



# PERCEPTION IN VIS

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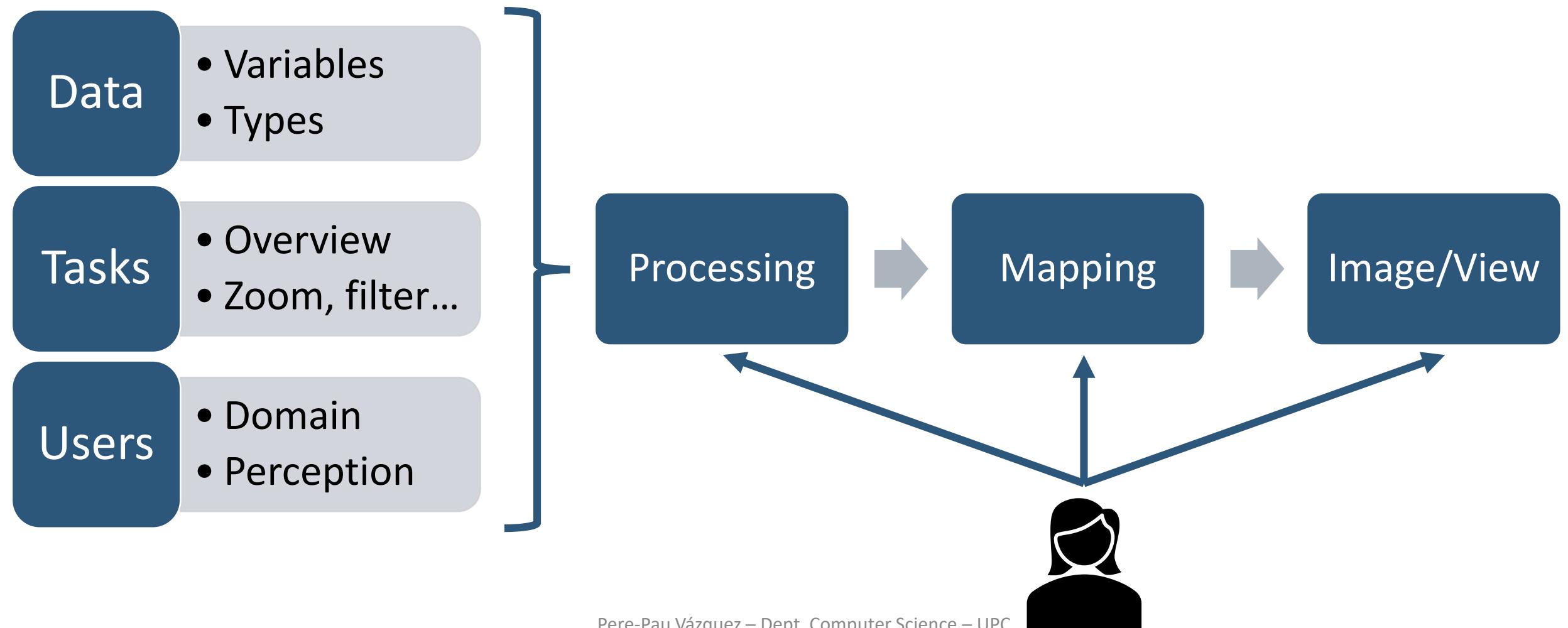
# OUTLINE

- Recap
- Introduction
- Preattentive Processing
- Perception Laws
- Applying Perception to Visualization

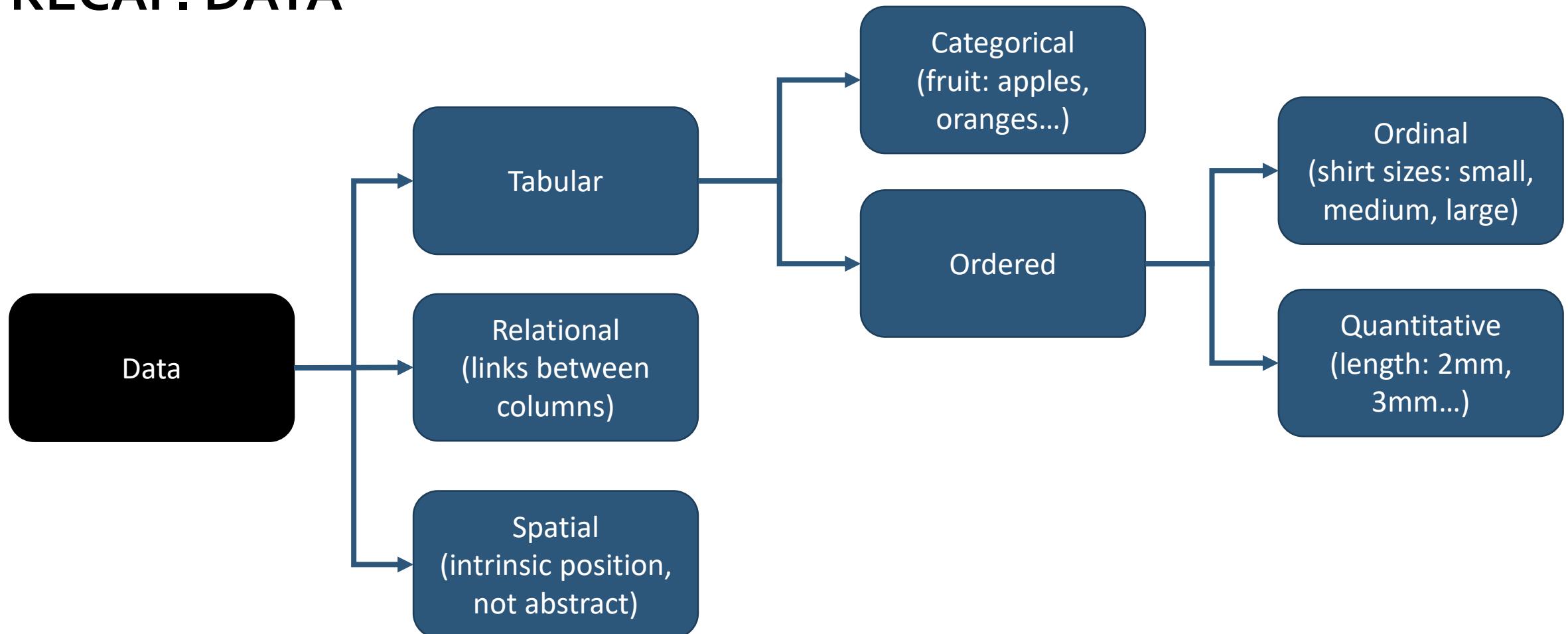
# OUTLINE

- Recap
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# RECAP. VISUALIZATION PROCESS



# RECAP. DATA



# RECAP. MARKS & VISUAL CHANNELS

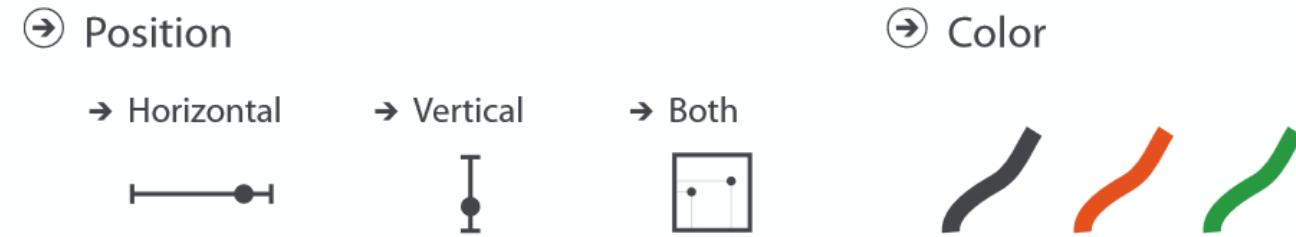
- Marks:
  - Geometric primitives
- Visual channels: control appearance of marks
  - Control appearance of marks
  - Can redundantly code with multiple channels

# RECAP. MARKS & VISUAL CHANNELS

## Marks



## Visual channels



## Size



# RECAP. TASKS & DATA TYPES

## High-level tasks

From Shneiderman, 1996

1	overview	gain an overview of the entire set of data
2	zoom	adjust the size of items of interest
3	filter	remove uninteresting items
4	details-on-demand	select one or more items and get details
5	relate	identify relationships between items
6	history	keep a history of actions to support undo/redo
7	Extract	extract subsets of items for separate analysis

# RECAP. TASKS & DATA TYPES

From Shneiderman, 1996

## Data types

1	1-dimensional	alphabetic lists, source code, text/documents
2	2-dimensional	planar or map data, photos
3	3-dimensional	molecules, human body, buildings
4	temporal	{start, finish}, e.g., medical records, project management, historical presentations
5	multi-dimensional	n attribute => points in n-dimensional space, e.g., relational DB
6	tree	Hierarchies or tree structured, e.g., file directories, business organizations
7	network	connected as graph(s), e.g., telecommunications network, www

# OUTLINE

- *Recap*
- **Introduction**
- Preattentive Processing
- Perception Laws
- Applying Perception to Visualization

# INTRODUCTION. MOTIVATION

- Vis creates **Visual** Representations
  - Need to understand how images are processed
- Many aspects will be affected:
  - Distribution of elements: can create groups, clutter...
  - Colors: may highlight, or make things invisible for all/some users
  - Geometric shapes: may communicate/skew/hide data
  - Size: of the screen/of the elements on the screen

**We need to understand all of those to infer how users will read our data**

# INTRODUCTION. MOTIVATION

- Visual design determines:
  - Understanding of information
    - Data
    - Text
  - Affordances: Perceived actionable elements
  - Tasks: e.g., understanding the data overview, relating elements...

# INTRODUCTION

- Simple case scenario:
  - Low number of dimensions → “easy”
  - “Any” visualization will work
    - No need for many visual variables
  - Many datapoints
    - Usually a real state problem

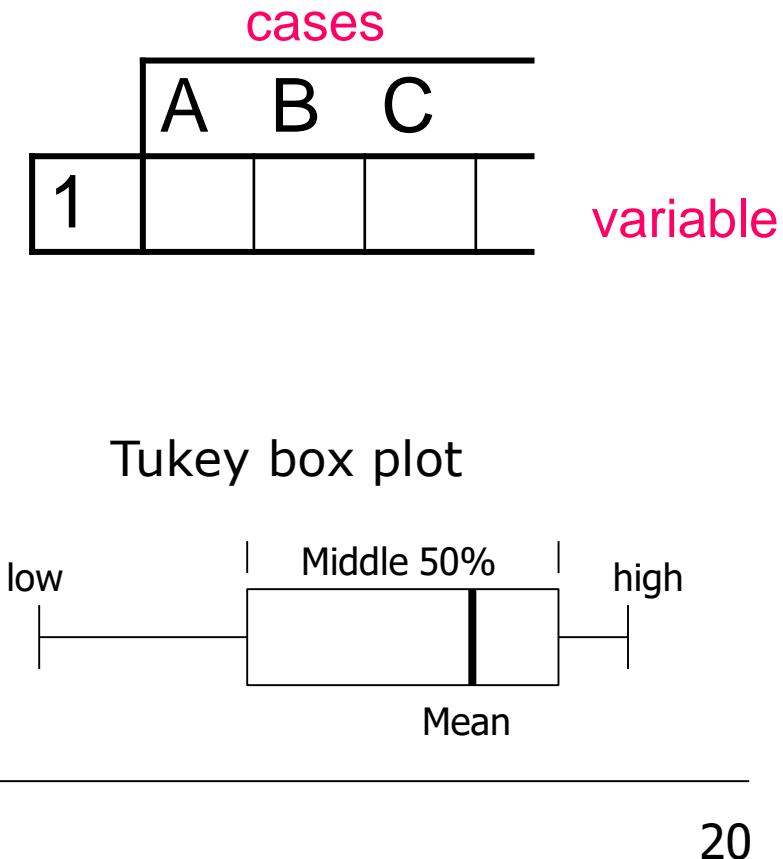
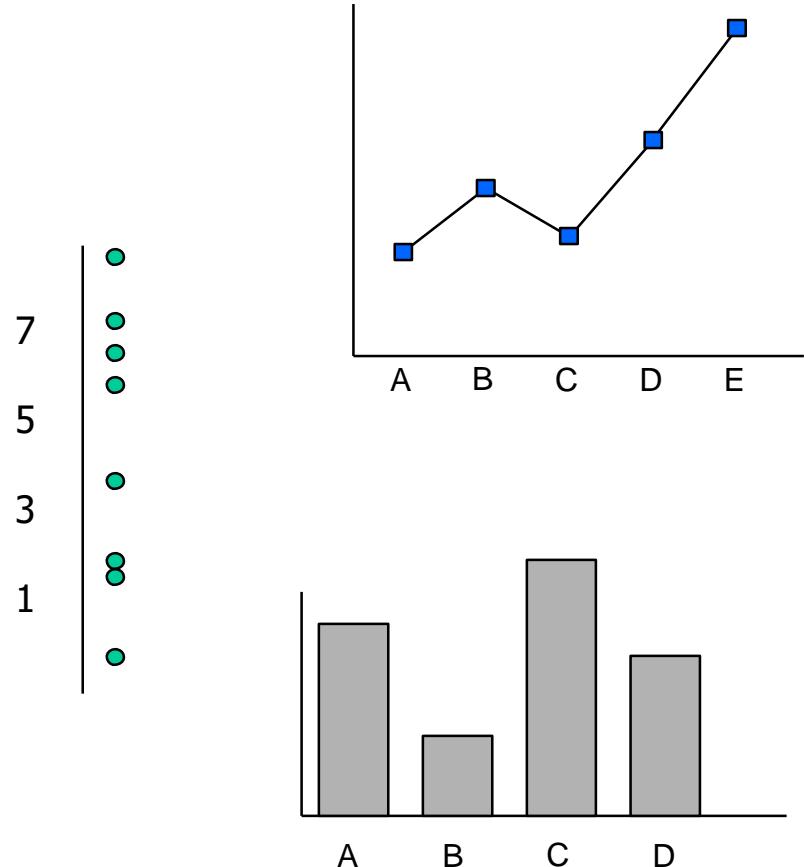
# INTRODUCTION

- Worst case scenario:
  - High number of dimensions → hard
  - Many visualization techniques will not work
    - Will fail at communicating data
    - Determining visual variables is difficult
      - They may collide
- If adding many datapoints:
  - Space organization issues (clutter) on top of the other problems

# INTRODUCTION

From Mackinlay, 2000

- Univariate data

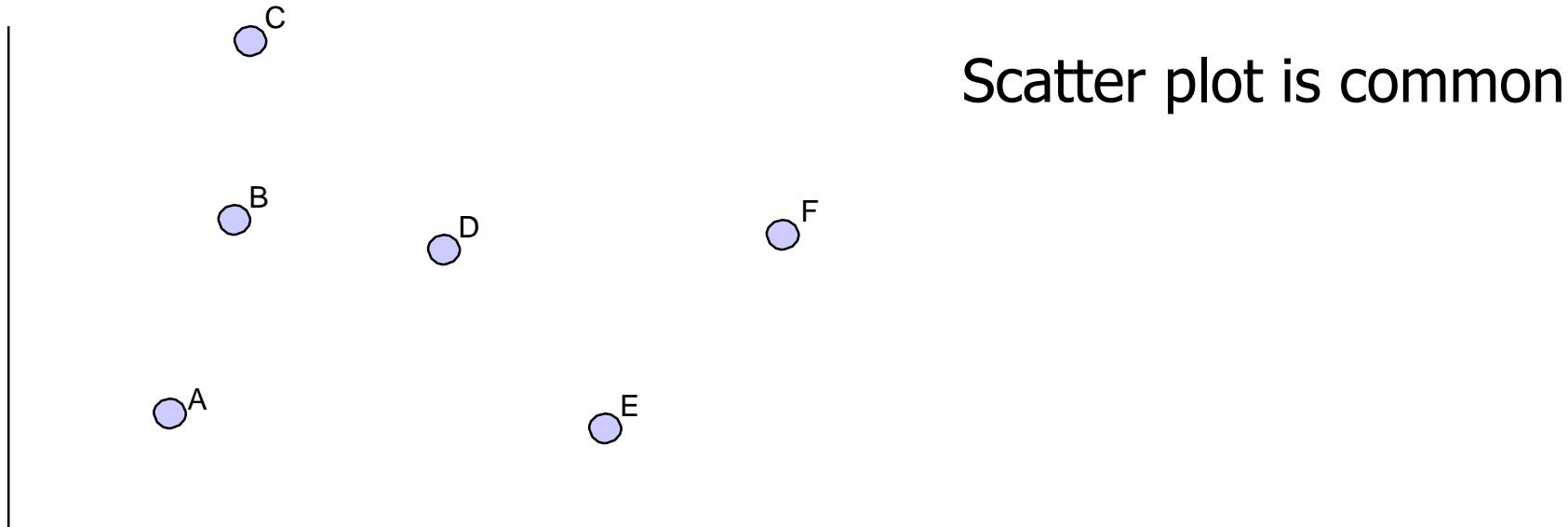


# INTRODUCTION

From Mackinlay, 2000

- Bivariate data

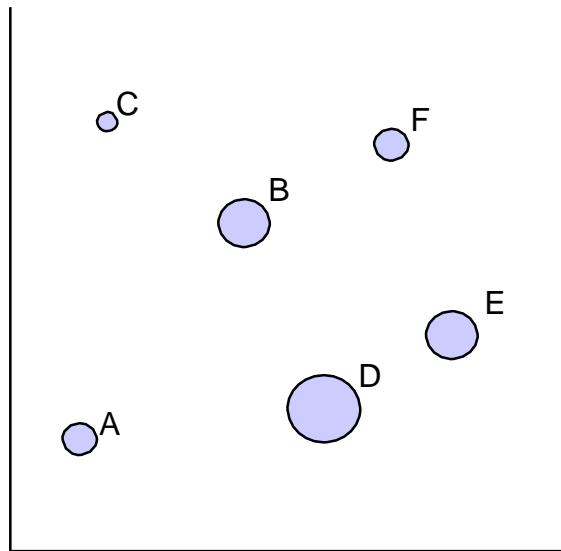
	A	B	C
1			
2			



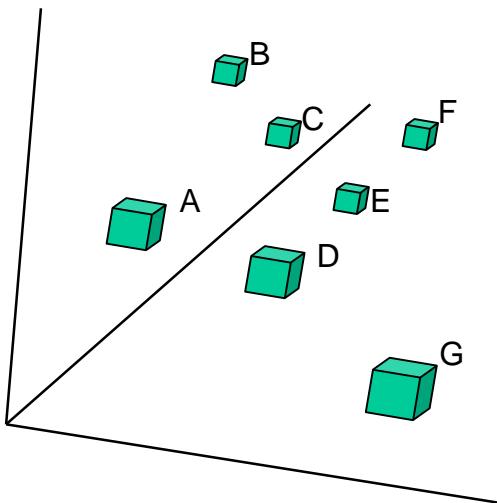
# INTRODUCTION

From Mackinlay, 2000

- Trivariate data



3D scatter plot is possible



	A	B	C
1			
2			
3			

# INTRODUCTION

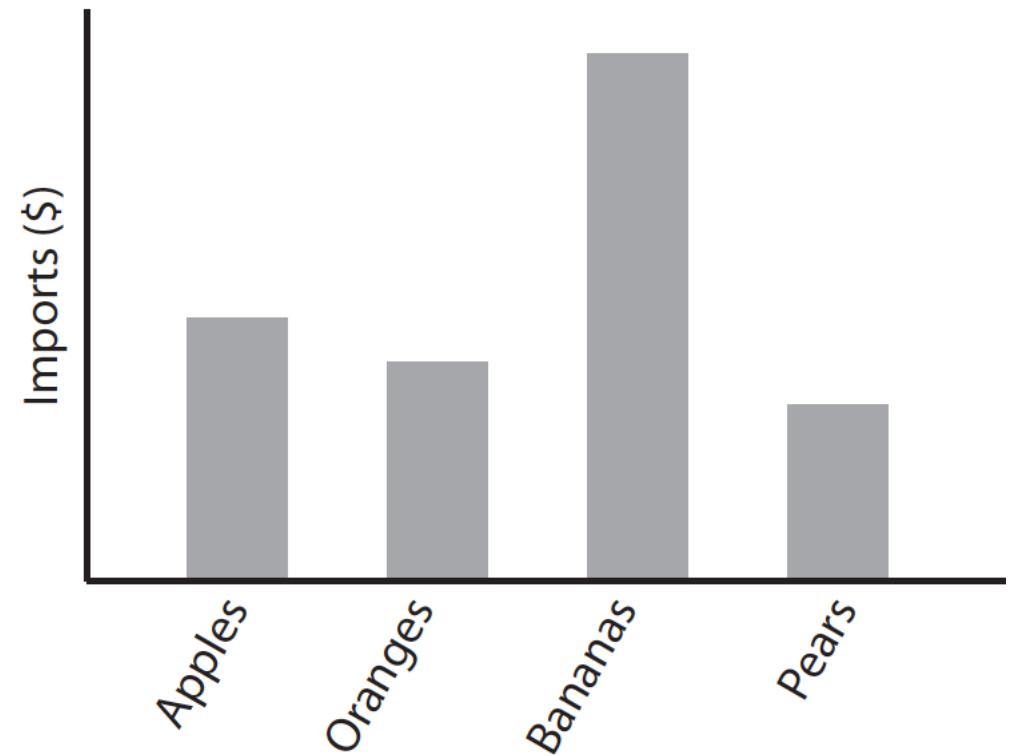
From Mackinlay, 2000

- Multivariate
  - How many dimensions?
  - Which visual encodings?

	A	B	C
1			
2			
3			
4			
5			
6			
7			
8			

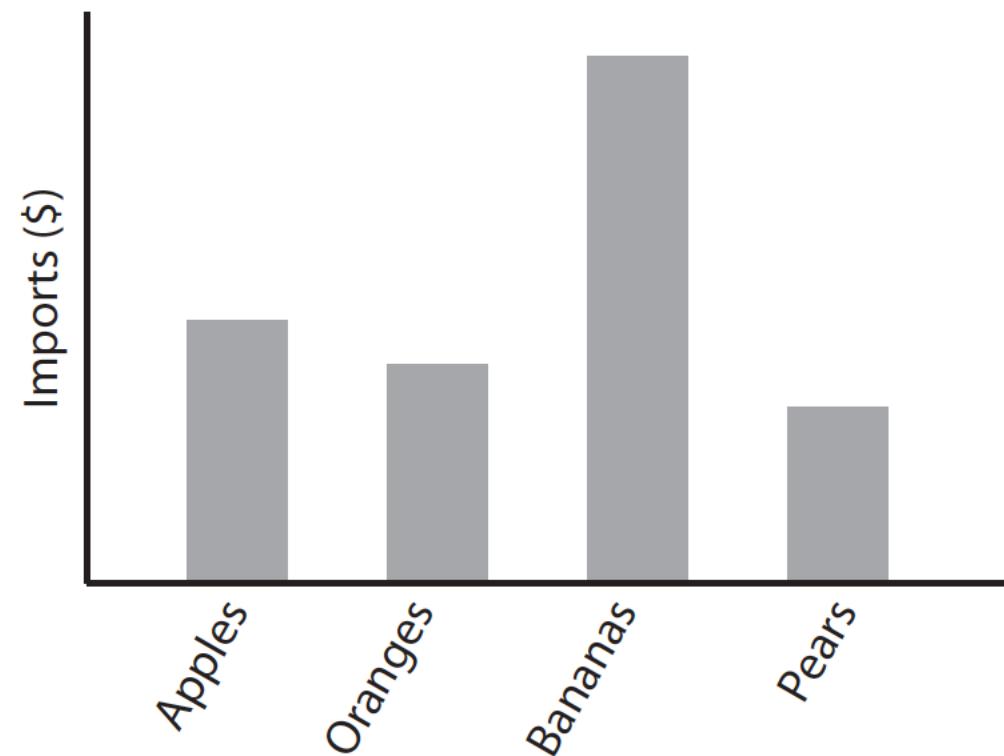
# INTRODUCTION. BACKGROUND

- Visual search: Find out which kind of fruit import is the largest by dollar value



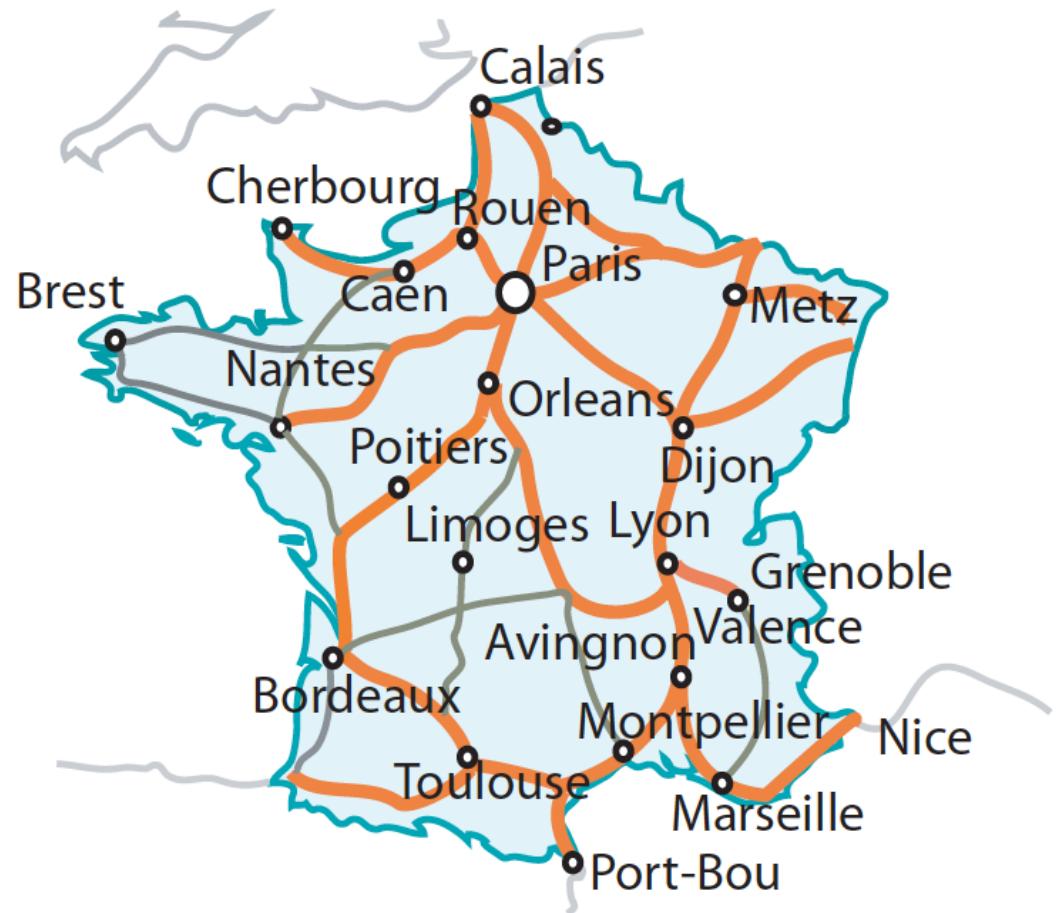
# INTRODUCTION. BACKGROUND

- Visual search: Find out which kind of fruit import is the largest by dollar value
  - Visual process:
    - Find the tallest bar
    - Then find and read the label beneath



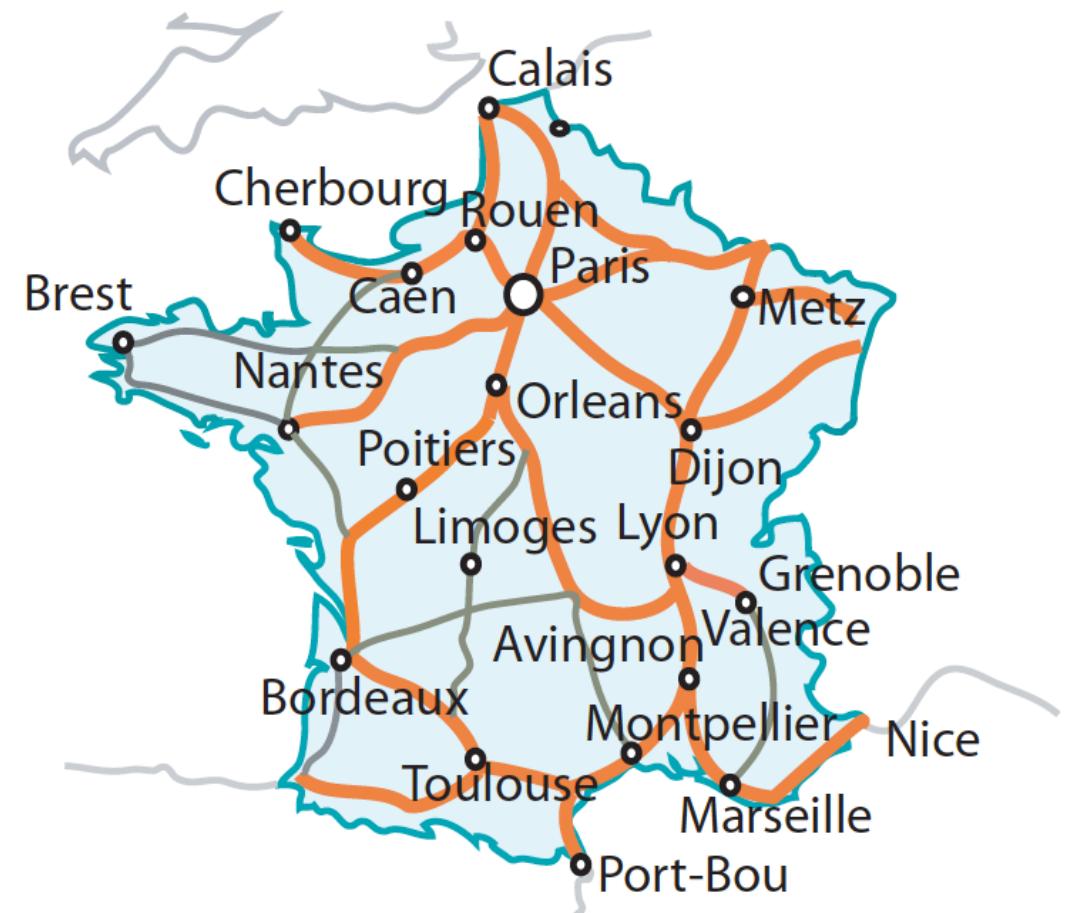
# INTRODUCTION. BACKGROUND

- Visual search: Find a fast route



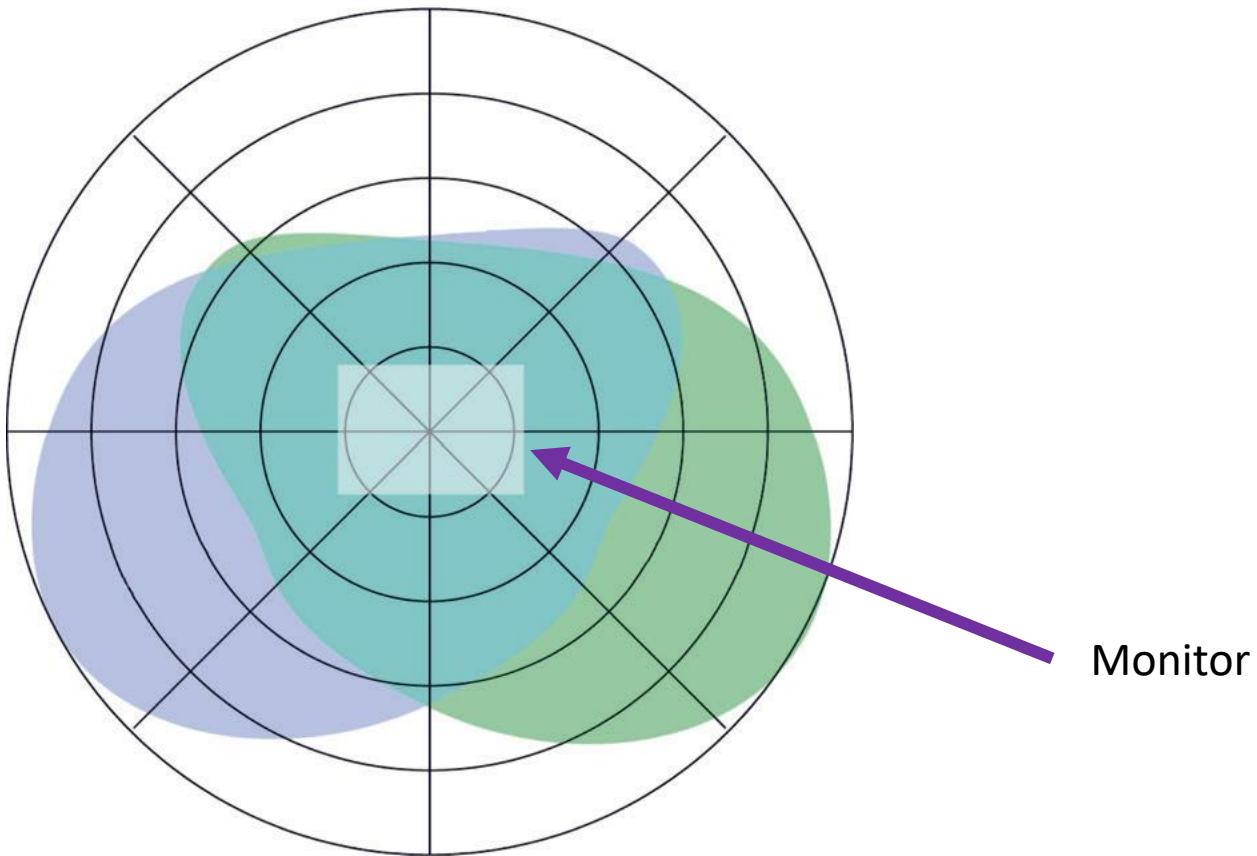
# INTRODUCTION. BACKGROUND

- Visual search: Find a fast route
  - Visual process:
    - Make visual queries to find the starting and ending cities
    - Then we make queries to find a connected red line, indicative of fast roads, between those points

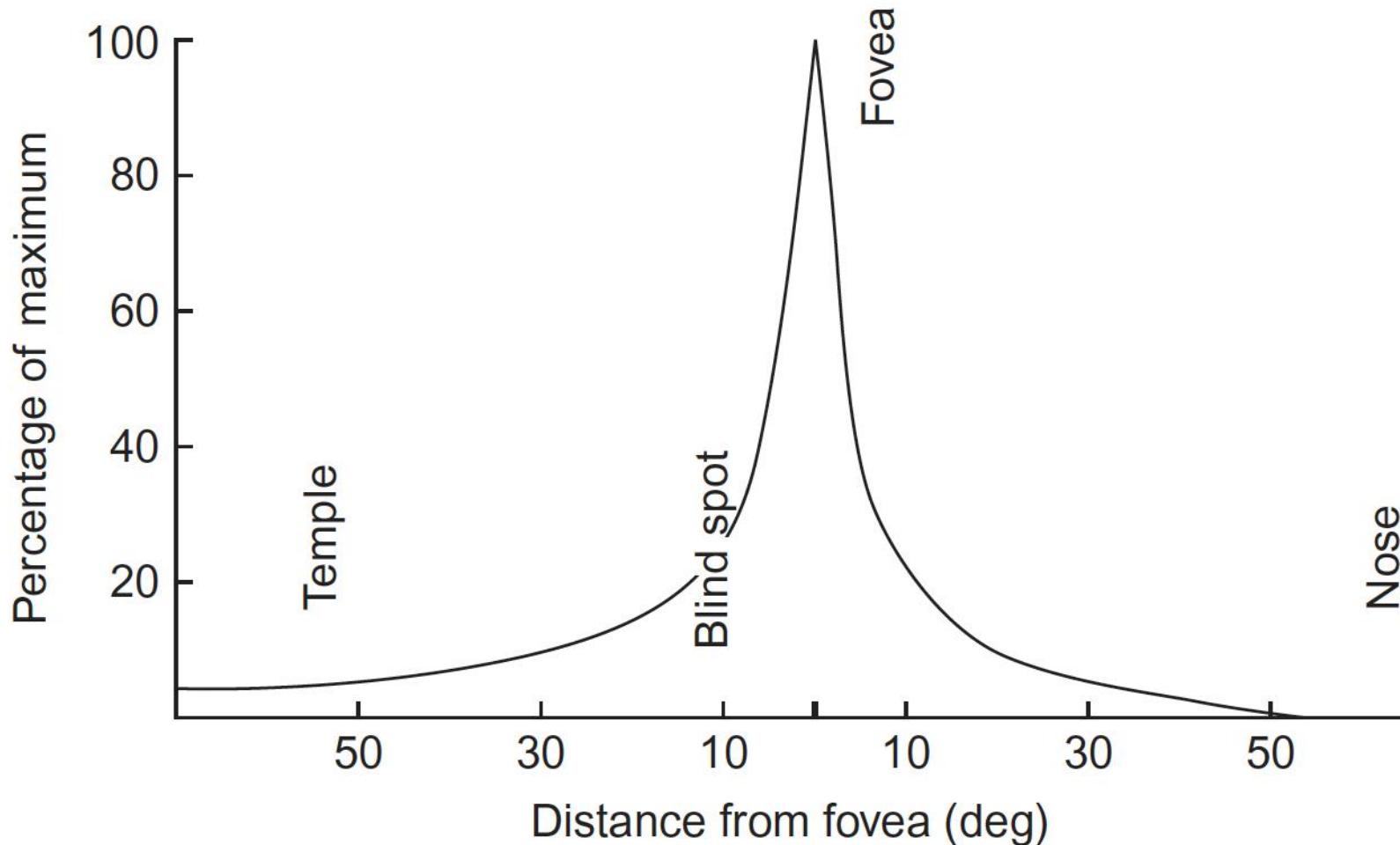


# INTRODUCTION. BACKGROUND

The visual field of view for a person gazing straight ahead



# INTRODUCTION. BACKGROUND



The acuity of the eye falls off rapidly with distance from the fovea.

# INTRODUCTION. BACKGROUND

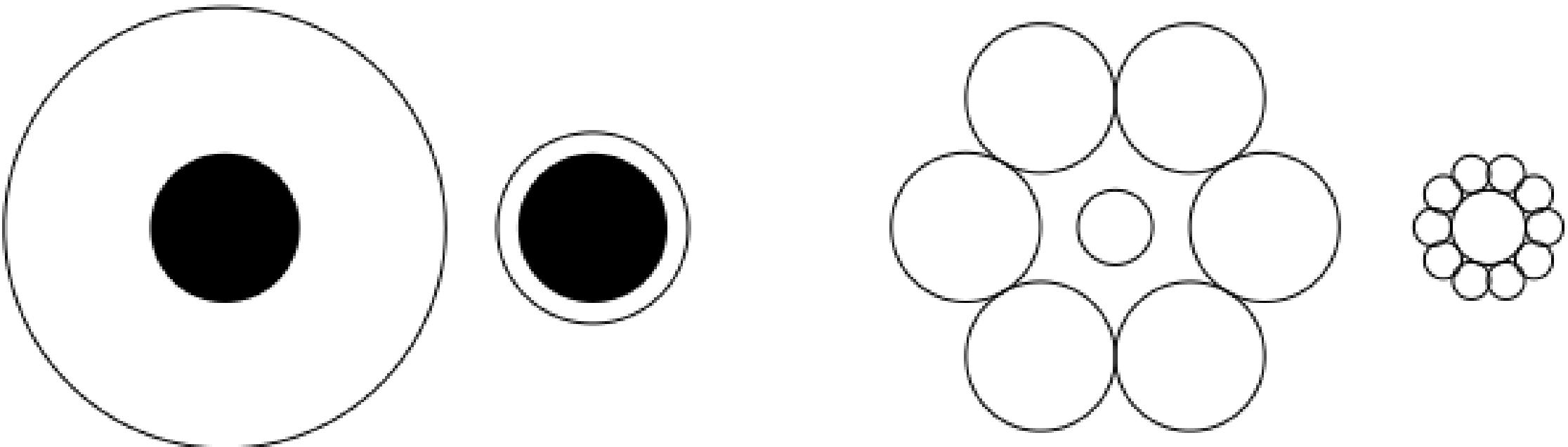
- Differently sized screens with same number of pixels have different areas of visual inefficiency
  - In small screens only a portion of the information hits the fovea, due to the size
    - We waste resolution
  - In large screens a big portion of the information does not project close to the fovea
    - We waste size

# INTRODUCTION. BACKGROUND

- Many elements affect our perception, such as the context
  - Shapes
  - Colors
  - Lines

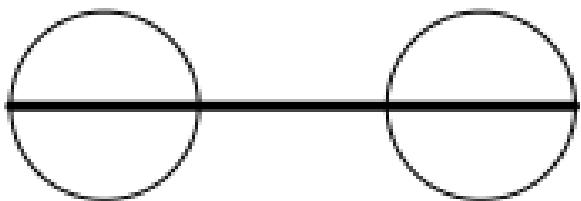
# INTRODUCTION. BACKGROUND

- Which of the inner circles is larger, or are they the same size?



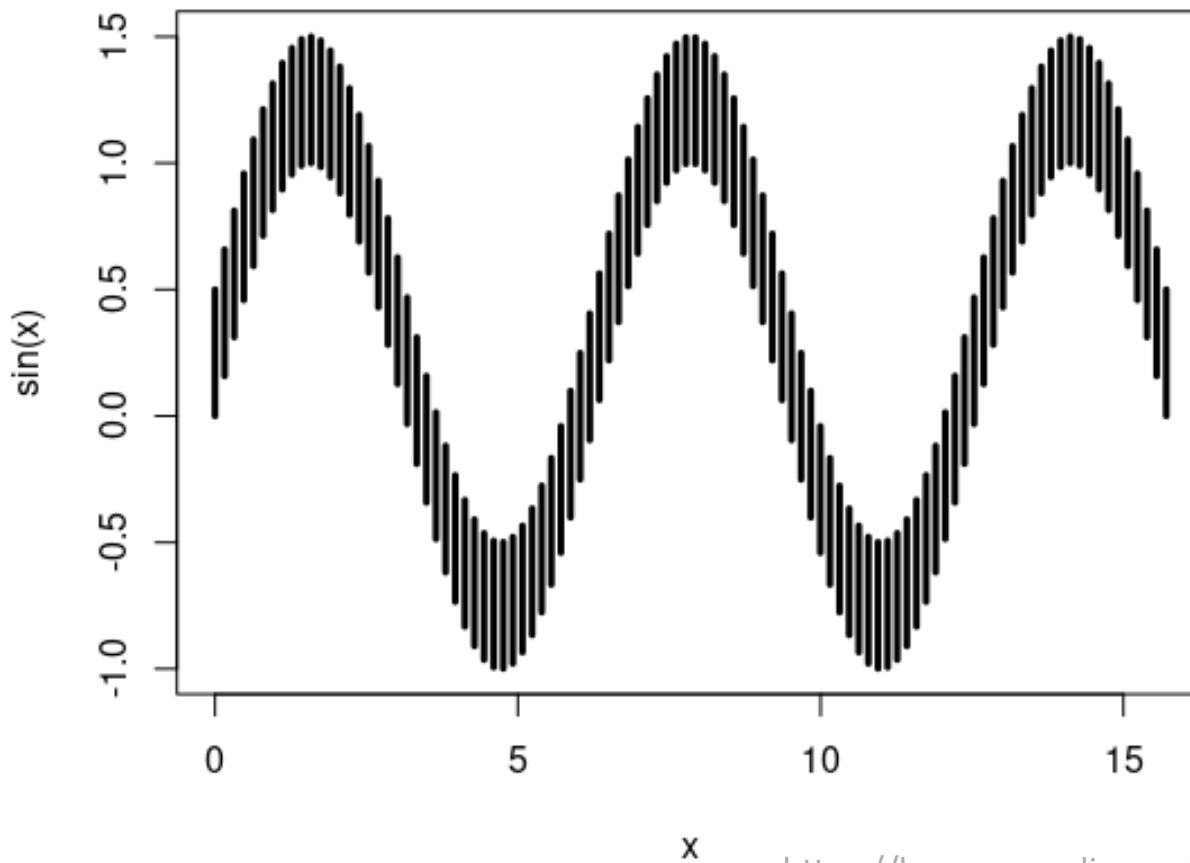
# INTRODUCTION. BACKGROUND

- Which of the lines is longer, or are they the same length?



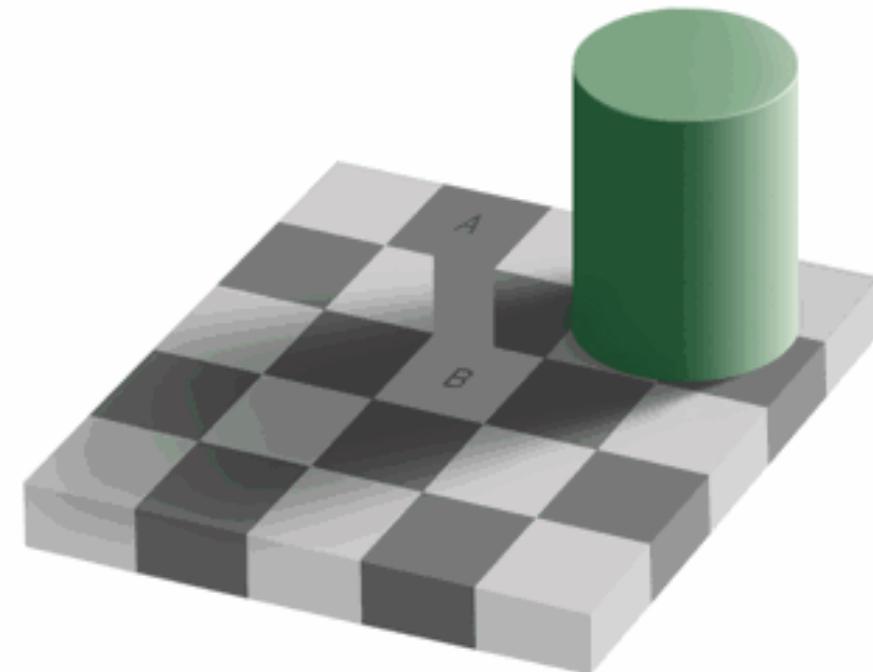
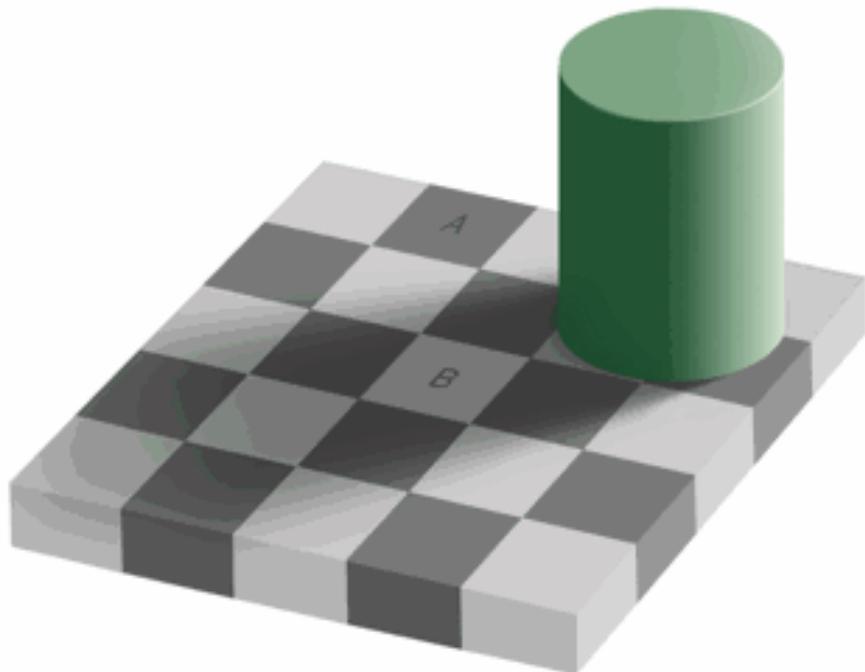
# INTRODUCTION. BACKGROUND

- The sine Illusion: which of the bars are longer, or are they the same length?



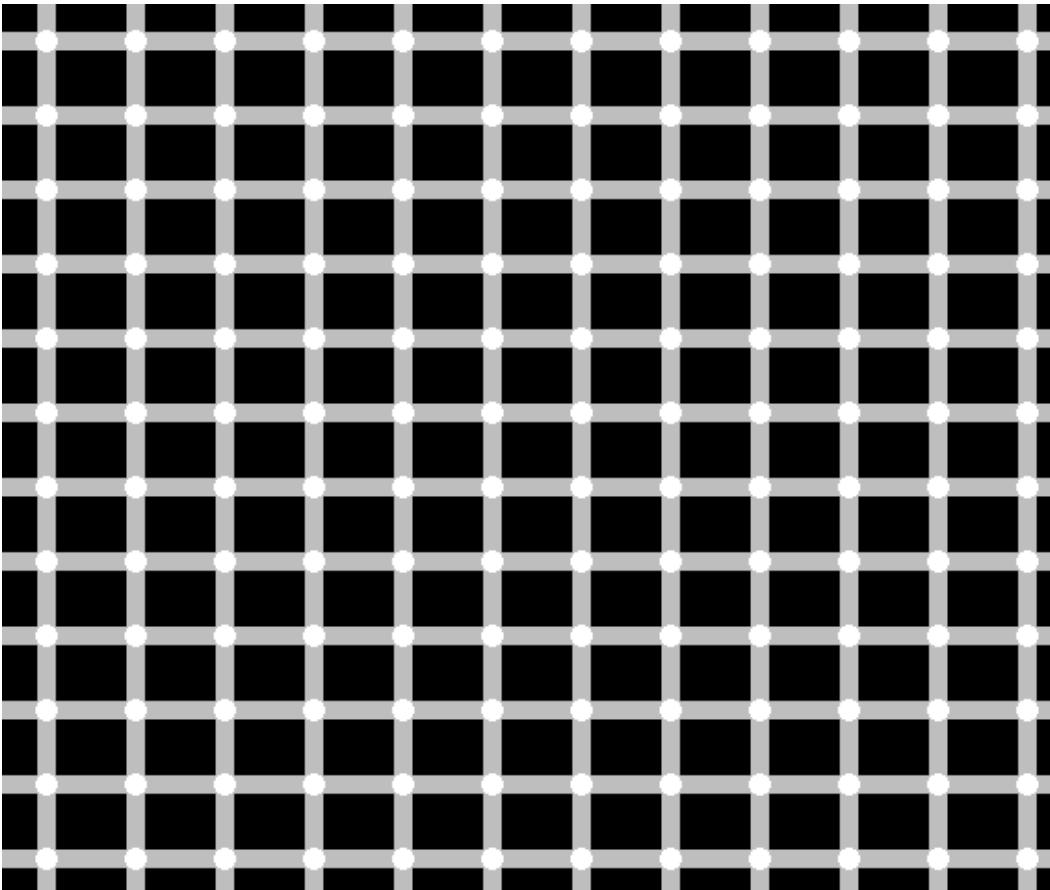
# INTRODUCTION. BACKGROUND

- Which of the squares A and B is darker, or are they the same shade?



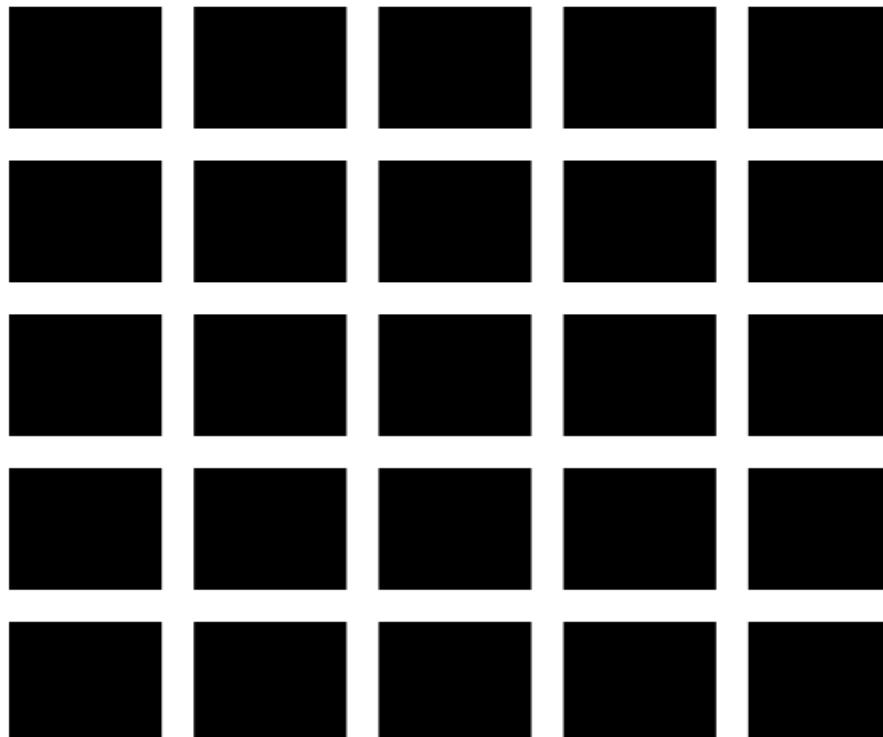
# INTRODUCTION. BACKGROUND

- Black dots at the intersections appear and disappear; are they real?



# INTRODUCTION. BACKGROUND

- Black dots at the intersections appear and disappear; are they real?



# INTRODUCTION. BACKGROUND

## Is Your State Doing Enough Coronavirus Testing?

12 states meet the testing target;  
5 are near the target; 34 are below the target;



Data source: NYTimes <[www.nytimes.com/interactive/2020/us/coronavirus-testing.html](http://www.nytimes.com/interactive/2020/us/coronavirus-testing.html)>

# INTRODUCTION. BACKGROUND

- Red, from black and white

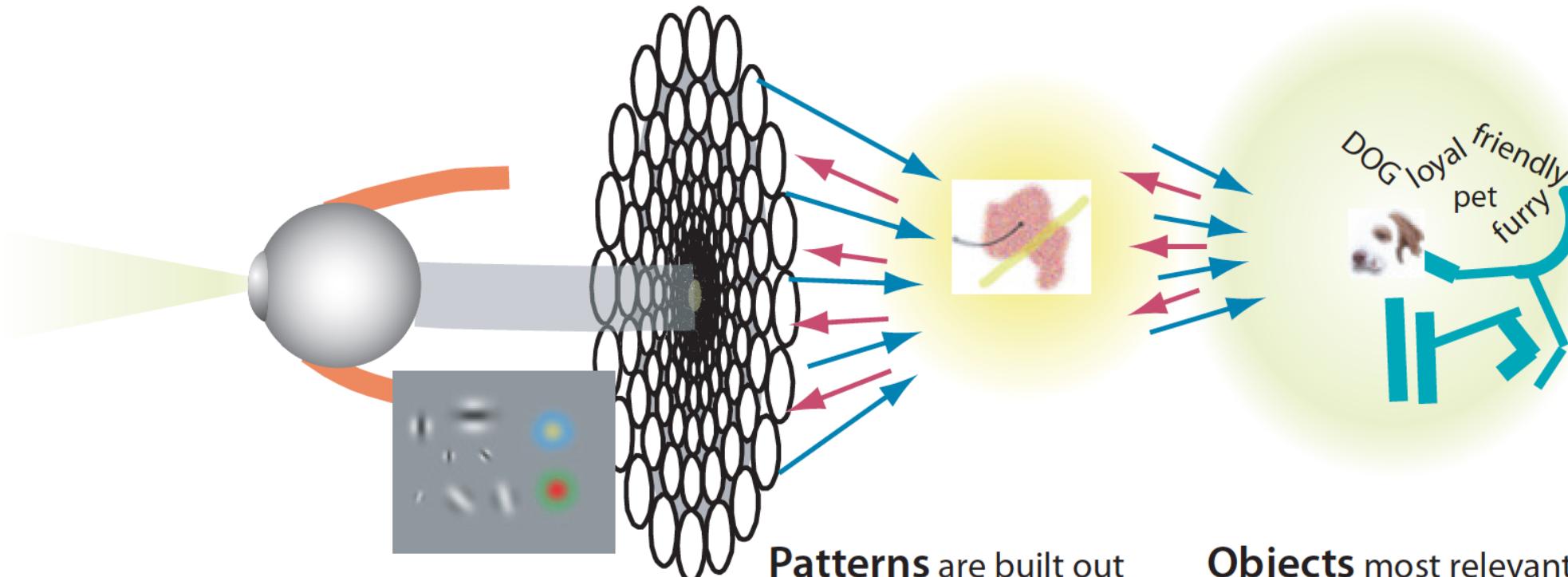


# OUTLINE

- *Recap*
- *Introduction*
- **Preattentive Processing**
- Perception Laws
- Applying Perception in Visualization

# PREATTENTIVE PROCESSING

- Design visual information to be efficiently perceivable – quick, unambiguous
- Need to understand how human visual perception and information processing works
- Perception science related to:
  - Physiology: study the physical, biochemical and information processing functions of living organisms
  - Cognitive psychology: studying internal mental processes
    - how do people learn, understand, solve problems with regard to sensory information?



**Features** are processed in parallel from every part of the visual field. Millions of features are processed simultaneously.

**Patterns** are built out of features depending on attentional demands. Attentional tuning reinforces those most relevant.

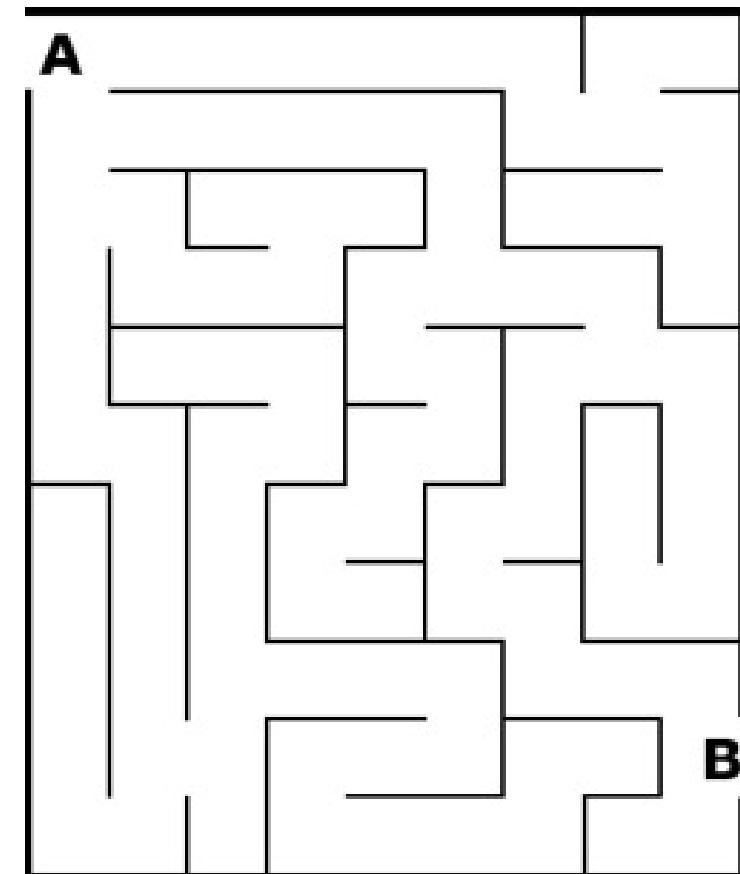
**Objects** most relevant to the task at hand are held in Visual Working Memory. Only between one and three are held at any instant. Objects have both non-visual and visual attributes.

**Bottom-up information drives pattern building**

**Top-down attentional processes reinforce relevant information**

# PREATTENTIVE PROCESSING. 3-STAGE MODEL

- Example. Route between the two letters?
  - Stage 1: automatic parallel extraction of colors, shapes, position, etc.
  - Stage 2: Pattern finding of black contours (lines) between two symbols (letters)
  - Stage 3:
    - Few objects are held in working memory at a time
    - Identify path sequentially (formulate new visual query)



# PREATTENTIVE PROCESSING

- Many perceptual processing models exist
- Simplified 3-stage model:
  - Iconic memory
  - Working memory (short-term)
  - Long-term memory

# PREATTENTIVE PROCESSING. ICONIC MEMORY

- Images remain in iconic memory for less than a second
- Processing in iconic memory is massively parallel and automatic
- This is called *preattentive processing*

# PREATTENTIVE PROCESSING. SHORT-TERM MEMORY

- Meaningful visual chunks moved from iconic memory to short term memory
  - Used by conscious, or attentive, processing
  - Attentive processing often involves conscious comparisons or search
- Short term memory is limited:
  - Information is retained for only a few seconds
  - Only three or four chunks can be held at a time
  - Chunks can be of varying size
    - A coherent pattern can form a single chunk even if it is quite large
- If more chunks are needed or needed longer they need to be reacquired (or retrieved from long term memory)

# PREATTENTIVE PROCESSING. LONG-TERM MEMORY

- Built up over a lifetime
  - Though infrequently used visual chunks may become lost
- Chunks processed repeatedly in working memory may be transferred to long term memory
- Common patterns and contextual information can be retrieved from long term memory for attentive processing in working memory

# PREATTENTIVE PROCESSING

- Visual Design Implications
  - Try to make as much use of preattentive features as possible
  - Recognize when preattentive features might mislead
  - For features that require attentive processing, keep in mind that working memory is limited

# PREATTENTIVE PROCESSING

- A limited set of basic visual properties are processed *preattentively*
  - Information that “pops out”
  - Parallel processing by the low-level visual system (Stage 1 in the model)
  - Occurs prior to conscious attention
  - Important for designing effective visualizations
    - What features can be perceived rapidly?
    - Which properties are good discriminators?
    - What can mislead viewers?
    - How to design information such that it pops out?

# PREATTENTIVE PROCESSING

- Example: Find the 3s

142416496357598475921765968474891728482  
285958819829450968504850695847612124044  
074674898985171495969124567659608020860  
608365416496457590643980479248576960781  
285960799918712845268101495969124567781  
874241649645757659608149596912456701285  
960799164964575127879918712845298496912  
223591649645759588198250963576596080596

# PREATTENTIVE PROCESSING

- Example: Find the 3s

142416496357598475921765968474891728482  
285958819829450968504850695847612124044  
074674898985171495969124567659608020860  
608**3**6541649645759064**3**980479248576960781  
285960799918712845268101495969124567781  
874241649645757659608149596912456701285  
960799164964575127879918712845298496912  
223591649645759588198250963576596080596

# PREATTENTIVE PROCESSING

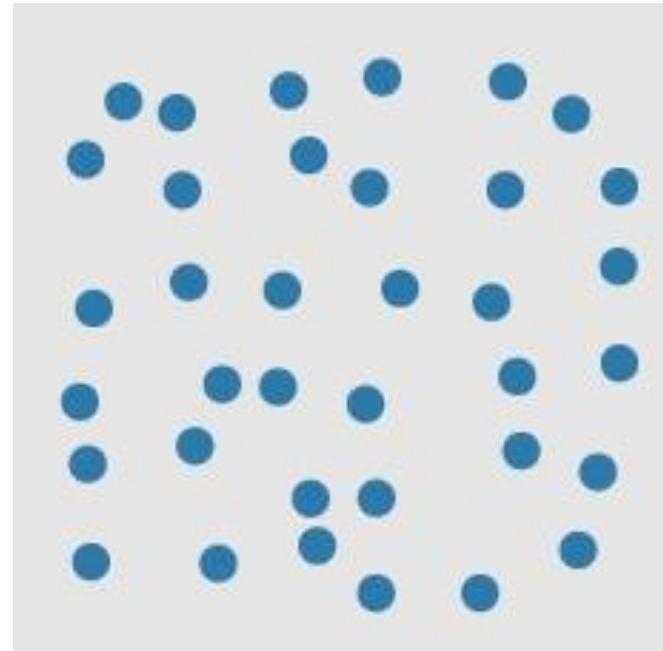
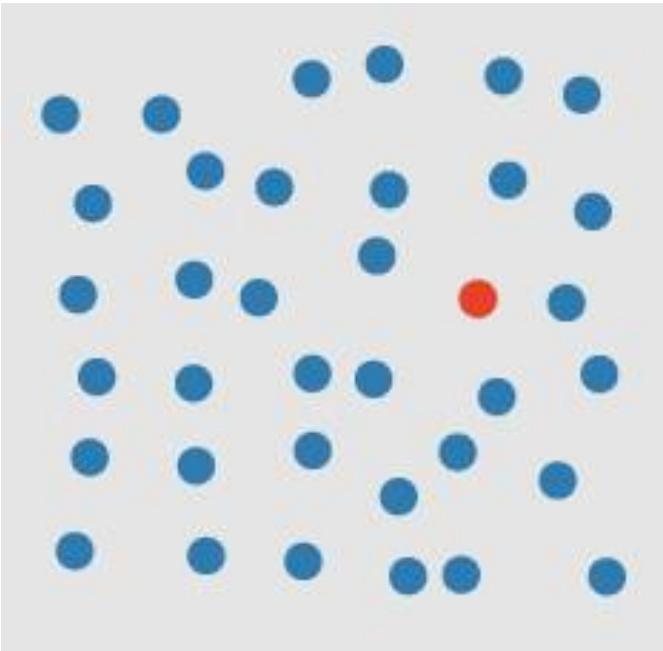
- How to find out if a visual attribute is preattentive?
  1. Measure response time for tasks
  2. Check whether time is smaller than a certain threshold (see next slide)
- Different **tasks** are possible
  - Detection of a target among distractors – Is the target present?
  - Boundary detection – Do items form two groups?
  - Counting – How many targets are there?

# PREATTENTIVE PROCESSING

- **Time threshold:**
  - Detection of targets on a large multi-element display
    - Times < 200 to 250 ms are considered preattentive
  - Eye movement takes at least 200 ms to initiate
- Example: is there a red target present in the images?

# PREATTENTIVE PROCESSING

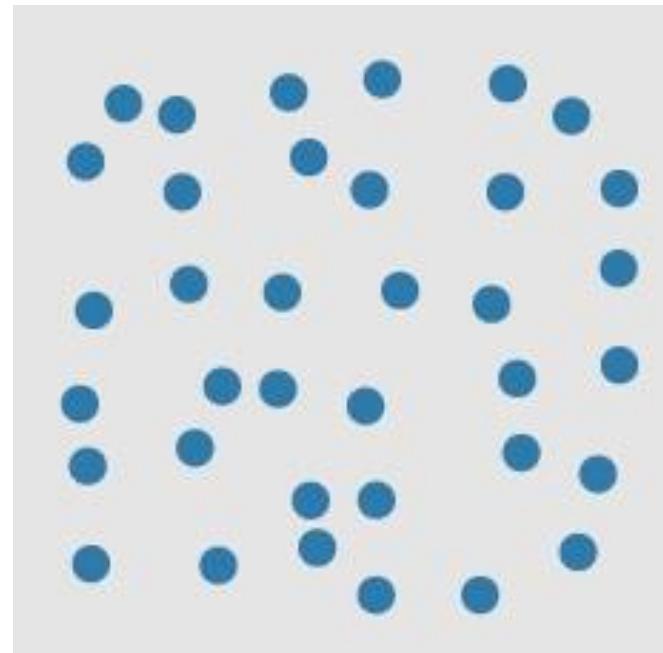
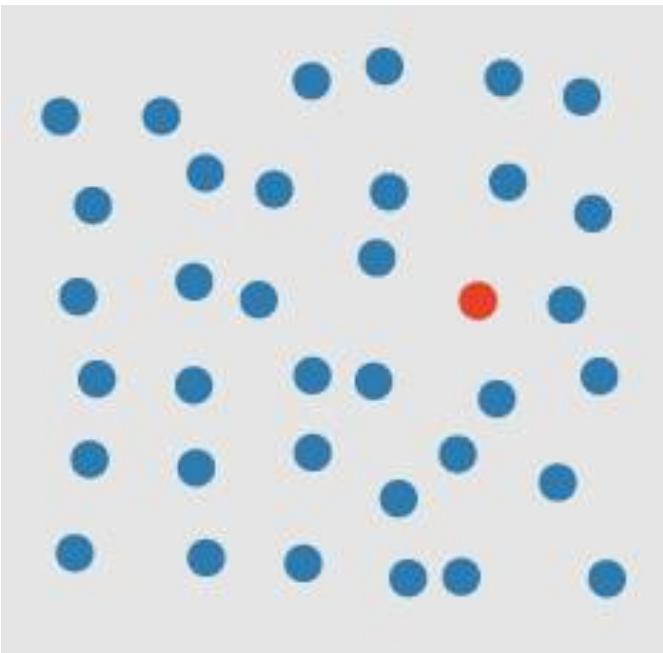
- Is there a red circle present in the image?



<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

- Is there a red circle present in the image?

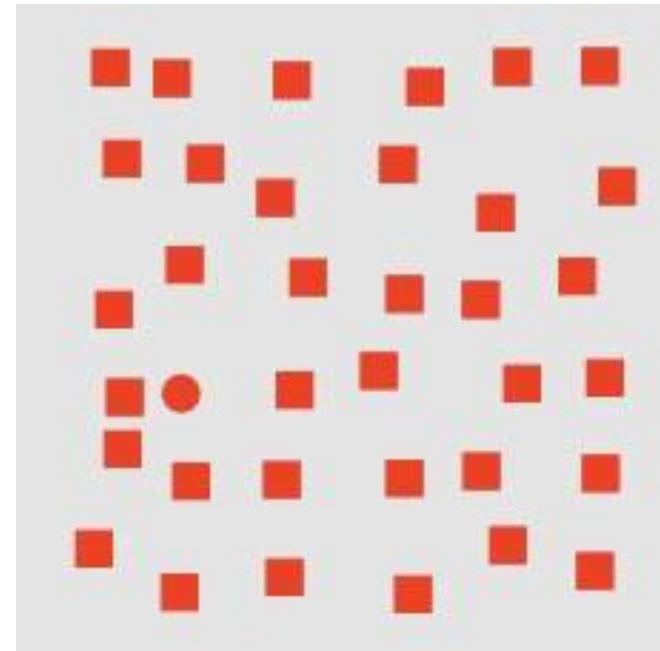
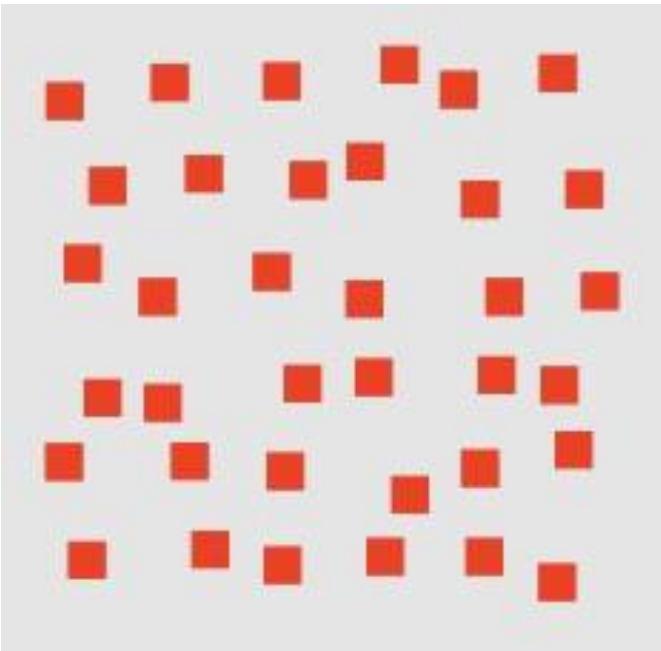


Color is preattentively processed!

<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

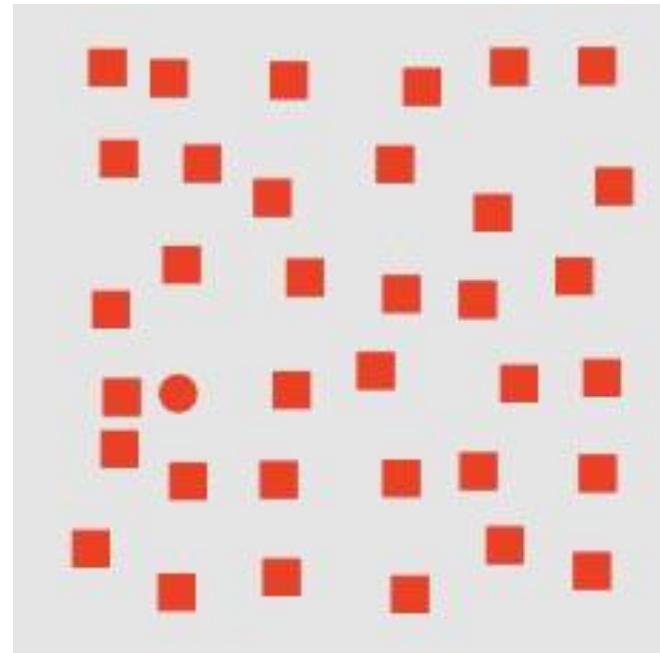
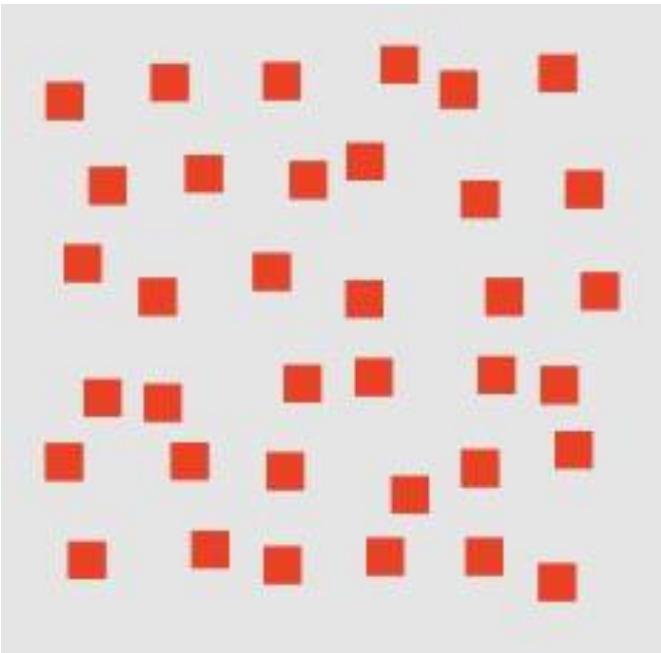
- Is there a red circle present in the image?



<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

- Is there a red circle present in the image?

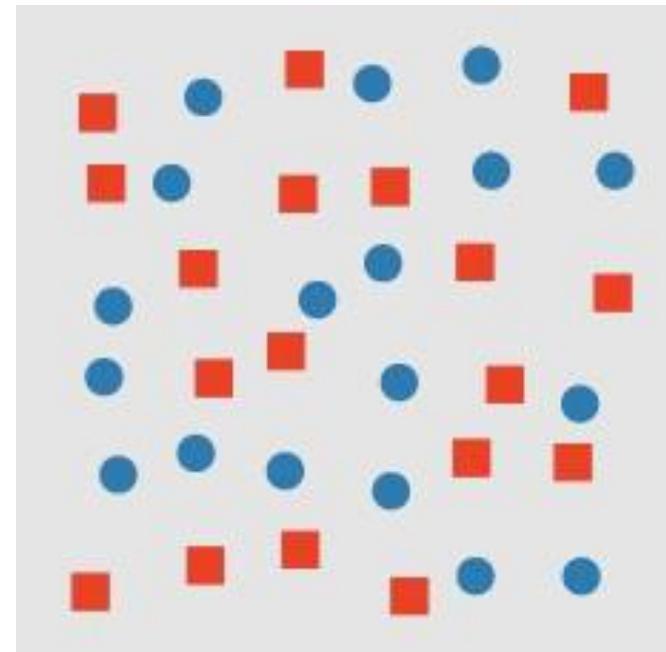
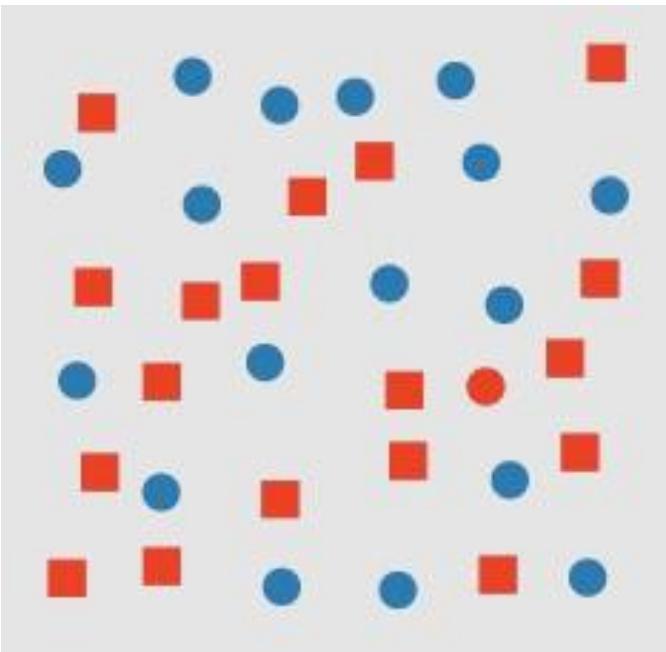


Shape is preattentively processed!

<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

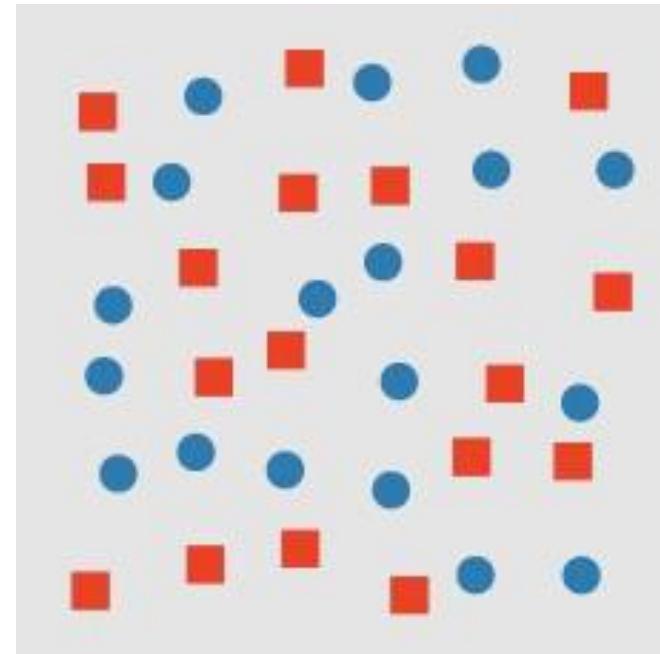
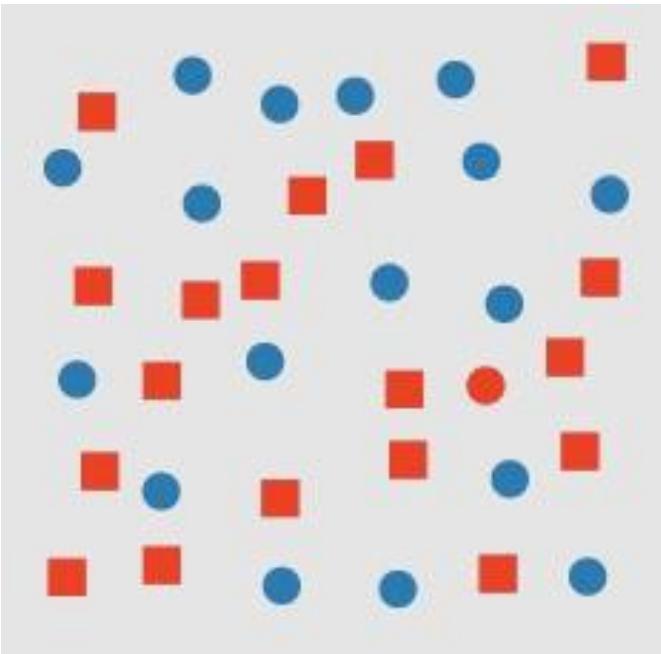
- Is there a red circle present in the image?



<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

- Is there a red circle present in the image?

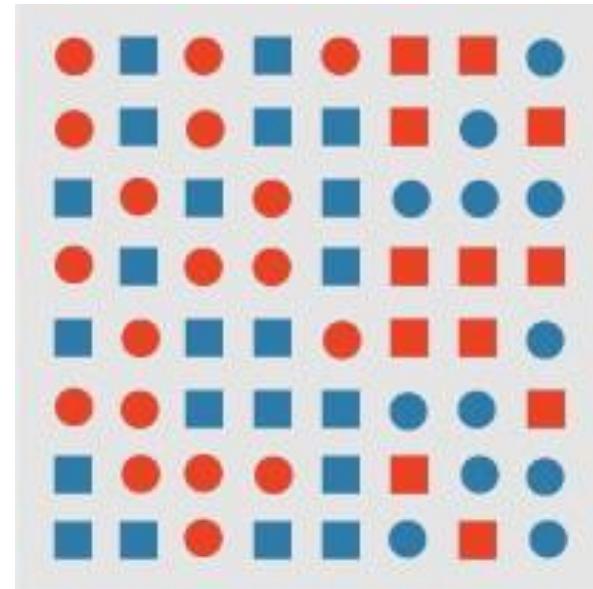
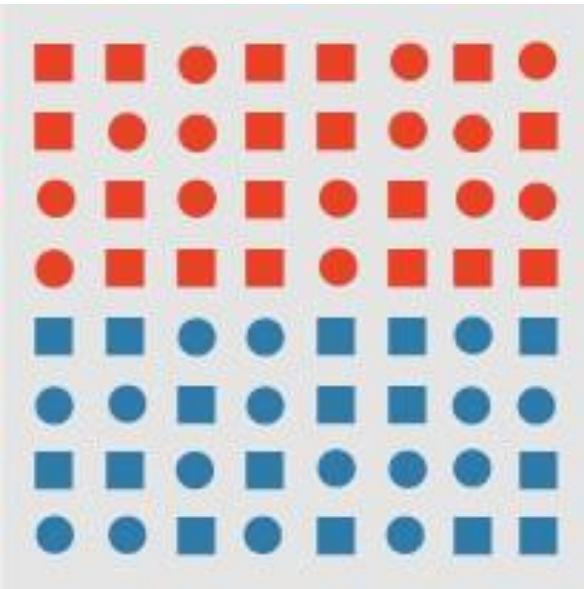


Conjunction of 2 properties is usually not preattentive

<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

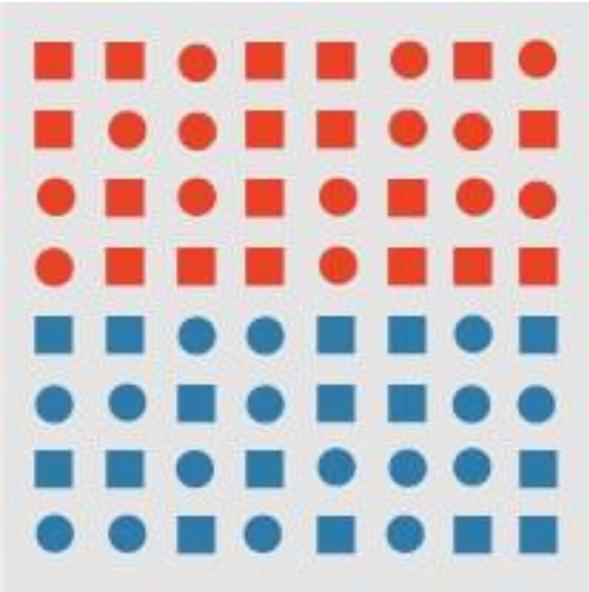
- Do items form a boundary? If yes, based on which attribute(s)?



<https://www.csc2.ncsu.edu/faculty/healey/PP/>

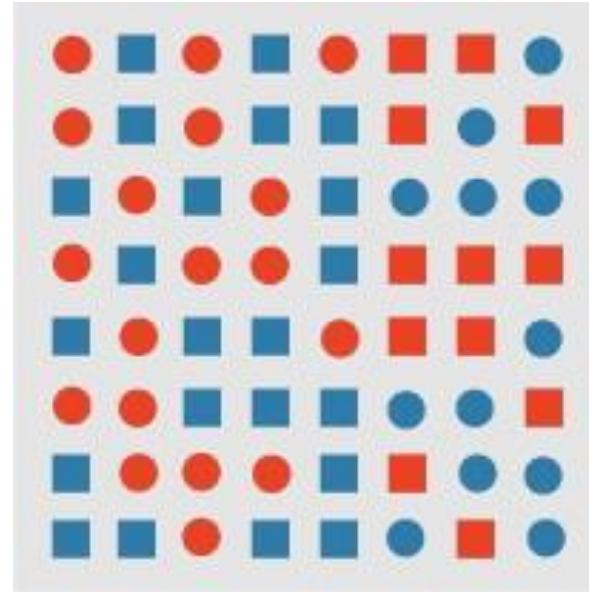
# PREATTENTIVE PROCESSING

- Do items form a boundary? If yes, based on which attribute(s)?



Preattentive: grouping by hue

<https://www.csc2.ncsu.edu/faculty/healey/PP/>

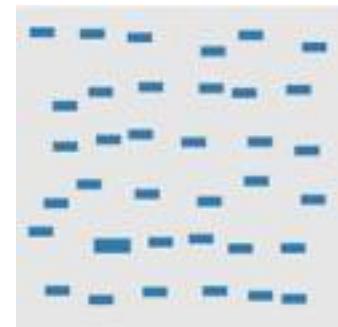
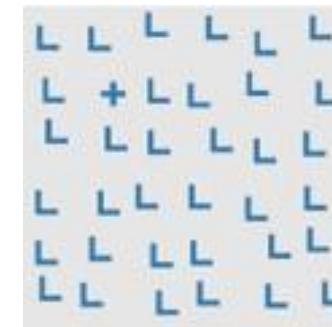
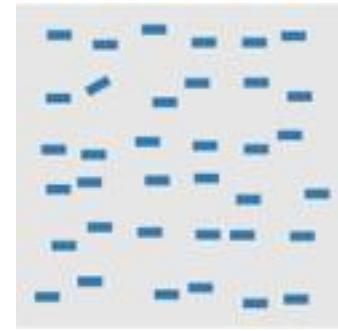
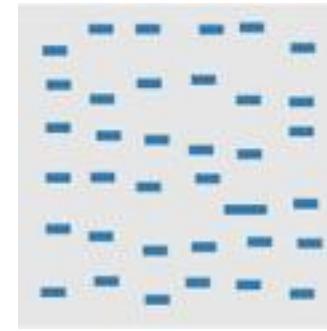


Conjunction search: grouping  
by hue and shape

# PREATTENTIVE PROCESSING

- Common Preattentive Properties

- Form
  - Line orientation
  - Line length
  - Line width
  - Size
  - Curvature
  - Shape
  - Spatial grouping

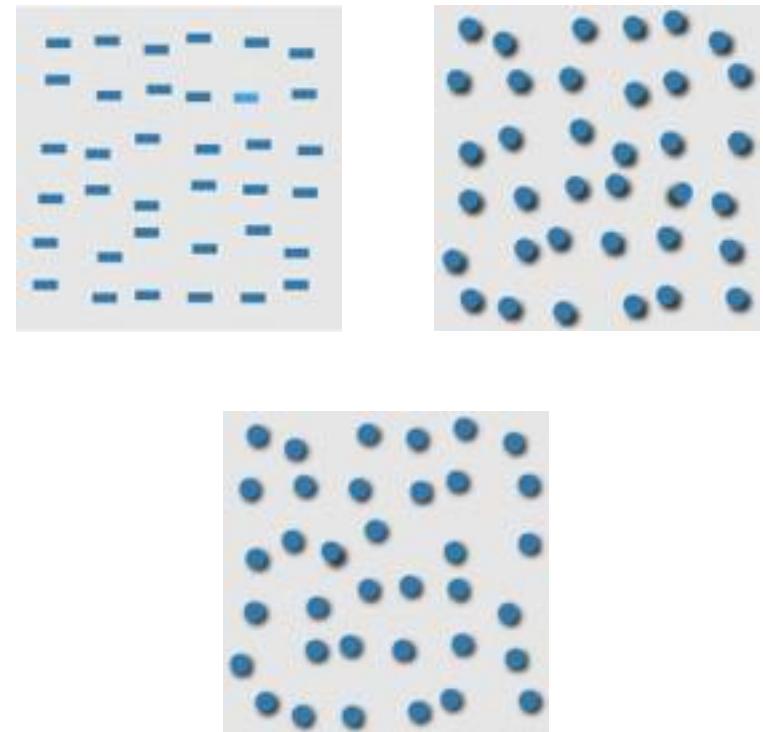


<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

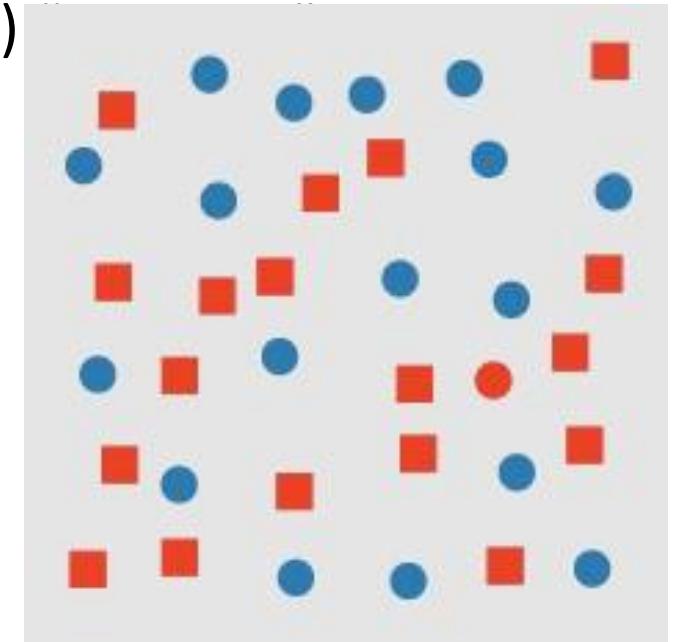
- Common Preattentive Properties

- Color
  - Hue
  - Intensity
  - Motion
  - Flicker
  - Direction of motion
  - Spatial Position
  - 2D position
  - Stereoscopic depth
  - Convexity / Concavity



# PREATTENTIVE PROCESSING

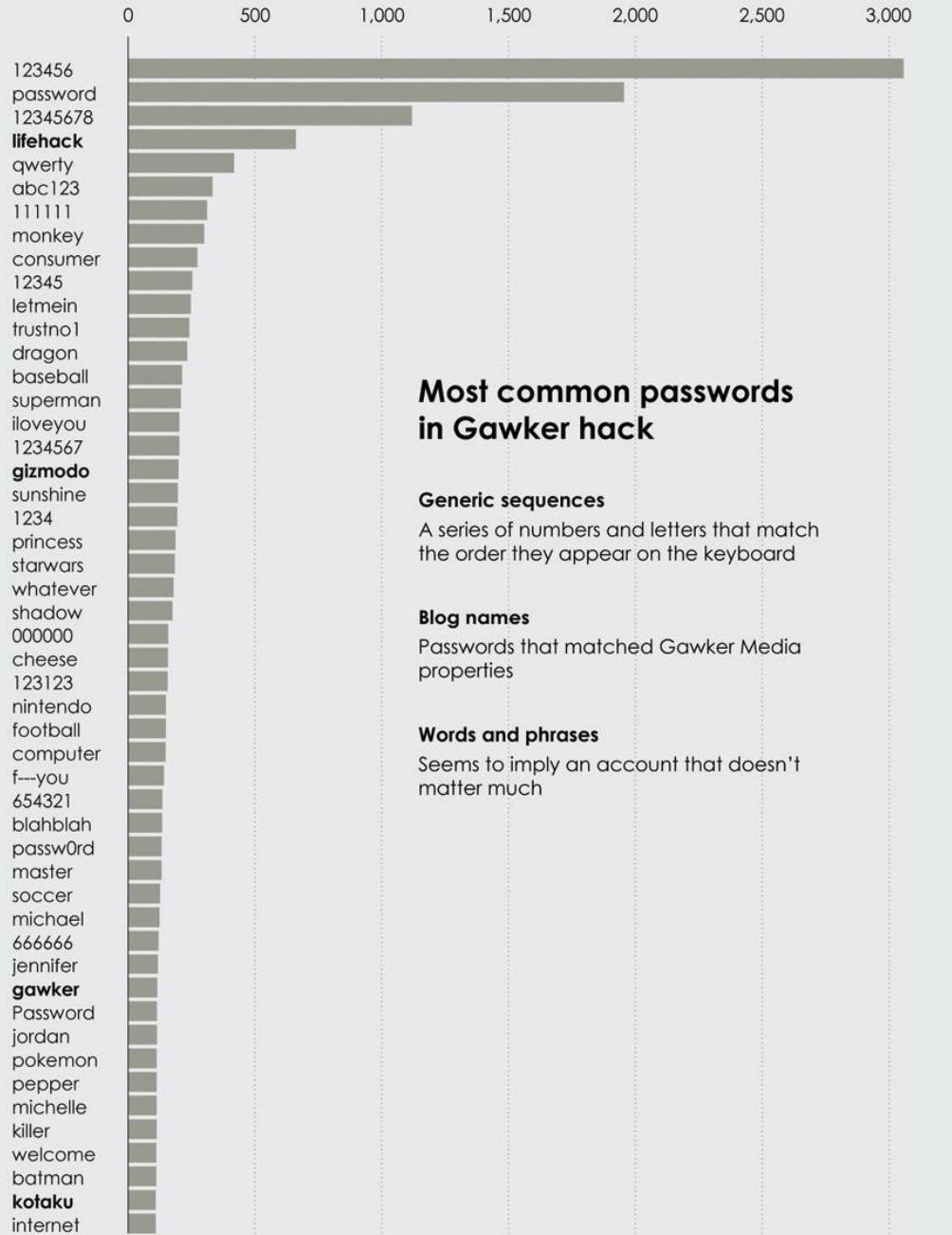
- Conjunction Search
  - A target with a unique visual property (e.g., shape OR color)
- Conjunction target is made up of non-unique features
  - Requires a time-consuming serial search, e.g.
    - For every red colored item: is it a circle?
    - For every circular item: is it red?



<https://www.csc2.ncsu.edu/faculty/healey/PP/>

# PREATTENTIVE PROCESSING

- Use of preattentive features in visualization. Some tips:
  - Remember preattentive features are asymmetric
    - E.g., a sloped line in a sea of vertical lines can be detected preattentively, but the opposite is not true
  - Consider the effect of background distractors with the target feature
  - Avoid use of conjunction targets



## Most common passwords in Gawker hack

### Generic sequences

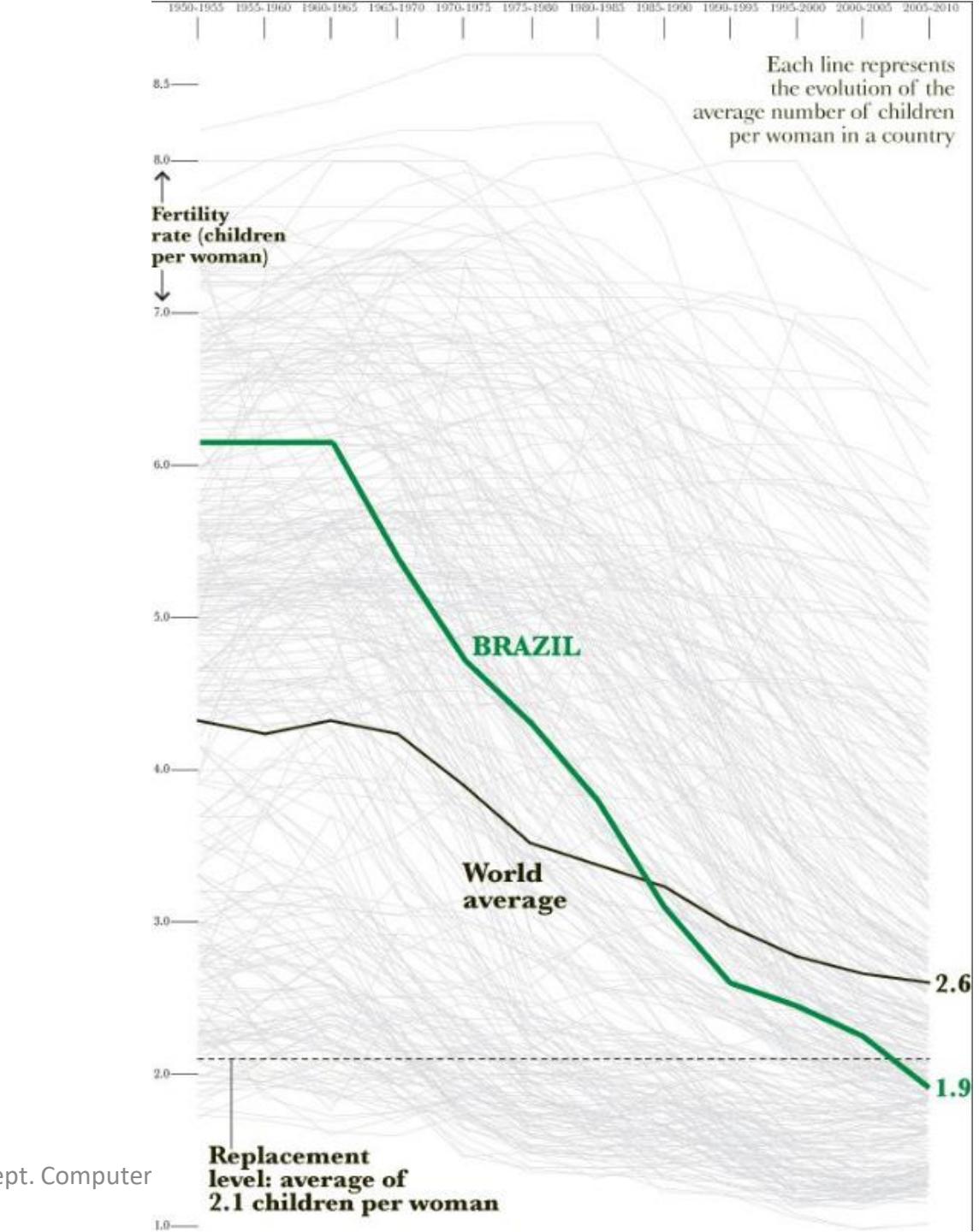
A series of numbers and letters that match the order they appear on the keyboard

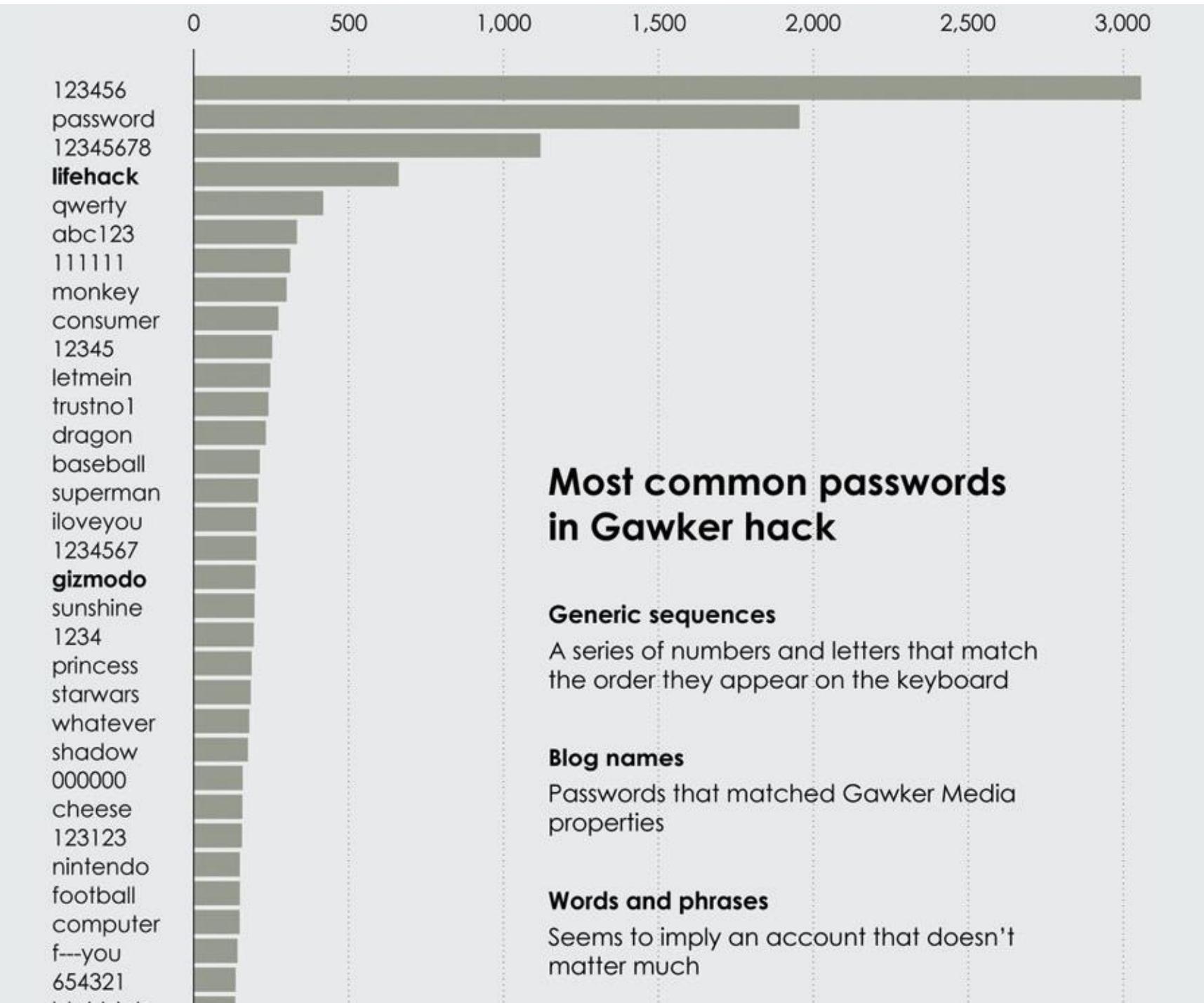
### Blog names

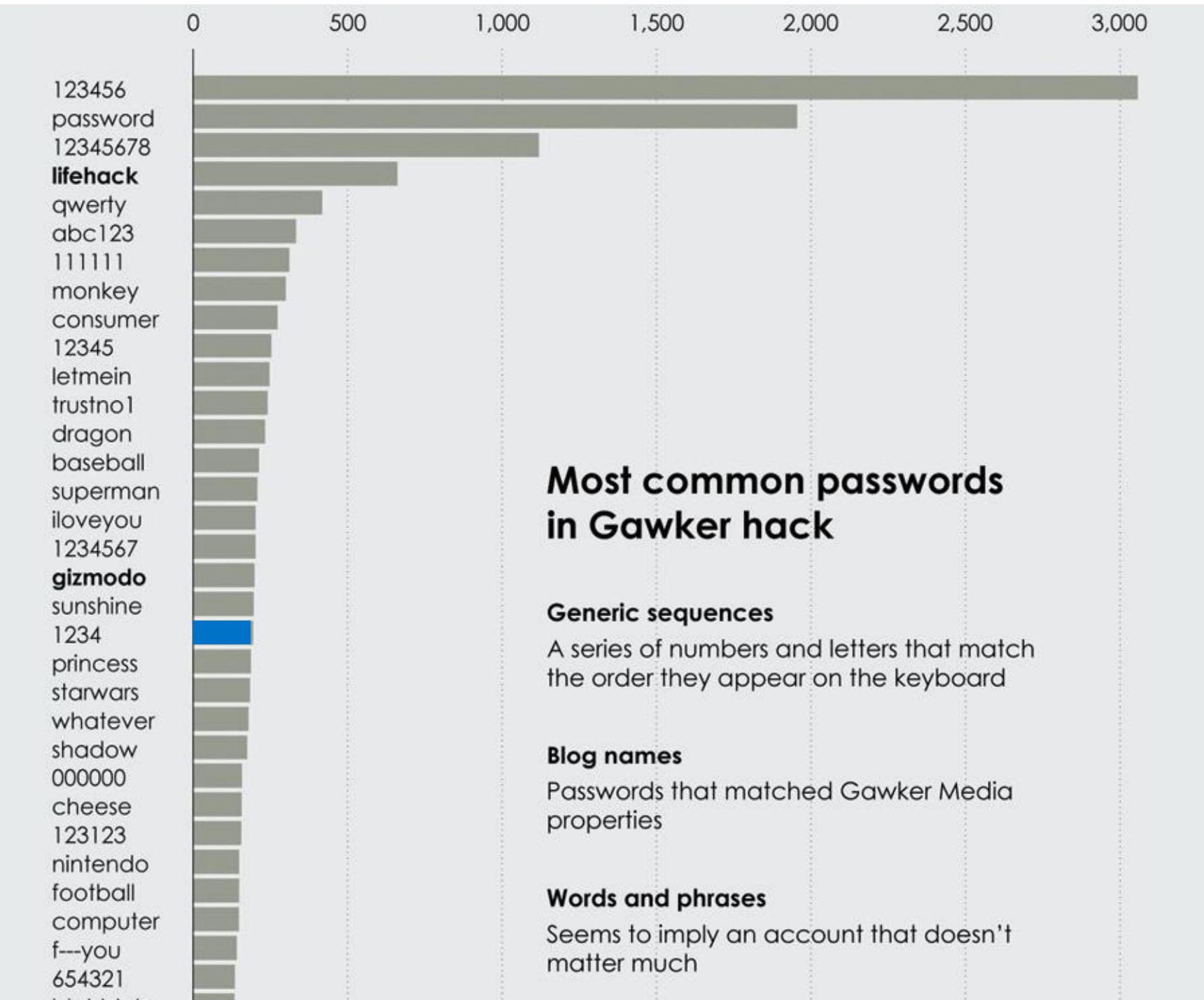
Passwords that matched Gawker Media properties

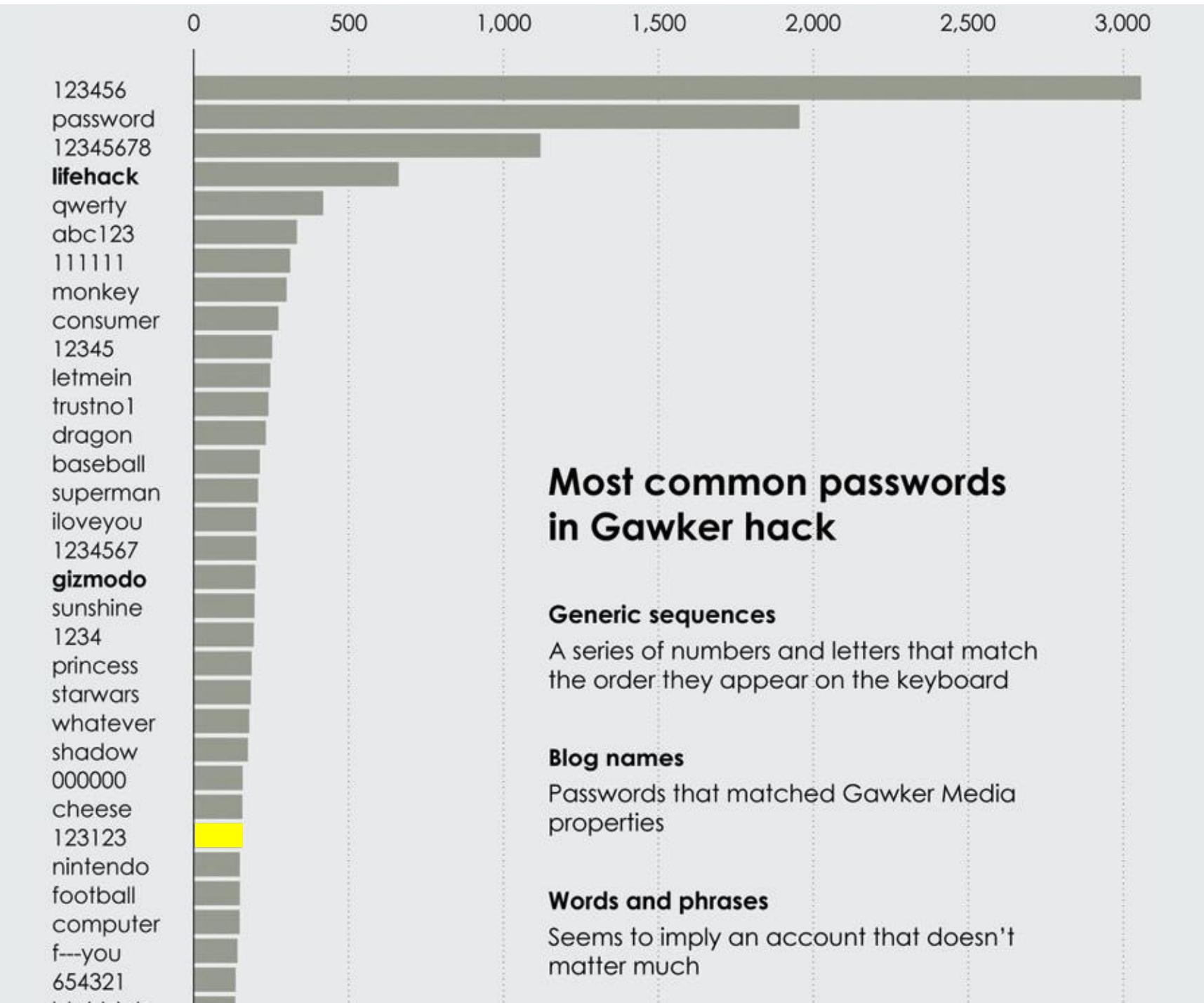
### Words and phrases

Seems to imply an account that doesn't matter much









# PREATTENTIVE PROCESSING. CONCLUSIONS

- Preattentive processing **works when we know what we are looking for**
  - Otherwise, most stimuli pass undetected
  - The brain lets the cells sensitive to the element searched for to have more relevant paper
    - While the other are partially silenced
  - Very sensitive to the distractors
  - Training does not have any influence
- Movement **ALWAYS** attracts our attention
  - Moving elements in webpages, flickering text or banners, are highly distracting!

# PREATTENTIVE PROCESSING. CONCLUSIONS

6  
difficult



easy

From Ware, 2013

2359807754321  
5478904820095  
3554687542558  
558932450●452  
9807754321884  
3554387542568  
2359807754321

# PREATTENTIVE PROCESSING. CONCLUSIONS



difficult

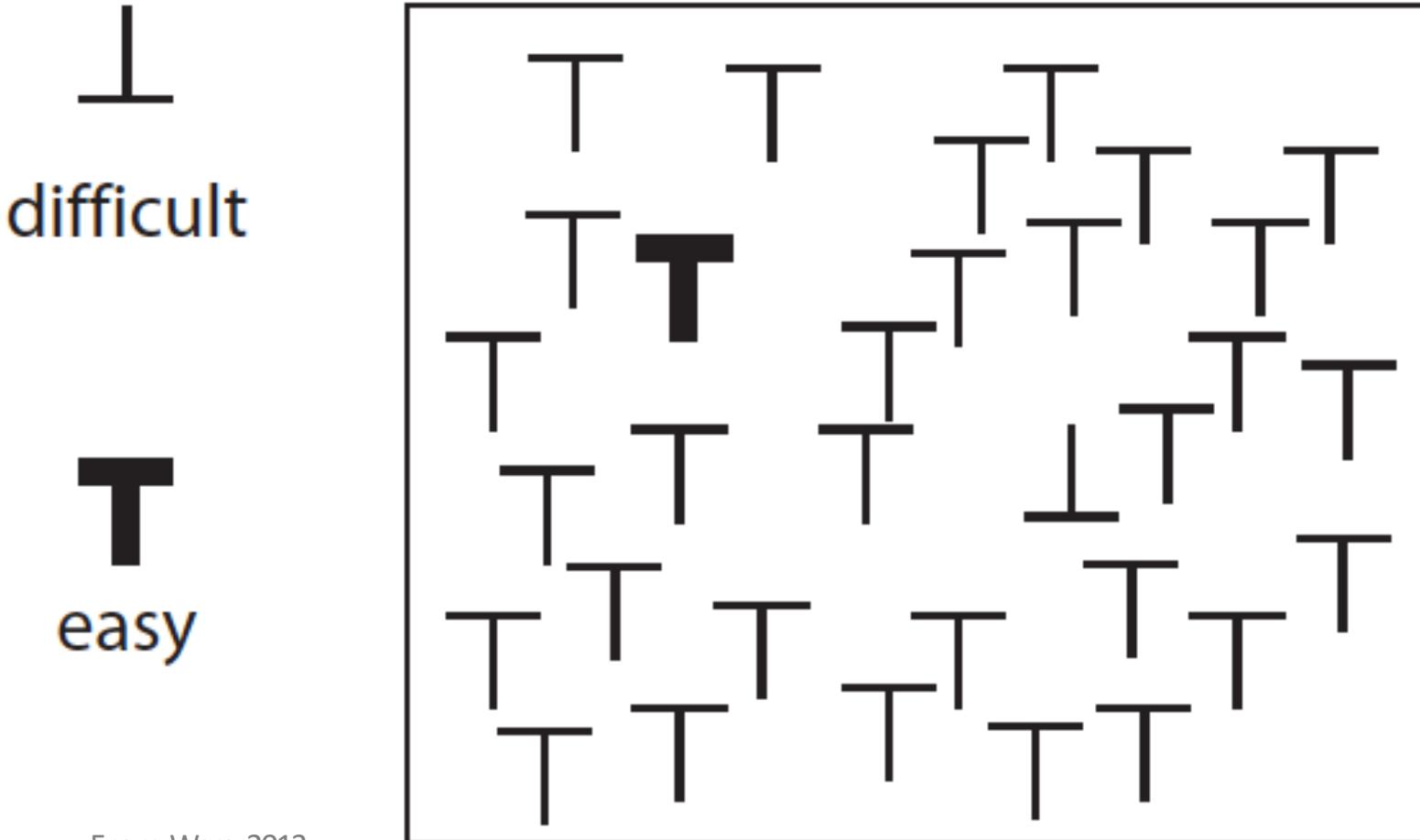


easy

From Ware, 2013



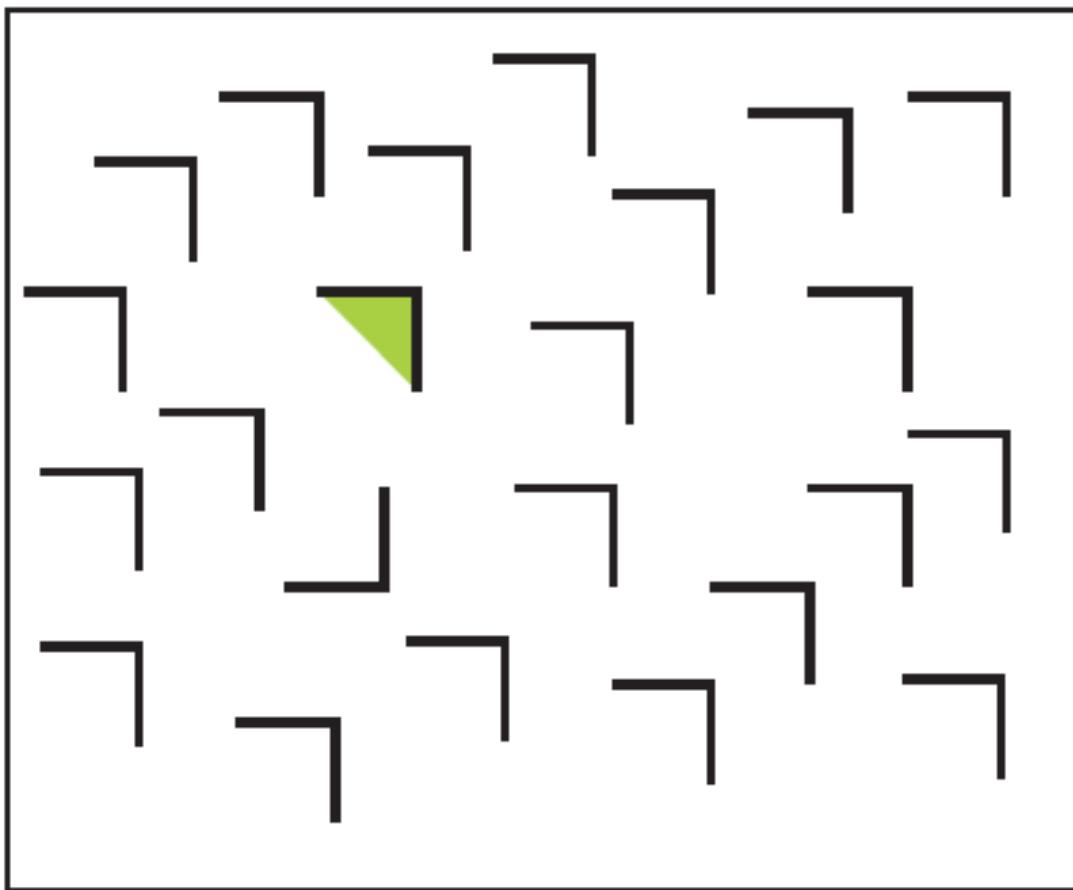
# PREATTENTIVE PROCESSING. CONCLUSIONS



# PREATTENTIVE PROCESSING. CONCLUSIONS

difficult  
  
easy  

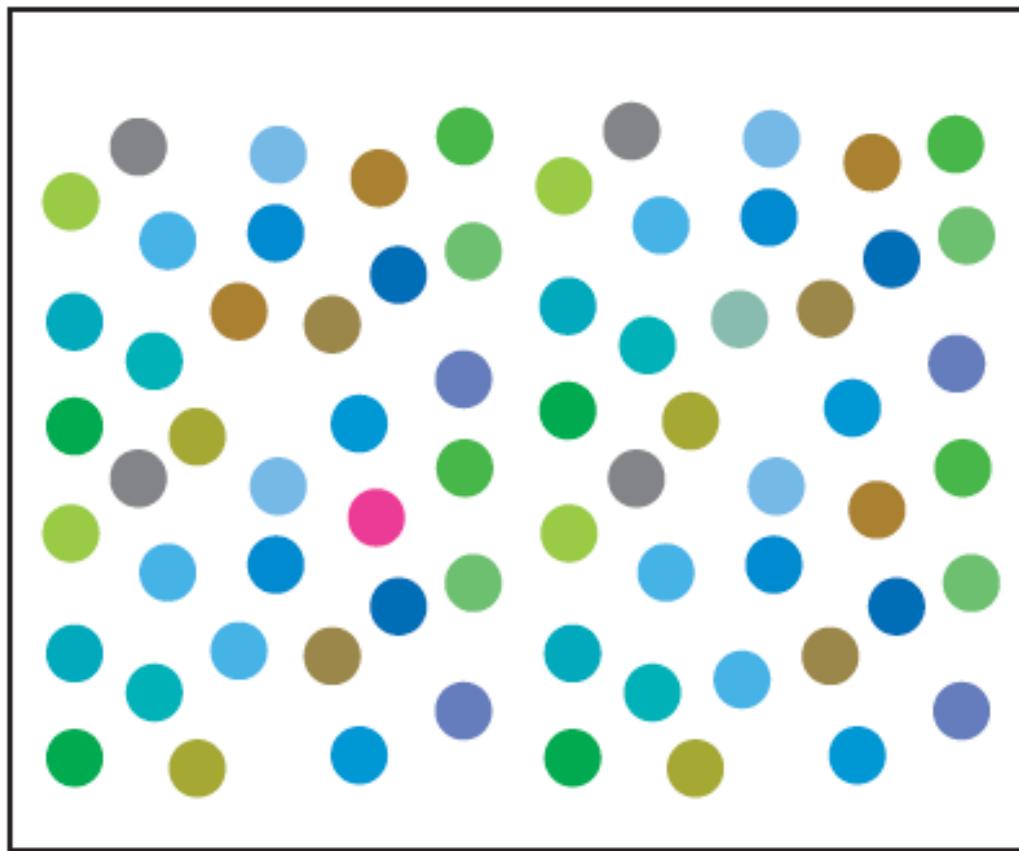

From Ware, 2013



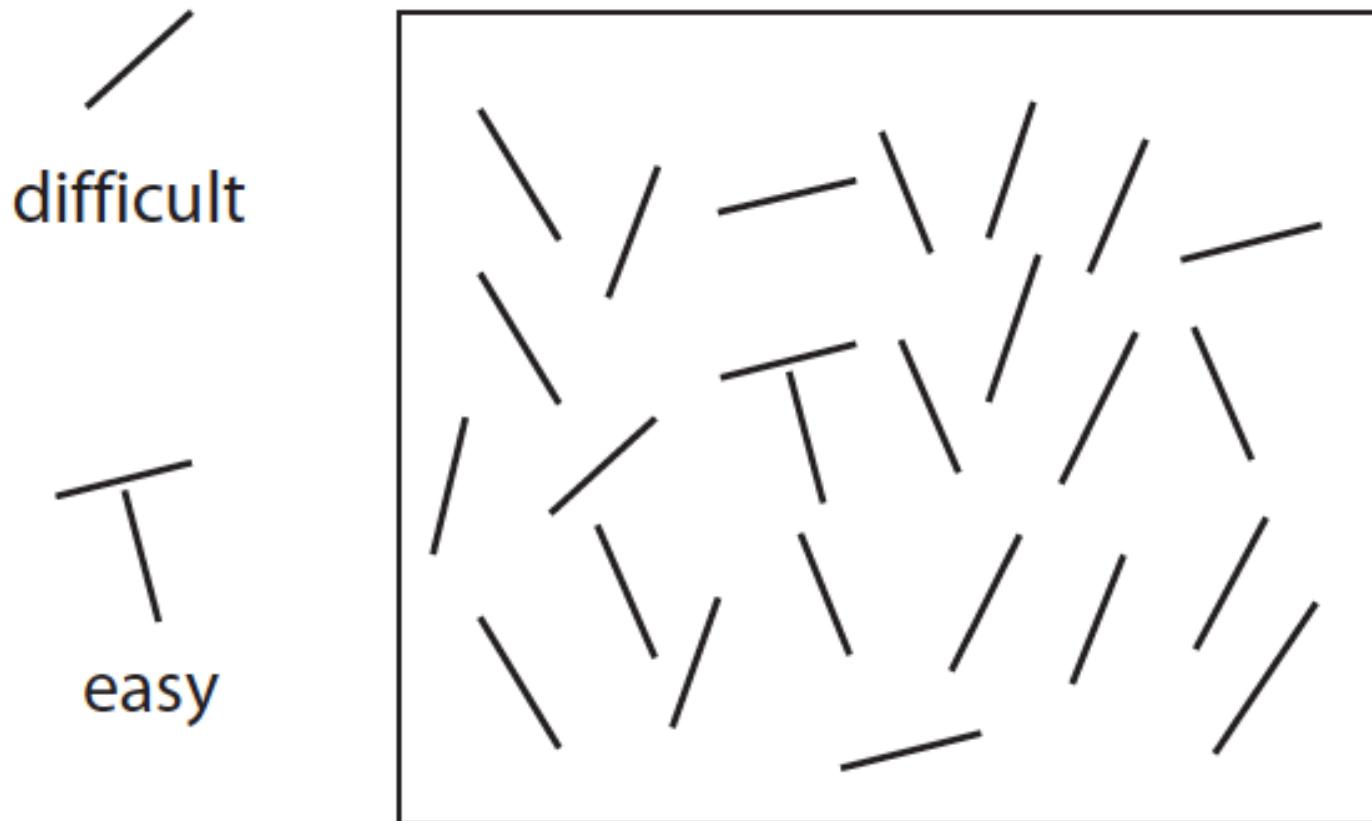
# PREATTENTIVE PROCESSING. CONCLUSIONS

difficult  
easy

From Ware, 2013



# PREATTENTIVE PROCESSING. CONCLUSIONS

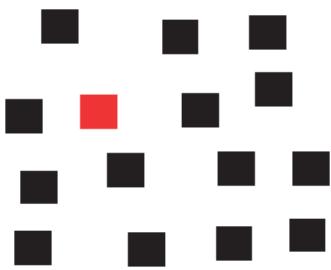


From Ware, 2013

# PREATTENTIVE PROCESSING. BASIC POP-OUT CHANNELS

Color

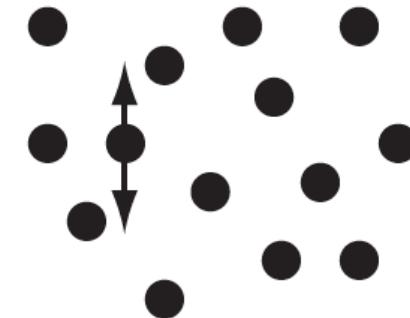
hue



lightness



Motion



Elementary shape

size



elongation



orientation



Spatial grouping



# OUTLINE

- *Recap*
- *Introduction*
- *Preattentive Processing*
- **Perception Laws**
- Applying Perception in Visualization

# PERCEPTION LAWS IN DESIGN



# PERCEPTION LAWS IN DESIGN

- Can you find the dog?
  - Dalmatinian exploring a leave covered forest floor
    - Once you have found it, try to think of the picture as a simple pattern of black and white again

# PERCEPTION LAWS IN DESIGN

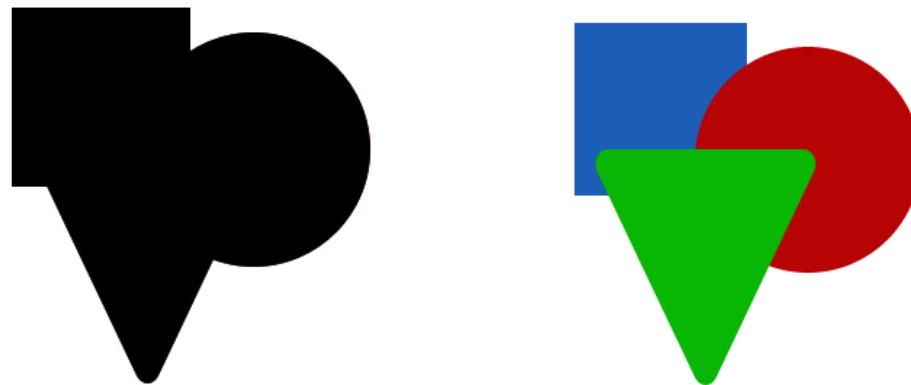


# PERCEPTION LAWS IN DESIGN

- Can you find the dog?
  - Dalmatinian exploring a leave covered forest floor
    - Once you have found it, try to think of the picture as a simple pattern of black and white again
  - Does it work?
    - Mind tries to detect anything meaningful by identifying patterns
    - Different tools are tried sequentially
- Perceptual organization is a powerful mechanism

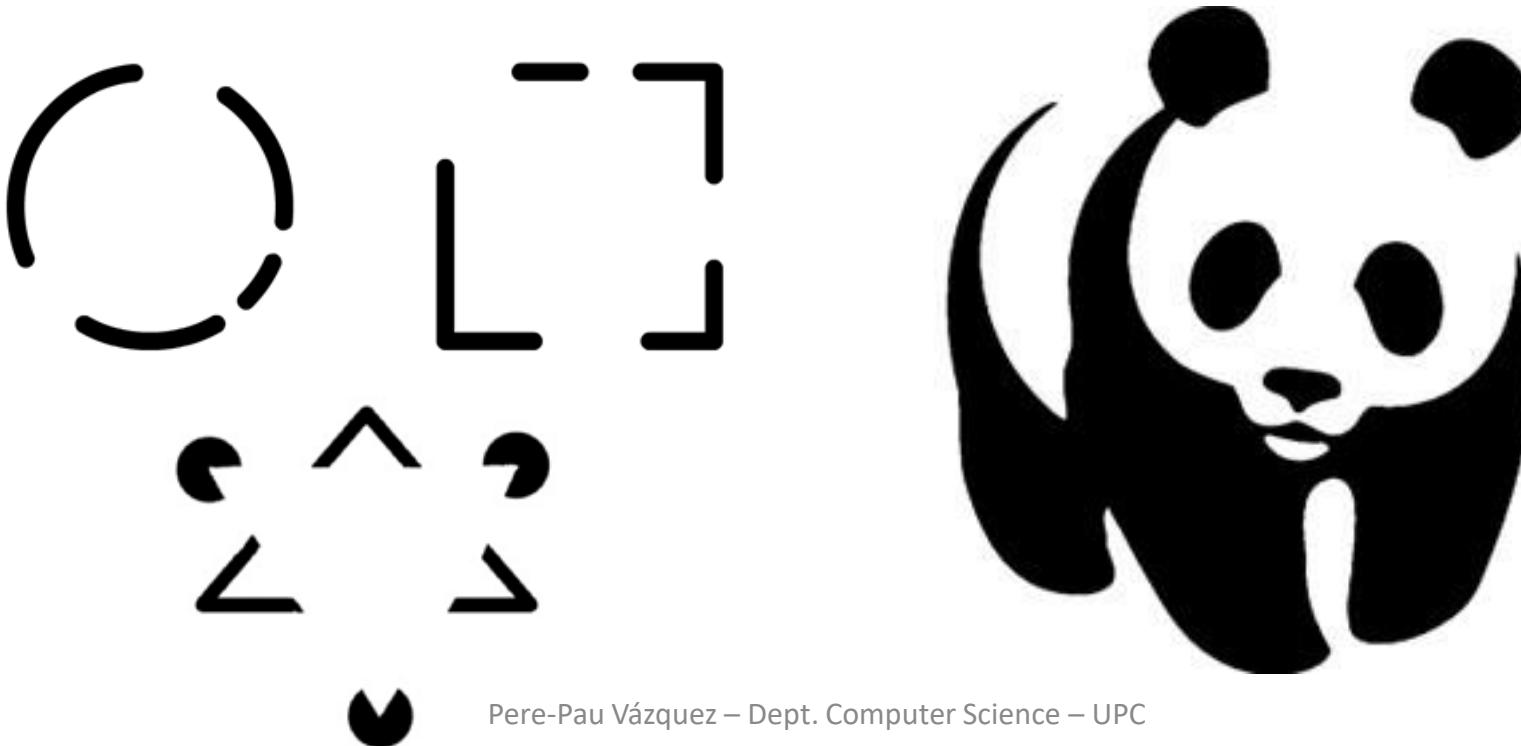
# PERCEPTION LAWS IN DESIGN

- Pragnänz Law: Law of good figure, simplicity: We tend to perceive simpler shapes



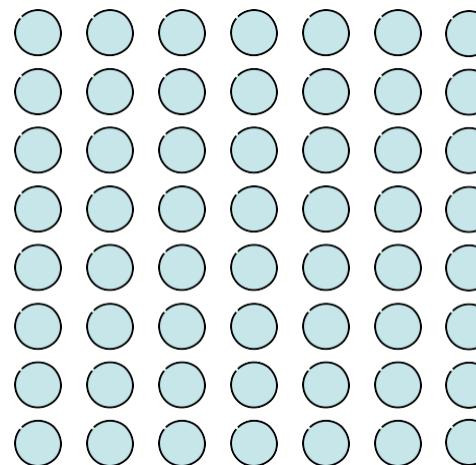
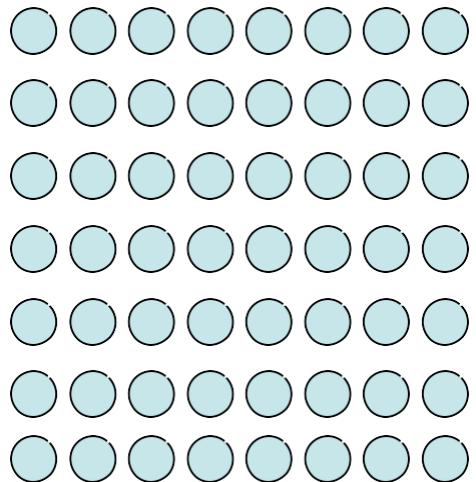
# PERCEPTION LAWS IN DESIGN

- The law of closure: The mind may experience elements it does not perceive through sensation, in order to complete a regular figure



# PERCEPTION LAWS IN DESIGN

- Grouping by spatial proximity
  - Columns or rows?

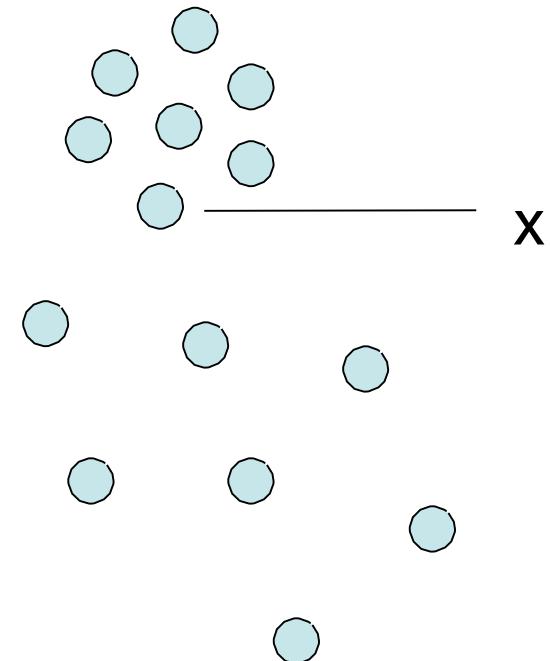


# PERCEPTION LAWS IN DESIGN

- Grouping by spatial proximity. Columns or rows?
  - Small difference in spacing causes change in perception
  - Use proximity to emphasize between display items
  - To which group (top / bottom) does the x dot belong? Spacing is equal for both groups!

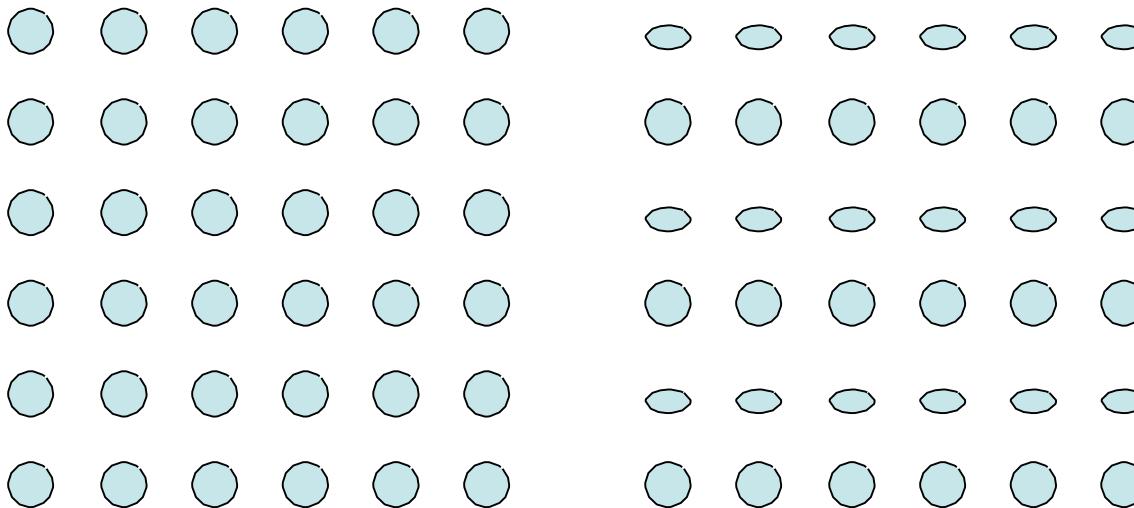
# PERCEPTION LAWS IN DESIGN

- Grouping by spatial proximity
  - Spatial concentration principle: we group regions of similar element density (Slocum1983)



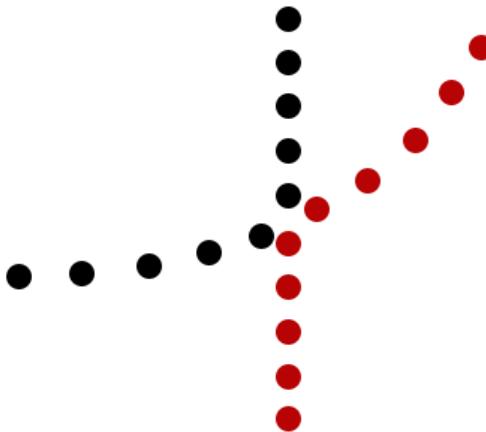
# PERCEPTION LAWS IN DESIGN

- Similarity
  - Rows or columns?
  - Similar elements tend to be grouped together



# PERCEPTION LAWS IN DESIGN

- The law of continuity: The mind continues visual, auditory, and kinetic patterns.
  - Elements on a line/curve may be perceived as more related than elements not on the line/curve.



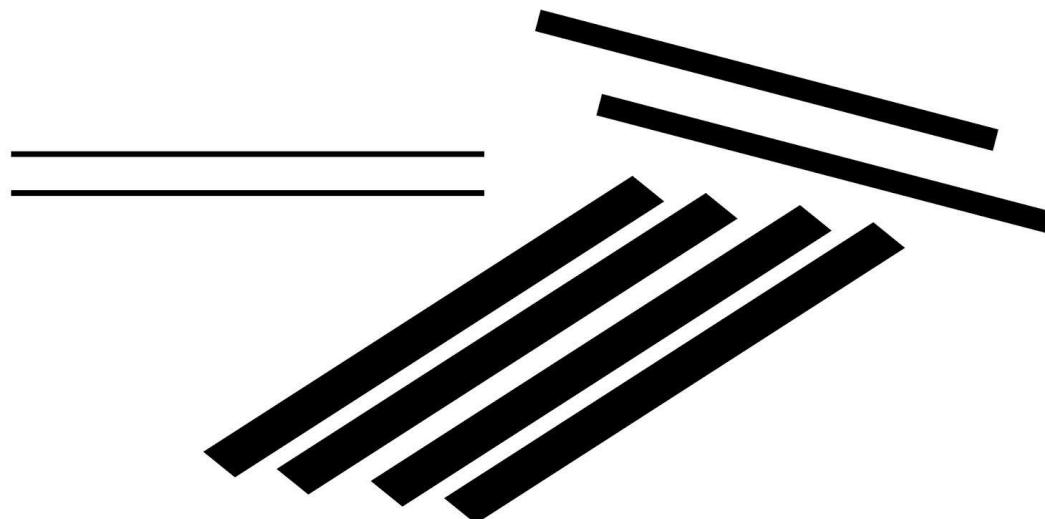
# PERCEPTION LAWS IN DESIGN

- The law of common fate: Elements with the same moving direction are perceived as a collective or unit.



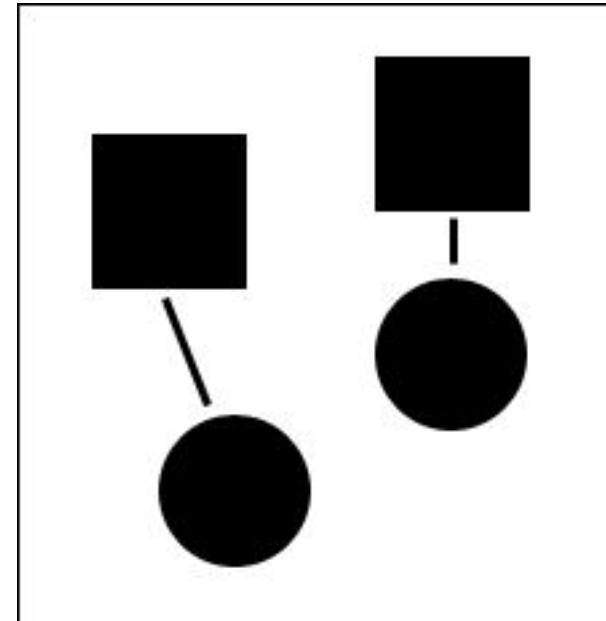
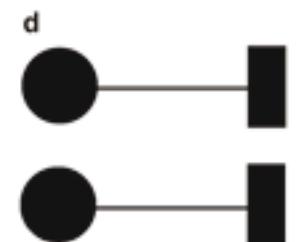
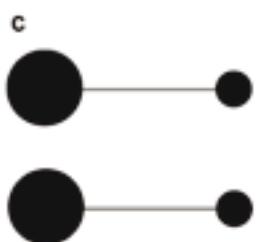
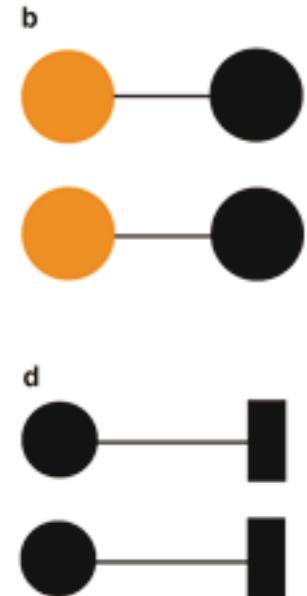
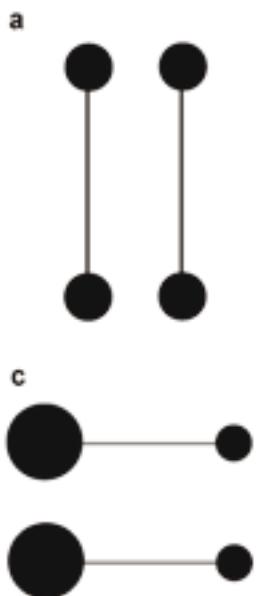
# PERCEPTION LAWS IN DESIGN

- Principle of parallelism: Parallel elements tend to be perceived as a group
  - Similar to principle of common fate since element are seen as pointing in the same direction



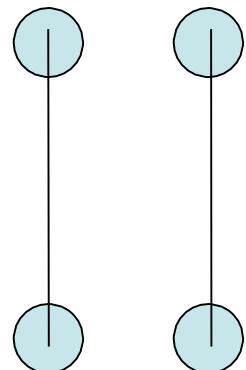
# PERCEPTION LAWS IN DESIGN

- Principle of connectedness
  - Elements being visually connected are perceived as more related than unconnected elements

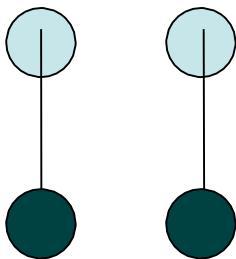


# PERCEPTION LAWS IN DESIGN

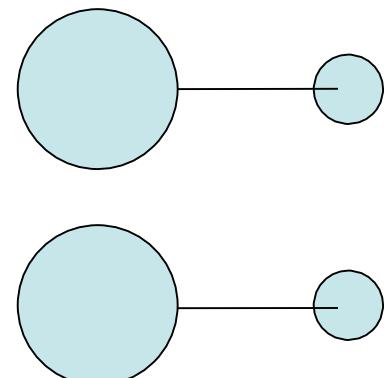
- Connectedness
  - Palmer & Rock 1994
  - Potentially more powerful organizing principle than proximity, color, size, shape



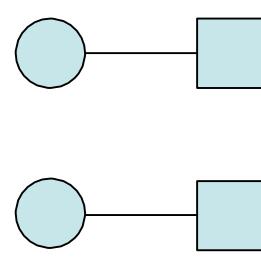
proximity



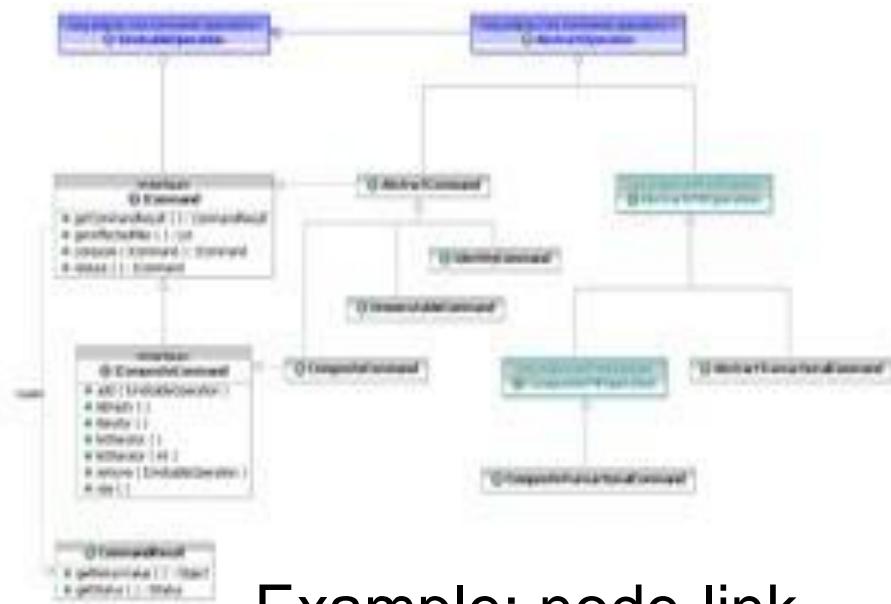
color



size



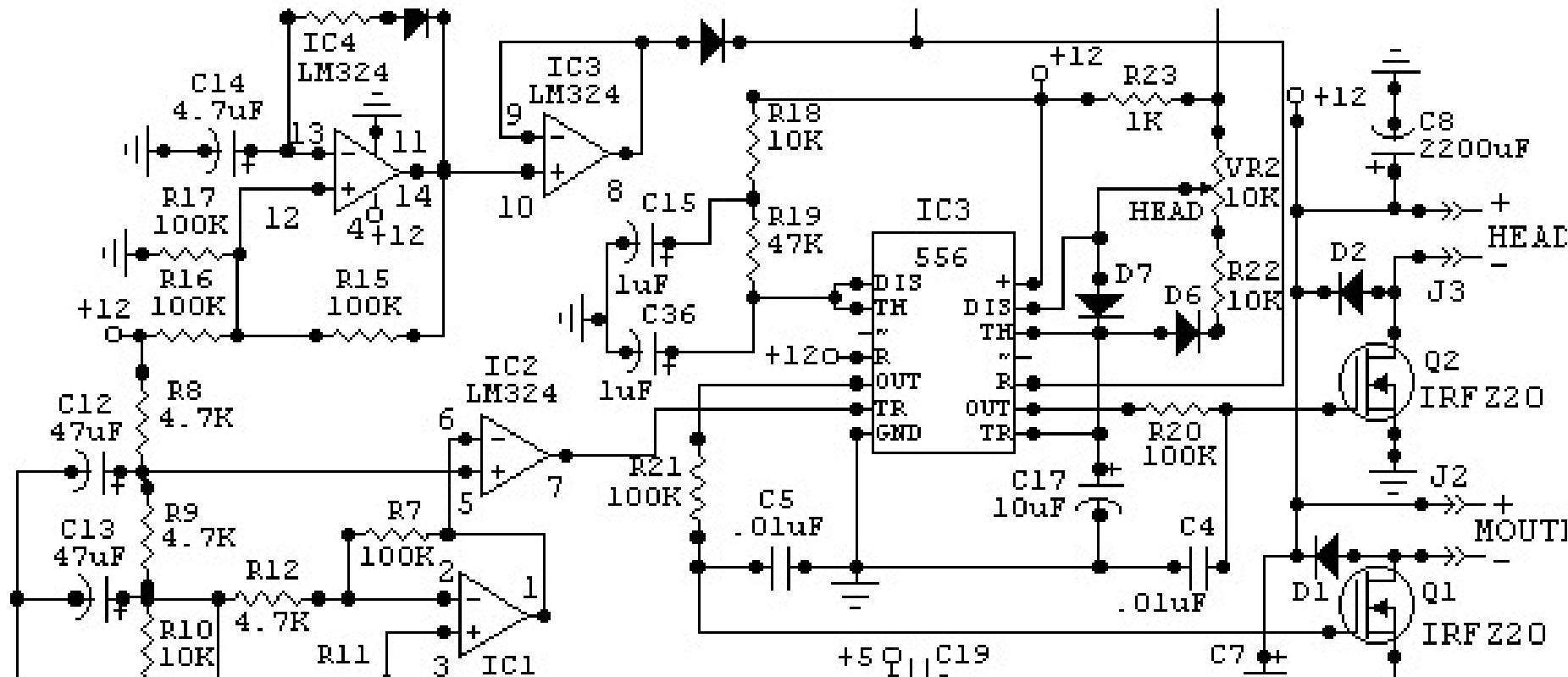
shape



Example: node-link  
diagram

# PERCEPTION LAWS IN DESIGN

- Connectedness & continuity, example:
    - Circuit design – understanding how components are connected



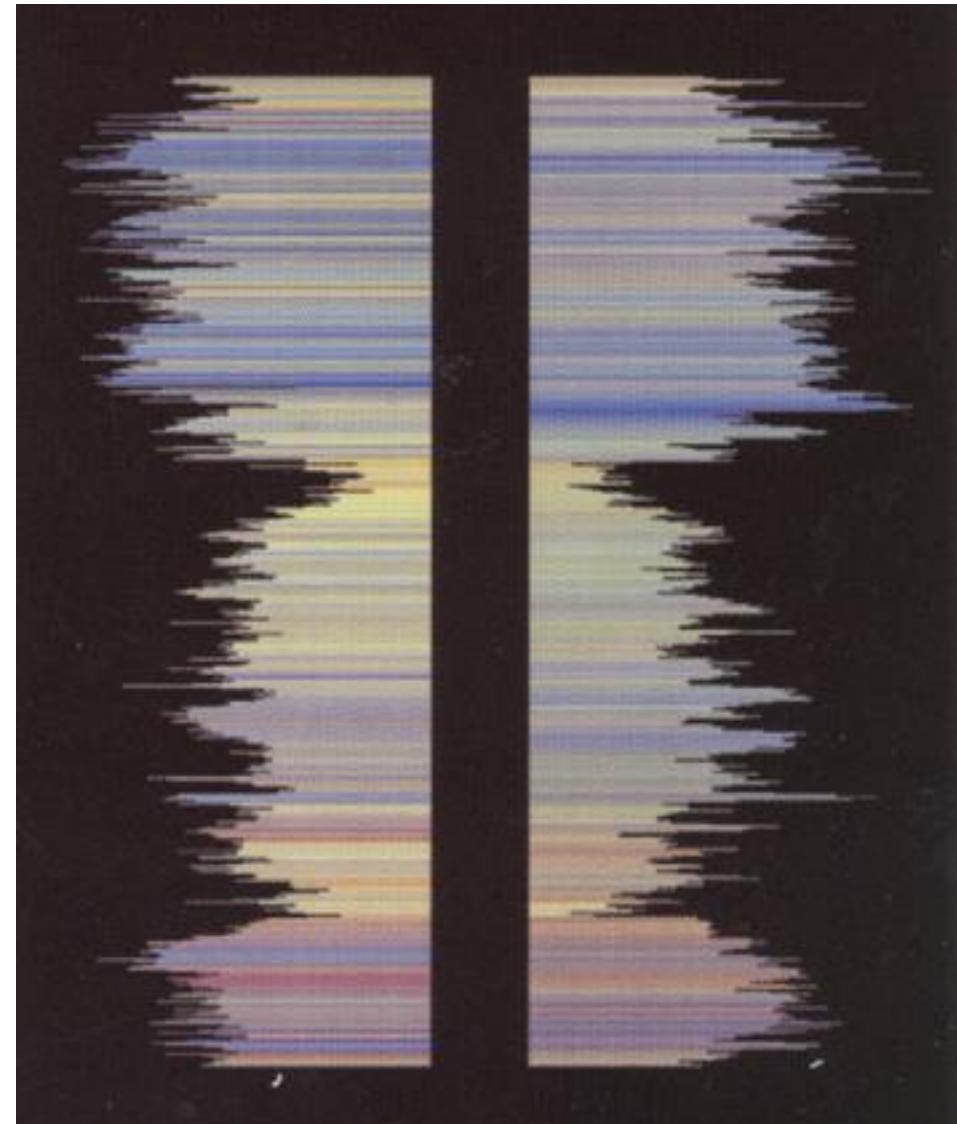
# PERCEPTION LAWS IN DESIGN

- The law of symmetry: Symmetrical images are perceived collectively, even in spite of distance.



# PERCEPTION LAWS IN DESIGN

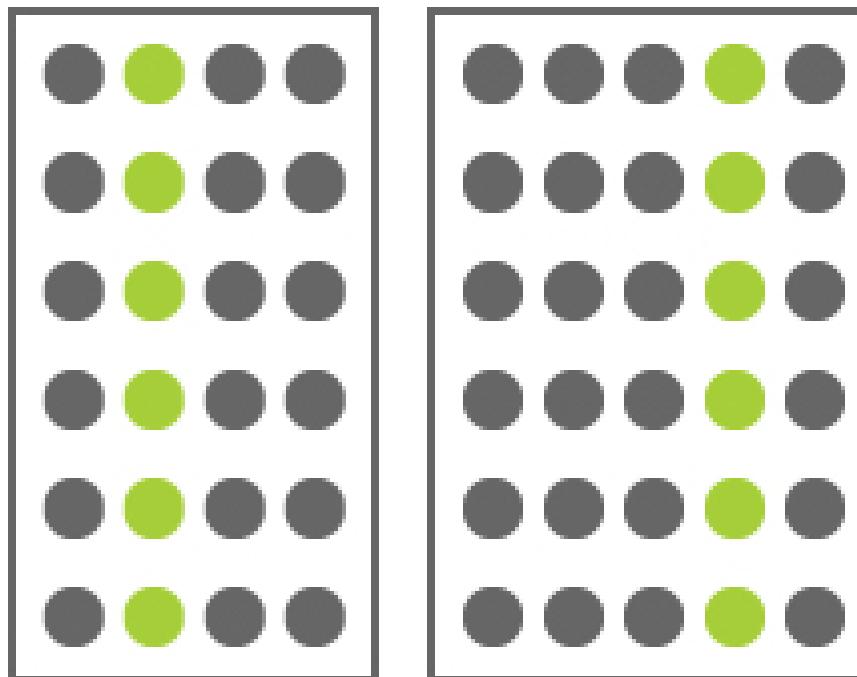
- Symmetry
  - Example of how symmetry detection may be exploited for visual data mining
  - Support the search for similar patterns in time-series plots (measurements of deep ocean drilling cores)



From Ware, 2001

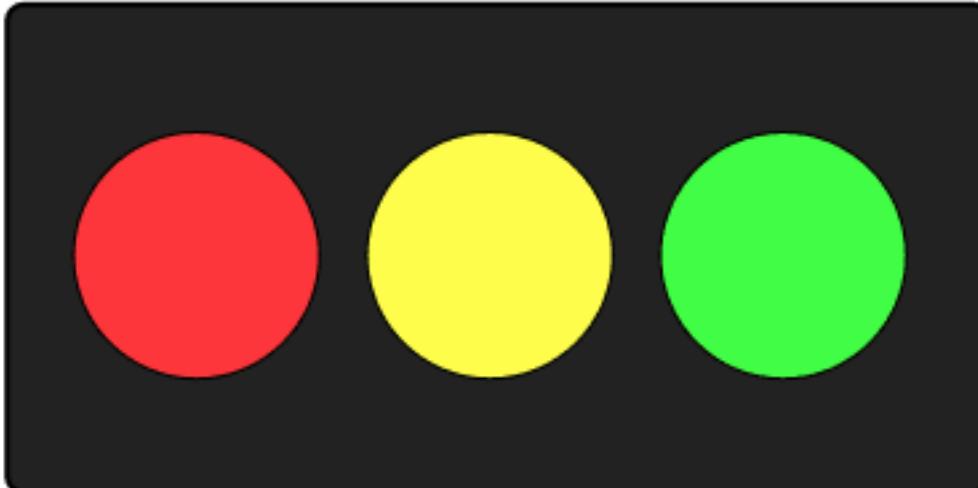
# PERCEPTION LAWS IN DESIGN

- Principle of common region: Elements located in the same closed region are perceived as a group (*containment*)



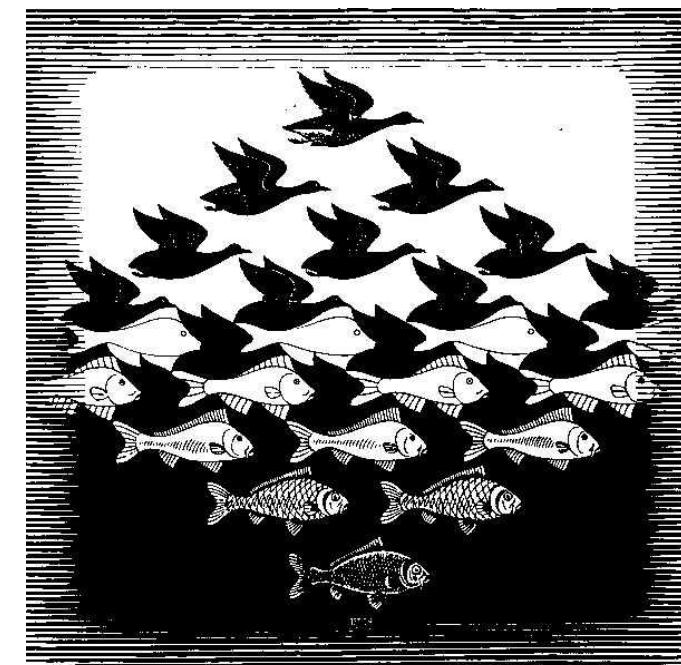
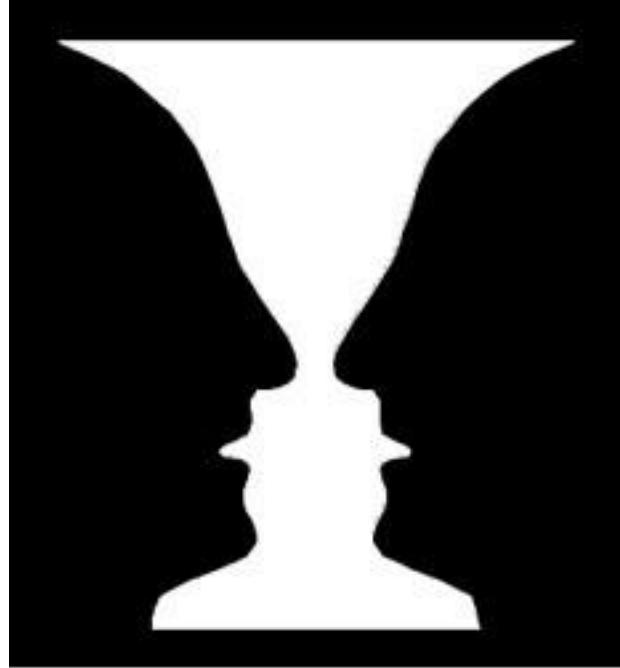
# PERCEPTION LAWS IN DESIGN

- Principle of past experience: People's experience influences their perception
  - Experience is unique to the individual but some experiences are shared, e.g., in a cultural circle



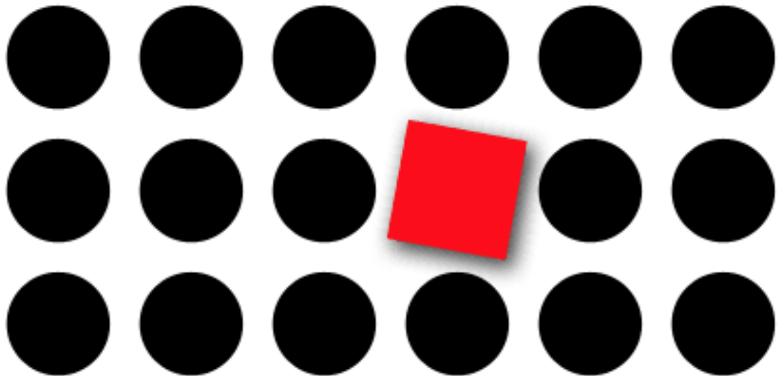
# PERCEPTION LAWS IN DESIGN

- We tend to divide scenes in figure & ground
  - Figure: something object-like that is perceived being in the foreground
  - Ground: whatever lies behind the figure
- Fundamental perceptual act of identifying objects
- All Gestalt laws contribute, e.g., closed contour, symmetry, area (e.g., larger elements -> background)
- Equally balanced cues for figure and ground can result in bistable perception



# PERCEPTION LAWS IN DESIGN

- Principle of focal point: Among elements, a point of interest, emphasis, or difference will capture the viewer's attention
  - Serve as an entry point into visualization





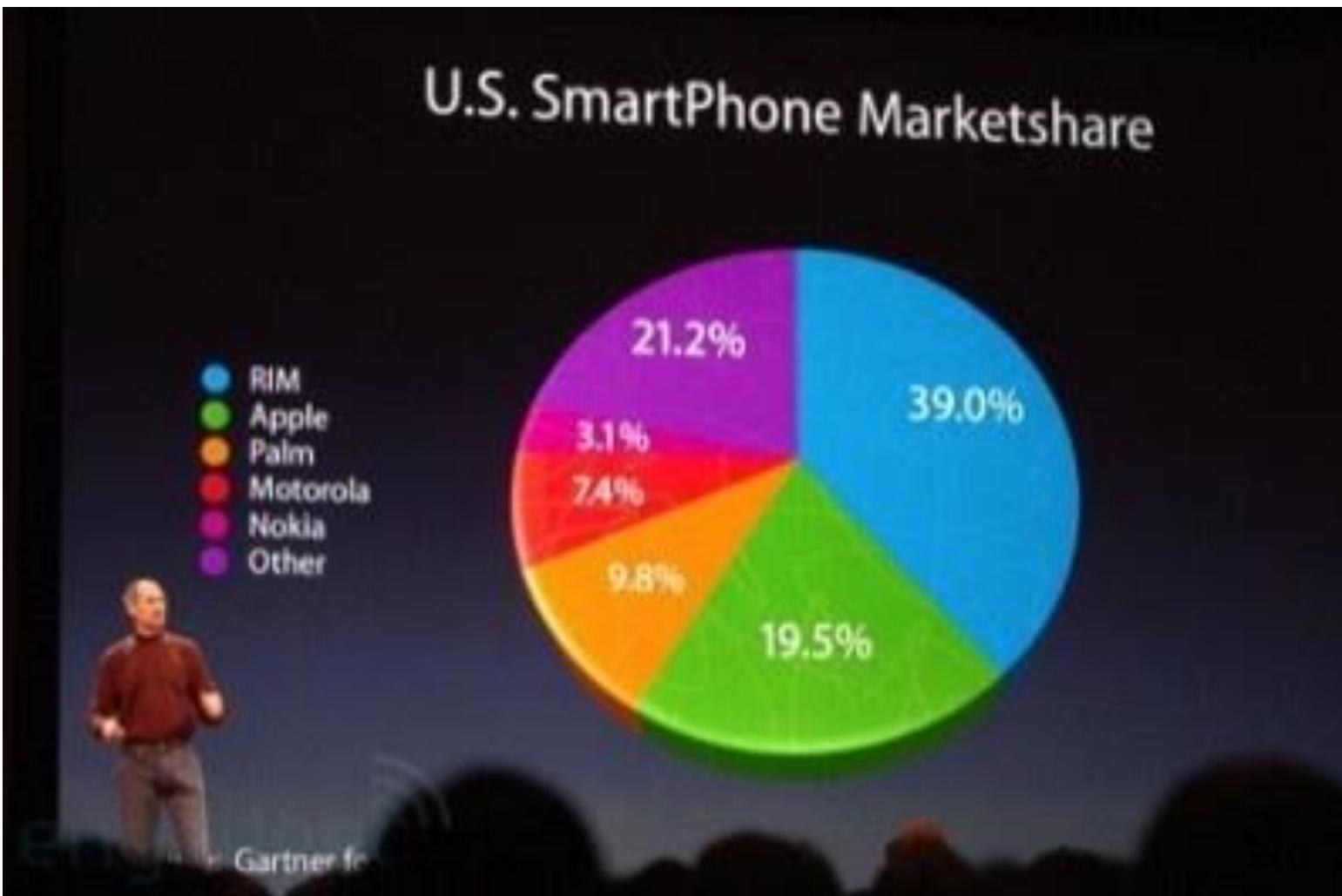
# EXERCISES

PERE-PAU VÁZQUEZ – VIRVIG GROUP – UPC

# EXERCISES

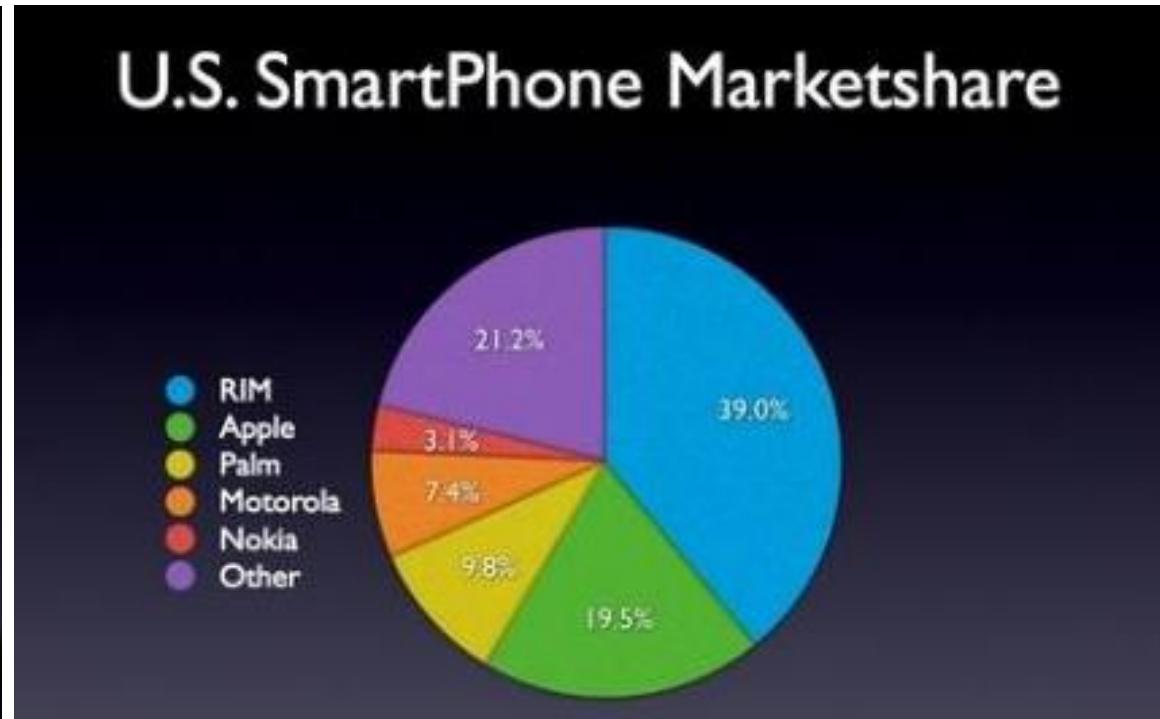
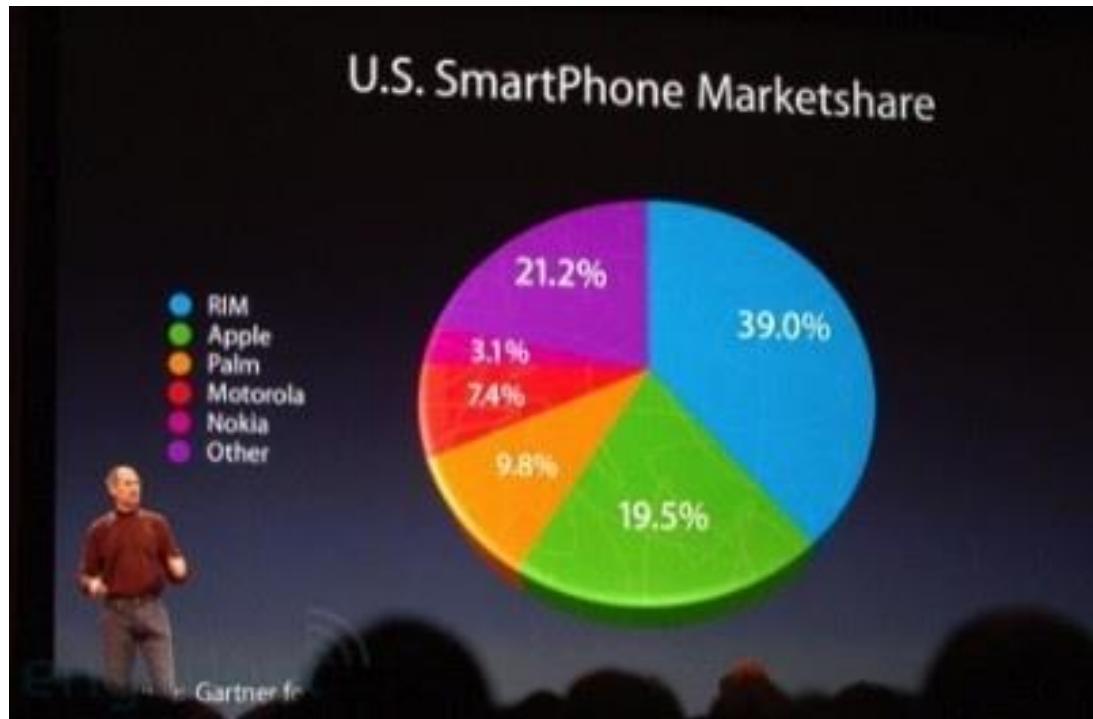
- How to approach the following exercises
  - What do you think is the main point or piece of information this visualization is trying to convey?
  - What elements of the visualization are used to communicate the information that is being conveyed?
    - Are they effective?
    - Are there distractors?
  - Would you change elements to make the meaning clearer?
    - Which ones?
    - How?

# EXERCISES



# EXERCISES

- Data distortion

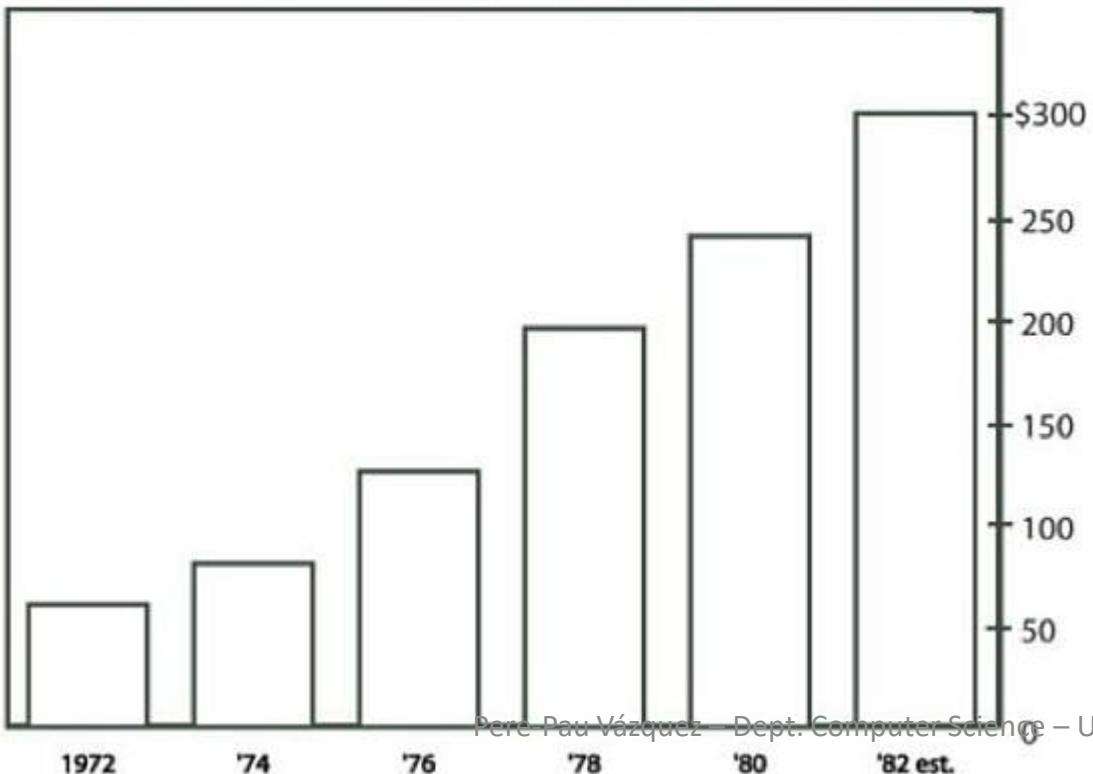


# EXERCISES

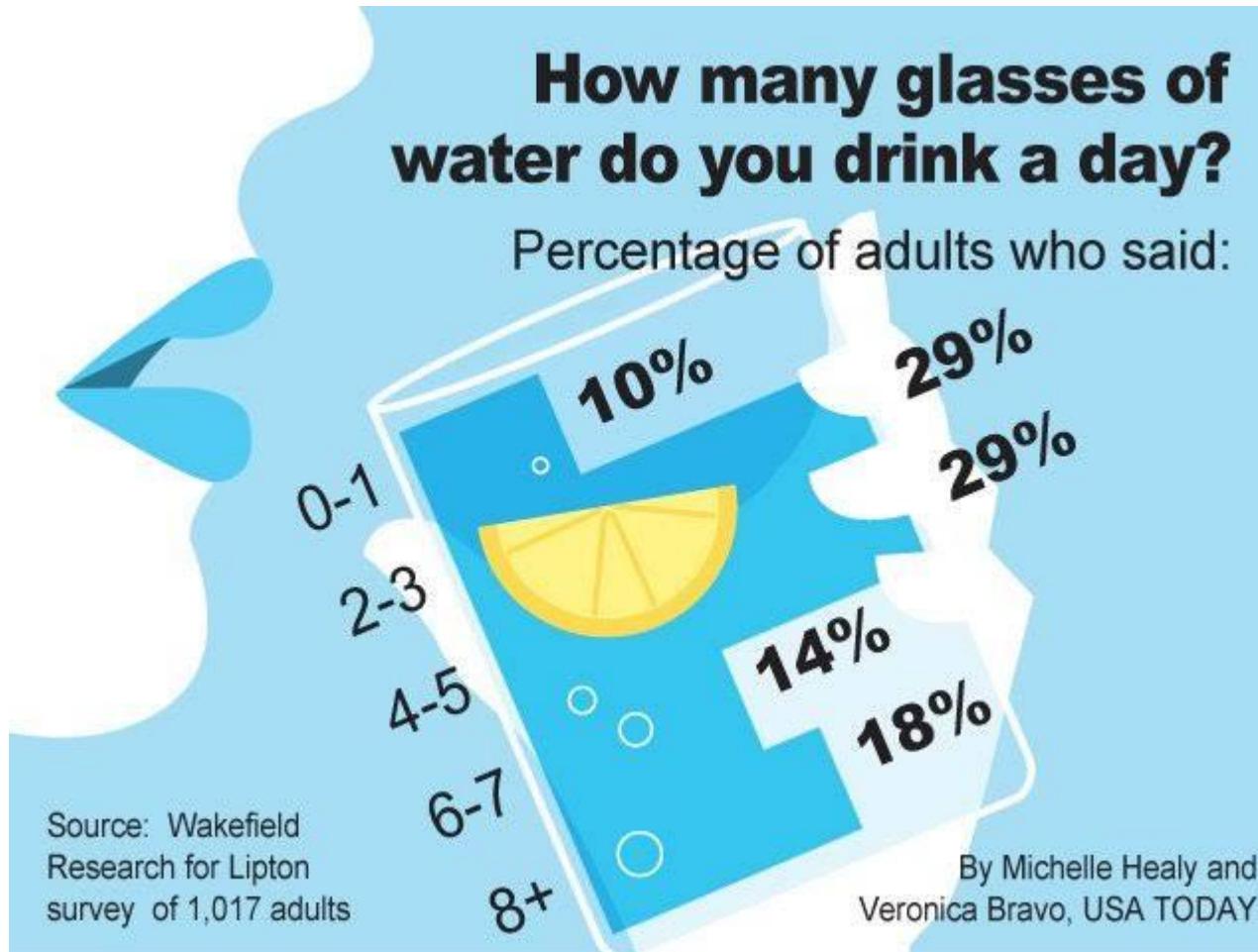


# EXERCISES

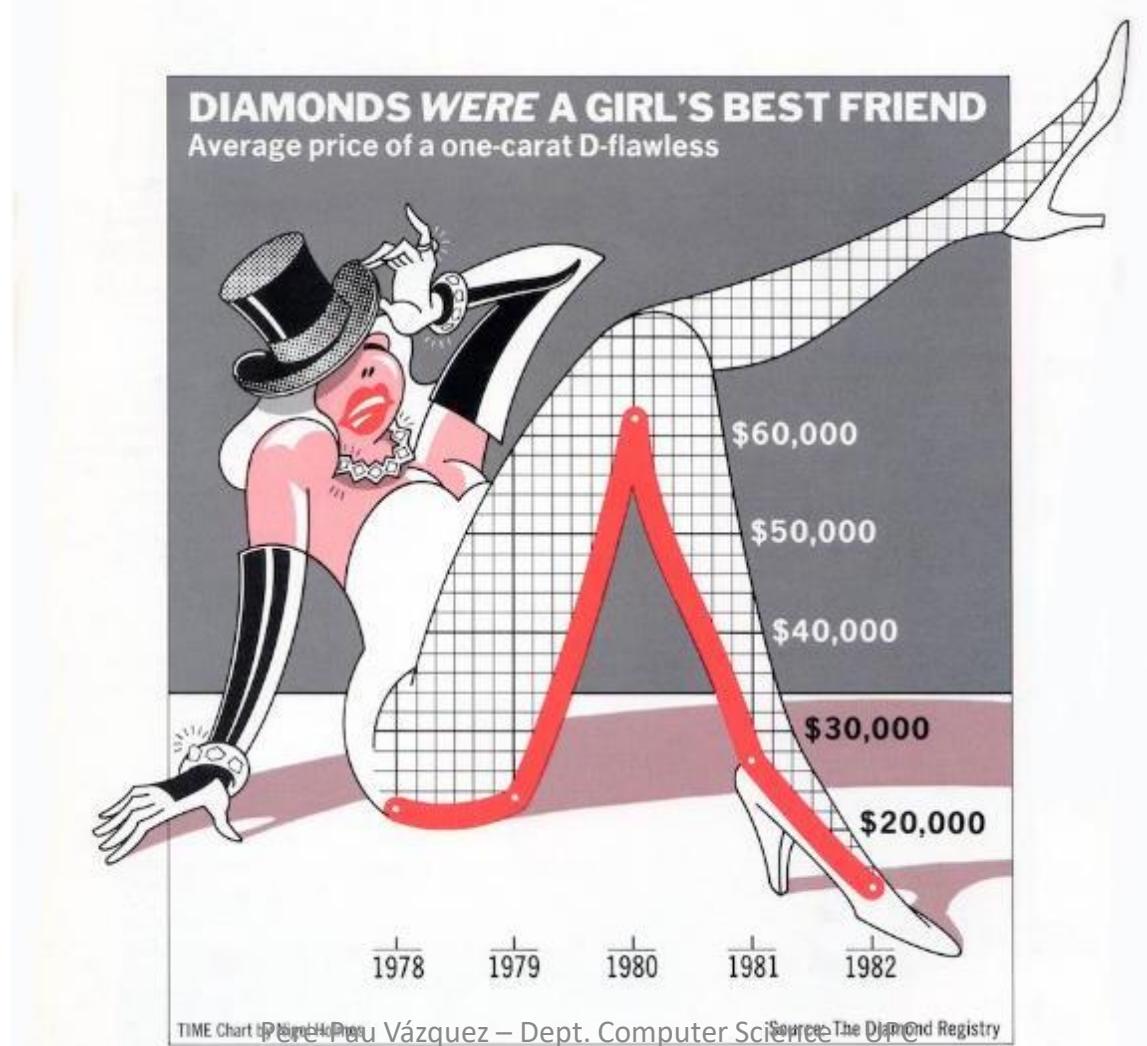
**MONSTROUS COSTS**  
Total House and Senate campaign expenditures, in millions



# EXERCISES



# EXERCISES



# EXERCISES

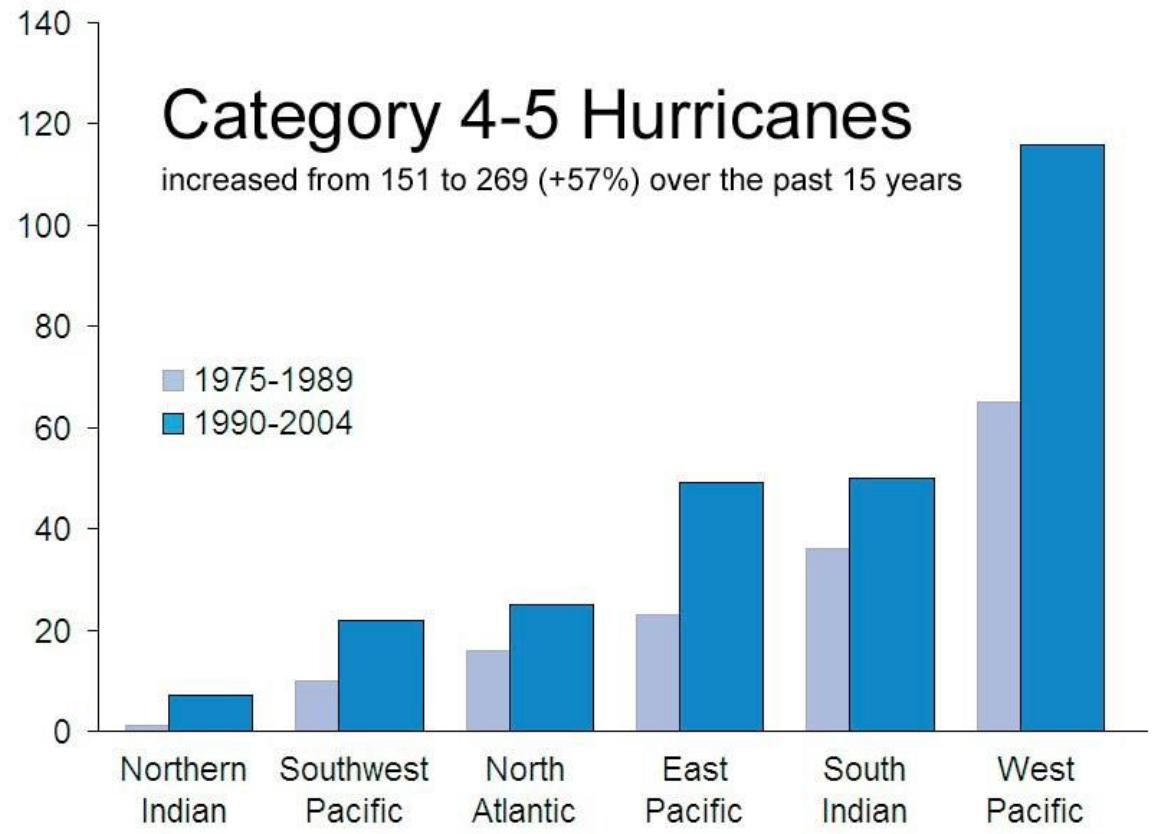


# EXERCISES

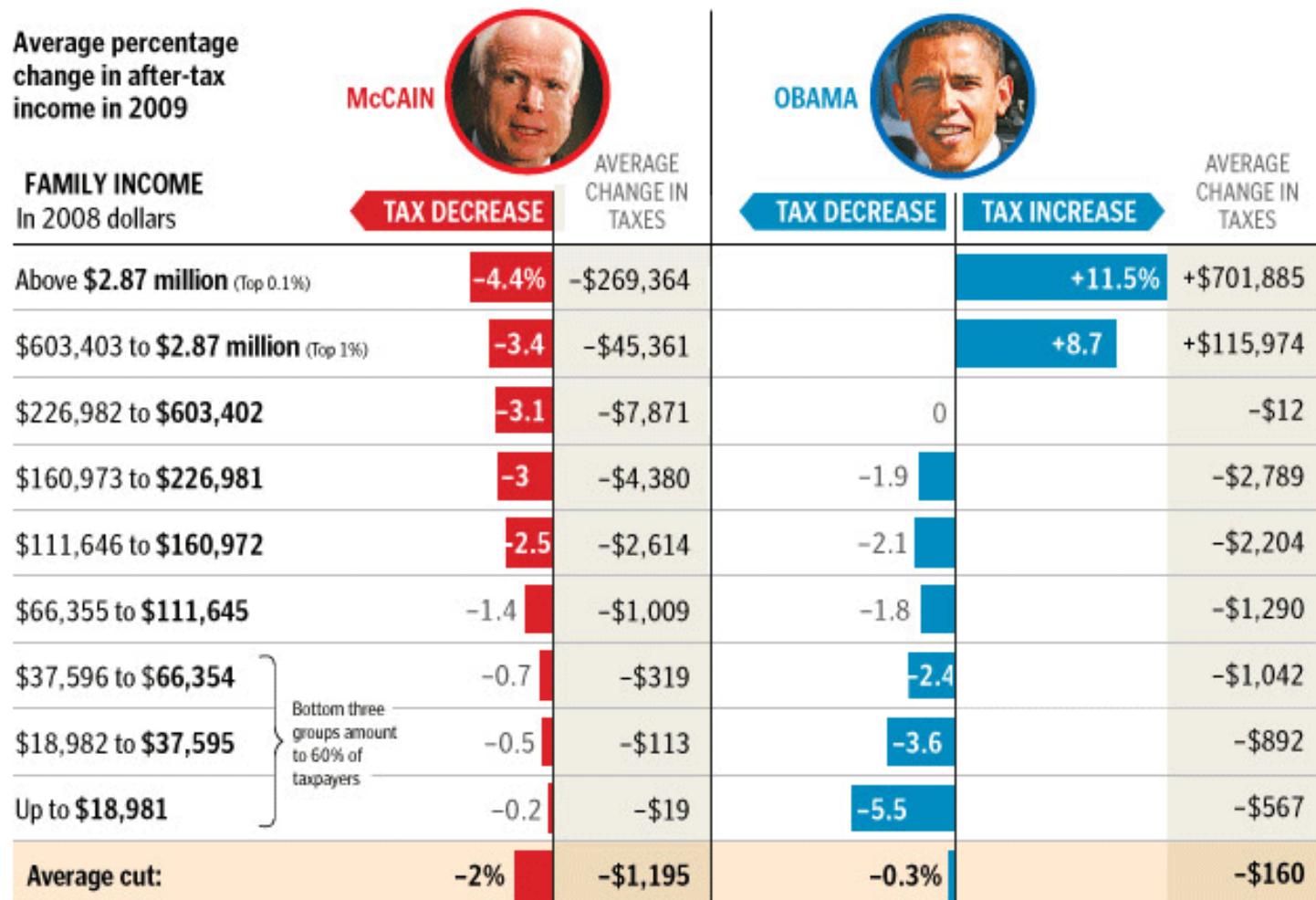


# EXERCISES

- Example:

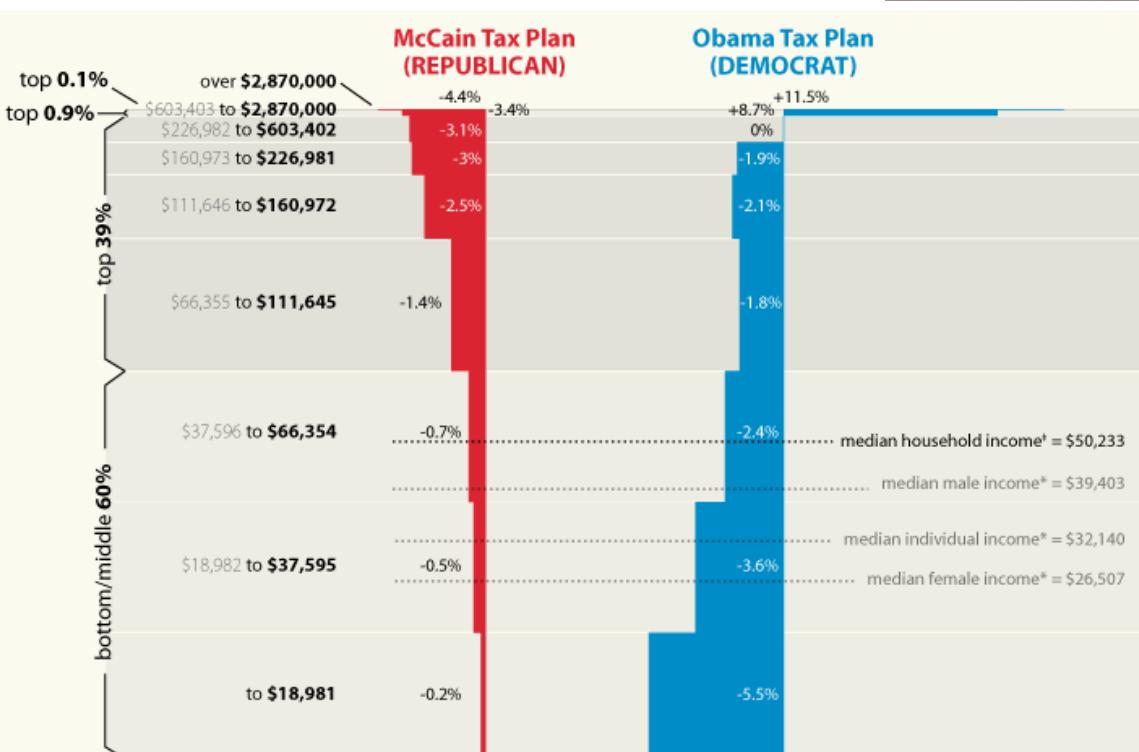


# EXERCISES



# EXERCISES

- Corrected version



Tax Plan data from Washington Post reporting of Tax Policy Center analysis.

Redrawn to scale with height of bars corresponding to population of each group, as given in original TPC data.

\*income for individuals age 25 or older with earnings.

2005 FY Data from US Census Bureau, 2006 via [http://en.wikipedia.org/wiki/Demographics\\_of\\_the\\_United\\_States](http://en.wikipedia.org/wiki/Demographics_of_the_United_States)

<sup>†</sup> US Census Bureau, Aug. 2008 press release

[http://www.census.gov/Press-Release/www/releases/archives/income\\_wealth/012528.html](http://www.census.gov/Press-Release/www/releases/archives/income_wealth/012528.html)



McCAIN



OBAMA

Average percentage  
change in after-tax  
income in 2009

FAMILY INCOME  
In 2008 dollars

	TAX DECREASE	AVERAGE CHANGE IN TAXES	TAX DECREASE	TAX INCREASE	AVERAGE CHANGE IN TAXES
Above \$2.87 million (top 0.1%)	-4.4%	-\$269,364			+11.5% +\$701,885
\$603,403 to \$2.87 million (Top 1%)	-3.4%	-\$45,361			+8.7% +\$115,974
\$226,982 to \$603,402	-3.1%	-\$7,871	0		-\$12
\$160,973 to \$226,981	-3%	-\$4,380	-1.9%		-\$2,789
\$111,646 to \$160,972	-2.5%	-\$2,614	-2.1%		-\$2,204
\$66,355 to \$111,645	-1.4%	-\$1,009	-1.8%		-\$1,290
\$37,596 to \$66,354	-0.7%	-\$319	-2.4%		-\$1,042
\$18,982 to \$37,595	-0.5%	-\$113	-3.6%		-\$892
Up to \$18,981	-0.2%	-\$19	-5.5%		-\$567
Average cut:	-2%	-\$1,195	-0.3%		-\$160



US Presidential Candidates tax plans, redrawn from Washington Post data by Viveka Weiley - <http://chartjunk.karmanaut.com>

Some Rights Reserved: Creative Commons Attribution Sharealike license: see [http://creativecommons.org/licenses/by-sa/2.5/au/](http://creativecommons.org/licenses/by-sa/2.5/)

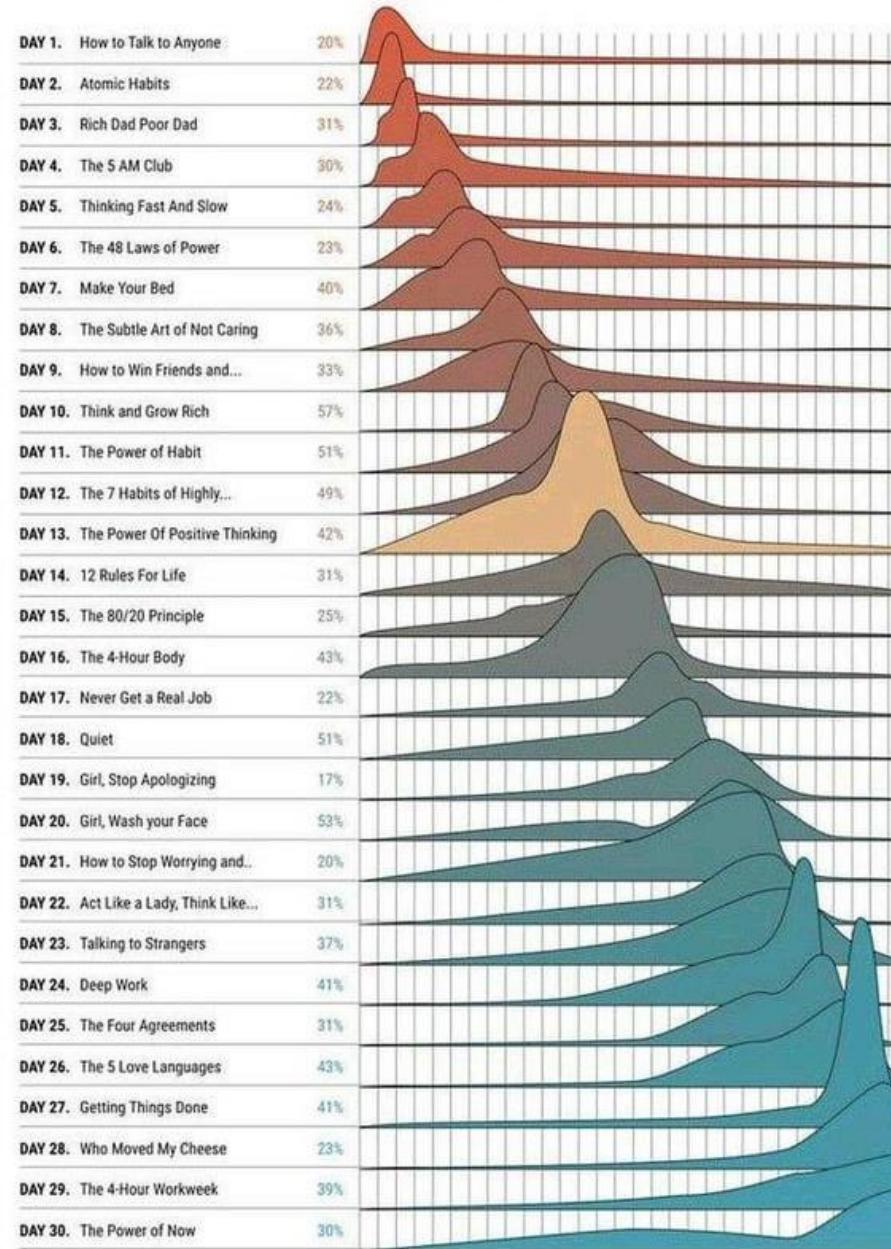
Briefly: you may use and redistribute this image, but must credit me and may not prevent others from sharing it.

# EXERCISES



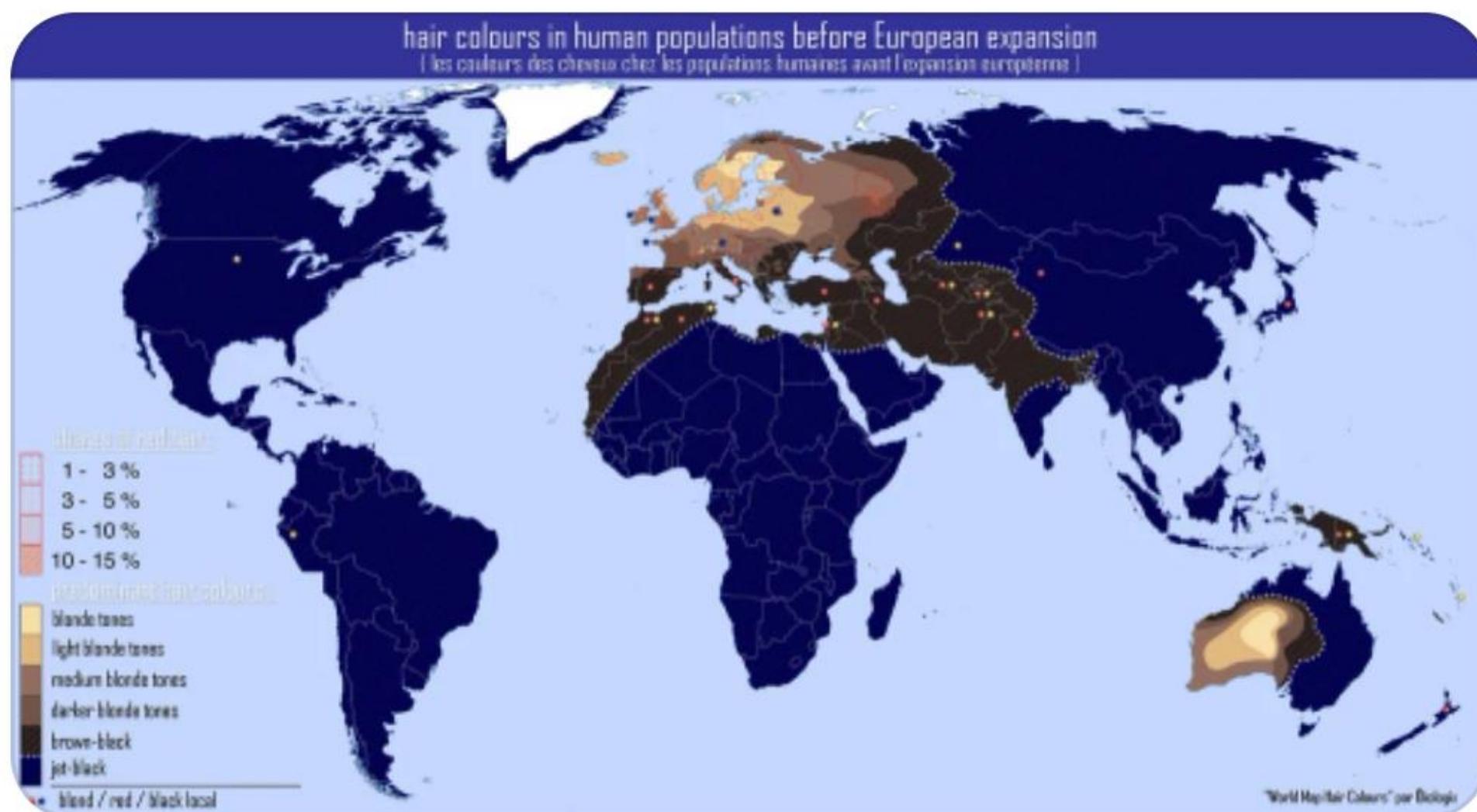
# EXERCISES

# 30 BOOKS TO CHANGE YOUR LIFE



EXE

# Hair colours in human populations before European expansion

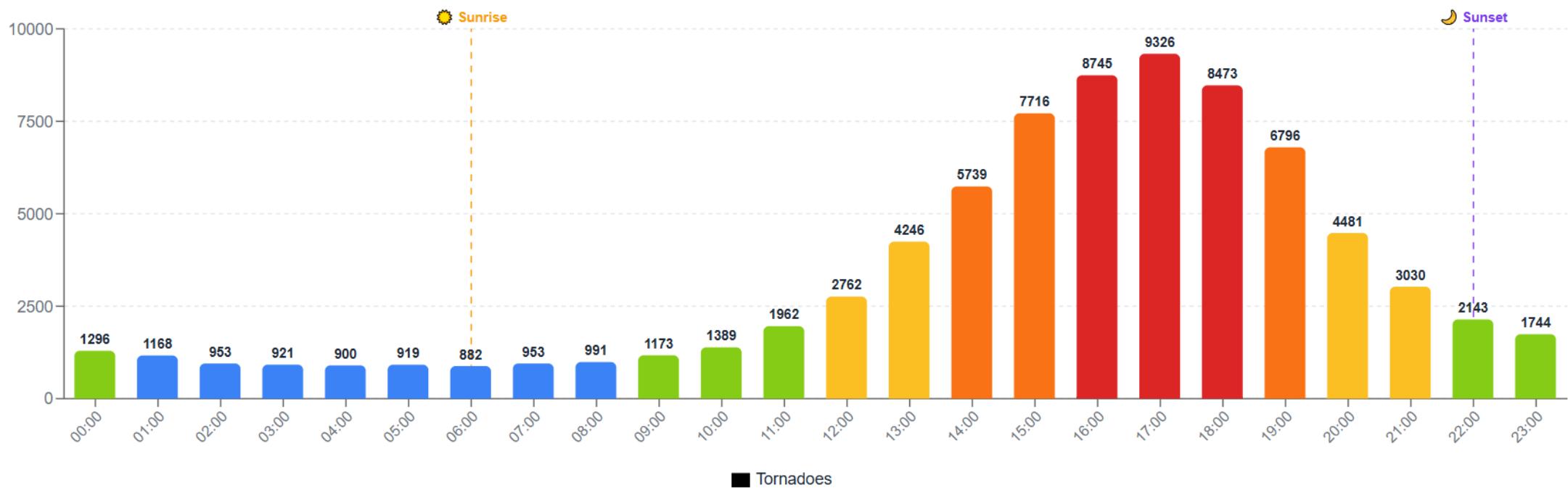


# EXERCISES

## ⌚ Time of Day Analysis

Reveals the hourly pattern of tornado occurrence, showing when tornadoes are most likely to strike. Late afternoon and early evening (3-7 PM) are peak tornado hours, while nighttime tornadoes are rare but especially dangerous.

 Times shown as recorded in each tornado's local timezone (mix of ET, CT, MT, PT, etc.).





# EXERCISES

PERE-PAU VÁZQUEZ – VIRVIG GROUP – UPC



# PERCEPTION IN VIS

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PERE-PAU VÁZQUEZ – VIRVIG GROUP – UPC