Visualization Research and the Human Mind

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How can empirical research in visualization be further improved?

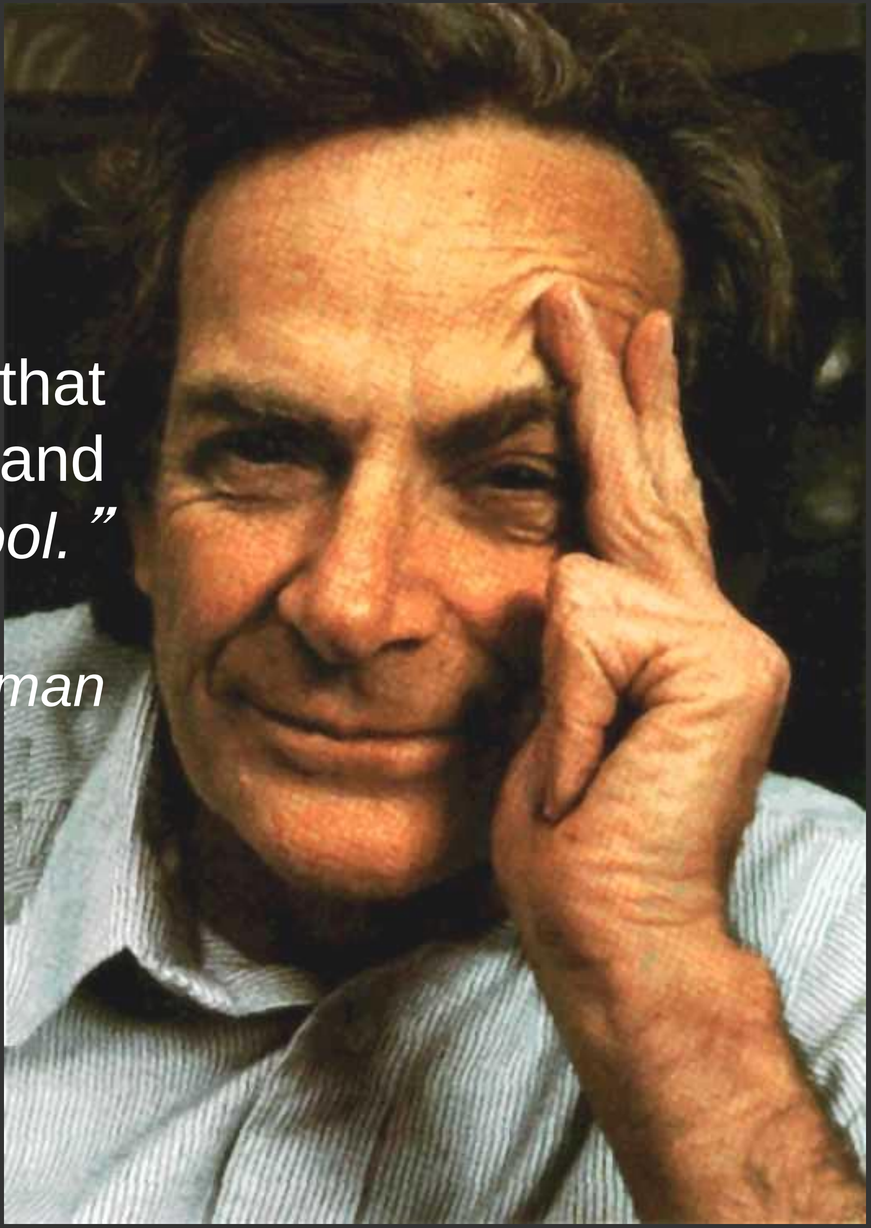
- more knowledge of high-level cognition

- more knowledge of visual perception

High-level cognition *(i.e., thinking)…*

“The first principle is that
you must not fool yourself, and
you are the easiest person to fool.”

–Richard Feynman



1. High-level Cognition: ***Finding Answers***

Human minds are not that logical (*e.g., Kahneman, 2011*)

- *tend to be “quick and dirty”*
- *typically follow particular heuristics*
- *we don’t notice how prevalent these are*

E.g.: Confirmation bias

Does system/method/theory X work?

System X	Test 1	✓

But – are you fooling yourself?

Advocacy?

E.g.: Confirmation bias

~~Does system/method/theory X work?~~

Is system/method/theory X *better than* Y, Z, etc?

System X	Test 1
System Y	Test 1
System Z	Test 1

?

- Compare *alternative candidates*

But – are you still fooling yourself? *Cherry picking?*

- multiple hypotheses *(competing hypotheses)*

E.g.: Confirmation bias

~~Does system/method/theory X work?~~

Is system/method/theory X *better than* Y, Z, etc?

System X	Test 1	Test 2	…
System Y	Test 1	Test 2	…
System Z	Test 1	Test 2	…

?

- Obtain *different kinds of evidence*

  - e.g., *control condition: varies only in the key factor;*
  (everything else is held constant)

High-level Cognition: Finding Answers

Recommendations: *(don't fool yourself!)*

- *be alert to the possibility your belief may be wrong*
- *design tests to distinguish between alternatives*
- *design tests that use multiple sources of evidence*

Look at books / articles on experimental methodology

2. *High-level Cognition:* ***Finding Questions***

Human minds are not that imaginative

- *have trouble dealing with alternatives*
- *have trouble dealing with uncertainty*
- *imagination is often limited to variations of the known*

This can interfere with creating new issues / new designs.

High-level Cognition: Finding Questions

Recommendations: *(don't fool yourself!)*

- *don't immediately reject any new idea / proposal*
  - *learn to be open to new ideas; give them consideration*
- *don't immediately reject strange findings / phenomena*
  - *learn to be open to feedback, esp. negative feedback*
- *try to focus on* ***differences that make a difference***
  - *try to evolve a feel for what the interesting issues might be*

All of these are skills; can be improved by training

(see e.g. Rensink, IEEE CG&A, Mar-Apr 2015)

What about issues specific to visualization?

Look at vision science…

1. Vision Science: **Mechanisms**

Knowledge of visual perception can help design effective visualizations (*e.g., Card, Mackinlay, & Shneiderman, 1999*)

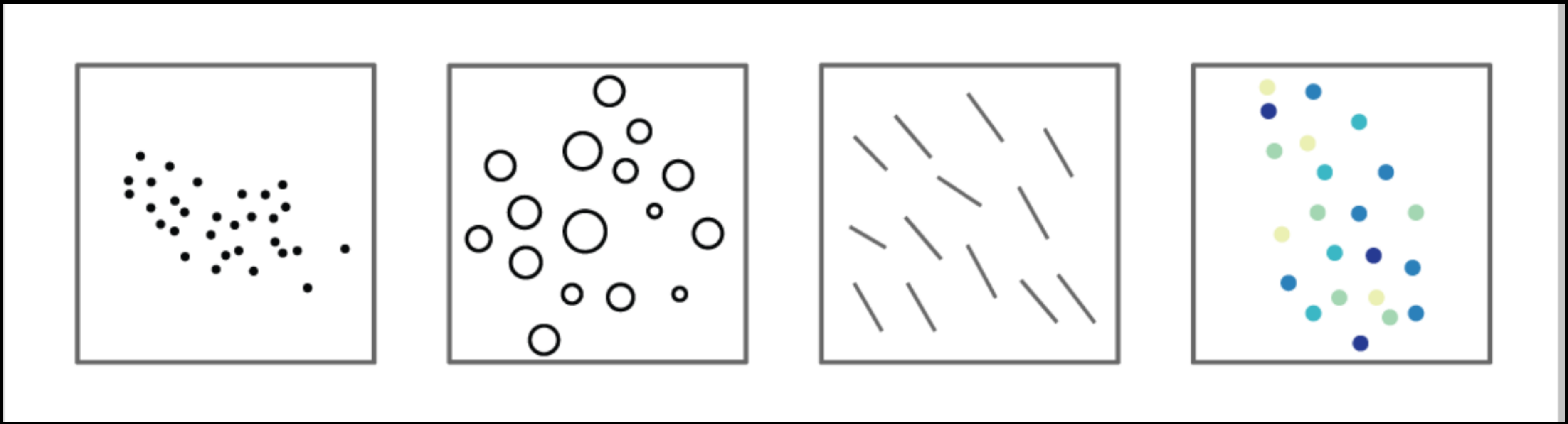
Introductory books are okay as a start.

But - our knowledge of how we see is

- *increasing at a rapid rate*
- *becoming increasingly counterintuitive*
- *becoming increasingly relevant for visualization*

E.g.: Ensemble coding

Within 100-150 ms, humans can perceive average



position size orientation color

(e.g., Safir, Haroz, Gleicher, & Franconeri, 2016)

Vision Science: Mechanisms

Recommendations: Stay in touch with this community

- *look at textbooks that are recent (≤ 10 yrs old)*
- *look at review articles that are recent (≤ 10 yrs old)*
- *talk to your friendly neighborhood vision scientist ☺*

2. Vision Science: **Methodology**

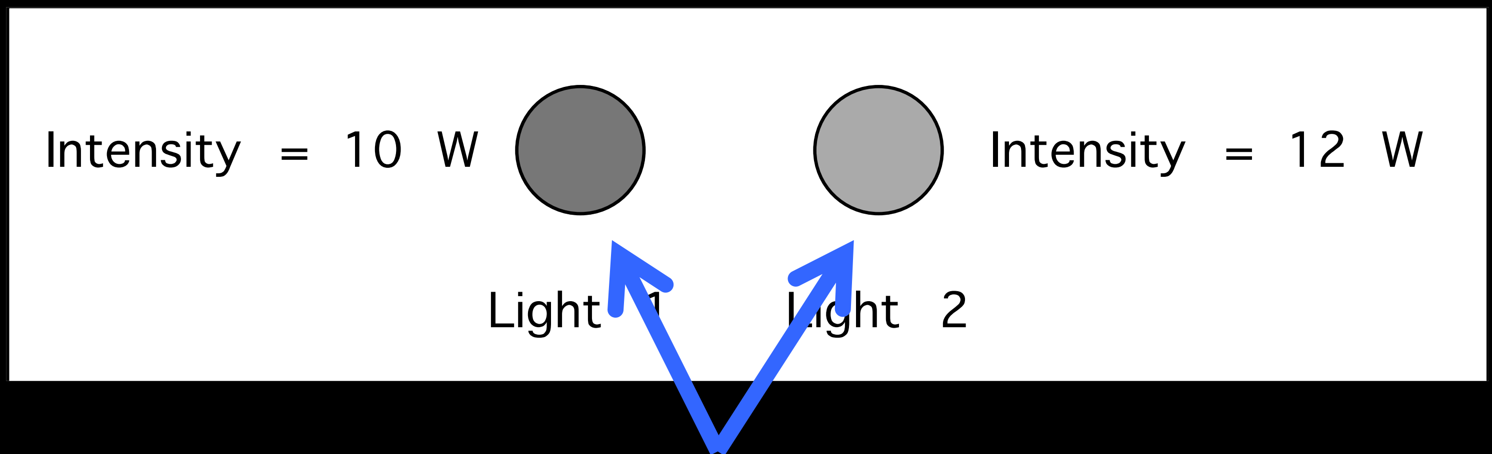
Many possible measures of performance of a design

Consider adapting those developed in vision science

- *highly sensitive assessment of visual performance*
  - *quantities measured are often not obvious*
- *result of long experience in avoiding "booby traps"*
- *can often be adapted to complex situations*

E.g.: Just noticeable difference (JND)

Q: Which light has the greater intensity?



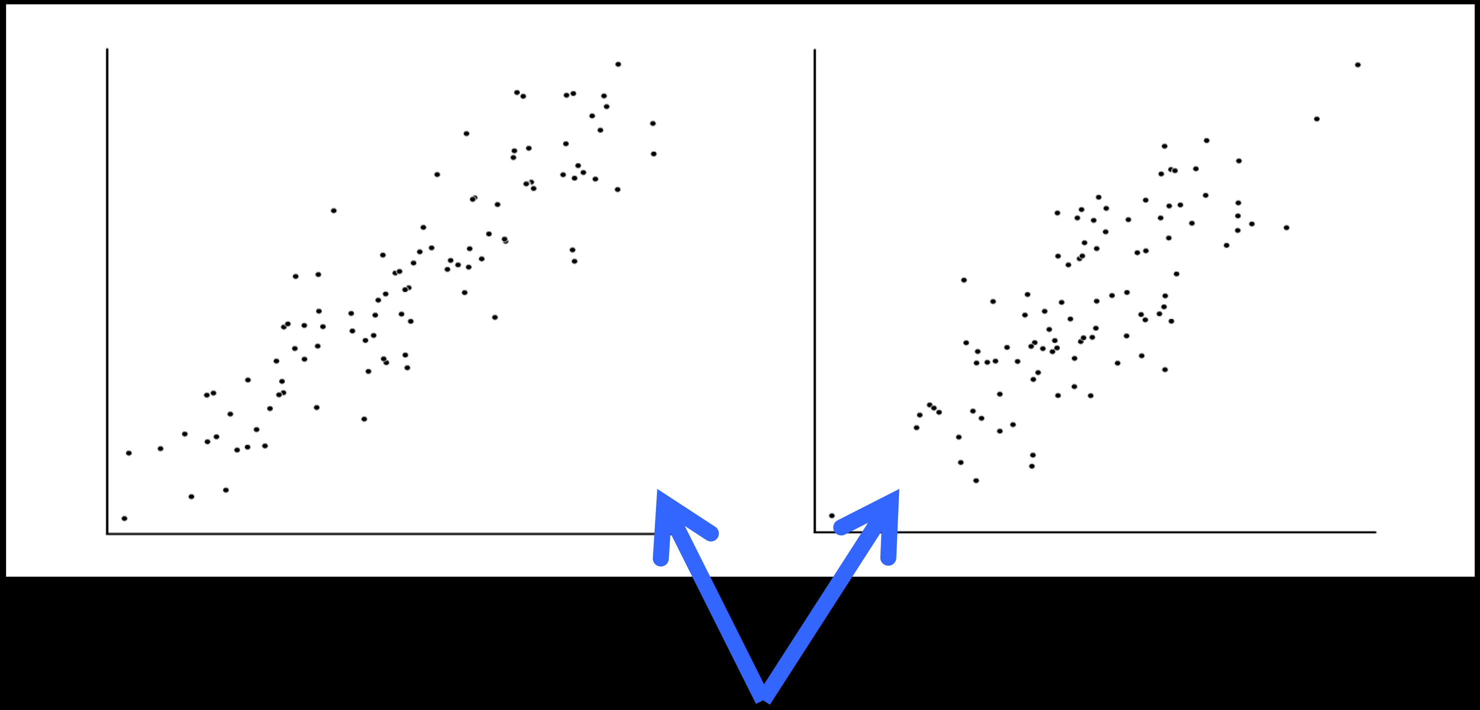
JND = the difference in intensity needed to choose correctly 75% of the time.

A measure of the precision (variability) of estimates

JND □ 1 / SNR = noise / signal

E.g.: Just noticeable difference (JND)

Q: Which scatterplot has the greater correlation?



JND(r) = separation (in *r*) for 75% correct

Results (n=20)

$\Delta r = k(1/b - r)$

k*: *variability
= 0.21 [.17, .24]

b*: *bias
= 0.90 [.84, .94]

(Let **u = 1 - br**)

$\Delta u = ku$

$$\frac{\Delta u}{u} = k$$

Weber's Law

Δr = JND (75% correct)

(Rensink, in press)

Ask a question at steveh.co/panel

Vision Science: Methodology

Recommendations:

- *try for measures with high sensitivity & robustness*
- *look at handbook chapters in vision science*
- *talk to your friendly neighborhood vision scientist ☺*

*3. Vision Science: **Goal***

Goal: Discover ***why*** a visualization works

1. measure performance under *various conditions*
2. look for *laws* that describe the results
3. look for *mechanisms* to account for these laws / results
4. connect these—if possible—to *vision science*

If we knew the laws or mechanisms, might be possible to

- determine the conditions in which the design will / won't work
- simplify some parts of evaluation
- inspire new, more effective designs

E.g.: Correlation perception in scatterplots

Precision

$JND(r) = k\,(1 / b_{disc} - r)$

Accuracy

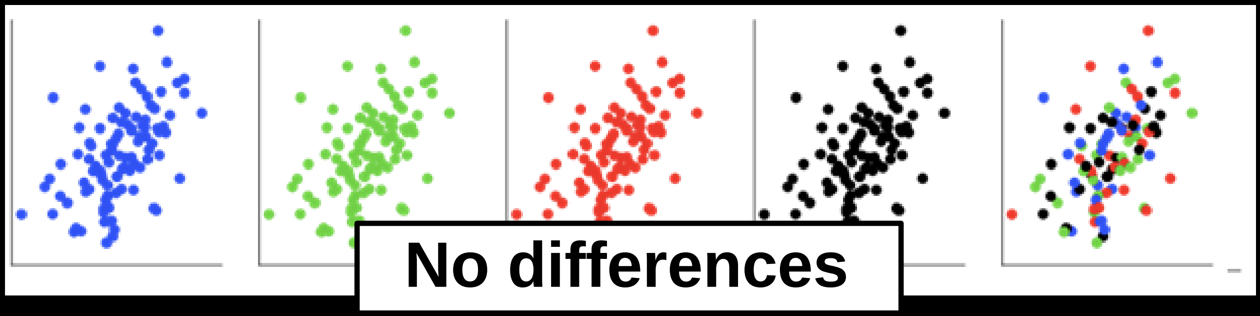
$g(r) = \dfrac{\ln(1 - b_{est}\, r)}{\ln(1 - b_{est})}$

Only two measurements needed to get *k, b*;
- describes both precision and accuracy(!)

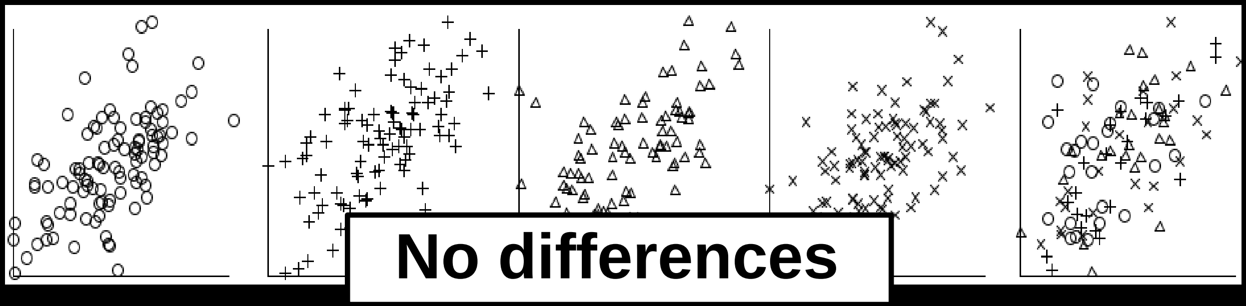
$b_{disc} = b_{est}$
(common bias *b*)

(Rensink, in press)

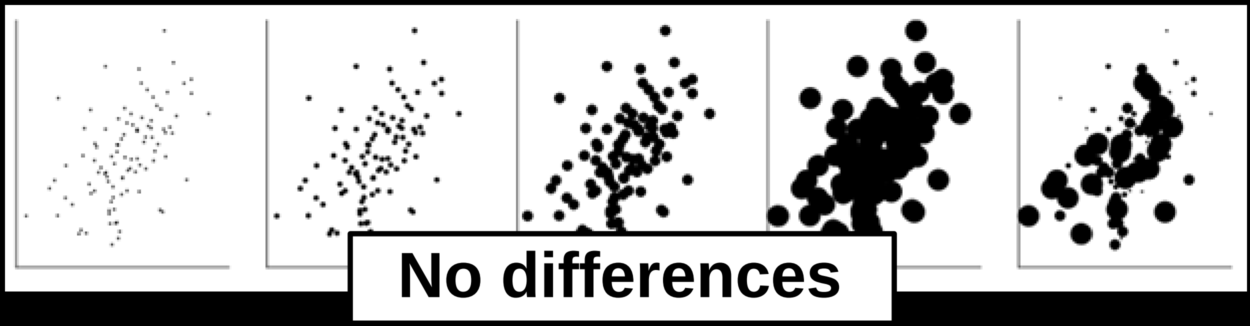
Color



Shape
(symmetric)



Size



Ask a question at steveh.co/panel

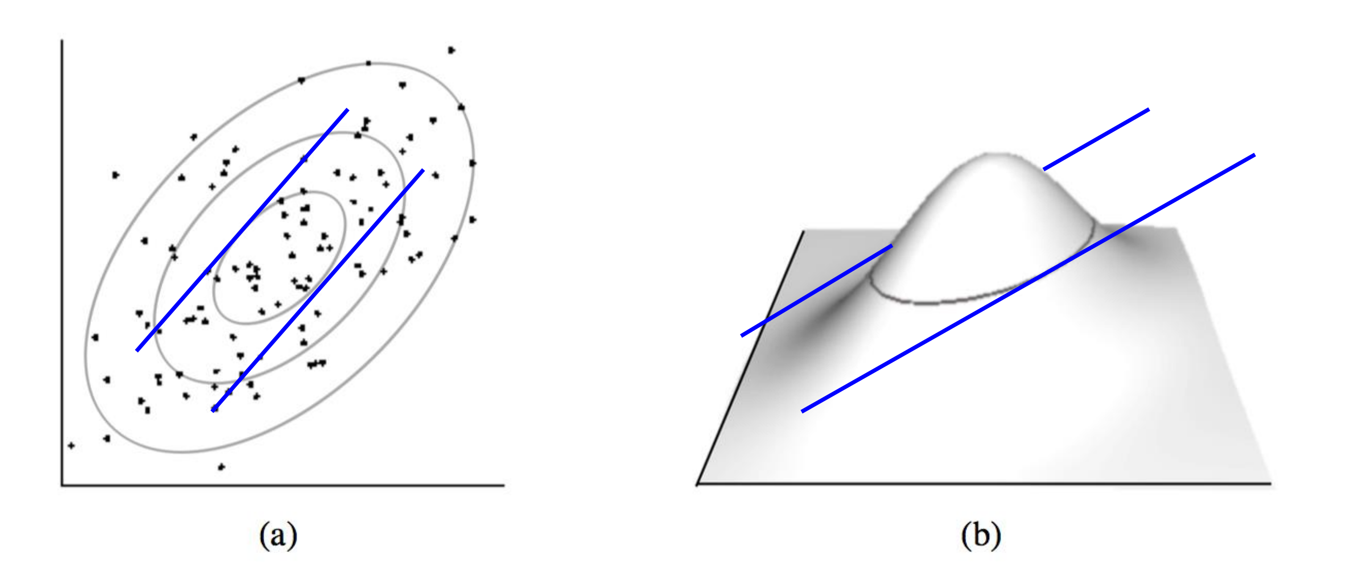
Rensink (2012)

What underlies all this?

Proposal (*Rensink, in press*):

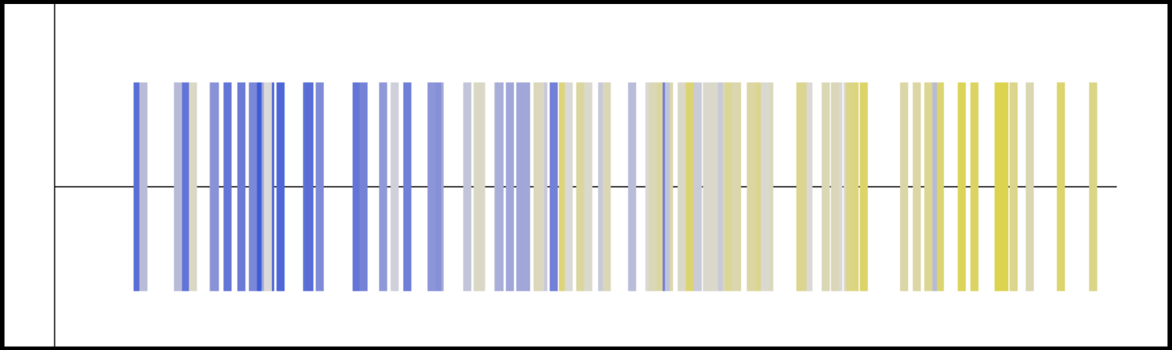
Our visual system perceives entropy

- Visual system infers a probability distribution from the dot cloud via ensemble coding (at early levels of visual processing)



- Logarithm of **the width of this distribution** approximates entropy
- This approximation is used as a proxy for Pearson correlation

Application: Other kinds of possible visualizations
- may work as well as scatterplots



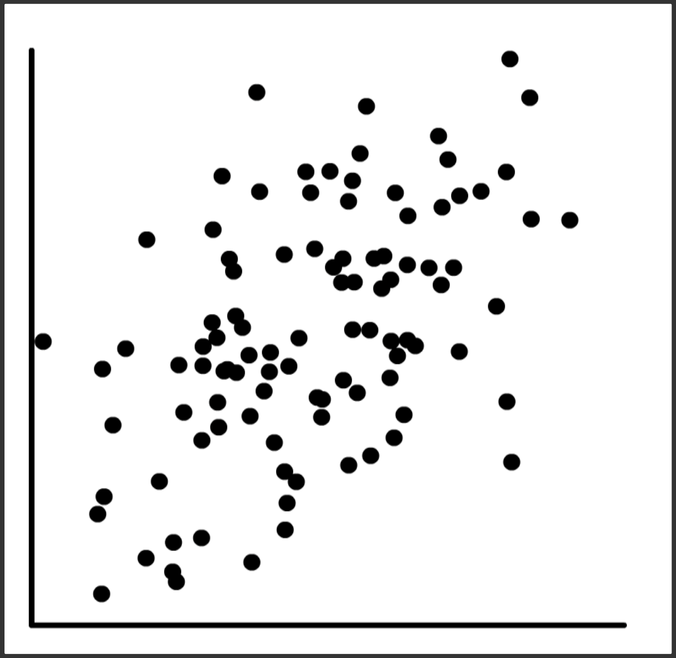
Second dimension is represented by **color** (position on blue-yellow axis)

Nonspatial carriers

<x1, x2>

(vertical)

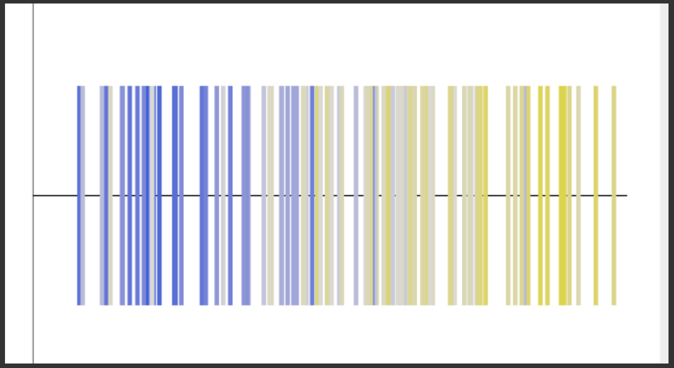
(horizontal)



<x1, x2>

(blue-yellow)

(horizontal)



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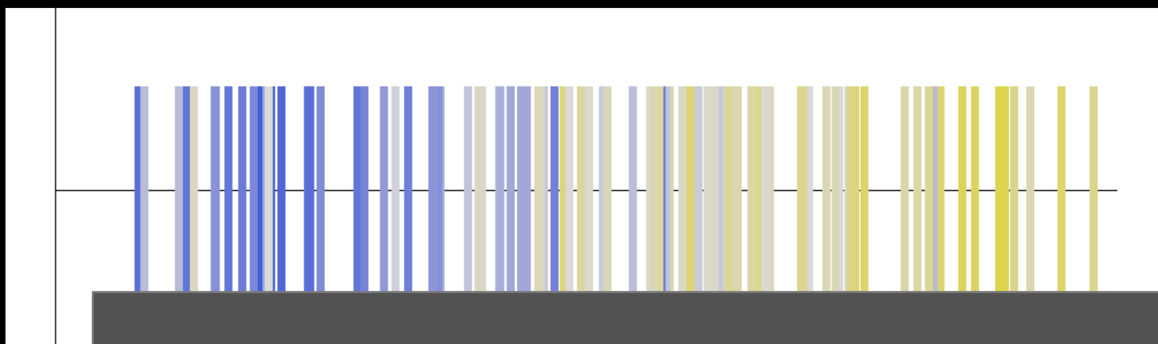
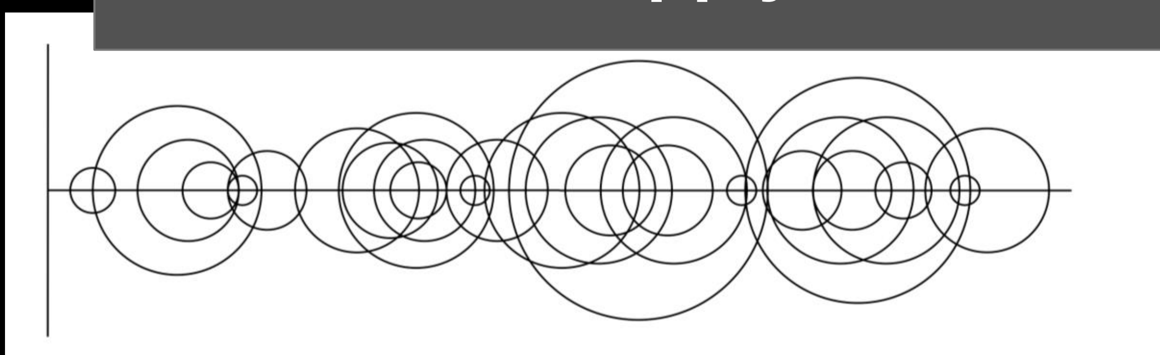


Second dimension is represented by **color** (position on blue-yellow axis)

Same laws apply! (Rensink, 2014, 2015)



Second dimension is represented by **size** (diameter) of the disk

Vision Science: Goal

Recommendations

- *research into "why" should be a distinct part of vis*
- *begin with simple versions of visualizations*
  - *cf . the use of fruit flies in biology* (see Rensink, 2014)
- *focus on particular aspects of these*

Possible development: *a science of visualization*

- *at least for some parts of vis ("islands")*
- *may simplify some parts of evaluation (?)*
- *may inspire new designs(?)*