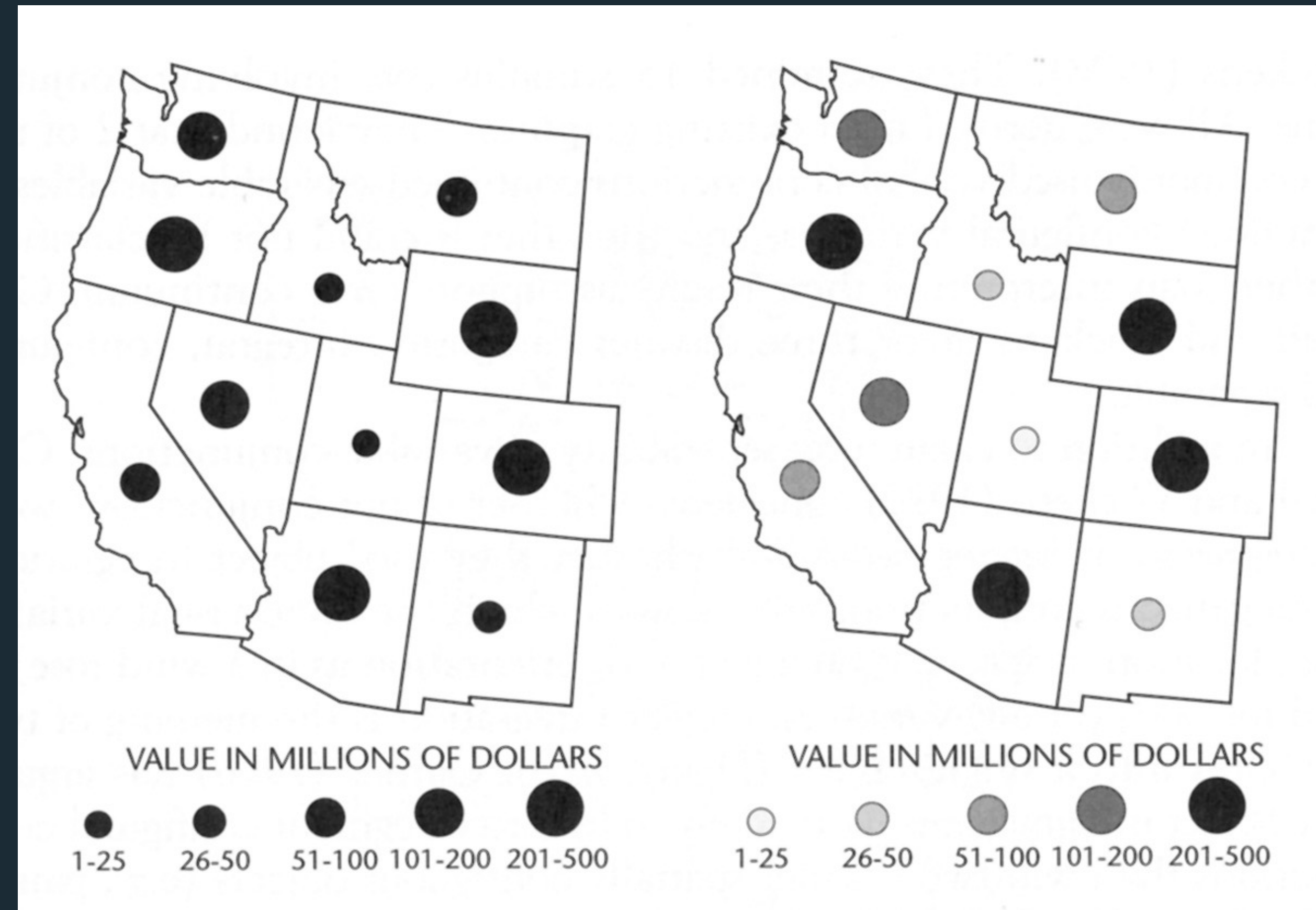
Configural

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Asymmetric

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Size & Value?



[MacEachren 1999]

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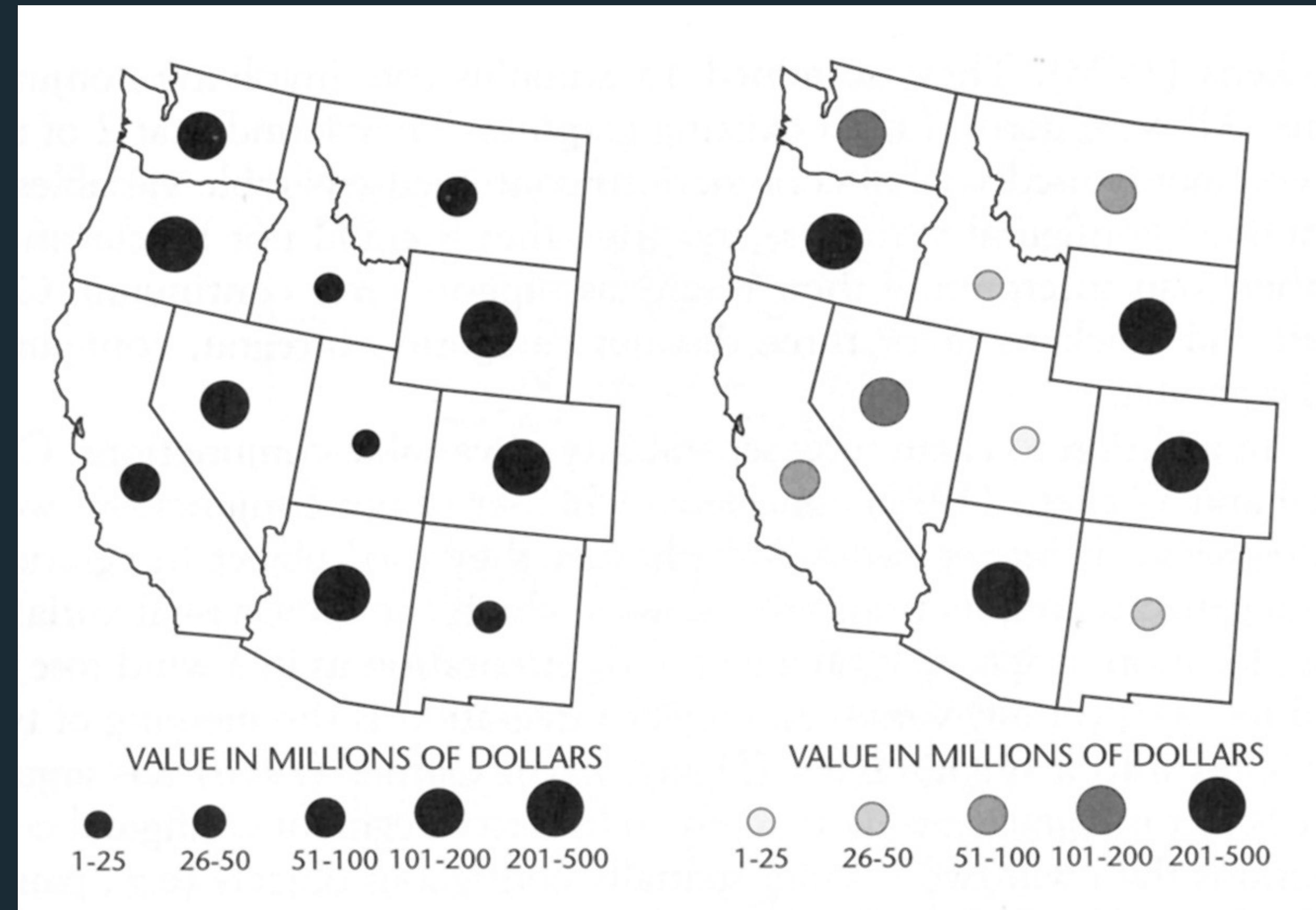
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Only interference. No redundancy gain.

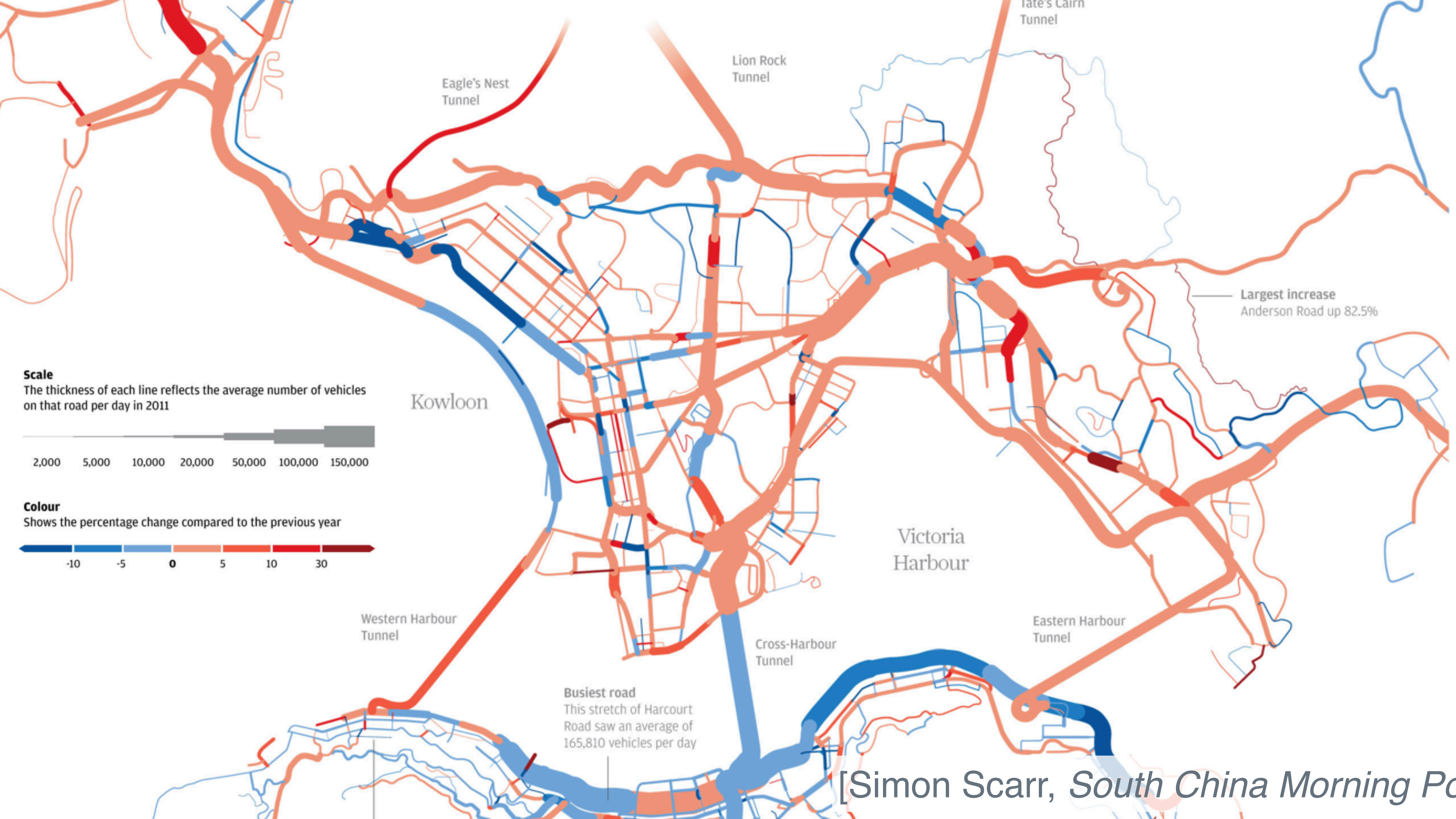
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One dimension is separable from the other, but not vice versa.

Size & Value?



[MacEachren 1999]



[Simon Scarr, *South China Morning Po*

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Shape & Size?

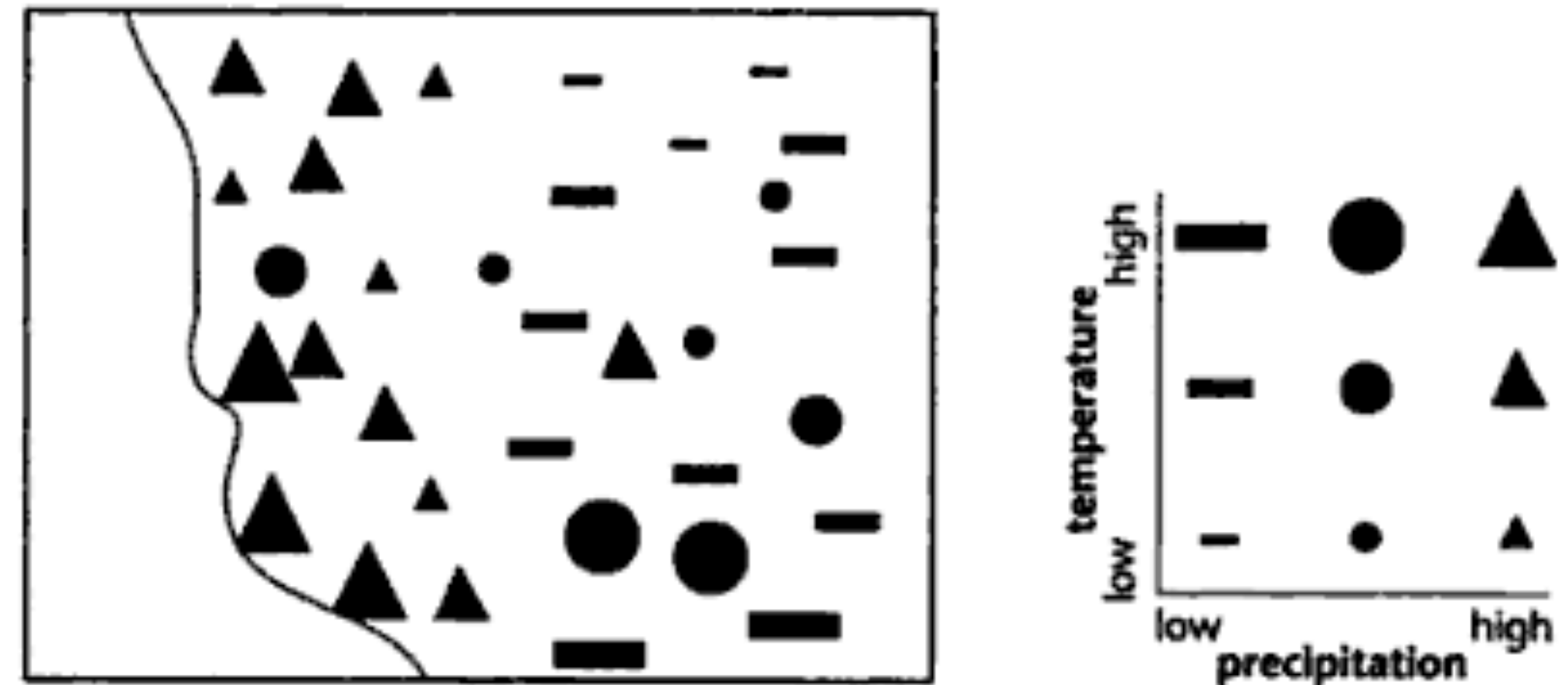


FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

[MacEachren 1999]

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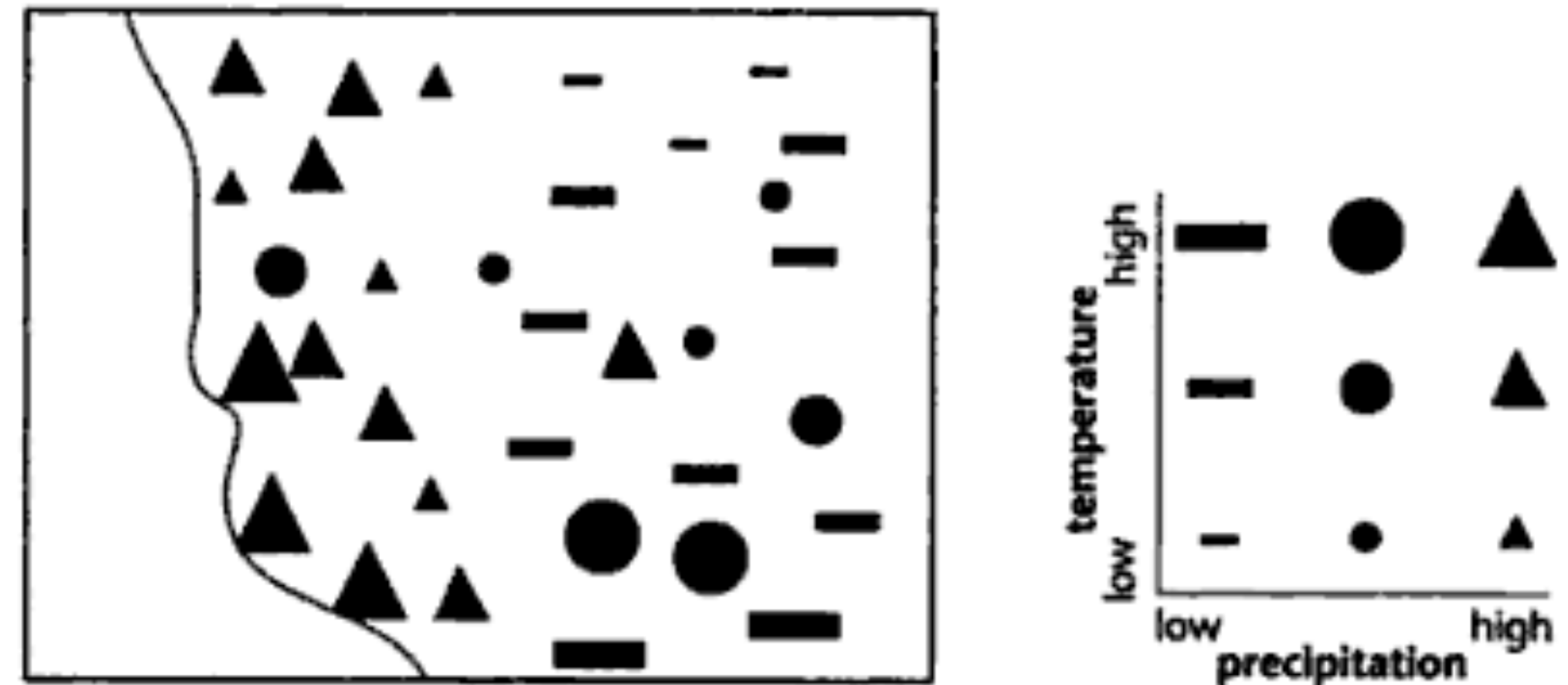


FIGURE 3.40. The bivariate temperature–precipitation map of Figure 3.36, this time using point symbols that vary in shape and size to represent the two quantities.

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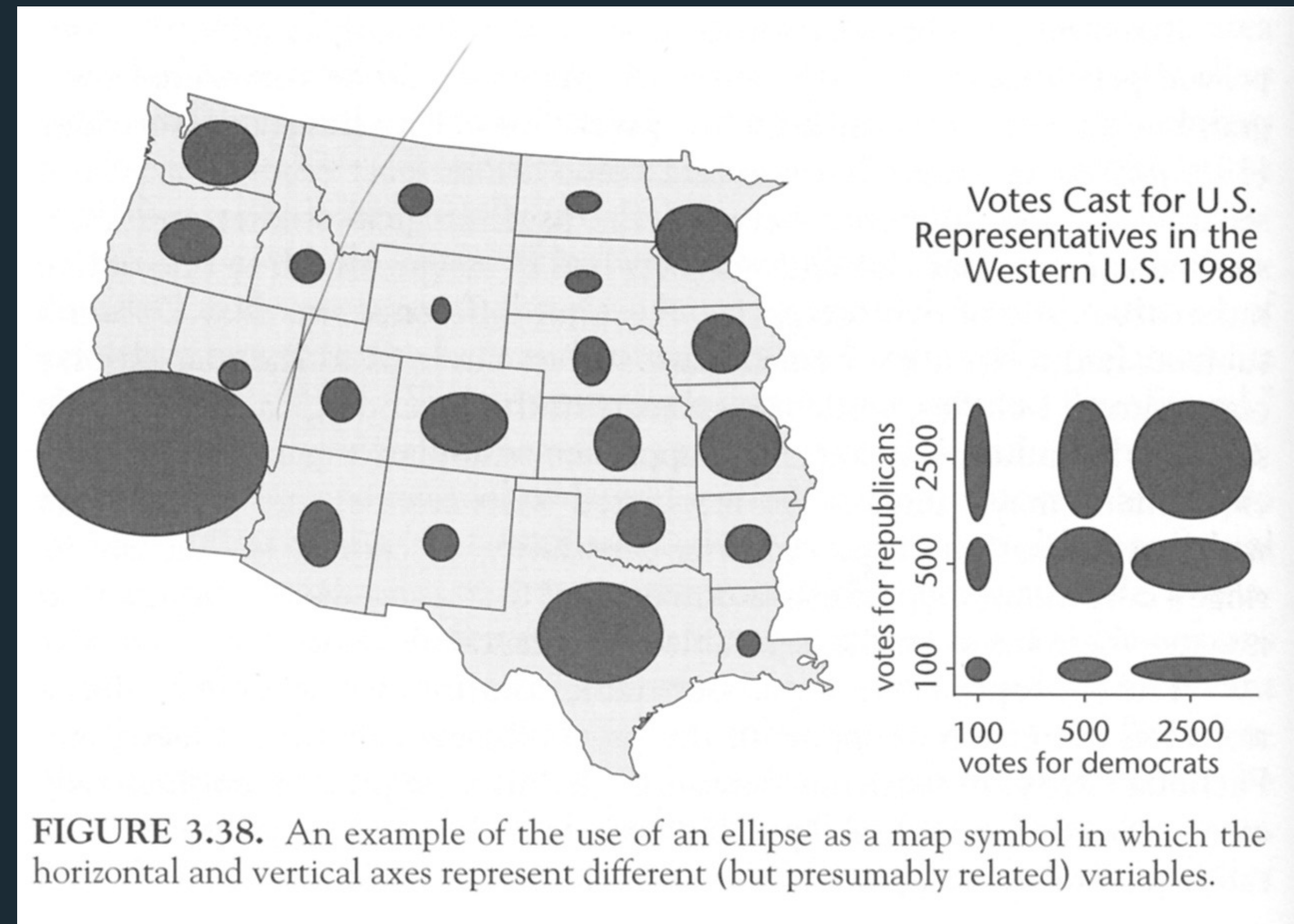
Configural

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Asymmetric

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Width & Height?



[MacEachren 1999]

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Integral

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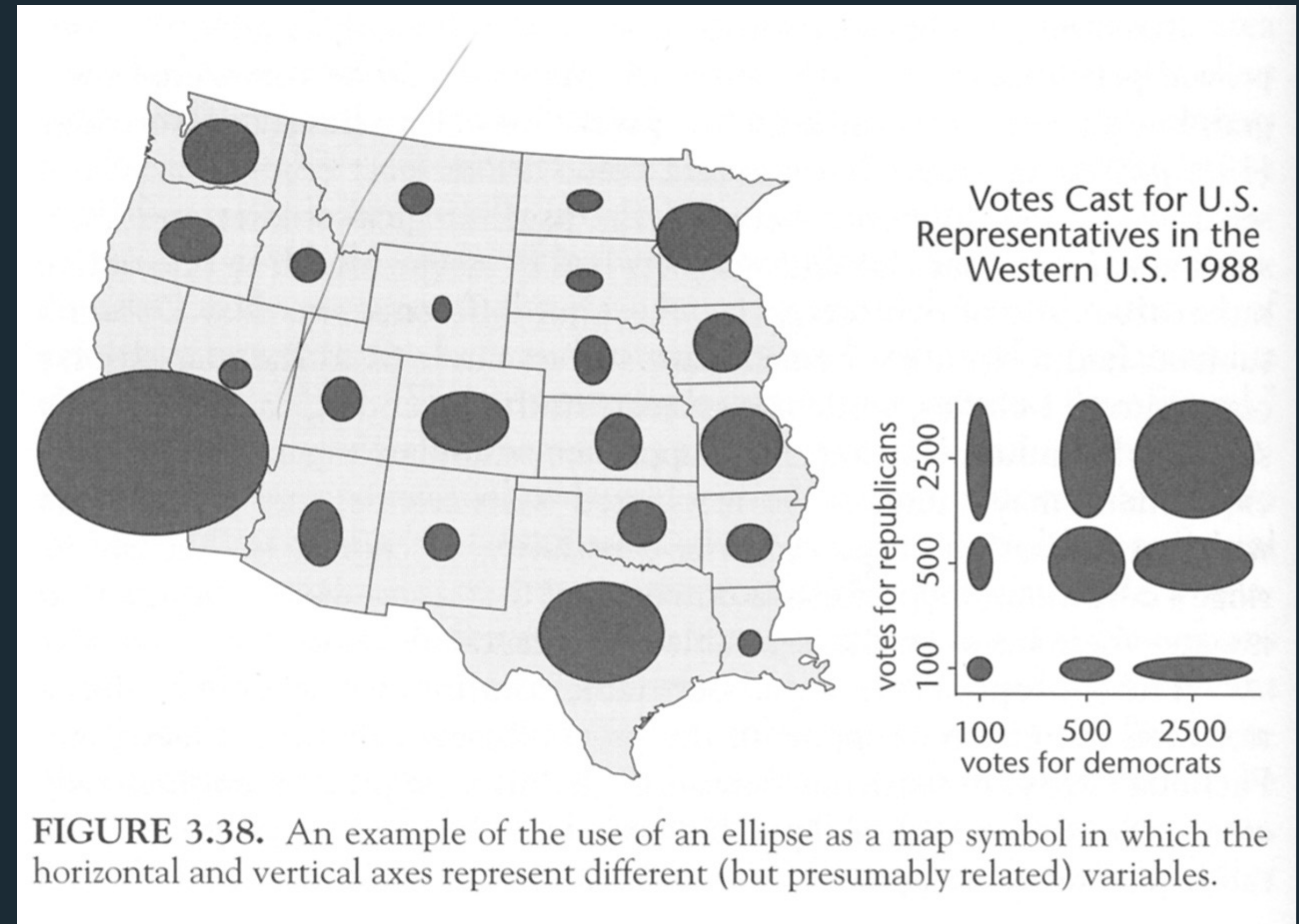
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[MacEachren 1999]

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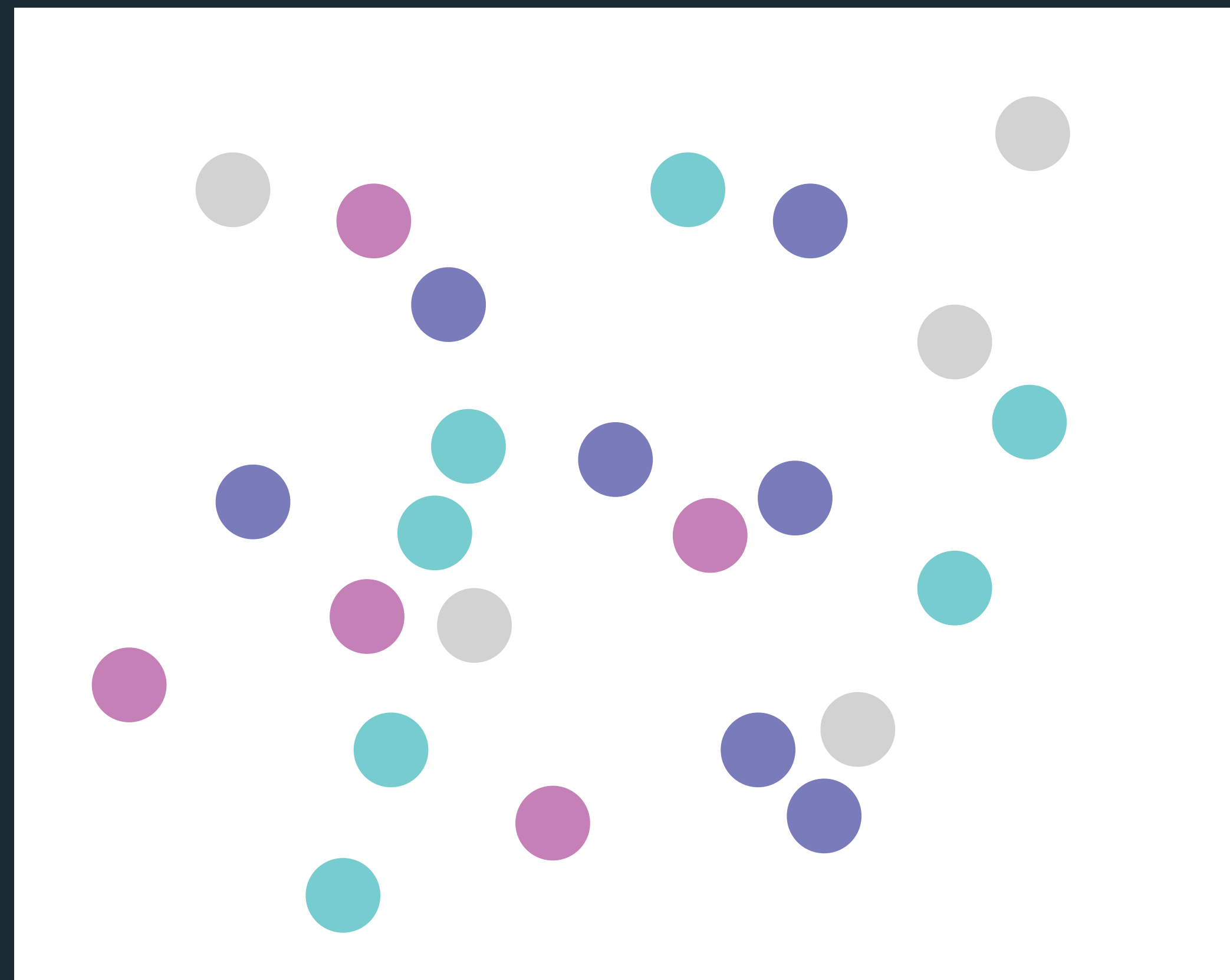
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Red & Green / Yellow & Blue?



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

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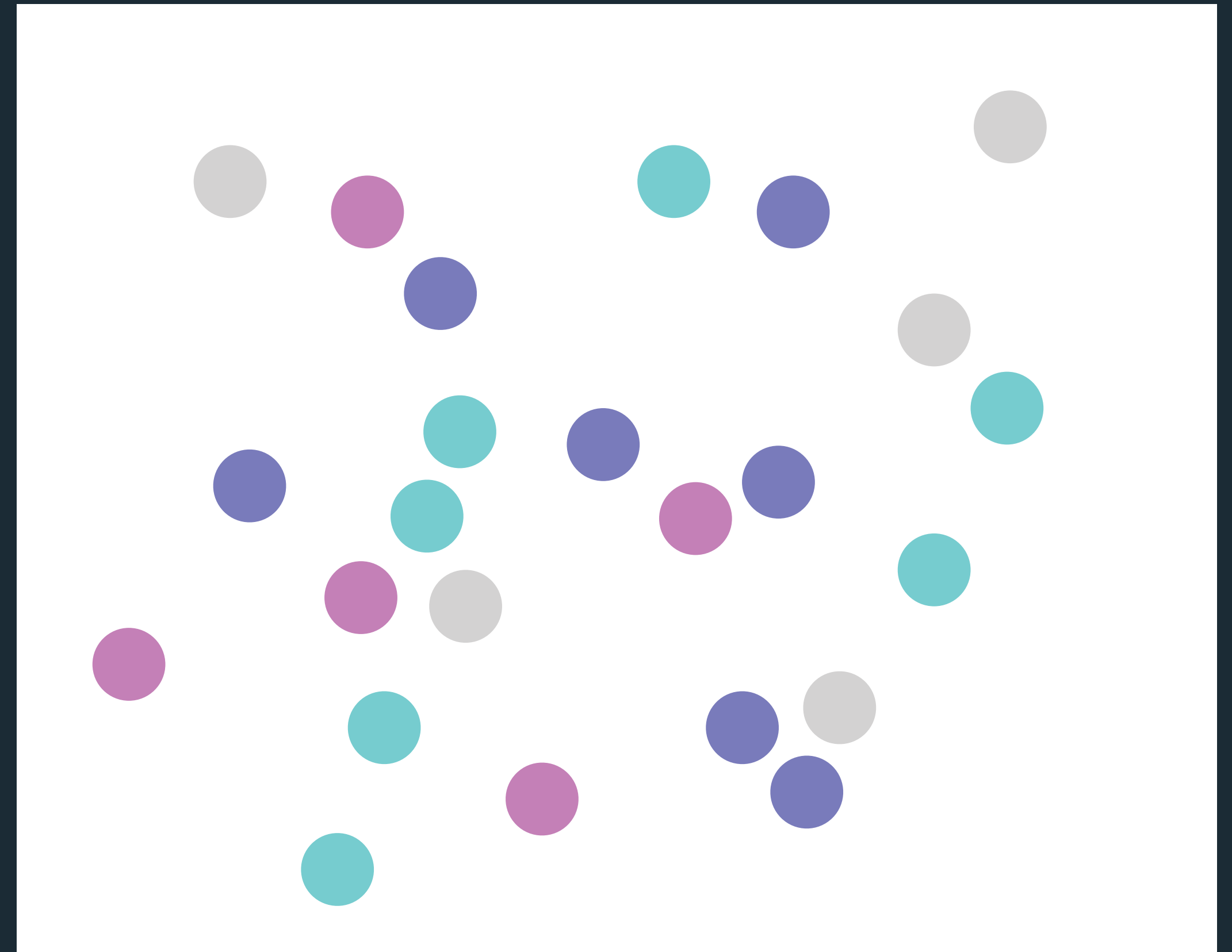
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One dimension is separable from the other, but not vice versa.

blue

yellow

red

green

orange

purple

Types of Dimensions

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

blue

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blue

yellow

red

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

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

Symmetry

Connectedness

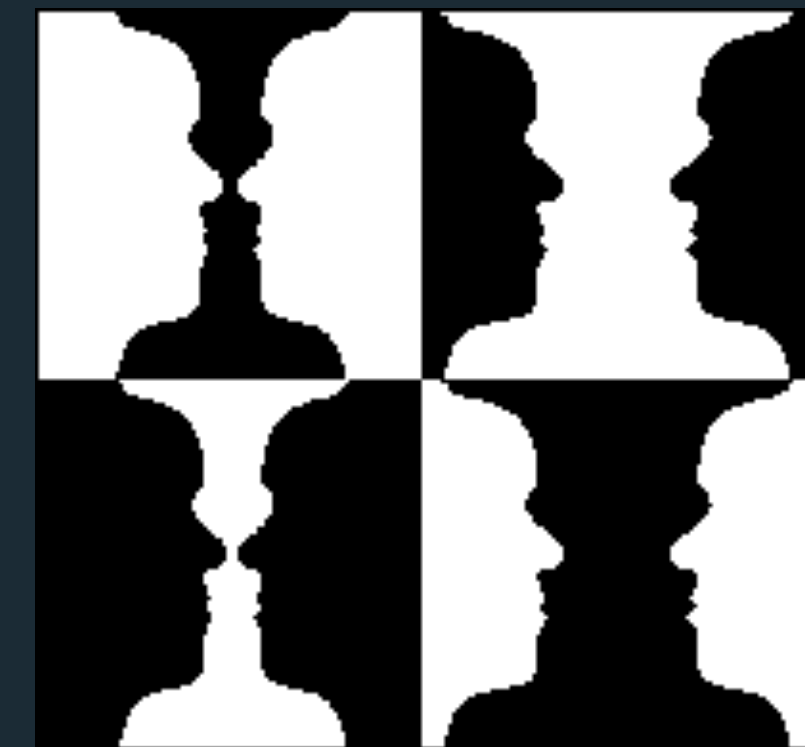
Continuity

Closure

Common Fate



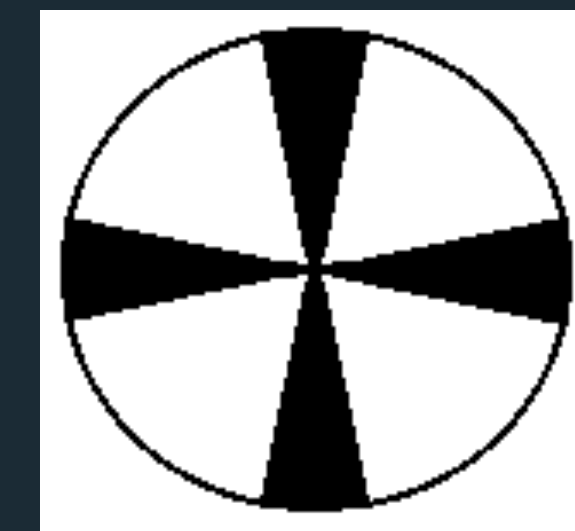
Ambiguous – vase or faces?



Unambiguous (?)



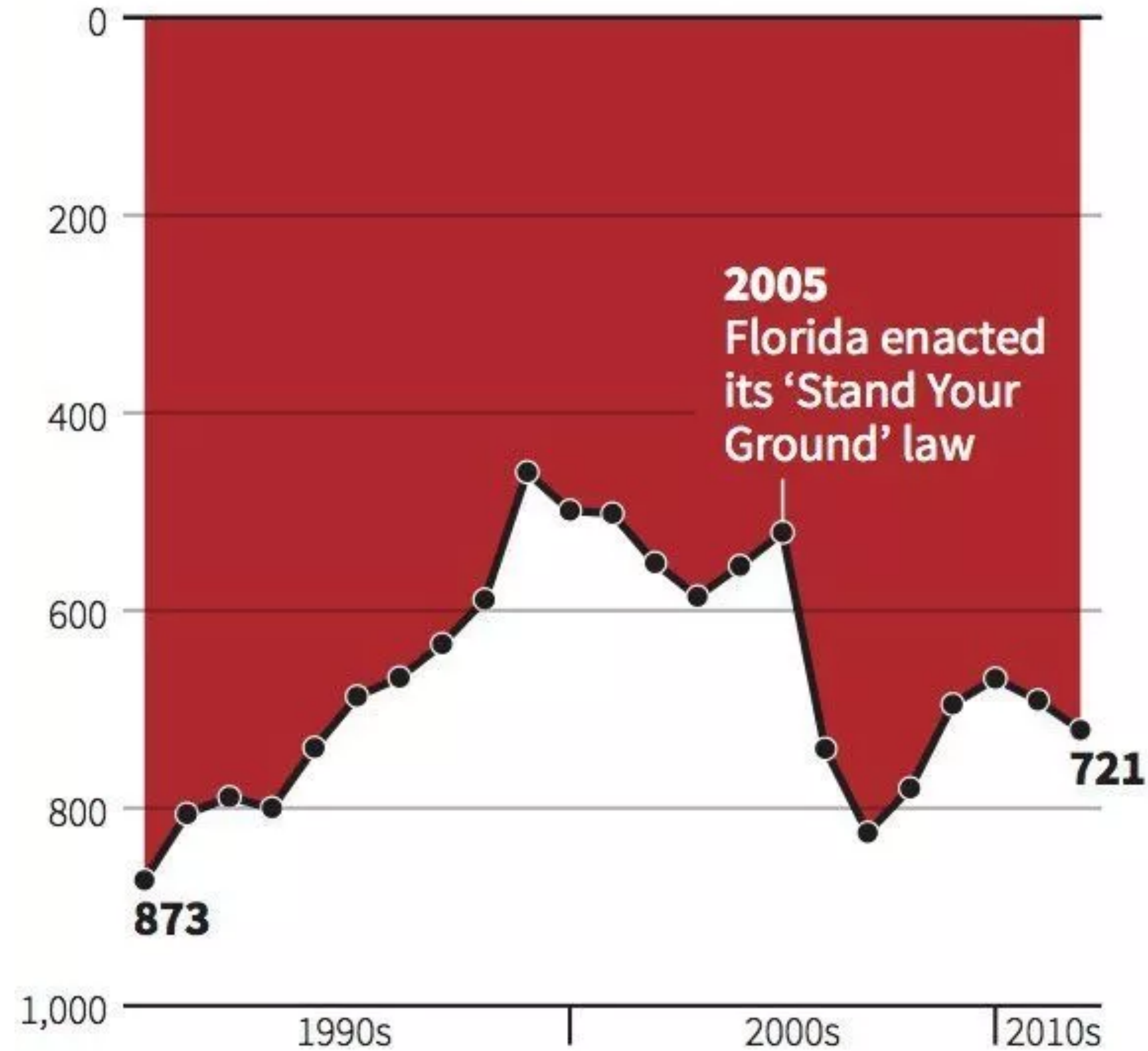
Principle of *surroundedness*.



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

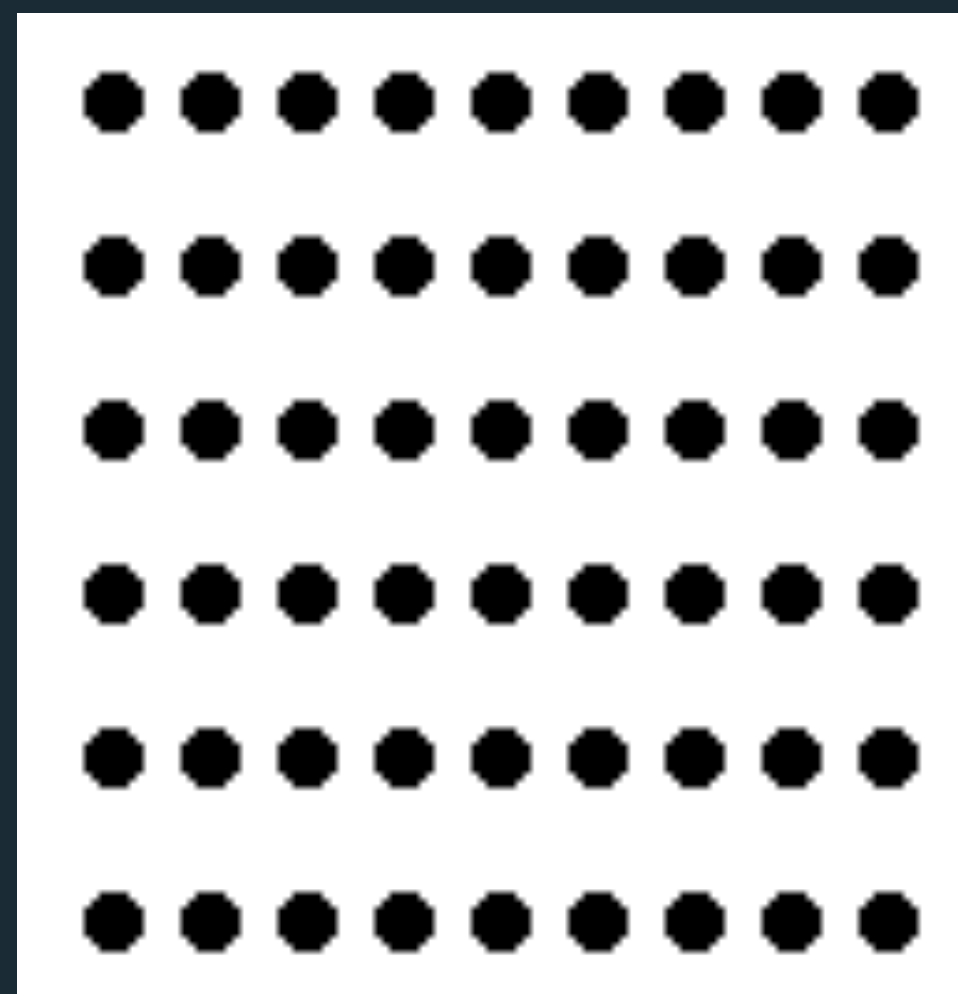
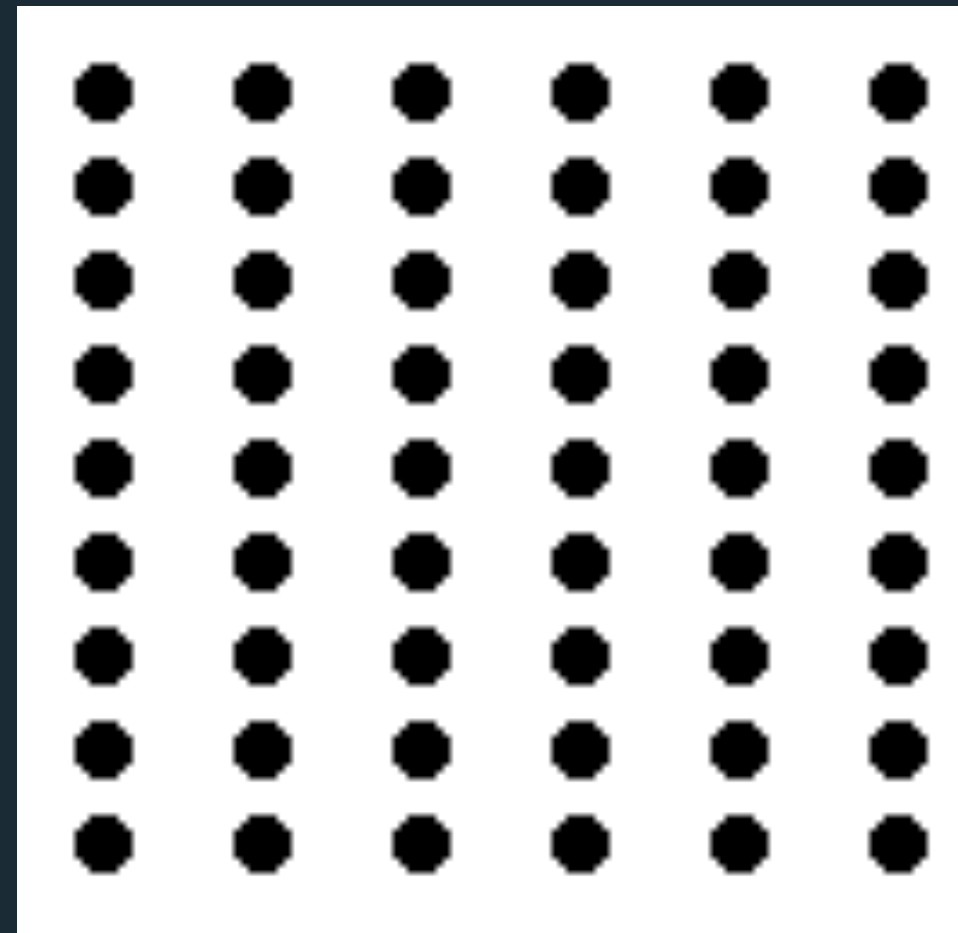
Symmetry

Connectedness

Continuity

Closure

Common Fate



Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

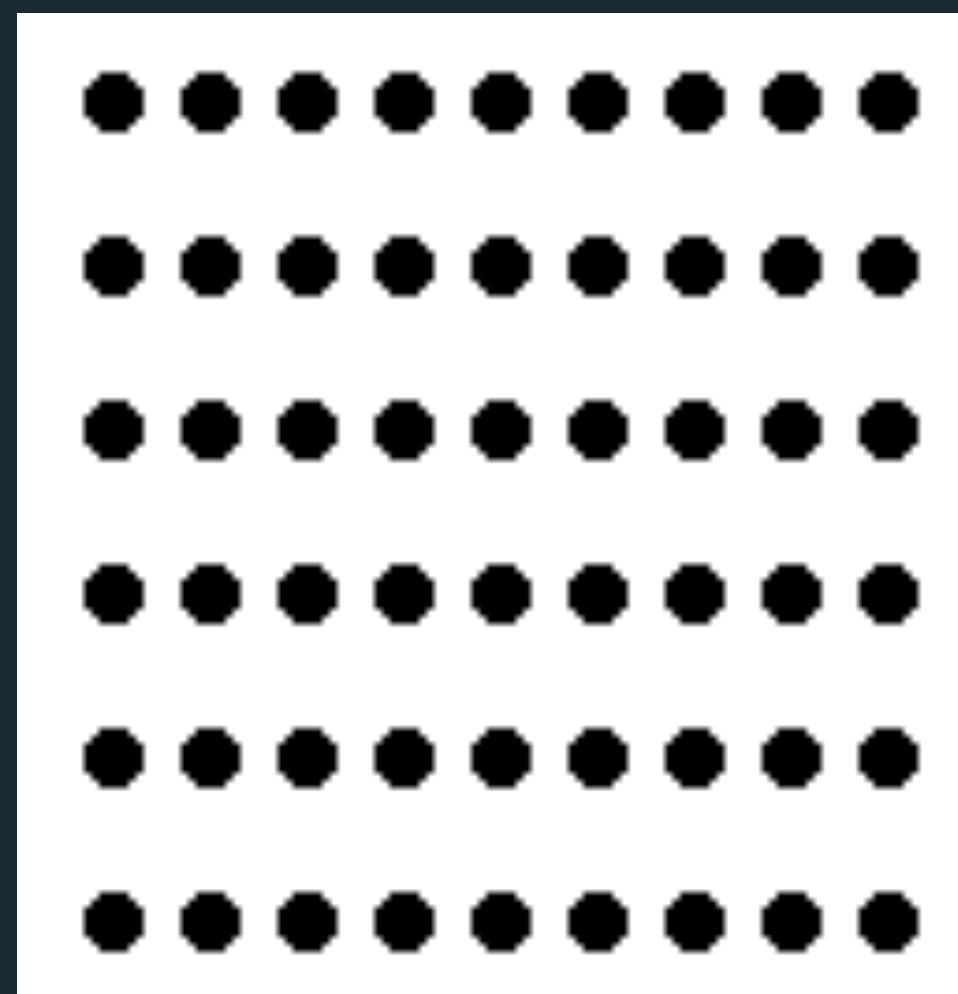
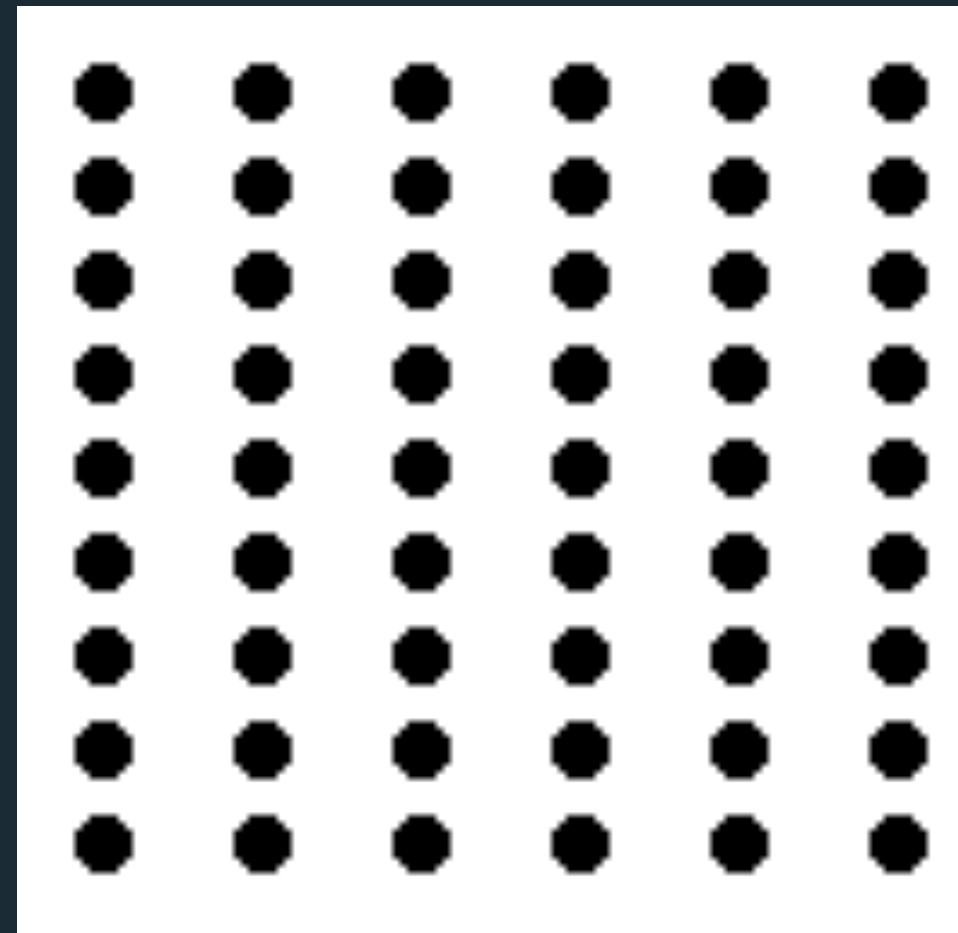
Symmetry

Connectedness

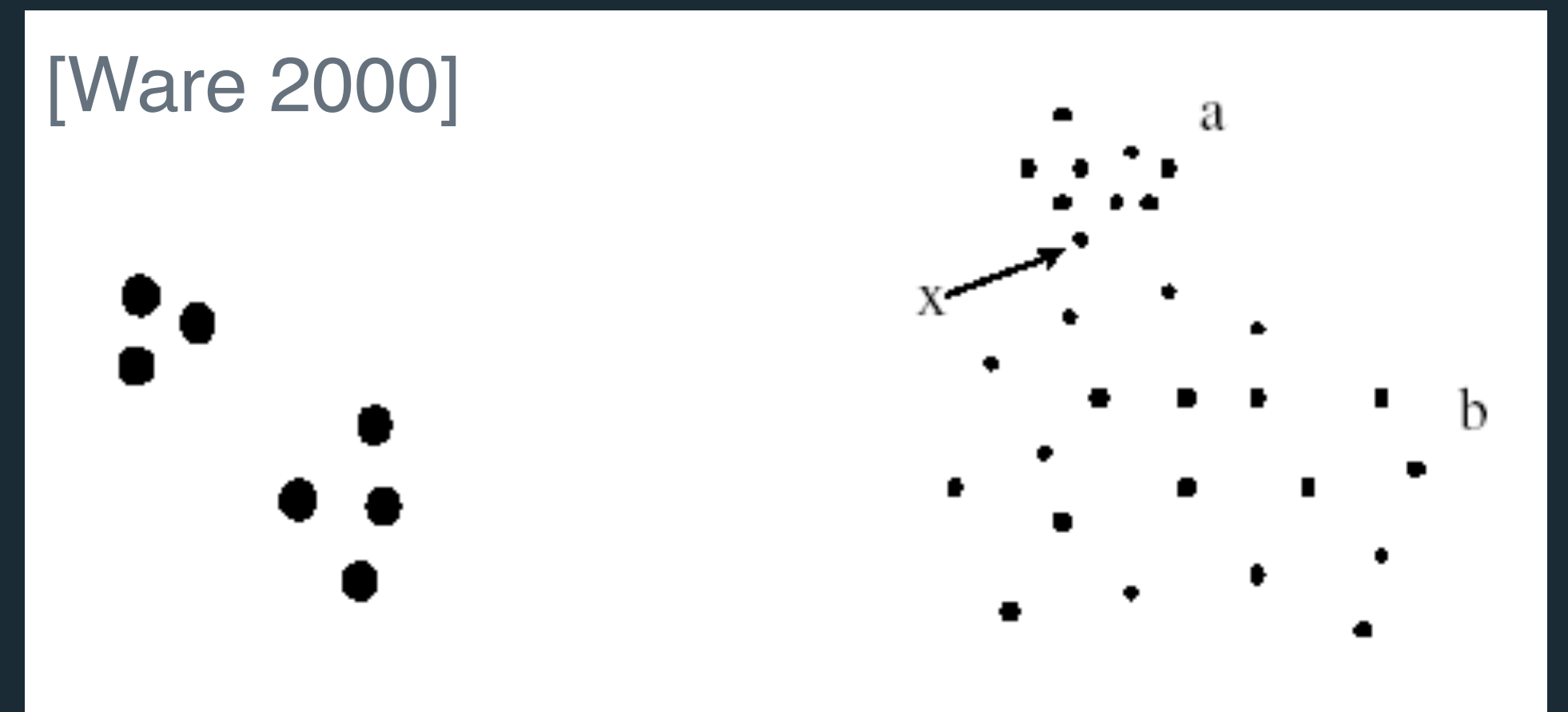
Continuity

Closure

Common Fate



[Ware 2000]



Principle of *concentration*.

Gestalt Principles

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Figure / Ground

Proximity

Similarity

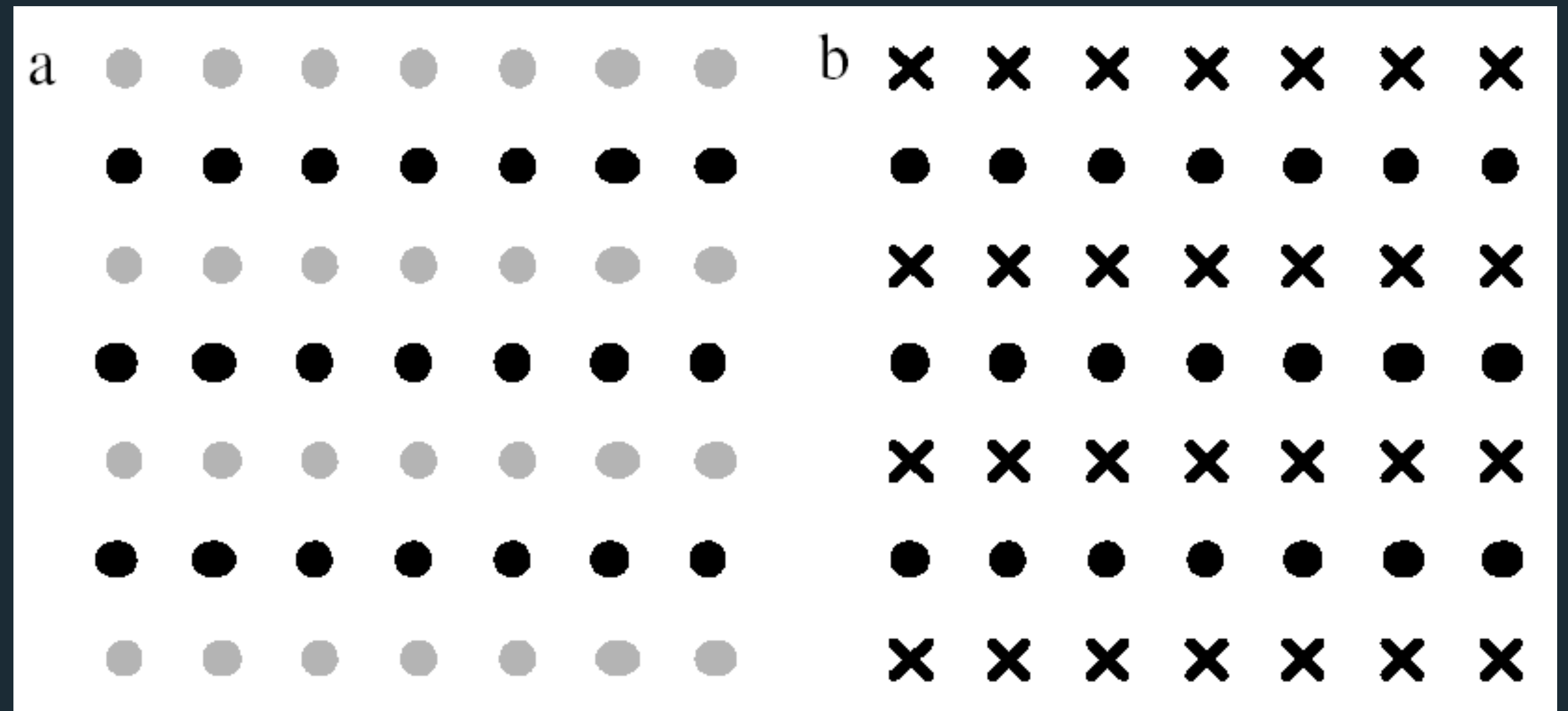
Symmetry

Connectedness

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Common Fate



Rows dominate due to similarity. [Ware 2004]

Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

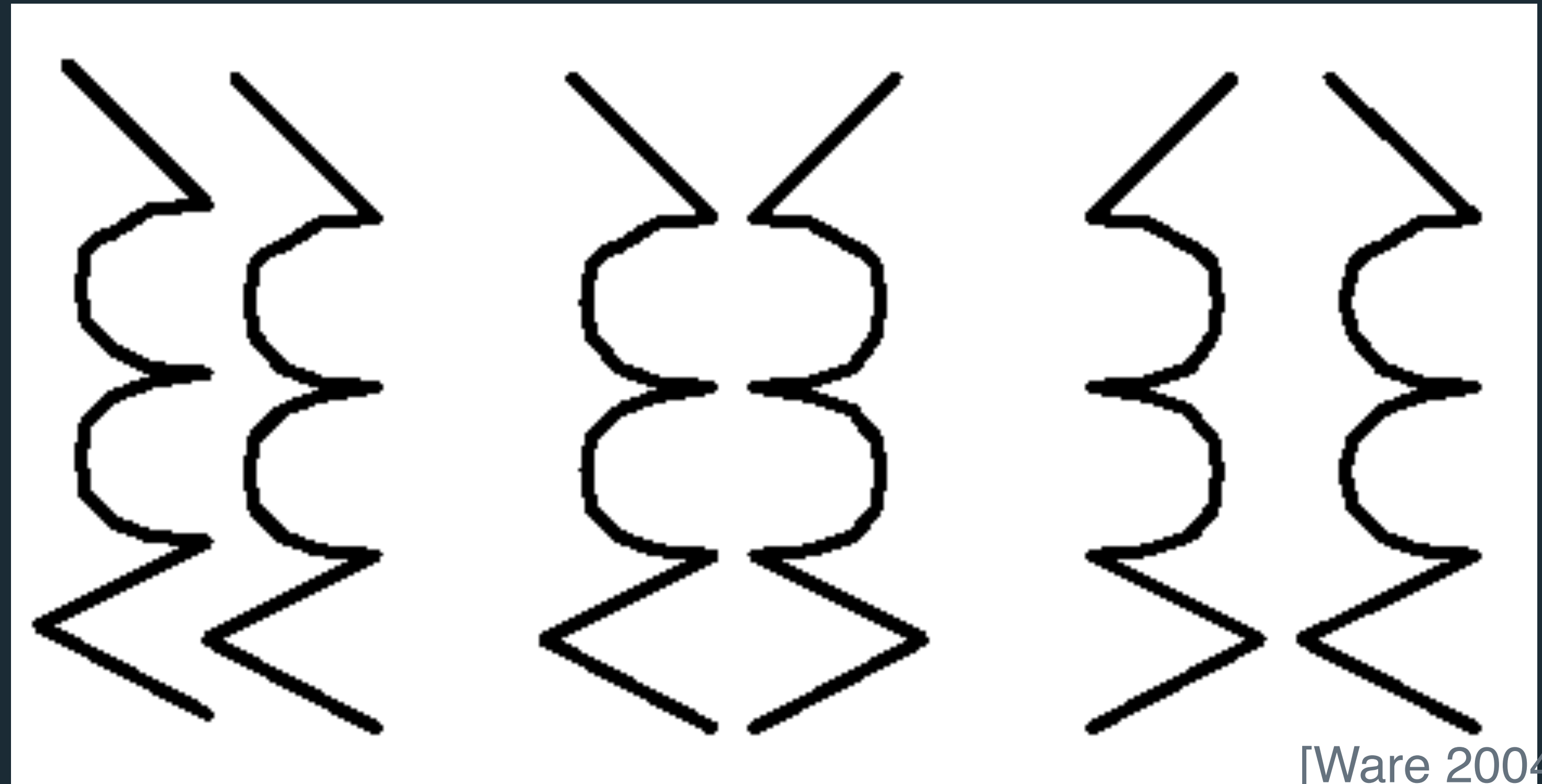
Symmetry

Connectedness

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Common Fate



Bilateral symmetry gives the strong sense of a figure.

Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

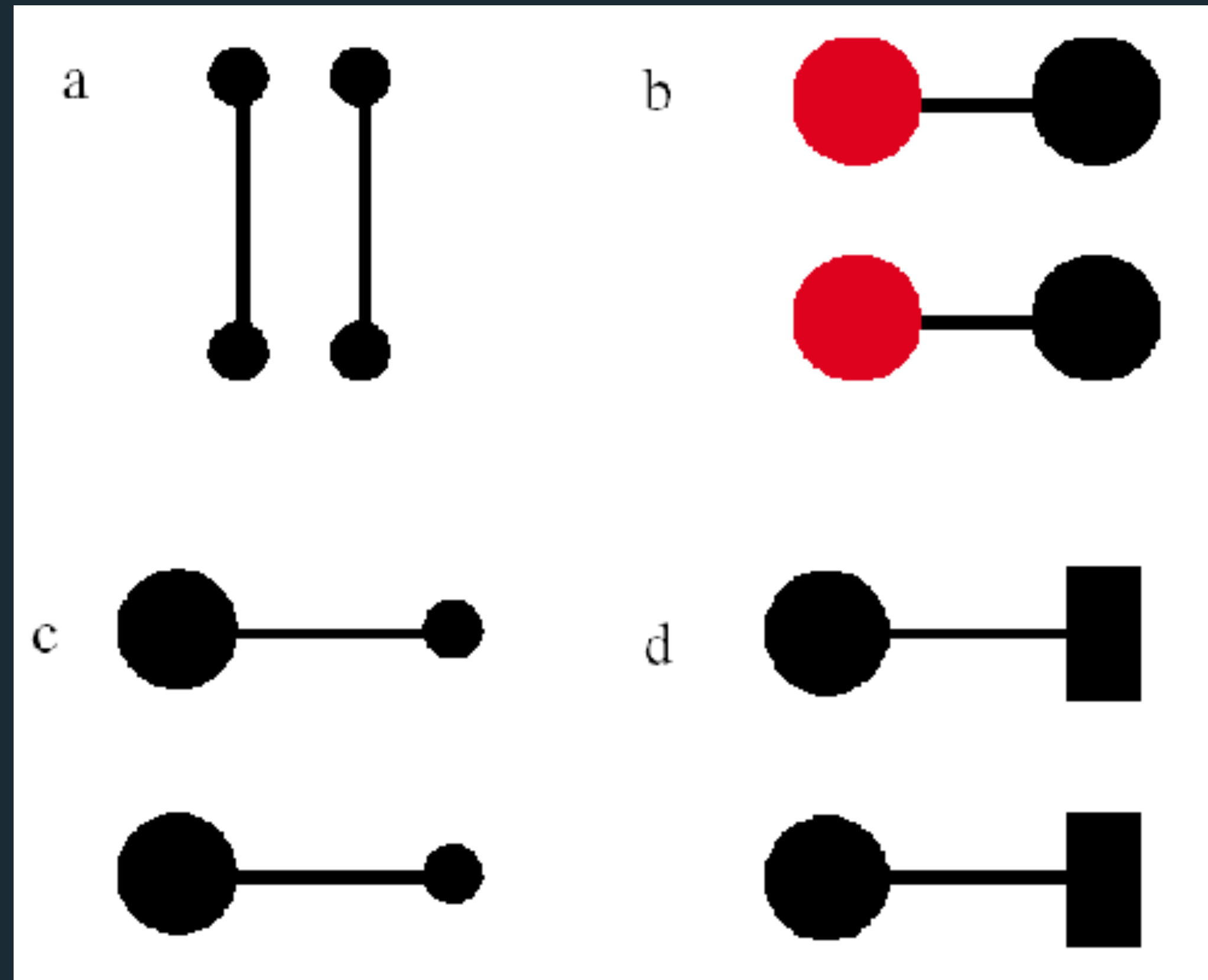
Symmetry

Connectedness

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Common Fate



[Ware 2004]

Connectedness overrules proximity, size, color, shape

Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

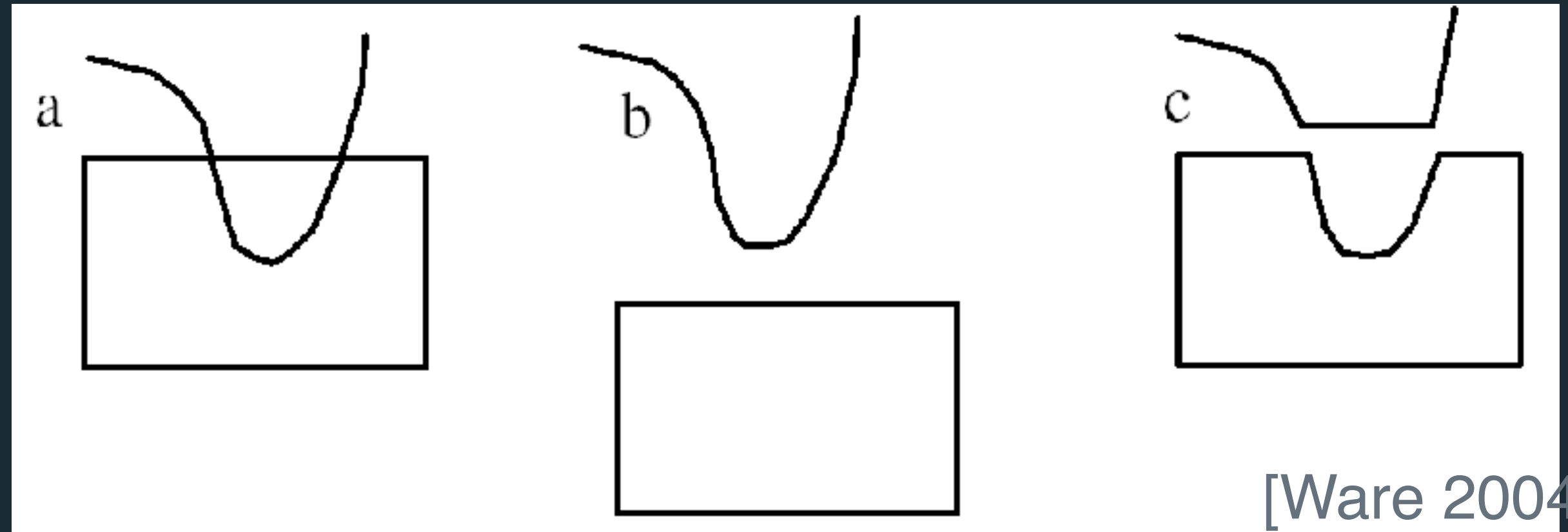
Symmetry

Connectedness

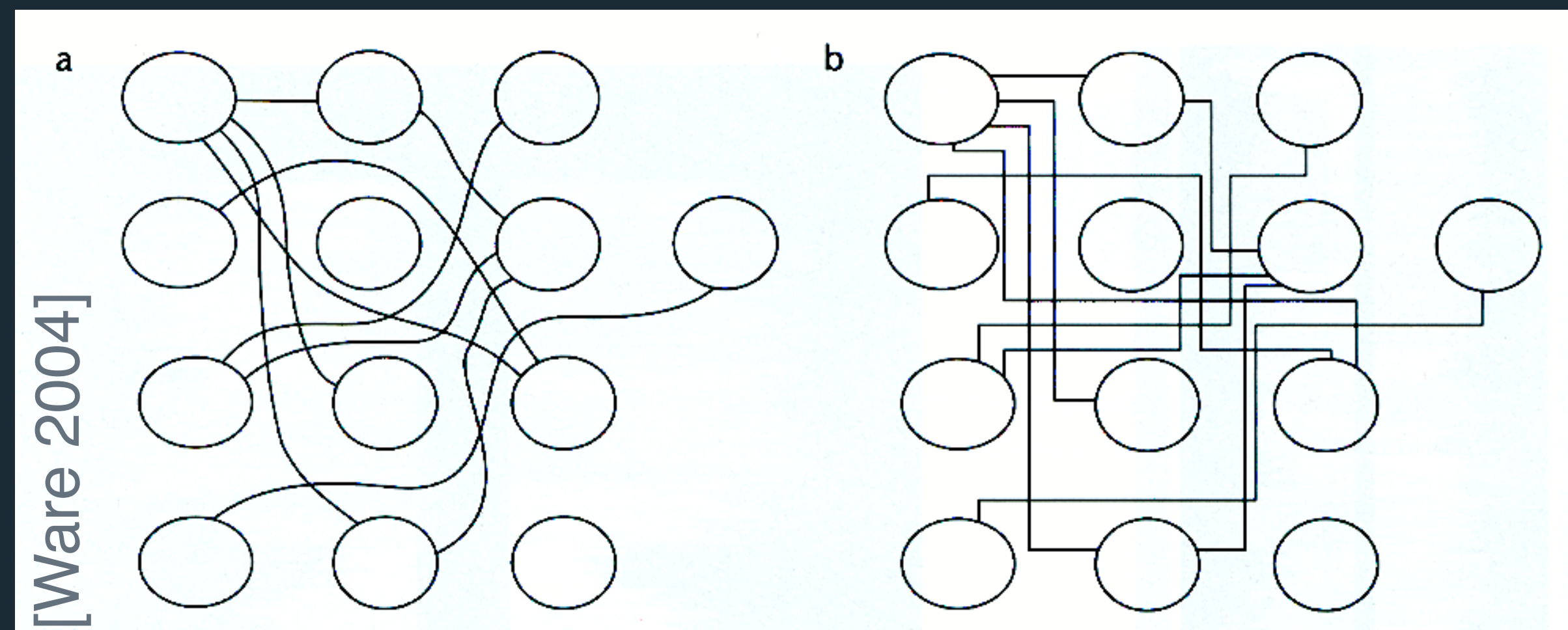
Continuity

Closure

Common Fate



We prefer smooth, not abrupt, changes.



Connections are clearer with smooth contours.

Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

Proximity

Similarity

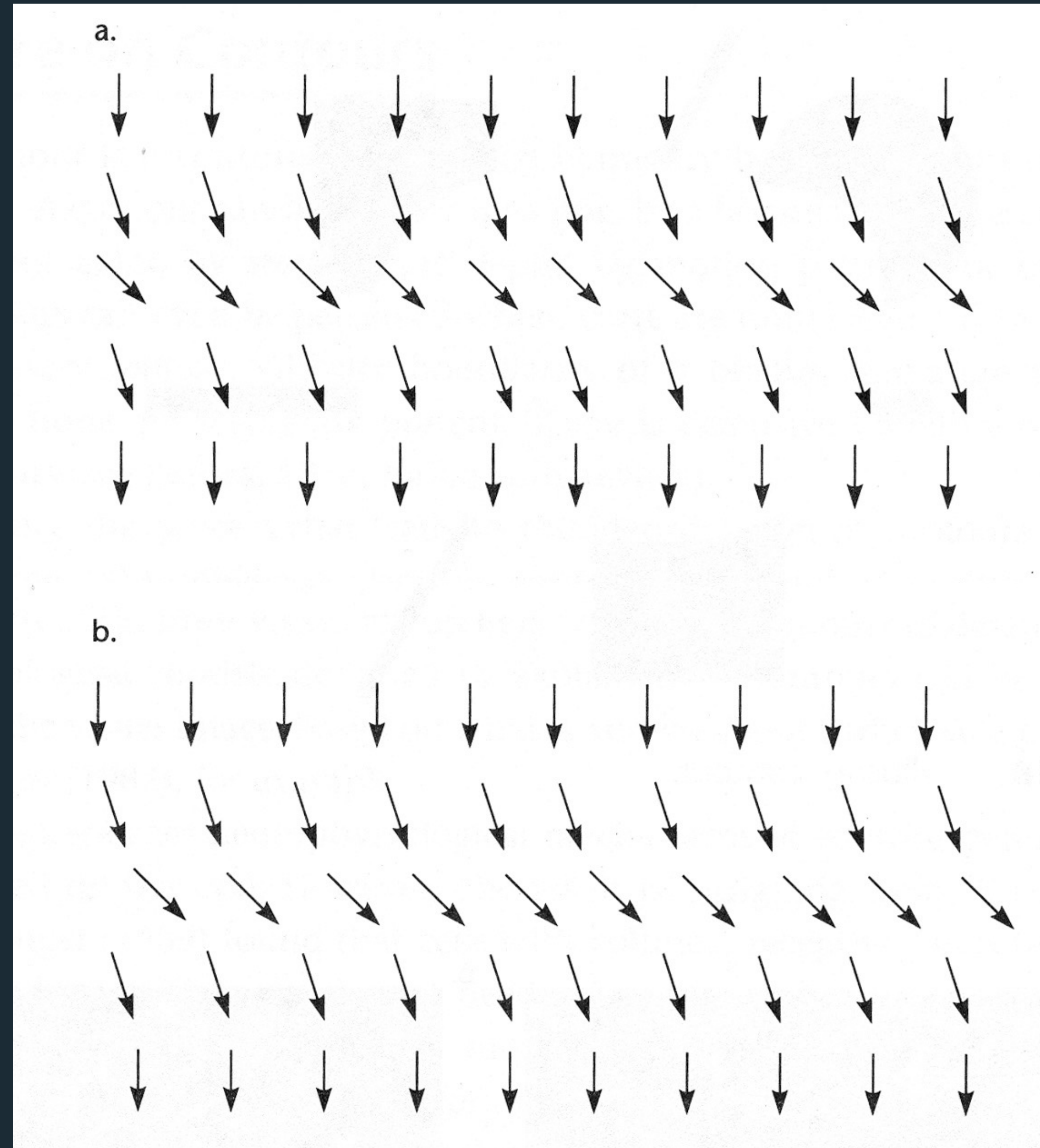
Symmetry

Connectedness

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Prefer field that shows smooth continuous contours

[Ware 2004]

Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

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Similarity

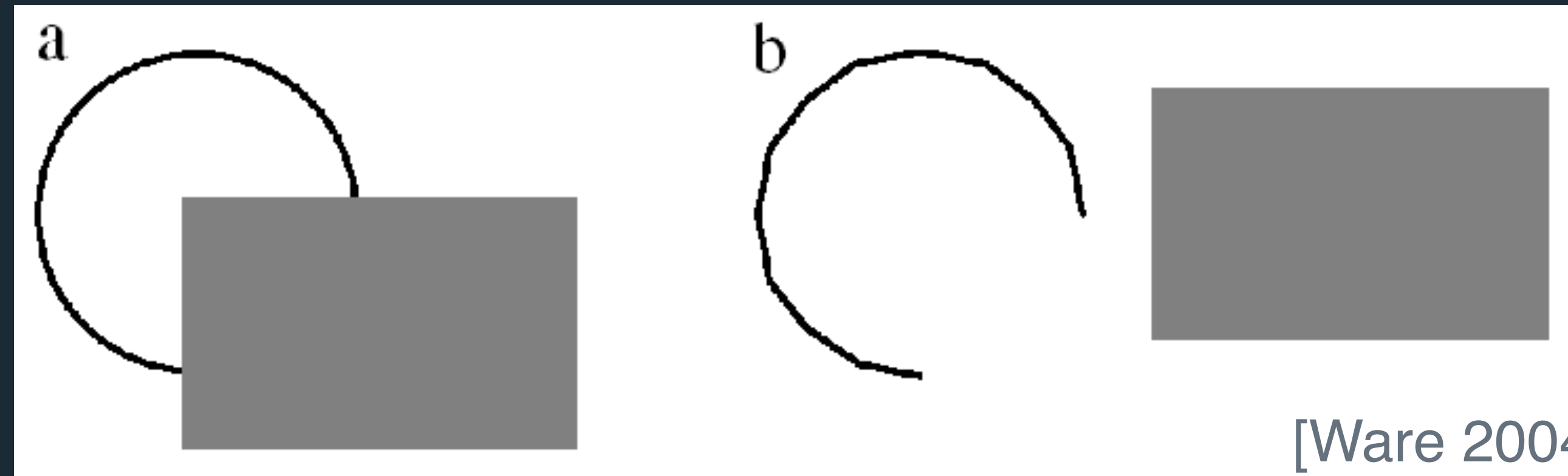
Symmetry

Connectedness

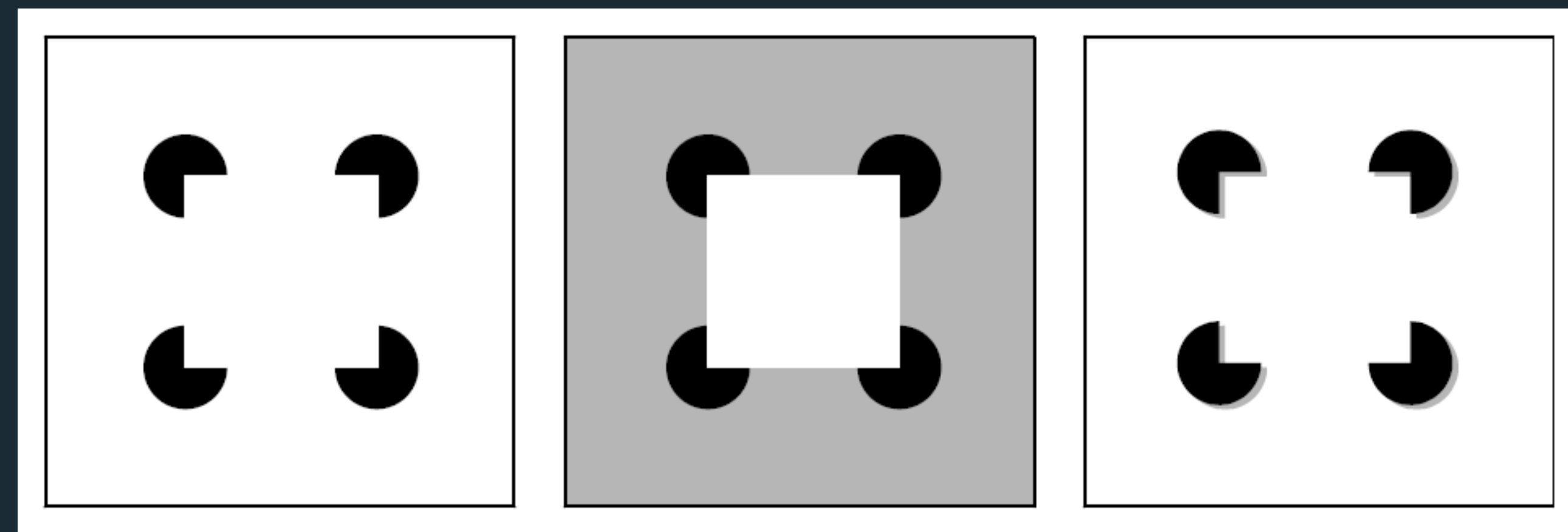
Continuity

Closure

Common Fate



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



Illusory contours

Gestalt Principles

Pragnanz: we favor the simplest and most stable interpretation

Figure / Ground

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Connectedness

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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.