

# The Science of Human graphical

Lecture5



# The **communication** process





X	Y	Z
0	2	3
-4	5	6
10	4.1	8.5

Data



Message

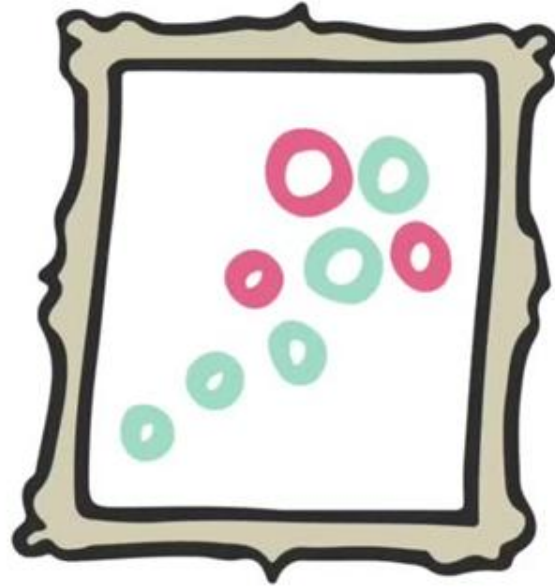


X	Y	Z
0	2	3
-4	5	6
10	4.1	8.5

Data



Message



Visualization

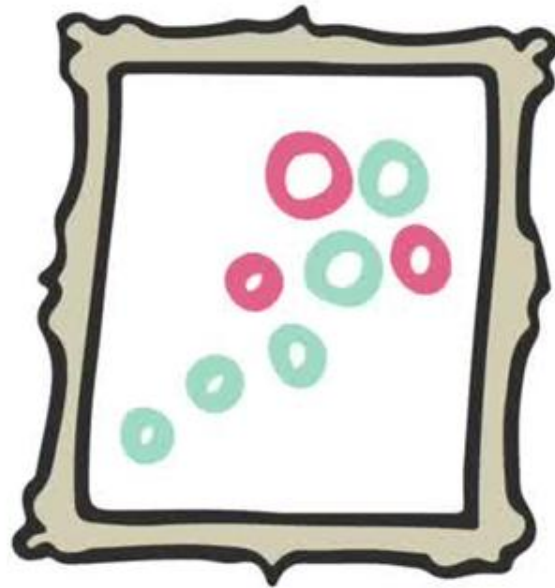


X	Y	Z
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10	4.1	8.5

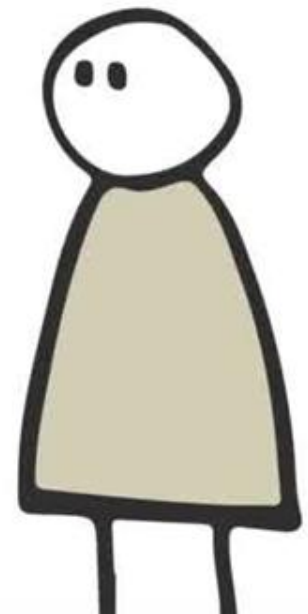
Data

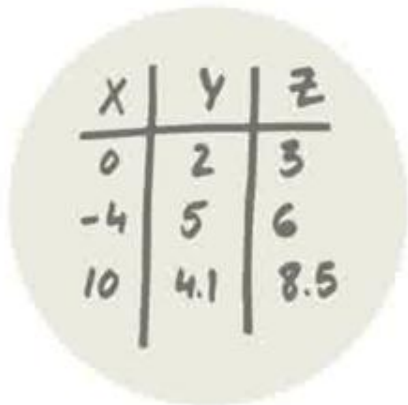


Message



Visualization



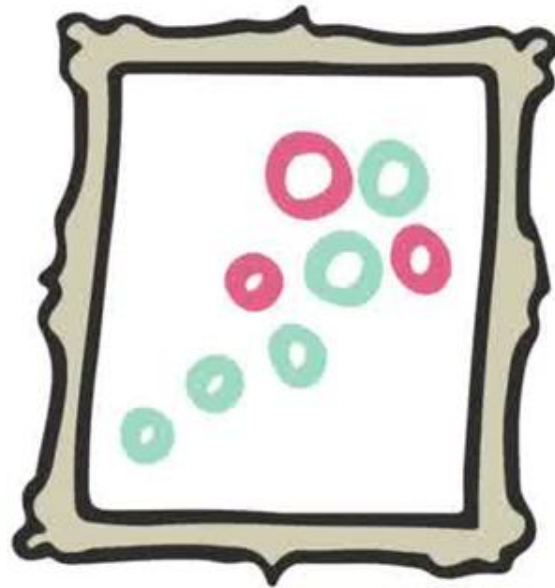


X	Y	Z
0	2	3
-4	5	6
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Data



Message



Visualization

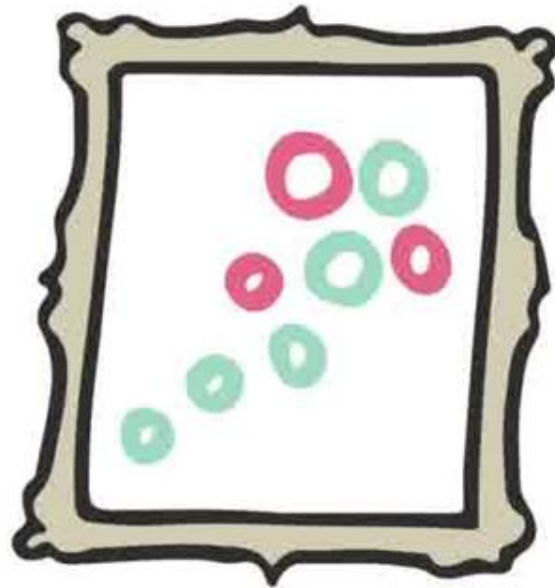


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Message



Visualization



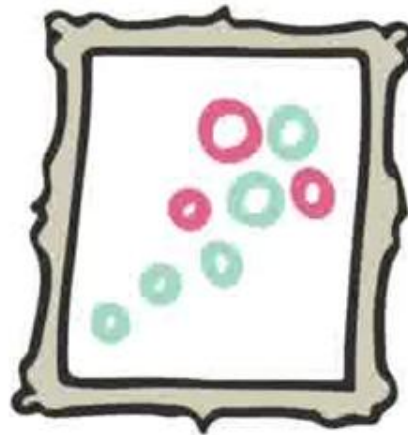
A circular icon with a scalloped edge containing a table with three columns and four rows.

X	Y	Z
0	2	3
-4	5	6
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Data



Message



Visualization



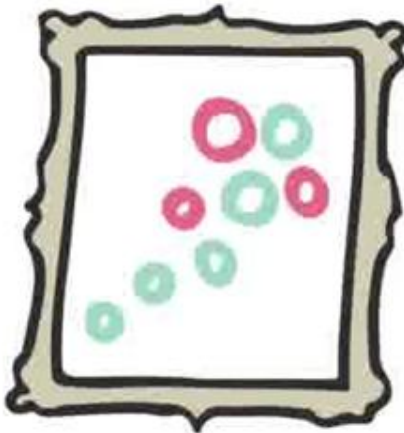
User / audience / reader

X	Y	Z
0	2	3
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Data



Message



Visualization



User / audience / reader

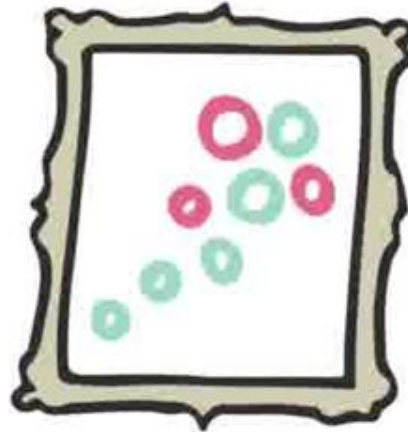


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Data



Message



Visualization



User / audience / reader

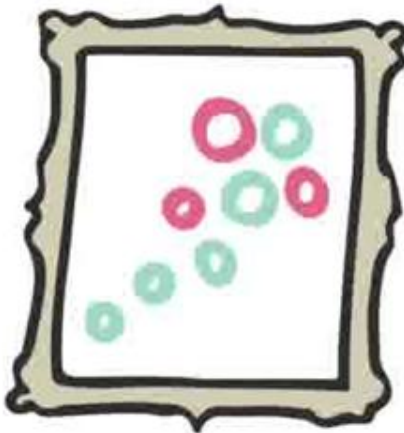
**Encoding**

X	Y	Z
0	2	3
-4	5	6
10	4.1	8.5

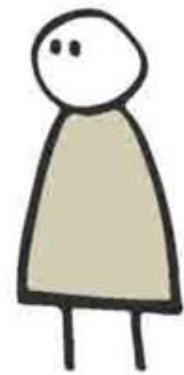
Data



Message



Visualization



User / audience / reader

**Encoding**

**Decoding**



*No matter how clever  
the choice of the information,  
and no matter how  
technologically impressive the encoding,  
a visualization fails if the decoding fails.*

**"The Elements of Graphing Data", William S. Cleveland**

**How to make sure the decoding does not fail?**

## How to make sure the decoding does not fail?

Speak in your audience's "language"

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### Speak in your audience's "language"

- We need to analyze what is the most **natural way to decode information** and to design the graph accordingly

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*e.g. if I know the user is going to decode the message in English, I should make sure that when I write the message, I do it in English.*

# How to make sure the decoding does not fail?

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- We need to analyze what is the most **natural way to decode information** and to design the graph accordingly

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## Visual language

# How to make sure the decoding does not fail?

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## Visual language

- How do I know which graphical features are more easily decoded by humans?

# How to make sure the decoding does not fail?

## Speak in your audience's "language"

- We need to analyze what is the most **natural way to decode information** and to design the graph accordingly

*e.g. if I know the user is going to decode the message in English, I should make sure that when I write the message, I do it in English.*

## Visual language

- How do I know which graphical features are more easily decoded by humans?

Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods.  
William S. Cleveland & Robert McGill  
Journal of the American Statistical Association  
Vol. 79, No. 387 (Sept 1984), PP. 531-554

### Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods

WILLIAM S. CLEVELAND and ROBERT MCGILL\*

The subject of graphical methods for data analysis and for data presentation needs a scientific foundation. In this article we take a few steps in the direction of establishing such a foundation. Our approach is based on graphical perception—the visual decoding of information encoded on graphs—and it includes both theory and experimentation to test the theory. The theory deals with a small but important piece of the whole process of graphical perception. The first part is an identification of a set of elementary perceptual tasks that are carried out when people extract quantitative information from graphs. The second part is an ordering of the tasks on the basis of how accurately people perform them. Elements of the theory are tested by experiments in which subjects record their judgments of the quantitative information on graphs. The experiments indicate three elements but also suggest that the set of elementary tasks should be expanded. The theory provides a guideline for graph construction: Graphs should employ elementary tasks as high as the ordering as possible. This principle is applied to a variety of graphs, including bar charts, divided bar charts, pie charts, and statistical maps with shading. The conclusion is that radial energy on these popular graphs is wasted, and in replacement we offer alternative graphical forms—see charts, dot charts and grouping, and funnel-rectangle charts.

KEY WORDS: Consumer graphics, Perceptual tasks.

#### 1 INTRODUCTION

Nearly 200 years ago William Playfair (1790) began the serious use of graphs for looking at data. More than 50 years ago a battle raged on the pages of the *Journal of the American Statistical Association* about the relative merits of bar charts and pie charts (Fells 1926, Croxall 1927, Croxall and Bryant 1927, von Holst 1927). Today graphs are a vital part of statistical data analysis and a vital part of communication in science and technology, business, education, and the mass media.

Still, graph design for data analysis and presentation is

largely unscientific. This is why Cox (1976) argued, "There is a danger of using for a theory of graphical methods" (p. 5), and why Kossuth (1977) stated "in choosing, constructing, and comparing graphical methods we have little to go on but intuition, rule of thumb, and a kind of untested experience passing along of information. . . . there is neither theory nor systematic body of experiment as a guide" (p. 28-29).

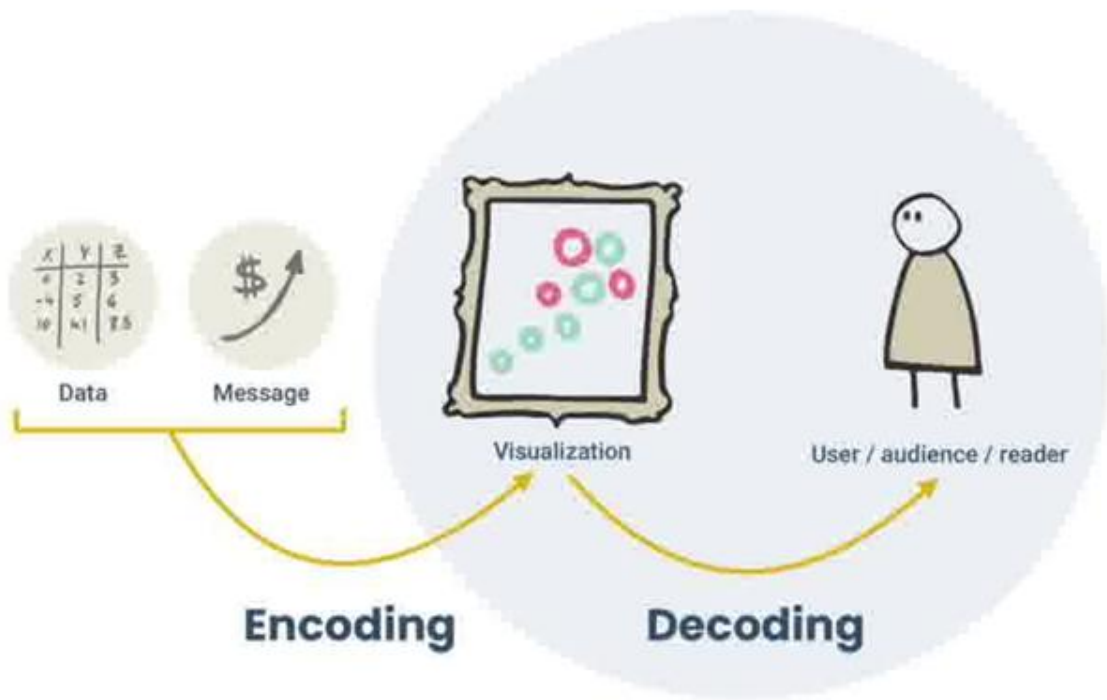
There is, of course, much good common sense about how to make a graph. There are many instances on graph construction (e.g., Tufte and Salsard 1979), and practice has been reported (e.g., Tufte 1981), graphic designers certainly have shown us how to make a graph appealing to the eye (e.g., Marten et al. 1980), statisticians have thought intensely about graphical methods for data analysis (e.g., Tufte 1977, Chouhury et al. 1980), and cartographers have discussed good ways to the construction of statistical maps (Doran 1973, Robinson, Selt, and Morrison 1976). The ANSI manual on line styles provides guidelines for making graphs, but the manual admits, "The standard . . . sets forth the best current usage, and offers standards for general agreement" rather than "by scientific test" (p. 16).

In this article we approach the science of graphs through testing graphical perception. Our approach includes both theory and experimentation to test it.

The first part of the theory is a list of elementary perceptual tasks that people perform in extracting quantitative information from graphs. In the second part we hypothesize an ordering of the elementary tasks based on how accurately people perform them. We do not argue that this accuracy of quantitative extraction is the only aspect of a graph for which one might want to develop a theory, but it is an important one.

The theory is testable; we aim to predict the relative performance of comparing graphs, and then we set experiments to check this actual performance. The experiments are of two types. In one, since the graphs are drawn, the evidence appears on a screen that it is taken pains to be as accurate as possible. When a strong effect is perceived by the subject's eyes and hands, it is likely that it will appear to most other people as well. In

\* William S. Cleveland and Robert McGill are coeditors of *CHI&T* (CHI & Technology), Menlo Park, CA 94025. The authors are indebted to John Chatterjee, Hans Cherniak, David Fisher, William S. Cleveland, John H. Friedman, Francis MacEachron, Henry P. Miller, Paul P. Wang, and the AAAI committee for numerous comments on an earlier version of the article.



## Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods

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The subject of graphical methods for data analysis and for data presentation needs a scientific foundation. In this article we take a few steps in the direction of establishing such a foundation. Our approach is based on graphical perception—the visual decoding of information encoded on graphs—and it includes both theory and a representative test of the theory. The theory deals with a small but important piece of the whole process of graphical perception. The first part is an identification of a set of elementary perceptual tasks that are carried out when people extract quantitative information from graphs. The second part is an ordering of the tasks on the basis of how accurately people perform these. Elements of the theory are tested by experiments in which subjects record their judgments of the quantitative information on graphs. The experiments validate these elements but also suggest that the set of elementary tasks should be expanded. The theory provides a guideline for graph construction: Graphs should employ elementary tasks as high in the ordering as possible. This guideline is applied to a variety of graphs, including bar charts, divided bar charts, pie charts, and statistical maps with shading. The conclusions in this article suggest an alternative graphical format—dot charts, dot charts with grouping, and formal-rectangle charts.

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In this article we approach the science of graphs through human graphical perception. Our approach includes both theory and experimentation to test it. The first part of the theory is a list of elementary perceptual tasks that people perform in extracting quantitative information from graphs. In the second part we hypothesize an ordering of the elementary tasks based on how accurately people perform them. We do not argue that this accuracy of quantitative extraction is the only aspect of a graph for which one might want to develop a theory, but it is an important one.

The theory is testable; we use it to predict the relative performance of comparing graphs, and then we set experiments to check the actual performance. The experiments are of two types: In one, most the graphs are drawn, the evidence appears so strong that it is taken prima facie to have established the case. When a strong effect is generated by the authors' eyes and hands, it is likely that it will appear to most other people as well. In

\* William S. Cleveland and Robert McGill are co-authors of *CHI 87: CHI Letters*, Nancy 1987, 1987. The authors are grateful to Don Chambers, Sam Chouhury, David Evans, William Fernald, Gary Nelson, Frances Nozick, Henry Park, Paul Panko, and the AAAI committee for numerous comments on an earlier version of the article.

**The goal of studying  
human graphical perception**

#1

IDENTIFICATION OF THE ESSENTIAL PERCEPTUAL TASKS

# #1

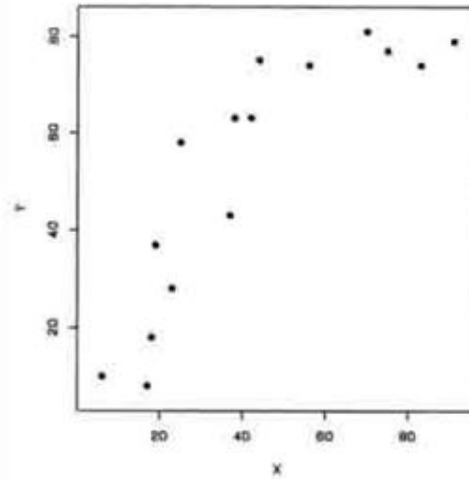
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"...that are carried out when people extract quantitative information from graphs."

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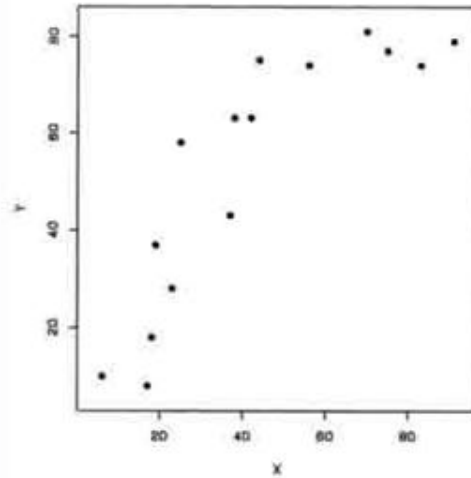


Position

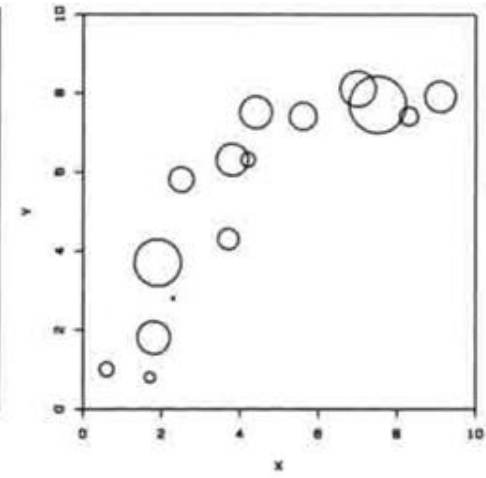
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Position



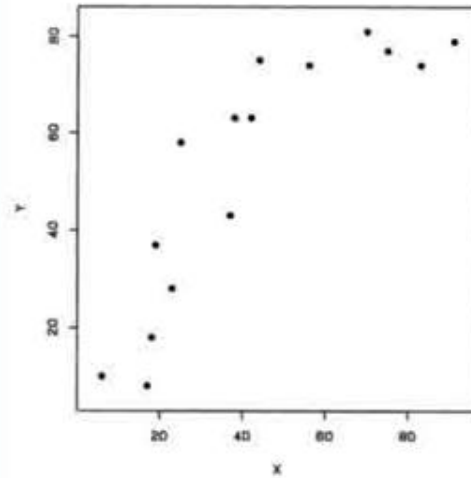
Position  
+  
Area

CLEVELAND & MCGILL (1984)  
FIGURE 7 AND 9

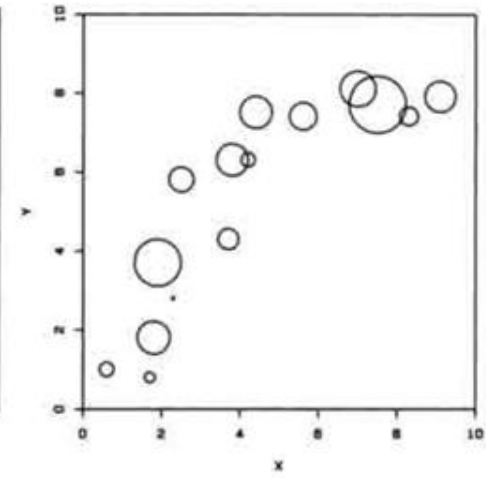
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Position  
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CLEVELAND & MCGILL (1984)  
FIGURE 7 AND 9

THE 10 ELEMENTARY PERCEPTUAL TASKS

# #1

## IDENTIFICATION OF THE ESSENTIAL PERCEPTUAL TASKS

"...that are carried out when people extract quantitative information from graphs."

# #2

## RANKING

# #1

## IDENTIFICATION OF THE ESSENTIAL PERCEPTUAL TASKS

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## RANKING

"Producing an ordering of the tasks on the basis of how accurately people perform them."

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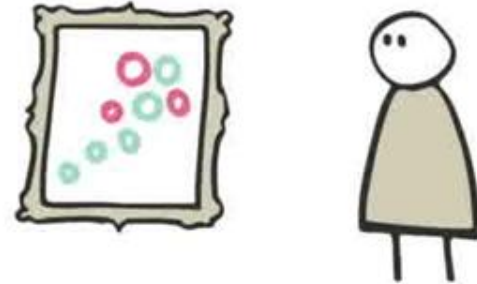
"...that are carried out when people extract quantitative information from graphs."

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## RANKING

"Producing an ordering of the tasks on the basis of how accurately people perform them."

Generally, when a user is trying to decode the information in the graph, one or more of these elementary tasks have to be performed.



# #1

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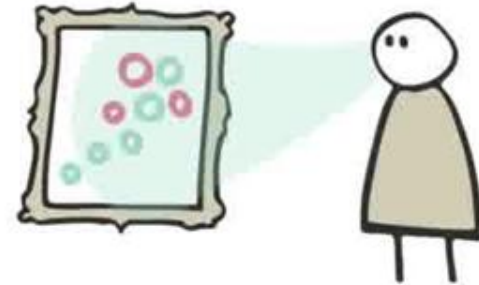
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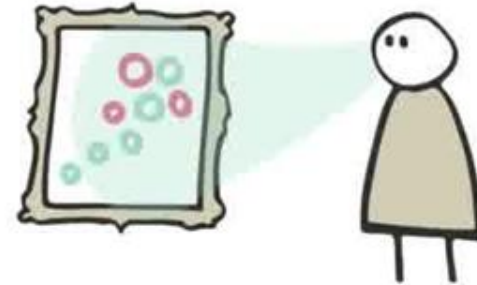
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Some of these tasks are **easier** to perform than others  
Some of these tasks yield to more **accurate** perceptions of the numerical quantities depicted

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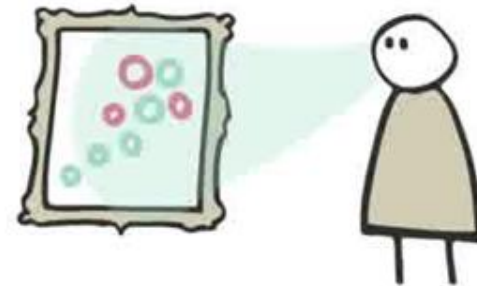
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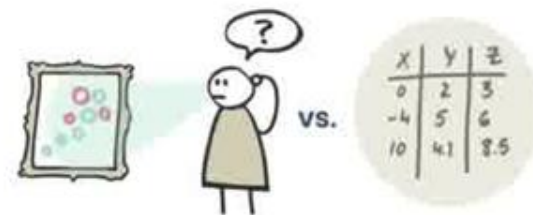
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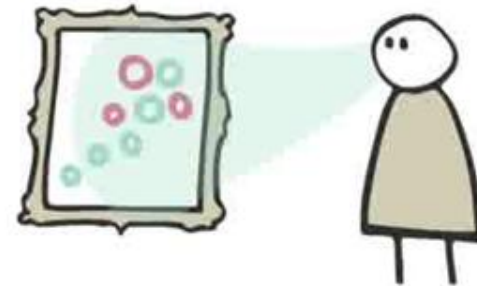
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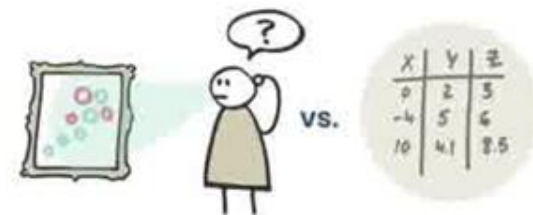
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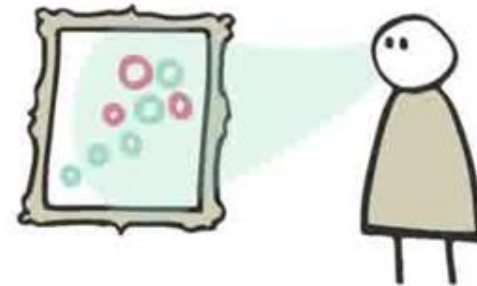
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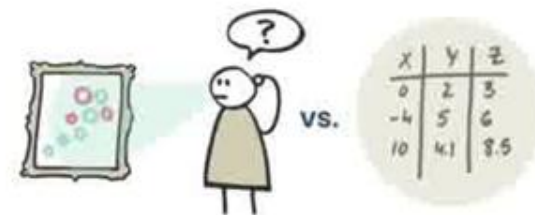
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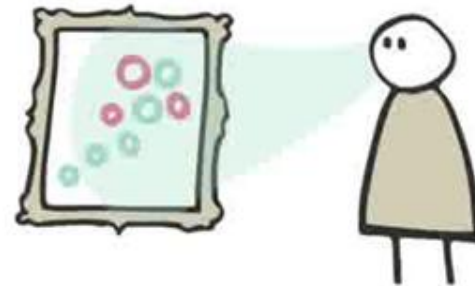
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## RANKING OF THE ELEMENTARY PERCEPTUAL TASKS

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# #3

## REDESIGN OLD GRAPHICAL FORMS AND DESIGN NEW ONES

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Graphs that require to do a **simpler** task will be **easier** to read and interpret than graphs requiring a difficult task.



SIMPLE



COMPLEX

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FEW



MANY

**REDESIGN** OF THE TRADITIONAL PLOTS

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