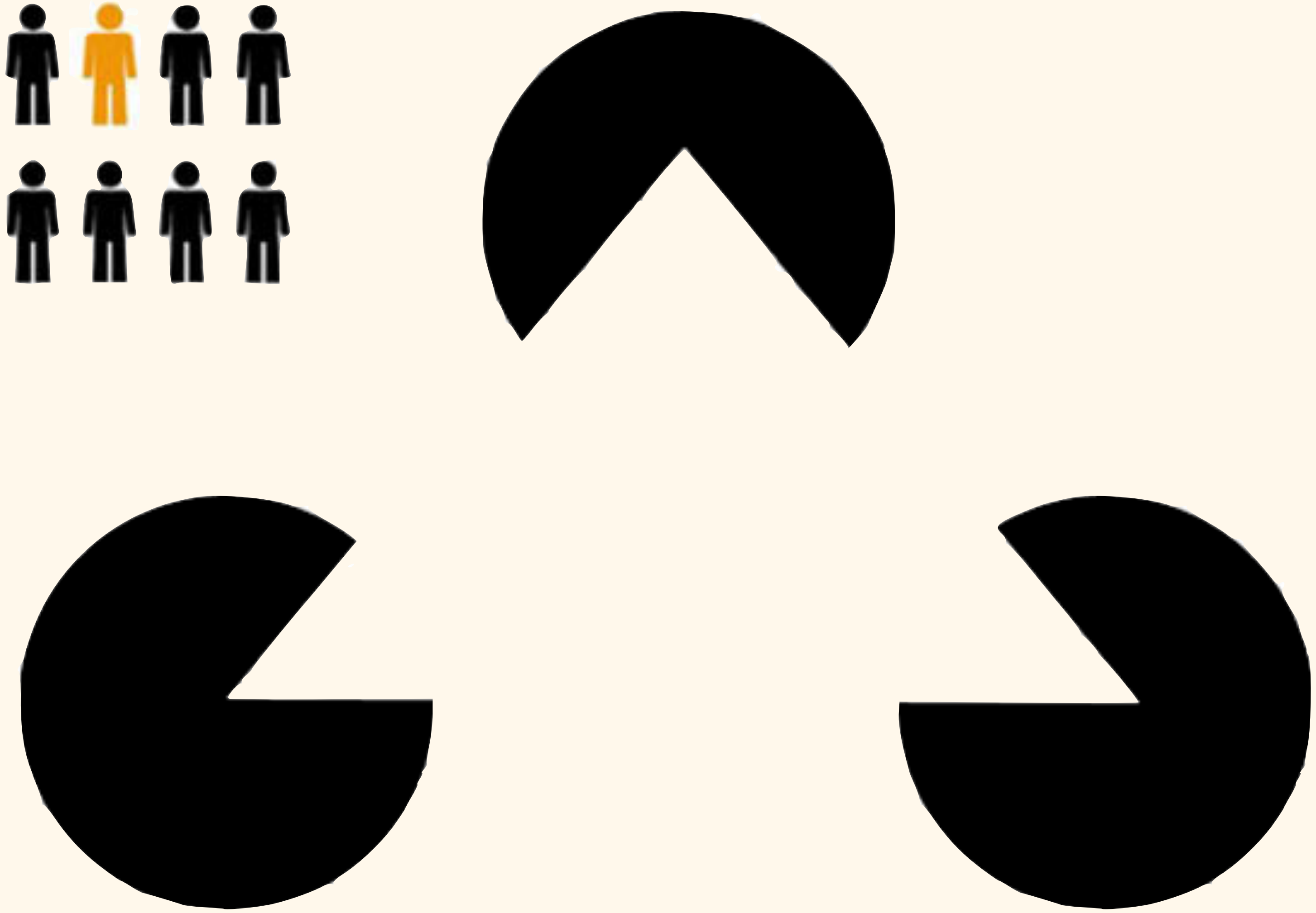
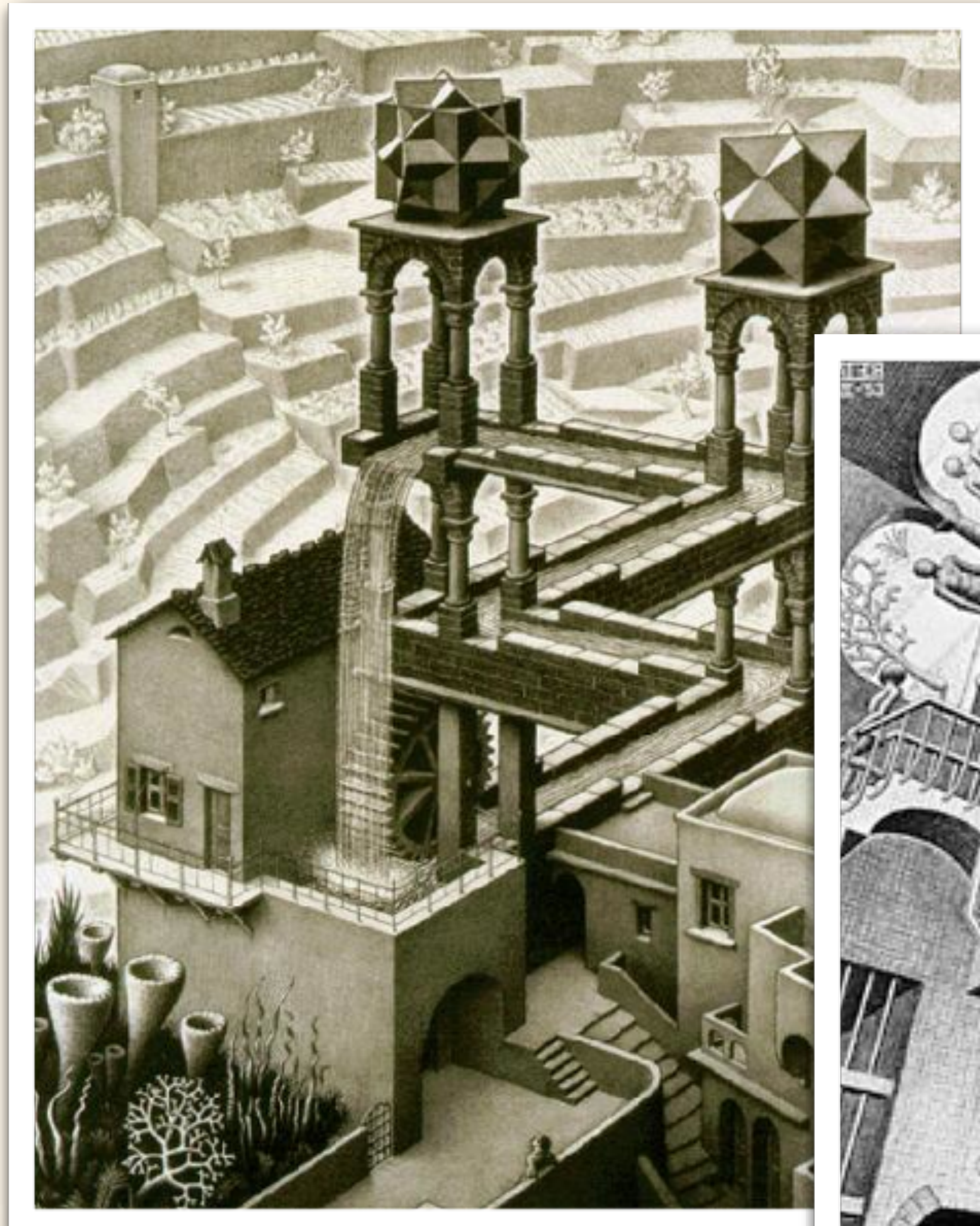
Preattentive properties & Gestalt perception



Jackie Wirz & Steven Bedrick & Alison Hill

CSE 631, 10/4/16



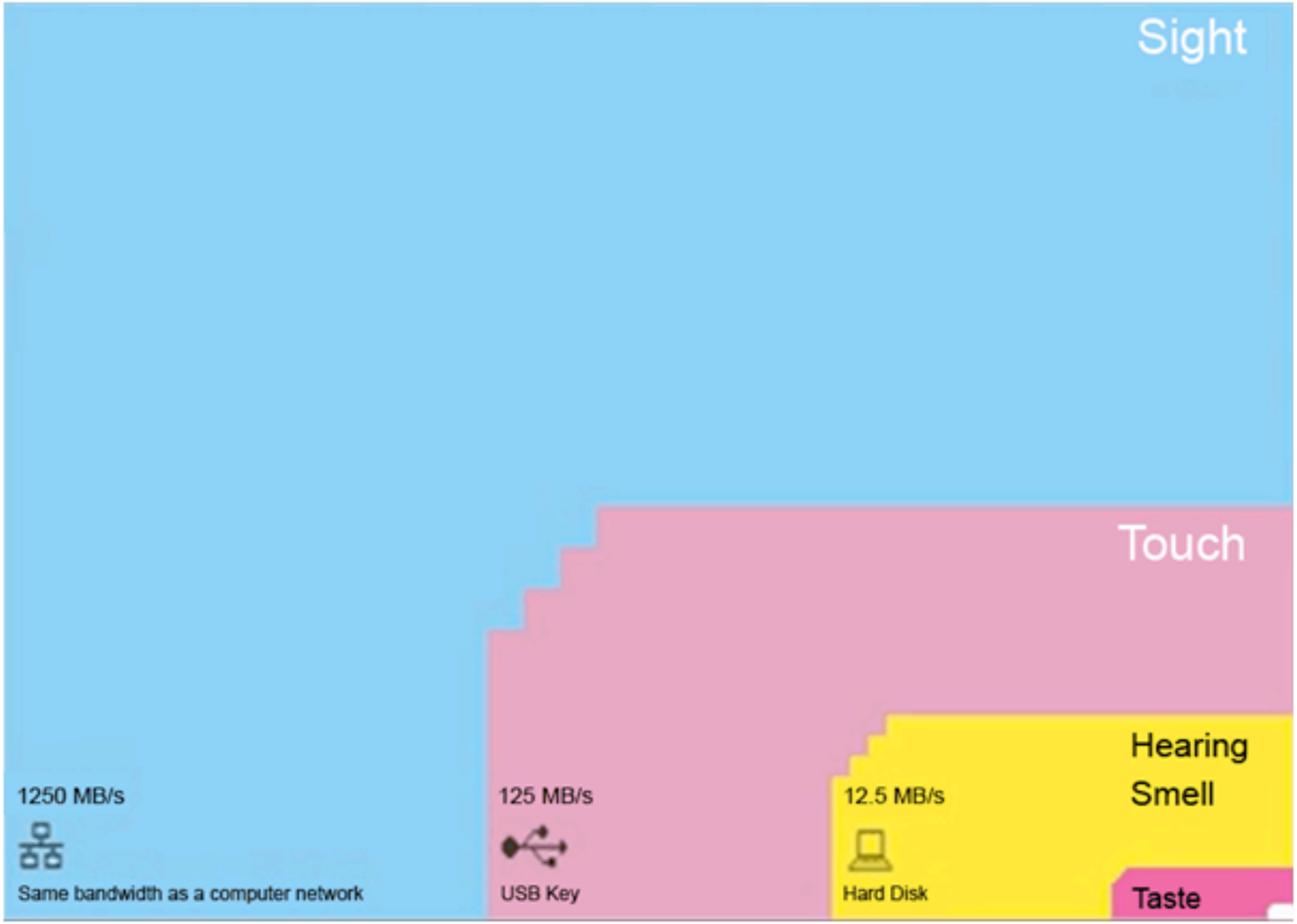
M.C. Escher, “Waterfall” https://en.wikipedia.org/wiki/File:Escher_Waterfall.jpg
M.C. Escher, “Relativity” https://en.wikipedia.org/wiki/File:Escher%27s_Relativity.jpg

"If information is presented orally, people remember about 10%... That number goes up by 65% if you add a picture."

Paul Martin Lester

Jerome Bruner

Our toolbox starts with our eyes and visual cortex.



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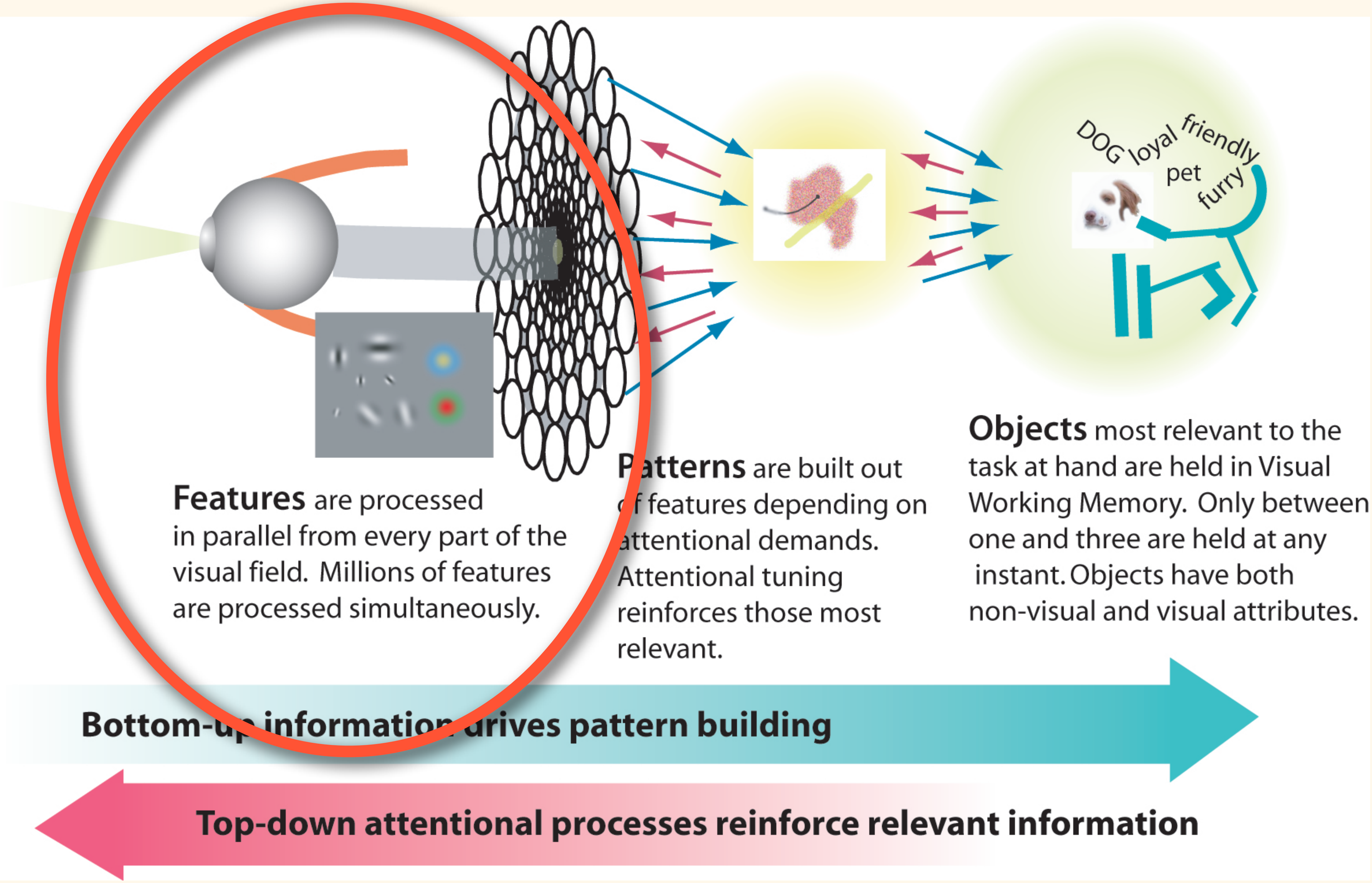
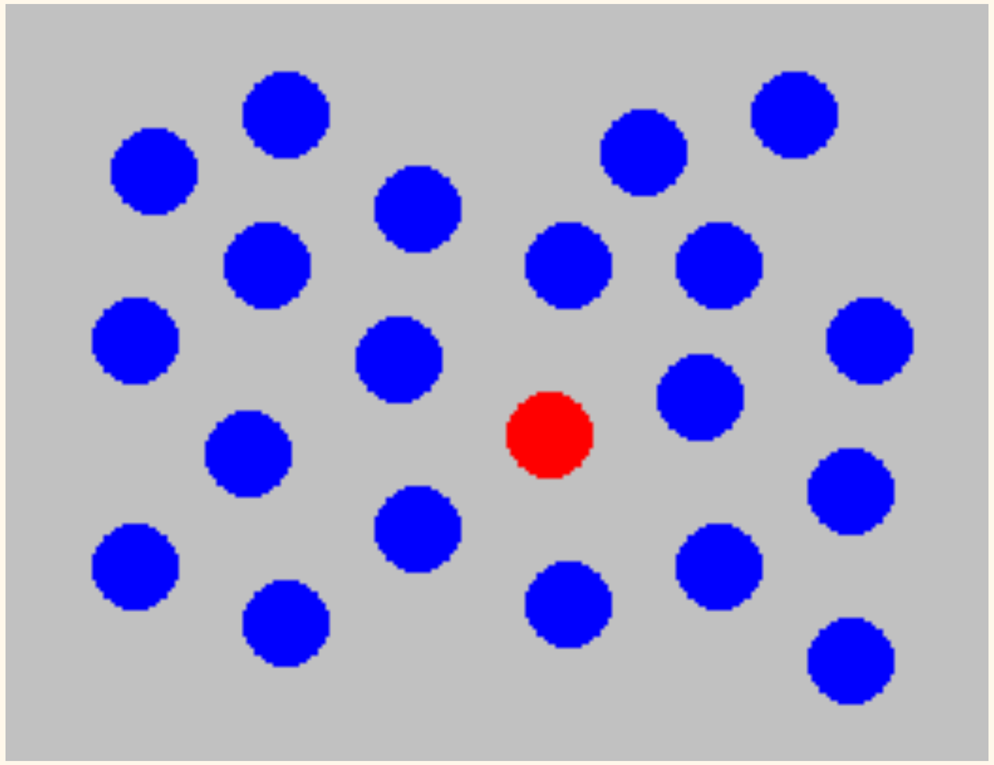
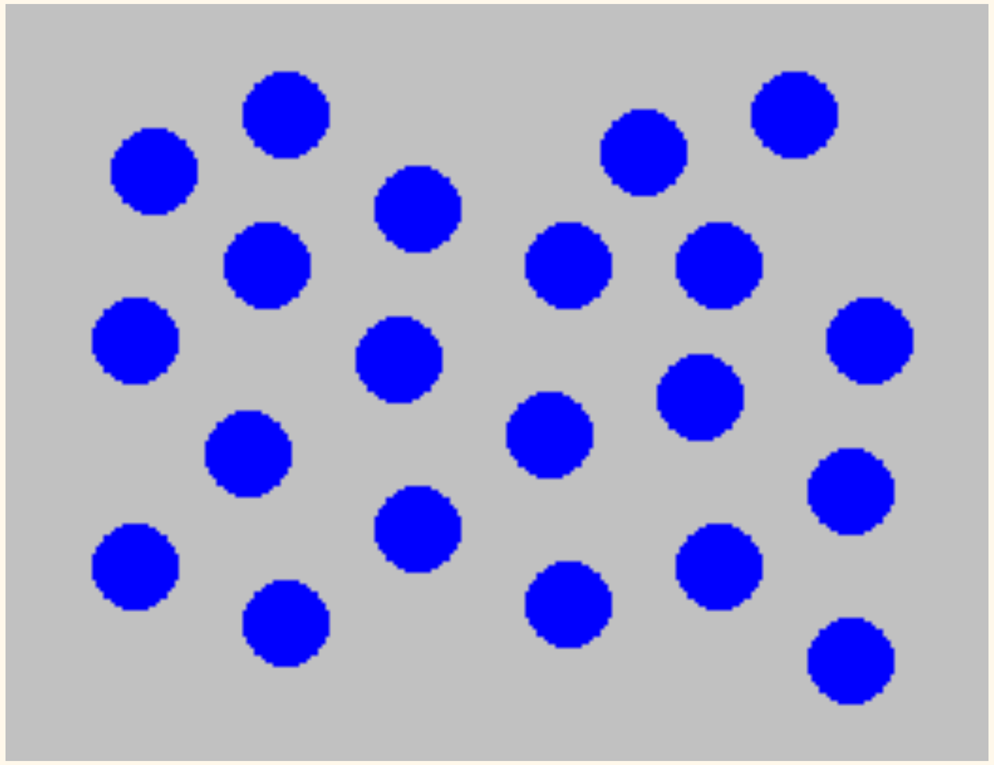


Stolen shamelessly from Ware, et al.

Certain visual inputs are processed almost instantaneously, and in parallel:

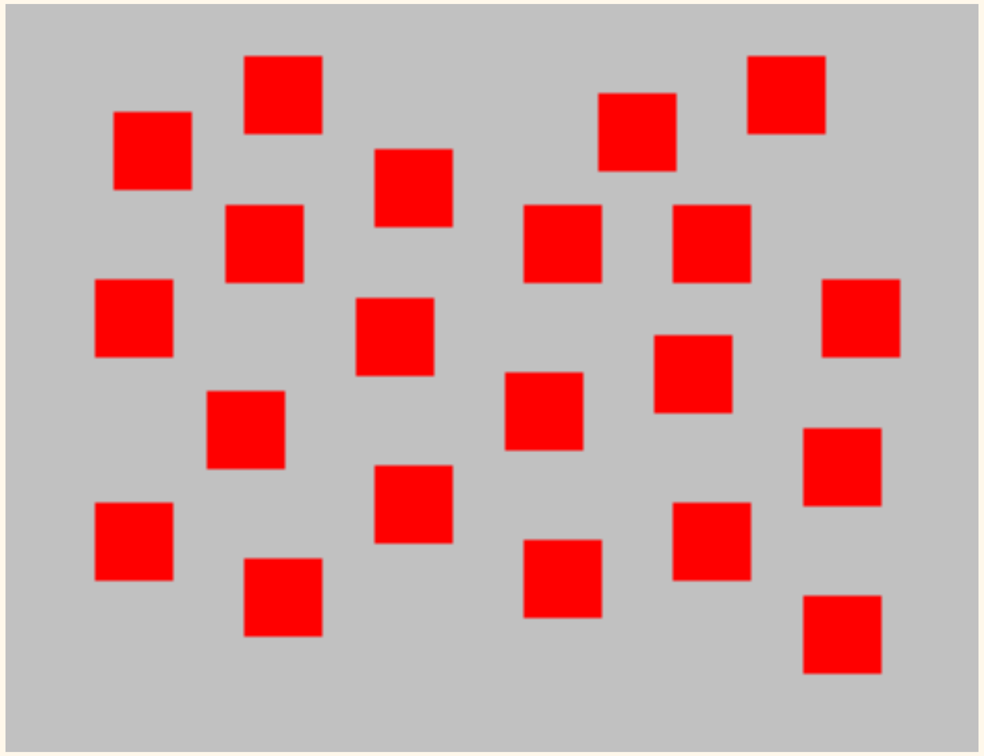


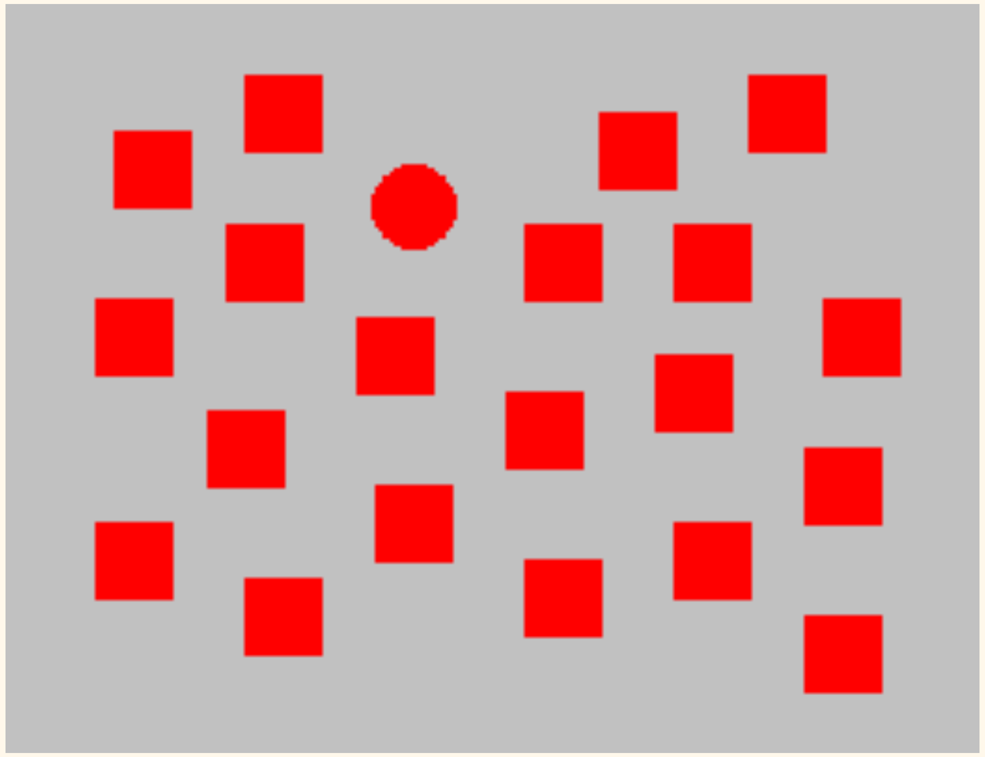


Is there a red circle present?

Taken from Healey *http://www.csc.ncsu.edu/faculty/healey/PP/index.html*

Certain visual inputs are processed almost instantaneously, and in parallel:





Is there a red circle present?

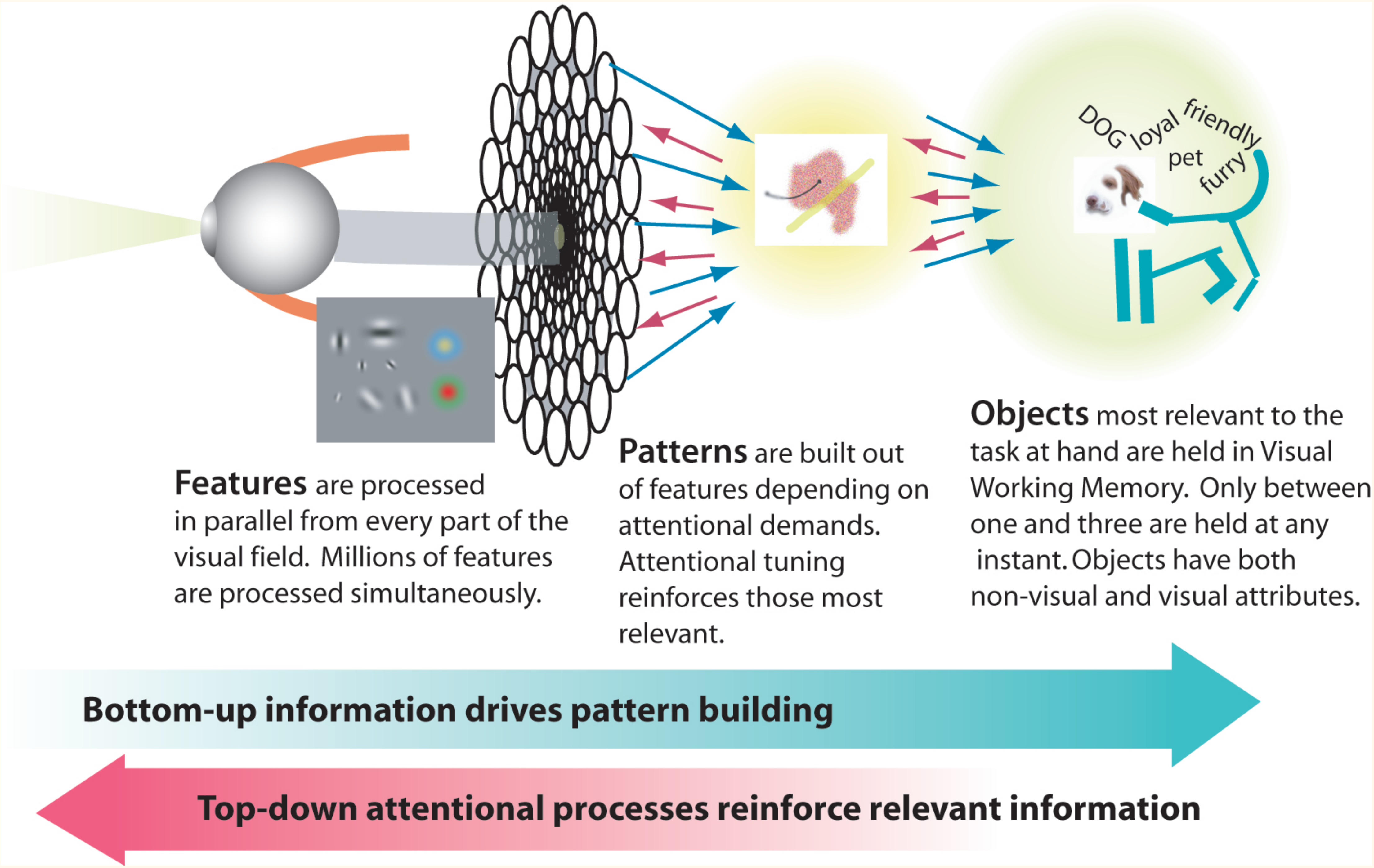
Taken from Healey http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Certain visual inputs are processed almost instantaneously, and in parallel:

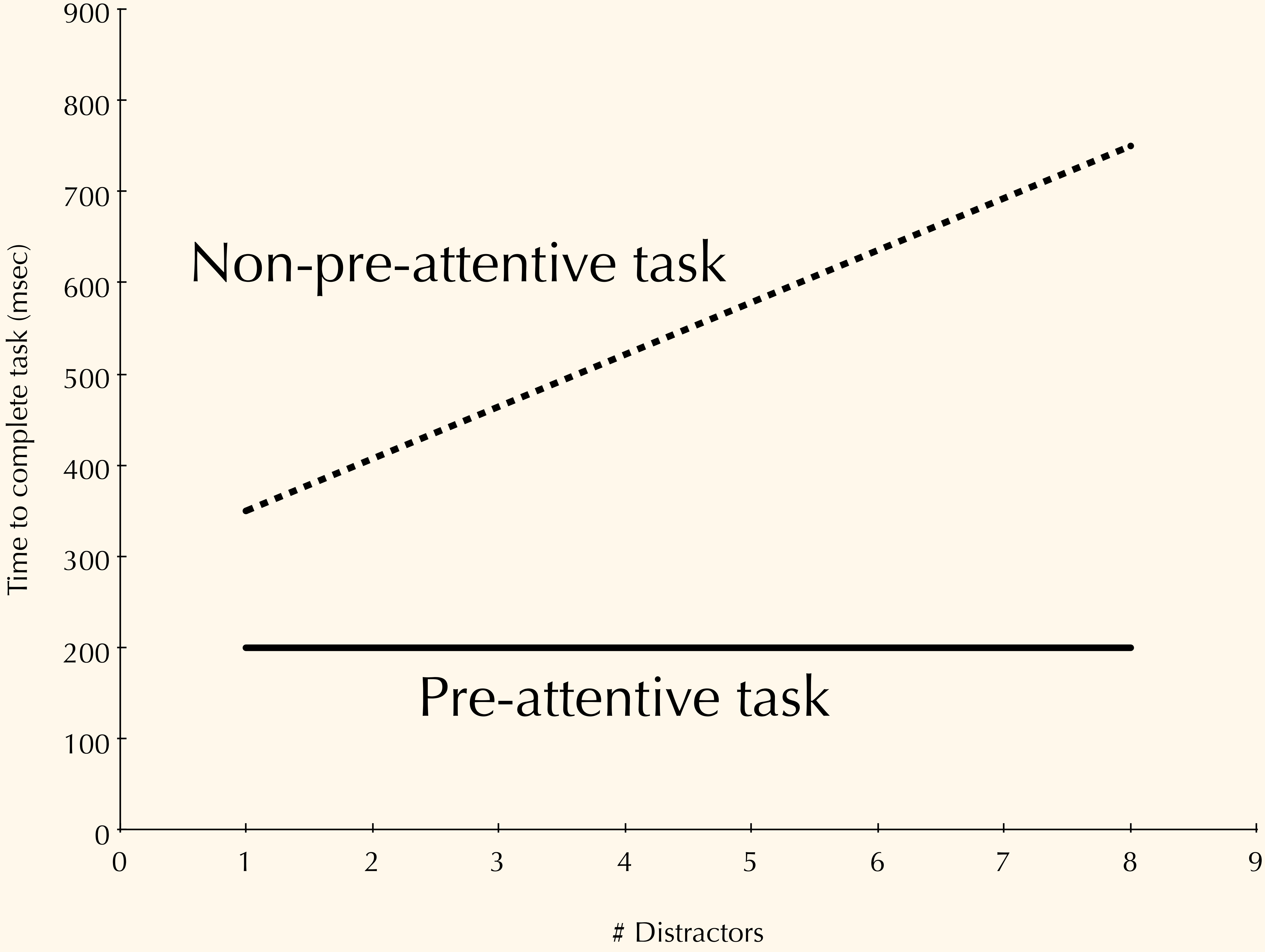
Is there a boundary?

Taken from Healey http://www.csc.ncsu.edu/faculty/healey/PP/index.html

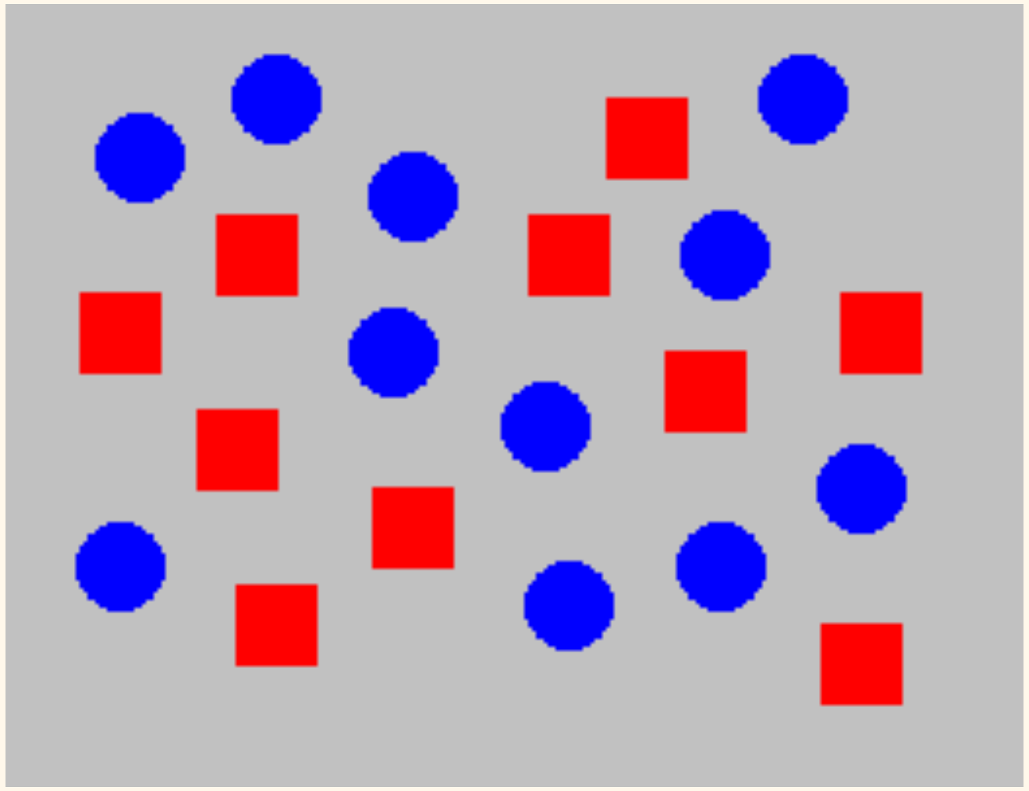
This "pre-attentive" perception happens very early in the vision pathway.

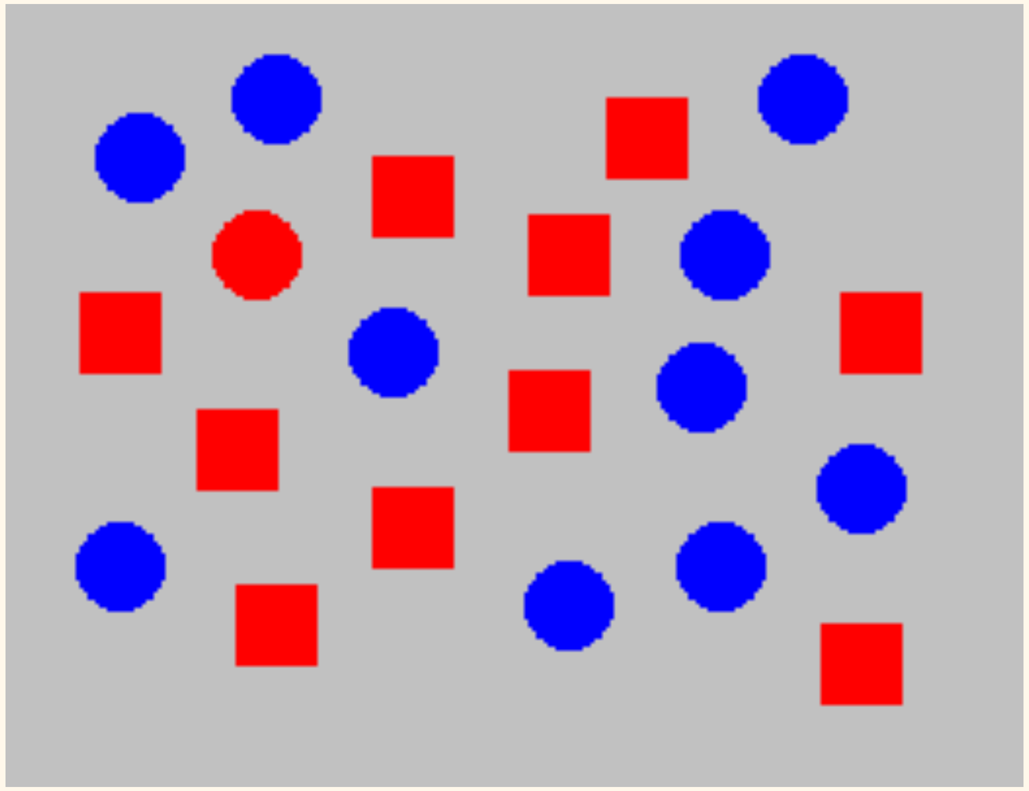


A pre-attentive task takes the same amount of time irrespective of the number of distractors.



Interestingly, this only works when the distractors differ on the same feature:





Is there a red circle present?

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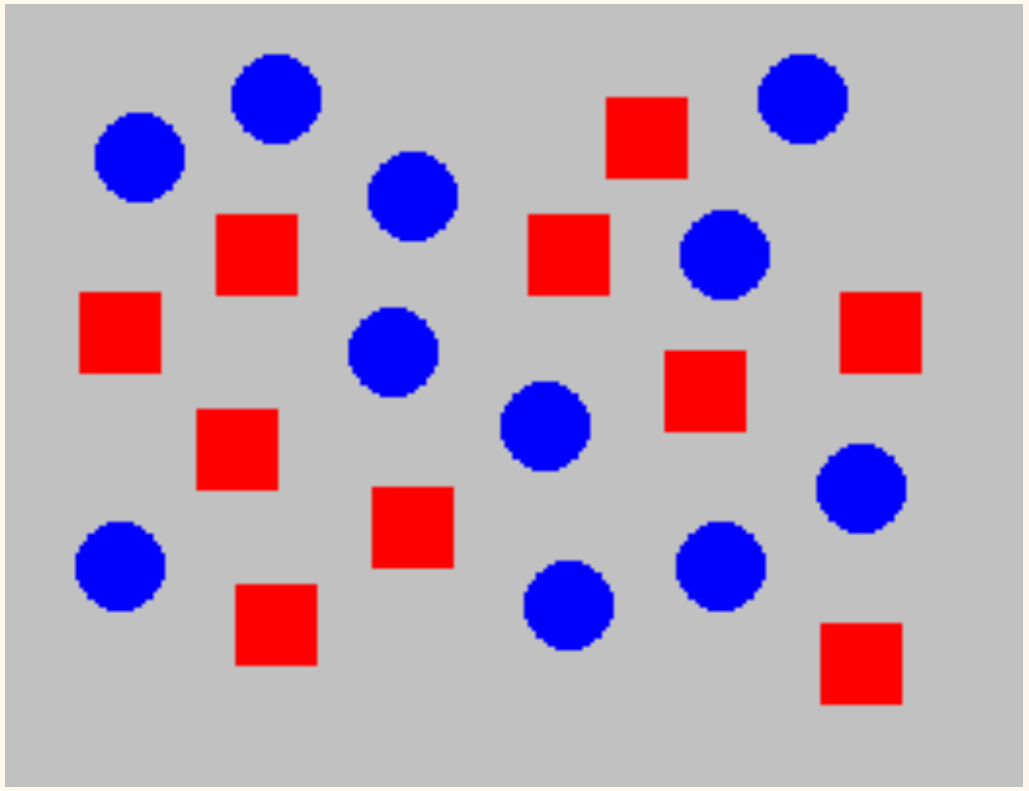
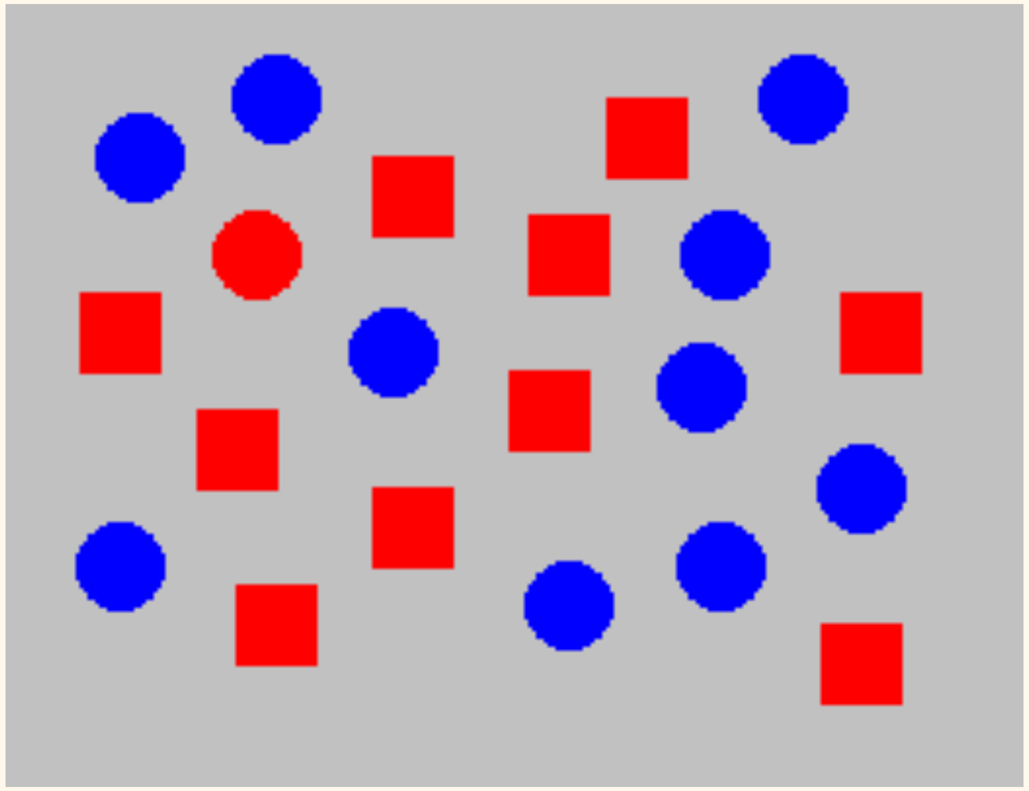
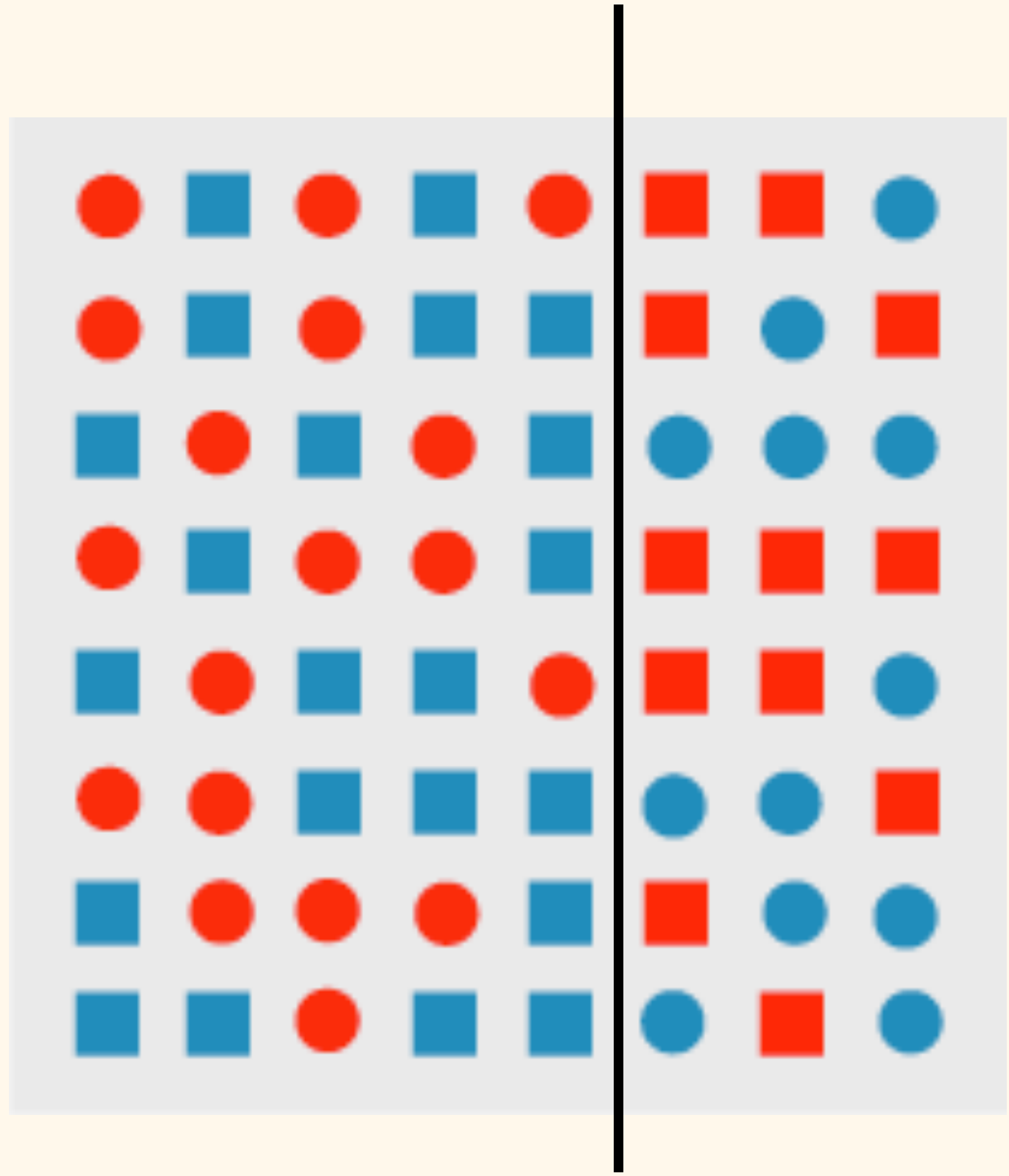




We must fall back on linear scanning when there is a "conjunction" of features.

Taken from Healey [*http://www.csc.ncsu.edu/faculty/healey/PP/index.html*](http://www.csc.ncsu.edu/faculty/healey/PP/index.html)

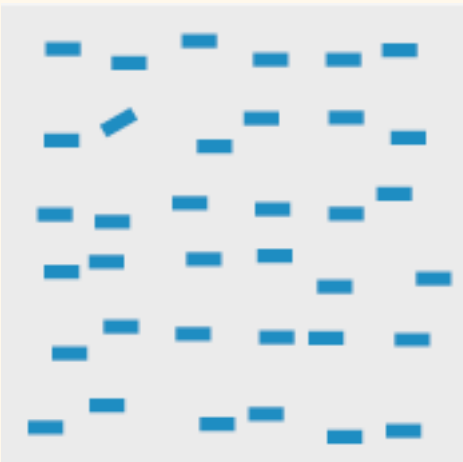
Interestingly, this only works when the distractors differ on the same feature:



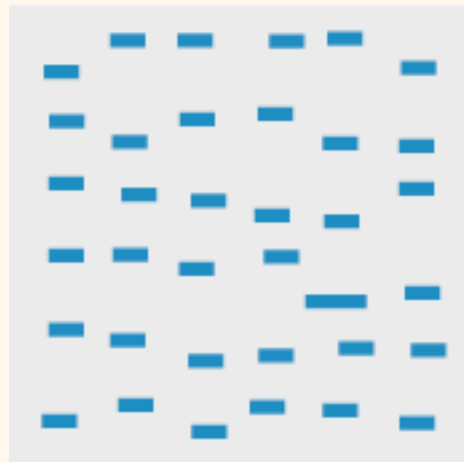
Is there a boundary? (hint: yes!)

Taken from Healey *http://www.csc.ncsu.edu/faculty/healey/PP/index.html*

Color and shape are only a few of the pre-attentive visual properties:

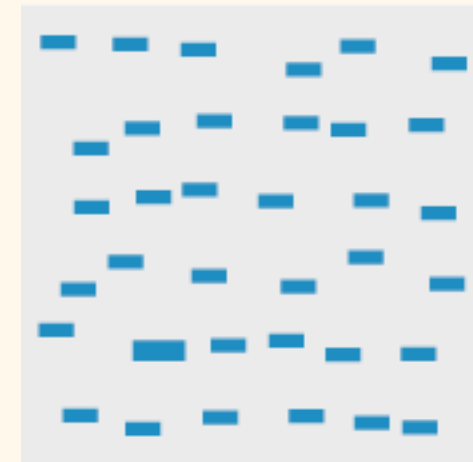


Orientation

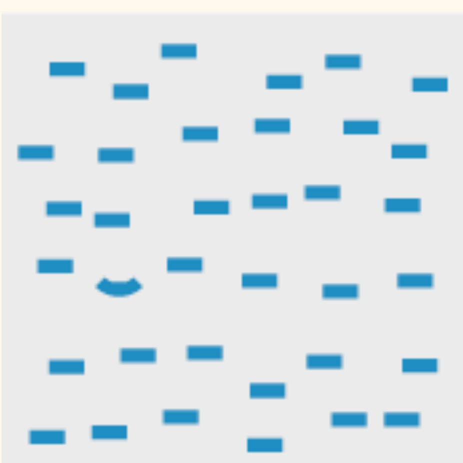


Length

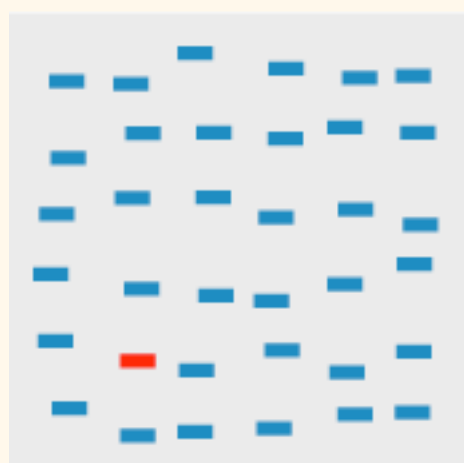
Closure



Size



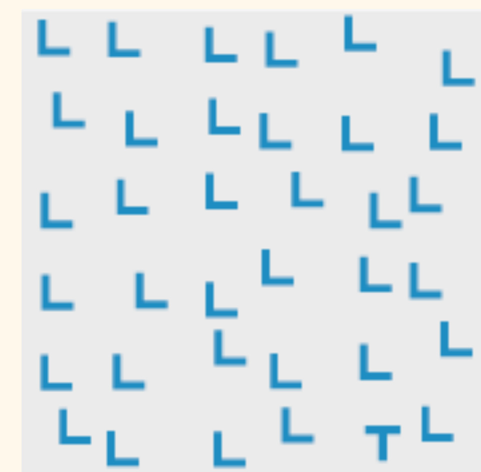
Curvature



Color

(hue & intensity operate independently)

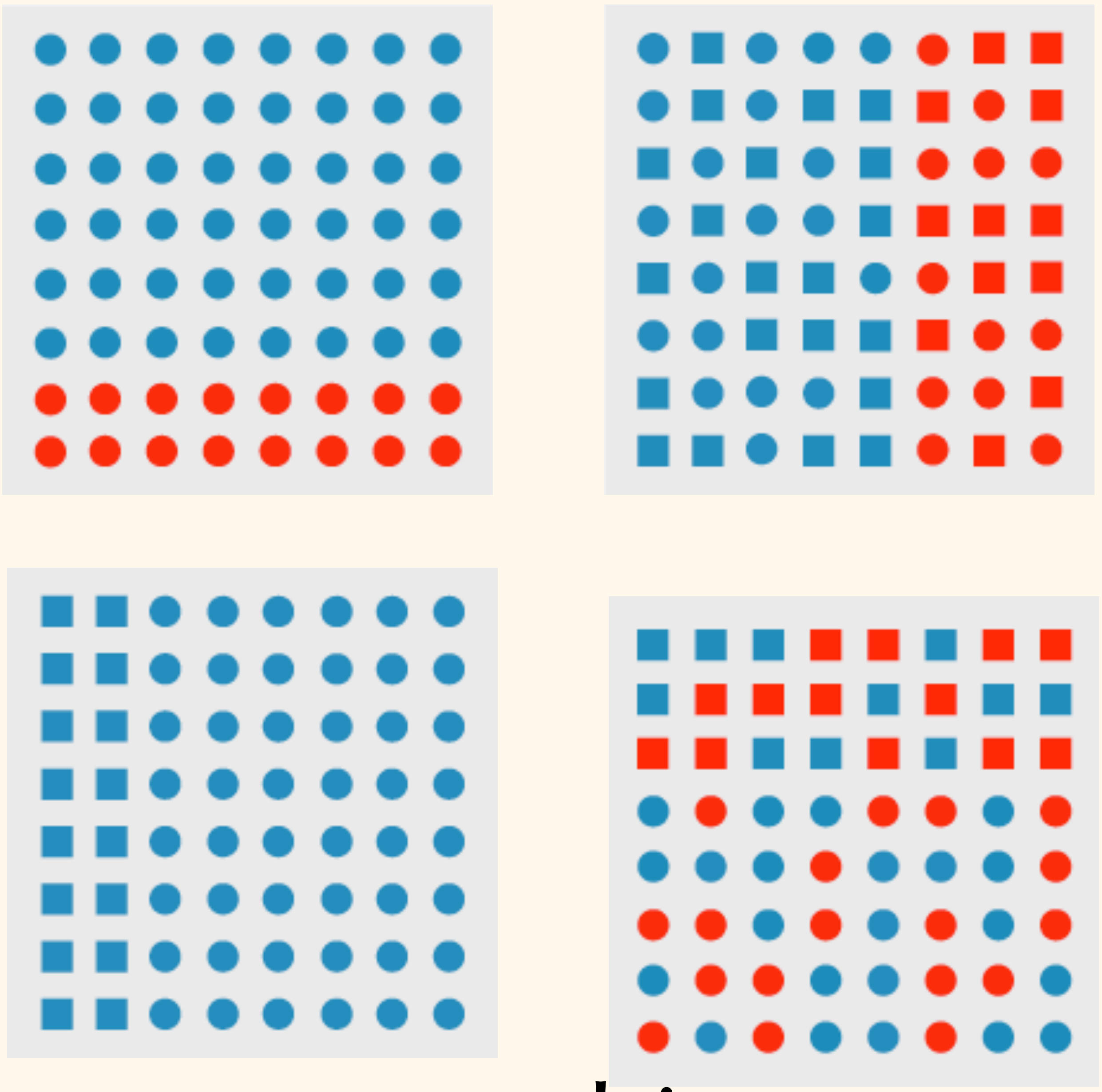
Terminators



Intersection

Taken from Healey http://www.csc.ncsu.edu/faculty/healey/PP/index.html

Note that these various features are not created equal!



We seem to have a strong bias towards color perception over shape perception, etc..

Taken from Healey *http://www.csc.ncsu.edu/faculty/healey/PP/index.html*

What does all of this mean?

1. Certain tasks that depend on pre-attentive features can sometimes be done "for free" by our brains:

Target detection *Boundary detection*

Region tracking *Counting (estimation)*

2. The more of our story we can tell using pre-attentive features, the faster and better our viewer will "get it."

3. We can easily mess up our viewer's ability to interpret our visualization by "triggering" pre-attentive perception inappropriately!

Many of the things that make a bad visualization "bad" can be traced back to problems in this area!

Another perspective: Gestalt perception

"Gestalt":

"An organized whole that is perceived as more than the sum of its parts." (Ox. Am. Dict.)

Possibly a mis-translation?

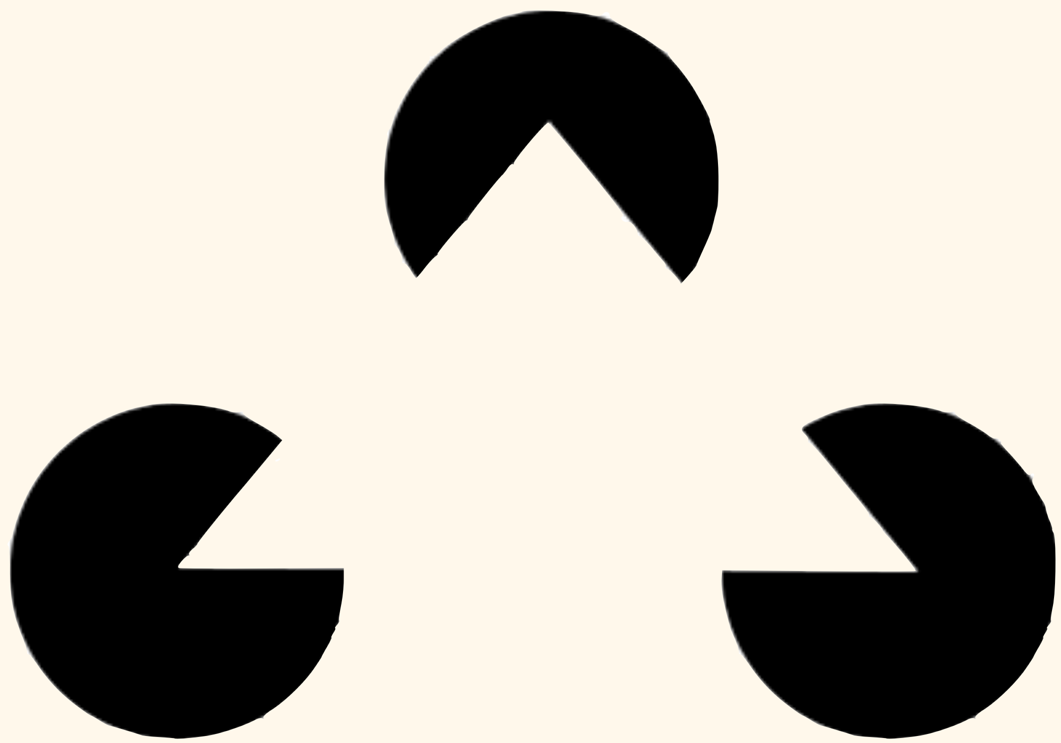
"The whole is other *than the sum of its parts."*
— Kurt Koffka (1886–1941)

The basic idea:

Our brains operate less on individual points, lines, etc....

... but rather on higher-level constructs...

... which is what our perceptual systems are optimized for.



We immediately see “triangle!”, not “circles with wedges removed...”

We don’t see “leg”, “ear”, etc., but rather “entire dog”.

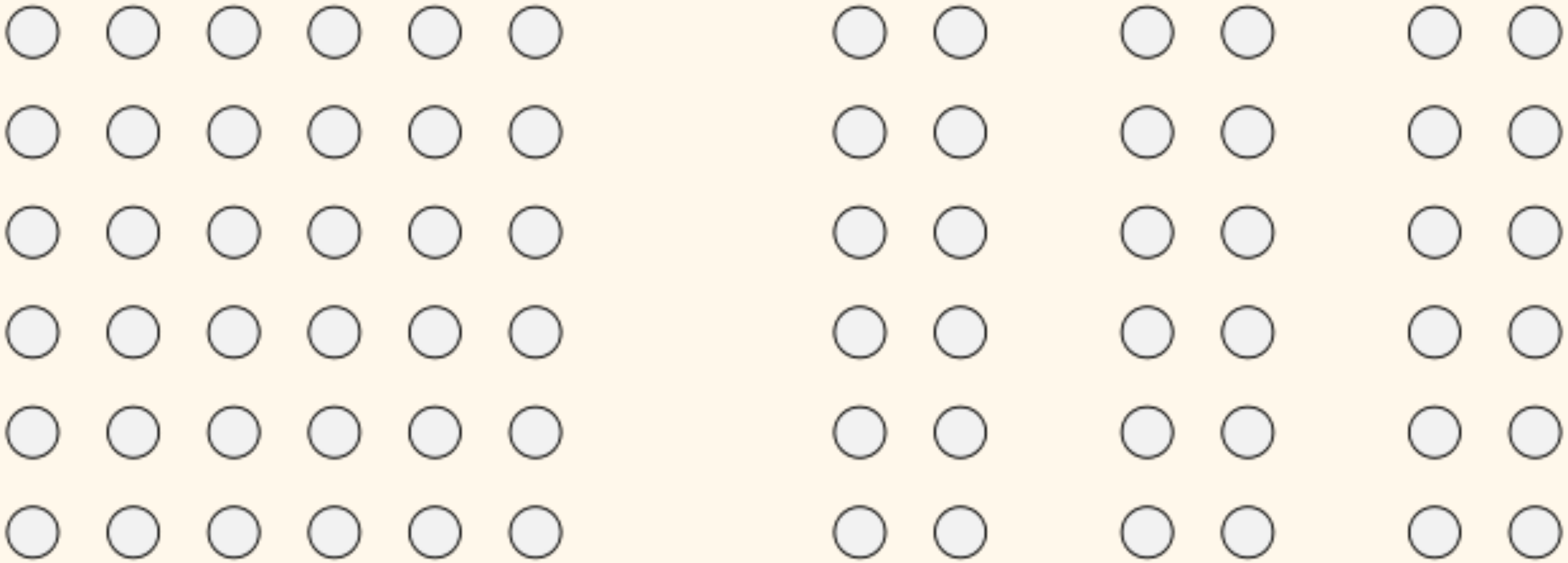
"Gestalt Principles" (Prägnanz):

To make sense of the world around us, our brains use several different heuristics:

1. Proximity
2. Similarity
3. Closure
4. Symmetry
5. Continuation
6. Figure & Ground

Proximity:

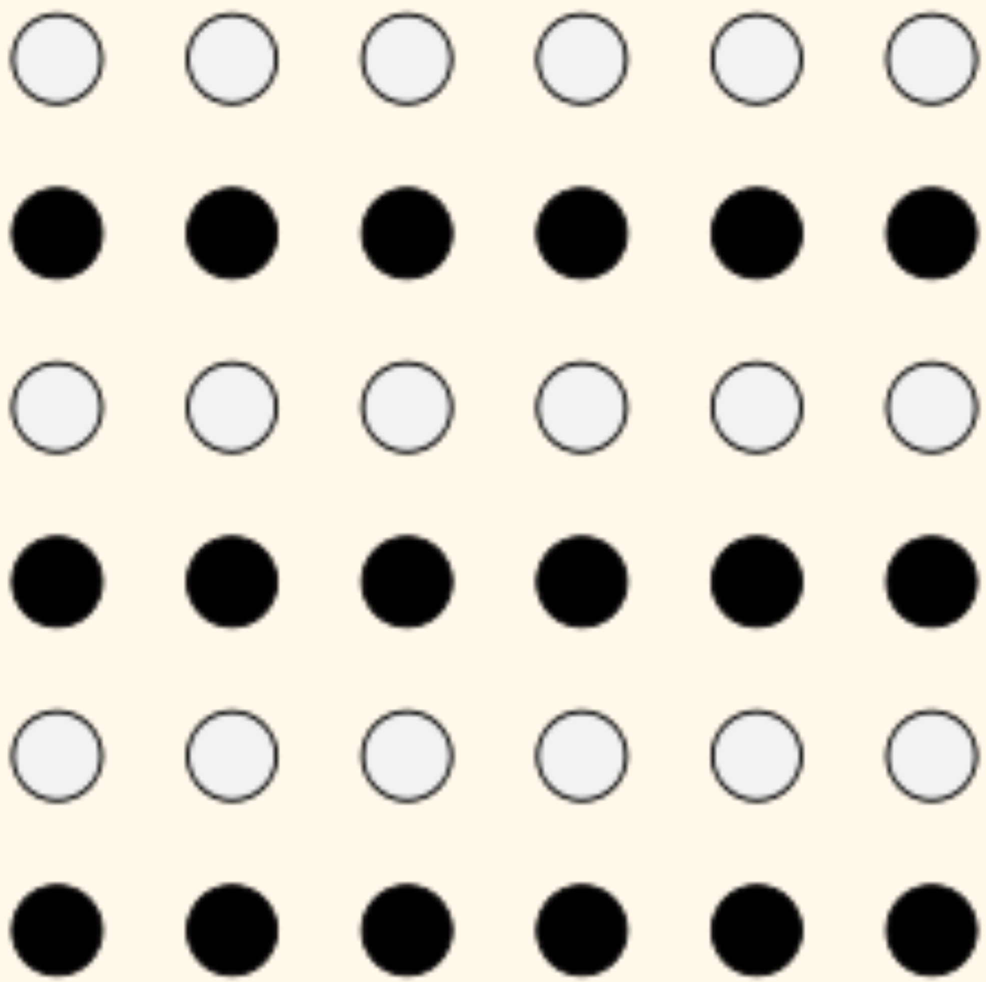
Stimuli that are in proximity to one another are perceived to be grouped together.

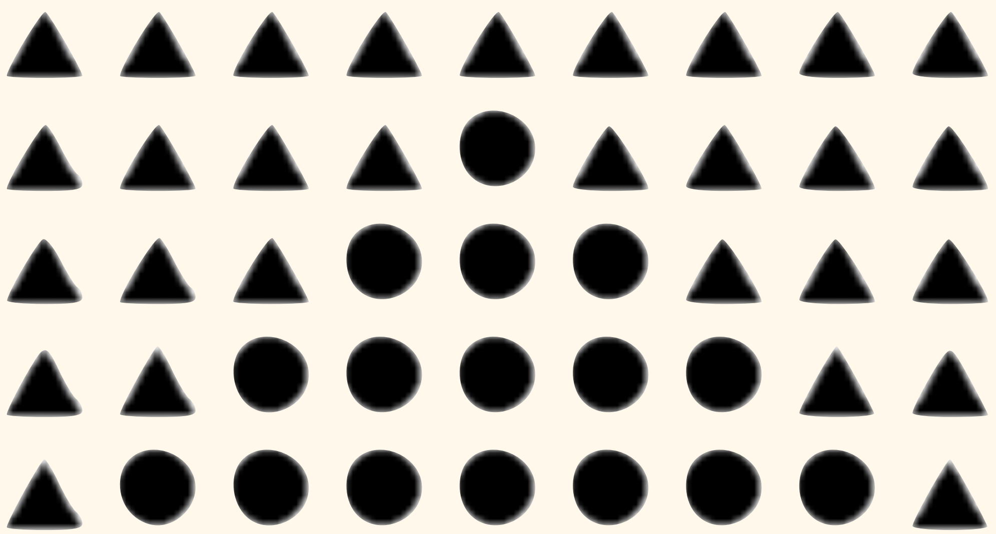


https://en.wikipedia.org/wiki/Gestalt_psychology#mediaviewer/File:Gestalt_proximity.svg

Similarity:

Elements are grouped together if they are similar to one another.

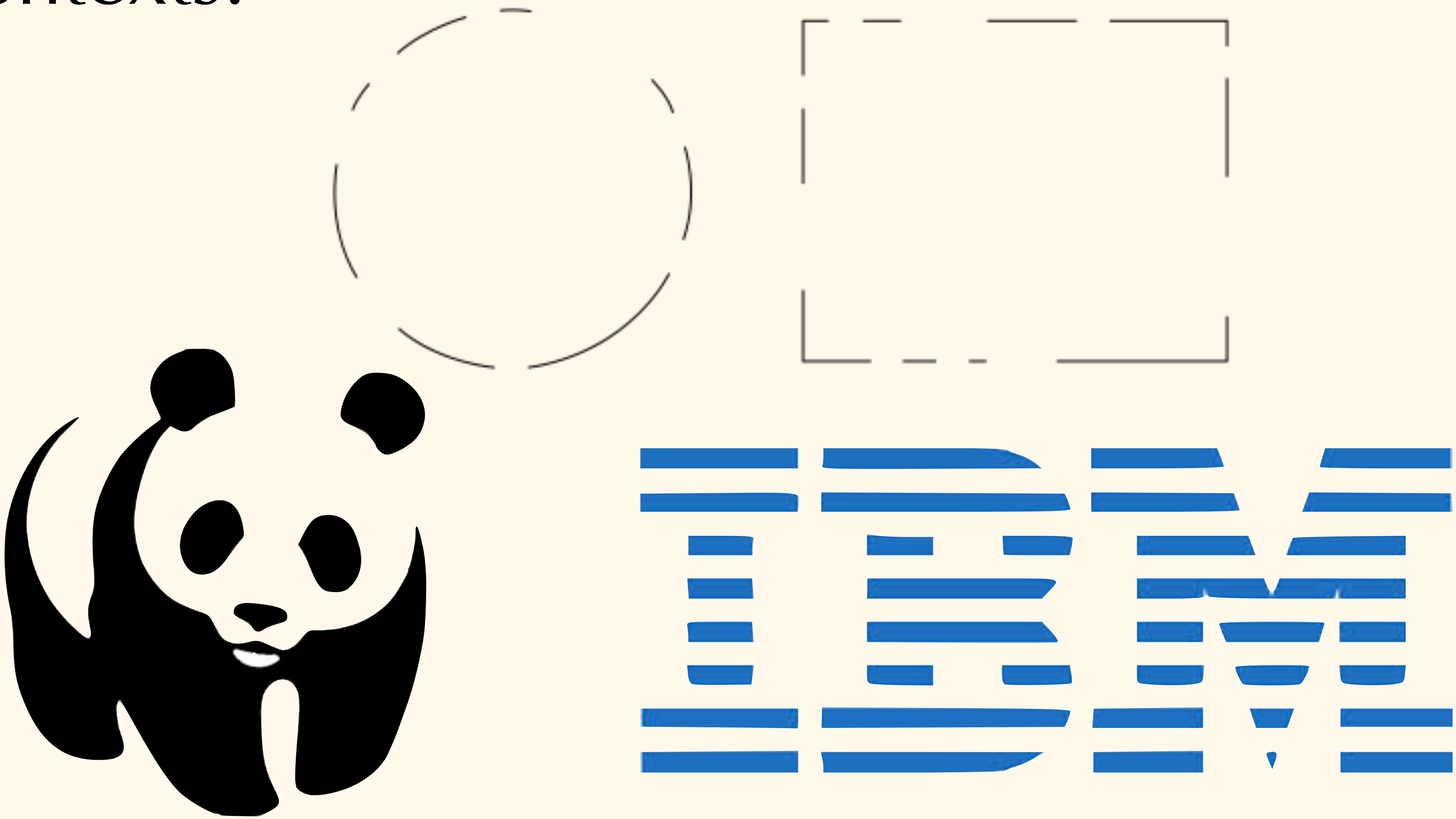




http://blog.templatemonster.com/2012/03/15/gestalt-similarity-law-templatemonster-templates/
https://en.wikipedia.org/wiki/Gestalt_psychology#mediaviewer/File:Gestalt_similarity.svg

Closure:

We see complete shapes in incomplete contexts.



https://en.wikipedia.org/wiki/Gestalt_psychology#mediaviewer/File:Gestalt_closure.svg

Symmetry:

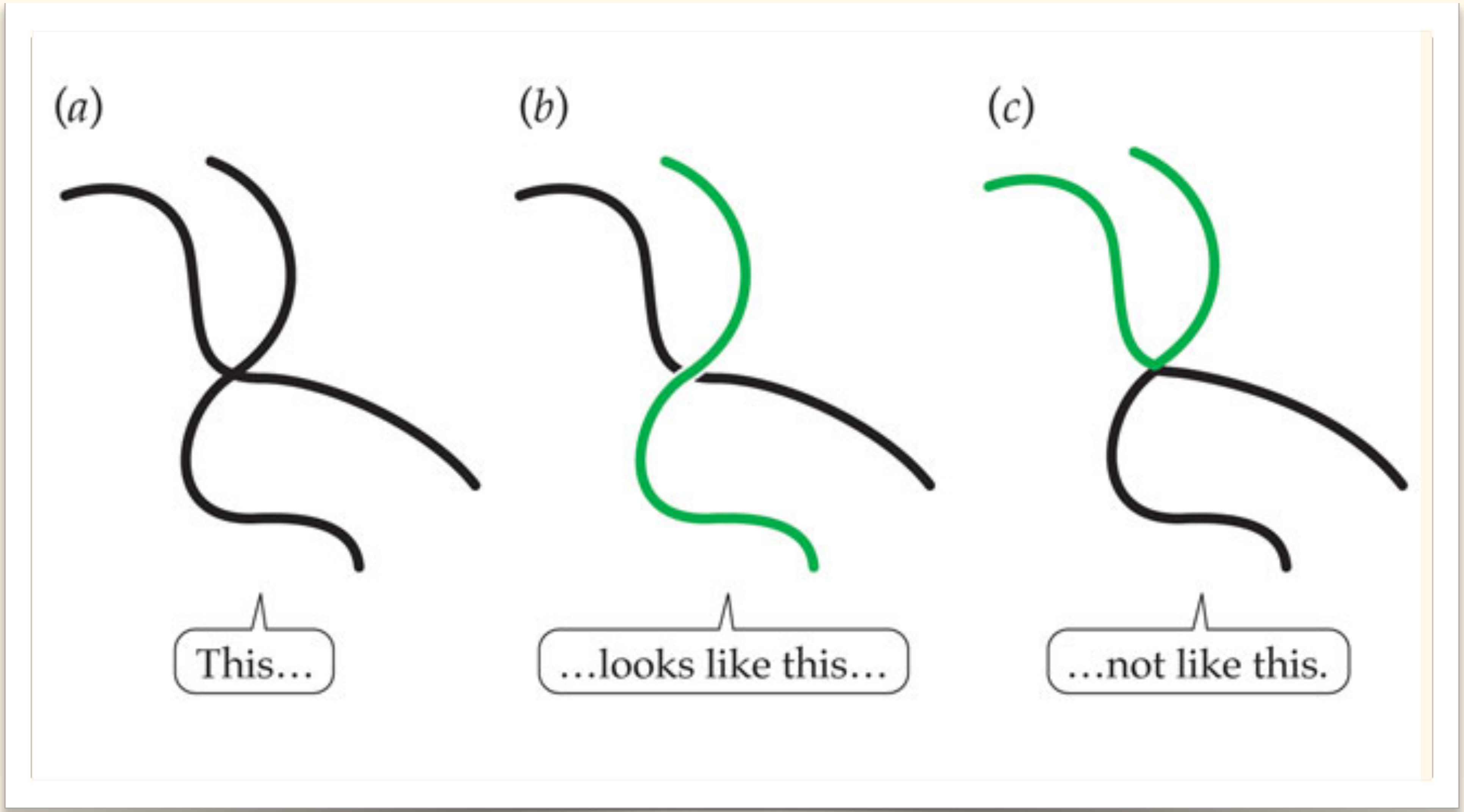
We naturally group things by central symmetry.

[ ]{ }[ ]

How many groups of elements are there?

Continuation

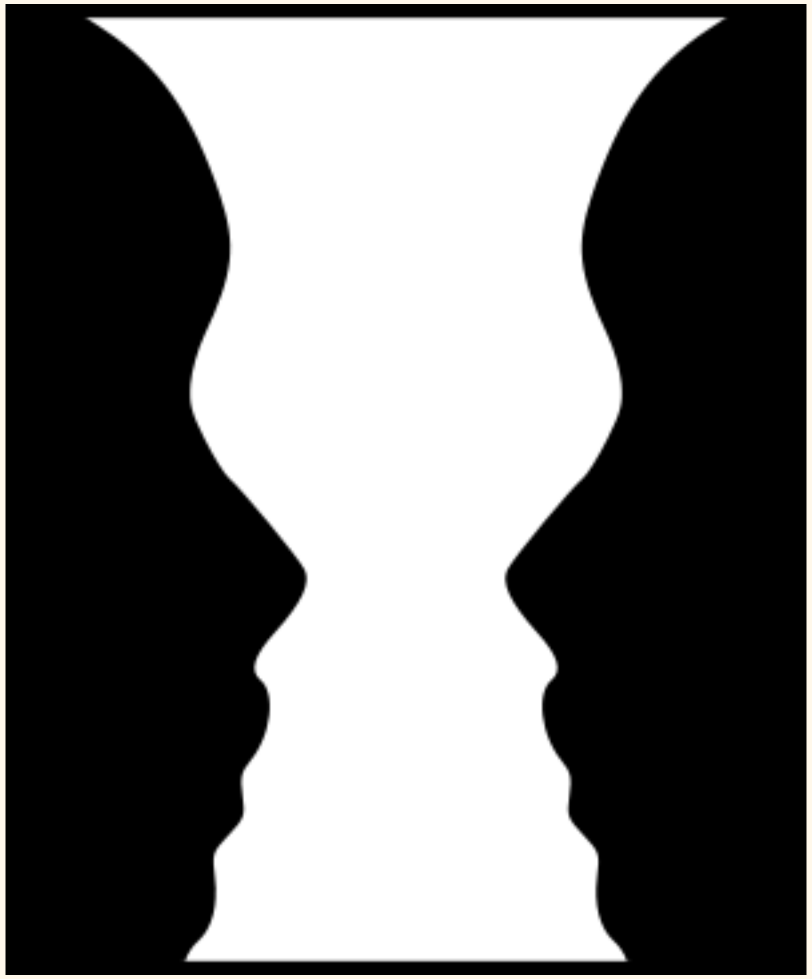
We try to follow the "simplest" path for connected/continuing elements:



Goldsein's Sensation & Perception, Fig. 4.7

Figure & Ground

We try and separate a *figure* from its *background*.



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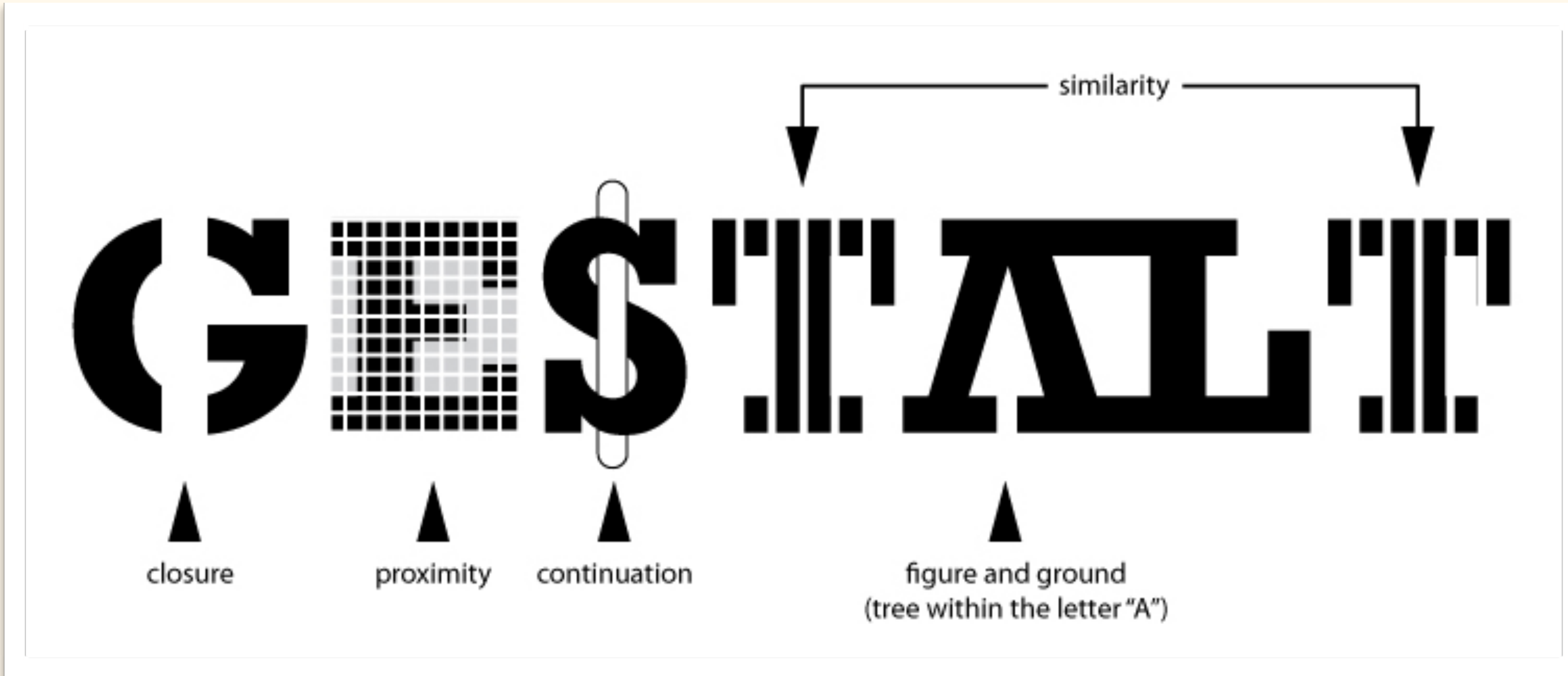
UNIVERSITY



https://yusylvia.wordpress.com/tag/gestalt/

In summary:

Our brains take lots of perceptual "shortcuts"...

... which can either help or harm our visualizations!

KNOWLEDGE IS POWER.

Let's get a bit more practical…

"The purpose of visualization is insight, not pictures."

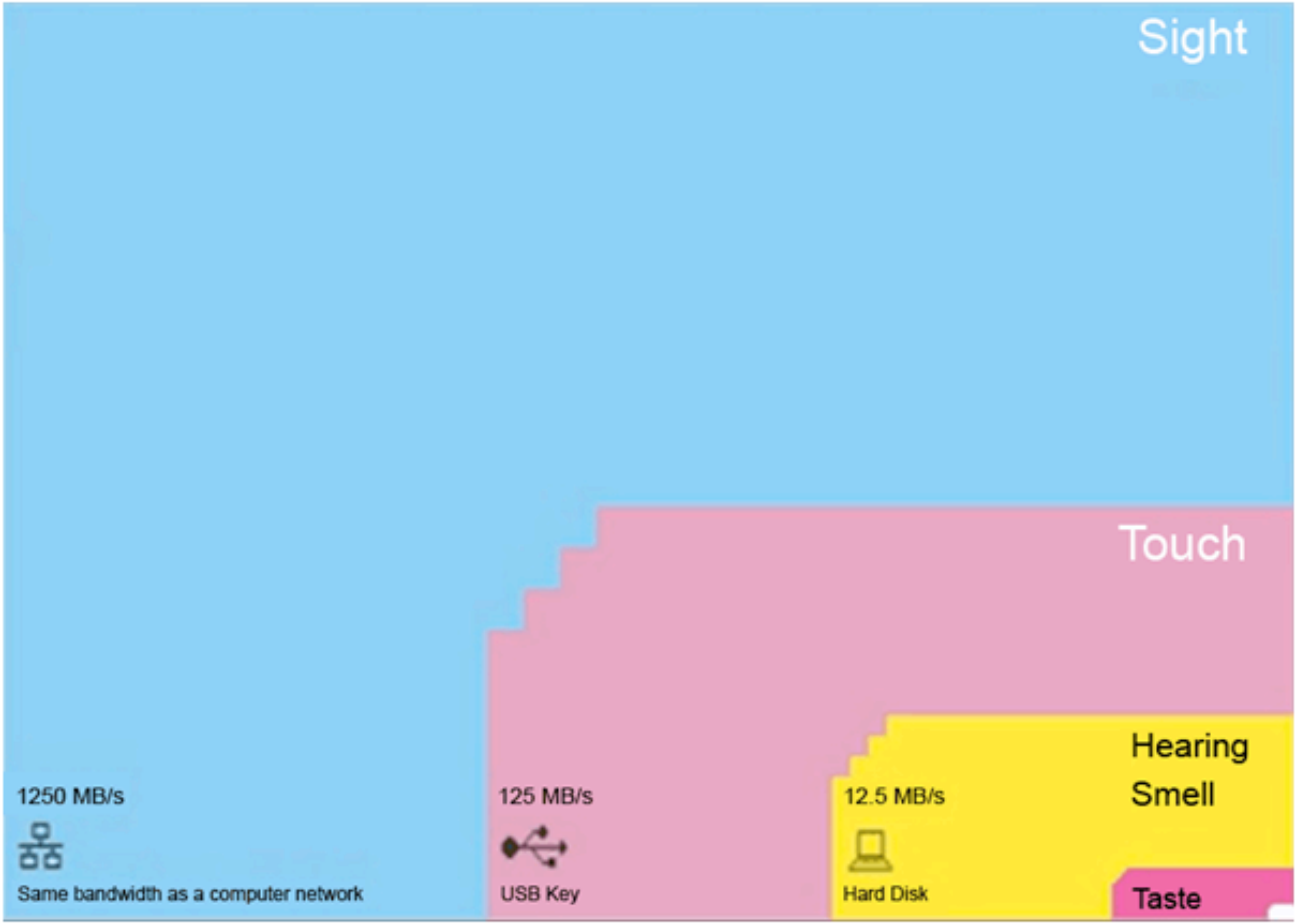
Ben Shneiderman
1947–

Alberto Cairo
1974–

"Graphics, charts, and maps aren't just tools to be seen, but to be read and scrutinized."

Card, Mackinlay, Shneiderman, *Readings in Information Visualization*. Academic Press,1999

Cairo, *The Functional Art*. Peachpit Press, 2013



http://www.mu-sigma.com/uvnewsletter/links.html#a

Visualizations support several basic tasks:

Presenting

"What variables and dimensions are we talking about?"

Enabling comparisons

"Is *this* quantity over here different from *that* quantity over there?"

Organizing

"Which things are grouped with what other things?"

Showing relationships

"Which other variables are linked/related to this variable?"

Different visualizations might have different purposes:

Data processing: to facilitate intensive, detailed analysis of data

Communication of information resulting from an analysis.

The former entails comprehensivity; the latter necessitates abstraction & simplification.

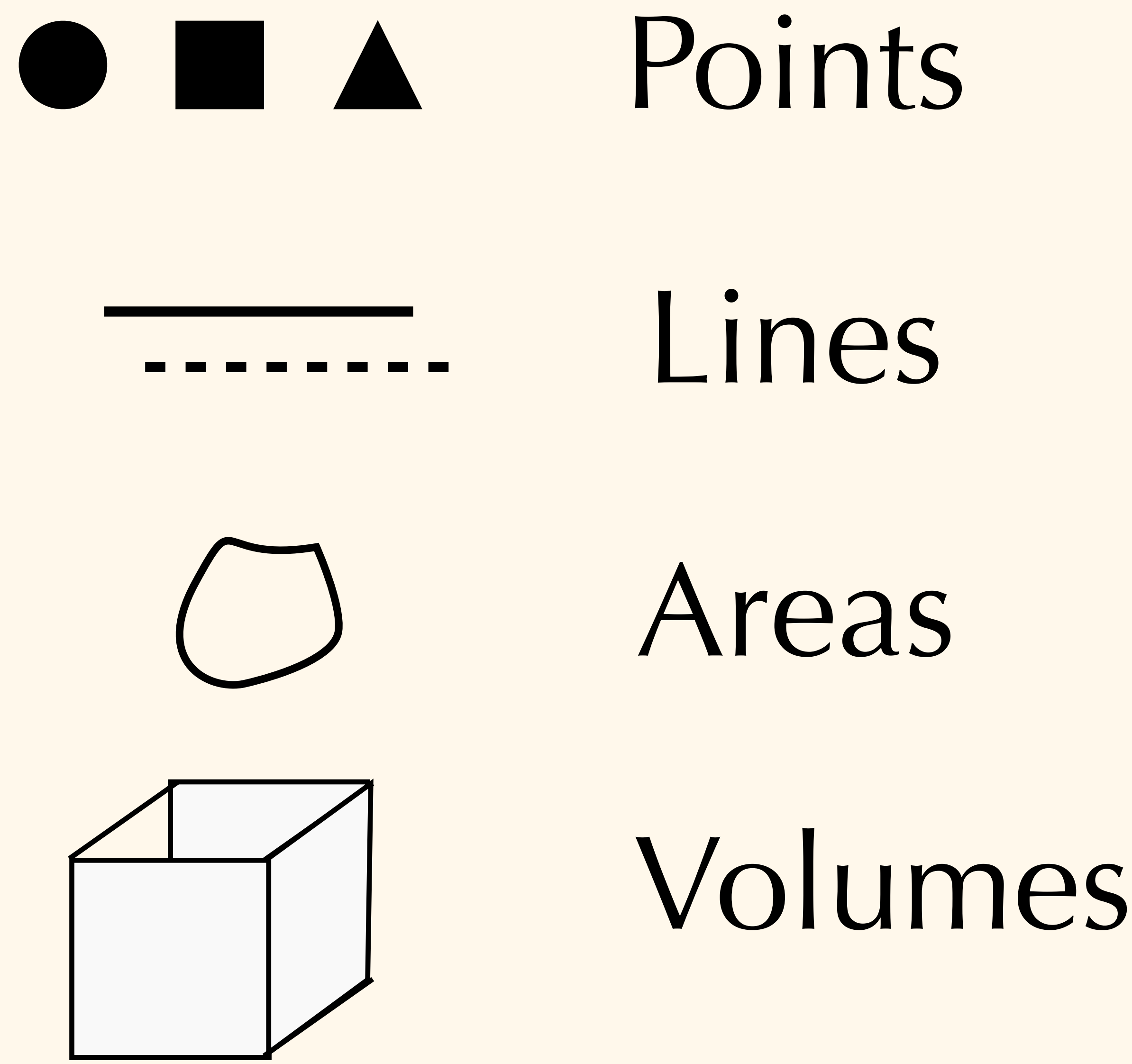
Jaques Bertin
1918–2010

Bertin, *Semiology of Graphics*. ESRI Press ed., 2010

Let’s get a bit more practical…

A visualization is made up of several basic graphical primitives:

"Marks:"



The second category of tools are the basic graphical primitives:

"Attributes of marks:"

Location

Texture

Orientation

Motion/Animation?

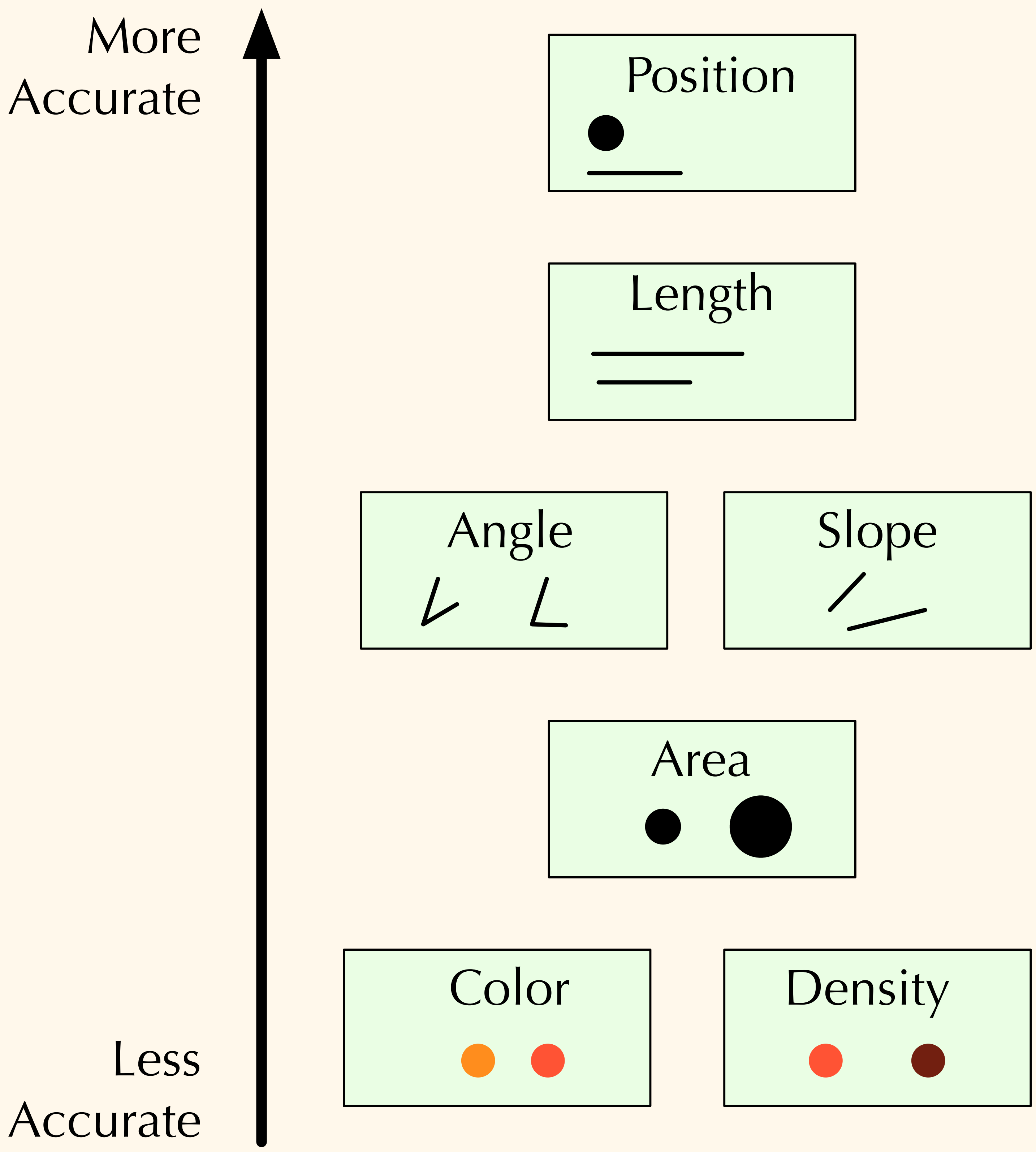
Size

Interactivity?

Color

Can you think of more?

Graphical primitives are not created equal!



Modified from Hearst's interpretation of Mackinlay '88

Steven's Psychophysical Power Law: $S= I^N$

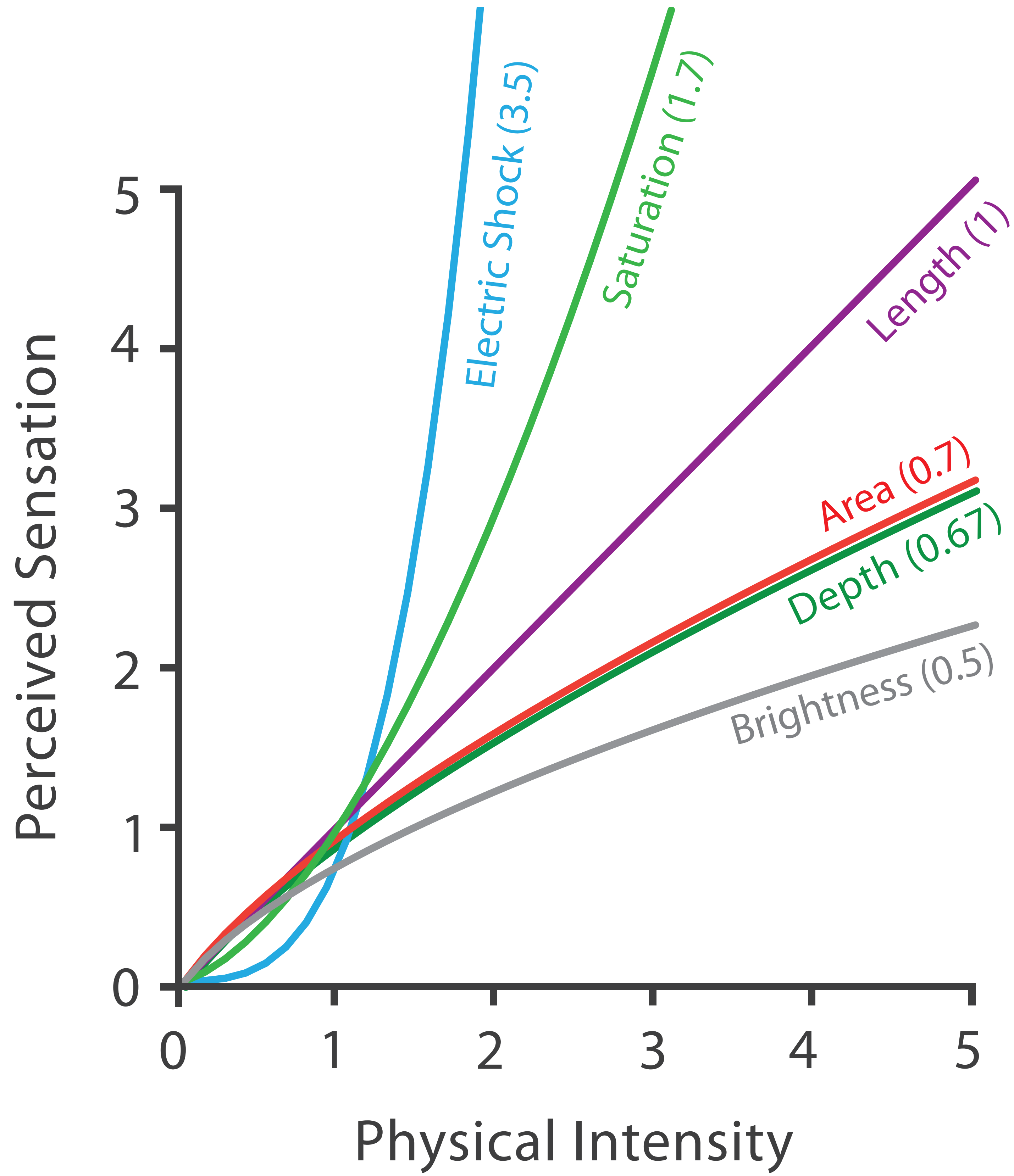
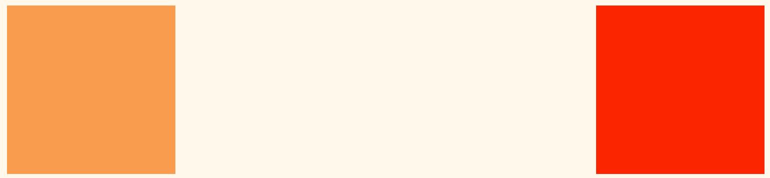


Figure from Tamara Munzer (CC-BY-SA): http://www.cs.ubc.ca/~tmm/talks/minicourse14/vad16act.pdf, after Stevens, S.S. (1957). "On the psychophysical law". *Psychological Review*. 64 (3): 153–181.

In other words:

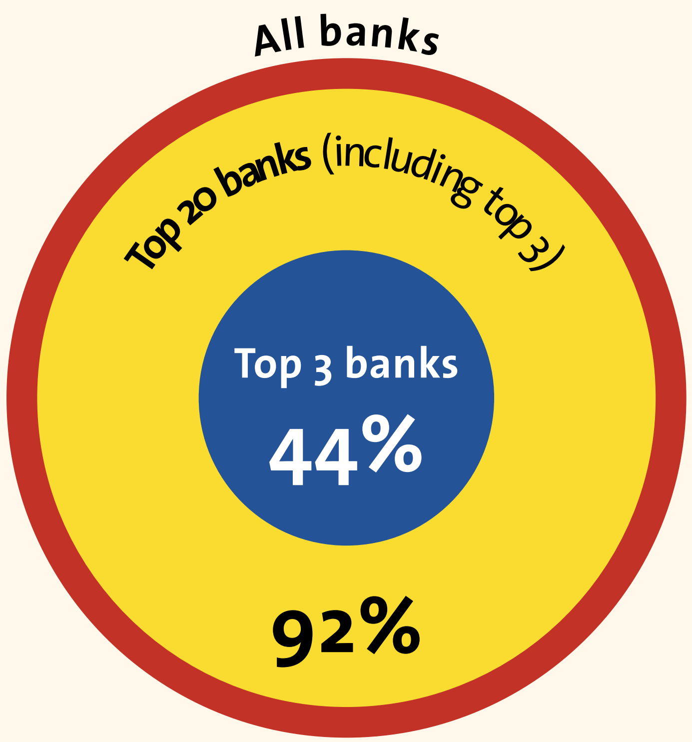
Humans are better at telling that one line is twice as long as another line...

... than they are at telling that one square is twice as red as another square.

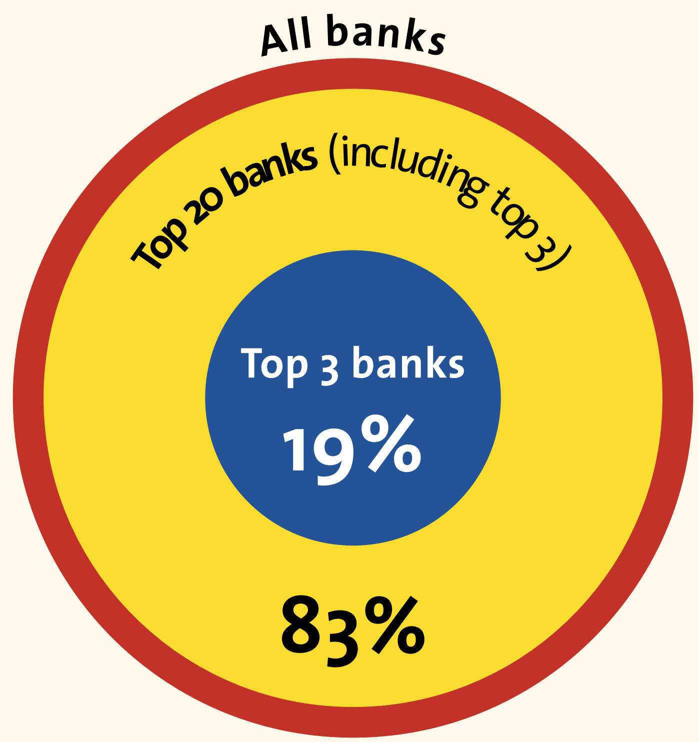


Therefore: using attributes from the bottom of the hierarchy for *quantitative* interpretation is probably a bad idea!

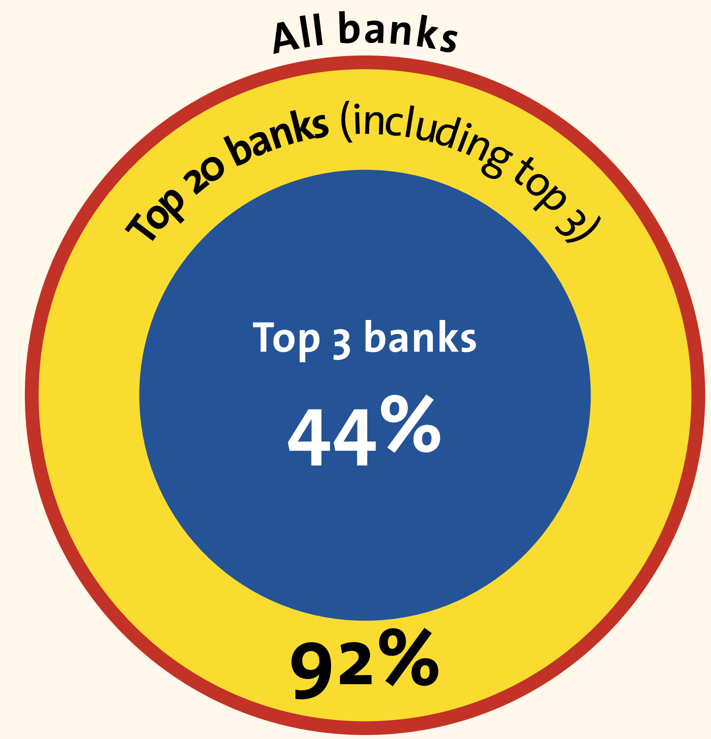
Area is another tricky one:



In *The New York Times*



Actual percentages of *The New York Times* diagrams



Correct diagram of *The New York Times* data

This is why so many people are anti-pie-chart!

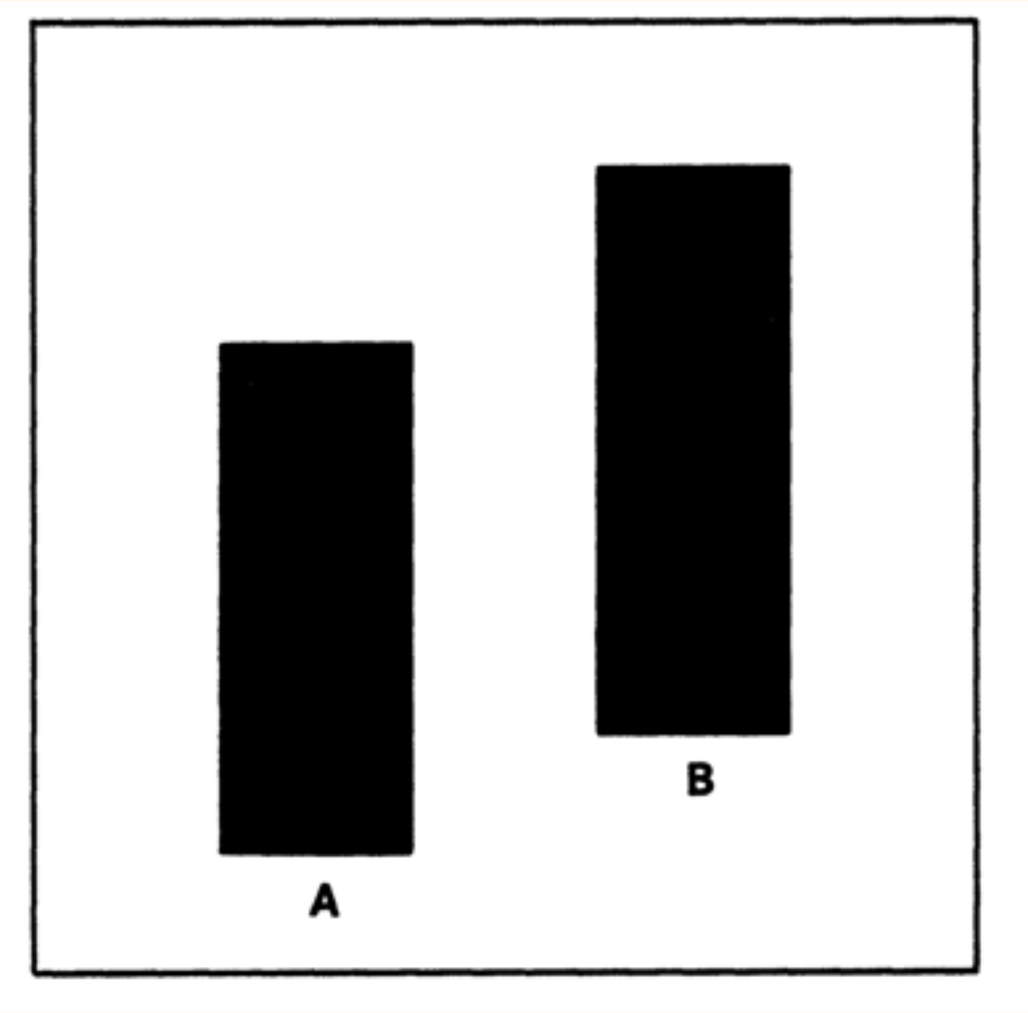
“Designing Information”, by Joel Katz, p.85

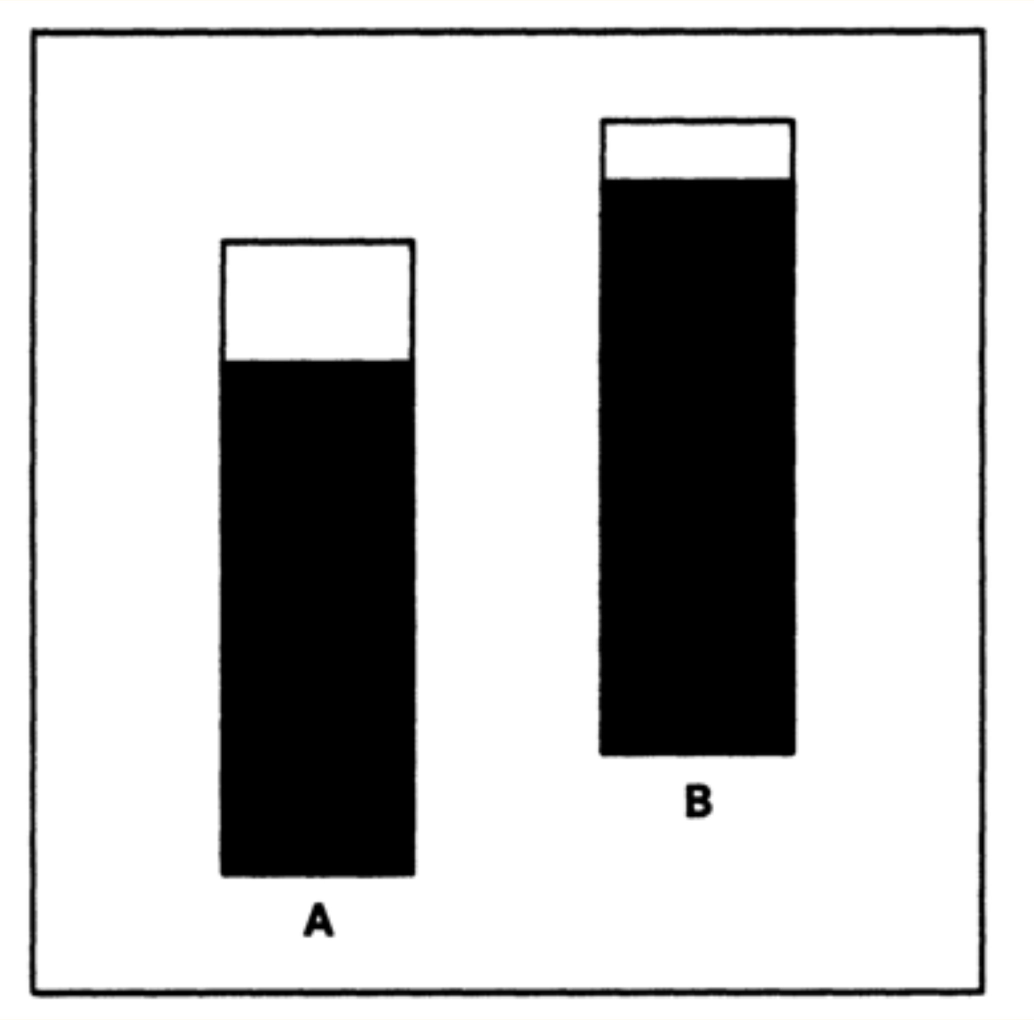
And, context matters a lot!

Length is *usually* a very accurate choice...

Except when it isn't!

And, context matters a lot!

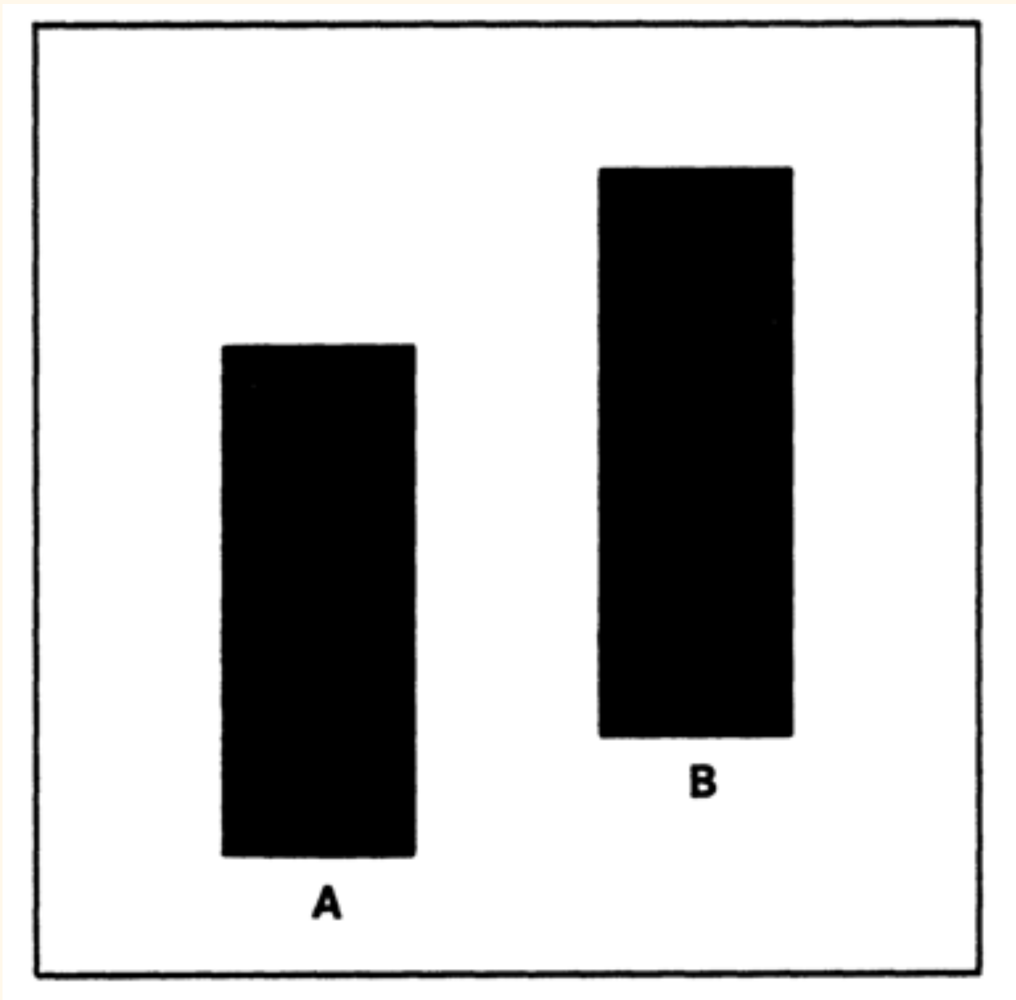


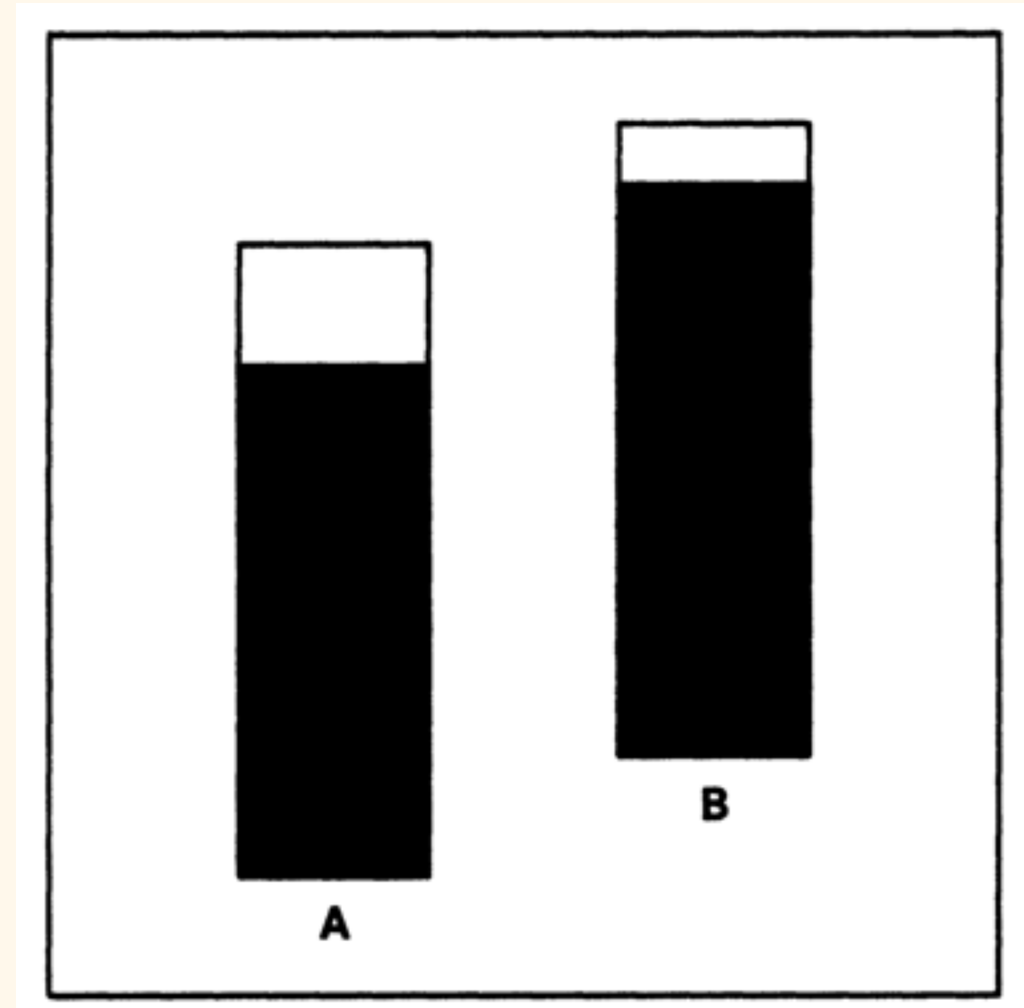


The black bars differ in *absolute* length exactly as much as do the white bars...

William S Cleveland RM. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Journal of the American Statistical Association. 1984;79(387):531–54.

Also, context matters a lot!

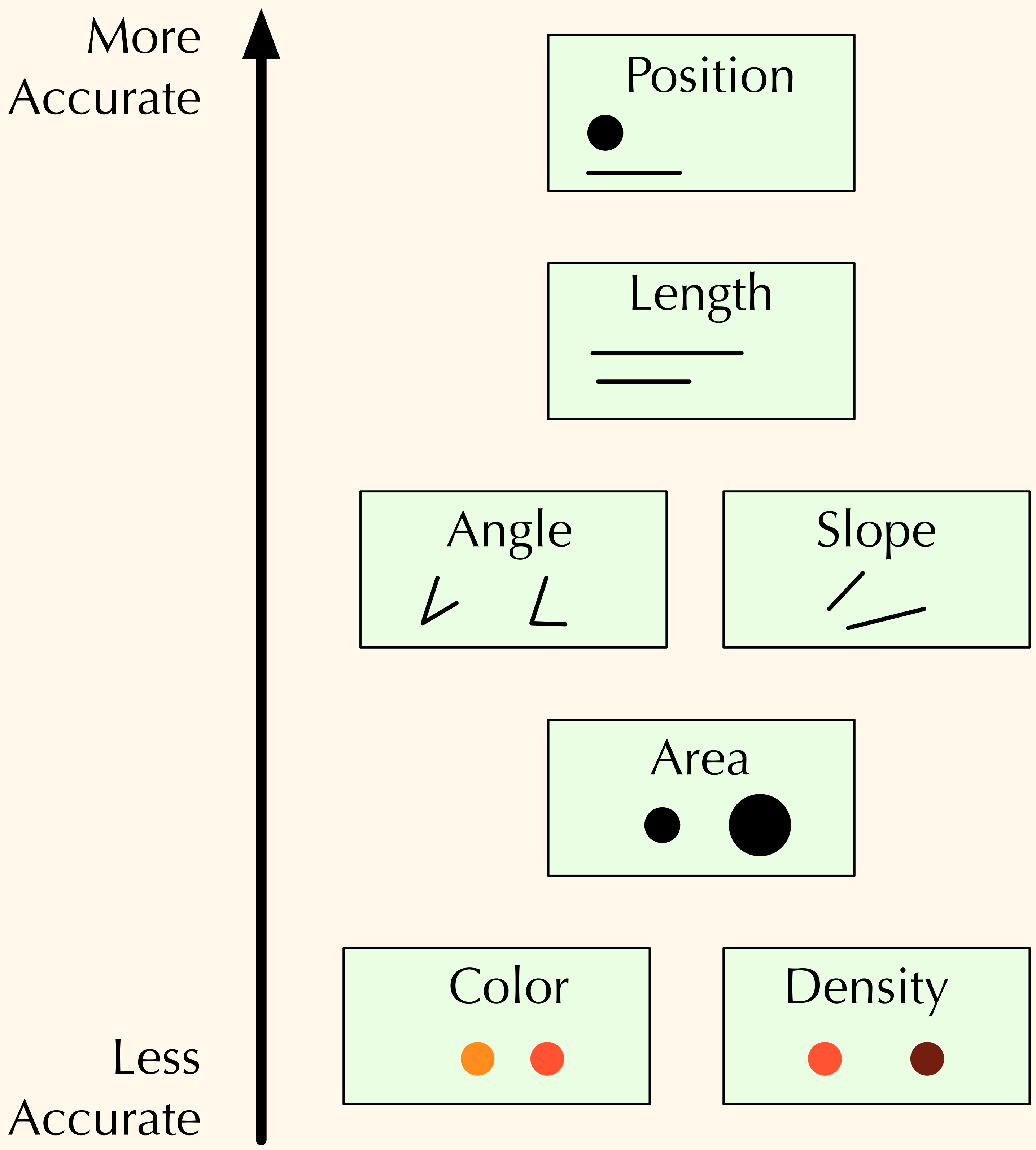




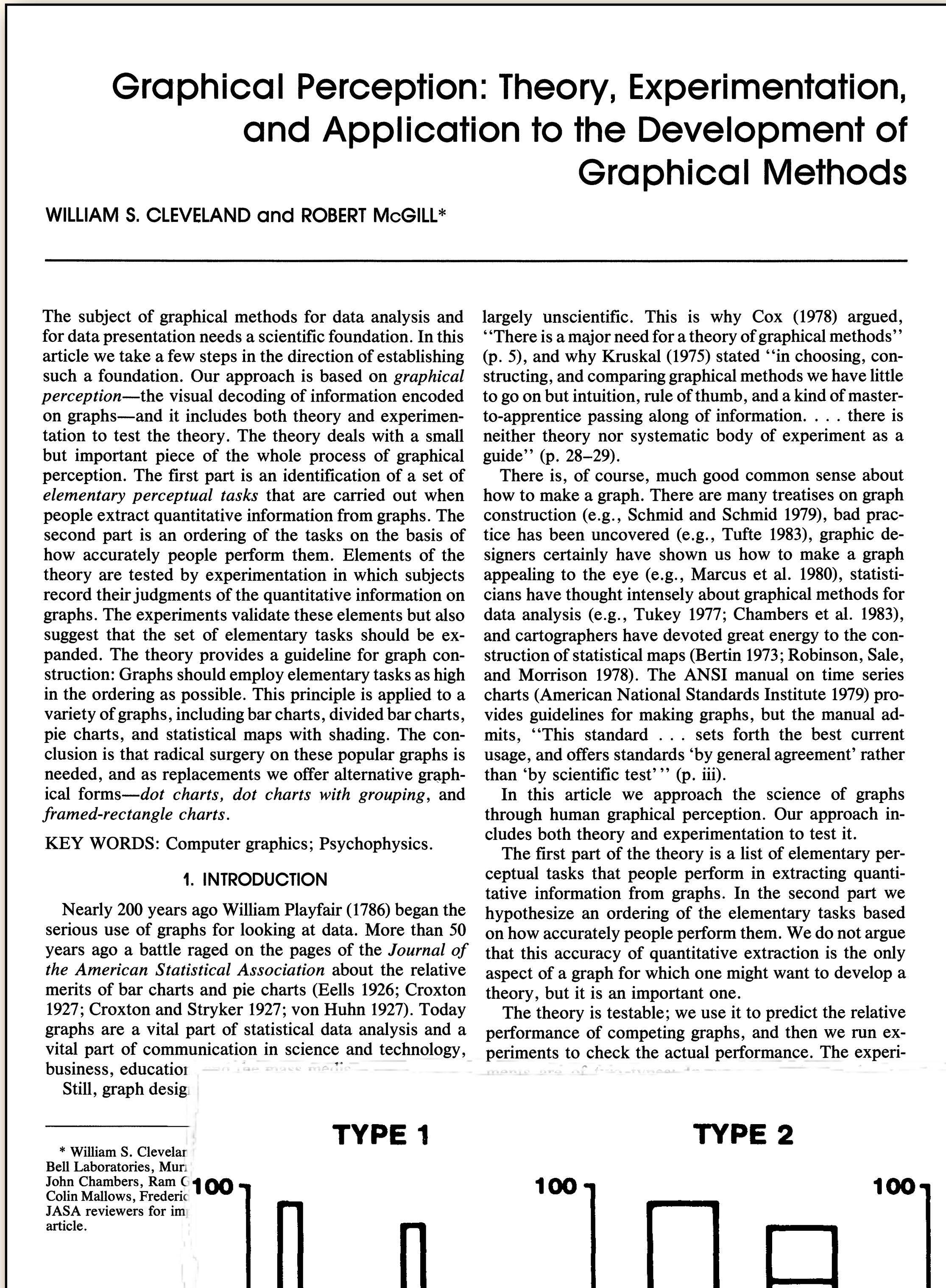
... but the white bars are *relatively* more different, and so the difference is more apparent (Weber's Law).

William S Cleveland RM. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Journal of the American Statistical Association. 1984;79(387):531–54.

Graphical primitives are not created equal!



Modified from Hearst's interpretation of Mackinlay '88



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 experimentation 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 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 radical surgery on these popular graphs is needed, and as replacements we offer alternative graphical forms—*dot charts, dot charts with grouping*, and *framed-rectangle charts*.

KEY WORDS: Computer graphics; Psychophysics.

1. INTRODUCTION

Nearly 200 years ago William Playfair (1786) 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 (Eells 1926; Croxton 1927; Croxton and Stryker 1927; von Huhn 1927). Today graphs are a vital part of statistical data analysis and a vital part of communication in science and technology, business, educatioı

Still, graph desig

largely unscientific. This is why Cox (1978) argued, "There is a major need for a theory of graphical methods" (p. 5), and why Kruskal (1975) stated "in choosing, constructing, and comparing graphical methods we have little to go on but intuition, rule of thumb, and a kind of master-to-apprentice 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 treatises on graph construction (e.g., Schmid and Schmid 1979), bad practice has been uncovered (e.g., Tufte 1983), graphic designers certainly have shown us how to make a graph appealing to the eye (e.g., Marcus et al. 1980), statisticians have thought intensely about graphical methods for data analysis (e.g., Tukey 1977; Chambers et al. 1983), and cartographers have devoted great energy to the construction of statistical maps (Bertin 1973; Robinson, Sale, and Morrison 1978). The ANSI manual on time series charts (American National Standards Institute 1979) provides guidelines for making graphs, but the manual admits, "This standard . . . sets forth the best current usage, and offers standards 'by general agreement' rather than 'by scientific test'" (p. iii).

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

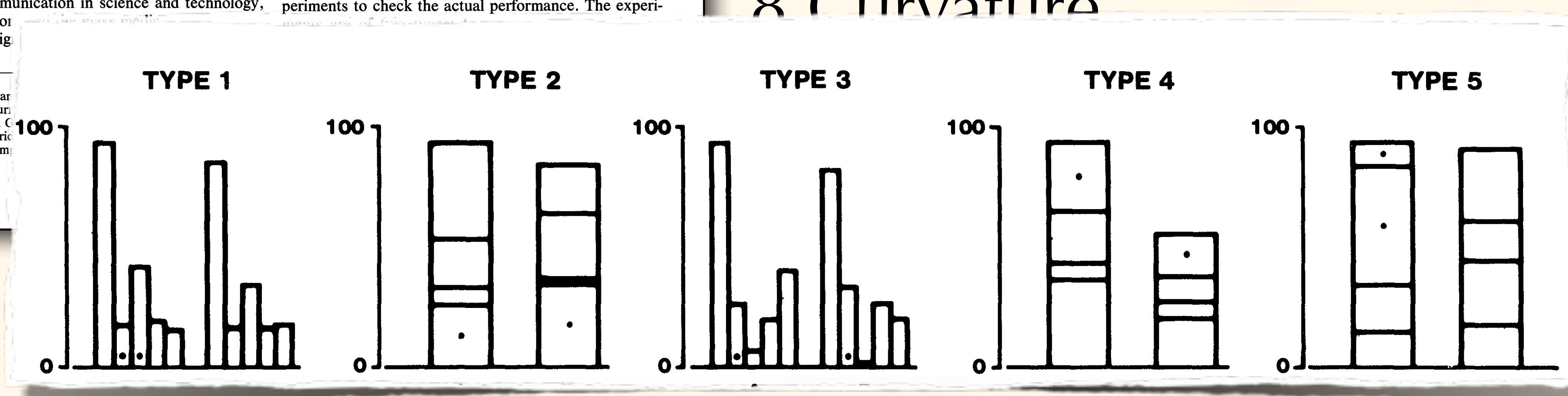
The first part of the theory is a list of elementary perceptual tasks that people perform in extracting quantitative information from graphs. In the second part we hypothesize an ordering of the elementary tasks based on how accurately people perform them. We do not argue that this accuracy of quantitative 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 competing graphs, and then we run experiments to check the actual performance. The experi-

* William S. Clevelar
Bell Laboratories, Mur
John Chambers, Ram C
Colin Mallows, Frederic
JASA reviewers for im
article.

10 Basic Perceptual Tasks:

1. Position along common scale
2. Position along non-aligned scales
3. Length
4. Direction
5. Angle
6. Area
7. Volume
8. Curvature



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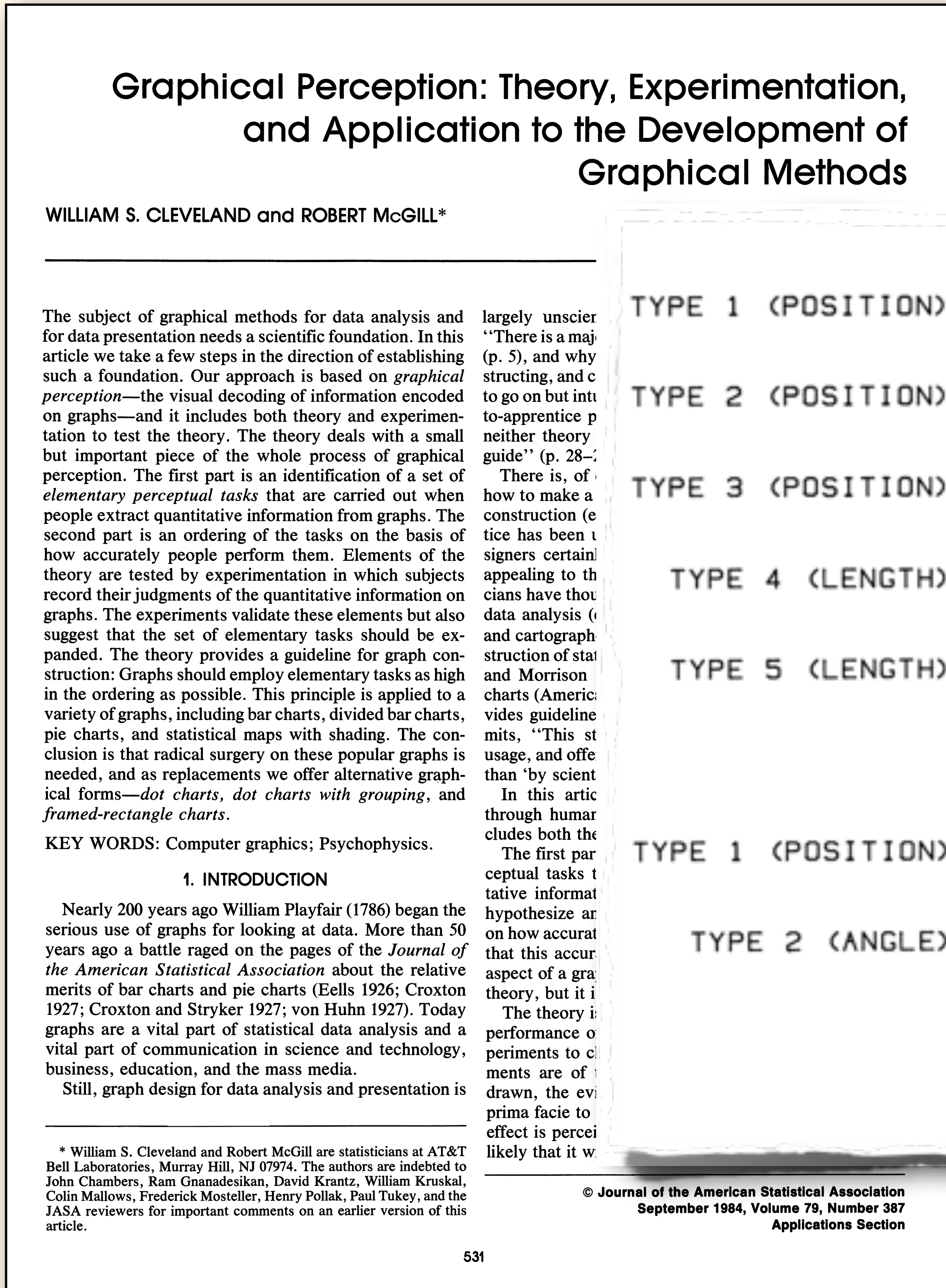

Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods

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 experimentation 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 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 radical surgery on these popular graphs is needed, and as replacements we offer alternative graphical forms—*dot charts, dot charts with grouping*, and *framed-rectangle charts*.

KEY WORDS: Computer graphics; Psychophysics.

1. INTRODUCTION

Nearly 200 years ago William Playfair (1786) 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 (Eells 1926; Croxton 1927; Croxton and Stryker 1927; von Huhn 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

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© Journal of the American Statistical Association
September 1984, Volume 79, Number 387
Applications Section

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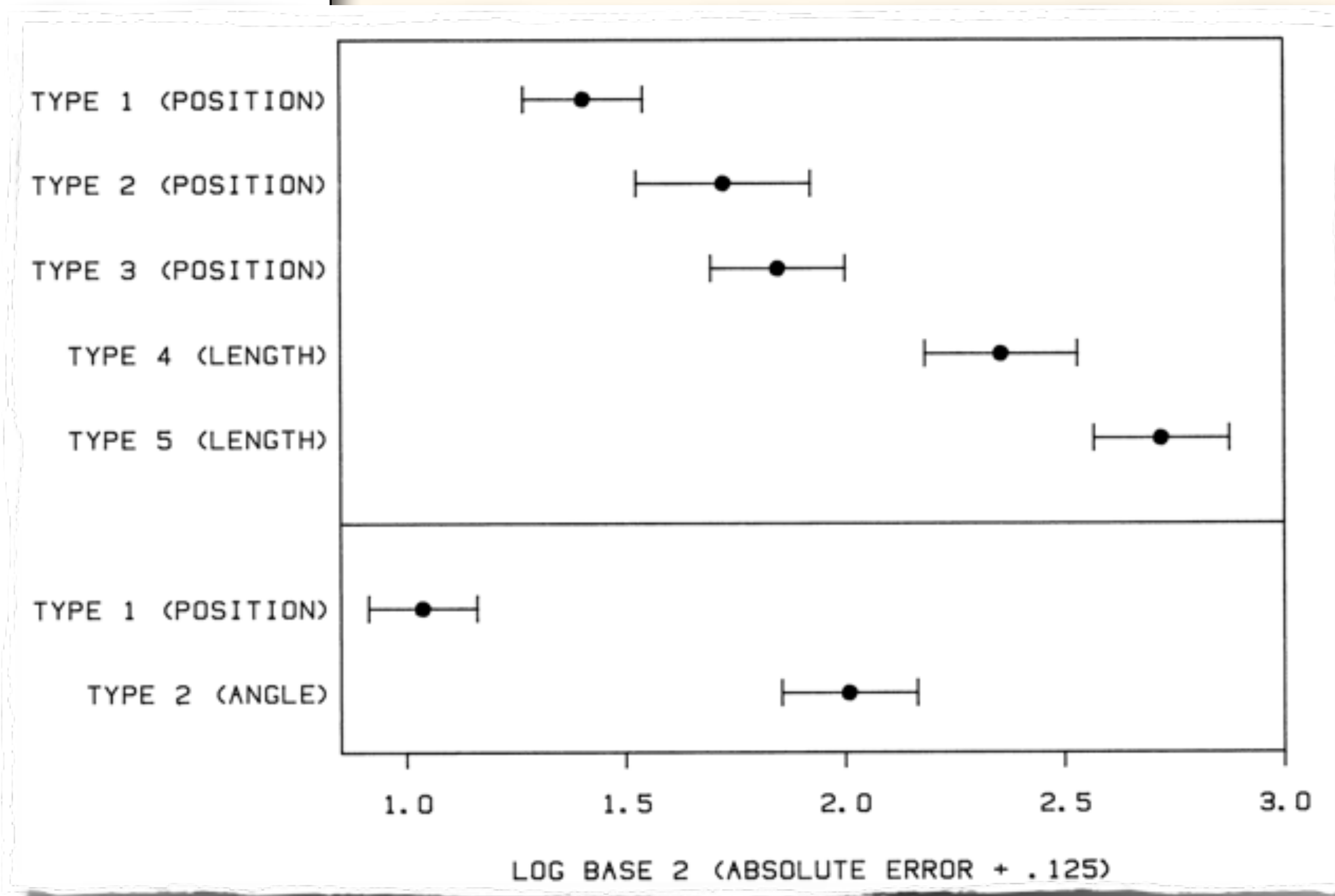
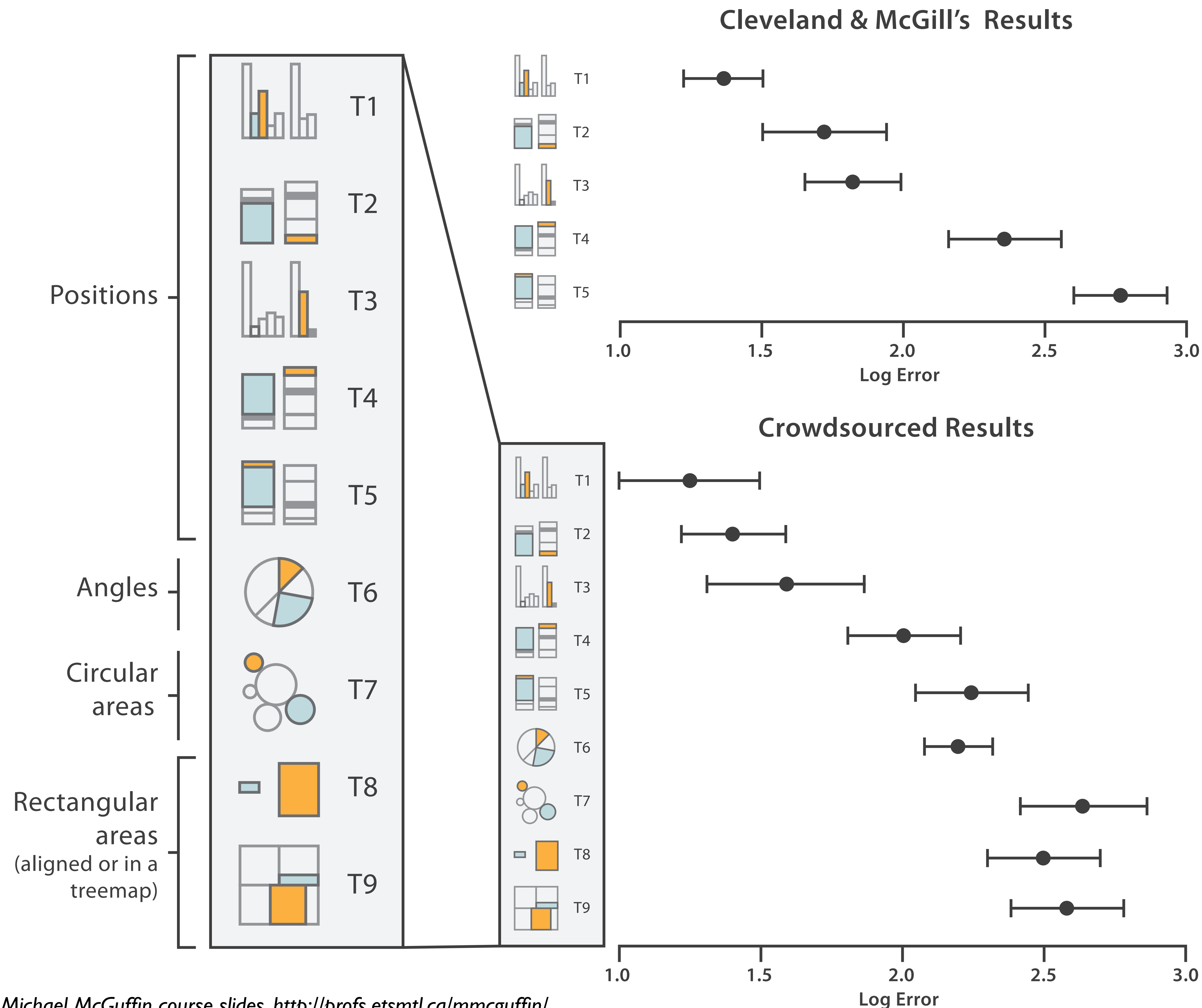


Key finding: accuracy of interpretation of a graph varies greatly depending on the type of judgment and type of graph.

William S Cleveland RM. Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Journal of the American Statistical Association. 1984;79(387):531–54.



after Michael McGuffin course slides, http://profs.etsmtl.ca/mmcguffin/

Figure from Tamara Munzer (CC-BY-SA): http://www.cs.ubc.ca/~tmm/talks/minicourse14/vad16act.pdf; Heer J, Bostock M. Crowdsourcing graphical perception: using mechanical turk to assess visualization design. ACM CHI '10; 2010. p. 203–12.

Variables on Scatterplots Look More Highly Correlated When the Scales Are Increased

Abstract. *Judged association between two variables represented on scatter[...] increased when the scales on the horizontal and vertical axes were simultaneo[...] increased so that the size of the point cloud within the frame of the plot decrea[...]*

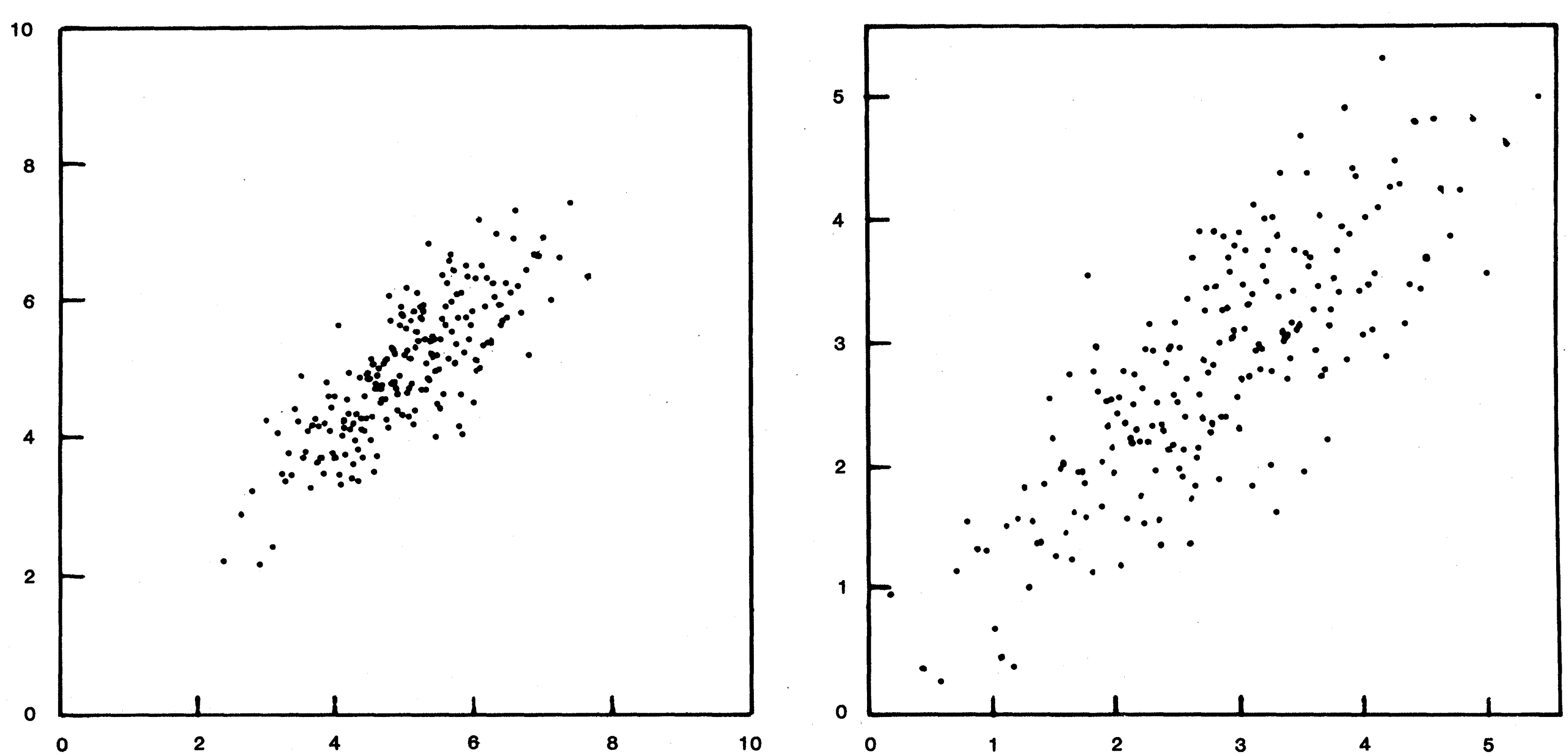


Fig. 1. Reductions of two scatterplots used in the three types of experiments. The left panel is point-cloud size 2 and the right panel is point-cloud size 4. In both panels w(r) = .4 and r = .8.

Cleveland WS, Diaconis P, McGill R. Variables on Scatterplots Look More Highly Correlated When the Scales Are Increased. Science; 1982;216(4550):1138–41.

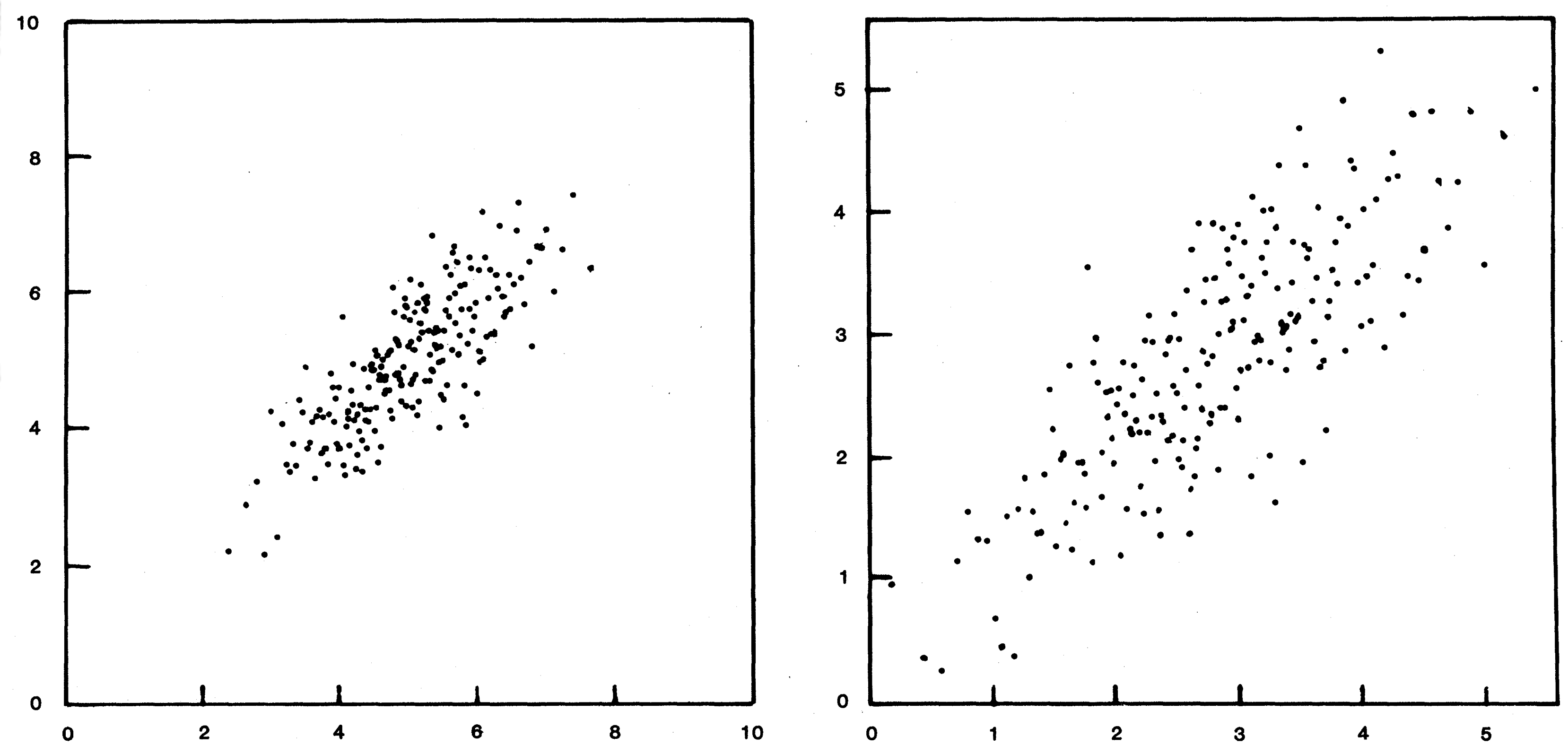


Fig. 1. Reductions of two scatterplots used in the three types of experiments. The left panel is point-cloud size 2 and the right panel is point-cloud size 4. In both panels $w(r)$ = .4 and r = .8.

Thus the second and third experiments strongly corroborate the conclusion of the first: increasing the scales on the horizontal and vertical axes of a scatterplot so as to decrease the point-cloud size increases the judged association.

Cleveland WS, Diaconis P, McGill R. Variables on Scatterplots Look More Highly Correlated When the Scales Are Increased. Science; 1982;216(4550):1138–41.

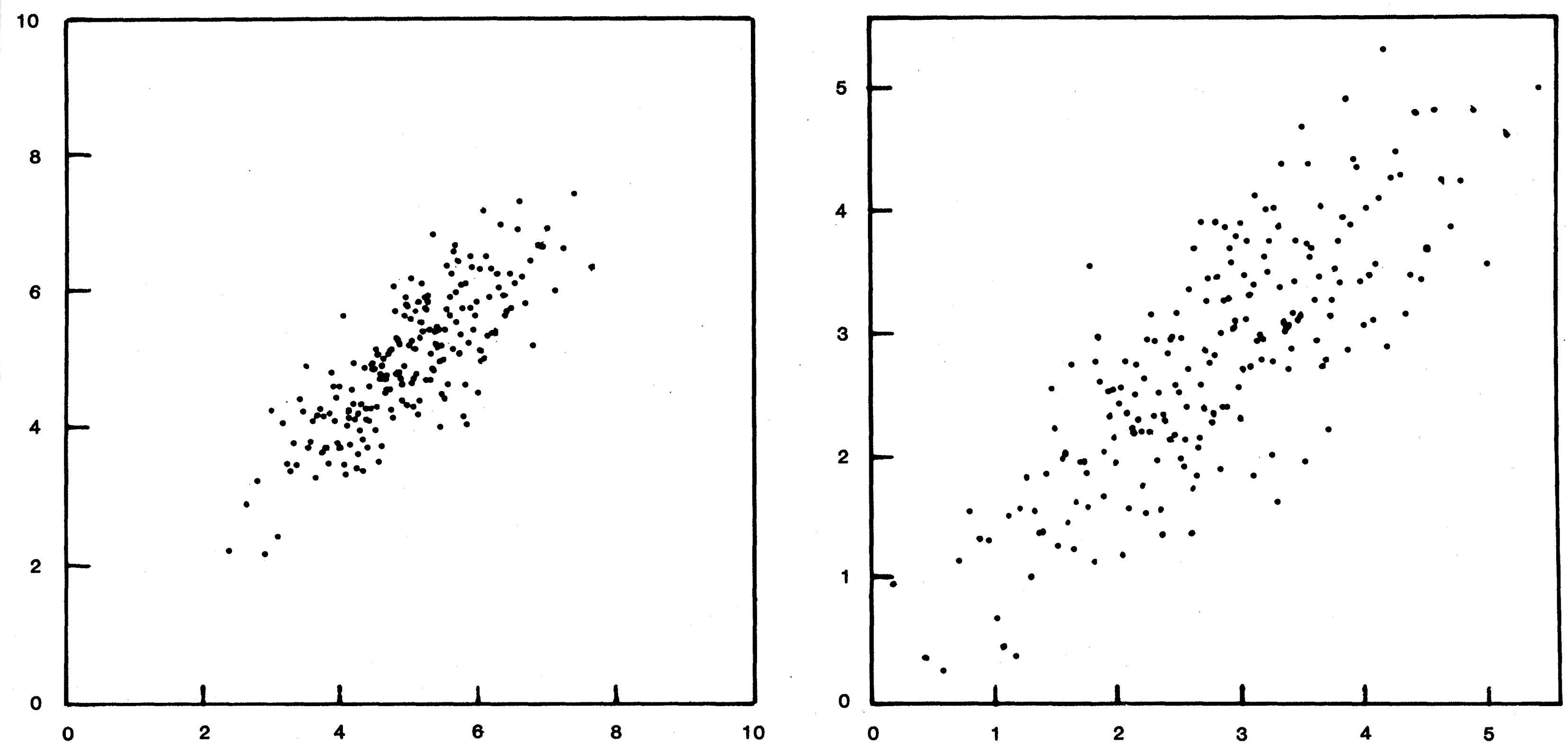
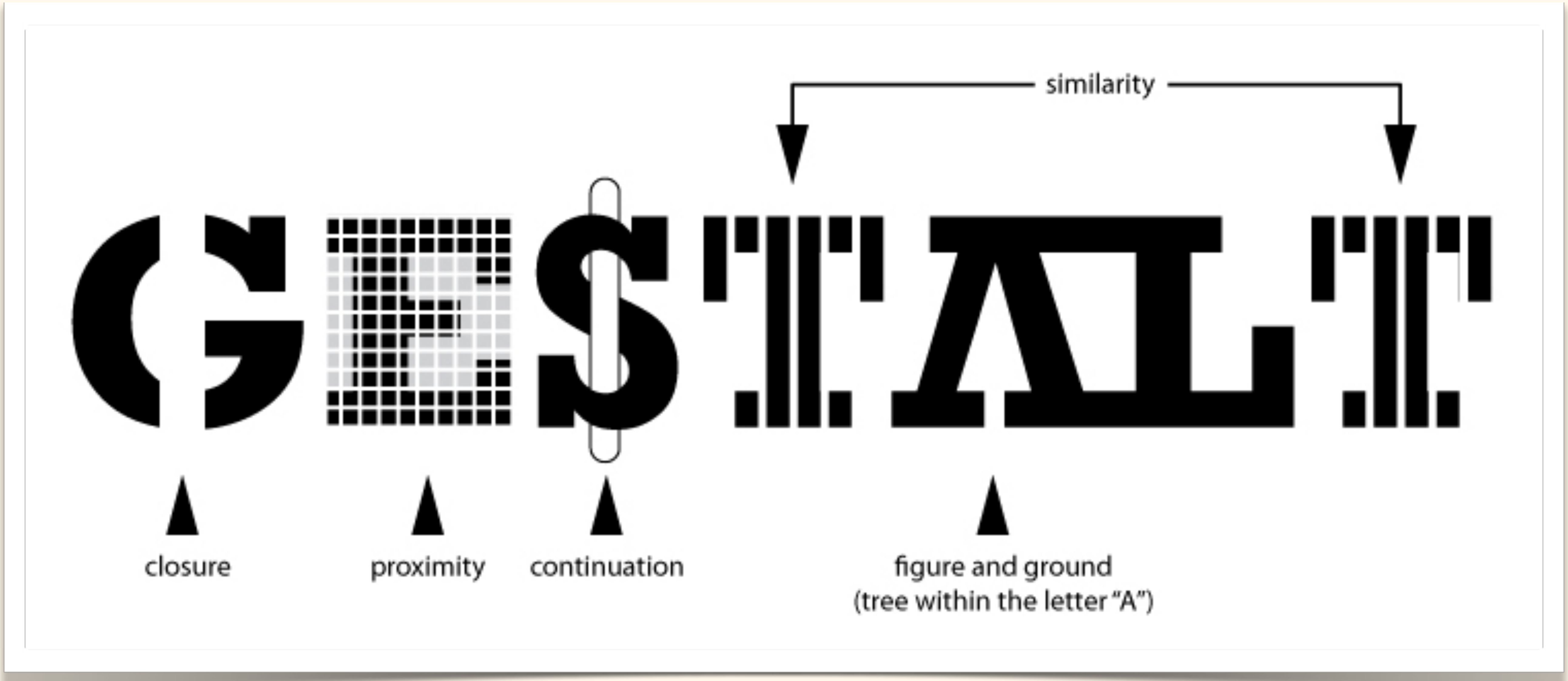


Fig. 1. Reductions of two scatterplots used in the three types of experiments. The left panel is point-cloud size 2 and the right panel is point-cloud

Pop Quiz: Why does this happen?

Cleveland WS, Diaconis P, McGill R. Variables on Scatterplots Look More Highly Correlated When the Scales Are Increased. Science; 1982;216(4550):1138–41.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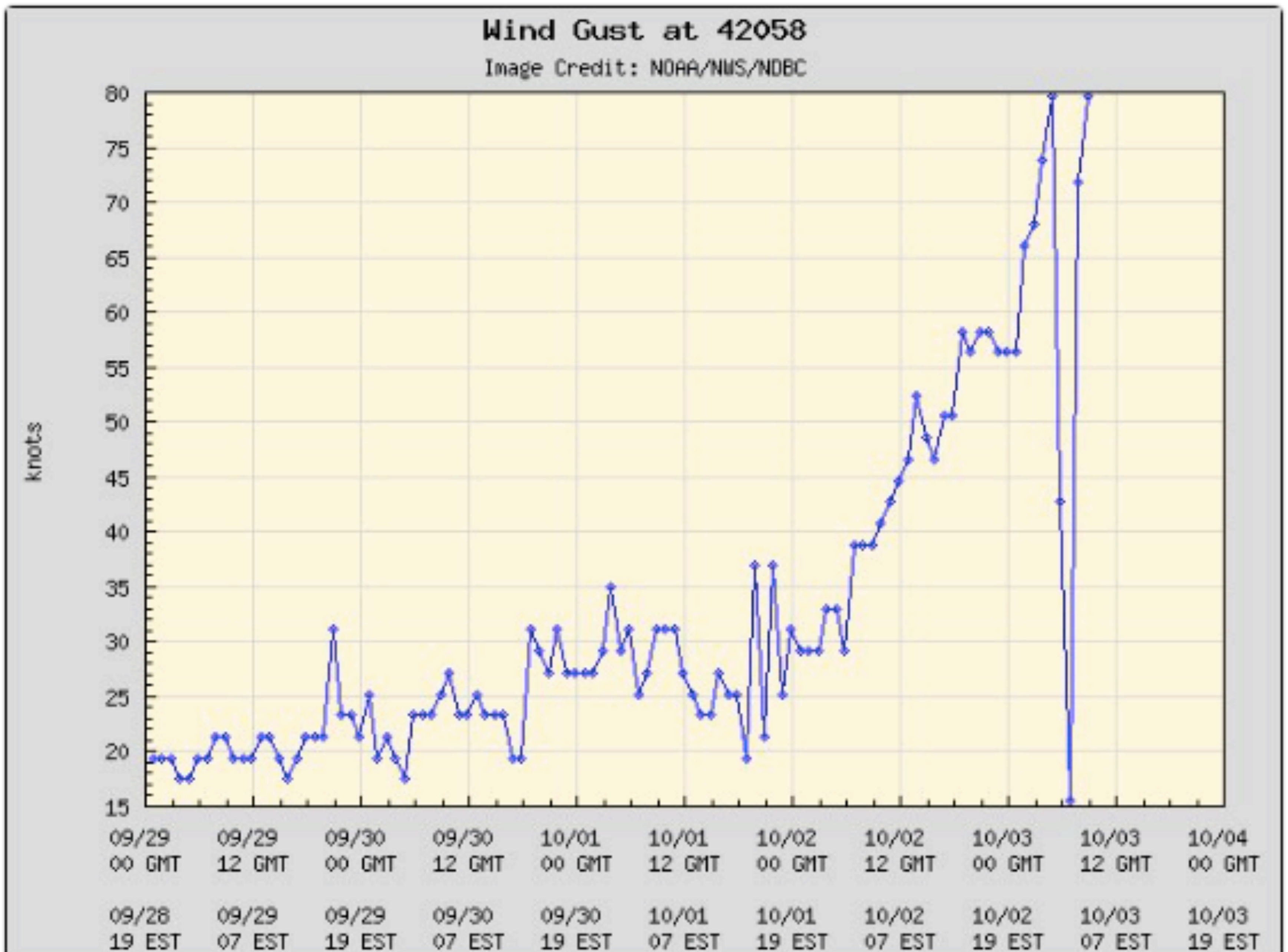
Matthew Potter
@mpotter_wx

Follow

That's no error. The eye of Hurricane #Matthew went right over a weather observation buoy in the middle of the Caribbean



RETWEETS 597 LIKES 680

Homework: find examples of both positive and negative preattentive/ Gestalt behavior in a visualization.

Either find new ones, or re-evaluate your existing +/- examples.