

Pre-attentive Properties

How Many 7s?

5	2	8	3	6	1	9	3	6	2	5	3	7	4	3	8	3
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9
1	0	2	7	5	2	8	3	6	1	6	2	9	3	8	3	8
5	8	4	7	2	0	3	7	3	5	4	7	1	8	2	0	1
2	5	3	6	4	3	9	1	0	8	9	5	7	3	4	5	3
2	7	5	2	8	3	6	1	6	2	9	3	8	3	8	5	8
4	7	2	0	3	7	3	5	4	7	1	8	2	0	1	9	6
2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	7	5
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	7	2
0	3	7	3	5	4	7	1	8	2	0	1	2	5	3	6	4
3	9	1	0	8	9	5	7	3	4	5	3	2	7	5	2	8
3	6	1	6	2	4	6	2	7	5	9	1	5	2	6	3	6

How Many 7s?

5	2	8	3	6	1	9	3	6	2	5	3	3	7	4	3	8	3
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9	
1	0	2	7	5	2	8	3	6	1	6	2	9	3	8	3	8	
5	8	4	7	2	0	3	7	3	5	4	7	1	8	2	0	1	
2	5	3	6	4	3	9	1	0	8	9	5	7	3	4	5	3	
2	7	5	2	8	3	6	1	6	2	9	3	8	3	8	5	8	
4	7	2	0	3	7	3	5	4	7	1	8	2	0	1	9	6	
2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	7	5	
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	7	2	
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3	9	1	0	8	9	5	7	3	4	5	3	2	7	5	2	8	
3	6	1	6	2	4	6	2	7	5	9	1	5	2	6	3	6	

How Many 7s?

5	2	8	3	6	1	9	3	6	2	5	3	3	7	4	3	8	3
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9	
1	0	2	7	5	2	8	3	6	1	6	2	9	3	8	3	8	
5	8	4	7	2	0	3	7	3	5	4	7	1	8	2	0	1	
2	5	3	6	4	3	9	1	0	8	9	5	7	3	4	5	3	
2	7	5	2	8	3	6	1	6	2	9	3	8	3	8	5	8	
4	7	2	0	3	7	3	5	4	7	1	8	2	0	1	9	6	
2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	7	5	
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	7	2	
0	3	7	3	5	4	7	1	8	2	0	1	2	5	3	6	4	
3	9	1	0	8	9	5	7	3	4	5	3	2	7	5	2	8	
3	6	1	6	2	4	6	2	7	5	9	1	5	2	6	3	6	

How Many 7s?

5	2	8	3	6	1	9	3	6	2	5	3	3	7	4	3	8	3
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9	
1	0	2	7	5	2	8	3	6	1	6	2	9	3	8	3	8	
5	8	4	7	2	0	3	7	3	5	4	7	1	8	2	0	1	
2	5	3	6	4	3	9	1	0	8	9	5	7	3	4	5	3	
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2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	7	5	
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	7	2	
0	3	7	3	5	4	7	1	8	2	0	1	2	5	3	6	4	
3	9	1	0	8	9	5	7	3	4	5	3	2	7	5	2	8	
3	6	1	6	2	4	6	2	7	5	9	1	5	2	6	3	6	

How Many 7s?

7 7

7 7

7 7

7 7

7 7

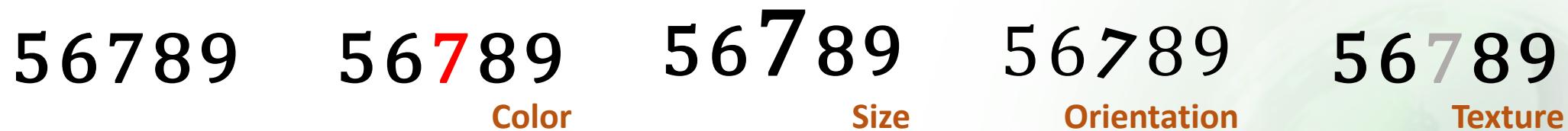
7 7

Pre-attentive Processing

- Certain basic *visual properties* are detected immediately by *low-level visual system (Iconic Memory)*
- “*Pop-out*” vs. *serial search*
- Tasks that can be performed in less than *200 to 250 milliseconds* on a complex display
 - *Eye movements* take at least *200 milliseconds* to initiate
 - Yet certain processing can be done *very quickly*, implying *low-level processing in parallel*

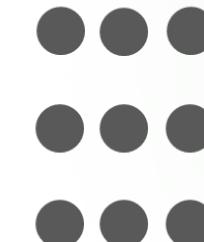
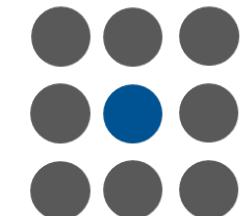
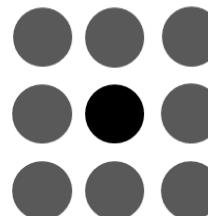
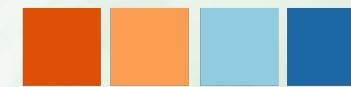
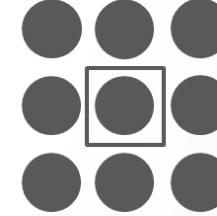
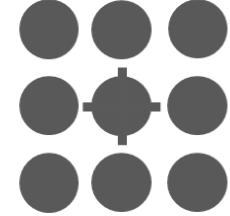
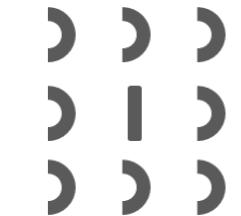
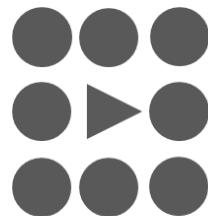
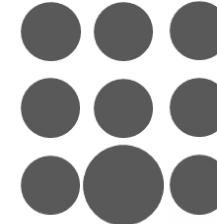
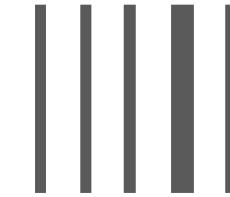
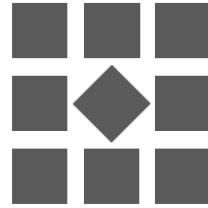
Pre-attentive Processing

- These *visual attributes/encodings* to be perceived by the pre-attentive processing (*without need for focusing attention*)



- Important for *art, design* of *visualizations*
 - What can be *perceived immediately*
 - What properties are *good discriminators*
 - What can *mislead viewers*

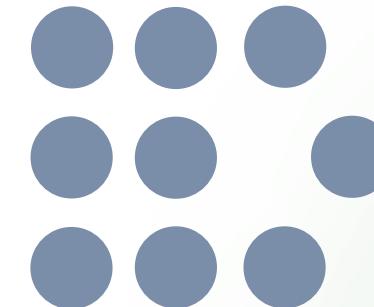
Pre-attentive Attributes



Precise Quantitative Comparisons



Length or Width



2D Position

How Many 7s?

7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
5	2	8	3	6	1	9	3	6	2	5	3	4	3	8	3	0
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9
1	0	2	5	2	8	3	6	1	6	2	9	3	8	3	8	3
5	8	4	2	0	3	3	5	4	1	8	2	0	1	3	5	4
2	5	3	6	4	3	9	1	0	8	9	5	3	4	5	3	1
2	5	2	8	3	6	1	6	2	9	3	8	3	8	5	8	8
4	2	0	3	3	5	4	1	8	2	0	1	9	6	2	0	1
2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	5	2
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	2	5
3	9	1	0	8	9	5	3	4	5	3	2	5	2	8	3	6
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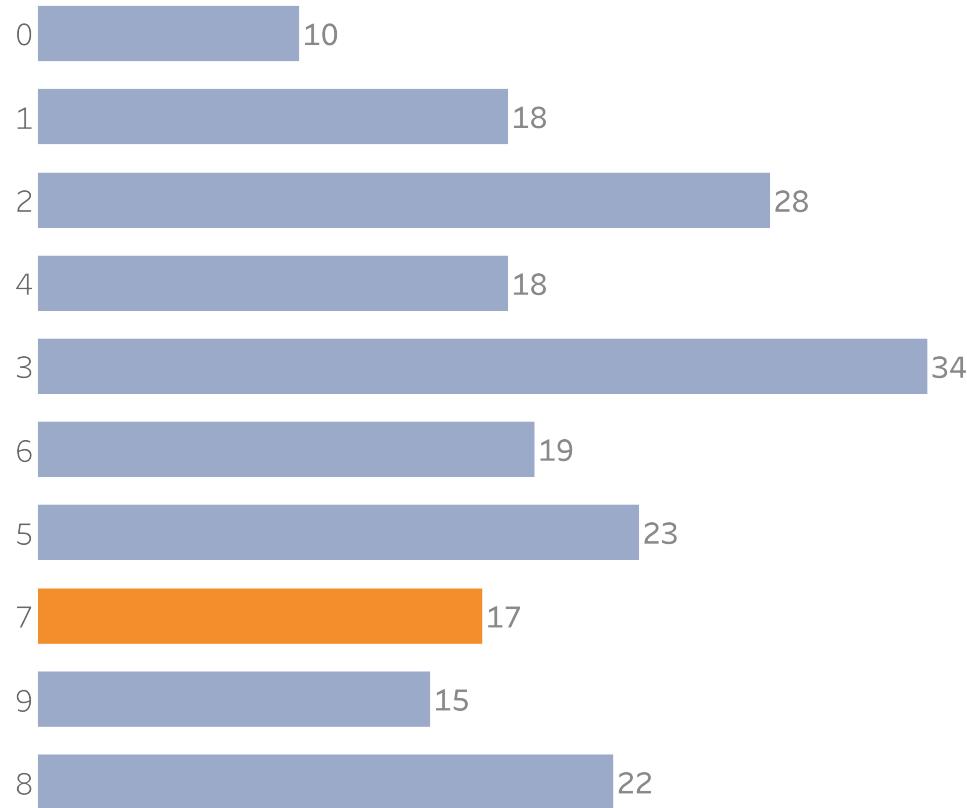
How Many 7s?

7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
5	2	8	3	6	1	9	3	6	2	5	3	4	3	8	3	0
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9
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5	8	4	2	0	3	3	5	4	1	8	2	0	1	3	5	4
2	5	3	6	4	3	9	1	0	8	9	5	3	4	5	3	1
2	5	2	8	3	6	1	6	2	9	3	8	3	8	5	8	8
4	2	0	3	3	5	4	1	8	2	0	1	9	6	2	0	1
2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	5	2
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	2	5
3	9	1	0	8	9	5	3	4	5	3	2	5	2	8	3	6
3	6	1	6	2	4	6	2	5	9	1	5	2	6	3	6	4

How Many 7s?

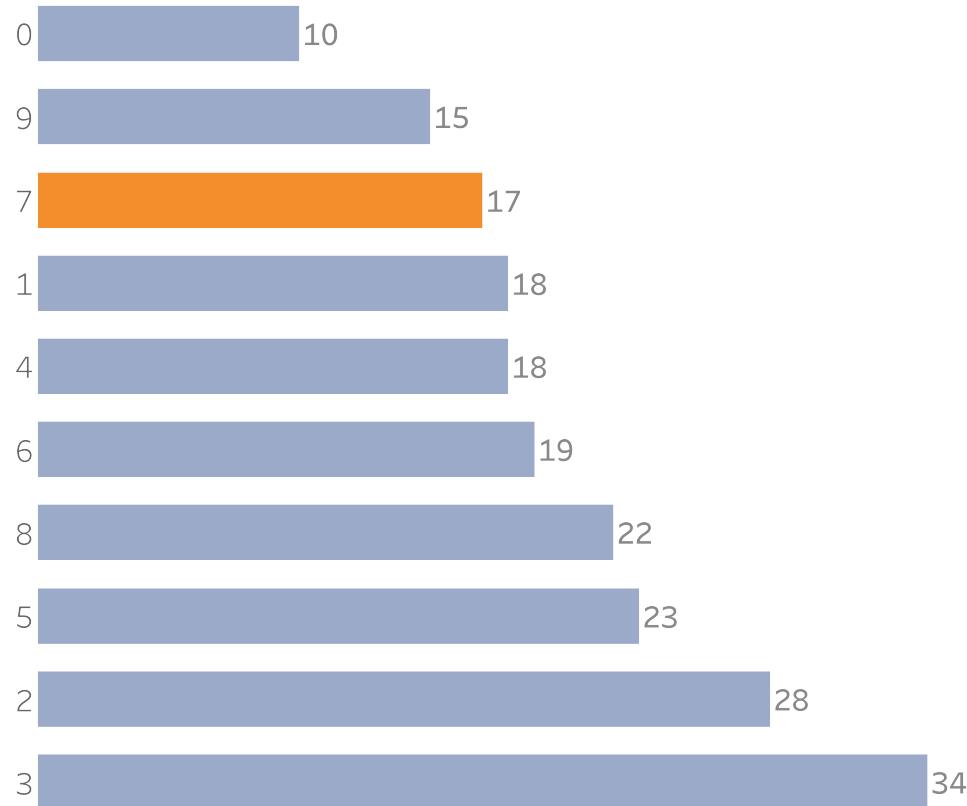
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8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9
1	0	2	5	2	8	3	6	1	6	2	9	3	8	3	8	3
5	8	4	2	0	3	3	5	4	1	8	2	0	1	3	5	4
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3	9	1	0	8	9	5	3	4	5	3	2	5	2	8	3	6
3	6	1	6	2	4	6	2	5	9	1	5	2	6	3	6	4

Number of Seven: 17



7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
5	2	8	3	6	1	9	3	6	2	5	3	4	3	8	3	0
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9
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2	5	3	6	4	3	9	1	0	8	9	5	3	4	5	3	1
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4	2	0	3	3	5	4	1	8	2	0	1	9	6	2	0	1
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2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	2	5
3	9	1	0	8	9	5	3	4	5	3	2	5	2	8	3	6
3	6	1	6	2	4	6	2	5	9	1	5	2	6	3	6	4

Number of Seven: 17



7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
5	2	8	3	6	1	9	3	6	2	5	3	4	3	8	3	0
8	5	8	9	6	2	1	4	4	3	9	3	6	5	2	4	9
1	0	2	5	2	8	3	6	1	6	2	9	3	8	3	8	3
5	8	4	2	0	3	3	5	4	1	8	2	0	1	3	5	4
2	5	3	6	4	3	9	1	0	8	9	5	3	4	5	3	1
2	5	2	8	3	6	1	6	2	9	3	8	3	8	5	8	8
4	2	0	3	3	5	4	1	8	2	0	1	9	6	2	0	1
2	1	4	4	3	9	3	6	5	2	4	9	1	0	2	5	2
2	8	3	6	1	6	2	9	3	8	3	8	5	8	4	2	5
3	9	1	0	8	9	5	3	4	5	3	2	5	2	8	3	6
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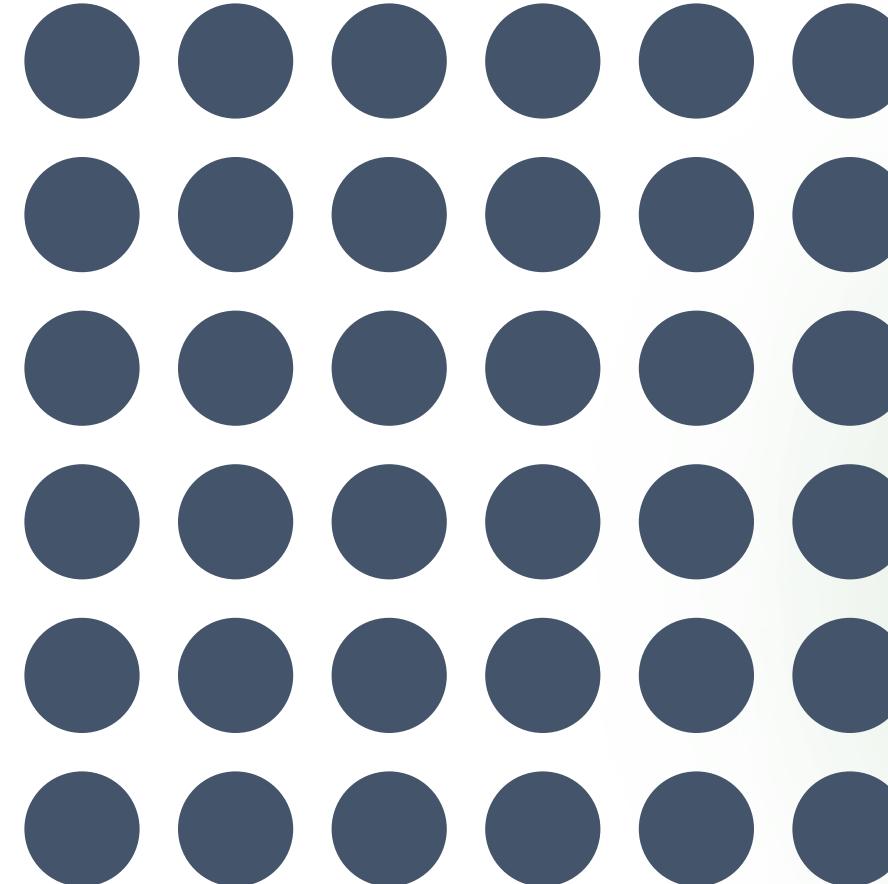
Making Sense of Our Visual World

Our *perception of data* on a typical page *is associated* with the following *visual variables*

Category	Form	Color	Spatial Position	Motion
Attribute	Shape Orientation Size Texture Value Length Width Enclosure Order ...	Hue Value Intensity	2D/3D position	Direction

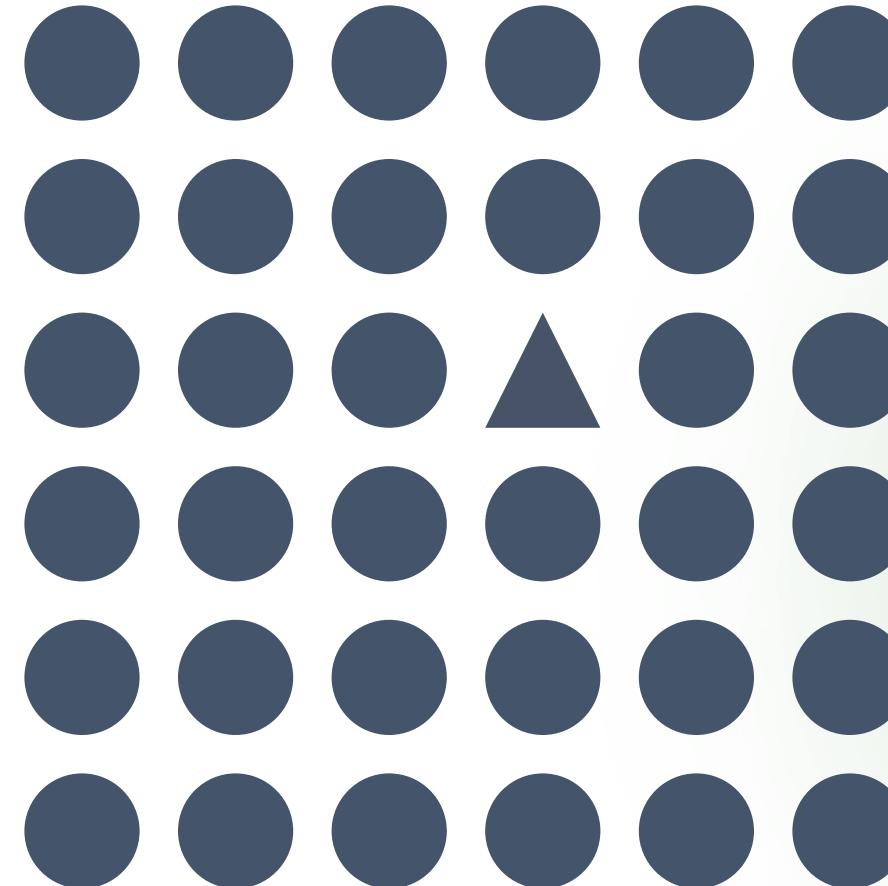
Pre-attentive Attribute

Form - Shape



Pre-attentive Attribute

Form - Shape



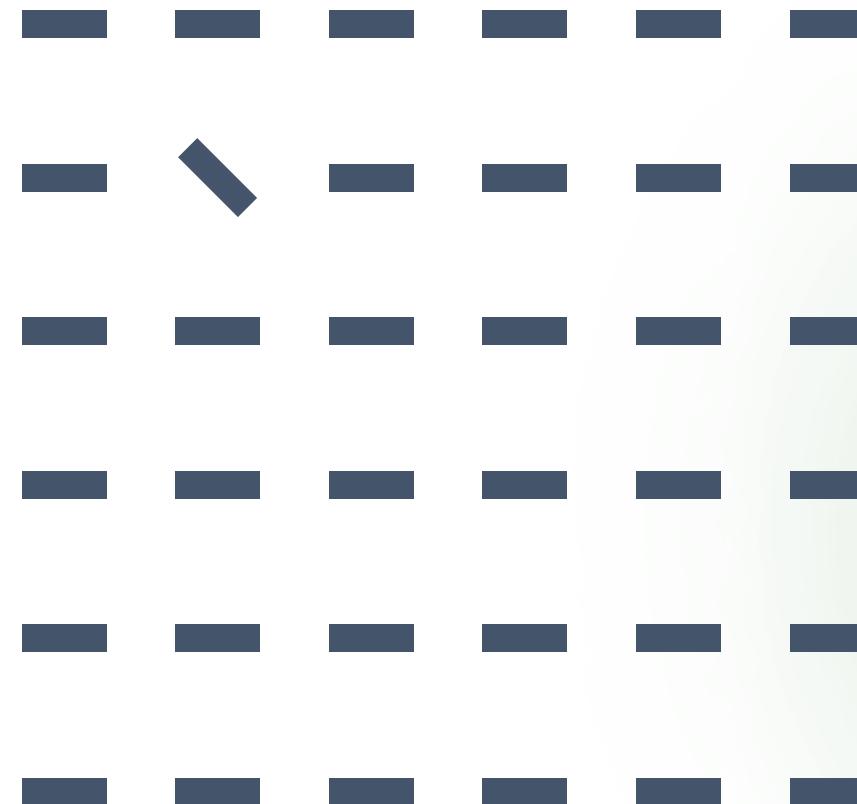
Pre-attentive Attribute

Form - Orientation



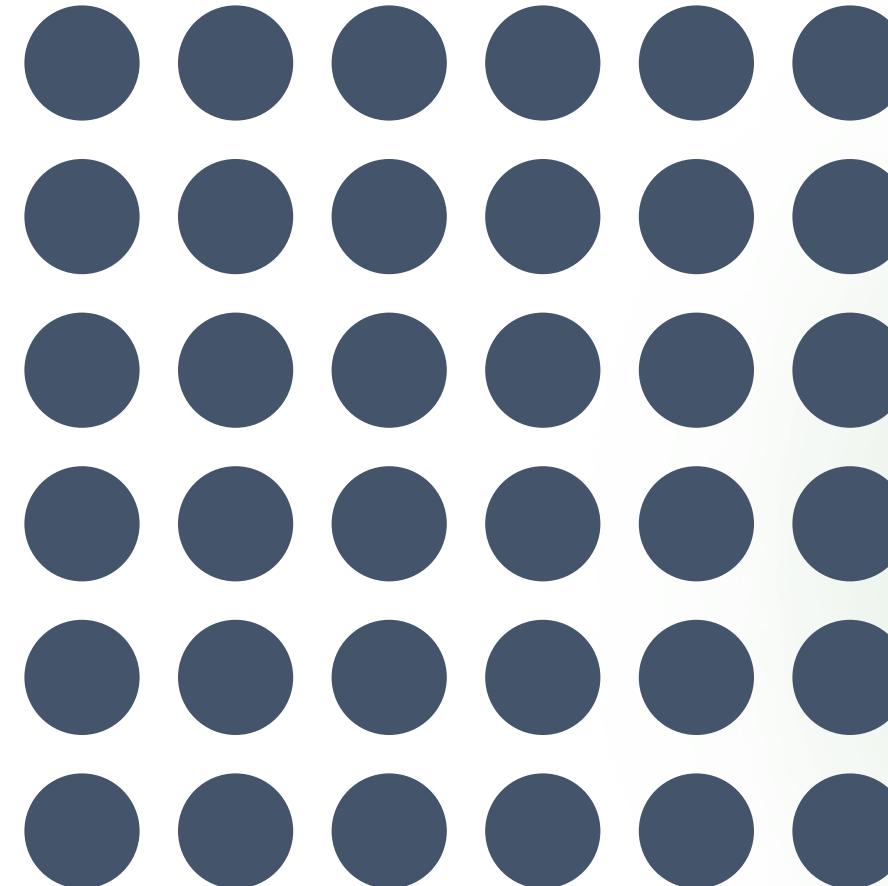
Pre-attentive Attribute

Form - Orientation



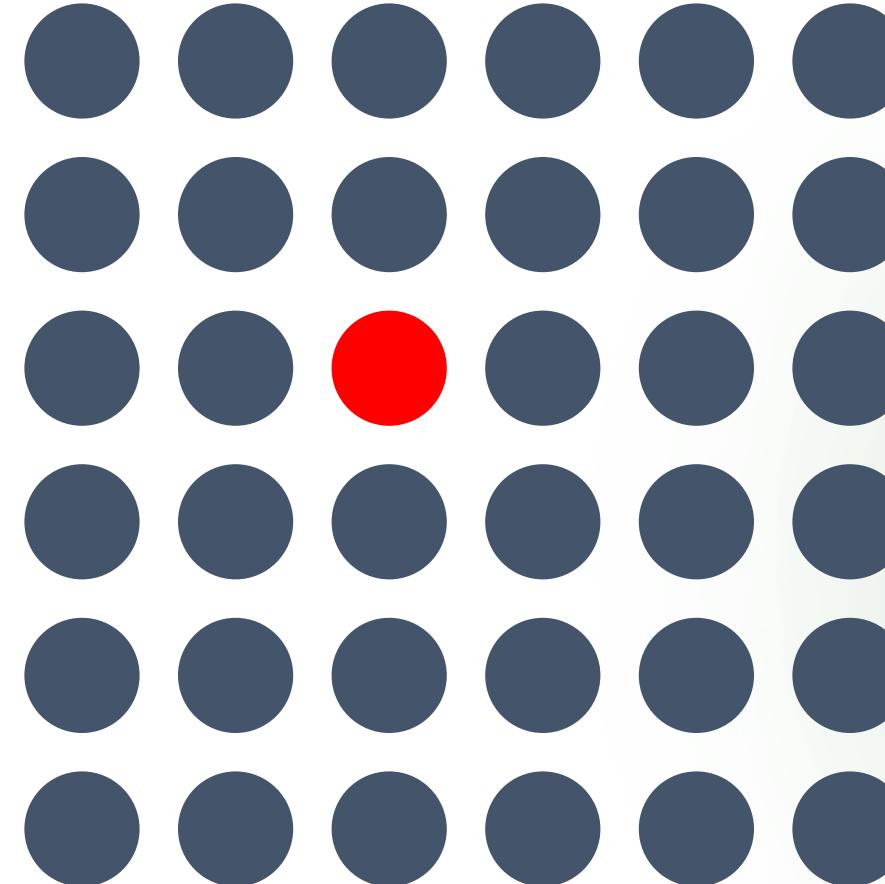
Pre-attentive Attribute

Color - Hue



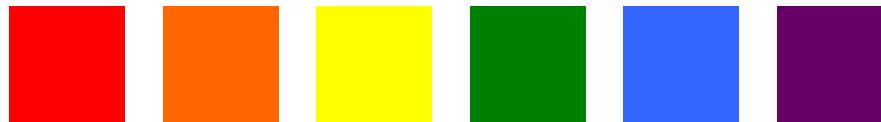
Pre-attentive Attribute

Color - Hue

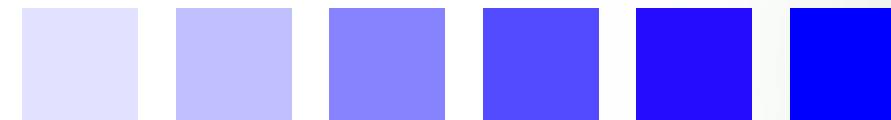


Color

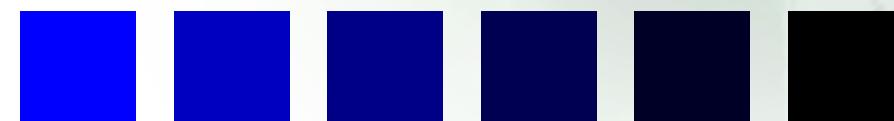
Changes to the **HUE** (color)



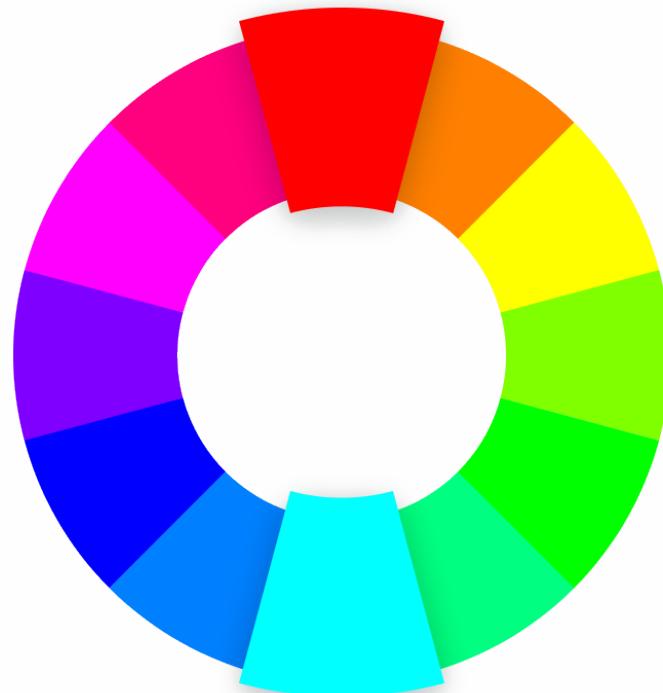
Changes to the **SATURATION** (intensity)



Changes to the **Value** (brightness)



Color Wheel

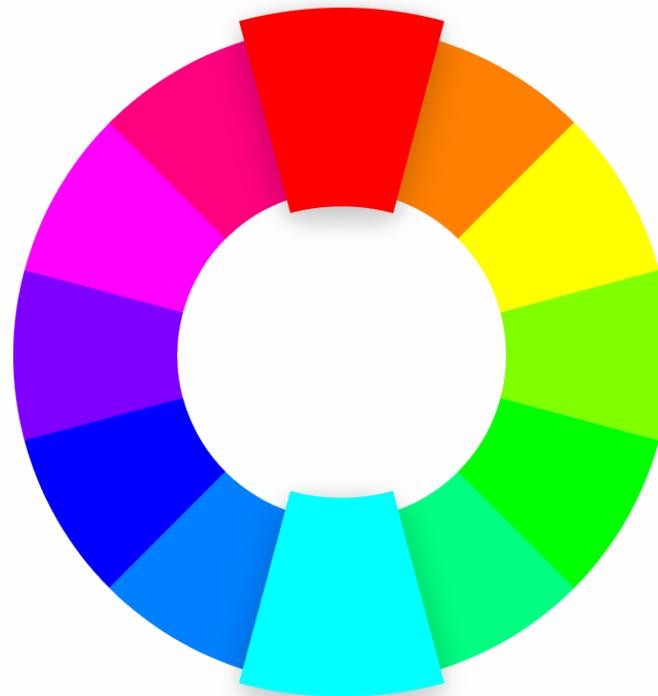


Isaac Newton (1666)

- For *designers* and *artists* to find the *perfect color combination*
- There are *two types* of color wheel
 - **RED, YELLOW, BLUE (RYB)** color wheel is typically used by *artists*
 - **RED, GREEN and BLUE (RGB)** color wheel, which is designed for *online use* (computer, television)

Color Wheel

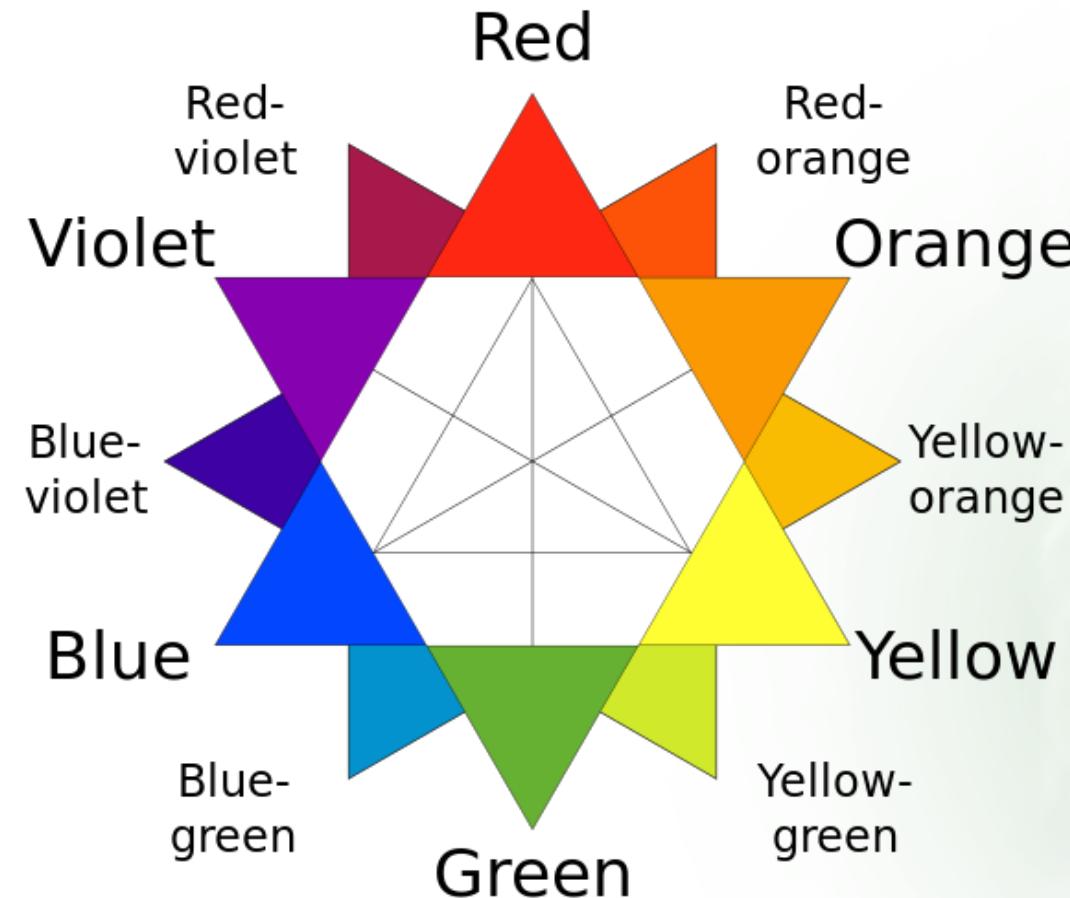
Primary, Secondary & Tertiary Colors



Isaac Newton (1666)

- **Primary colors** in the RGB color wheel are the colors, **RED**, **GREEN** and **BLUE**, that, added together, create pure white light
- **Secondary colors** are colors that result from mixing two primary colors: **CYAN**, **MAGENTA** and **YELLOW**
- **Tertiary colors** are colors made by combining a secondary color with a primary color: **ORANGE**, **CHARTREUSE GREEN**, **SPRING GREEN**, **AZURE**, **VIOLET** and **ROSE**

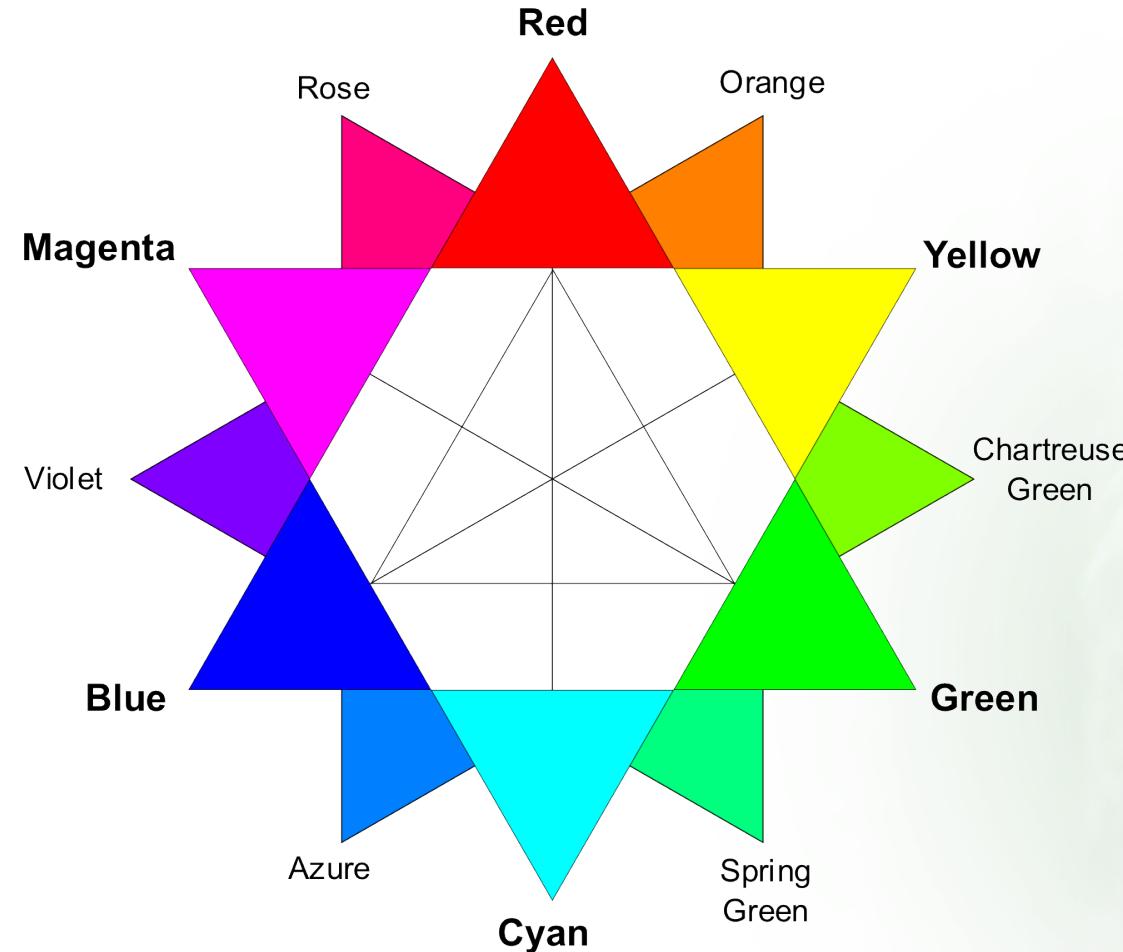
Relationships on Traditional Color Wheel



The primary colors are red, yellow, and blue

Classical painters would have used this arrangement to find compliments

Relationships on RGB Color Wheel



*Computer displays use red, green, and blue elements
This results in a shifted arrangement of complimentary colors*

Use of Color in Data Visualization

SEQUENTIAL

color is ordered from low to high



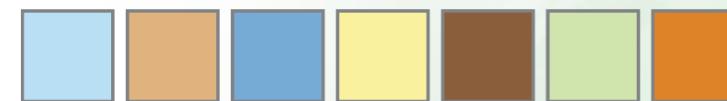
DIVERGING

two sequential colors with a neutral midpoint



CATEGORICAL

contrasting colors for individual comparison



HIGHLIGHT

color used to highlight something



ALERT

color used to alert or warn reader



FIGURE 1.16 Use of color in data visualization.

Does This Color Enhance or Detract?



The screenshot shows a mobile view of The Wall Street Journal website from Saturday, August 7, 2010. The main headline is "Job Market Loses Steam With 14.6 Million Seeking Work". Below it, a sub-headline reads "Private Sector Expands Slightly, but Governments Cut Jobs; Treasury Yields Dip". The article by Sudeep Reddy discusses job market statistics, noting a loss of 131,000 jobs in July. To the right is a dual-axis chart comparing nonfarm payrolls (in thousands) and the yield on the two-year Treasury note from 2008 to 2010. The chart highlights a significant dip in payrolls and a rise in yields in July 2010. A callout box on the chart provides specific data: "July's change in jobs -131,000" and "Friday's closing yield 0.514%". The right sidebar lists several other news stories.

Front Section...

- 2 of 26 Articles
- H-P Chief Quits in Scandal
- Job Market Loses Steam With 14.6 Million Seeking Work**
- Busted Russian Spy Wants Old Life Back
- Good Thing Hotels Don't Charge For Left-Behind Chargers
- Fannie Mae Critic Sues Over Firing
- Target Discovers Downside to Political Contributions
- City Resorts to Pac-Man for a Reboot
- As the East Roasts, the West Chills Out
- Fed Board

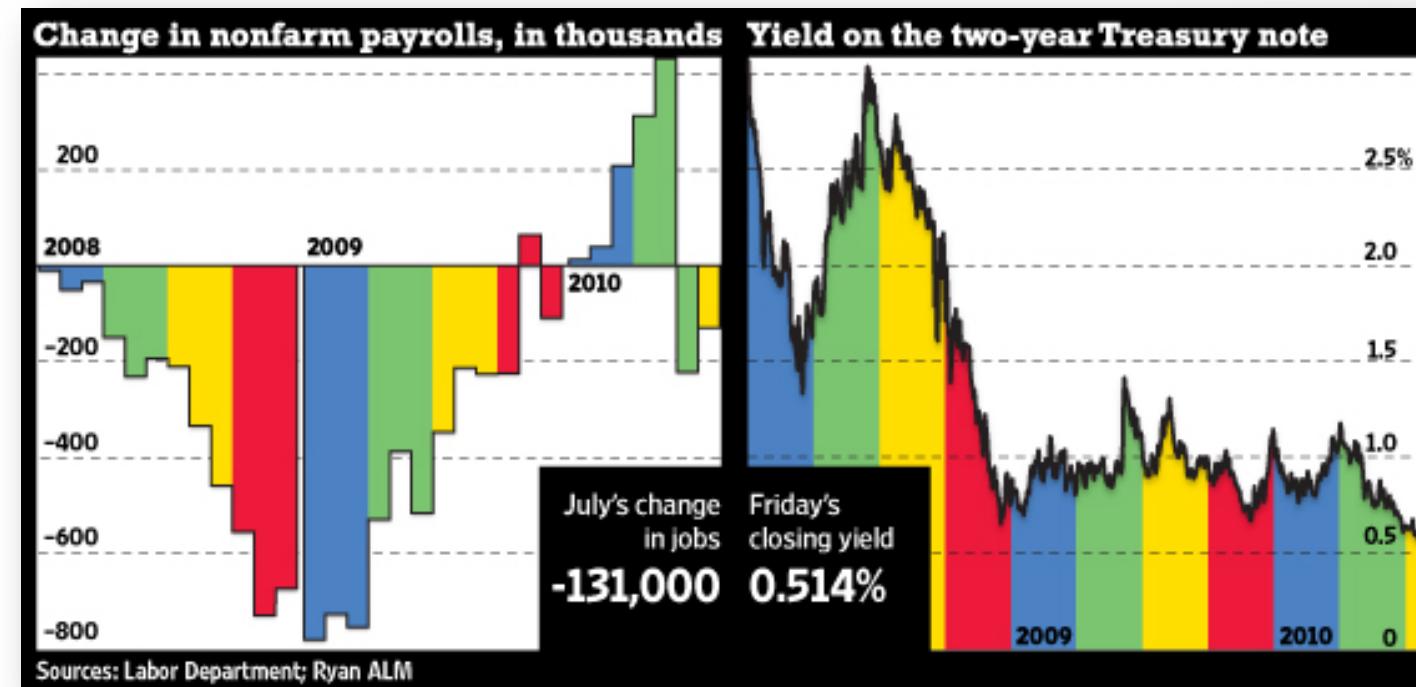
Article continues...

2011 BUICK REGAL

ISSUE 20% DOWNLOADED | Tools | Sections | Next »

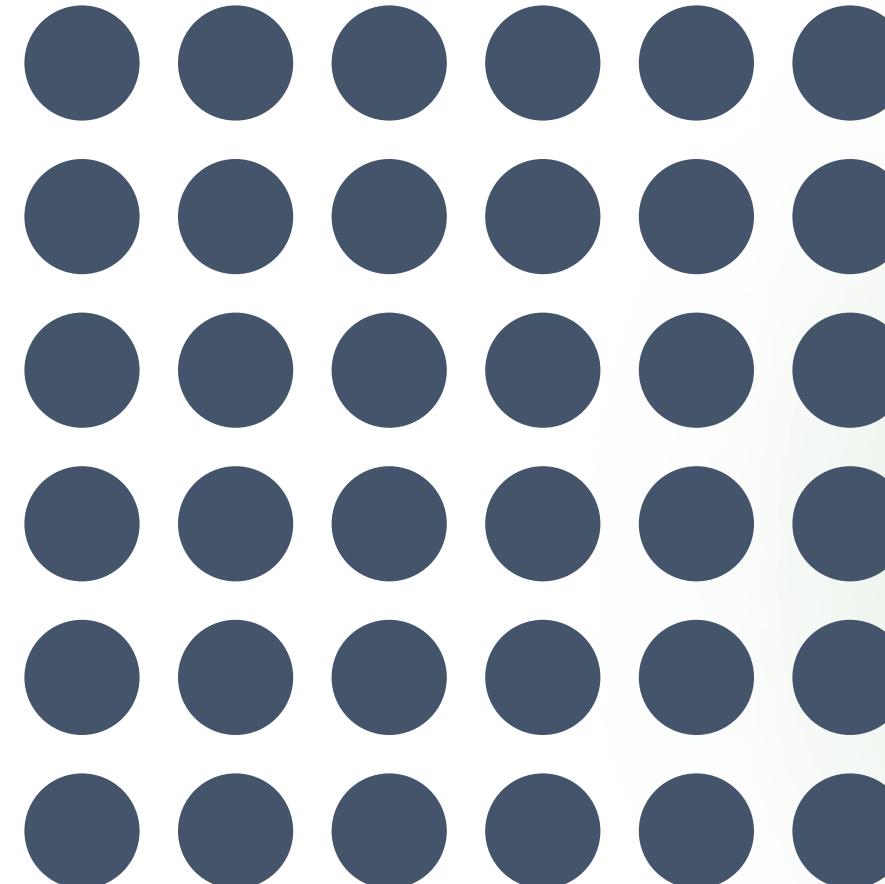
From <http://online.wsj.com> - The Wall Street Journal Online, originally published August 7, 2010

What Does Color Even Mean Here?



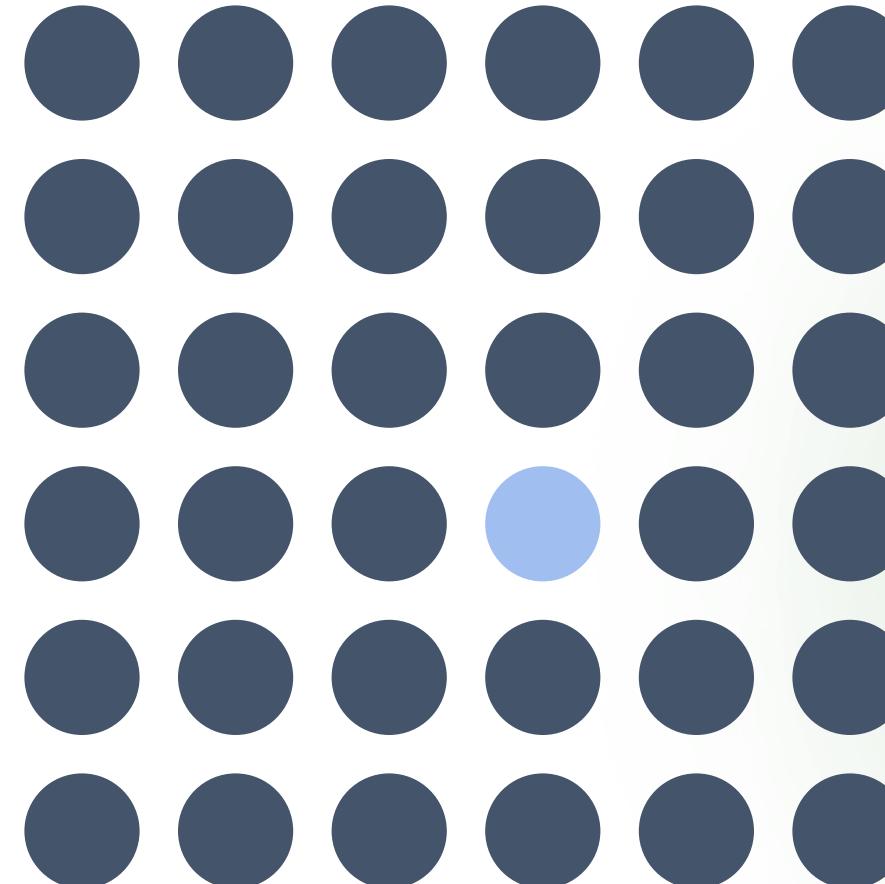
Pre-attentive Attribute

Color – Value (Luminance)



Pre-attentive Attribute

Color – Value (Luminance)



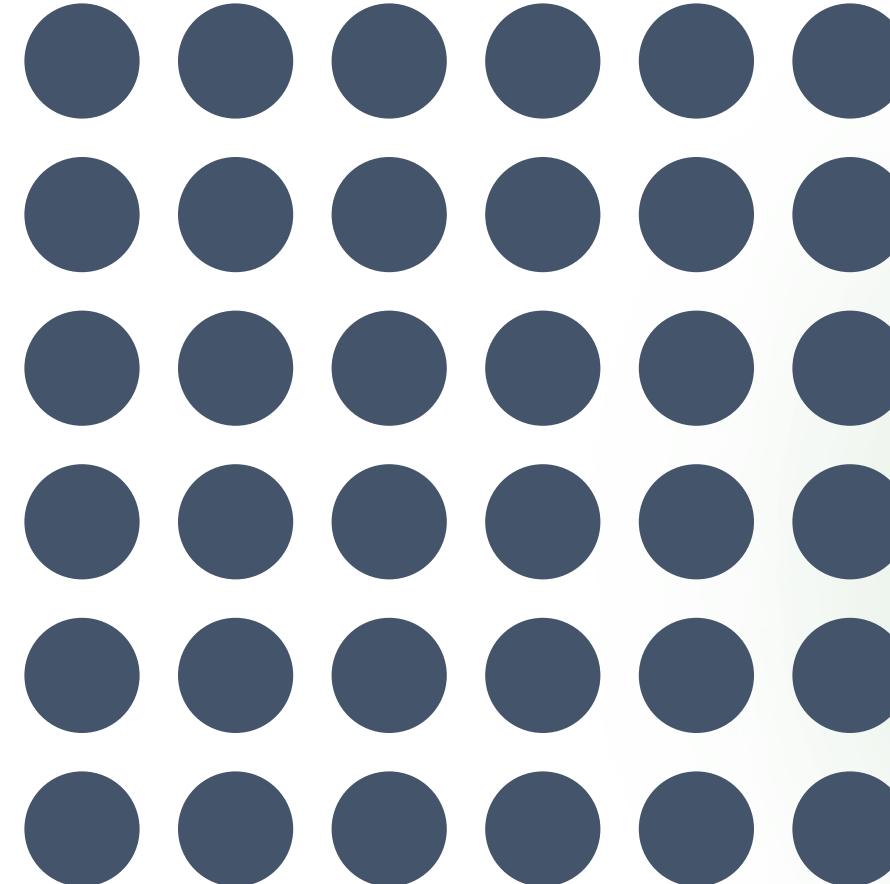
Color Value



Good for encoding QUANTITATIVE VALUE

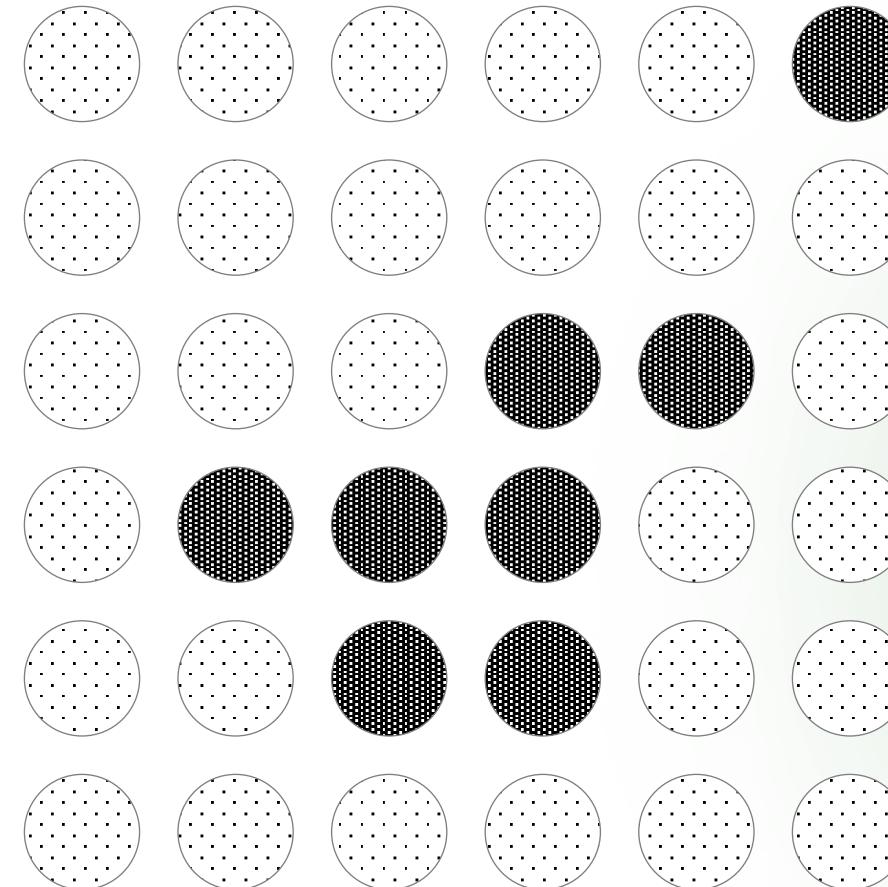
Pre-attentive Attribute

Form – Texture



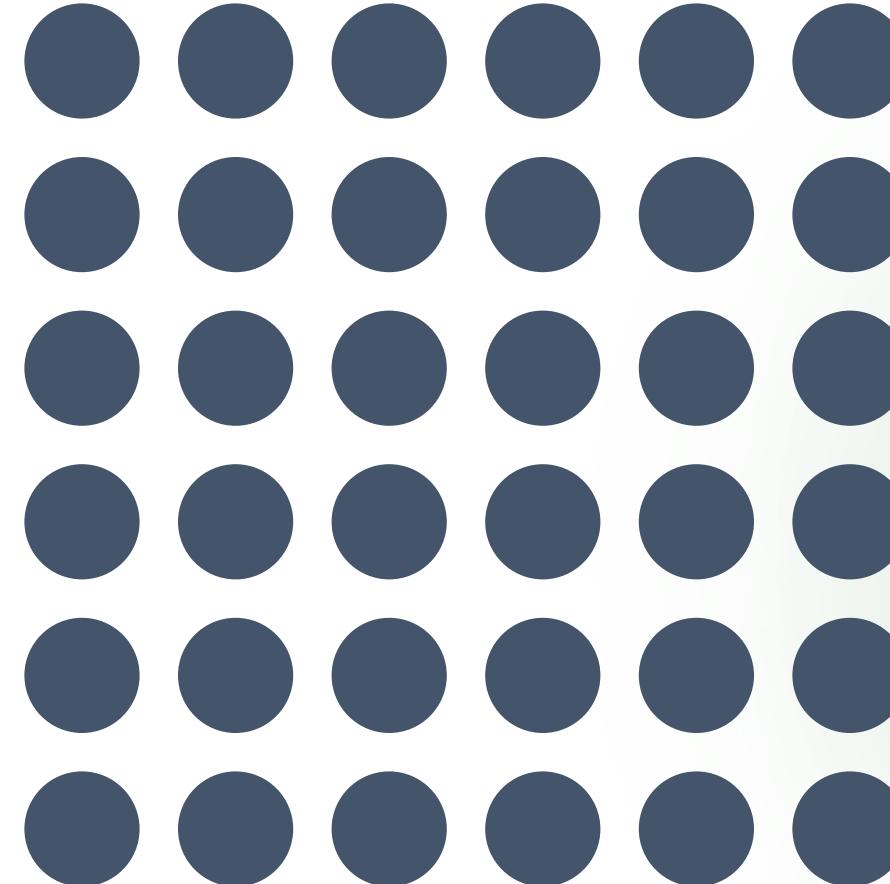
Pre-attentive Attribute

Form – Texture



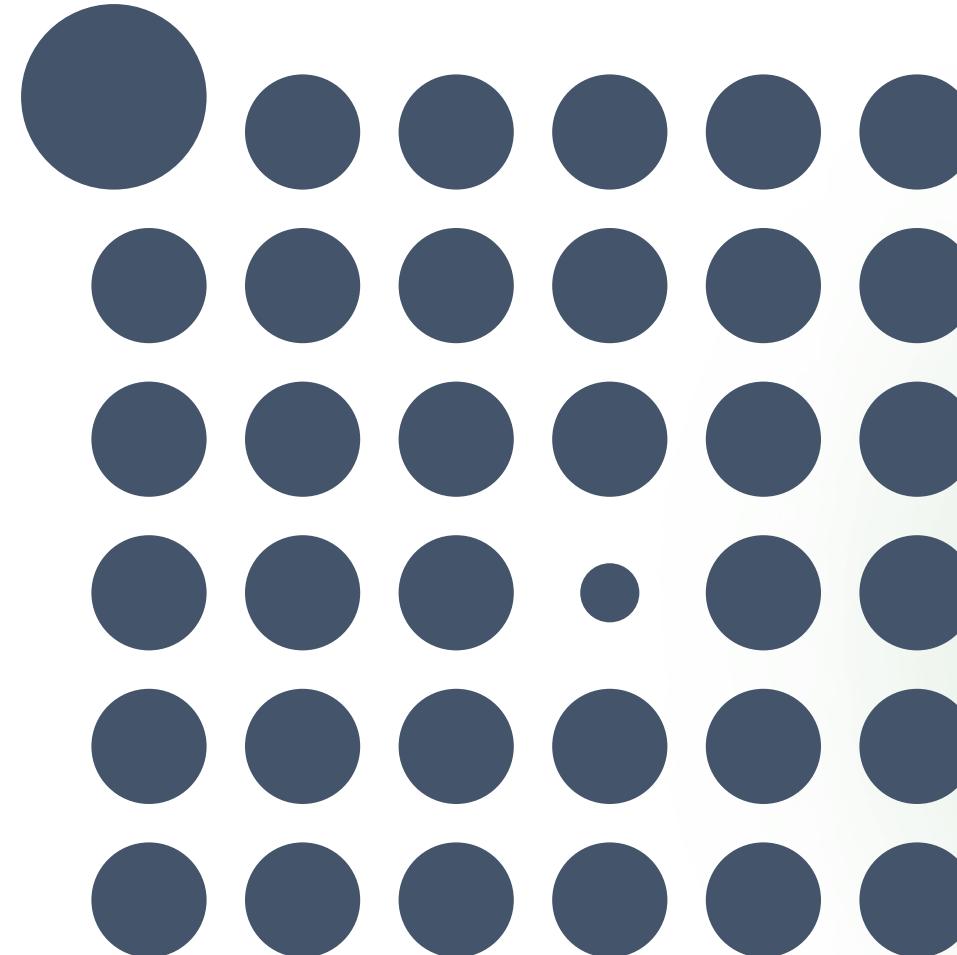
Pre-attentive Attribute

Form – Size



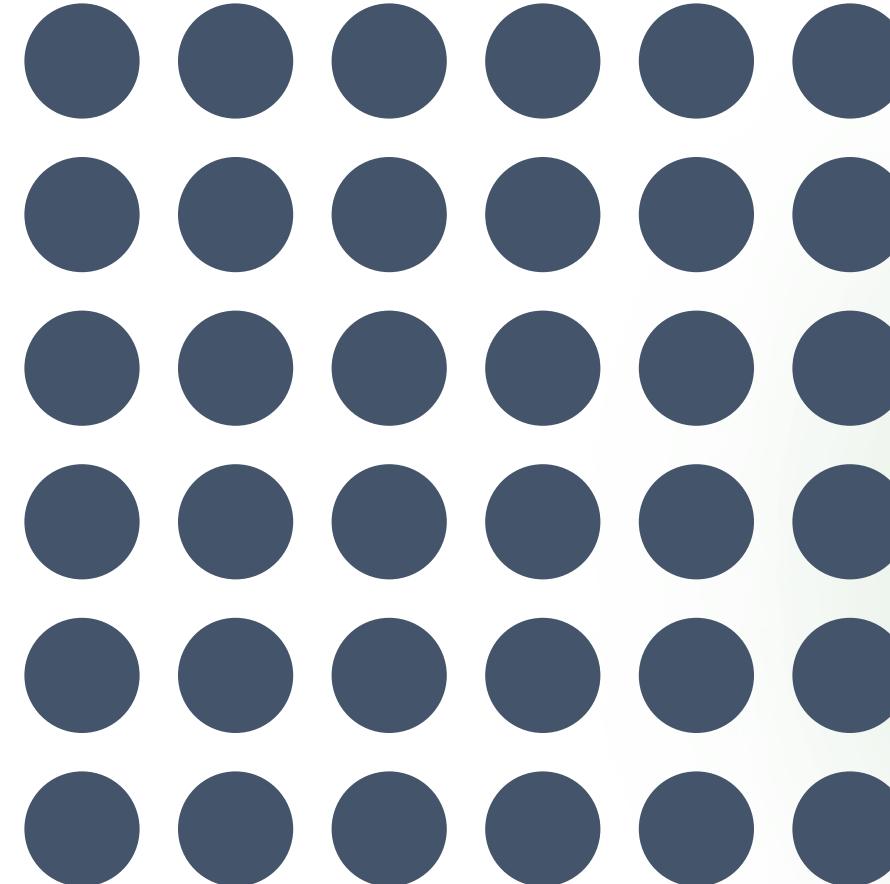
Pre-attentive Attribute

Form – Size



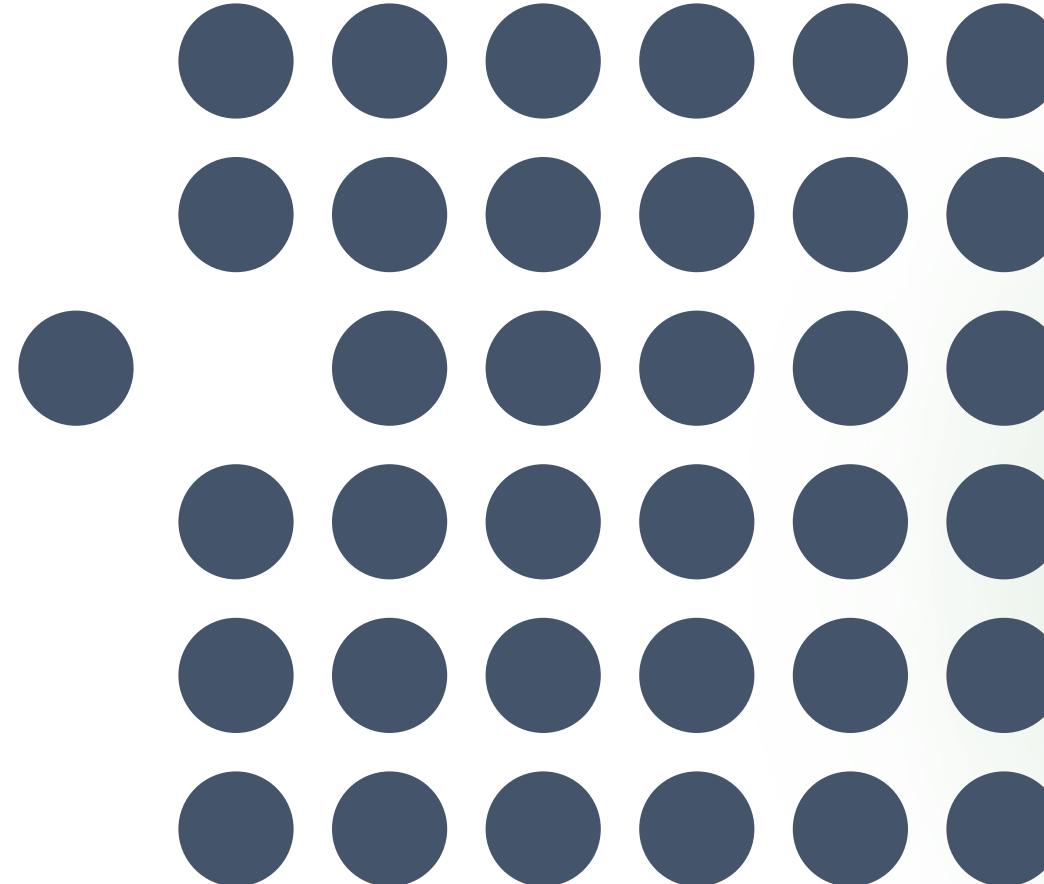
Pre-attentive Attribute

Form – Position



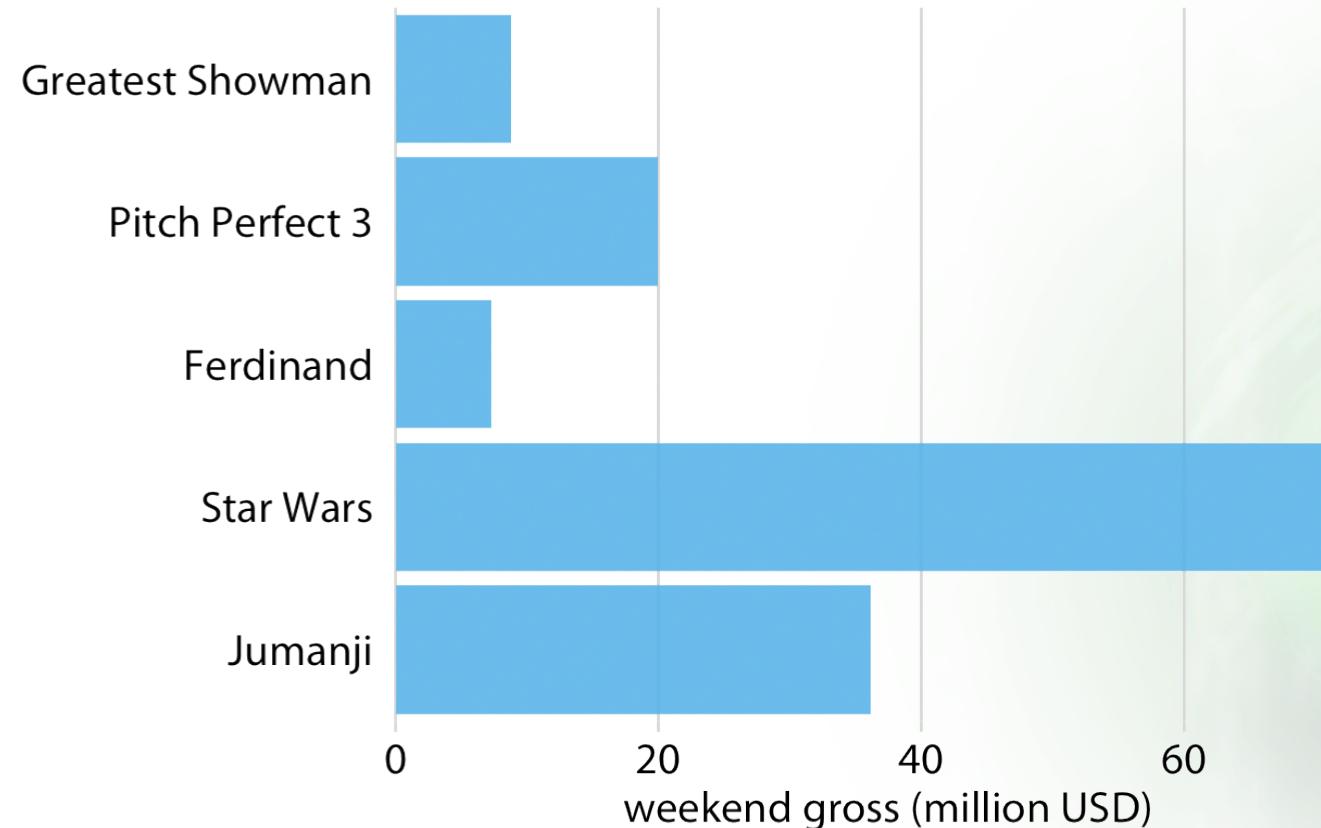
Pre-attentive Attribute

Form – Position



Pre-attentive Attribute

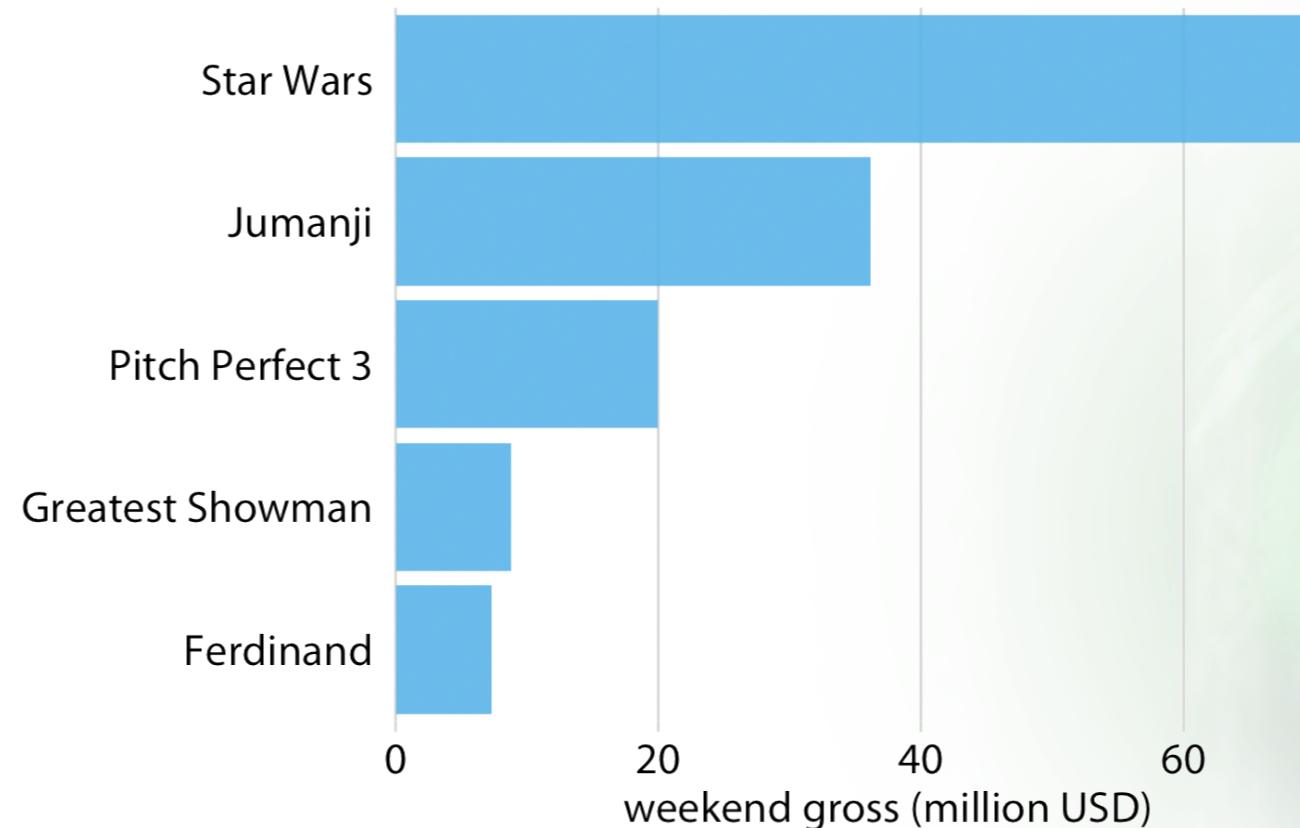
Form – Order



Highest-grossing movies for the weekend of December 22–24, 2017,

Pre-attentive Attribute

Form – Order



Highest-grossing movies for the weekend of December 22–24, 2017,

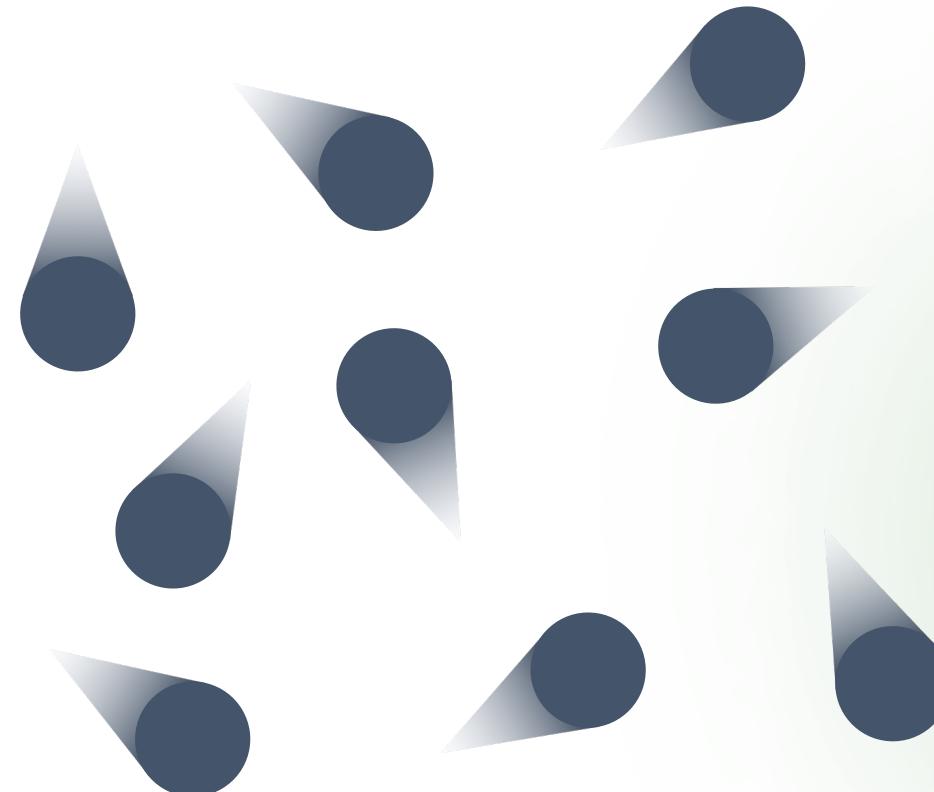
Pre-attentive Attribute

Spatial – 2D Position



Pre-attentive Attribute

Motion – Direction



Encoding Values

Quantitative vs *categorical* difference

- Values represented as *lines of different lengths* are perceived as *quantitatively* different (longer lines greater values)
- Values represented as *different colors* are only *categorically* different (e.g., red is not “*greater*” than blue)
 - However, e.g. *intensity is perceived quantitatively*

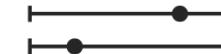
Type	Attribute	Quantitative
Form	Length	Yes
	Width	Yes (limited)
	Orientation	No
	Size	Yes (limited)
	Shape	No
	Enclosure	No
Color	Hue	No
	Intensity	Yes (limited)
Position	2D Position	Yes

Rankings of Visual Attributes

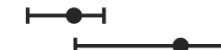
Effectiveness

④ 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)



④ Identity Channels: Categorical Attributes

Spatial region



Color hue



Motion



Shape



↑ Most Effectiveness ↓ Least Effectiveness

Same

Interpretations of Visual Attributes

Some properties *discriminated more accurately* but *have no intrinsic meaning*

- **Density (Greyscale)**: *Darker → More*
- **Size / Length / Area**: *Larger → More*
- **Position**: *Leftmost → first, Topmost → first*
- **Hue**: *no intrinsic meaning*
- **Slope**: *no intrinsic meaning*

Gestalt Principles

Gestalt Principles

Overview

- *Gestalt* is a psychology term which means "*unified whole*"
- It refers to *theories of visual perception* developed by German psychologists in the 1920s
 - Focus on *understanding* how we *perceive*, *understand* and *organize* what we see
 - Mind has *self-organizing tendencies* → Gestalt laws/principles of grouping

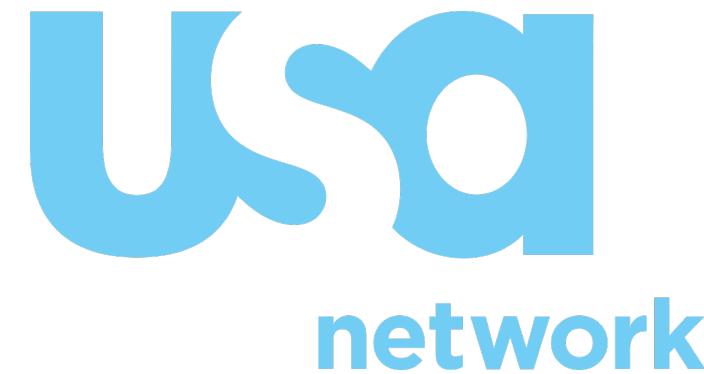
"The whole is other than the sum of the parts!"

by Kurt Koffka

Four Key Ideas

Emergence

- People tend to identify elements first *in their general outlined form*
- Our brain recognizes a *simple, well-defined object quicker* than a *detailed one*



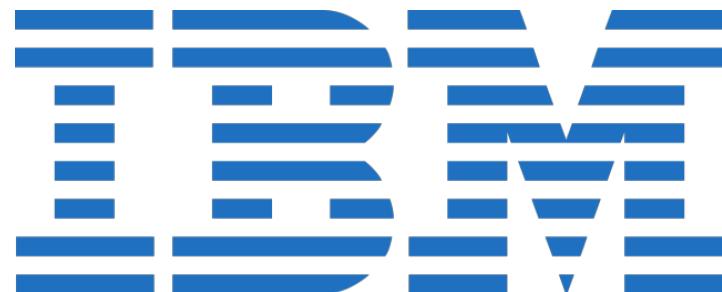
USA
network



Four Key Ideas

Reification

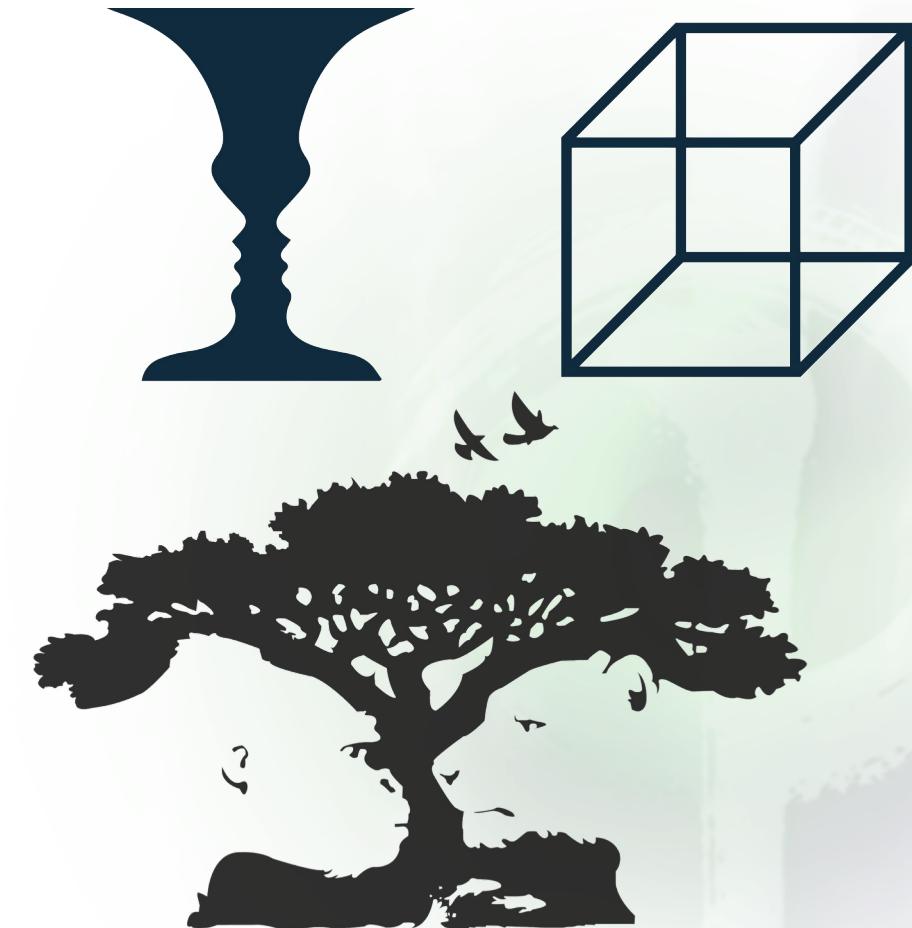
- People can *recognize objects* even when there are *parts of them missing*
- Our brain matches what we see with *familiar patterns* stored in our memory and *fills in the gaps*



Four Key Ideas

Multi-Stability

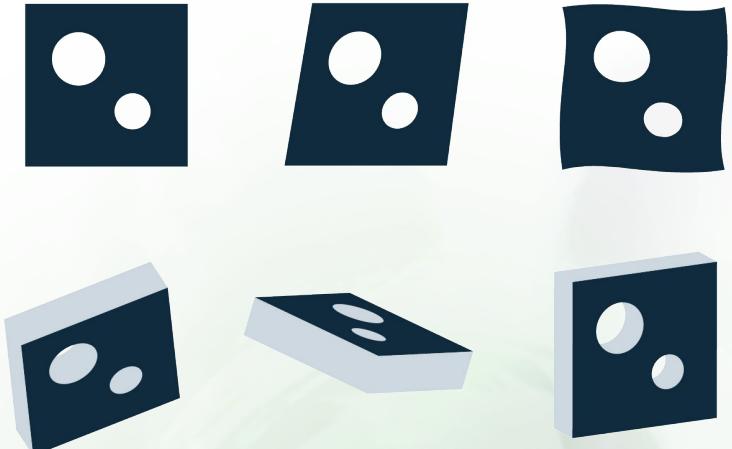
- People will often *interpret ambiguous* objects in *more than one ways*
- Our brains will *bounce back and forth* between the alternatives *seeking certainty*



Four Key Ideas

Invariance

- People can recognize simple objects independently of their *rotation*, *scale* and *translation*
- Our brain can perceive objects from *different perspectives*, despite their different appearance

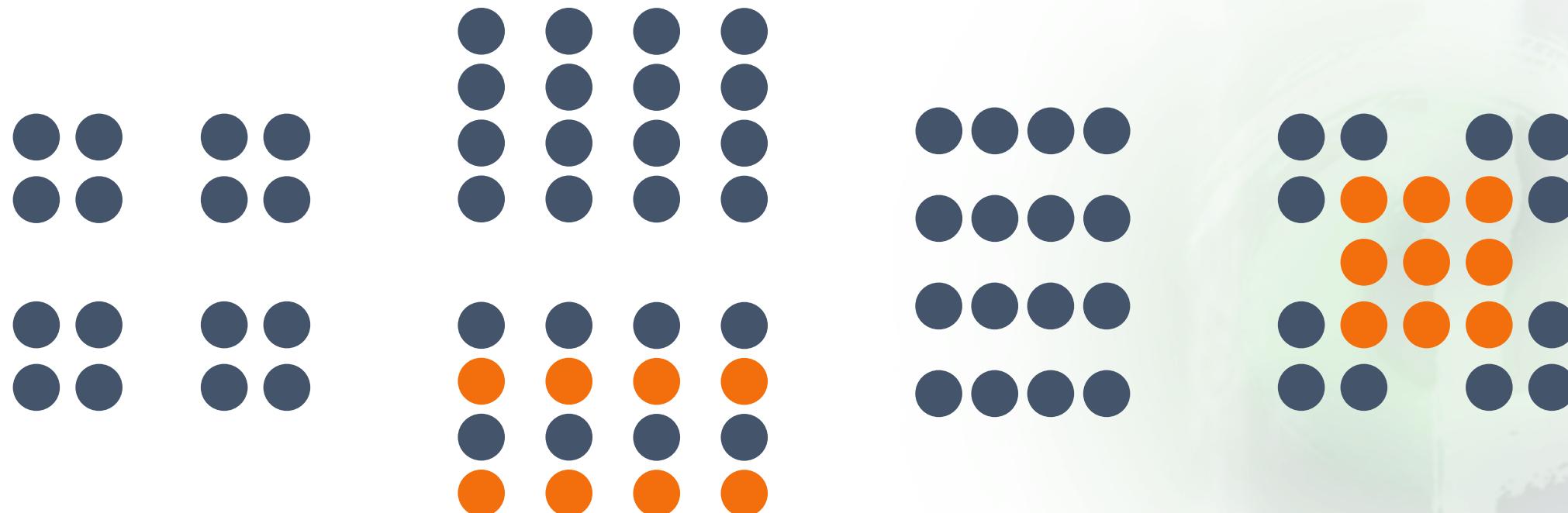


The Gestalt Principles

- *Principle of Proximity*
- *Principle of Similarity*
- *Principle of Enclosure*
- *Principle of Closure*
- *Principle of Continuity*
- *Principle of Connection*

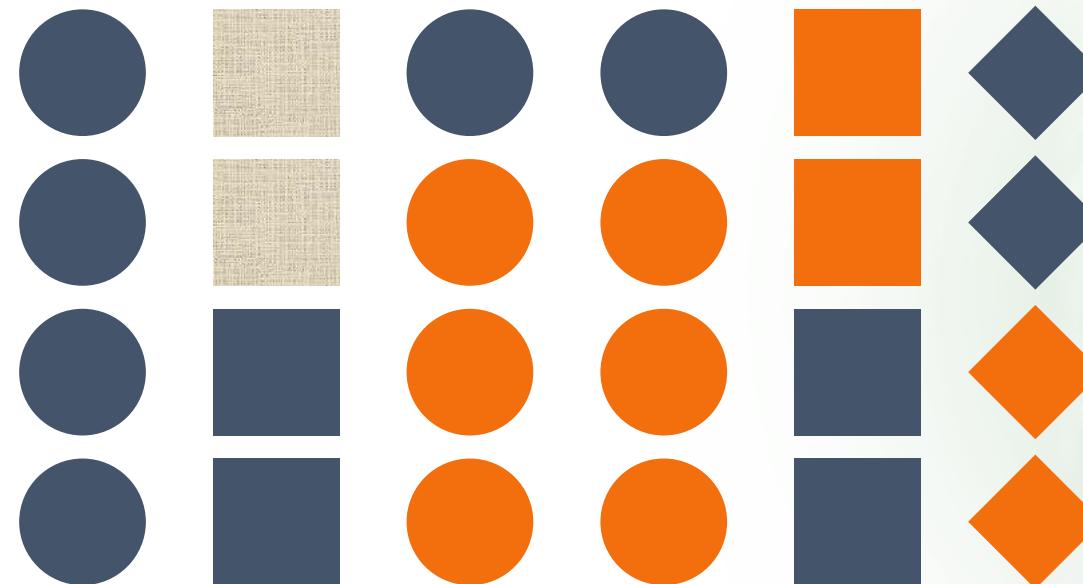
Principle of Proximity

- Objects close to each other are perceived as forming a group



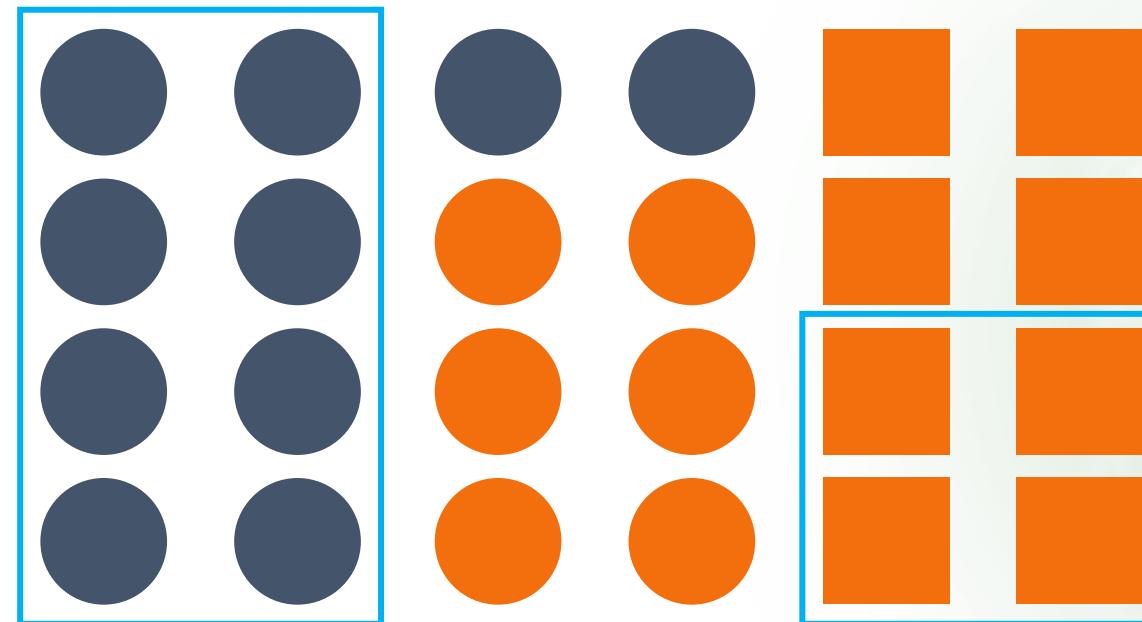
Principle of Similarity

- Tendency to group together object which are *similar* in *color*, *shape* or *orientation*



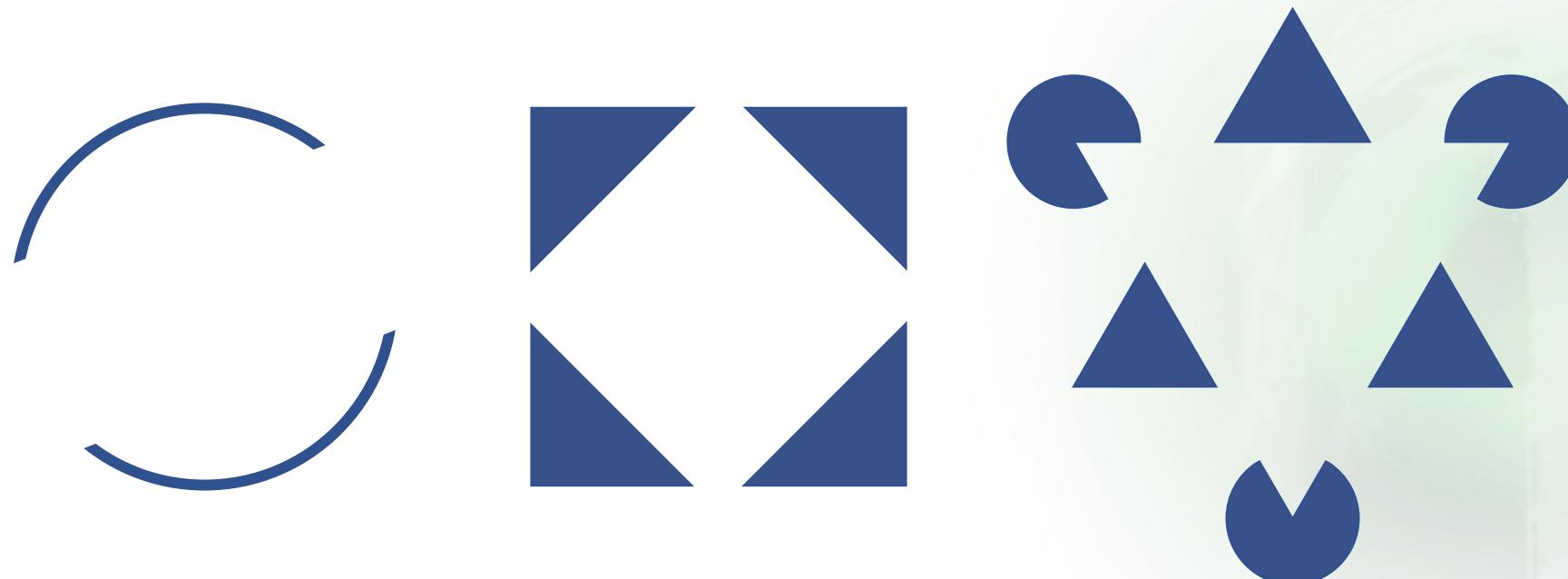
Principle of Enclosure

- We perceive objects belonging together when they are somehow *enclosed*



Principle of Closure

- If there is an *ambiguous* stimuli we will try to *eliminate* the ambiguity
- We prefer to see objects as *closed*, *complete* and *regular*



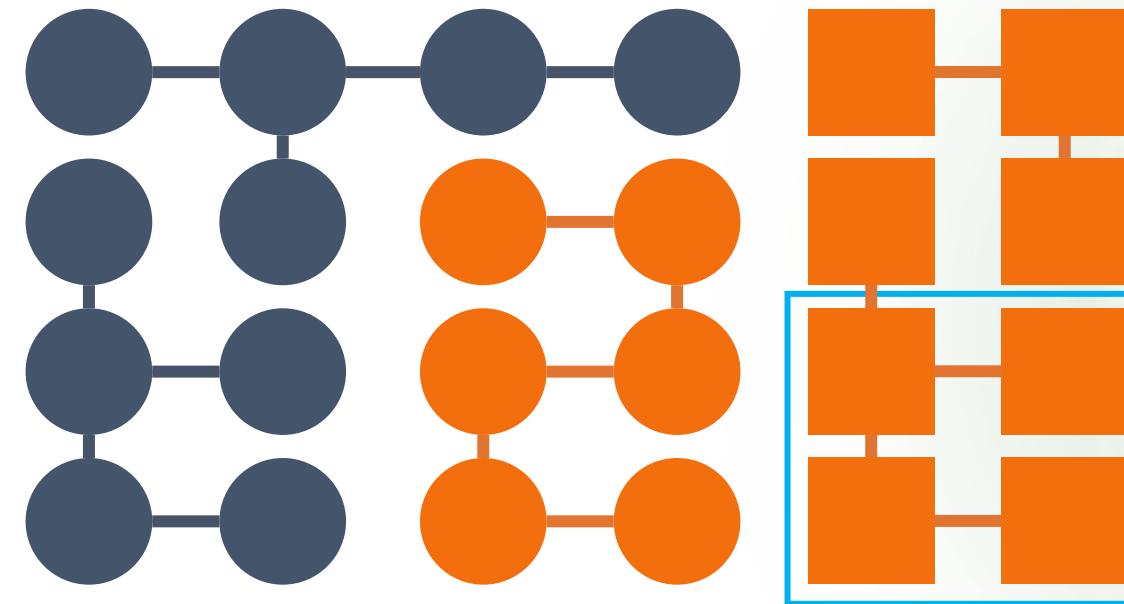
Principle of Continuity

- We perceive objects as belonging together, forming a whole, if they are *aligned* or *connected* to *one another*



Principle of Connection

- *Connected objects* are perceived as *part of a group*, it exercises *greater power* than *proximity* or *similarity* but less than *enclosure*



Visual Perception - The Limitation

Limits to Distinct Perception

- *Too much visual attributes or values per attribute can harm*

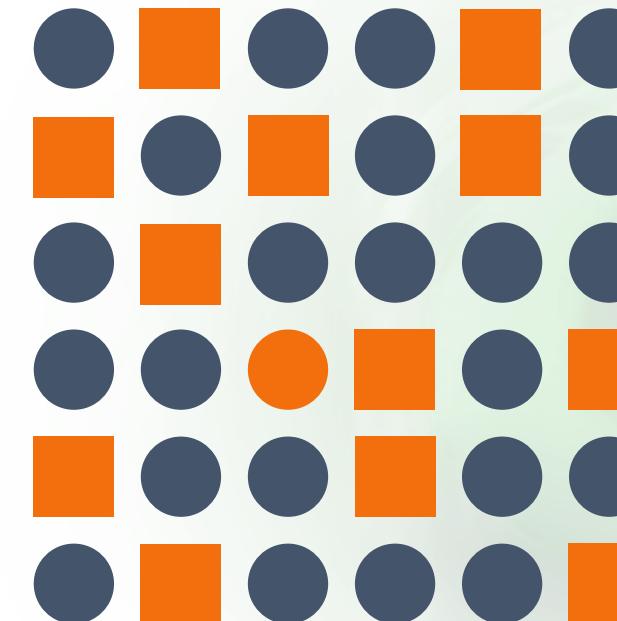
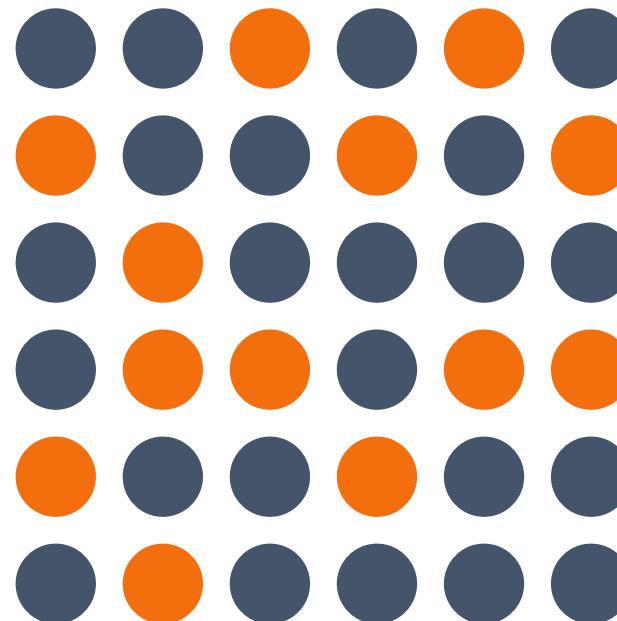
“It is simple to spot a single hawk in a sky full of pigeons, but it would be more difficult if the sky contained more types of birds”
(Ware, 2004)

- Using *larger number of values* forces readers to use the *slower attentive processing* which allows to store only up to *four distinctive values* at a time

Limits to Distinct Perception

Conjunction of Attributes

- Pre-attentive processing usually *cannot handle more than one visual attribute* of an object at a time

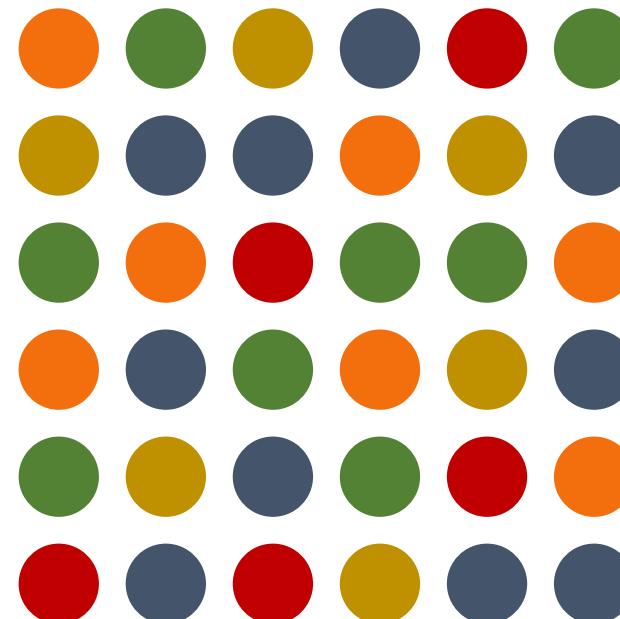


Identify the orange circle

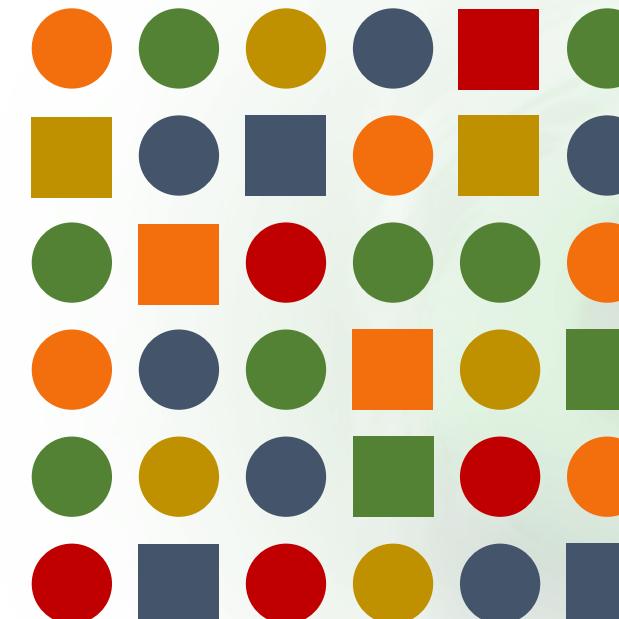
Limits to Distinct Perception

Conjunction of Attributes

- Pre-attentive processing usually *cannot handle more than one visual attribute* of an object at a time

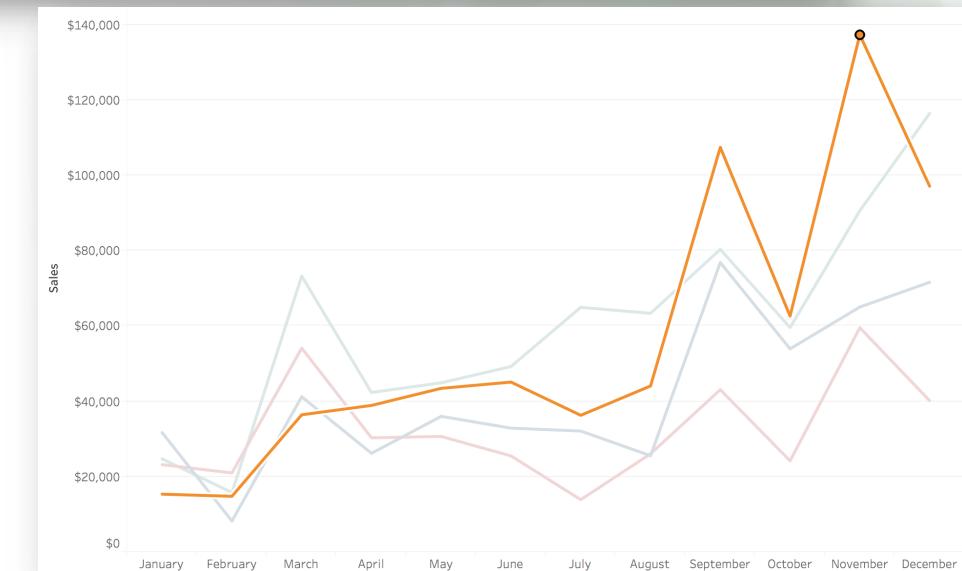
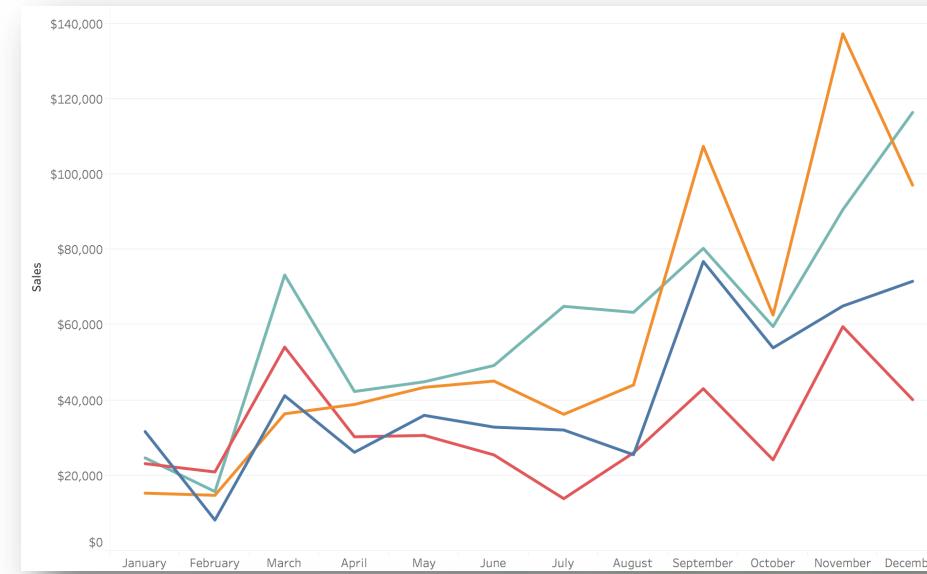
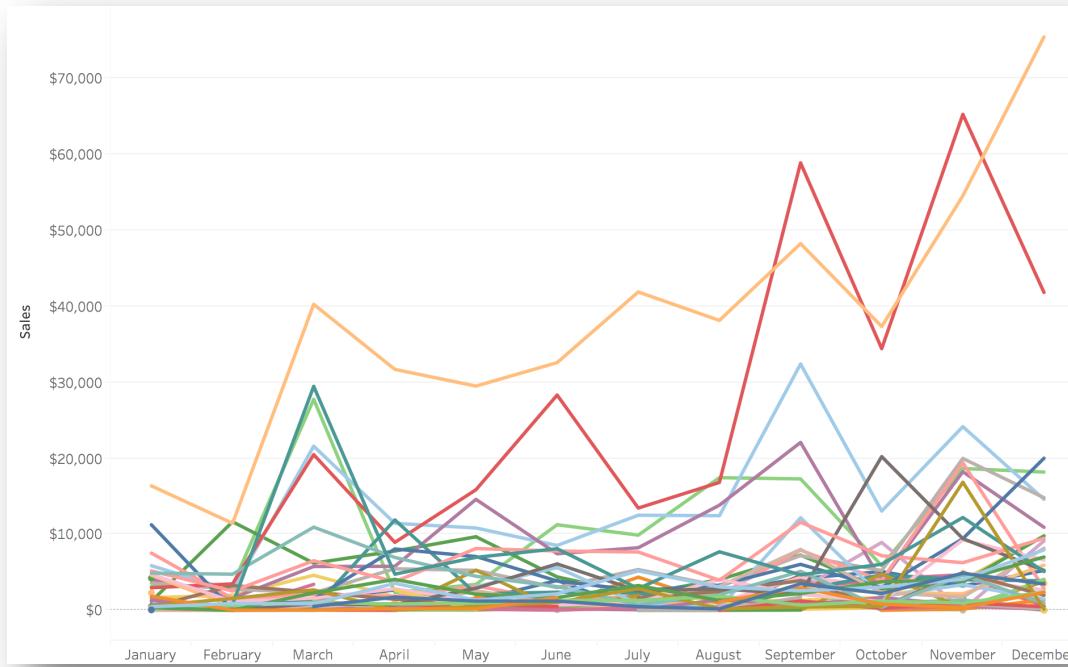


Focus on orange objects



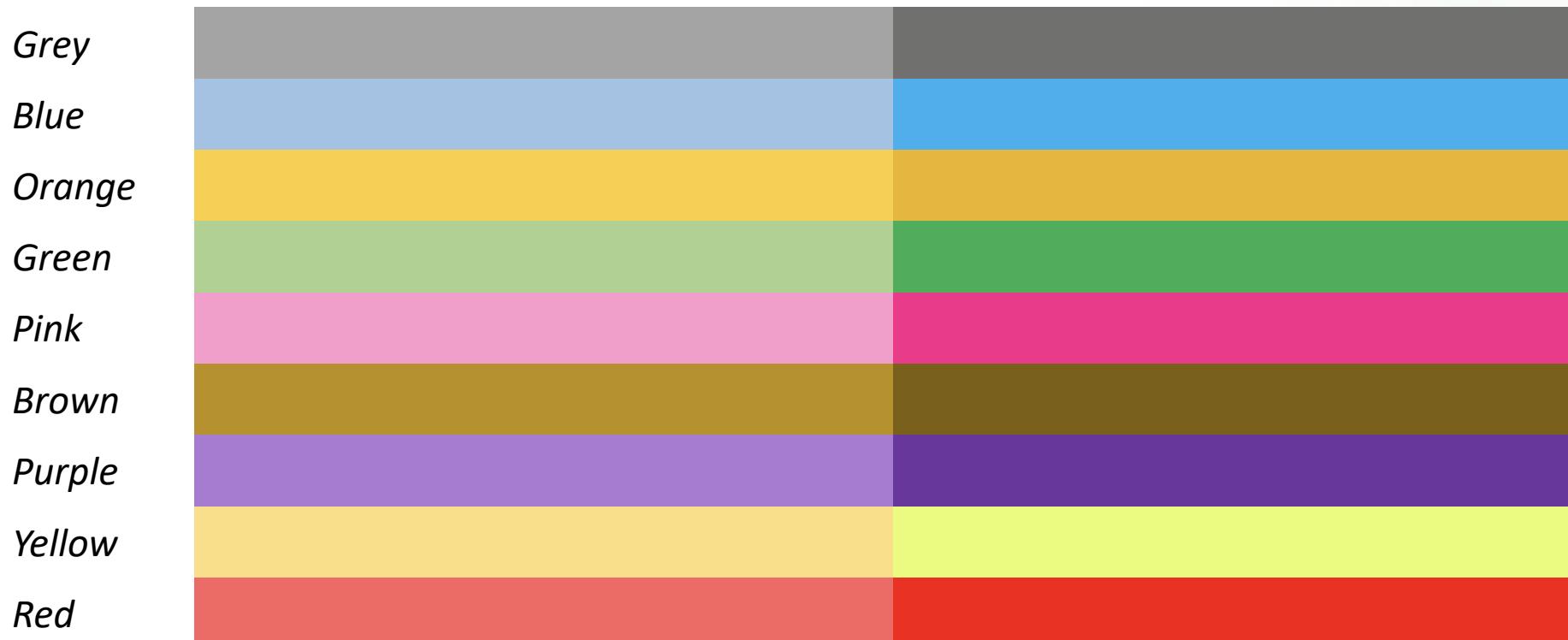
Focus on orange objects, orange squares

Color Choice



Limits to Distinct Perception

There are *nine hues* that are easy to recognize

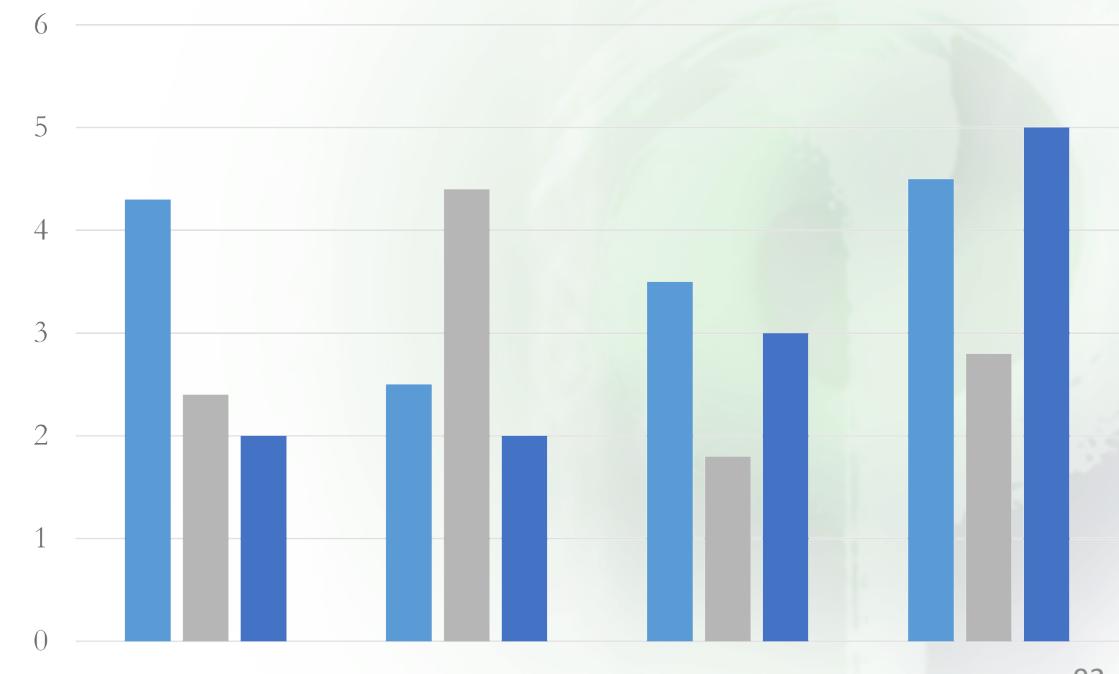
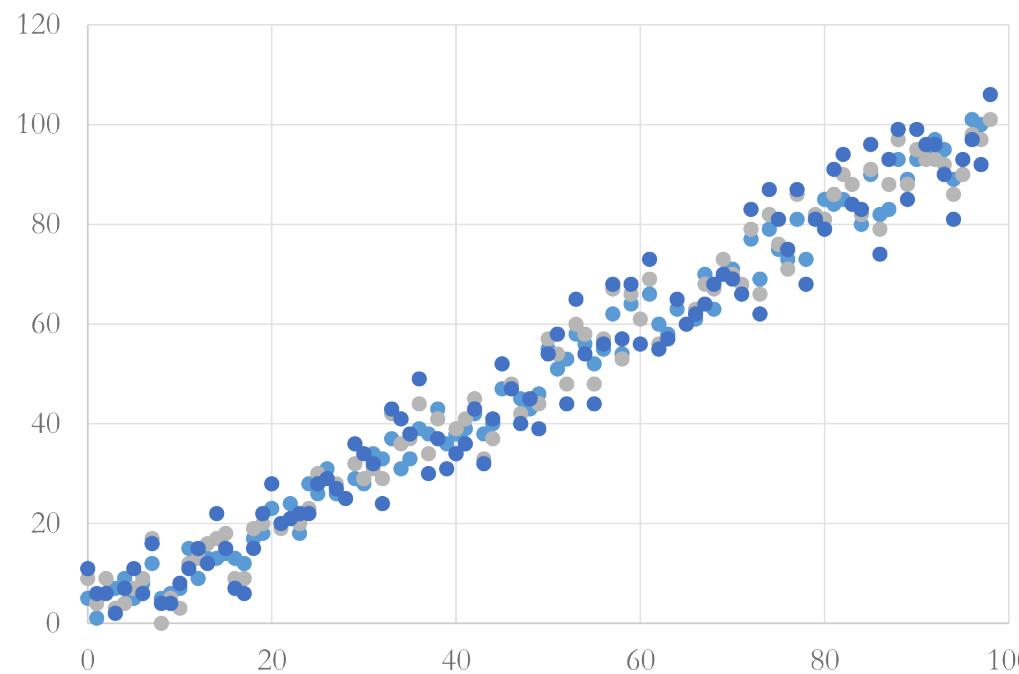


*Soothing colors, suitable for Tables &
Graphs*

*Vibrant colors, suitable for
highlighting*

Limits to Distinct Perception

The *ability to distinguish colors decreases* along *with the sizes* of objects → *small* objects (points in graph) should be *darker* than *large* objects such as bars



Text Is NOT Pre-attentive

SUBJECT PUNCHED QUICKLY OXIDIZED TCEJBUS DEHCNUP YLKCIUQ DEZIDIXO
CERTAIN QUICKLY PUNCHED METHODS NIATREC YLKCIUQ DEHCNUP SDOHTEM
SCIENCE ENGLISH RECORDS COLUMNS ECNEICS HSILGNE SDROCER SNMULOC
GOVERNS PRECISE EXAMPLE MERCURY SNREVOG ESICERP ELPMAXE YRUCREM
CERTAIN QUICKLY PUNCHED METHODS NIATREC YLKCIUQ DEHCNUP SDOHTEM
GOVERNS PRECISE EXAMPLE MERCURY SNREVOG ESICERP ELPMAXE YRUCREM
SCIENCE ENGLISH RECORDS COLUMNS ECNEICS HSILGNE SDROCER SNMULOC
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CERTAIN QUICKLY PUNCHED METHODS NIATREC YLKCIUQ DEHCNUP SDOHTEM
SCIENCE ENGLISH RECORDS COLUMNS ECNEICS HSILGNE SDROCER SNMULOC

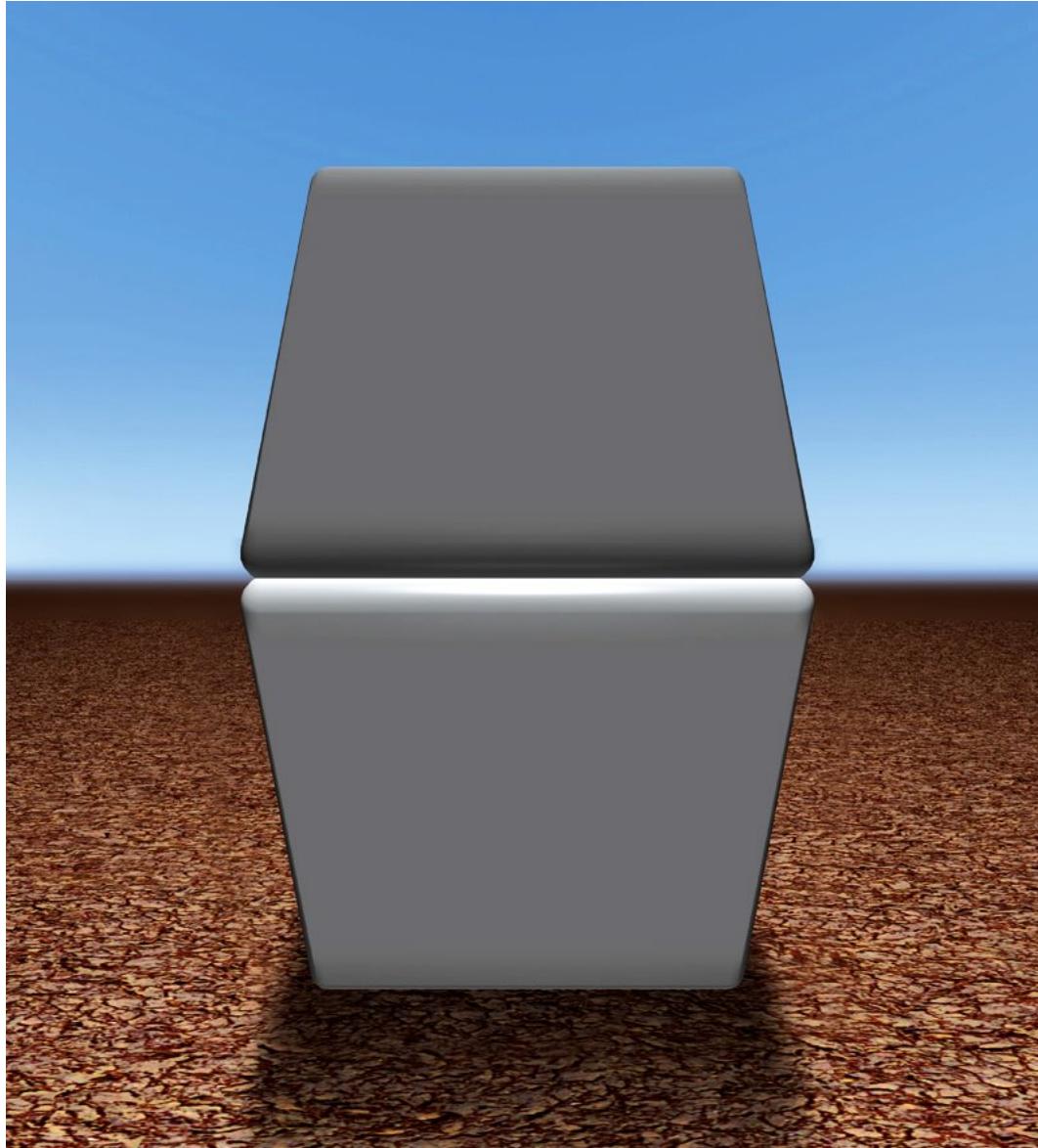
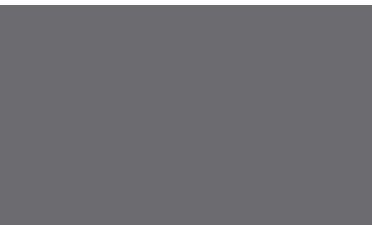
Visual Basis

Known as Visual Illusions

Basis of Visual Perception

- People do *not perceive length, area, angle, brightness* the way they “*should*”
- Some *illusions* have been reclassified as *systematic perceptual errors*
 - E.g., *brightness contrasts* (*grey square on white background vs. on black background*)
 - Partly due to increase in *our understanding* of the *relevant parts of the visual system*
- Nevertheless, the visual system *does some really unexpected things*

Effects of Context



Dr. Beau Lotto (www.LottoLab.org)

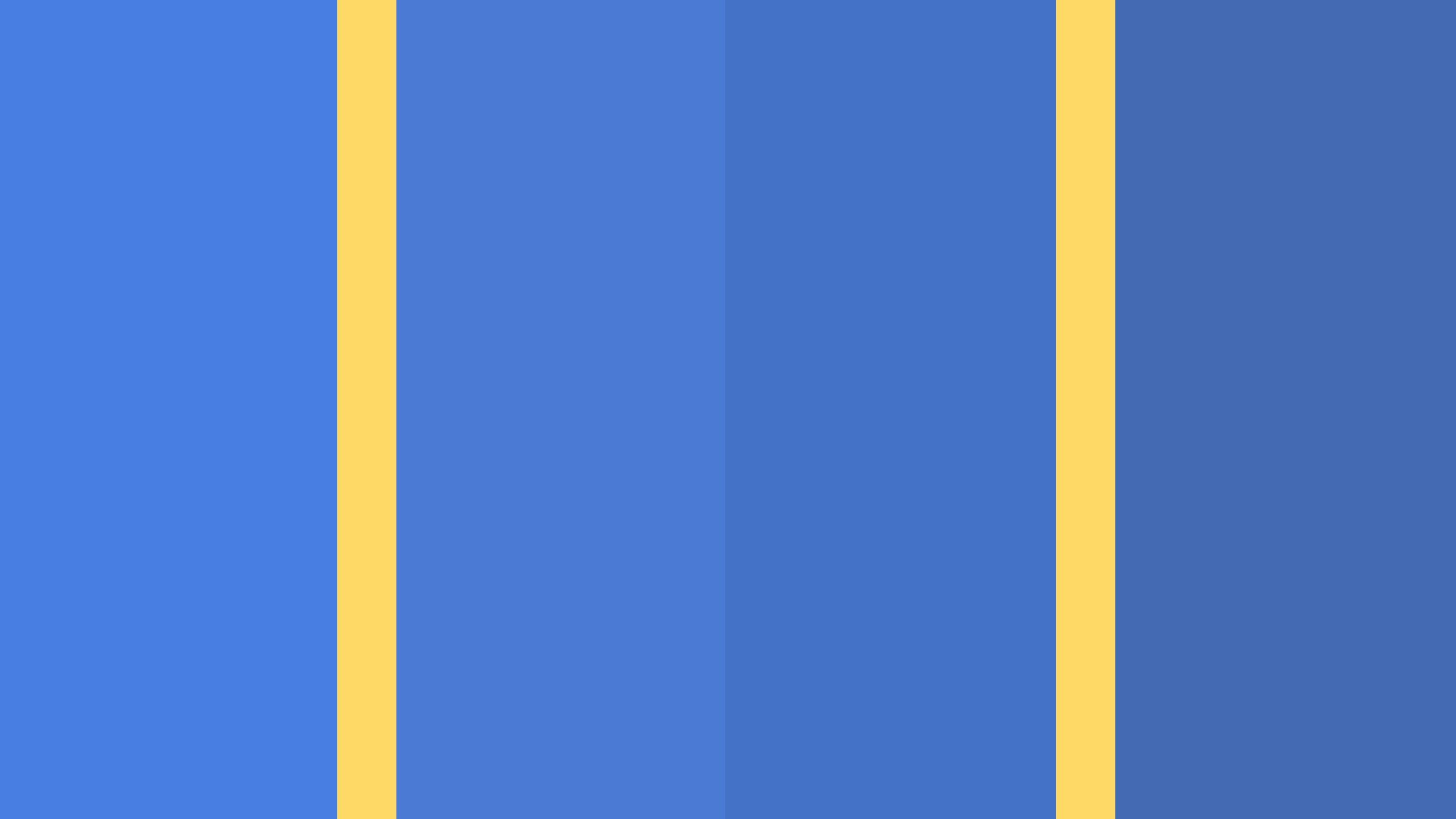
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DATA

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DATA

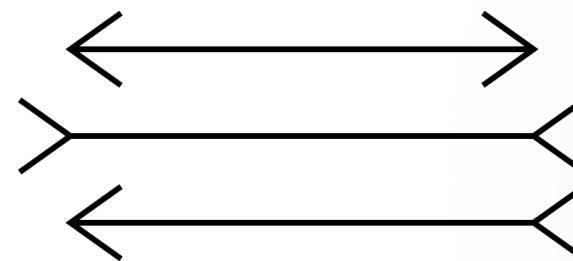
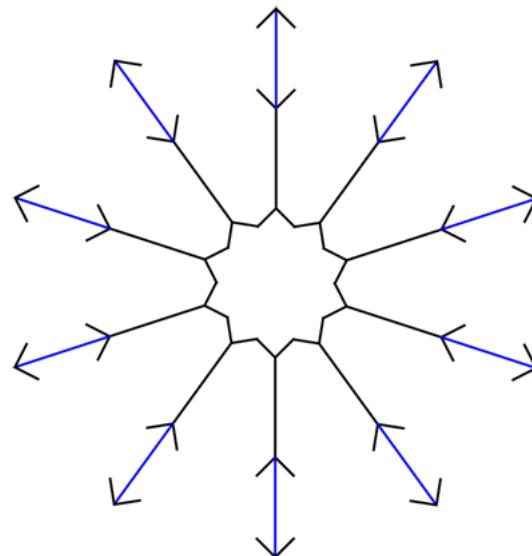




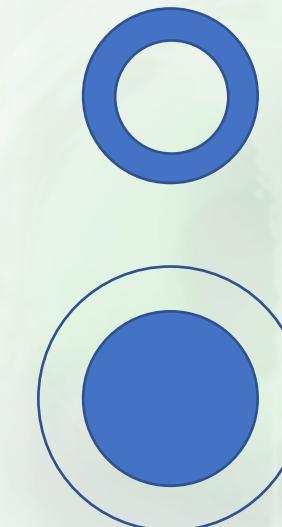
Visual Illusions

Mueller-Lyon (Line)

Sarcone's Dynamic Müller-Lyer Illusion

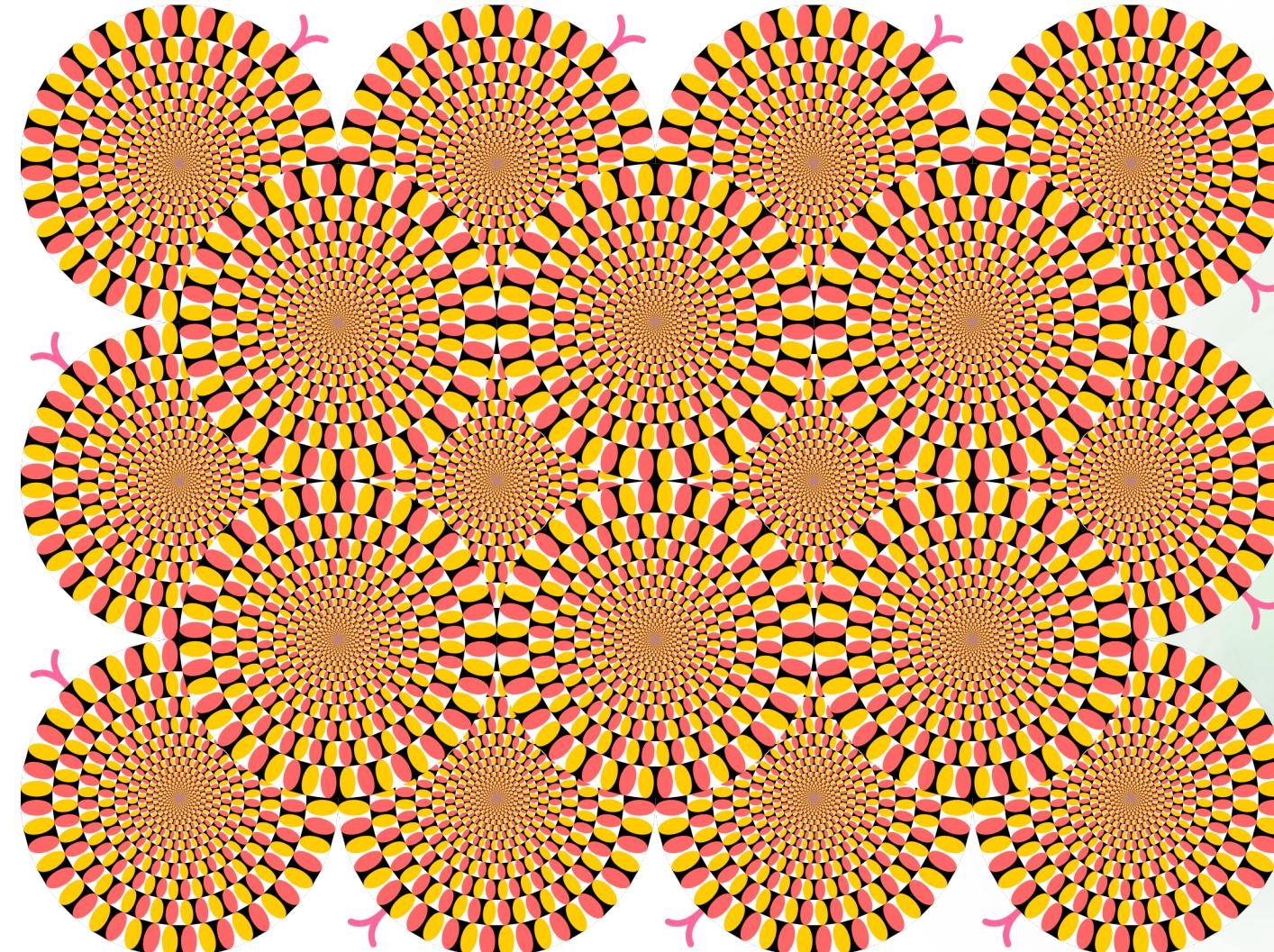


Delboeuf Illusion (Area)



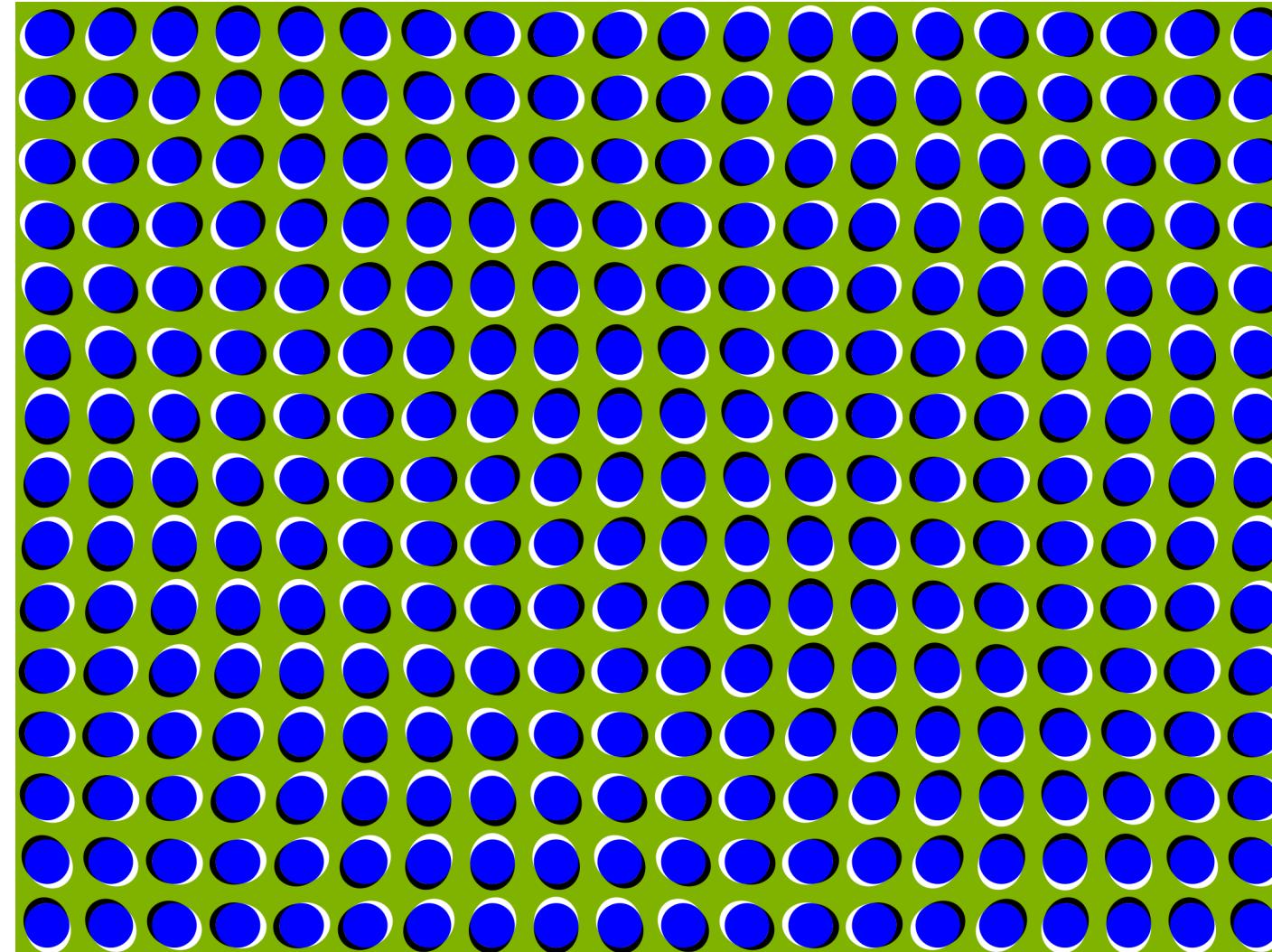
Optical Illusion

Motion Illusion



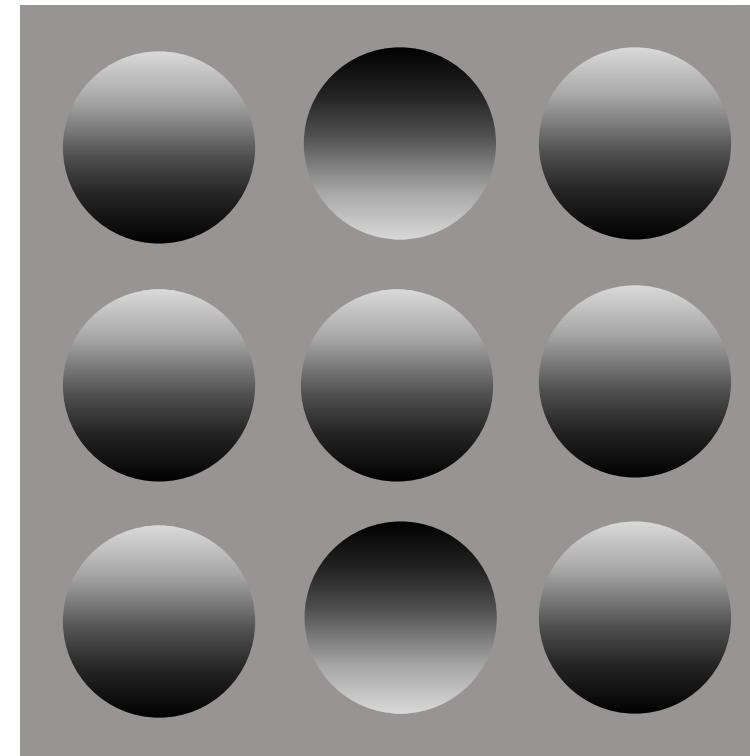
Optical Illusion

Motion Illusion



Evolutionary Basis

Visual perception is deeply *evolutionary ingrained*



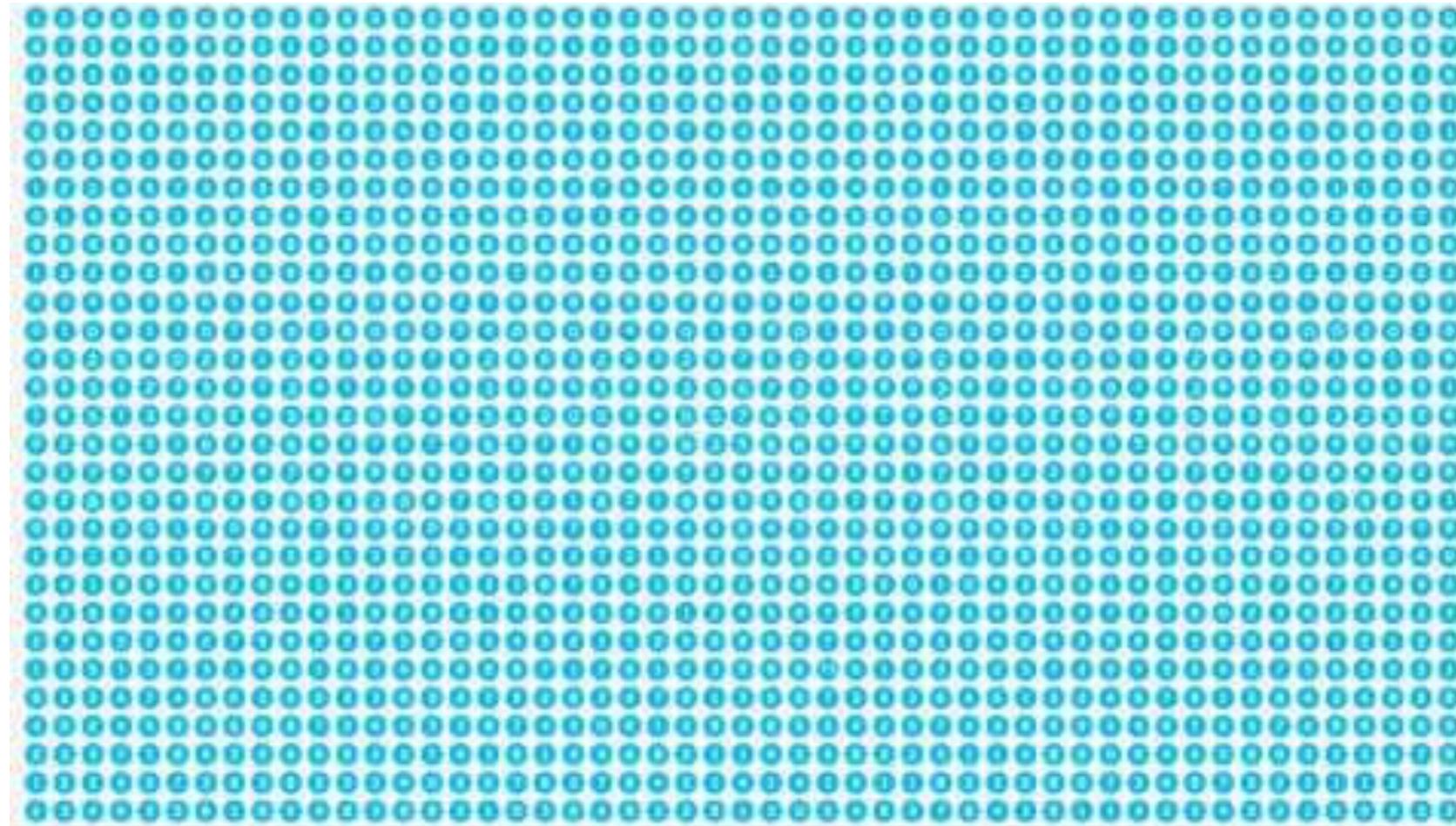


Source: Wikipedia (from the Lunar and Planetary Institute: <http://www.lpi.usra.edu>)

Thinking Systems

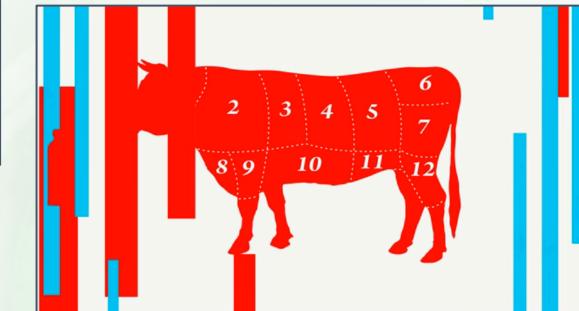
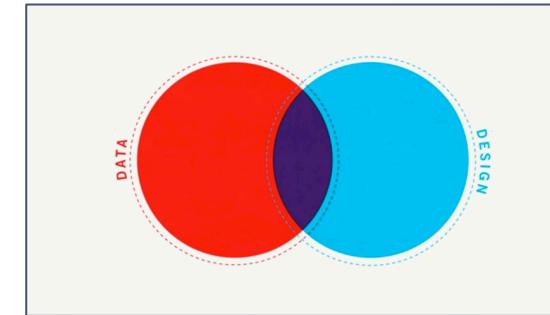
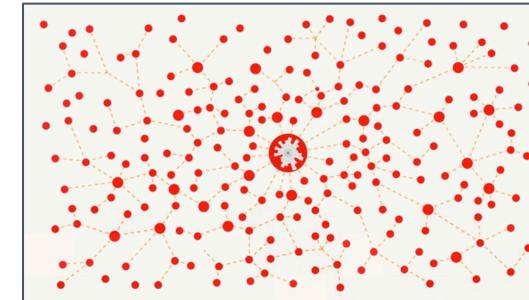
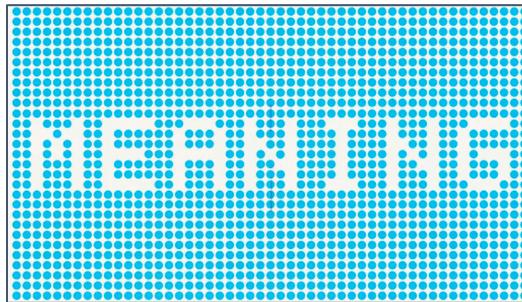
Value of Data Visualization

by Column5



Other Attributes

- What feelings did you experience during the video?



- How is it different than what you feel now?
 - *Motion*, *medium*, and *context* are also influencers on how we *perceive data* and *information*

We Have Built in Biases

Psychologists recognize two “*thinking systems*” that we use to *make sense* of the world

- **System 1** (BOTTOM UP) – operates *automatically* and *quickly*, with *little* or *no effort* and *no sense of voluntary control*
- **System 2** (TOP DOWN) – allocates *attention* to the *effortful mental activities* that demand it, including *complex computations*

We Have Built in Biases

- **System 1** generates *impressions, intuitions, intentions, and feelings* for **System 2**
- **System 2** can be engaged as needed to *solve more complex problems* or where **System 1 runs into difficulty**



System 1 informs...

You get an automatic impression...

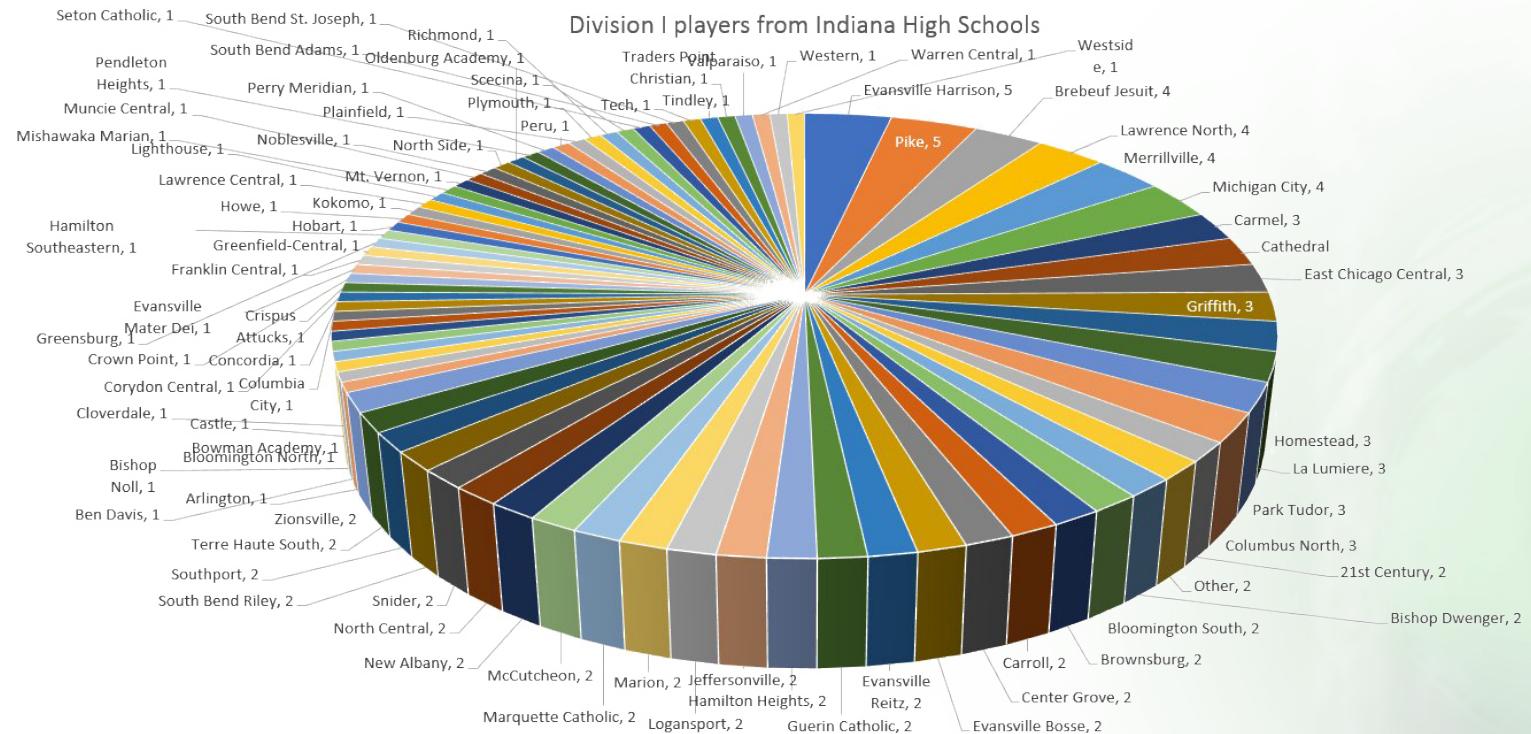
What is the Answer?

$$19 \times 23$$

System 2 shifts into gear to figure out the answer!

It is 437!!

... and What Happens Now?



Resulting...

Impressions in System 1 affect the *conclusions* of System 2

- *Presentation* impacts *the way data is perceived*
- *Mood* and *emotions* impact *critical thinking*
- **Caution:** *over-simplification* can result in *distorted understanding*

References

- Healey, C., & Enns, J. (2011). *Attention and visual memory in visualization and computer graphics*. IEEE transactions on visualization and computer graphics, 18(7), 1170-1188.
- Exploring Pre-attentive Attributes ([Link](#))

Acknowledgements

Some of the materials are adapted from:

- David Hoksza, 2019
- Jeffrey A. Shaffer, 2019
- Eleana Gkogka, 2018
- Marti Hearst, 2003