Introduction to Data Visualization & Visual Perception

Adapted for CGT 575 Data Visualization Tools & Applications

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Adjunct Faculty, University of Cincinnati
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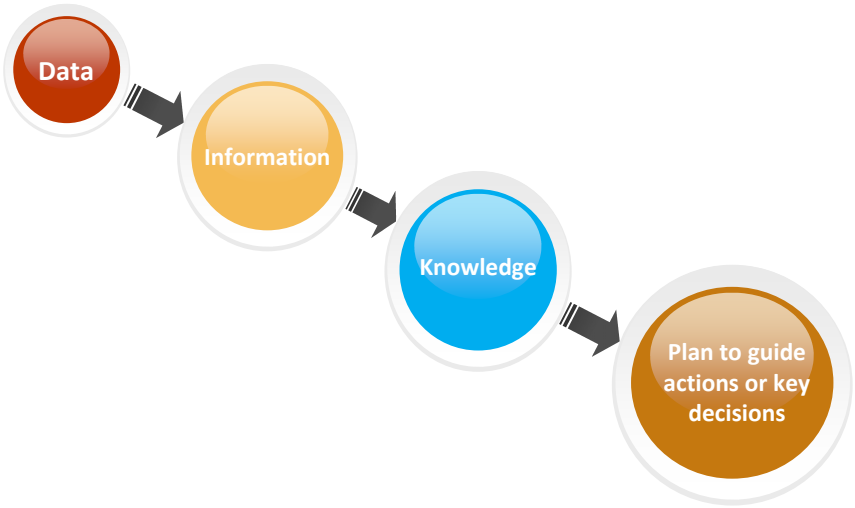
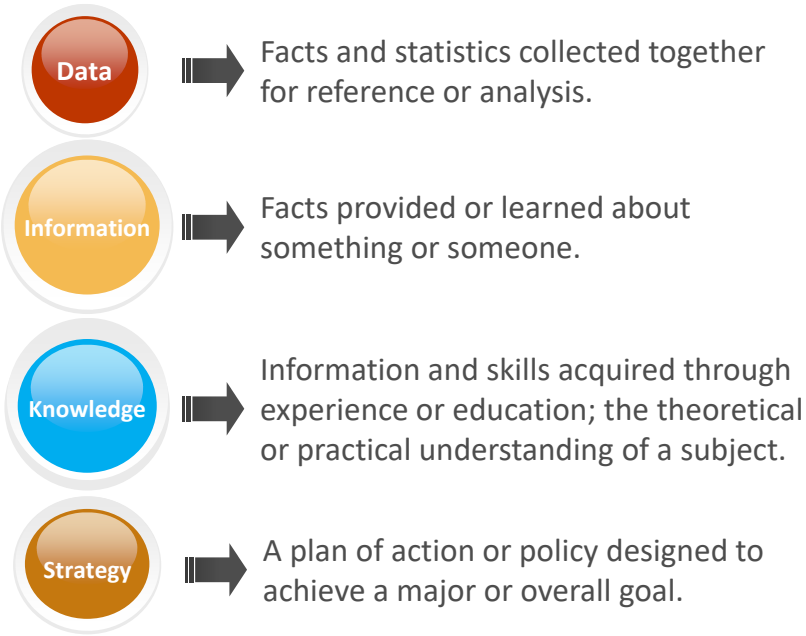
Visual analytics is a growing field…

- Data visualization classes now taught at universities
  - Has become part of Business Analytics, Statistics, Information Systems, Business Administration and Econometrics.
- Companies adding visual analyst positions
  - Visually trained business analysts with a data orientation
  - Growing ranks of data “storytellers” and “data visualization” positions

Business Intelligence

Moving from data to action….





How many times does the digit 7 appear?

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

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

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

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
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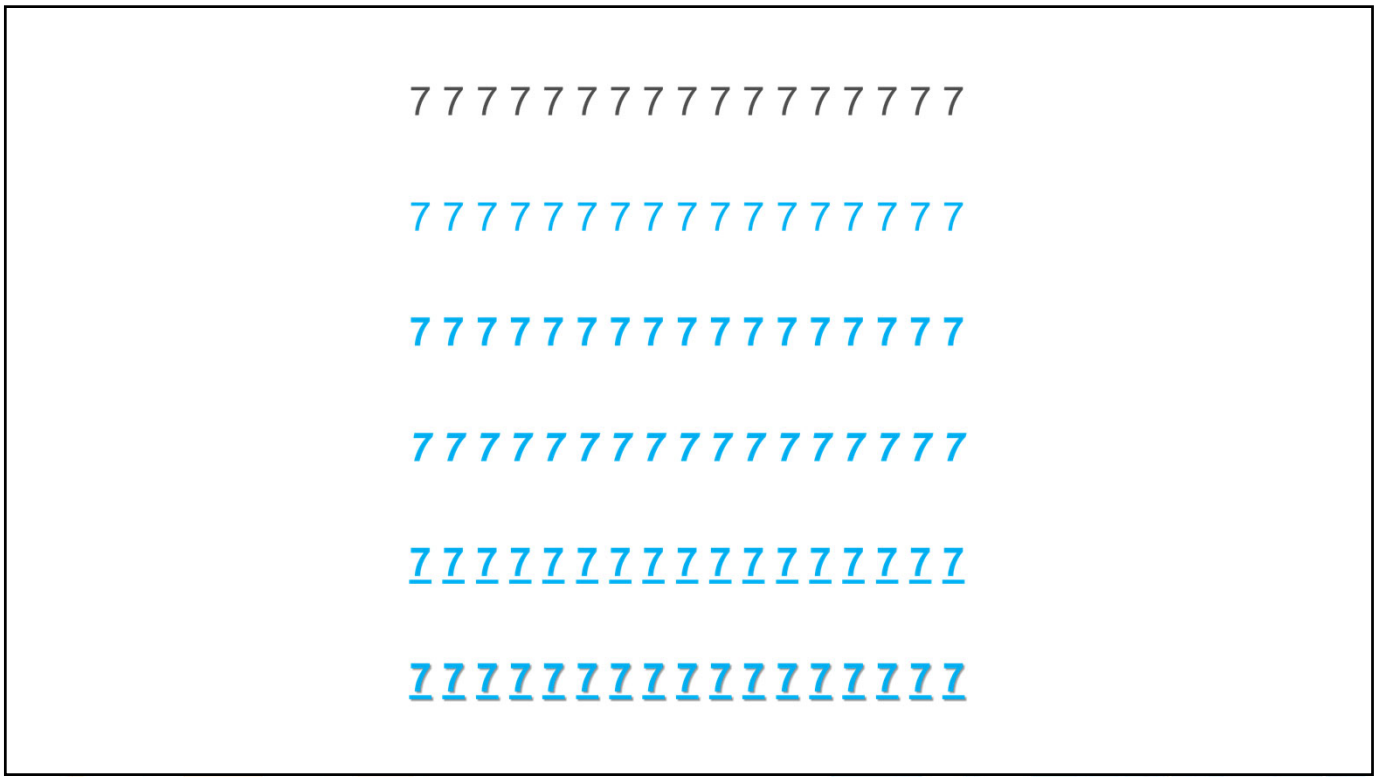
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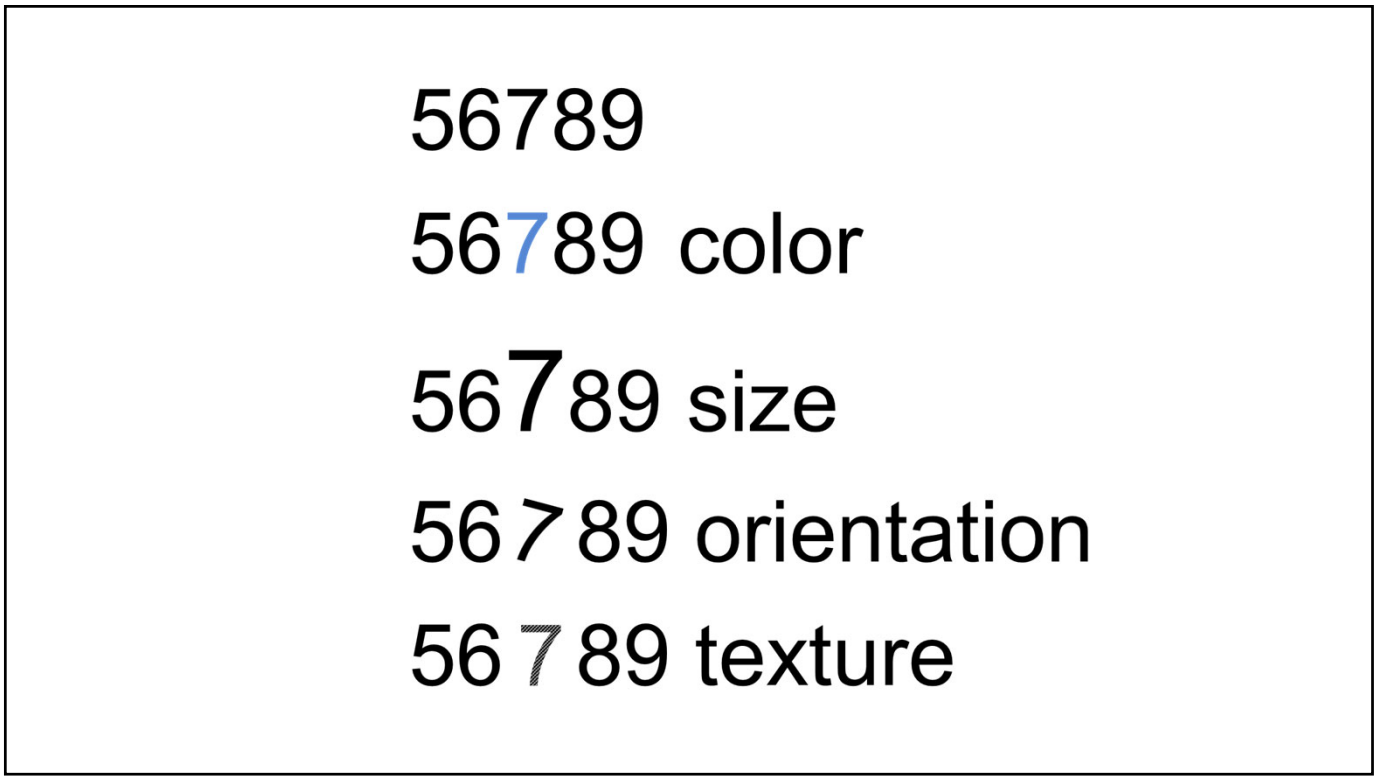
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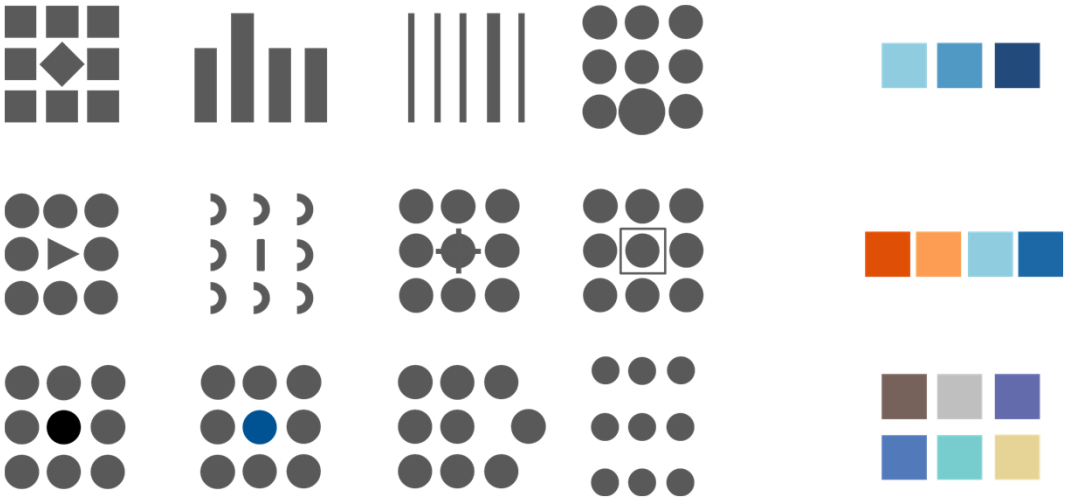
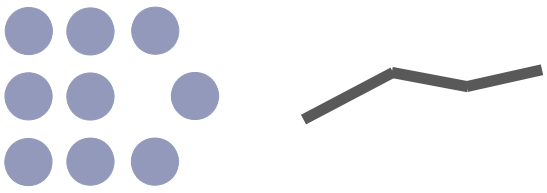


Preattentive attributes of visual perception and use of color

Precise Quantitative Comparisons

Length or Width



2D Position

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

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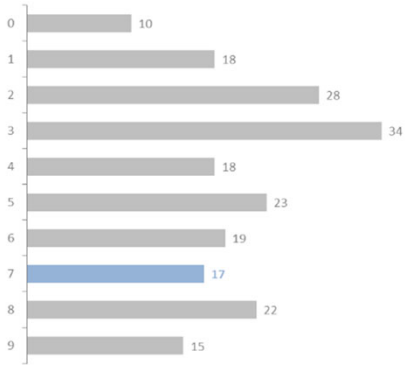
8	5	4	8	2	0	3	3	5	4	1	8	2	0	1	2	5
3	6	4	3	9	1	0	8	9	5	3	4	5	3	2	5	2
8	3	6	1	6	2	4	6	2	5	9	1	5	2	6	3	6

# of times digit 7 appears: 17



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 8
5 8 9 6 2 1 4 4 3 9 3 6 5 2 4 9 1
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4 2 0 3 3 5 4 1 8 2 0 1 2 5 3 6 4
3 9 1 0 8 9 5 3 4 5 3 2 5 2 8 3 6
1 6 2 9 3 8 3 8 5 8 4 2 0 3 3 5 4
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4 9 1 0 2 5 2 8 3 6 1 6 2 9 3 8 3
8 5 4 8 2 0 3 3 5 4 1 8 2 0 1 2 5
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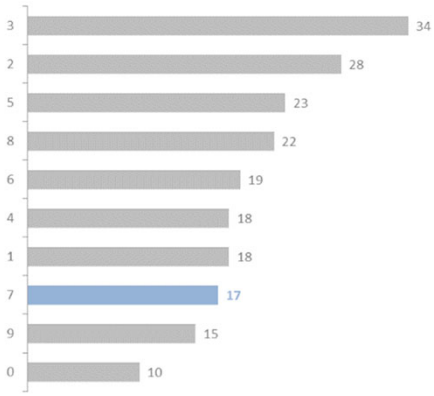
# of times digit 7 appears: 17



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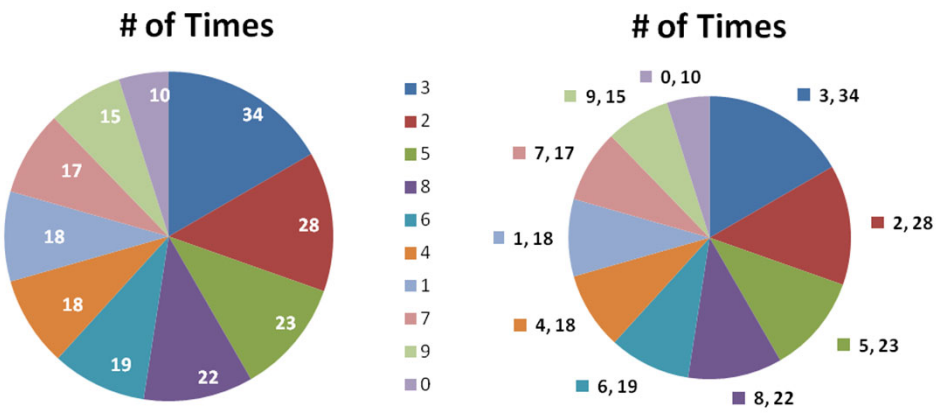
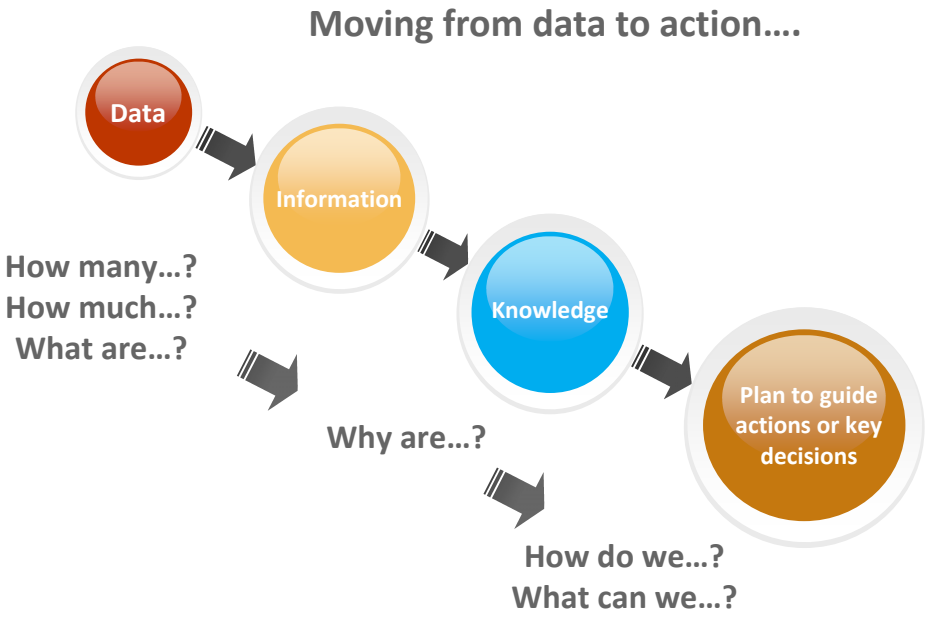
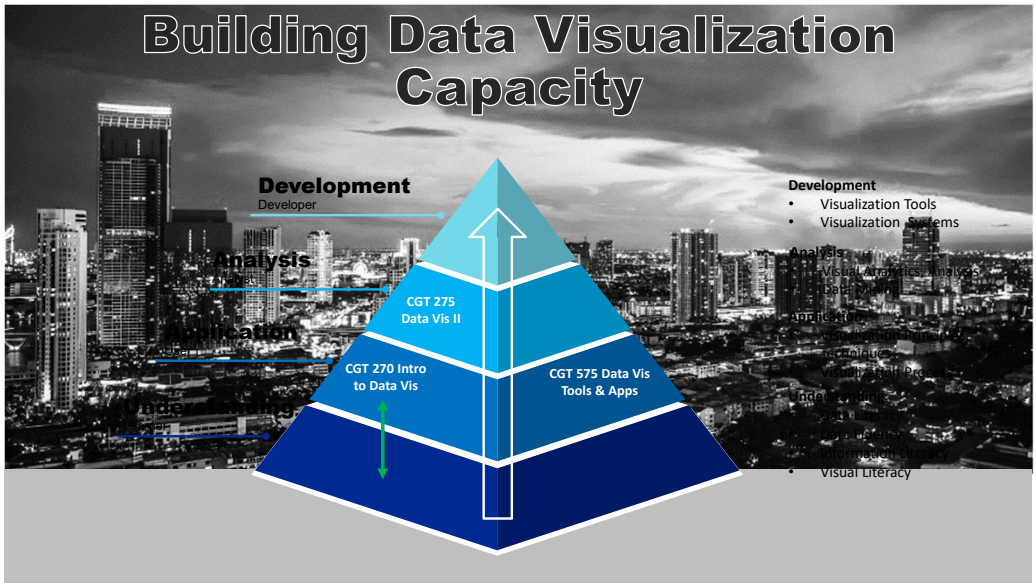


- Label problems
- Color problems
- Hard to make visual comparisons
- Do we get the same Information?

Business Intelligence





Byrd Vis Lab

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A Brief History of Data Analytics

The Early Years – 2nd Century CE

A copy of the *Almagest* from the 9th century, in Greek, on parchment

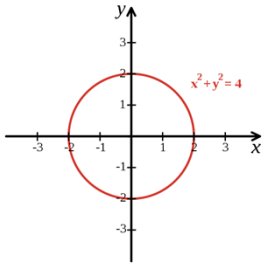
- Claudius Ptolemy published the *Almagest* around 150 CE in Egypt, providing a thorough treatise on astronomy, solar, lunar, and planetary theory[1]
- **Earliest preserved use of a table**; held detailed astronomical information[2]

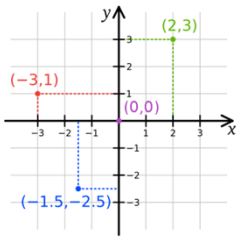
17th Century

René Descartes

(1596-1650)

- Invented a method of presenting number-based data using 2-D coordinate scales[2]
- Originally designed to allow algebraic equations to be expressed visually, linking Euclidean geometry and algebra[3,4]
- Later became known as the Cartesian coordinate system[3]



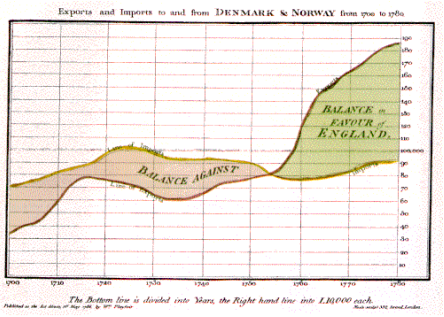


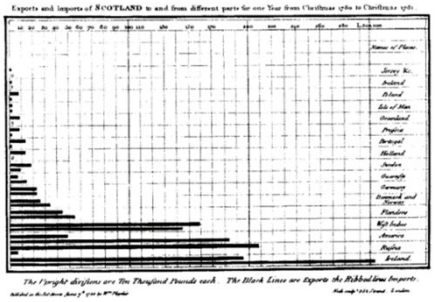
Late 18th – Early 19th Century

William Playfair

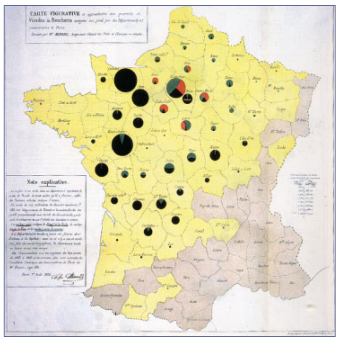
(1759-1823)

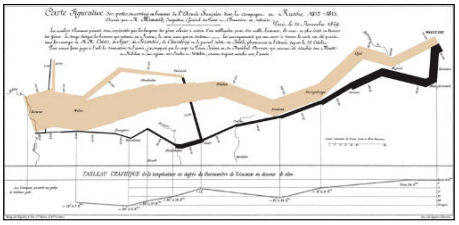
- Scottish engineer and political economist[5]
- Founder of graphical methods of statistics
- Developed new designs and improved existing methods to provide "systematic visual representations of his 'linear arithmetic.'"[6]
- Created the time-series line graph, bar chart, and pie chart.[7]





Early 19th Century





Charles Minard

(1781-1870)

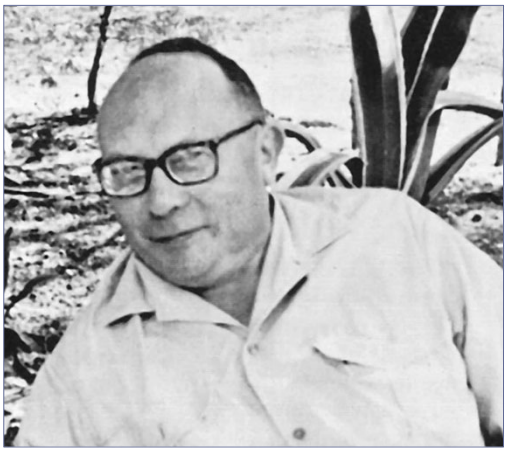
- French civil engineer; produced an array of graphics that combine a many data points into a compelling visual story
- Produced 70+ depictions including thematic maps and graphic tables between 1844-1870.[7]
- Map of Napoleon's Russian campaign regarded by some as the "best statistical graphic ever drawn."[8]

20th Century

Jacques Bertin

(1918-2010)

- French cartographer and theorist
- Author of many scientific maps, articles, and other papers on *semiology*, the study of signs, and how we process visual information
- 1967 – Published *Sémiologie Graphique* (Semiology of Graphics), asserting that our visual perception follows rules that can be followed



20th Century

John Tukey

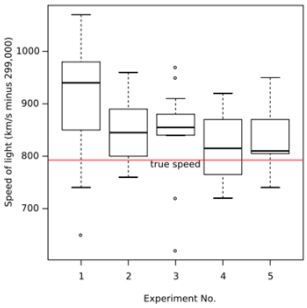
(1915-2000)

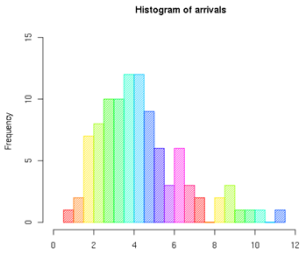
- American statistician
- Introduced the **box plot** in *Exploratory Data Analysis*, published in 1977
- Exploratory Data Analysis (EDA) emphasized presentation of the main characteristics of a data set in a visual, easy to understand form, without using a statistical model or hypothesis[10]

20th Century

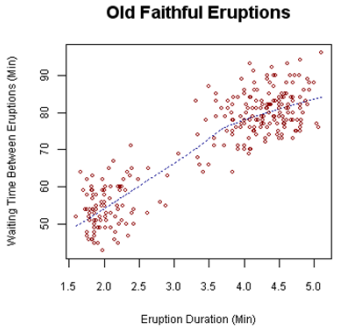
Visualization techniques used in EDA include:

- Box plot
- Histogram
- Pareto chart
- Scatter plot





Sample histogram.



Sample scatter plot.

Tukey's advocacy for EDA encouraged the development of software for statistical computing like S, *which inspired* S-Plus *and* R.[10]

Contemporary Practitioners

Edward R. Tufte

(b. 1942)

- American statistician, sculptor, and Professor Emeritus of Political Science, Statistics, and Computer Science, Yale University
- Widely recognized expert in the fields of information design and visual literacy[11]
- Credited as a pioneer in teaching the fundamental skills required for visual communication[3]

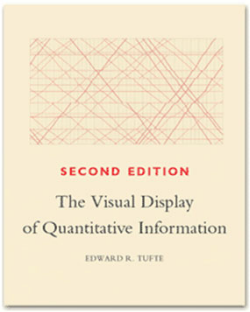
Edward Tufte photo from http://www.edwardtufte.com/bboard/images/0003mW-10280.jpg

Contemporary Practitioners

Edward R. Tufte

The Visual Display of Quantitative Information (1983)

- Provides an essential reference for how effective design can positively influence understanding



Tufte also invented sparklines

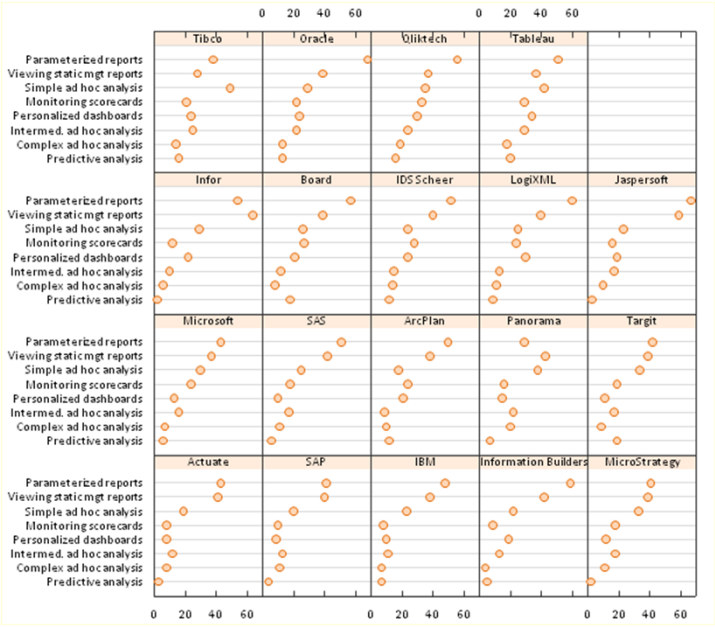
Contemporary Practitioners

William S. Cleveland photo from http://www.stat.purdue.edu/~wsc/

William S. Cleveland

- Professor of Statistics and Courtesy Professor of Computer Science at Purdue University; previously worked at Bell Labs
- Authored over 100 papers/publications including
  Visualizing Data (1993) and
  The Elements of Graphing Data (1994), to enhance awareness and provide examples of effective data presentation
- Initial developer of **trellis charts**, which make visualization possible in data sets with multiple variables

Trellis Chart Example



Graphic from http://peltiertech.com/WordPress/trellis-plot-alternative-to-stacked-bar-chart/

Contemporary Practitioners

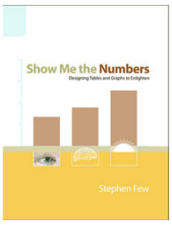
Stephen Few

Prolific writer and author with a focus on designing simple information displays that are effective and communicative.

Books include:

- *Show Me The Numbers* (2004)
- *Now You See It* (2009)
- *Information Dashboard Design, 2nd ed.* (2013)

Several of Few's examples will be used in class.



Few's biography retrieved from http://www.perceptualedge.com/about.php

Other Critical Events

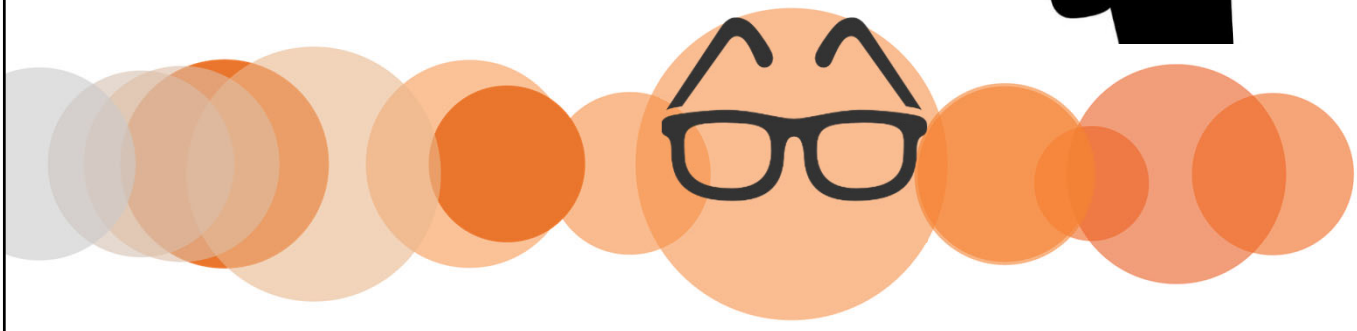
- 1984 - Apple Computer introduces the Macintosh
- The Macintosh was the first popular and affordable computer designed to display graphics in an interactive interface.[3]

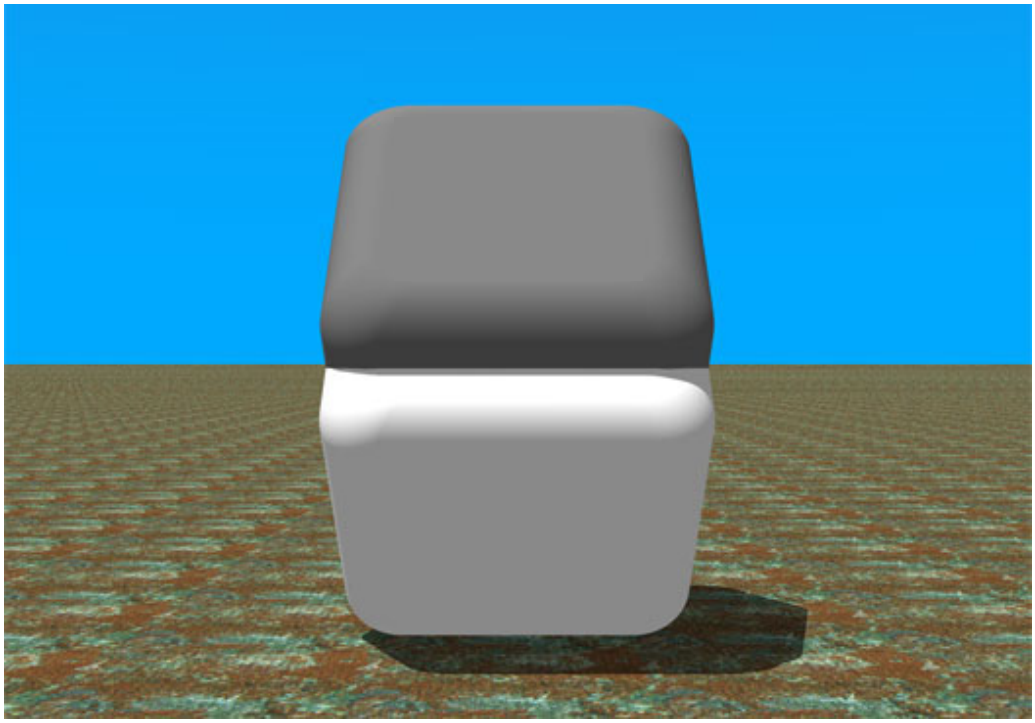
- Innovations, like the graphical user interface and mouse, are invented at Xerox Palo Alto Research Center (Xerox PARC).

Visual Perception

"I See"

"Show me"





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DATA

DATA

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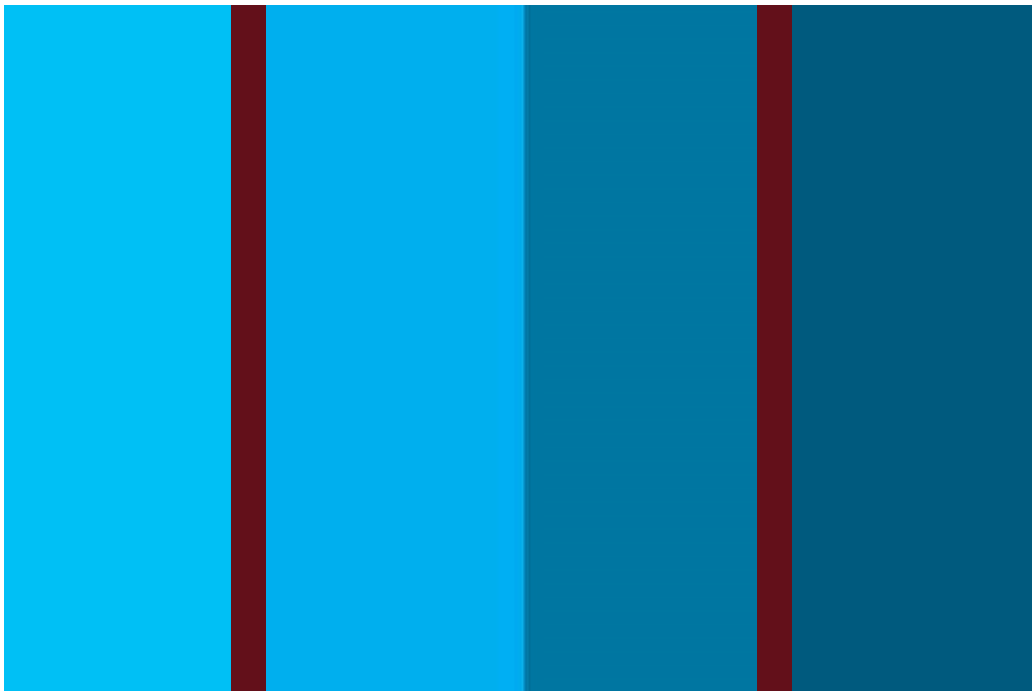
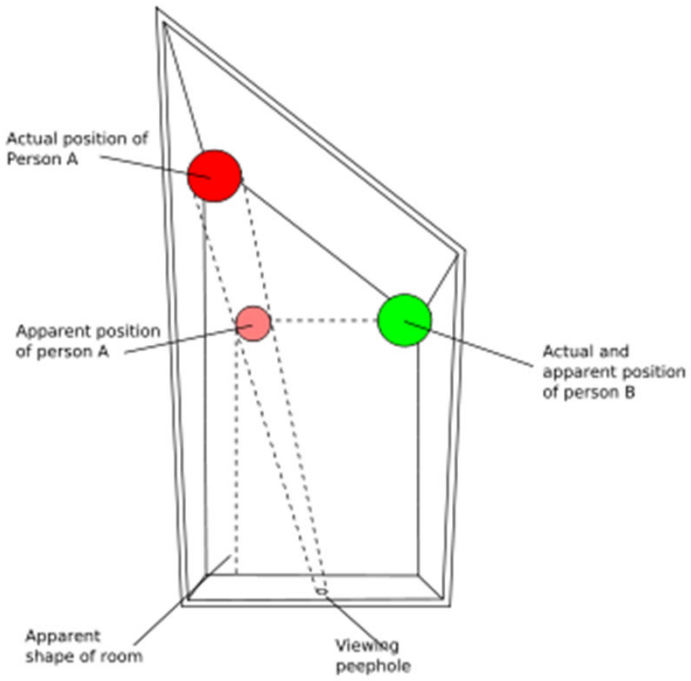
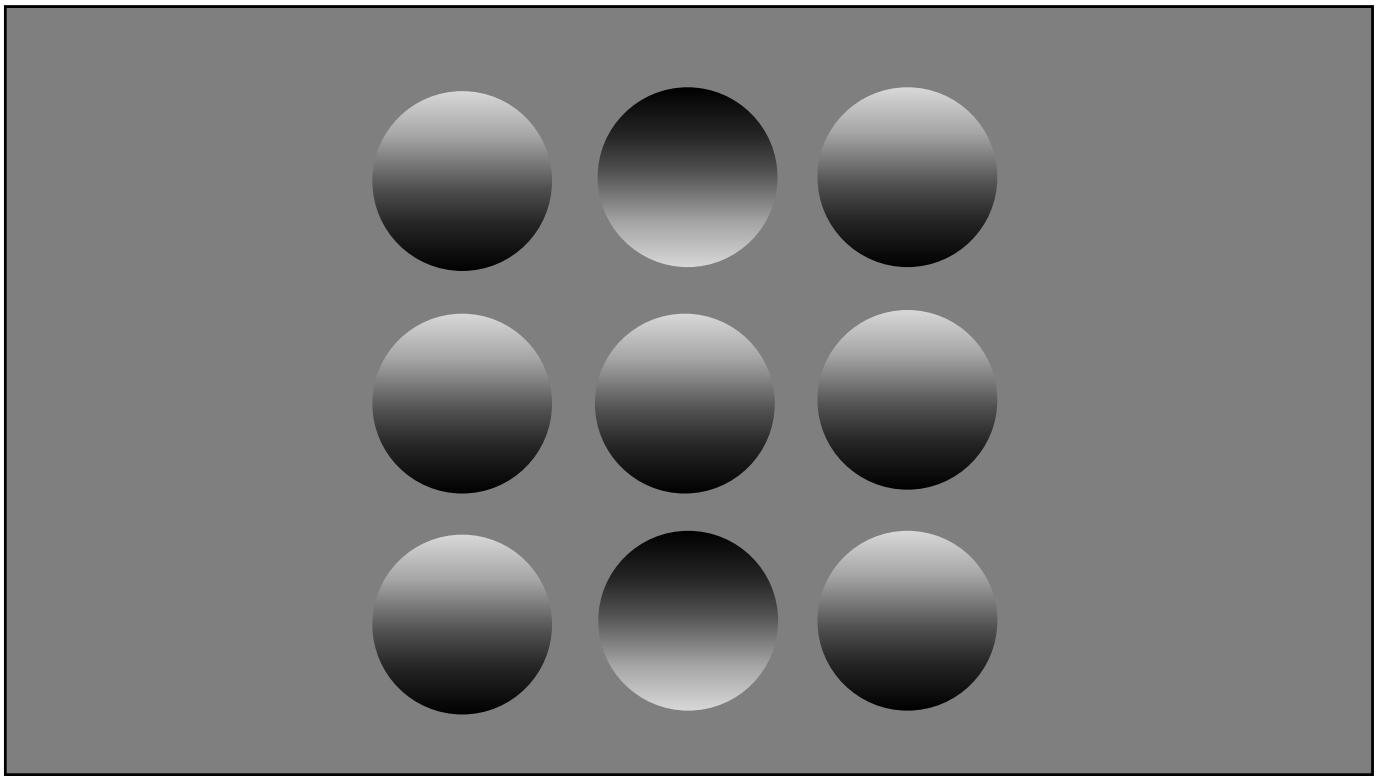


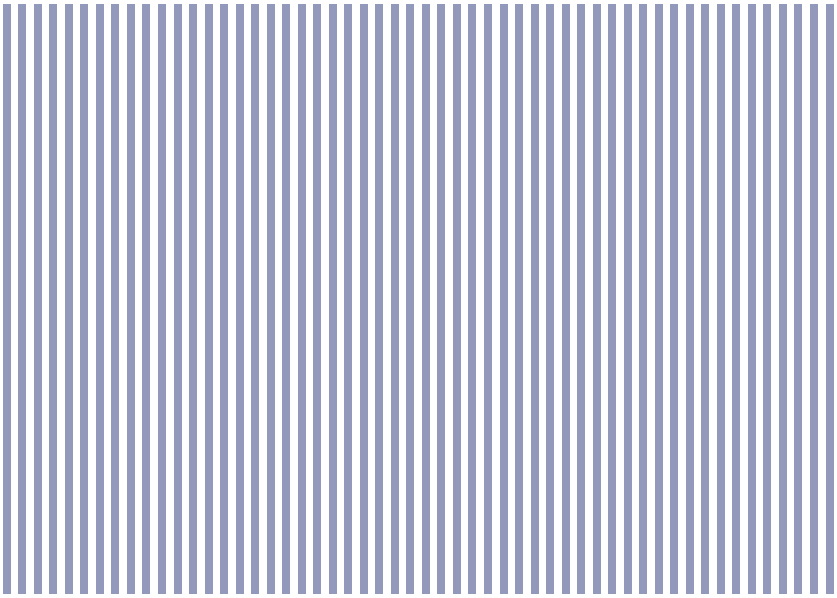


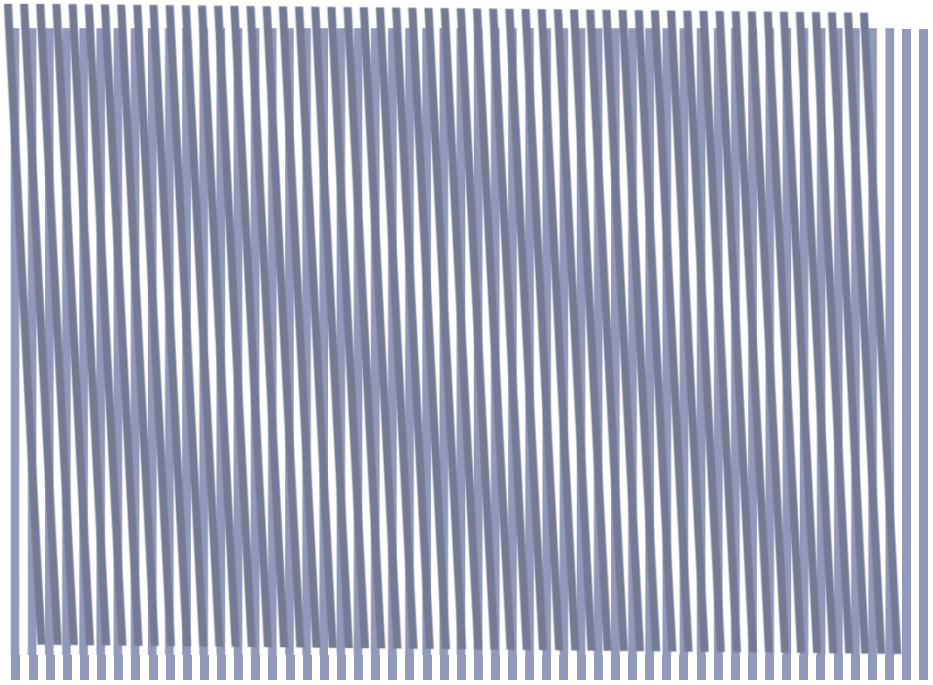
Source: Wiki Commons (Lotus, Illinois Railroad Tracks)

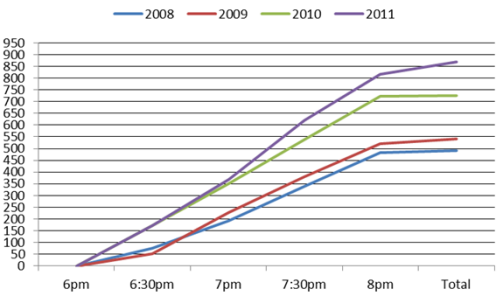


Source: Wikipedia (from the Lunar and Planetary Institute: http://www.lpi.usra.edu)

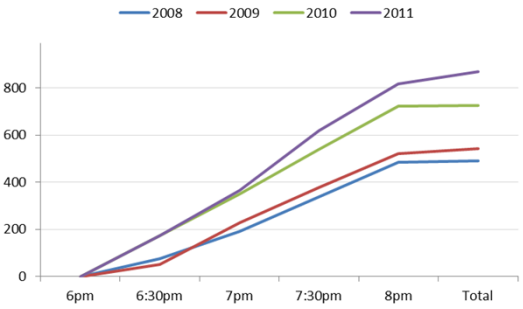
The Moiré effect

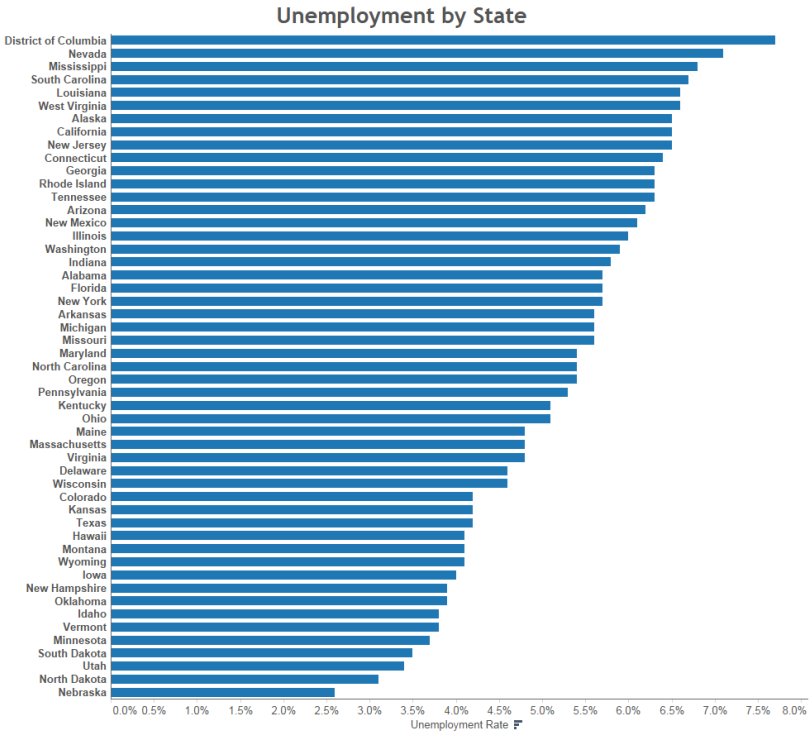






Gridlines spaced and muted



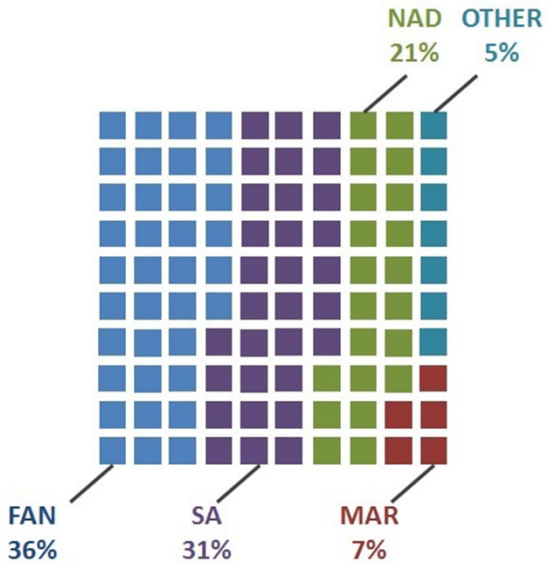


The Hermann effect

(the scintillating grid)

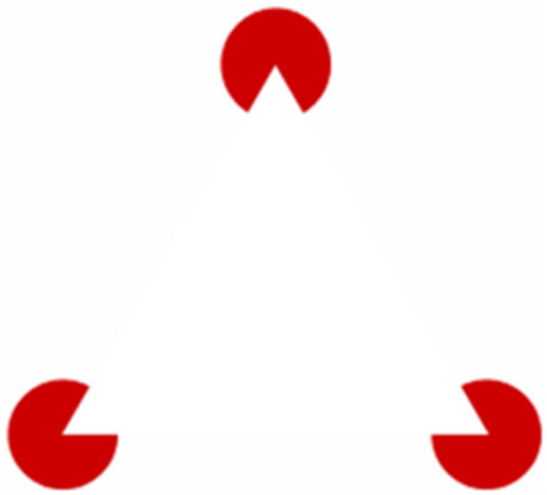
Unit Chart

(notice Hermann effect)



Gestalt Principle - Closure

(Kanizsa triangle)

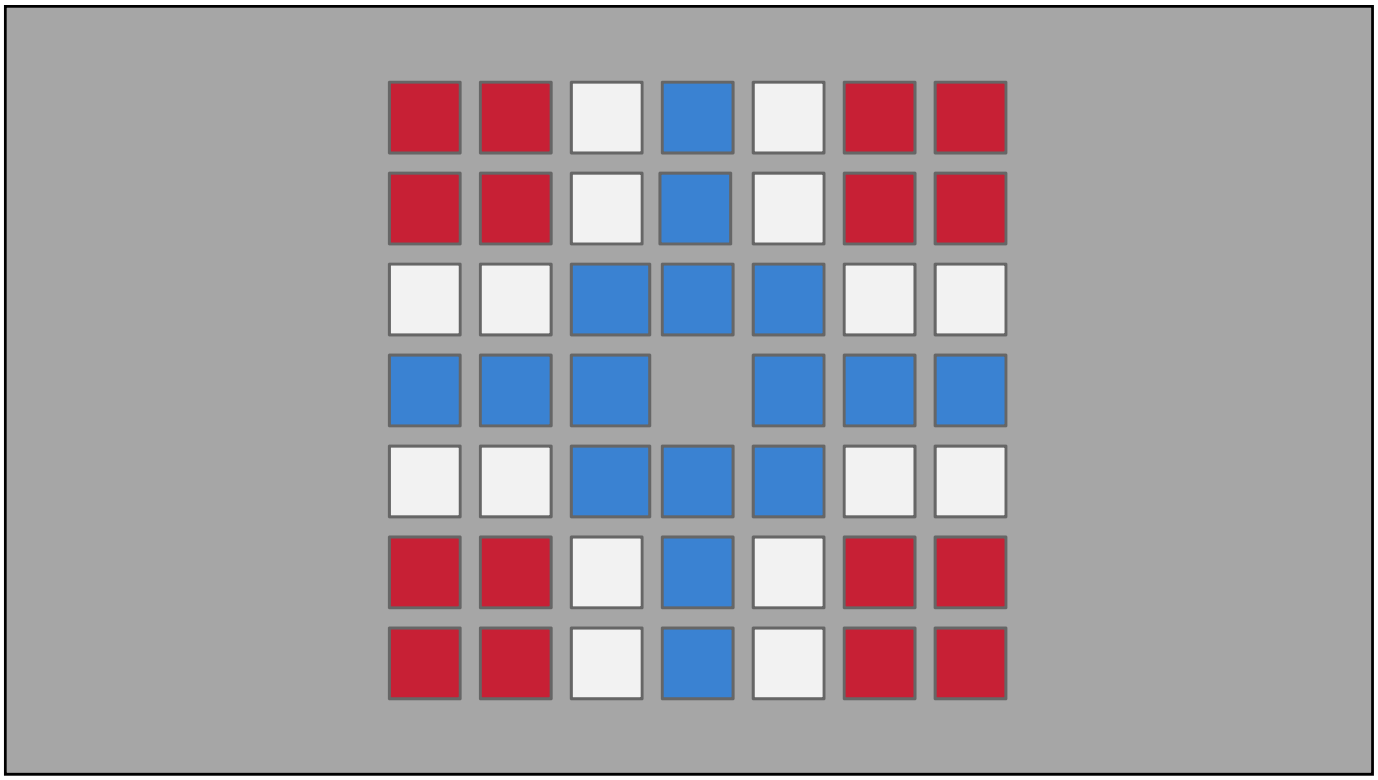


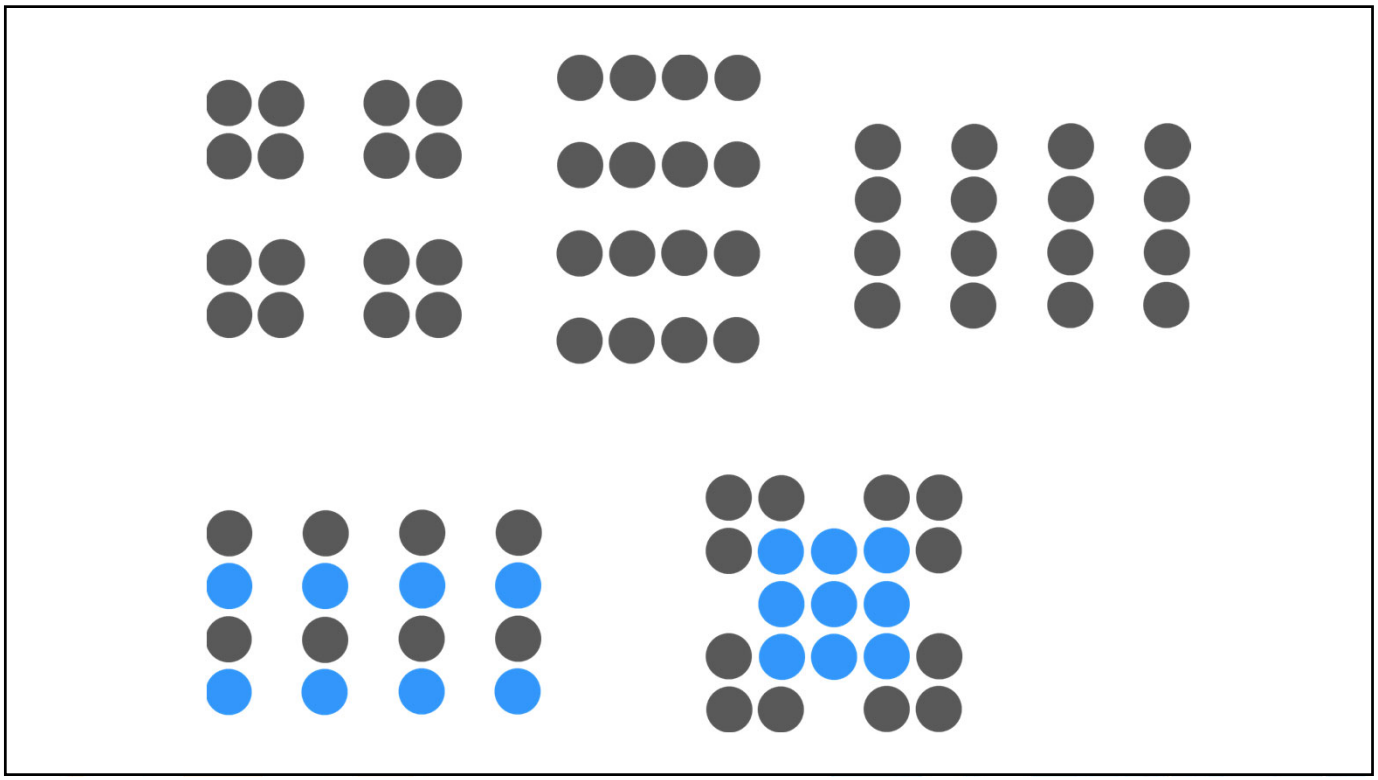
Gestalt Principle - Closure

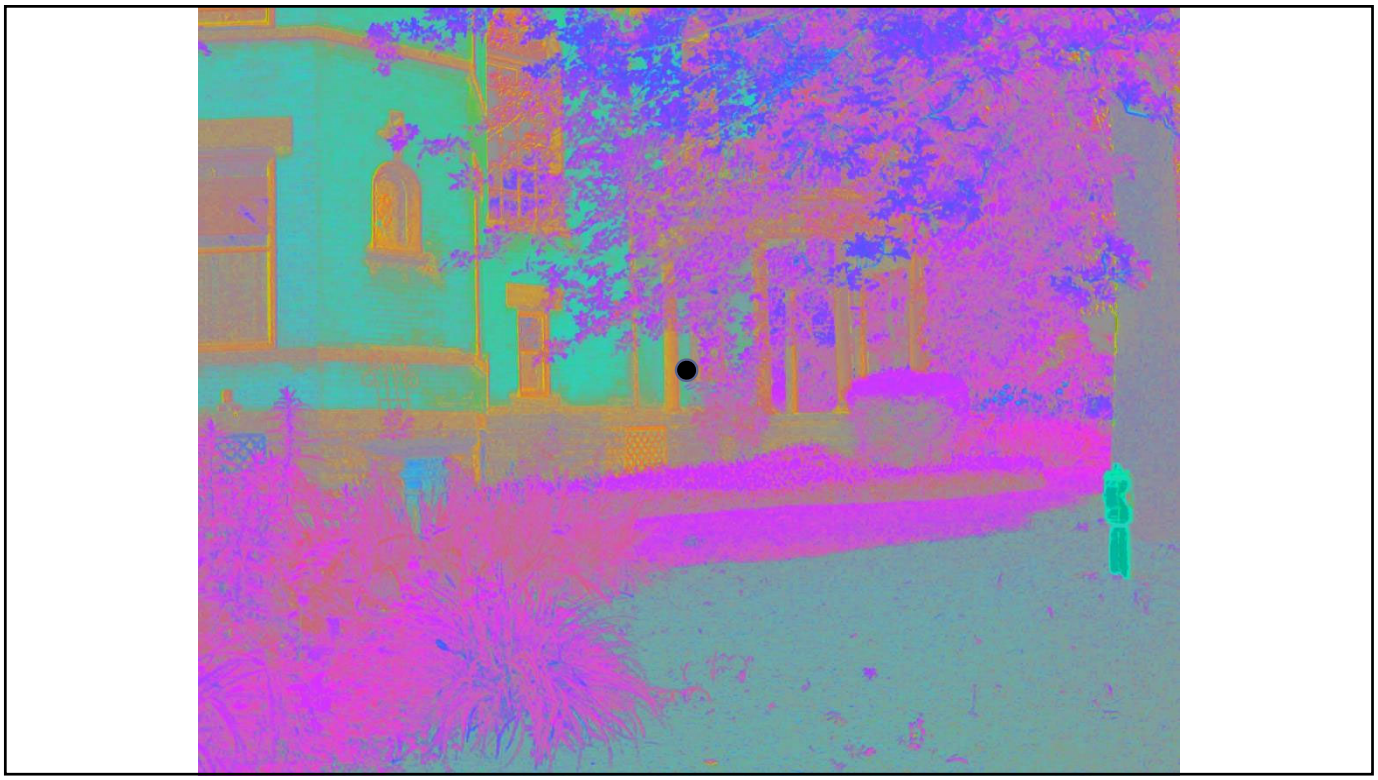
What letter is this?

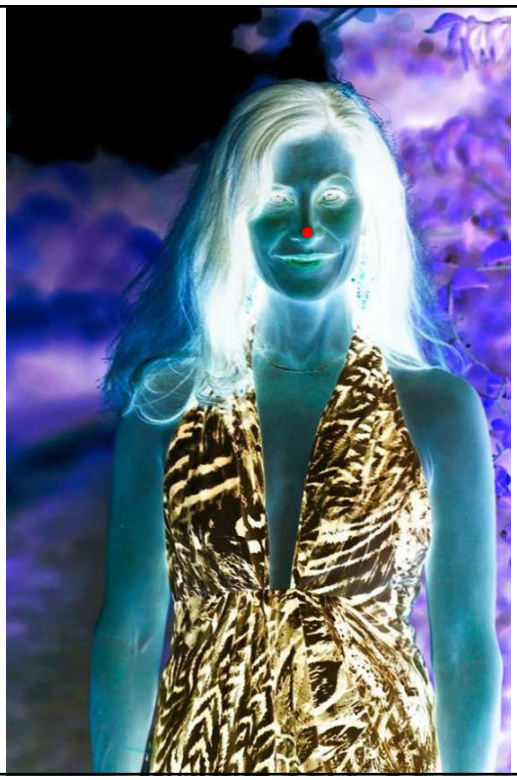
T
C /-\ T
E

Adapted from Lera Boroditsky as seen on Brain Games









Putting it all together

- We live in a world that is rich with data
- Tools let us look at the past, present, and "try out" future scenarios
- Ultimately, we want to understand our world and make better choices, change behavior, grow wealth, improve quality of life, etc.
- We discover *how* to do these things by asking questions through data…

Putting it all together

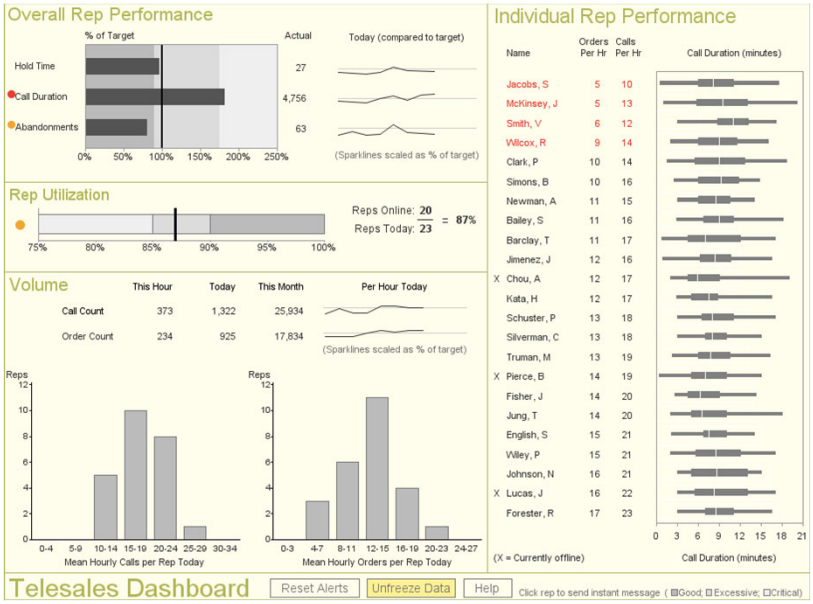
- The understanding and interpretation of data is an activity of human cognition
  - **Asking questions, discovering patterns, drawing meaning from the data**
  - **Creative, visually-driven process; also requires empirical and mathematical skills**
  - **Requires subject matter knowledge**
  - **Built-in rules (or at least, guidelines) affect the way we process information**

Easy, right? Not so fast…

- Software promises to reveal the answers…but…
  - **Computers can't figure out what our data means, "how it connects to the business or problem," and what to do**
  - **Data needs are changing** (*e.g.,* big data)
  - **Users expect "iPhone easy"**
- We don't train for visual intelligence

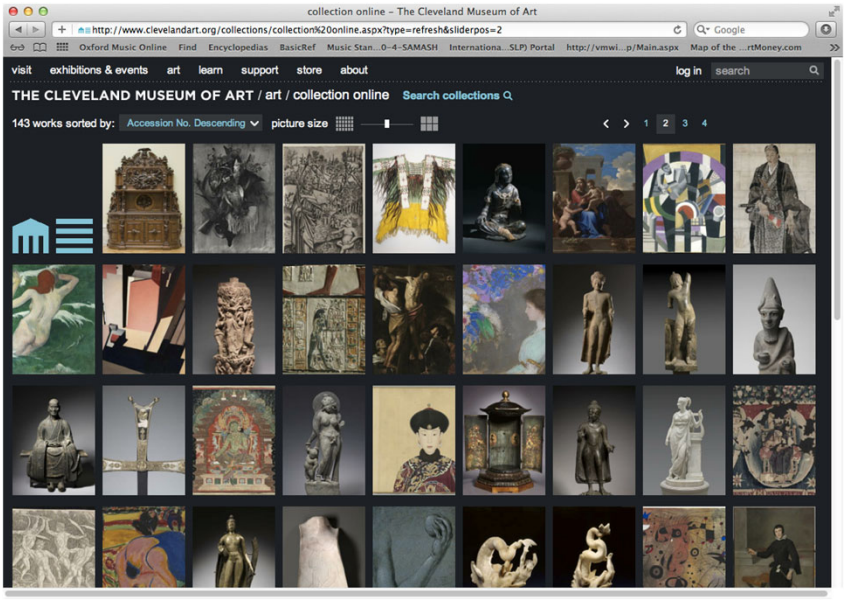
Data + tools + brains >>> **business intelligence**

Most people agree that this is data visualization…



Source: *Information Dashboard Design* (2 Ed.) by Stephen Few

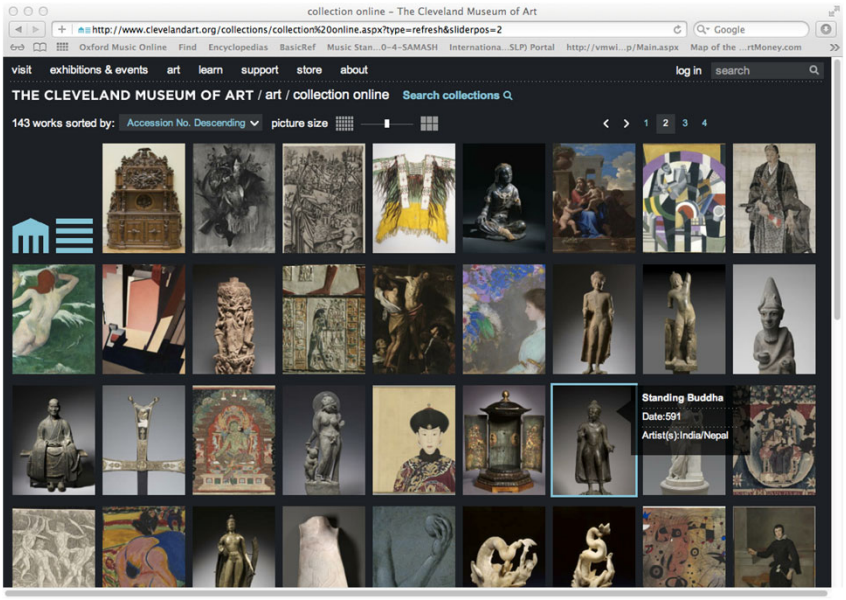
Stretching our thinking about data…



…what about this?

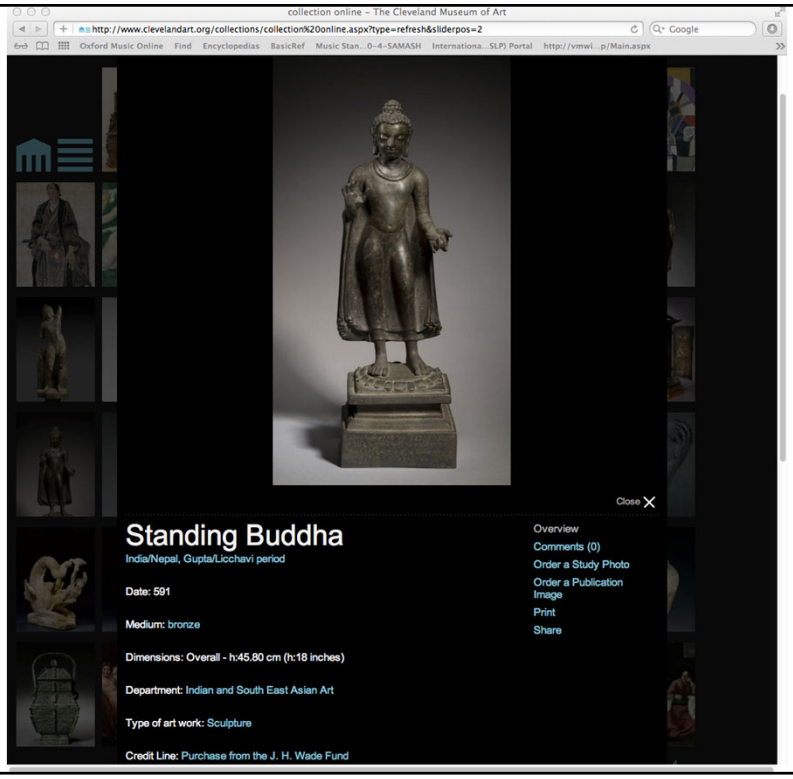
Source: http://www.clevelandart.org/art/collection/search

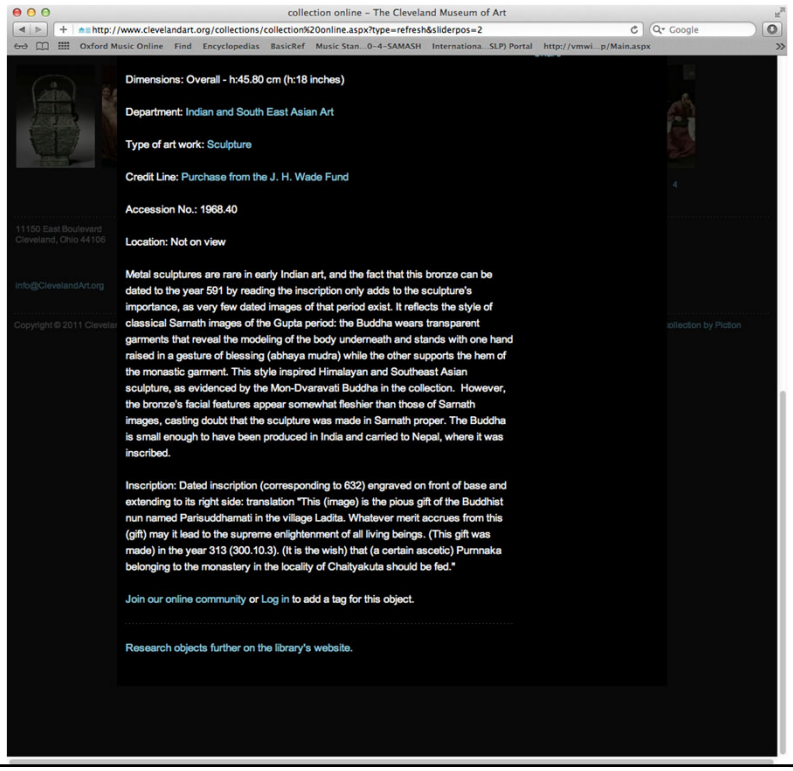
Stretching our thinking about data…



…what about this?

Source: http://www.clevelandart.org/art/collection/search

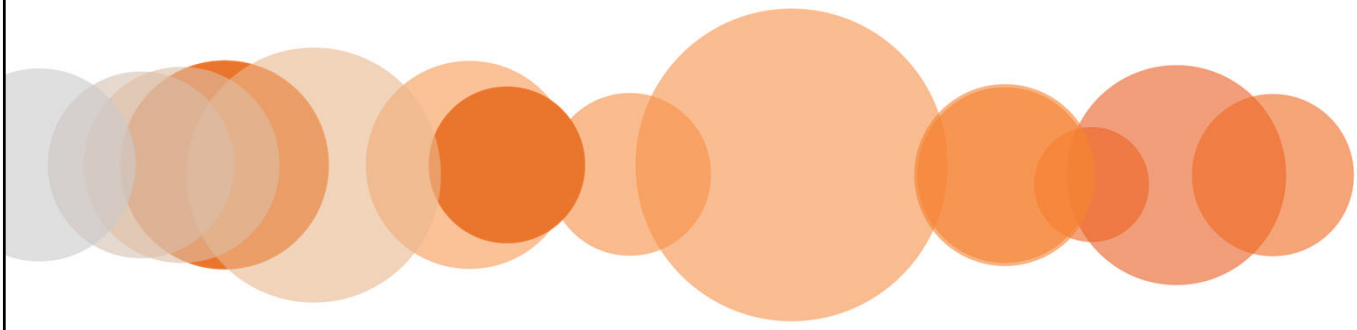




Concluding Thoughts

- Ultimately, we're trying to understand our world and make better choices, change behavior, enhance wealth, or improve quality of life.
- Learning more about the way our brains work, how we perceive and process data, and improving how we practice visualization **is essential** to achieving these goals.

The Building Blocks of Data Visualization



We are born with an enhanced visual path to cognition

- Approximately 70% of sense receptors are in our eyes
- 40% of the cerebral cortex is involved in processing visual information
- The visual connection to the brain has more bandwidth than other paths
- Visual perception is intimately connected to understanding
- This is reflected in language
  - "I see what you're talking about…"
  - "Sketch out the idea…"
  - "Seeing is believing…"

Our brain is powerful…
but working memory is limited

- Long-term memory is very important
- Working memory limited to a small number of "chunks"
- Visualization allows us to consolidate complex statistics so we can process more data simultaneously (seeing the forest along with the trees)
- The picture is not the end goal – It's what we do with it that is important

Making sense of our visual world…

According to Bertin, our perception of data on a typical printed page is associated with the following visual variables:[9]

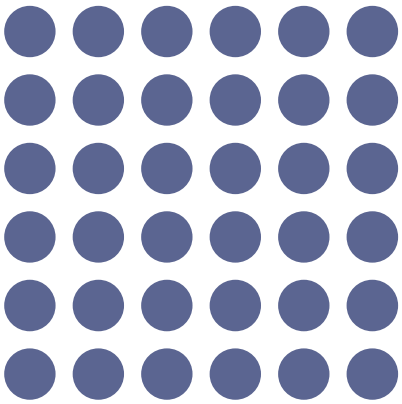
- **Shape**
- **Orientation**
- **Color**
- **Texture**
- **Value**
- **Size**

…and the two planar dimensions (x and y) which are encoded in **Position** and **Order.**

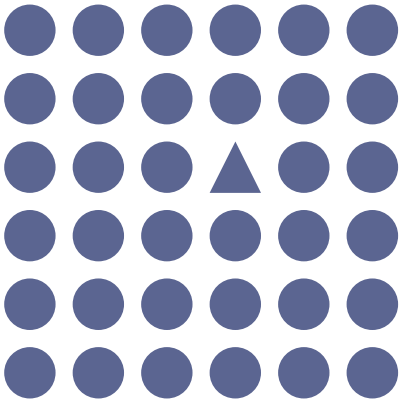
Based on the contemporary preponderance of digital technology, these factors have also become critical:

- **Motion** – animated presentation of frames of data
- **Medium** – the physical strata on which data is displayed
- **Context** – the sensory and emotional environment

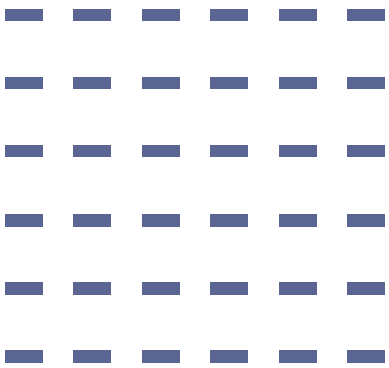
Shape



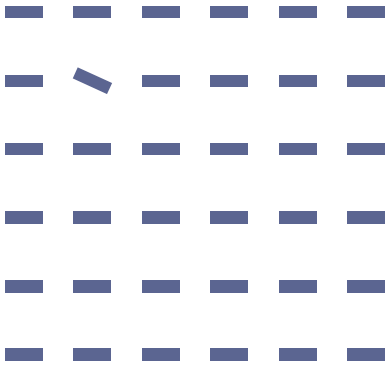
Shape



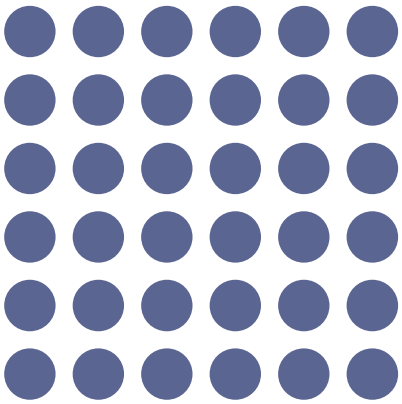
Orientation



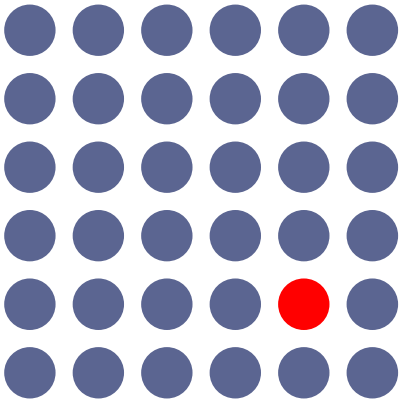
Orientation



Color (Hue)



Color (Hue)

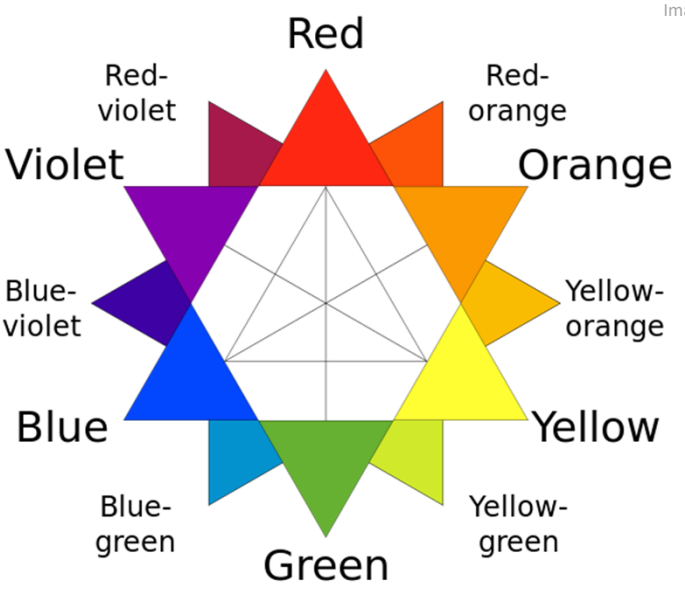


Changes to the **HUE (color)**

Changes to the **SATURATION (intensity)**

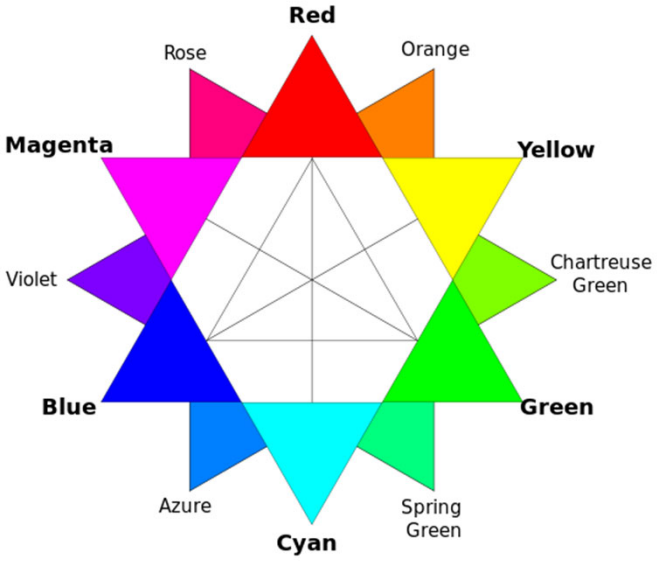
Changes to the **Value (brightness)**

Relationships on a Traditional Color Wheel



The primary colors are red, yellow, and blue.
Classical painters would have used this arrangement to find compliments.

Relationships on a RGB Color Wheel

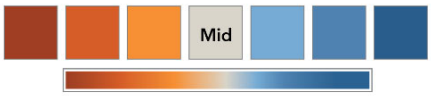


Computer displays use red, green, and blue elements.
This results in a shifted arrangement of complimentary colors.

The 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

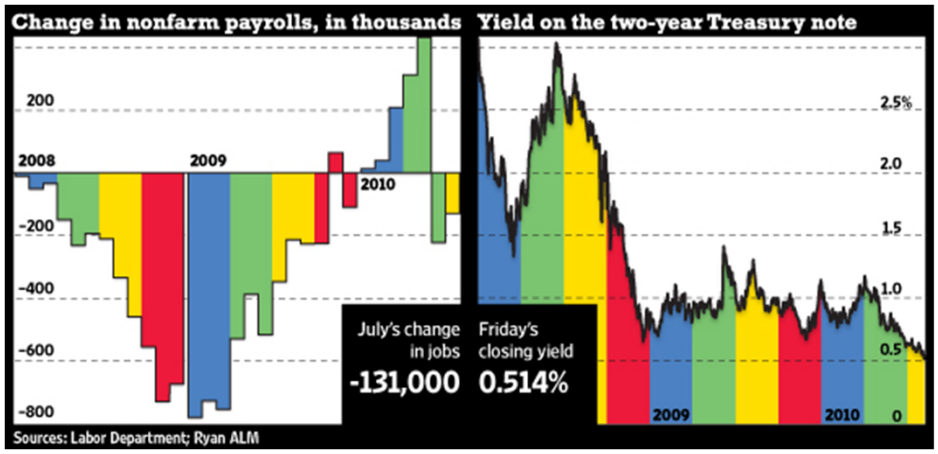
Highlight
color used to highlight something

Alert
color used to get reader's attention

Source: *The Big Book of Dashboards* (page 15)

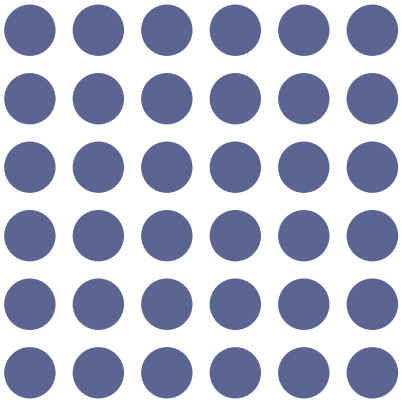
Does this color use enhance or detract?

What does color even mean here?

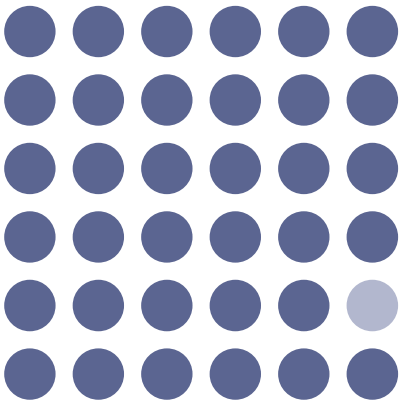


From http://online.wsj.com - *The Wall Street Journal Online, originally published August 7, 2010*

Color (Value)

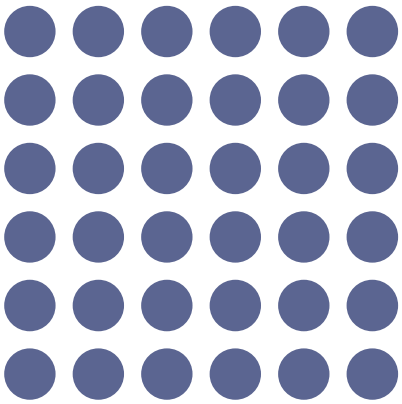


Color (Value)

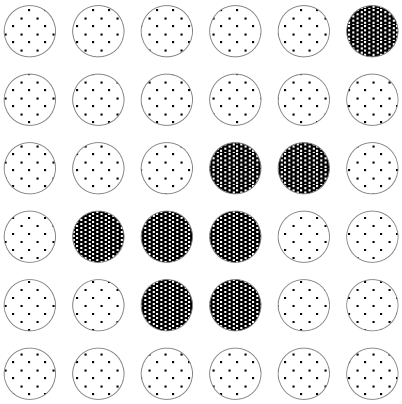


Color (Value)

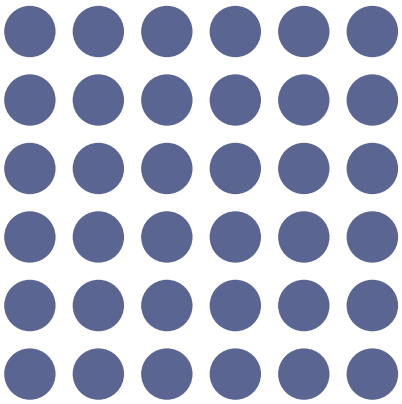
Texture



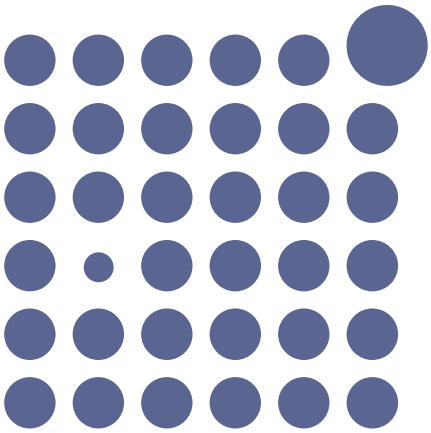
Texture



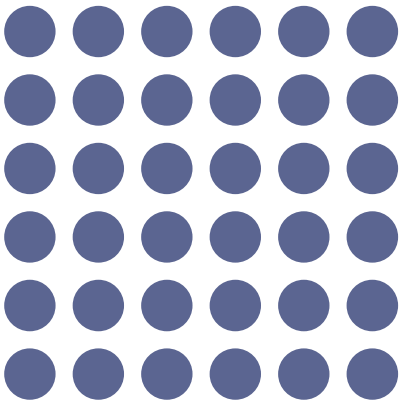
Size



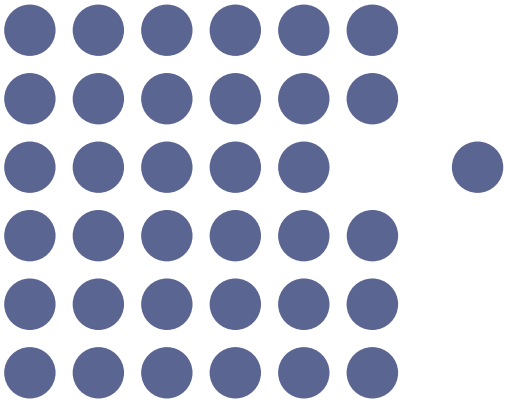
Size



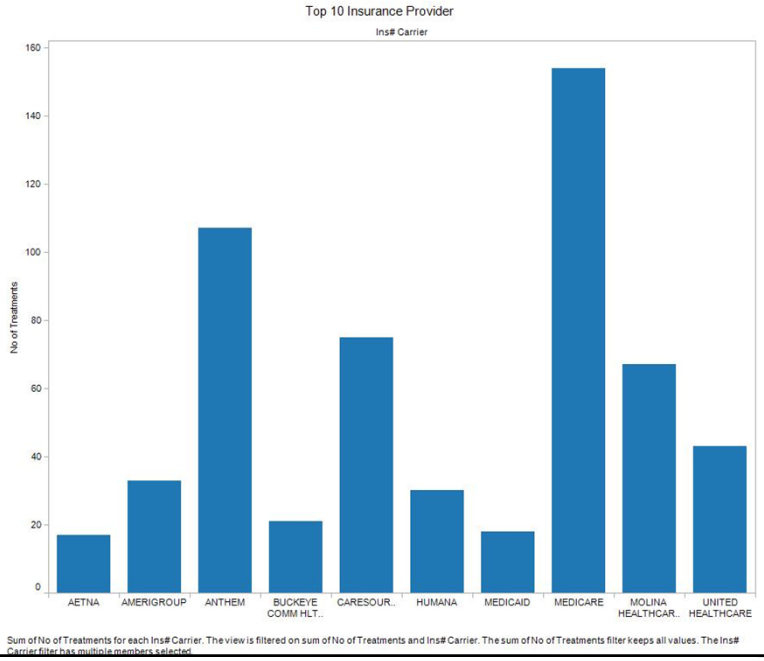
Position



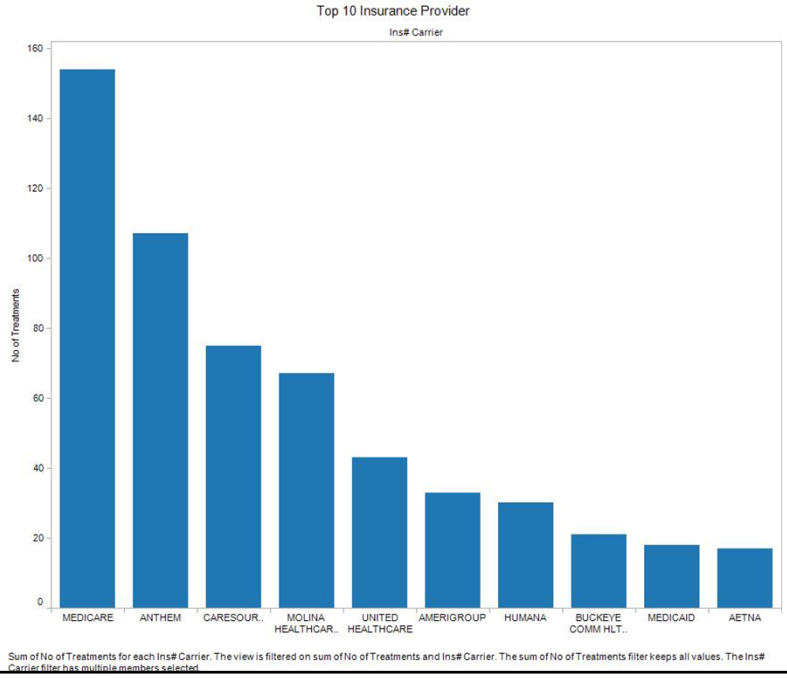
Position



Order


Top 10 Insurance Provider
Ins# Carrier
No of Treatments
0
20
40
60
80
100
120
140
160
AETNA
AMERIGROUP
ANTHEM
BUCKEYE COMM HLT..
CARESOUR..
HUMANA
MEDICAID
MEDICARE
MOLINA HEALTHCAR..
UNITED HEALTHCARE
Sum of No of Treatments for each Ins# Carrier. The view is filtered on sum of No of Treatments and Ins# Carrier. The sum of No of Treatments filter keeps all values. The Ins# Carrier filter has multiple members selected.

Order


Top 10 Insurance Provider
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0
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120
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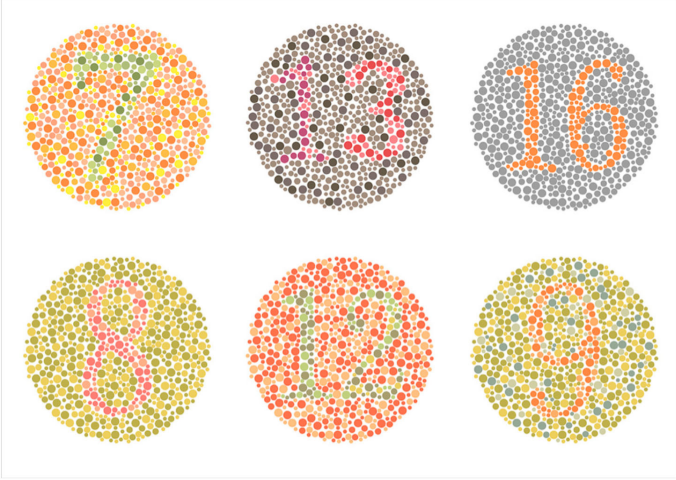
CARESOUR..
MOLINA HEALTHCAR..
UNITED HEALTHCARE
AMERIGROUP
HUMANA
BUCKEYE COMM HLT..
MEDICAID
AETNA
Sum of No of Treatments for each Ins# Carrier. The view is filtered on sum of No of Treatments and Ins# Carrier. The sum of No of Treatments filter keeps all values. The Ins# Carrier filter has multiple members selected.

5 tips on designing colorblind-friendly visualizations

by Tableau Zen Master Jeffrey Shaffer.

https://www.tableau.com/about/blog/2016/4/examining-data-viz-rules-dont-use-red-green-together-53463#:~:text=For%20example%2C%20blue%2Forange%20is,palette%20designed%20by%20Maureen%20Stone.

Don't use red and green together



The data-viz rule: "Don't use red & green together."
The issue: "Ten percent of men are colorblind and mostly red/green issues."
Reaction: "Don't use red and green together."

Studies have shown that around 8% of men and 0.5% of women have color vision deficiency (CVD). This is more commonly referred to as colorblindness, although colorblindness is not the most accurate term.

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Having CVD does not mean that a person can't see color unless you are the very rare person (one in 33,000 people) with achromatopsia. For the more common person with CVD, the key problem is that colors most people see as different will look the same.

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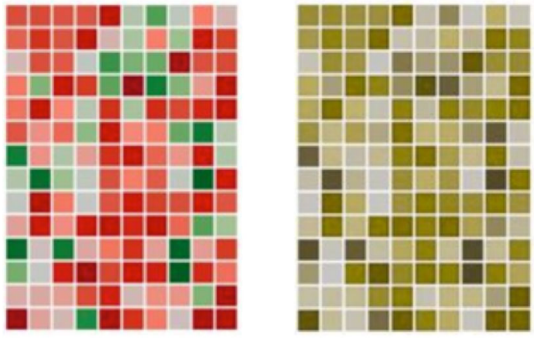
Having CVD does not mean that a person can't see color unless you are the very rare person (one in 33,000 people) with achromatopsia. For the more common person with CVD, the key problem is that colors most people see as different will look the same.

Here are some tips for designing vizzes that are colorblind-friendly.

1. Red and green together can be problematic, but they can sometimes be used together

So indeed, using red and green together is a common problem. People with strong CVD (strong meaning a more severe condition of CVD) would see both red and green as brown. People with weak CVD can see strong red and green colors as red and green. However, this can still be problematic when the colors are weak or blended together.

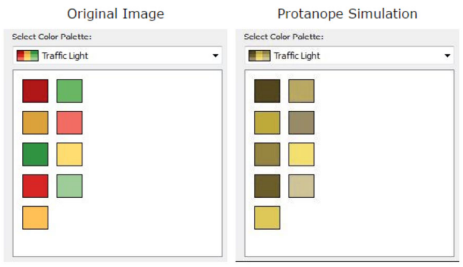
Keep in mind that being able to tell these colors apart is only an issue if color is the only encoding method used to make a distinct comparison—for example, a good number vs. a bad number in a table, or one line vs. another line in the same line chart. For example, in the chart below, color is needed to tell a good square from a bad square. Using deuteranope simulation, we can see how difficult this would be.



2. Be aware that it's not just red and green

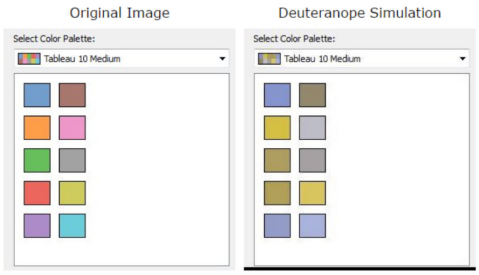
Many data visualization tools have a "stoplight" palette built into them, and there are many companies (and clients and bosses) that still insist on using the stoplight palette. With all the talk of stoplight colors and the nicknames for the CVD conditions, it's no wonder that the data visualization rule has simply become "don't use red and green." Below is a simulation of Tableau's stoplight colors using protanope simulation.

Your Results:



Also, pink and gray together and gray and brown together can be problematic. Below is the Tableau 10 color palette using a deuteranope simulation. Not only are red, green, and brown problematic but so are blue and purple, pink and gray, and gray and brown.

Your Results:

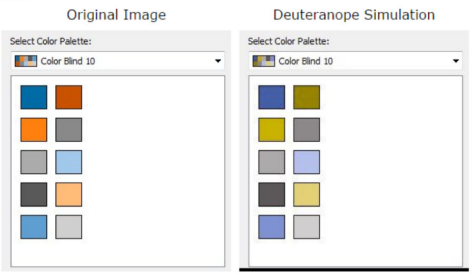


3. Use a colorblind-friendly palette when appropriate

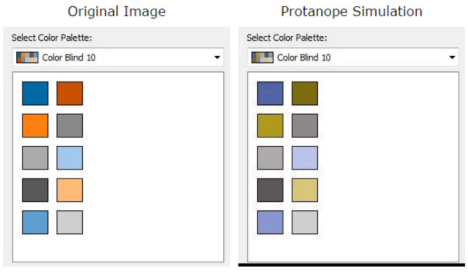
One color used together in combination with another color is generally fine when one of them is not usually associated with CVD. For example, blue/orange is a common colorblind-friendly palette. Blue/red or blue/brown would also work. For the most common conditions of CVD, all of these work well, since blue would generally look blue to someone with CVD.

Tableau has a built-in colorblind-friendly palette designed by Maureen Stone. This palette works very well for the common cases of CVD. Below is the Tableau colorblind-friendly palette under both deuteranope and protanope simulation. Notice how well this color palette works for the various comparisons of color.

Your Results:



Your Results:



4. If you must use red and green together, leverage light vs. dark

For someone with CVD, the problem is primarily with color hue (e.g. red vs. green) and not with the color value (light vs. dark).

Almost anyone can tell the difference between a very light color and a very dark color, so another option when using red and green together is to use a really light green, a medium yellow, and a very dark red. This would appear to be more of a sequential color scheme to someone who has strong CVD, but the person would at least be able to distinguish red from green based on light vs. dark.

5. If you must use red and green together, offer alternate methods of distinguishing data

- Add icons, directional arrows, labels, annotations, or other indicators that would allow a person with CVD to see that something is bad (red) vs. good (green).
- Use a checkbox for a user to switch the color palette for the entire visualization to a colorblind-friendly palette.

Citations

[1] From *Rome Reborn: The Vatican Library & Renaissance Culture*, Library of Congress website. Accessed on 2/18/2012. http://www.loc.gov/exhibits/vatican/math.html

[2] Few, Stephen (2007), *Data Visualization: Past, Present, and Future,* p.3

[3] Wikipedia entry *René Descartes*, used under the Creative Commons-Share Alike 3.0 Unported license. Accessed on 2/18/2012. http://en.wikipedia.org/wiki/Rene_descartes

[4] Wikipedia entry *Cartesian Coordinate System*, used under the Creative Commons-Share Alike 3.0 Unported license. Accessed on 2/18/2012 http://en.wikipedia.org/wiki/Cartesian_coordinate_system

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