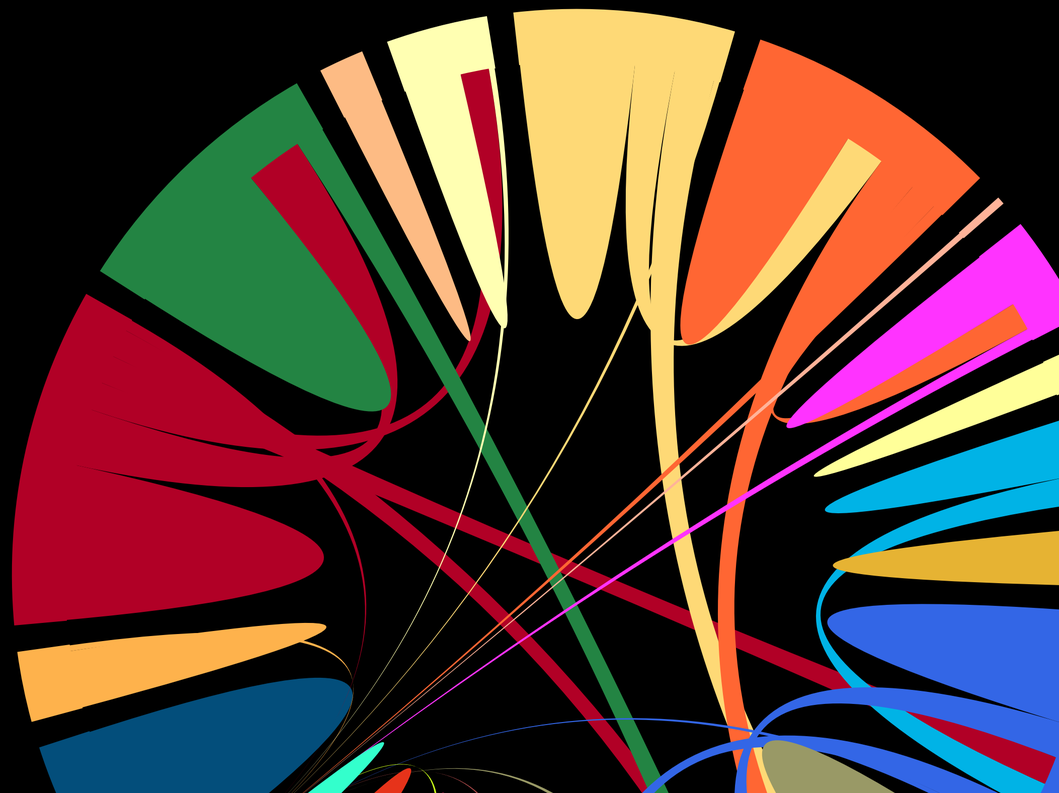
Information Visualization INFO250

Chapter 4: Cognitive Theory

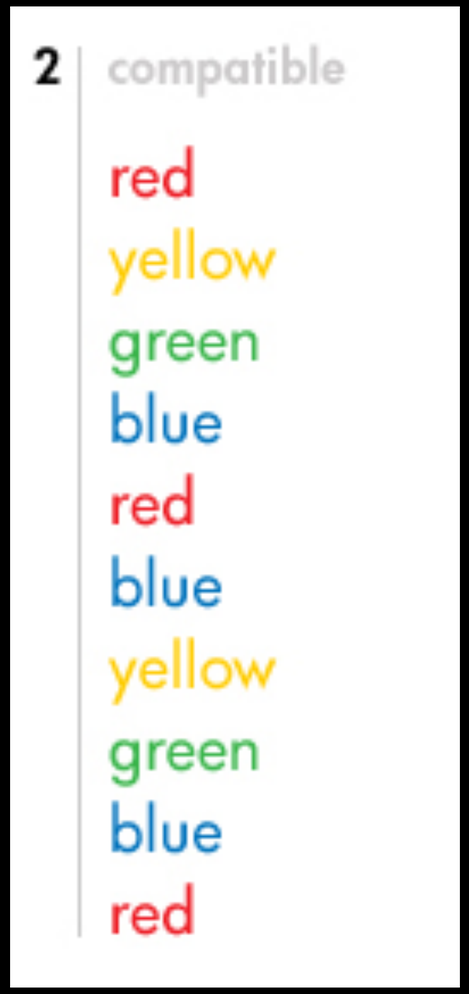


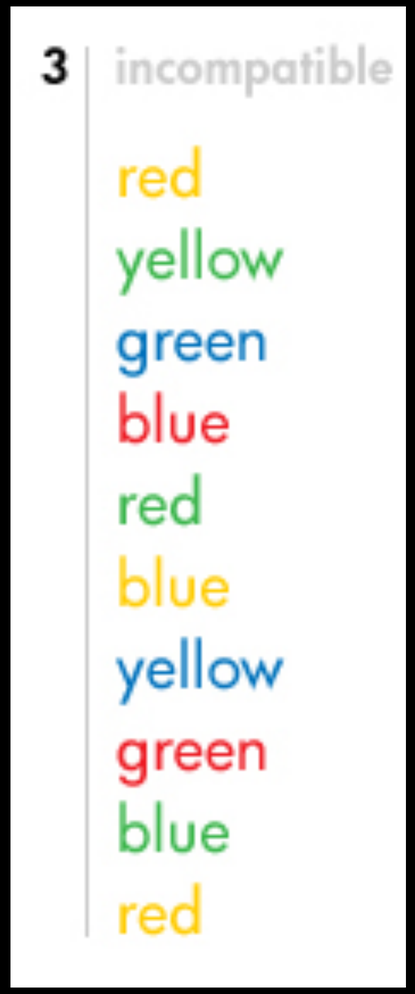
Luís Cruz - l.cruz@tudelft.nl

Cognitive theory is an approach to psychology that attempts to explain human behavior by understanding thought processes.

Stroop Effect

Say the COLOR of each word





Stroop Effect

Say the COLOR of each word in each column

https://inquireables.com/color-words

Stroop Effect

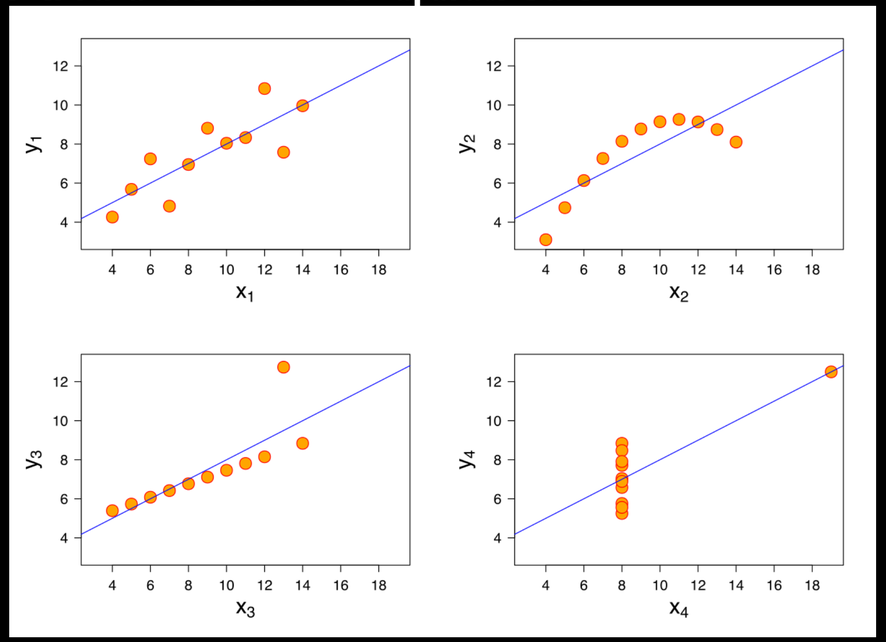
- Discovered by **John Ridley Stroop** in 1935.
- We can say the color of each word for columns 1 and 2 with no problem.
  Our reaction time is much slower with column 3.
- Happens due to **semantic interference**.
- When we look at the words we process the **color** and the **meaning** of its word. We use different parts of the brain.
- If color and meaning are incongruent we have to make a conscious decision on which stimulus we will pay more attention.
- We are used to pay more attention to the meaning of words than their colors. In this test, we are instructed to do the opposite and **interference occurs**.

Miriah Meyer - Information Visualization for Scientific Discover

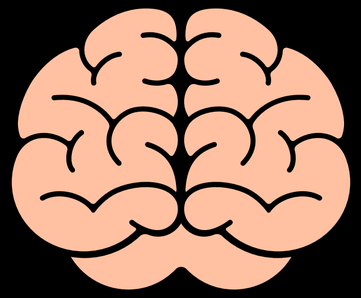
https://surfdrive.surf.nl/files/index.php/s/PGkKKKWXAhaEod9

Miriah Meyer - Information Visualization for Scientific Discover

- Anscombe's quartet



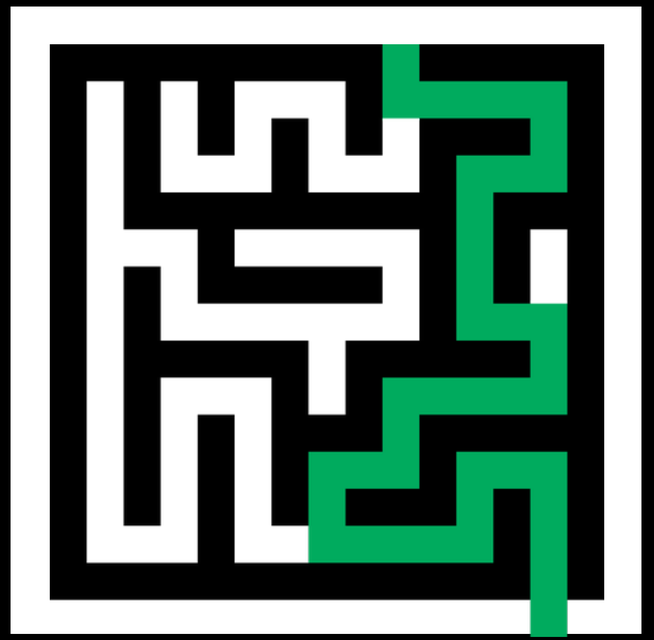
- Color is harder to process than spacial encoding (position). **Important.**



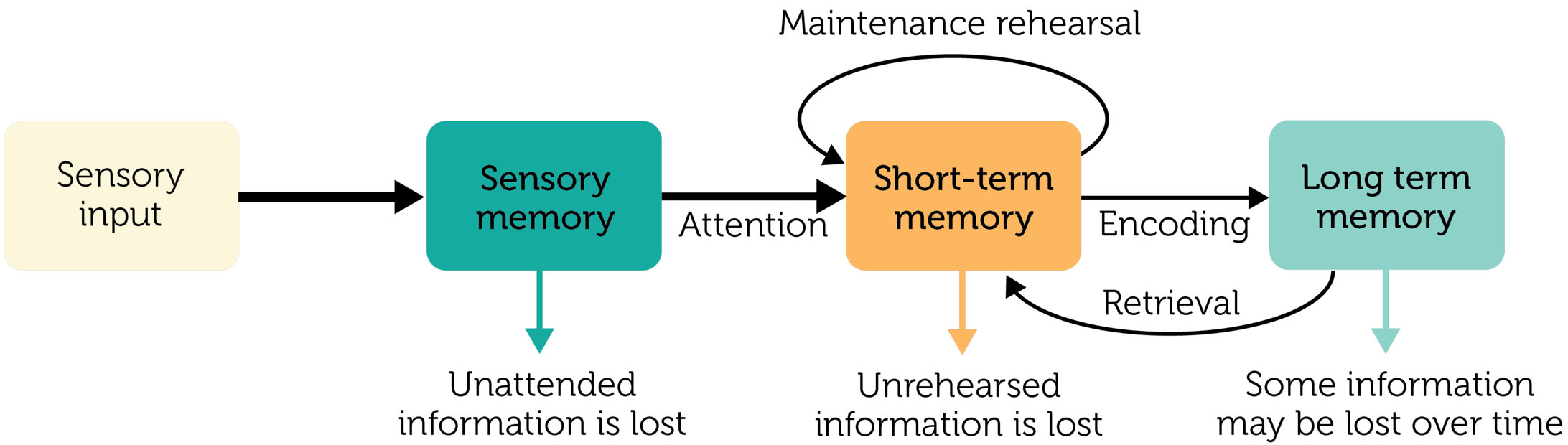
Understanding how our brain works helps us create better Information Visualizations

Outline

- Memory
- Attention
- Cognitive Tunneling
- Procedural Knowledge
- Impact of Cognitive Theories on Information Visualization



Memory
A basic model



Memory

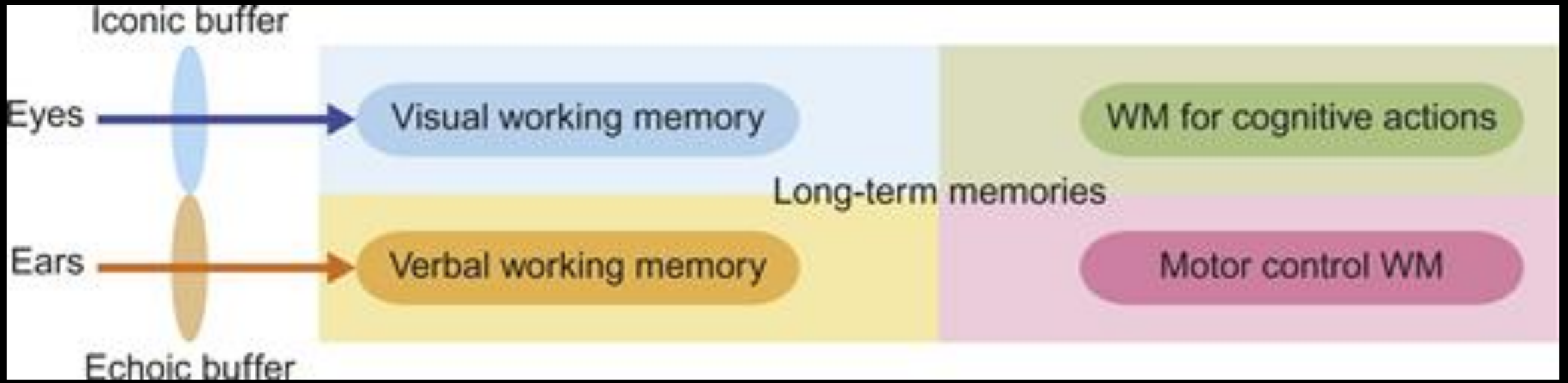
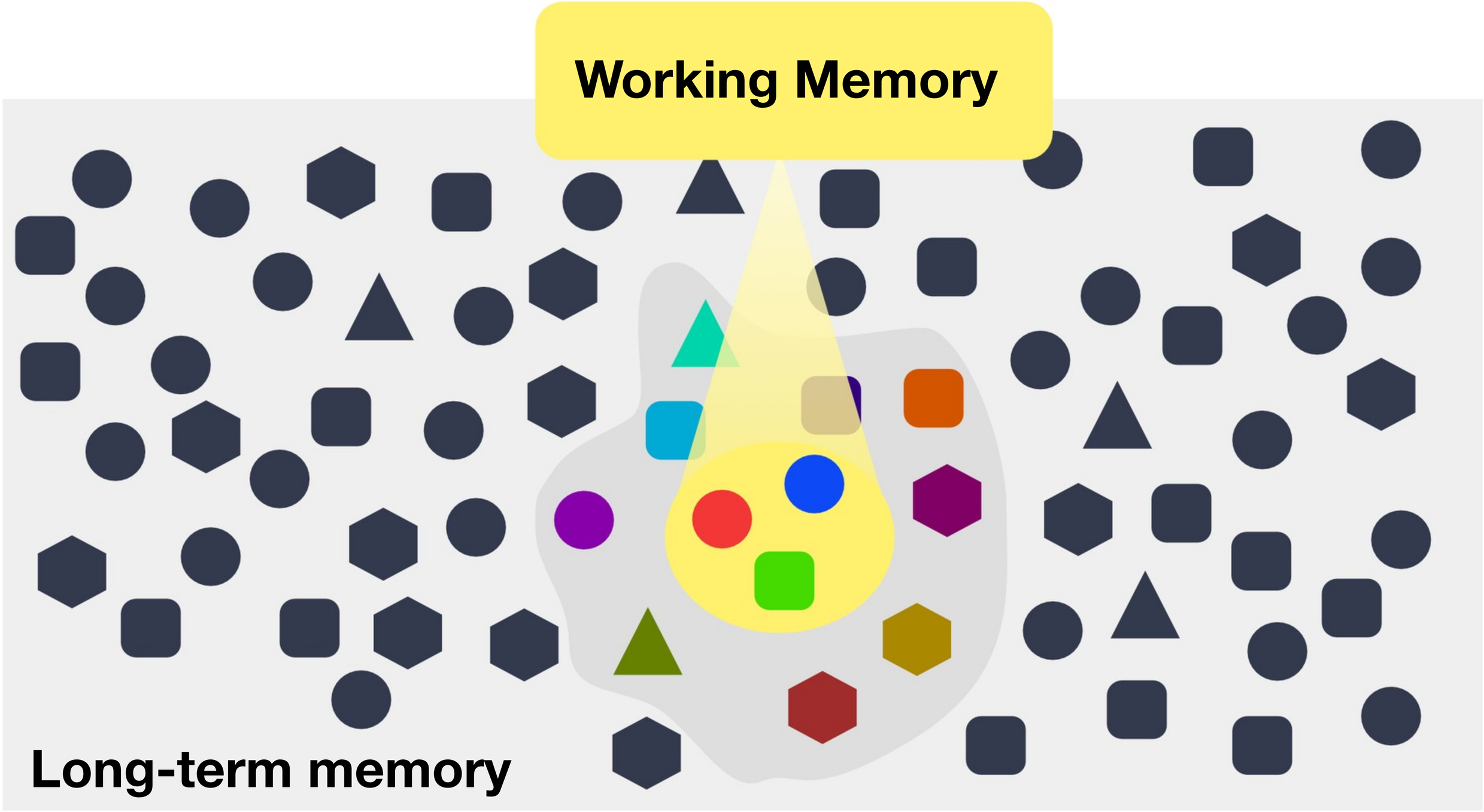


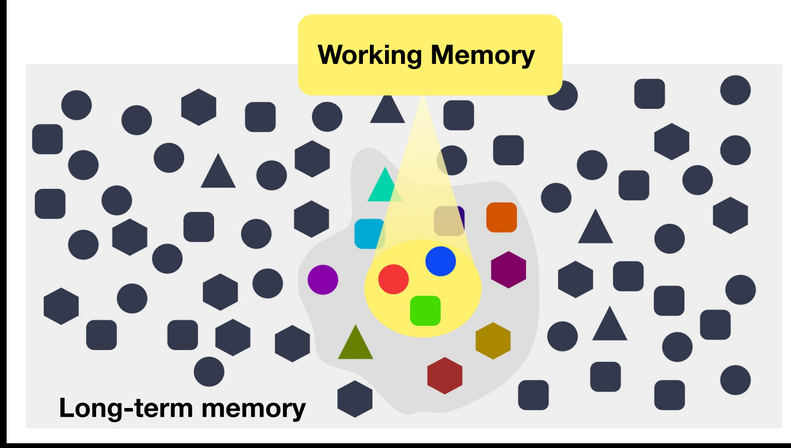
Image from: Ware, Colin. “Information Visualization”

Sensory Memory

- In information visualization we mostly use the **iconic buffer**.
  - Large capacity.
  - Decays very rapidly. Lasts around 300–500ms.


Working Memory
Long-term memory

Working Memory



- Activates particular parts of the long-term memory, based on the received sensory input/ stimulus.
- A combination of external visual information made meaningful through the experiences stored in long-term memory.
- **Short-term** memory. Holds information for a few seconds.
  You can extend it by rehearsing it multiple times.
- Very **small capacity**. Can only store about **7**(±2) basic things at a time.
  This number decreases to **3**, if things differ in position, shape, color, texture, shade, etc.
- **Example:** memorizing a phone number. Over +/- 9 digits, we need to take note.
- Holds and manipulates information. This is the memory we use to process an information visualization.

Working Memory Test

4 numbers

?

5 numbers

?

6 numbers

?

7 numbers

?

8 numbers

?

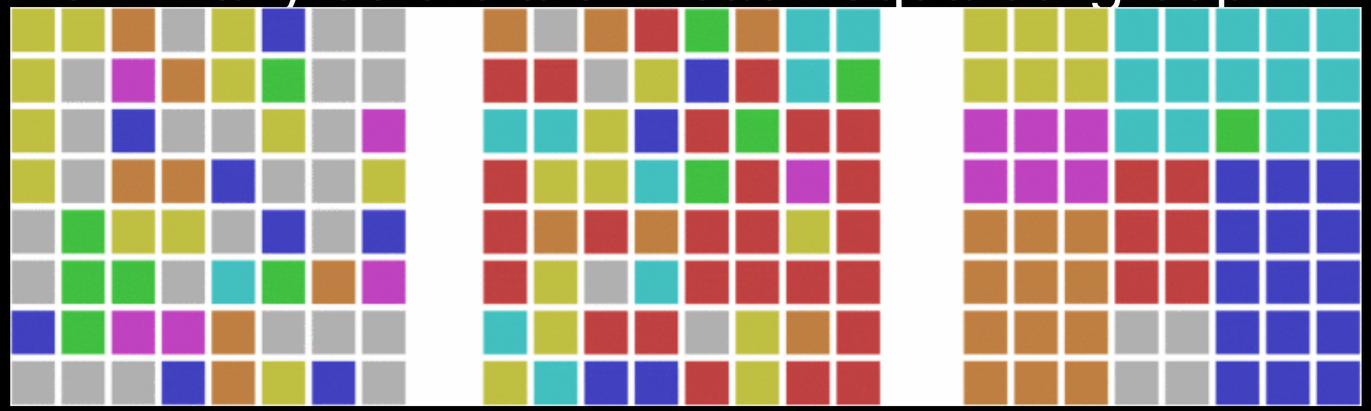
Assignment 14

https://luiscruz.github.io/course_infovis/assignments/assignment14

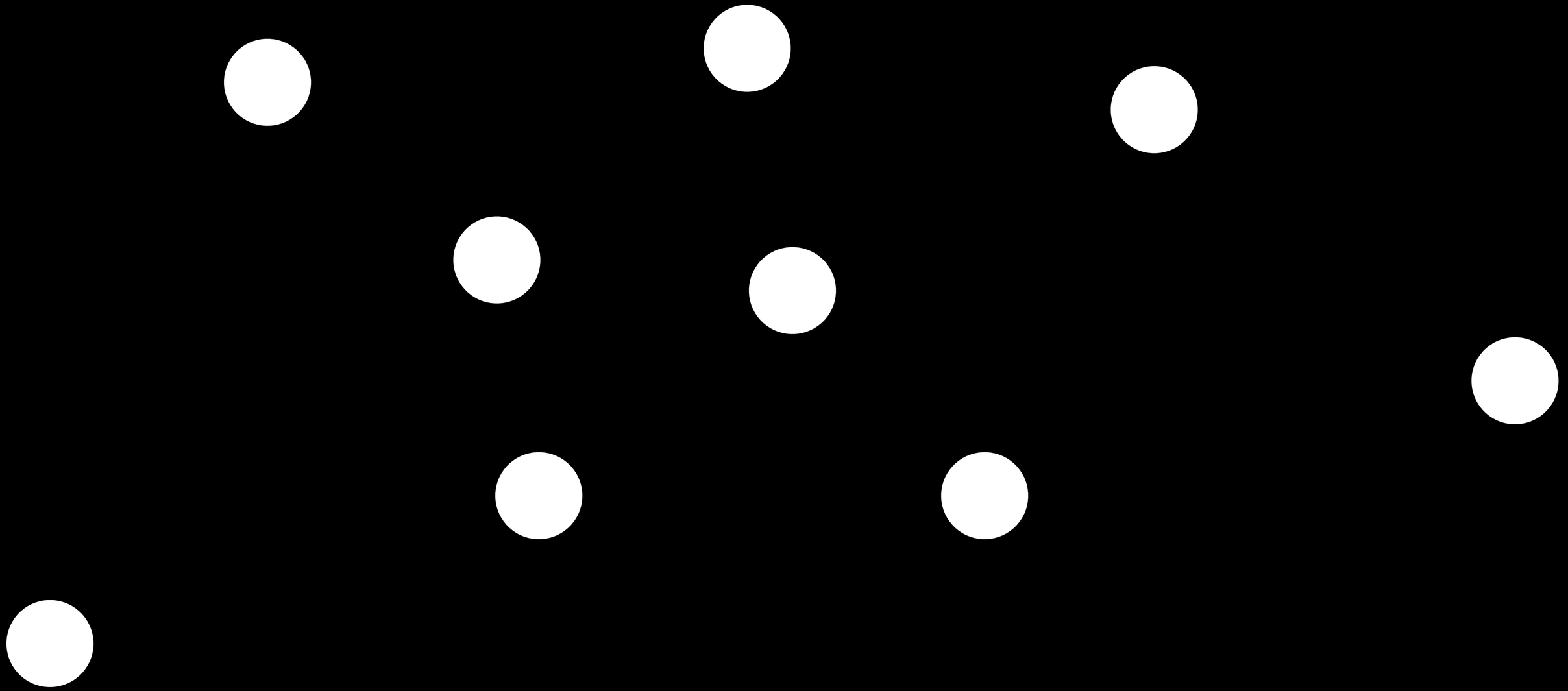
Attention Resources

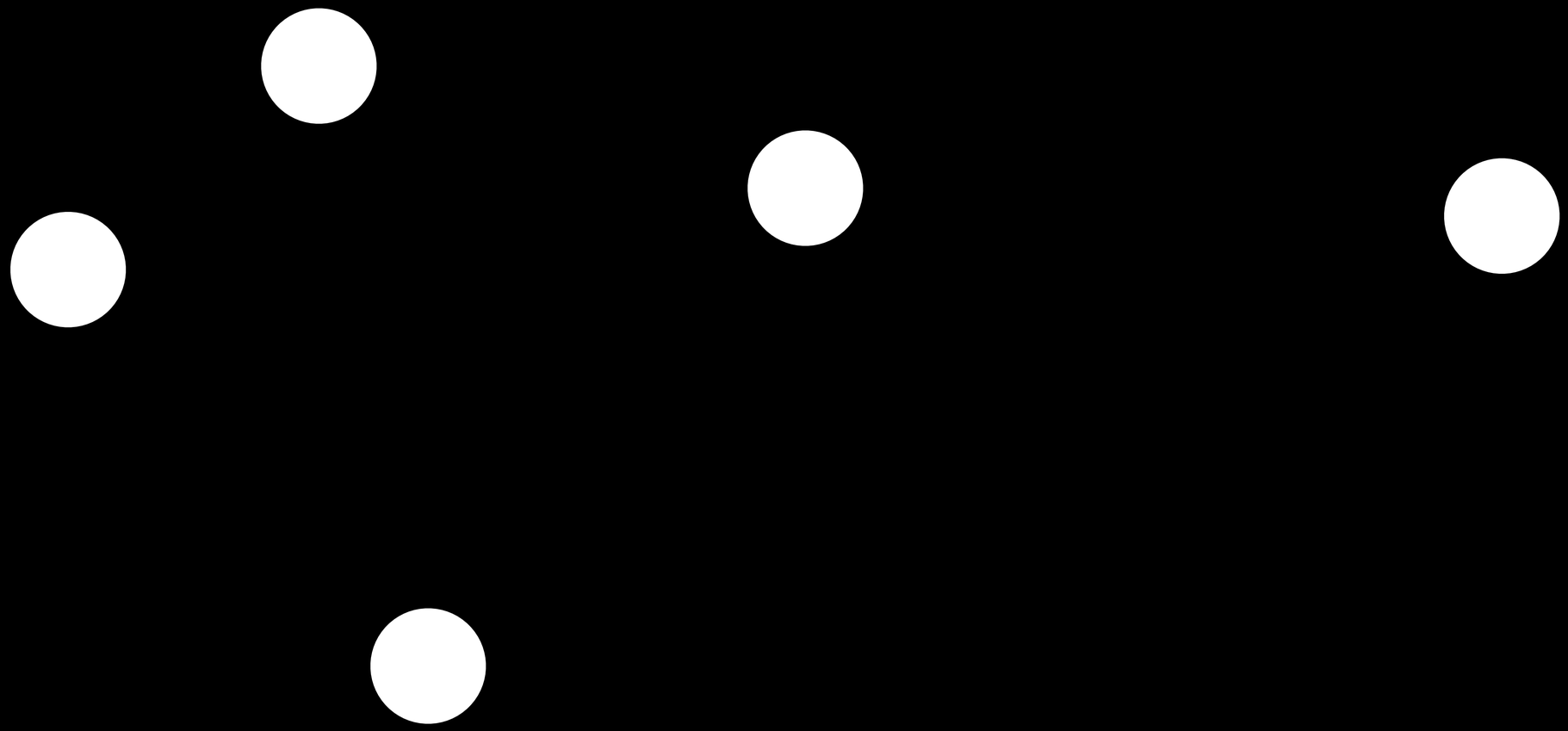
Cognitive ability

- The ability to choose and concentrate on relevant stimuli
- Our attention is limited. Our brain can only process ≈1% of the visual input data.
- In a visualization, information is competing for our attention.
- How many colors are in each squared-group?



Example





What was the difference?

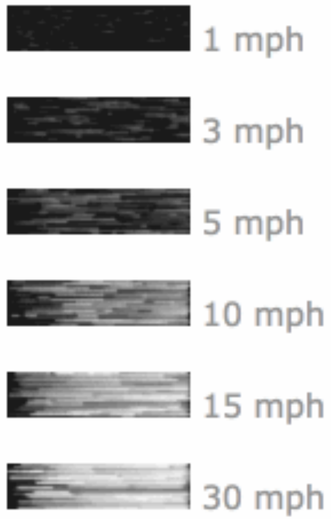
Cognitive Tunneling

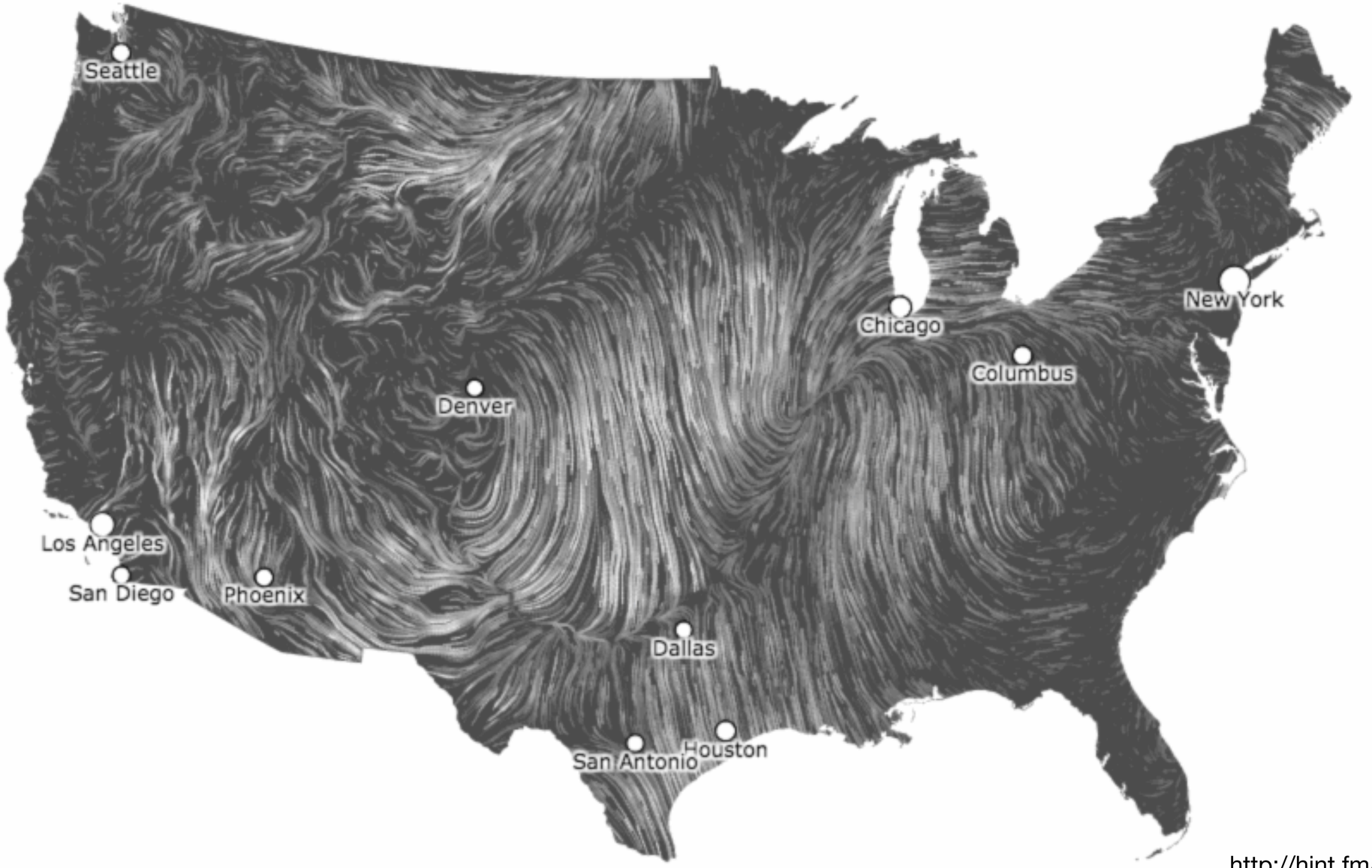
- Mental state in which your **brain focuses on a particular thing** and does not see the rest of the environment, or other relevant data.
- Information visualizations should avoid **unwanted cognitive tunneling**.

wind map

Dec. 21, 2017
10:36 pm EST
(time of forecast download)

top speed: **24.0 mph**
average: **7.3 mph**





http://hint.fm/wind/

Were you able to analyze a particular city in the graph?

How was the wind in the city you analyzed?

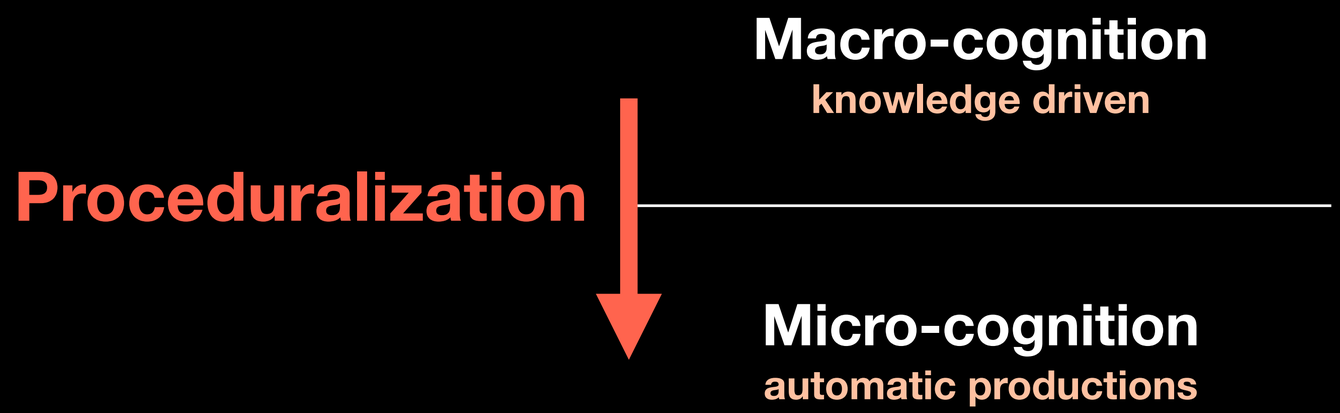
Cognitive Tunneling

Example

- The animation provides a nice overview of the wind speed and direction across the U.S.
- The animation creates a nice effect.
- But it also makes it difficult to direct readers to the relevant content.
- There is unwanted cognitive tunneling to the animation.

Proceduralization

- Process where **knowledge-directed productions** (macro-cognition) are instantiated into **automatic productions** (micro-cognition).
- It is what happens when we **learn a skill**.



Proceduralization

This is what happens when we learn a skill.

- 1. “cognitive” stage involves an initial encoding.
- Requires high-load of **working memory**.
- Frequent errors.

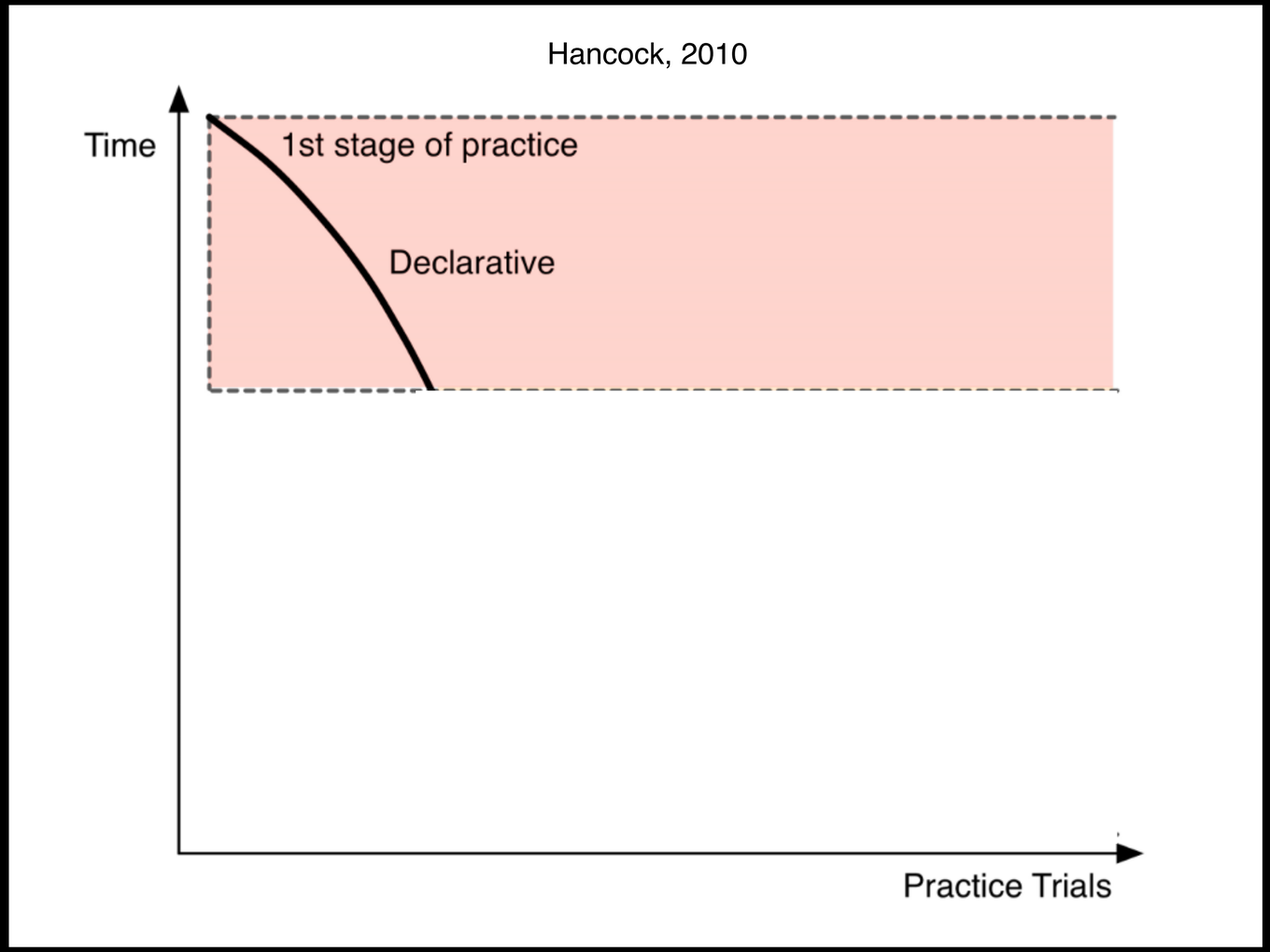


Image by Hancock (2010); based on Fitts (1964) and Anderson (1982)

Proceduralization

This is what happens when we learn a skill.

- 2. “associative” stage is characterized by task performance being “smoothed out.”
- Errors in task or skill performance are detected and reduced.

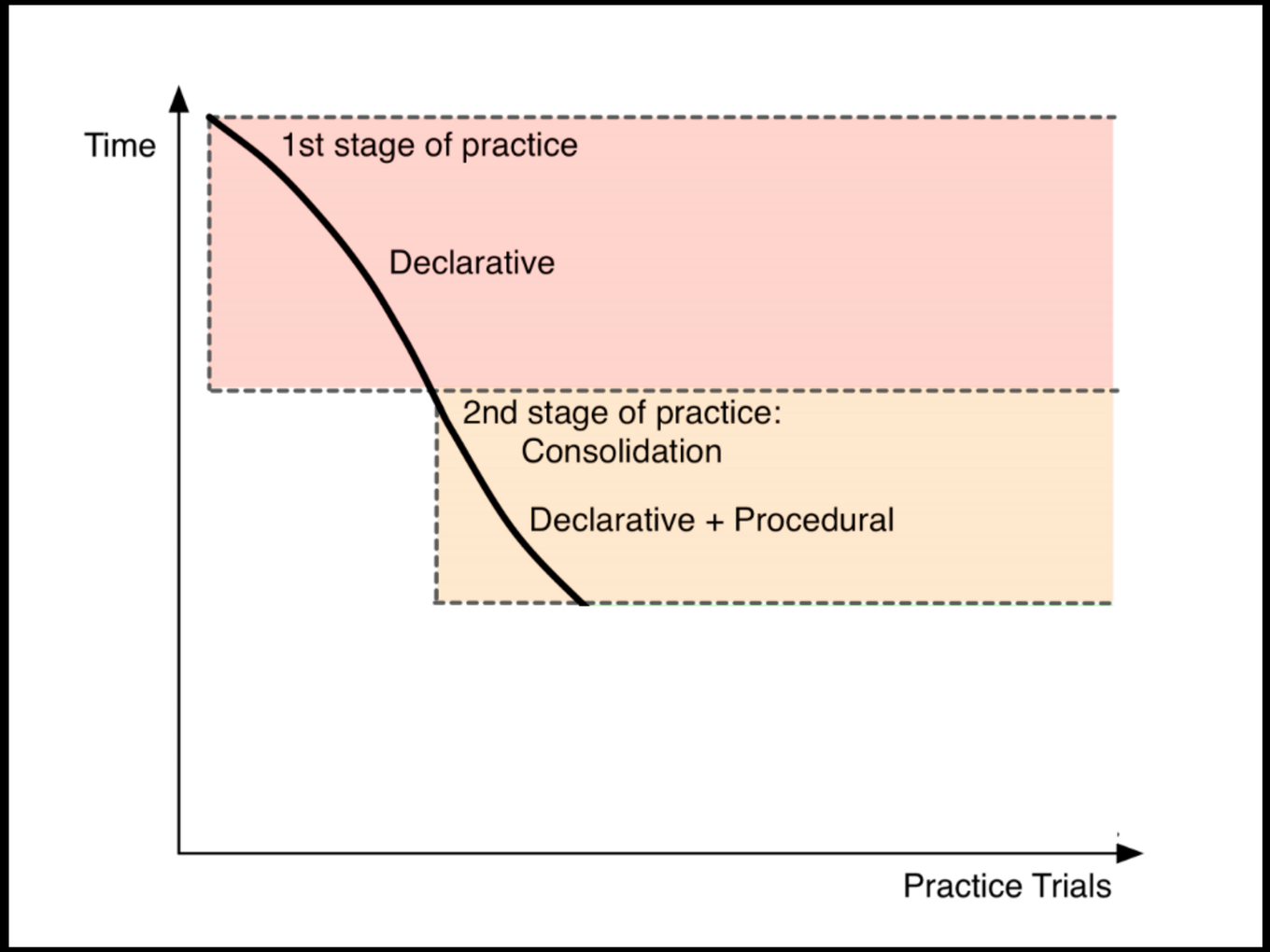


Image by Hancock (2010); based on Fitts (1964) and Anderson (1982)

Proceduralization

This is what happens when we learn a skill.

- The third “autonomous” stage sees greater improvement in the tuning of skilled performance
- Procedural knowledge is a collection of if-then statements
- Performance becomes faster and less prone to error.
  - Embeds factual knowledge into these procedures, eliminating the need for **working memory**.

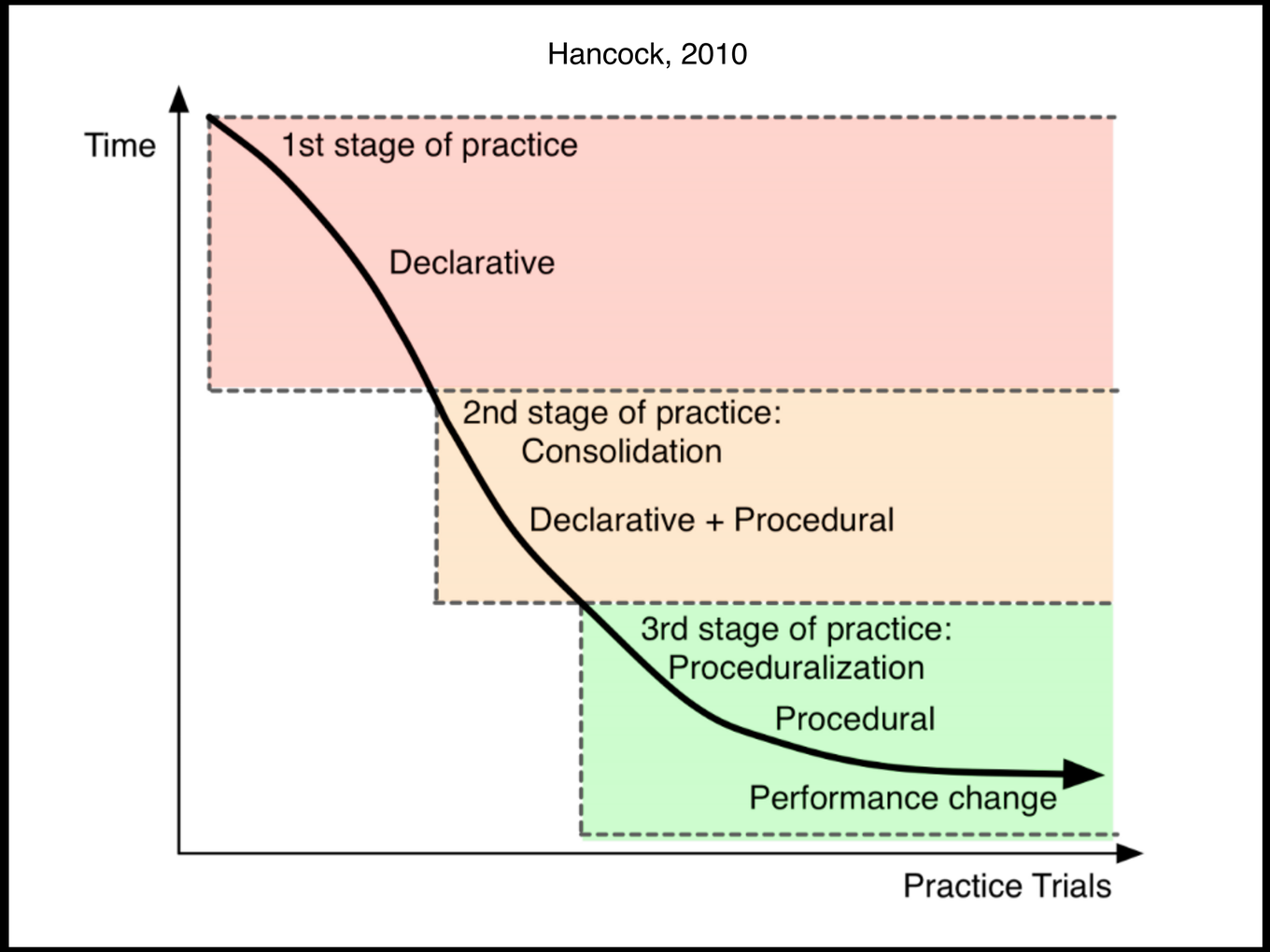


Image by Hancock (2010); based on Fitts (1964) and Anderson (1982)

Learning to drive a car

Example of procedural knowledge

- **Declarative.** Driving lessons begin with an instructor providing declarative knowledge regarding the keys, shift stick, gas pedal, etc. Initially, the novice driver's movement are slow, clunky, and prone to error.
- **Consolidation: Declarative + Procedural.** Over time the knowledge becomes matched and replaced by practiced productions.
- **Procedural.** Eventually, the expert might even have difficulty describing this process to the novice driver, as declarative knowledge has become obsolete.

Procedural knowledge in Information Visualization

A few example

- We can rapidly recognize **green as “good”** ✅ and red as **“wrong”** ⛔.
- Or **red as hot** 🔥 and **blue as cold** 🧊.
- We want to get the most out of the meta-learning

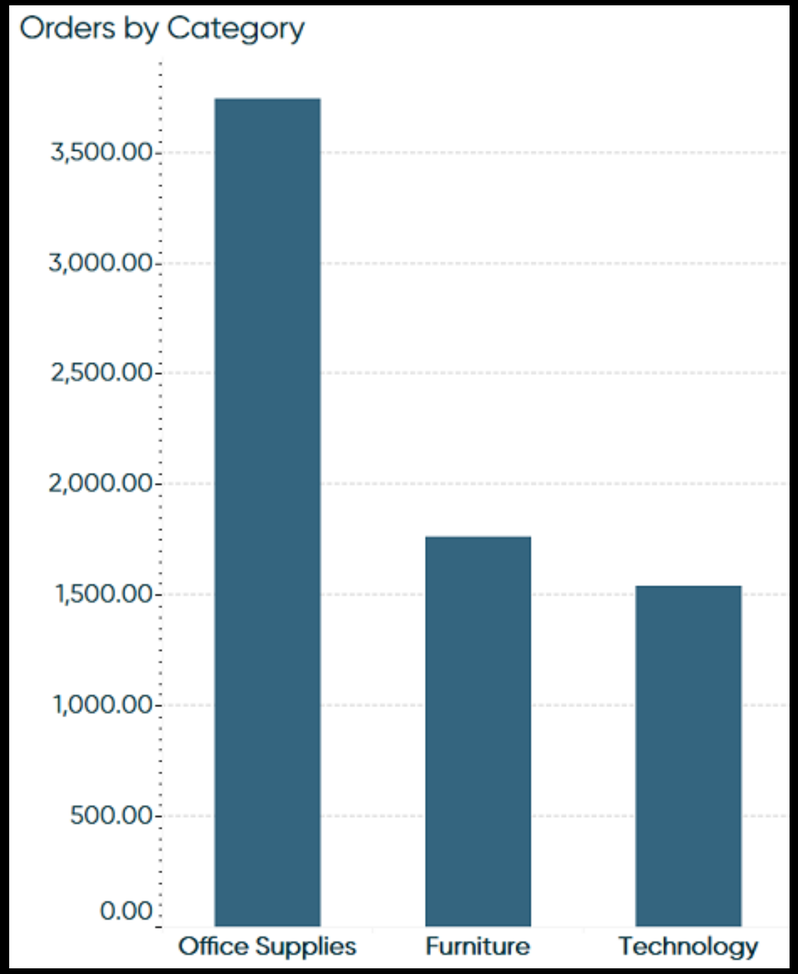
When creating information visualizations we…

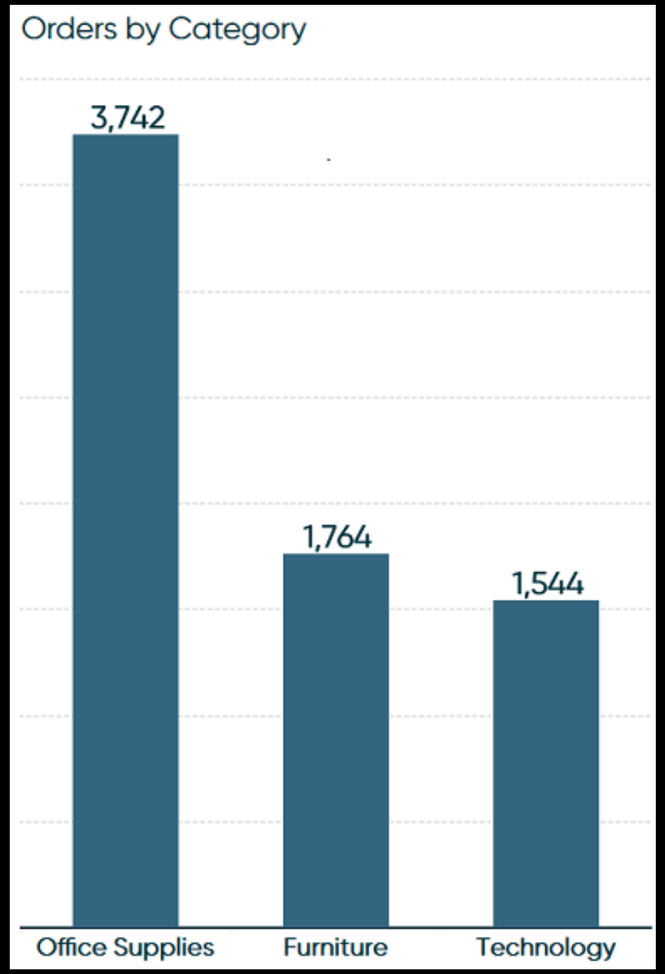
- should avoid **information overload**.
- need to provide a **minimum amount of information** to make sense of the issue.
- should consider the limitations of the **working memory capacity.**
- should use **procedural knowledge** as much as possible.

How does **cognitive theory** support the guidelines for **effective visualizations**?

Label elements directly, avoiding indirect look-up.

E.g., use a legend only when space is tight.

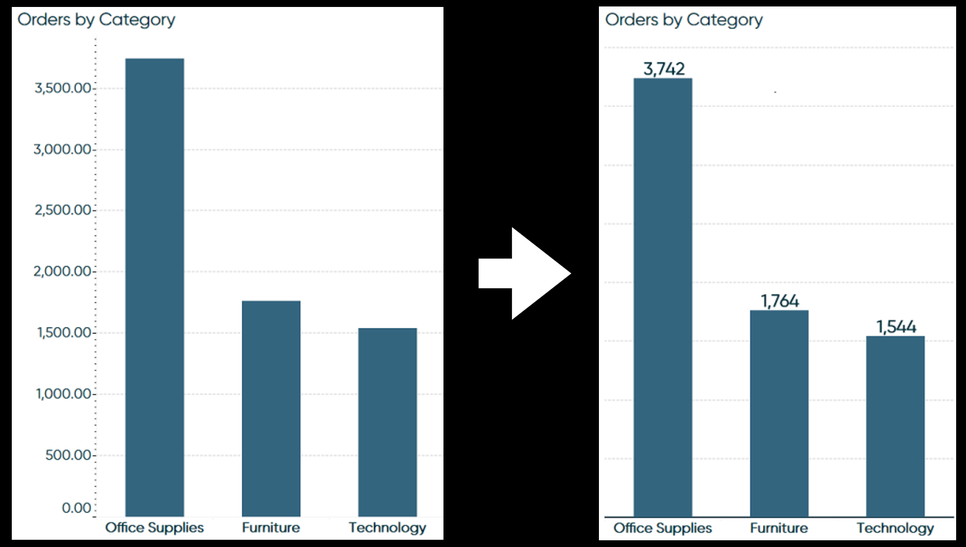




Label elements directly, avoiding indirect look-up.

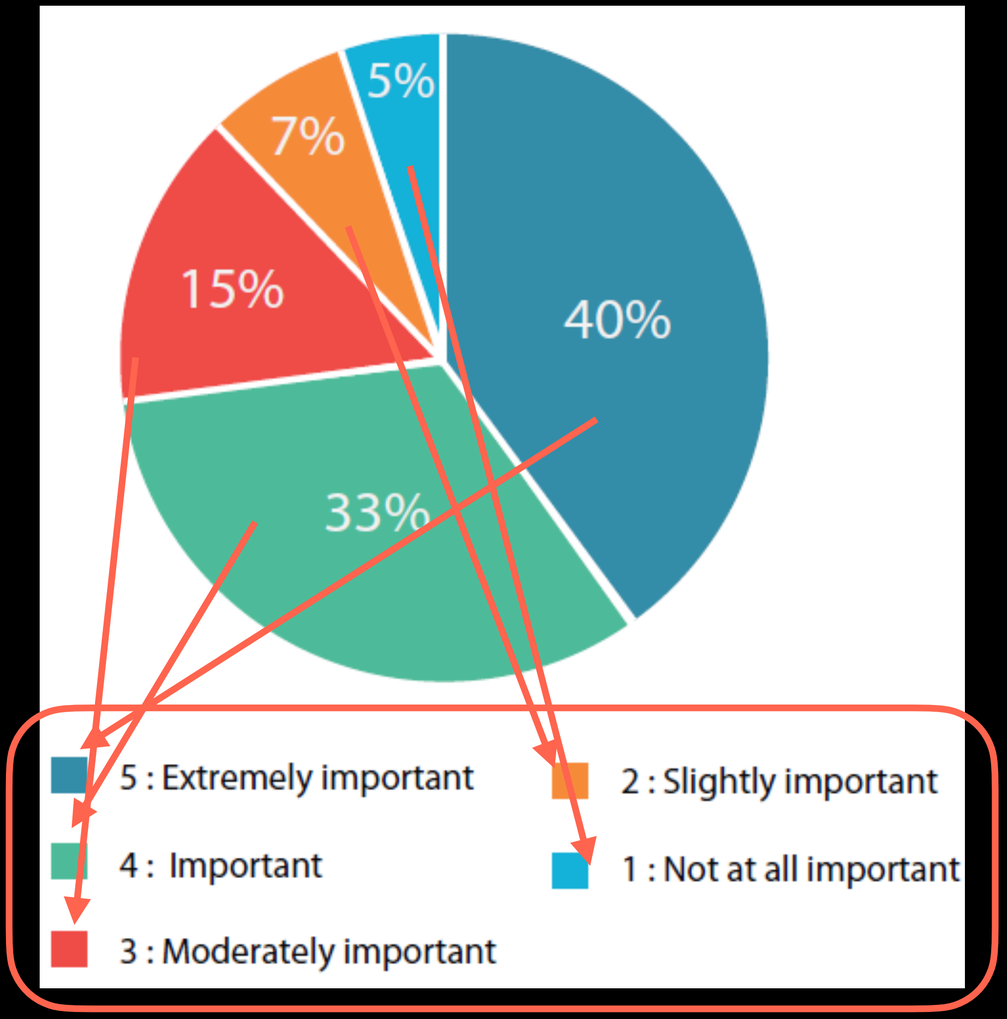
E.g., use a legend only when space is tight.

- **Cognitive tunnelling** may naturally happen when looking at a visual element in the graph.
  - If that happens, the user will not lose relevant information as long as the labels are close.
- If the user goes back and forth to the legend, it will have to process other elements in the graph which may **overload the working memory**.

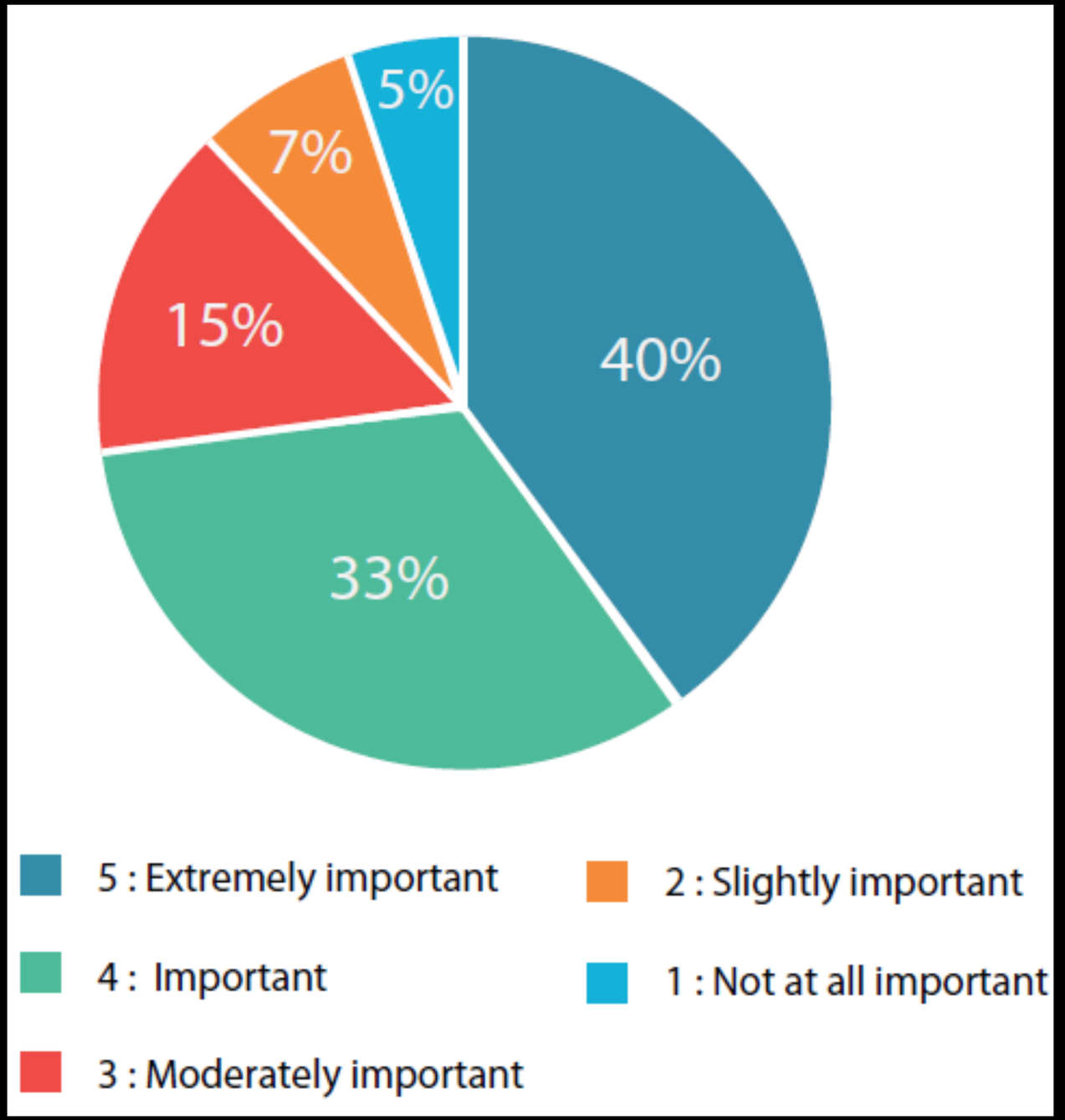


Avoid legends. Use labels instead.
(Whenever possible)

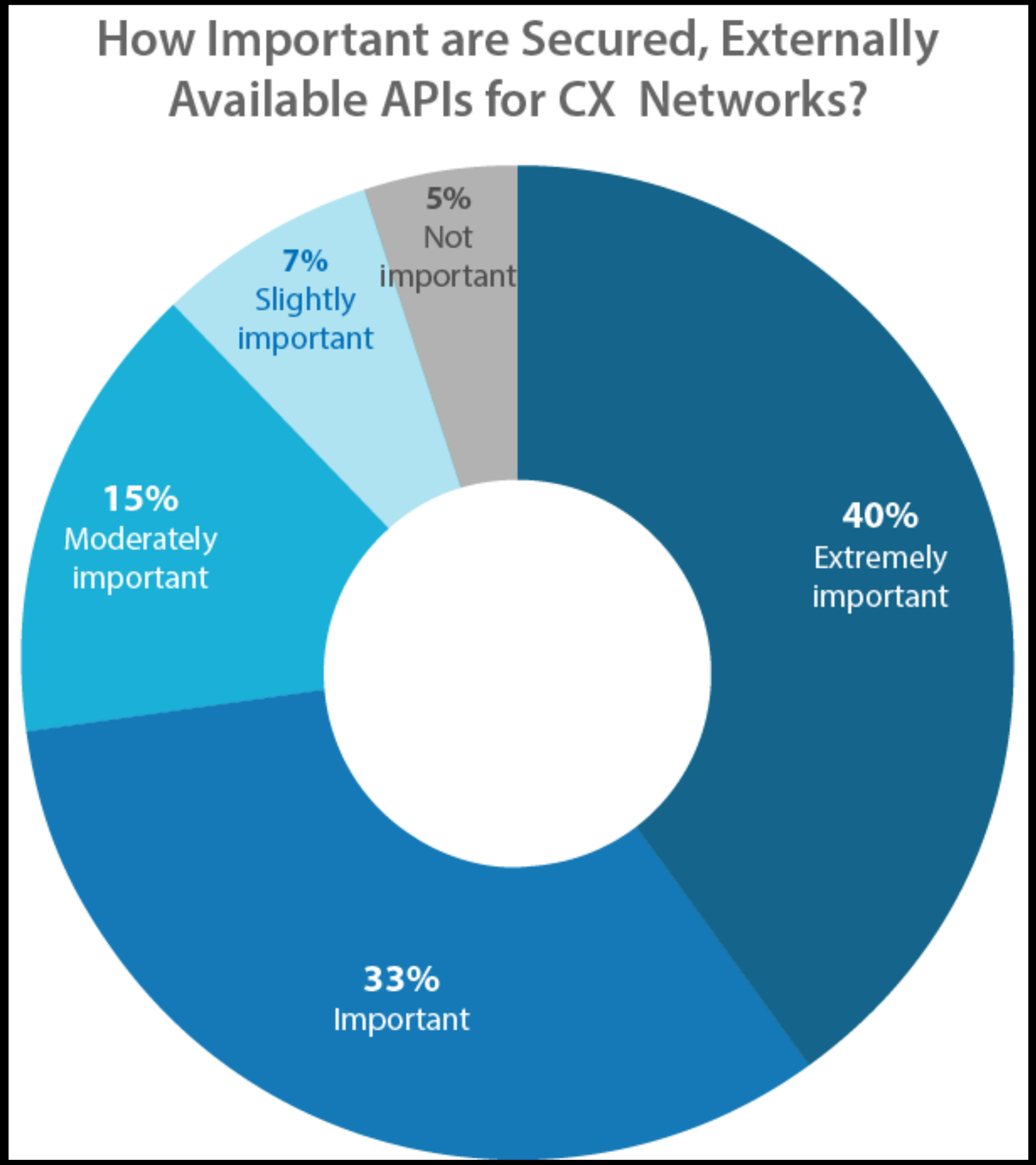
- Legends require the reader to go back and forward.
- They will not easily focus on the picture as a whole.
- If the reader enters a stage of cognitive tunnelling, he/she will not be able to process the graph.
- The reader will have to load the working memory with the legend.



This?

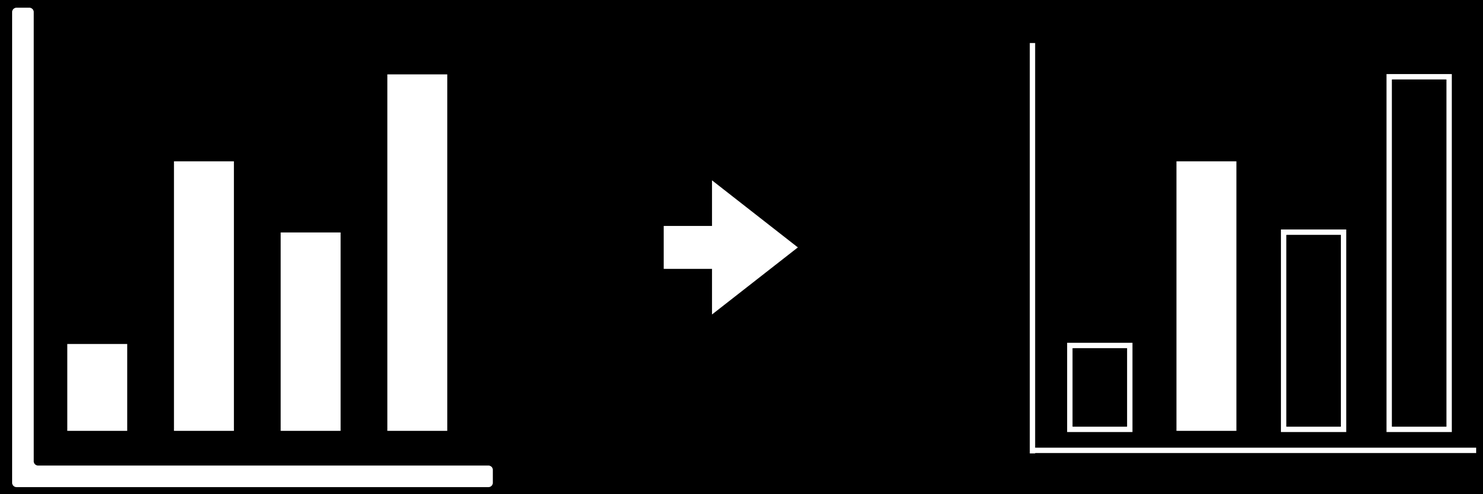

5%
7%
15%
40%
33%
5 : Extremely important
4 : Important
3 : Moderately important
2 : Slightly important
1 : Not at all important

Or This?


How Important are Secured, Externally Available APIs for CX Networks?
5% Not important
7% Slightly important
15% Moderately important
40% Extremely important
33% Important

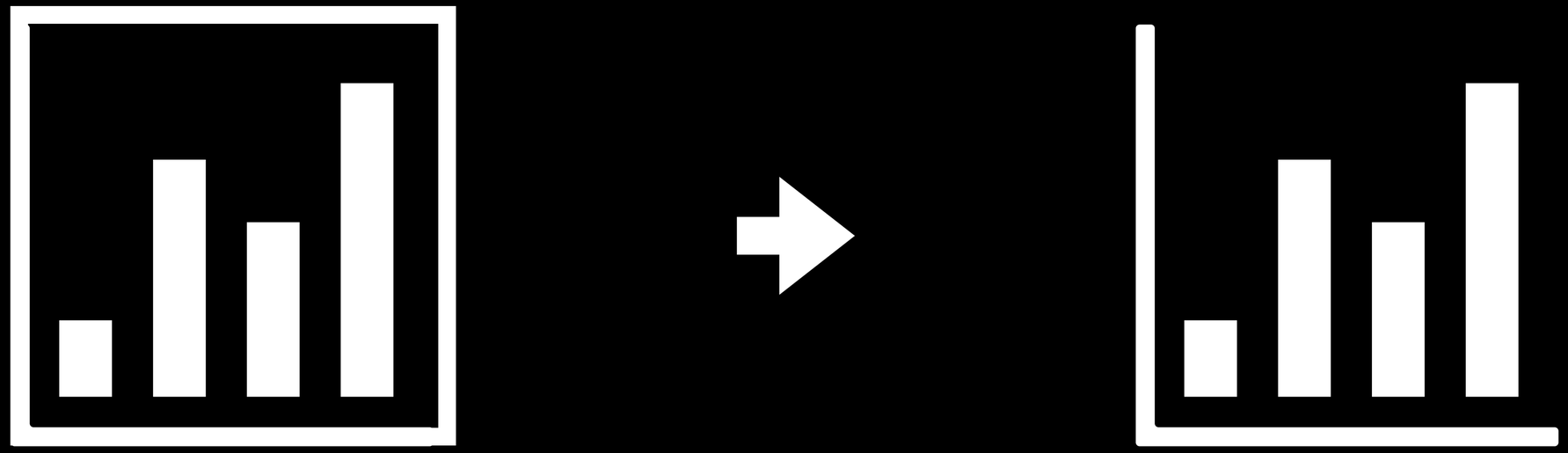
Use bold type/lines only to emphasize something.

- Our **procedural knowledge** immediately recognises bold objects as important.
- If those objects are meaningless, our brain will have conflicting stimulus.



Turn off the box around the figure

- Our brain can only process 1% of the visual data. Reduce the number of elements it has to process in the figure
-

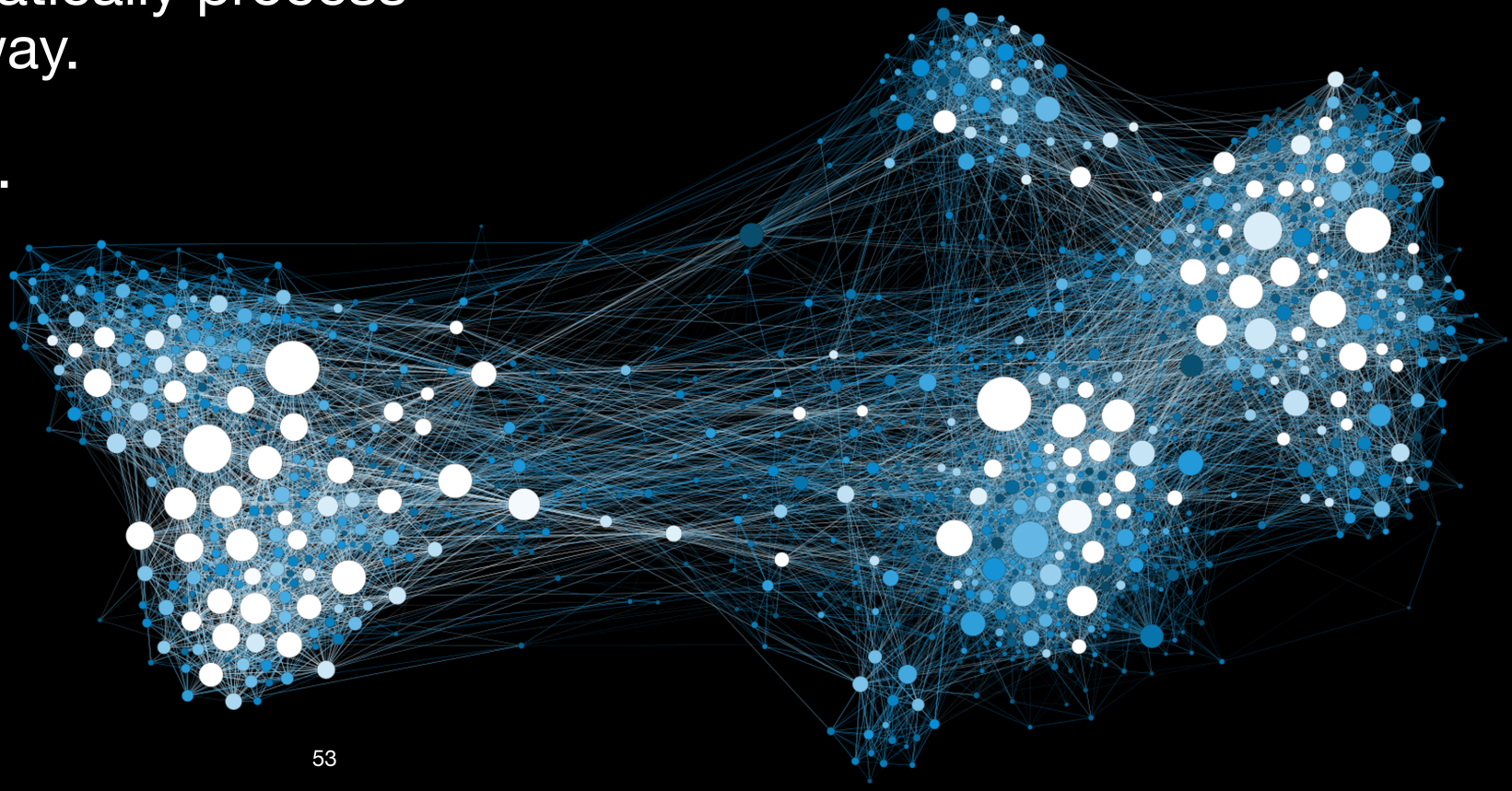


Size

- If a visual element is twice the size of another, the **same variation should be found in the data**.
- We process the size visual variable using our **procedural knowledge**.
- If it does not reflect the data, we will be creating **cognitive interference**.
  - The graphic will be harder to process, or will actually be misleading.

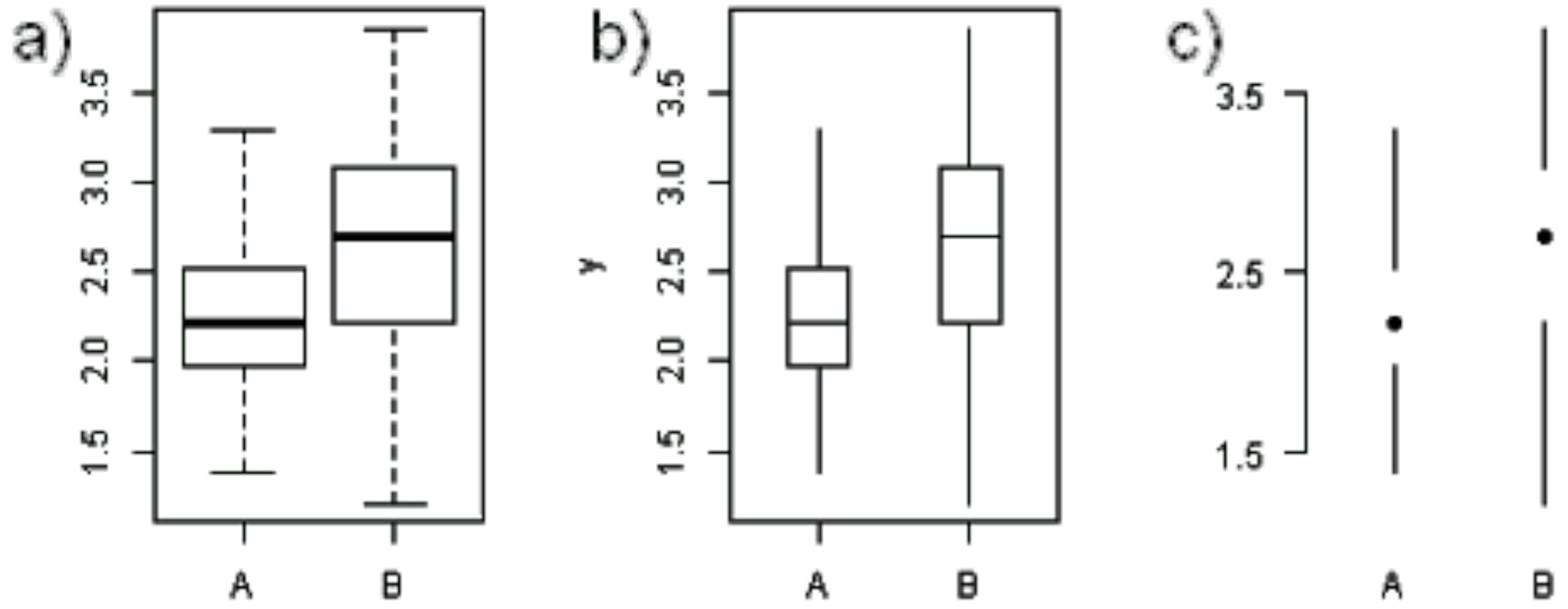
Position / Proximity

- If a group of elements are closer to each other our brain will automatically process them as similar in some way.
- Example: network graphs.



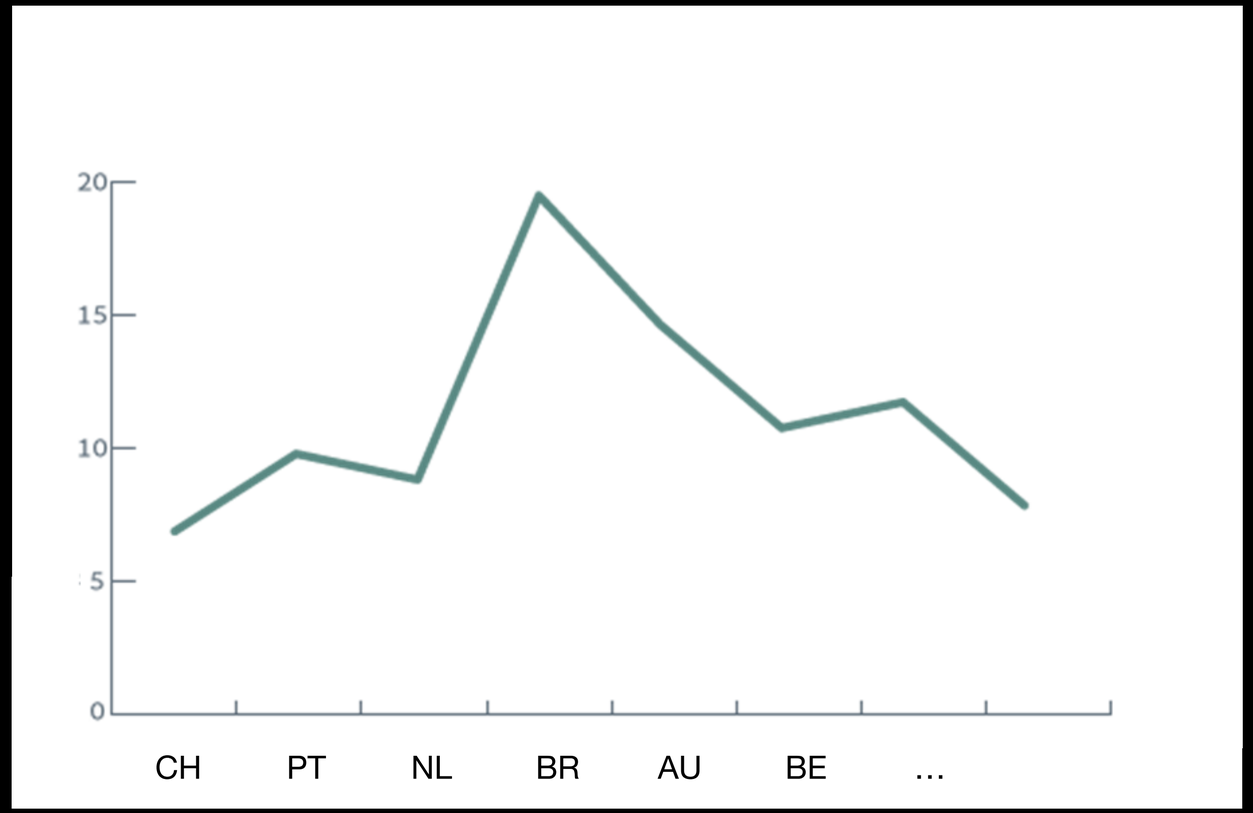
Use standards when available

- If we **use standards**, people can read your visualizations using their procedural knowledge acquired when reading other visualizations.



Choose the Right Type of Graph

- Wrong types of graphs will trigger procedural knowledge from our brain that will only interfere with the reader's efforts to read the graph.



Reading Material

- Brendan Conway-Smith. Metacognitive Proceduralization. http://cognitivemodelinglab.com/index.php/proceduralization/
- Jiajing Guo (2017). How Is Data Visualization Influenced By Our Cognitive Processes? https://medium.com/@jiajingguo/how-is-data-visualization-influenced-by-our-cognitive-processes-281d8486abfe
- Colin Ware (2013). Information Visualization – Perception for Design.

Midterm exam

Midterm Exam

- Duration: 1h30. No breaks.
- Closed book.
- Online, mobile app. (More steps in the next slide).
- 14 questions. Short-answer, multiple-choice.
- Two versions.
- No questions about matplotlib.
- Chapters were kept up-to-date throughout the classes.
  Download the slides again.
- Some students did not understand exactly how to avoid **spurious correlations**.
- There are **5 principles** of graphical excellence. Some students thought there were only 3.

Exam Guidelines - 1/4

- All the students are only allowed to answer the questions by **the mobile app of Xuexitong (学习通移动端App)**.
- You **cannot switch out the app** during the exam.
  We will invigilate by the app to check if students switch out of the app or not.
  If they do, **students may get exam failure** or a very low score, and we have the right to directly gather their papers in advance.

Exam Guidelines - 2/4

- **Students must join the exam in the scheduled classroom**.
- If some students are absent in the classroom without irresistible reasons but submit the answers, they may **get exam failure** or a very low score.

Exam Guidelines - 3/4

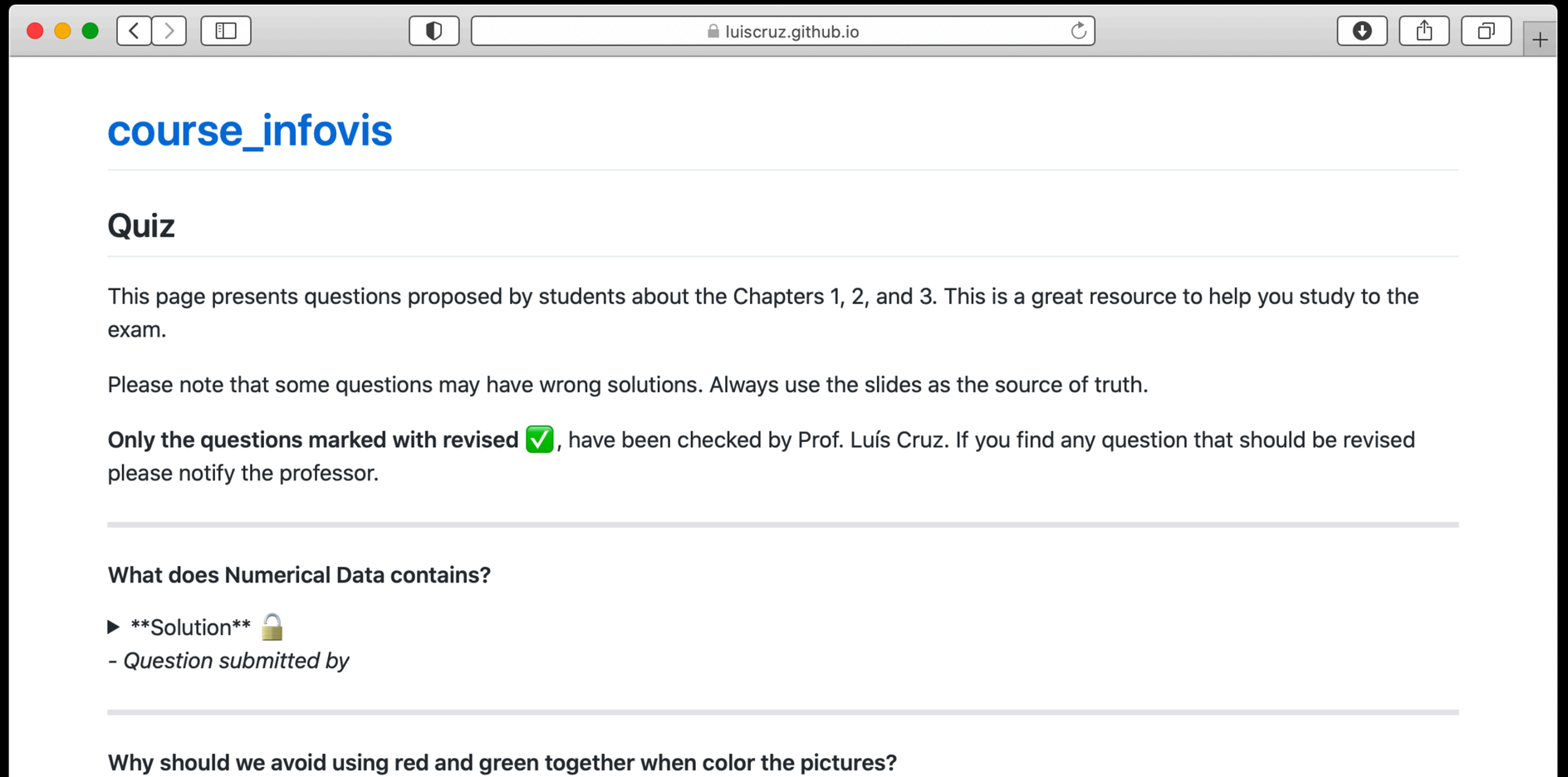
- Students must show up **on time** for the exam.
- 8:30–10:00 for Class No. 2 and 4
- 10:30–12:00 for Class No. 1 and 3.

Exam Guidelines - 4/4

- Students must install the mobile app of Xuexitong (学习通移动端App) and **test whether their accounts work well or not in advance**.

Quiz

https://luiscruz.github.io/course_infovis/quiz

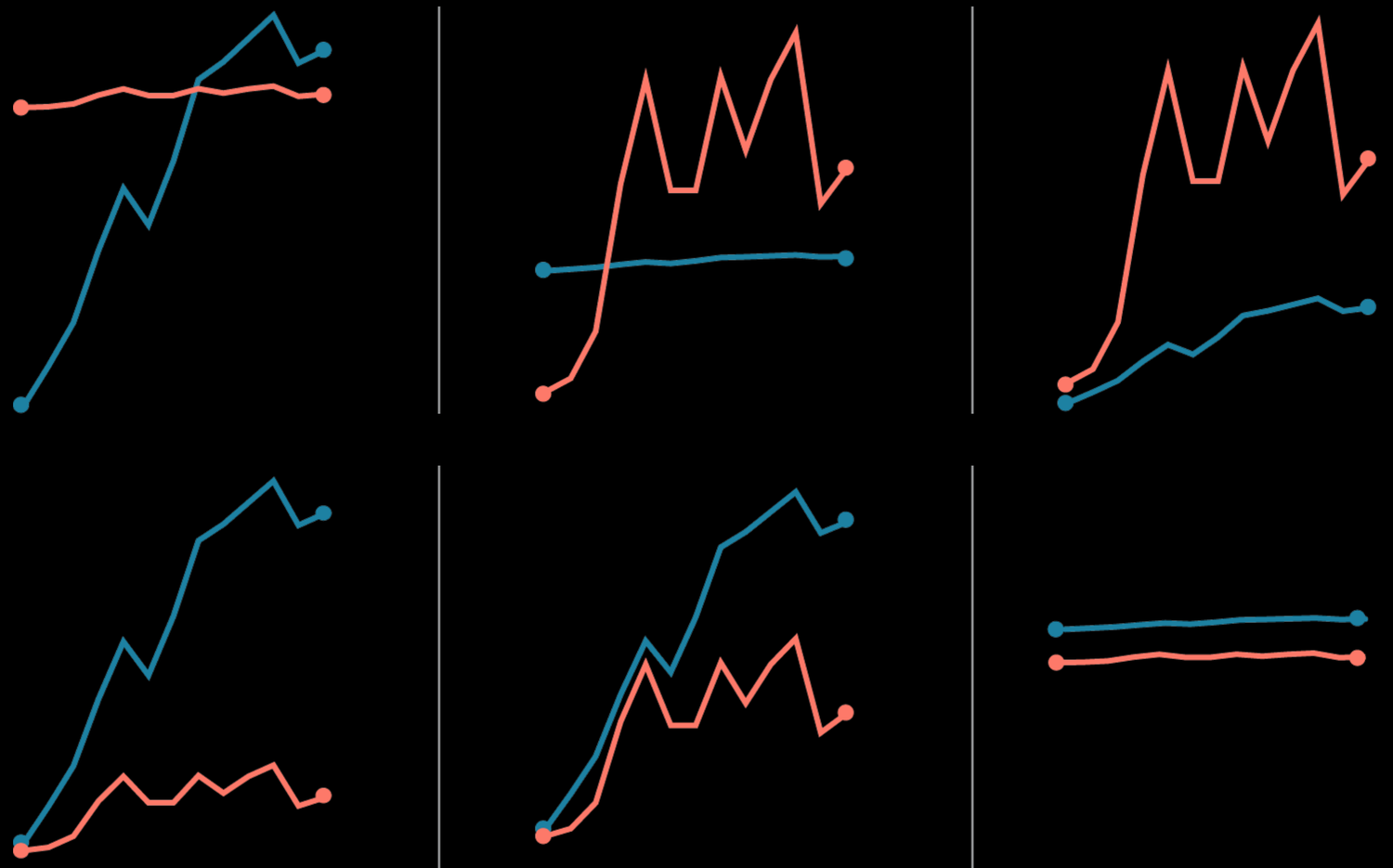


Some students did not understand exactly how to avoid **spurious correlations**.

Spurious correlation: How to avoid?

Chapter 2, Slide 71

- To avoid spurious correlation, **we should NOT**:
  - Plot unrelated things together;
  - Using two y-axes in any graph;
  - Cut numerical axes in any graph;
  - Use Pareto chart (https://datavizproject.com/data-type/pareto-chart/)



https://blog.datawrapper.de/dualaxis/

There are
5 principles of graphical excellence.
Some students thought there were only 3.

Visualization Principles

(that work for most visualizations) Chapter 3 - Slide 11

1. **Above all else, show the data**. Create the simplest graph that conveys the information you want to present.

2. **Maximize** the **data-ink ratio**. Every bit of ink requires a reason. Nearly always, that reason should be to present new information

3. **Erase non-data-ink**.

4. **Erase redundant** data-ink.

5. **Revise** and **edit**.

Assignment 16

https://luiscruz.github.io/course_infovis/assignments/assignment16