

CSC2537 / STA2555 - INFORMATION VISUALIZATION  
FUNDAMENTS OF VISUALIZATION

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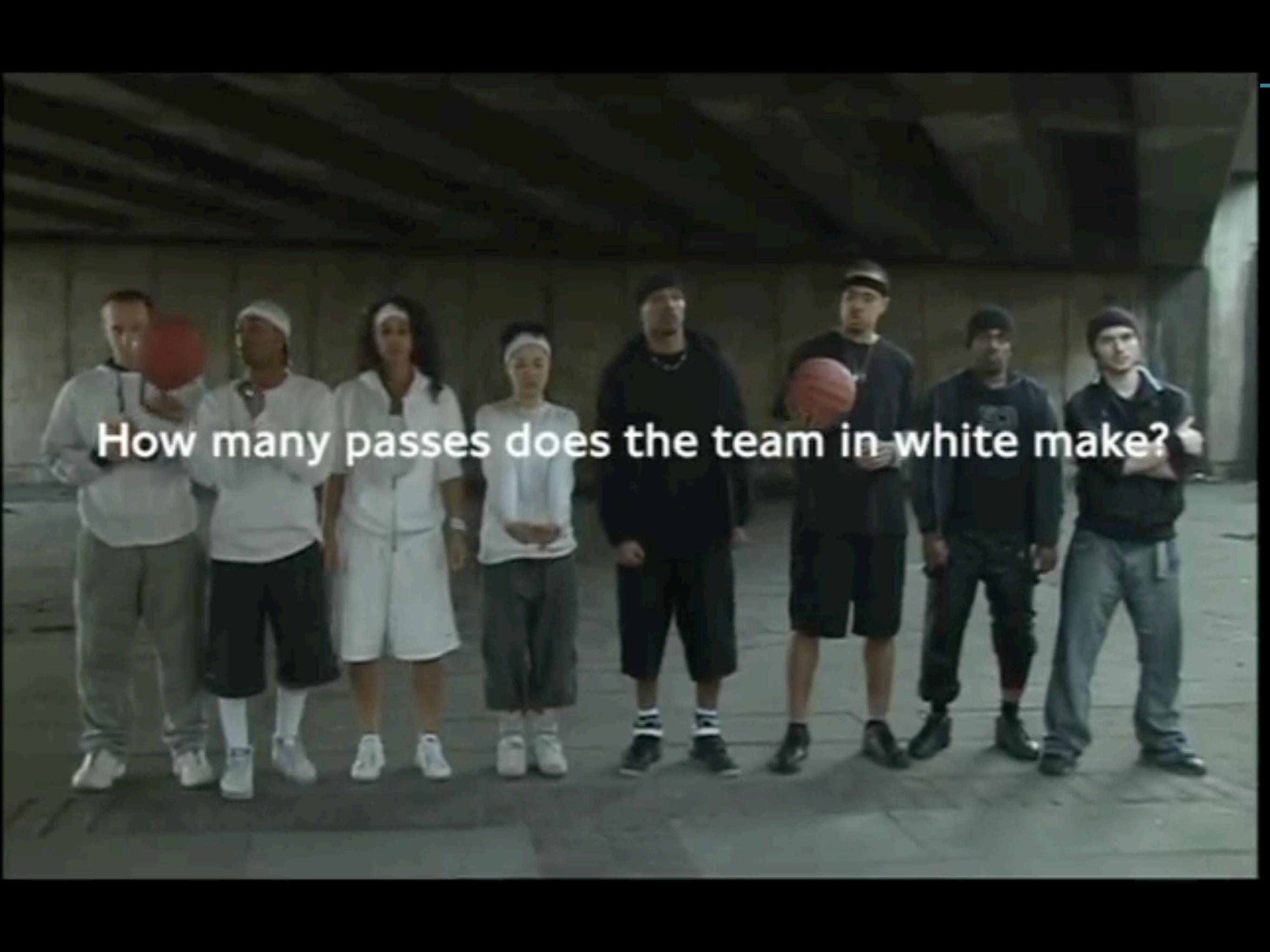
Fanny CHEVALIER



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"I ONLY BELIEVE IN WHAT I SEE WITH MY OWN EYES"

BRAIN BUGS



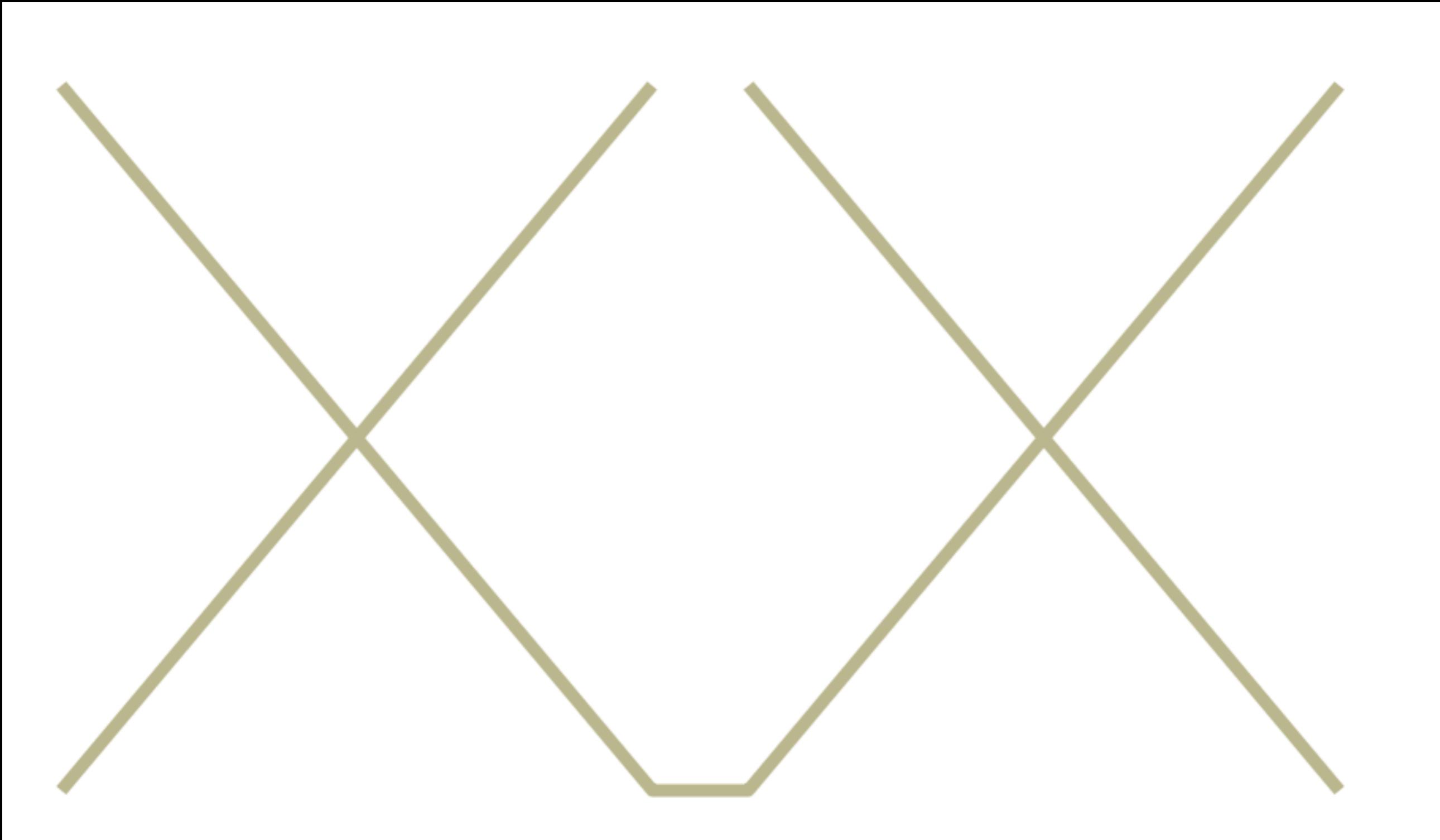
How many passes does the team in white make? ↗





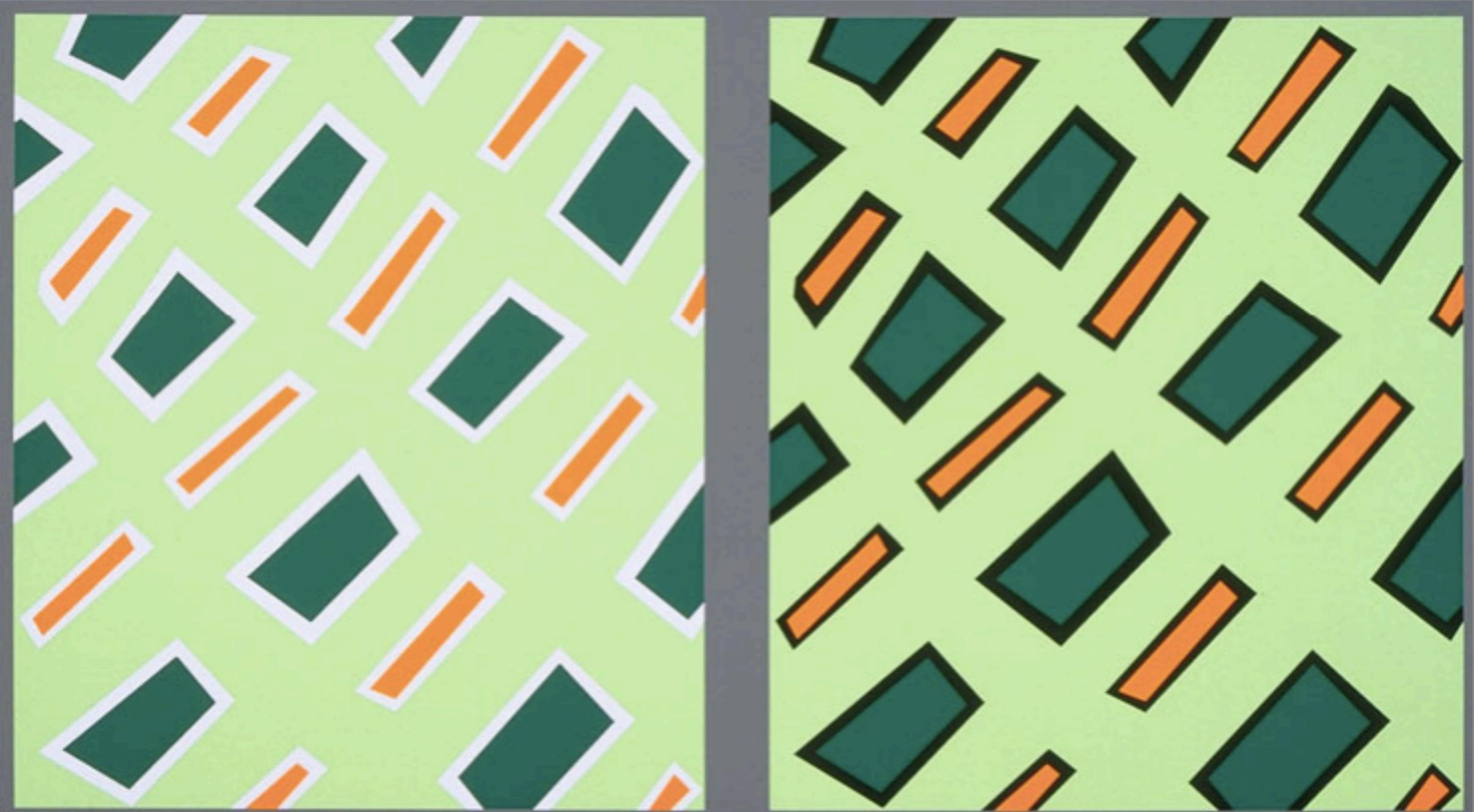


# SIMULTANEOUS CONTRAST

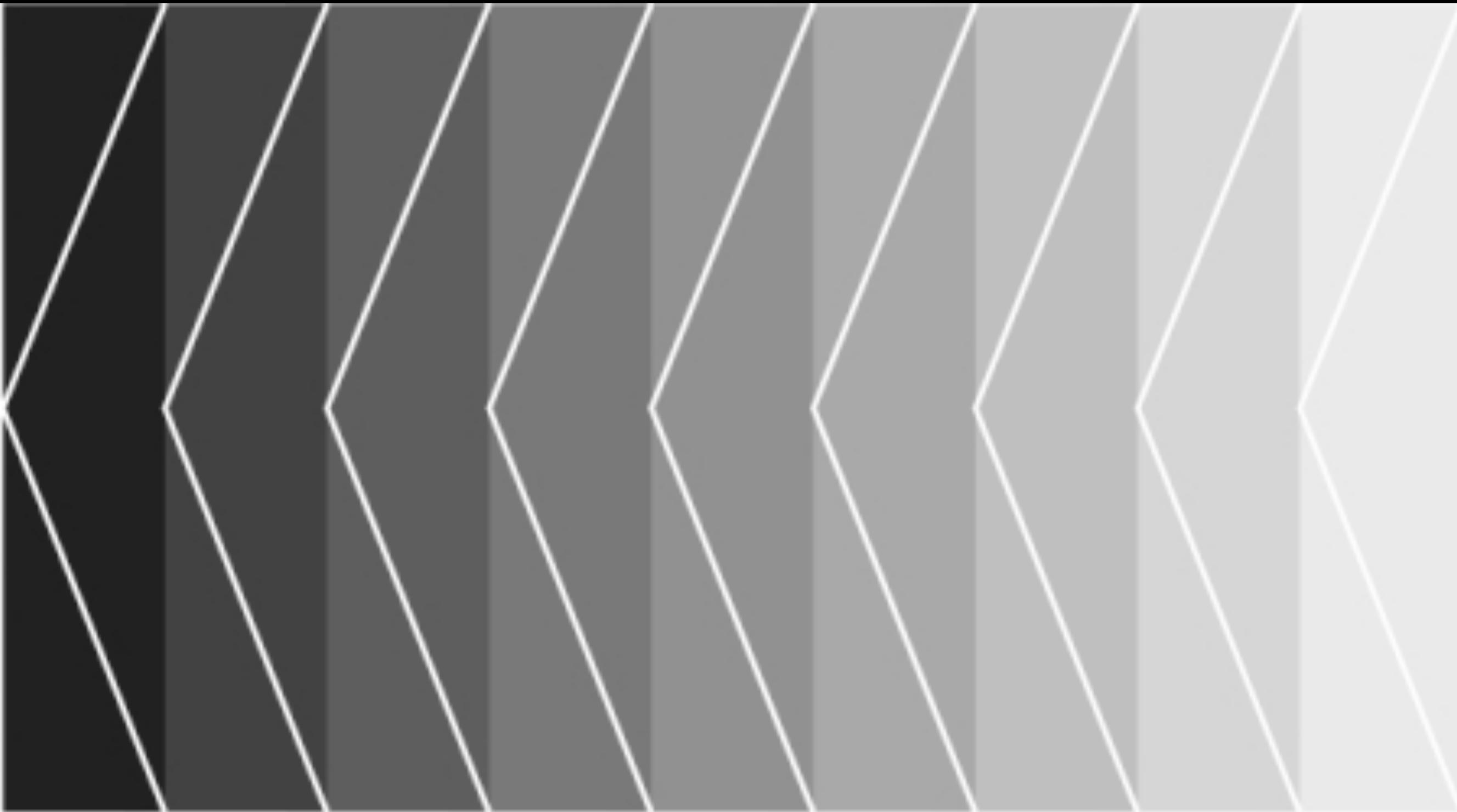


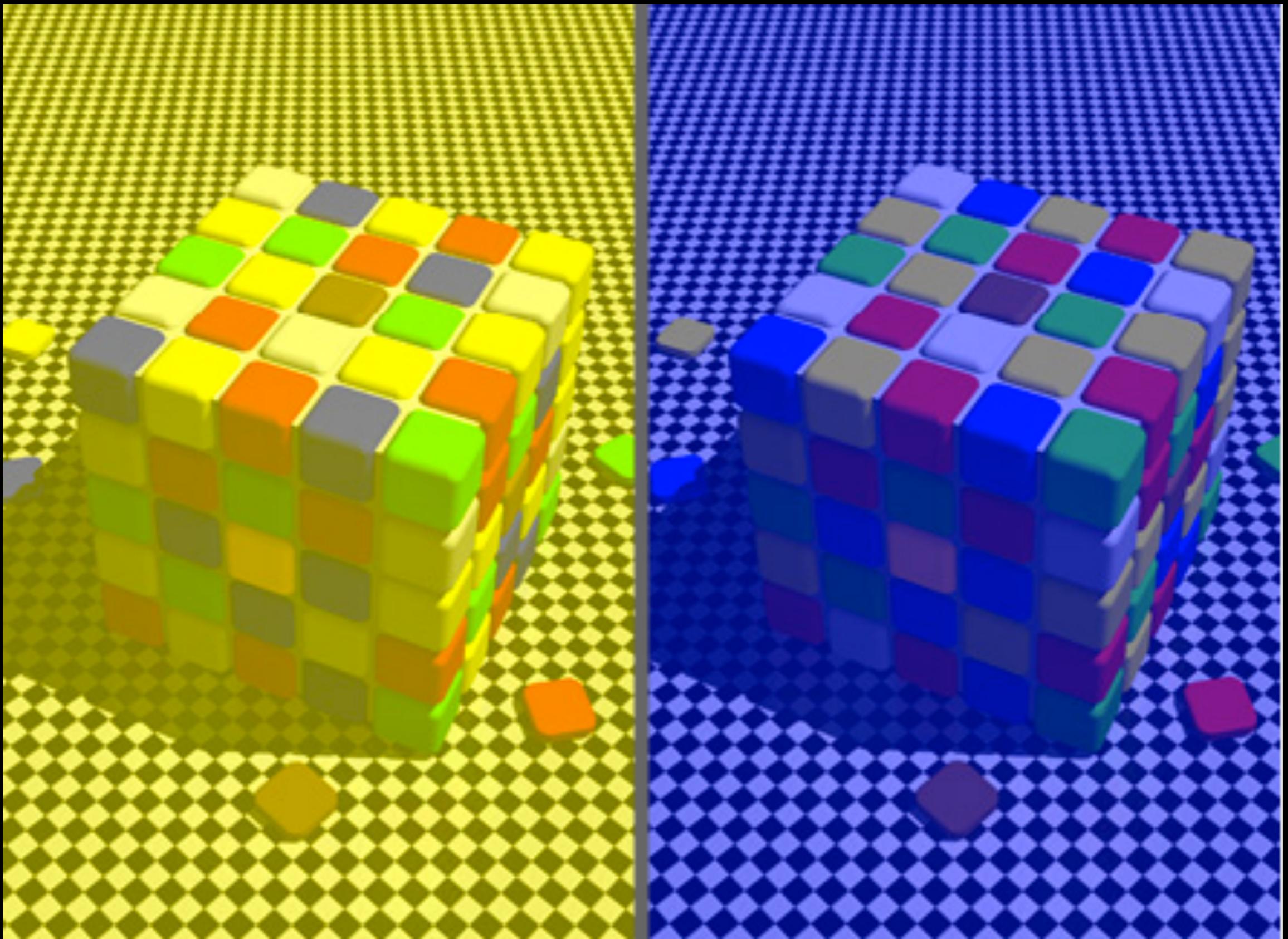


# BEZOLD EFFECT

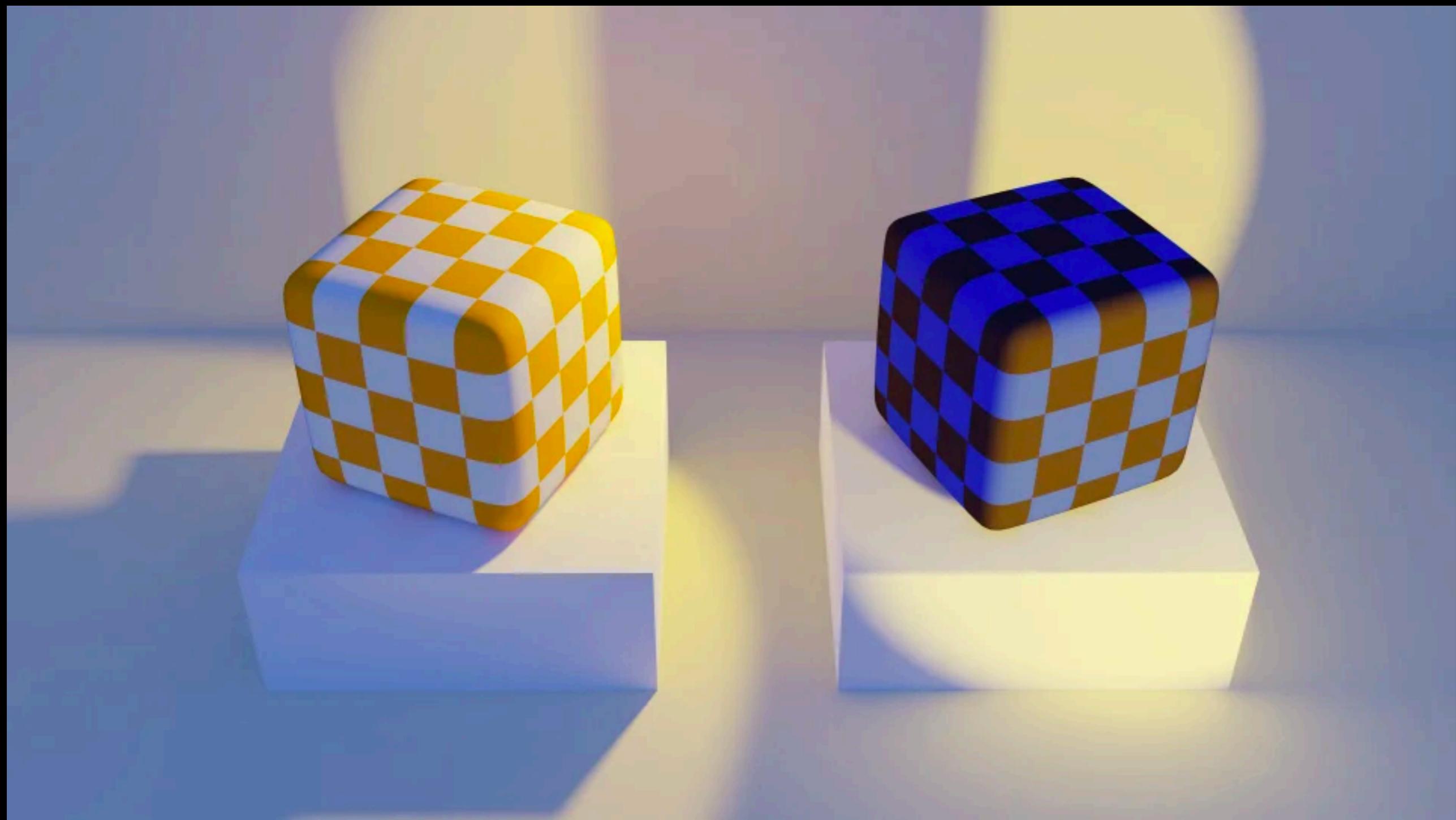


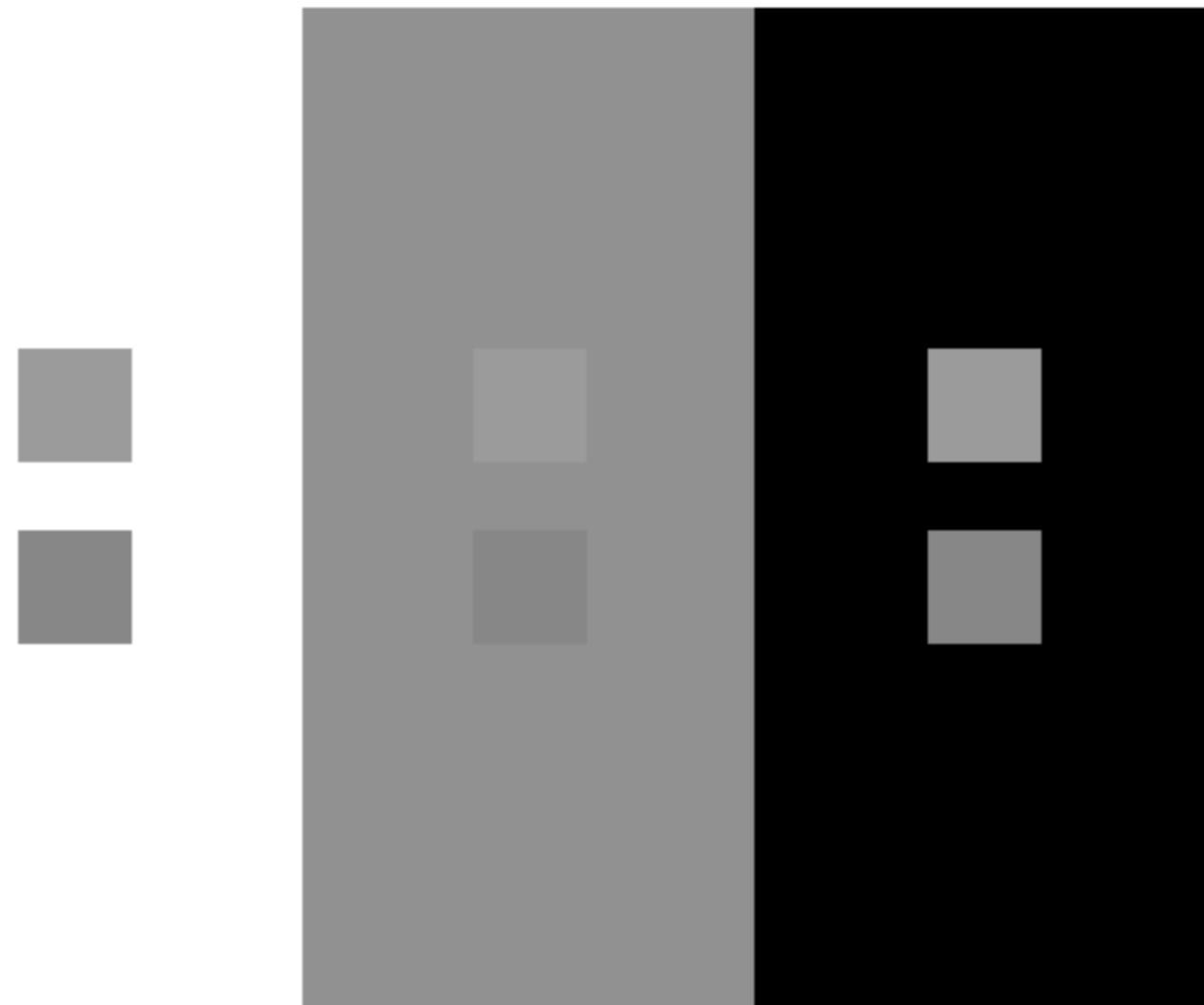




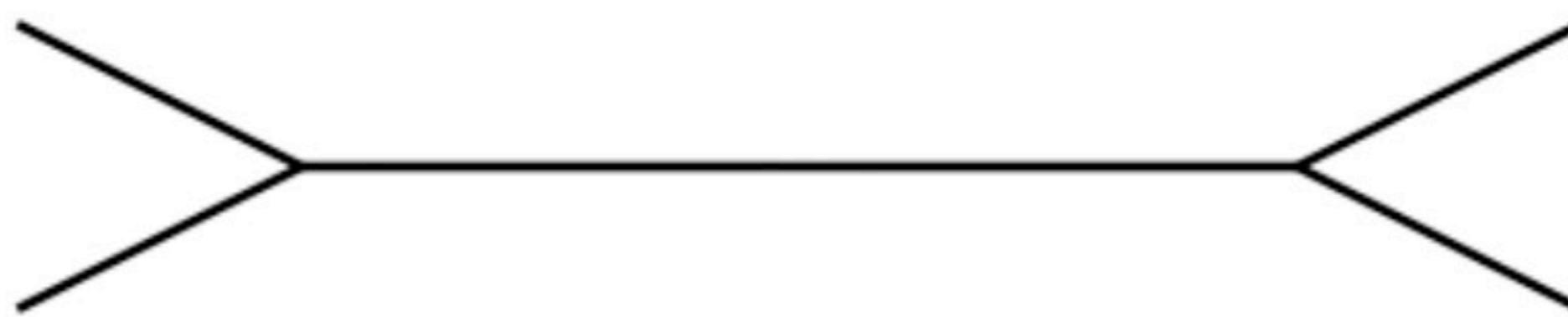
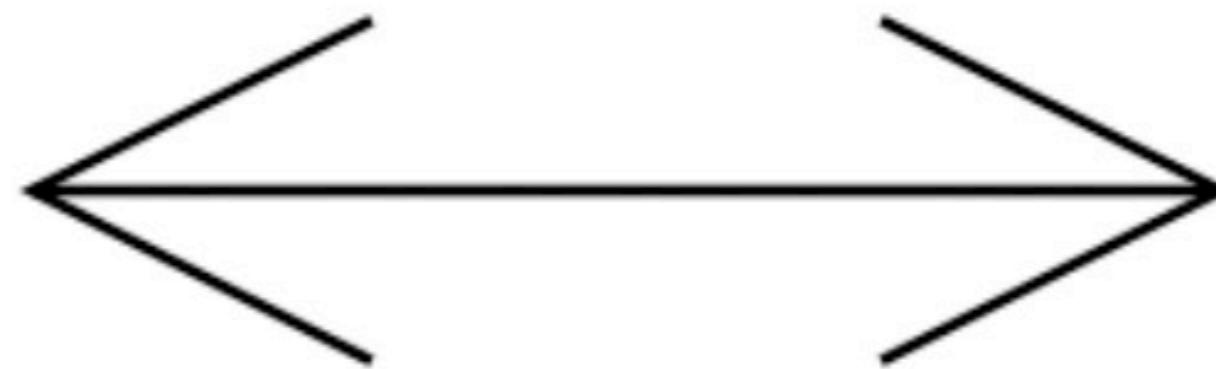


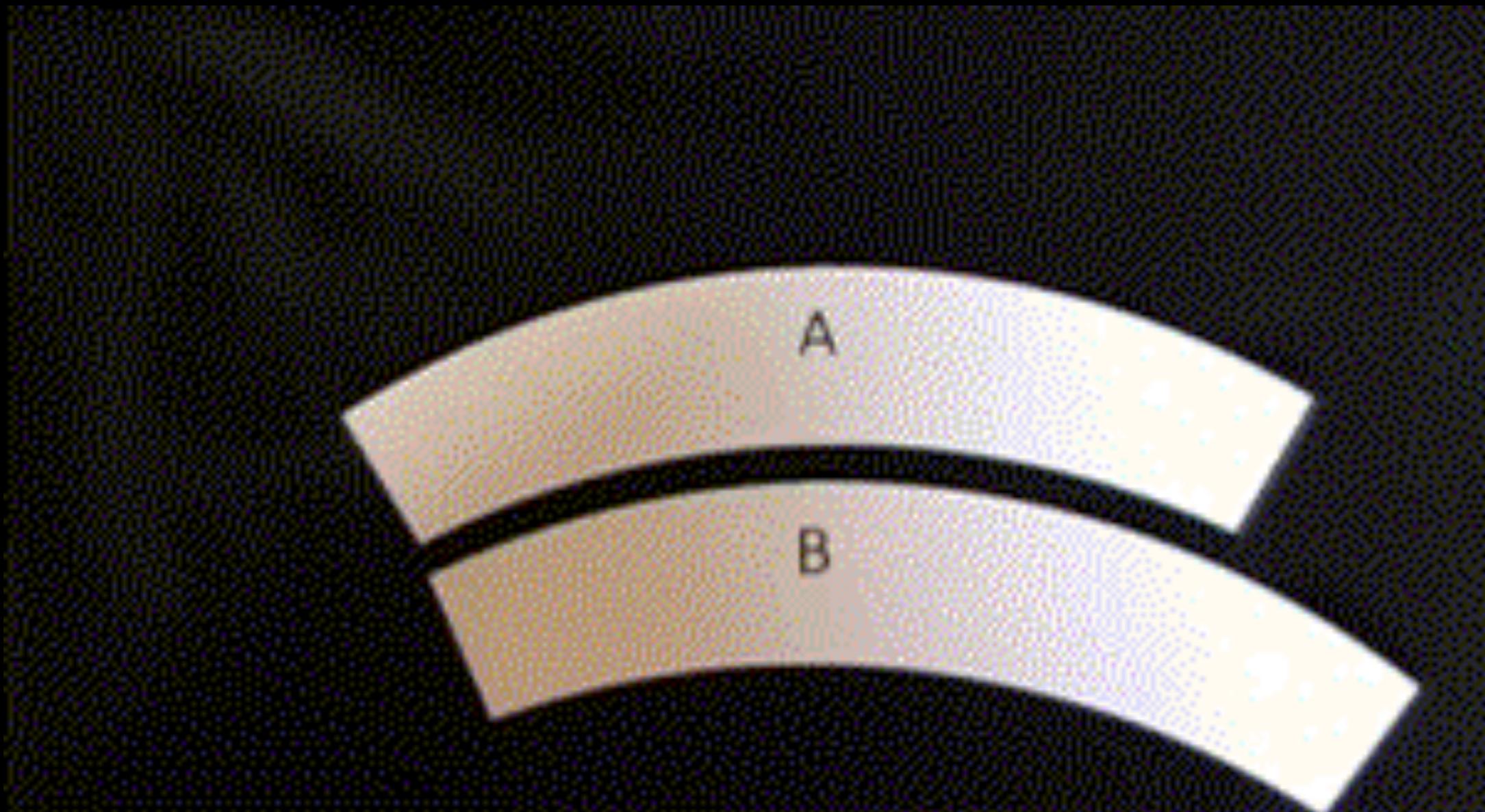


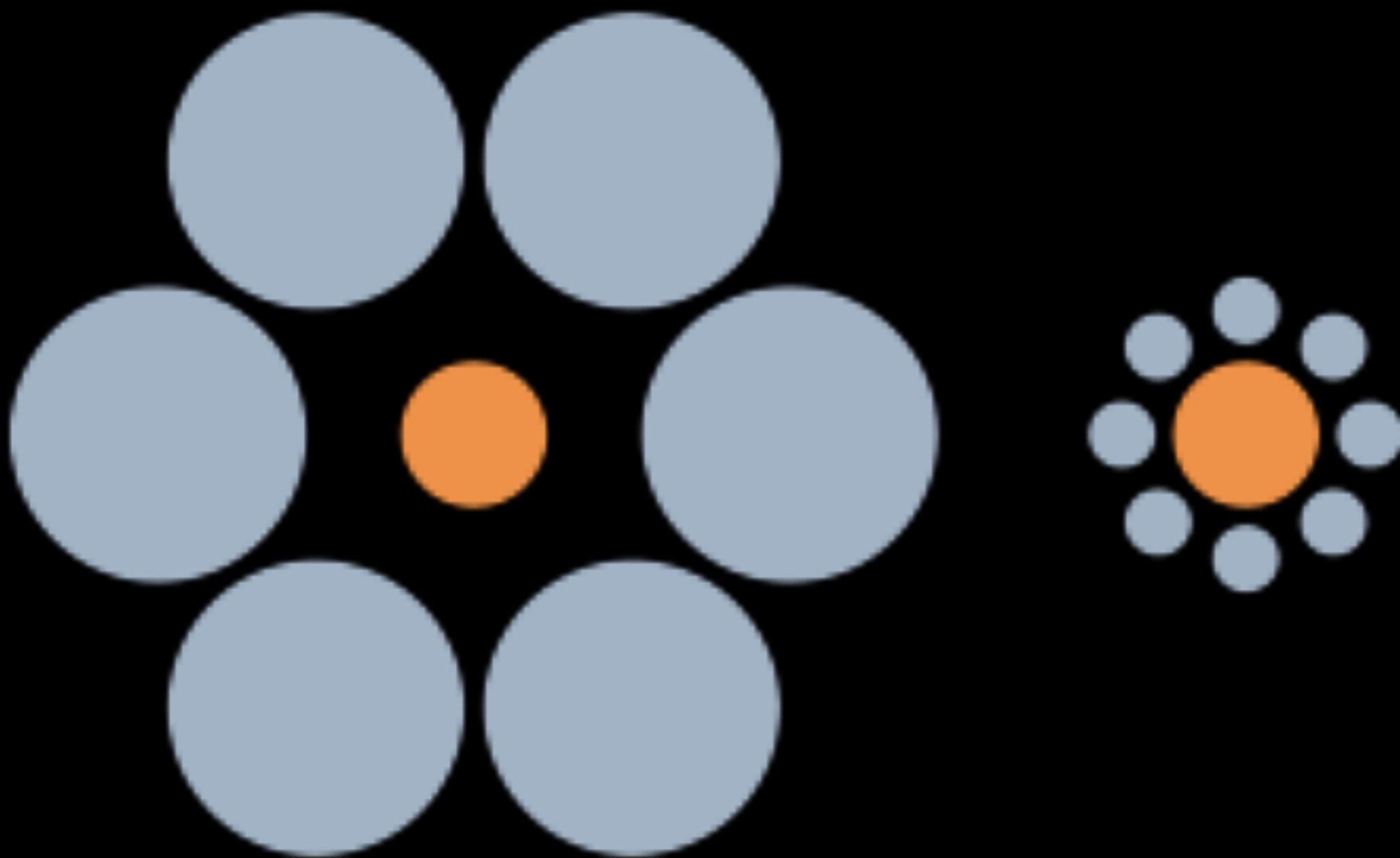


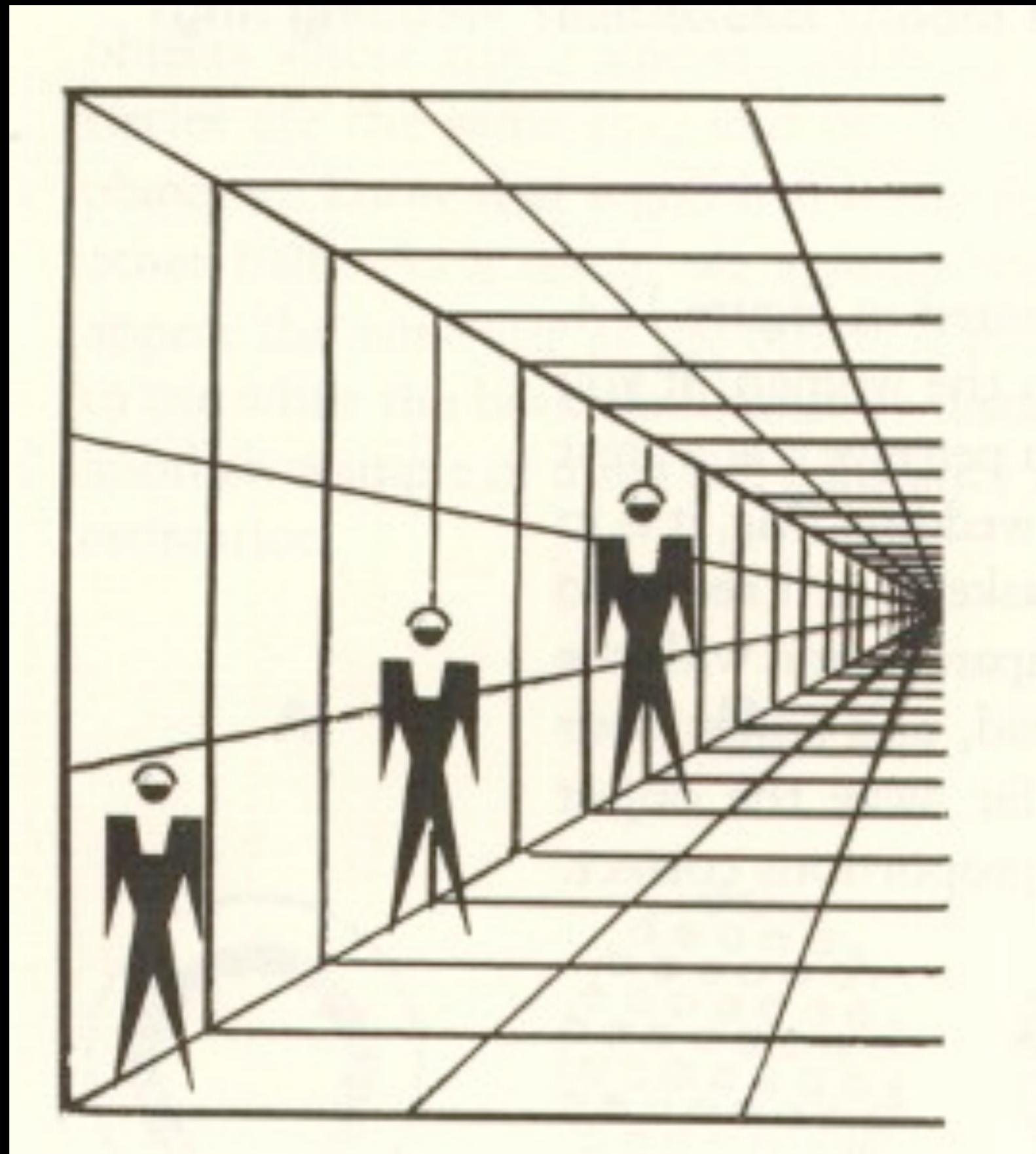


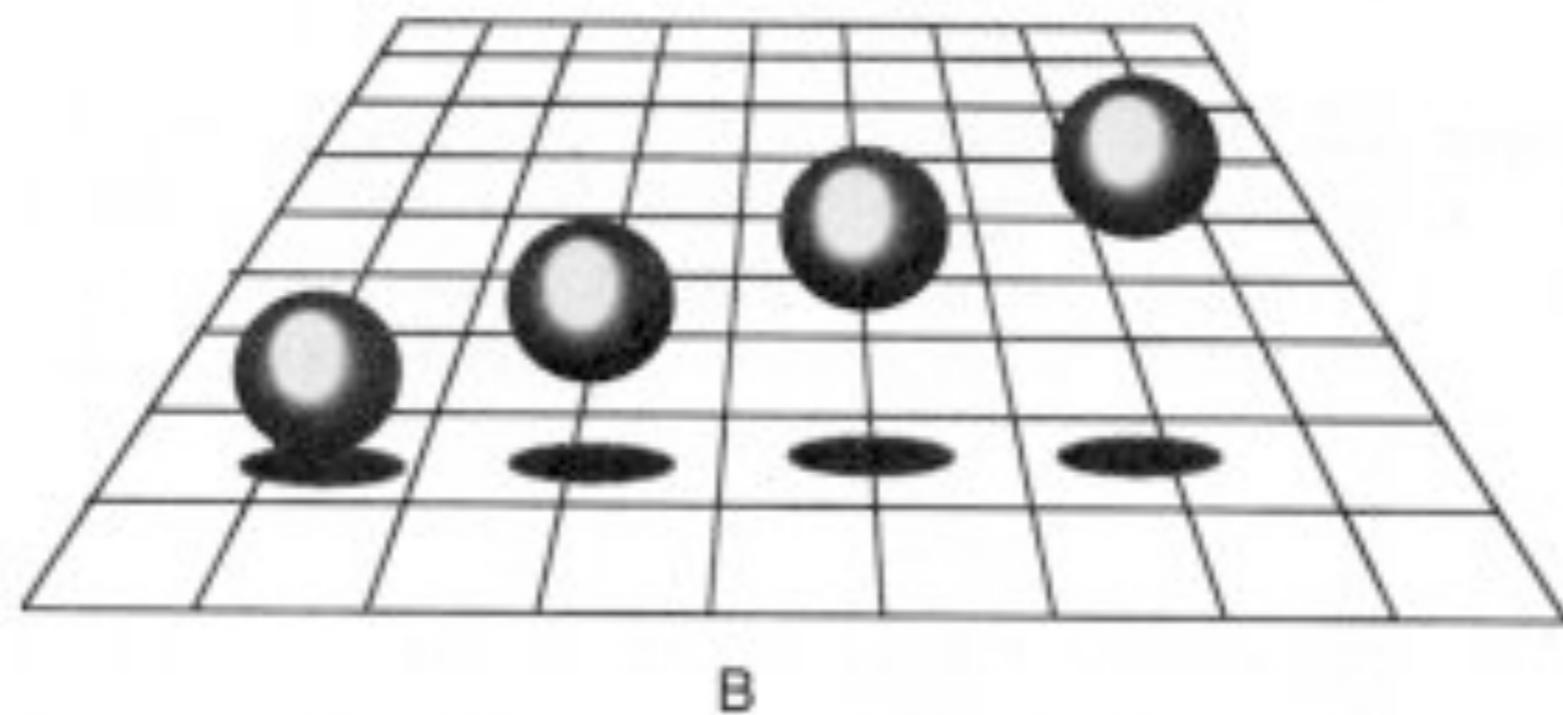
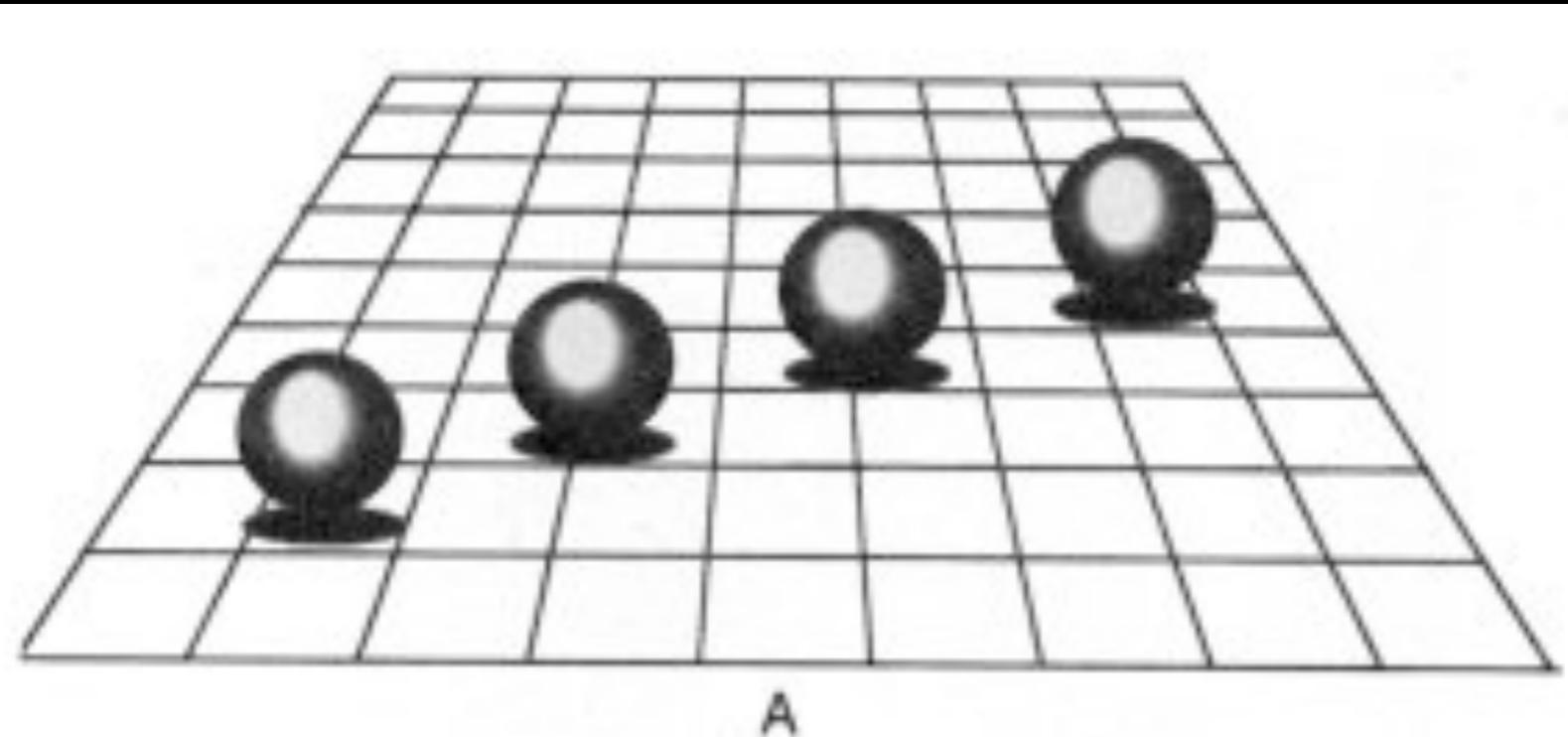
From Fairchild, *Color Appearance Models*







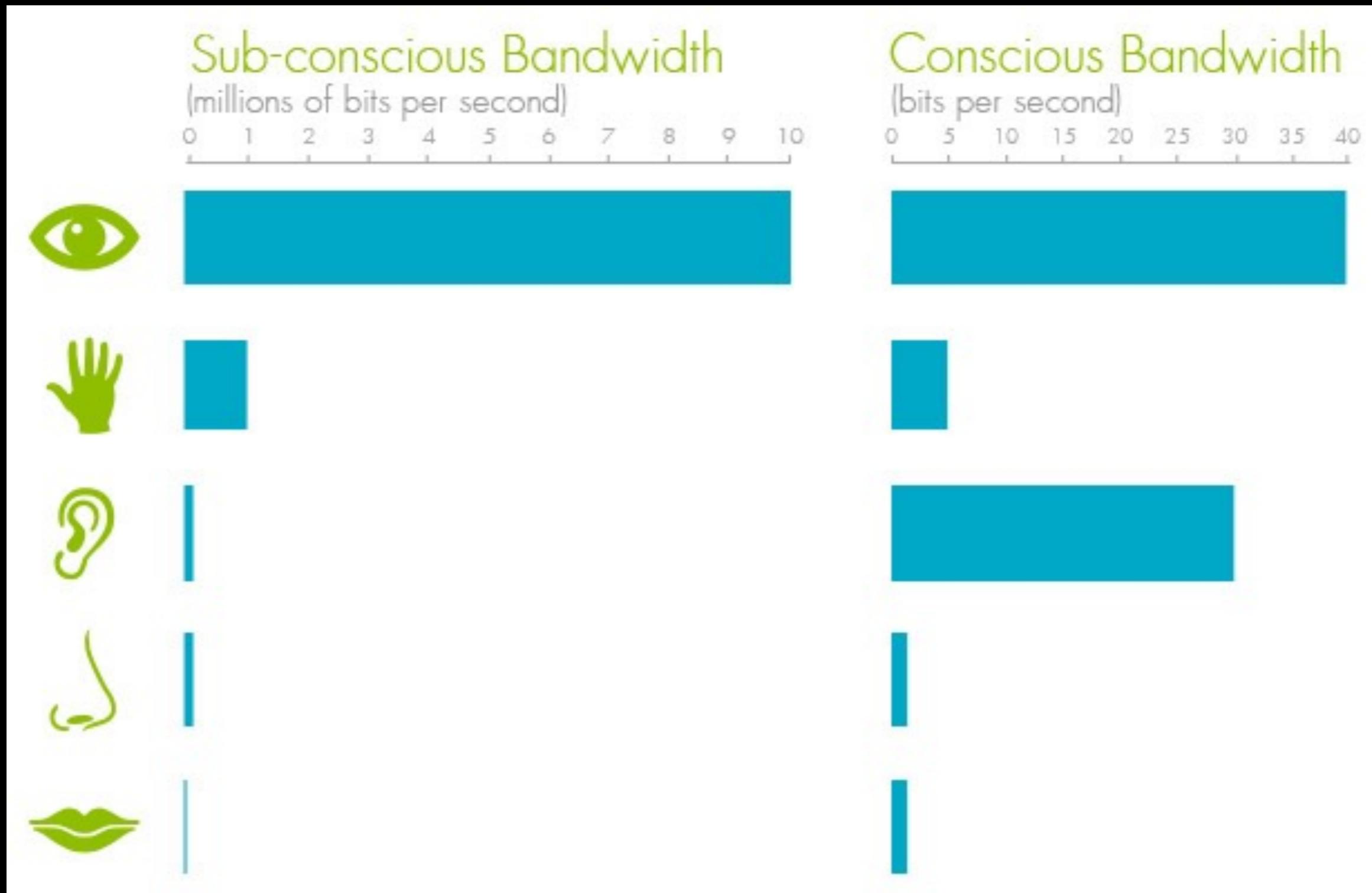






VISUAL PERCEPTION & COGNITION

WHY RELYING ON VISUALS?





VISUAL PERCEPTION & COGNITION  
KNOWING HOW WE PERCEIVE  
... TO BETTER REPRESENT

# Temporal perception

- reaction time: 200ms to initiate a conscious observation
  - stimuli <100ms apart are not perceived

## Visual acuity

- Lines can be detected from 0.5"
  - Distance between two lines from 30" to 1"

# Implications for Information Visualisation

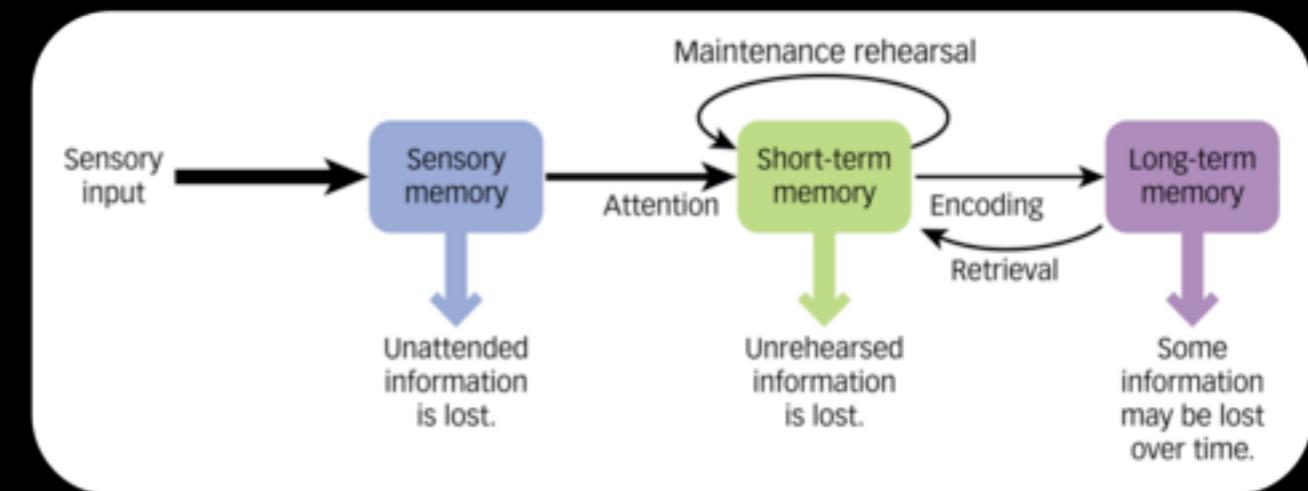
- Animations should have cycles  $> 1/10^\circ$  seconds
  - Large datasets: guarantee that the data displayed remains above limits

arcminute ('') = 1/60 of one degree. arcsecond ('') : 1/60 of one arcminute

# COGNITION & VISION: COGNITIVE LOAD

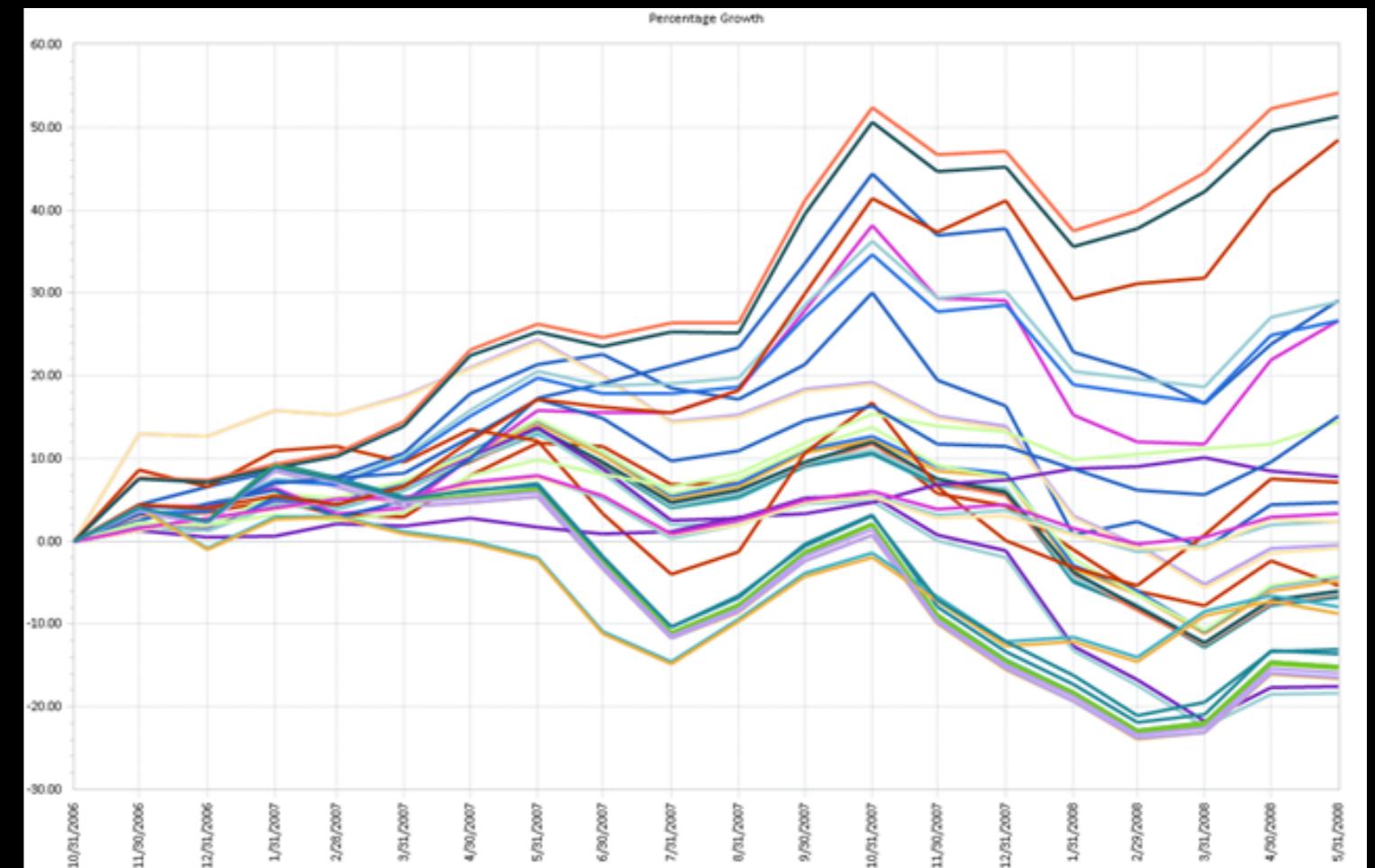
# Problems with cognitive load

- **short-term memory** = working memory
  - **memory span** is limited : [Miller 1956]  
 $7 \pm 2$  *independent* memorable items
  - Critical for visualization of large datasets



# Implications for Infovis

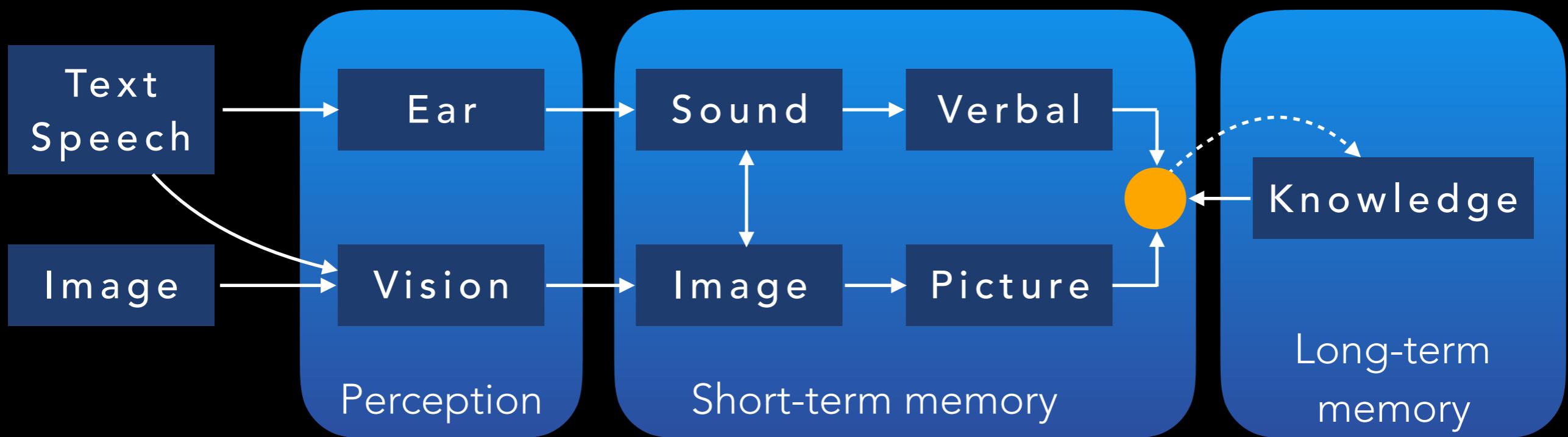
- Group, aggregate in **chunks**  
(analogy: phone numbers)
  - Never require to compare  
more than 3 independent  
elements at a time



# COGNITION & VISION: COGNITIVE LOAD

Cognitive load : workarounds

- **Multimodality** to limit cognitive overload  
Multimodality —> different cognitive pathways (i.e. visuospatial sketch pad, phonological loop, episodic buffer) [Baddeley A., Wilson B.A., 2002]

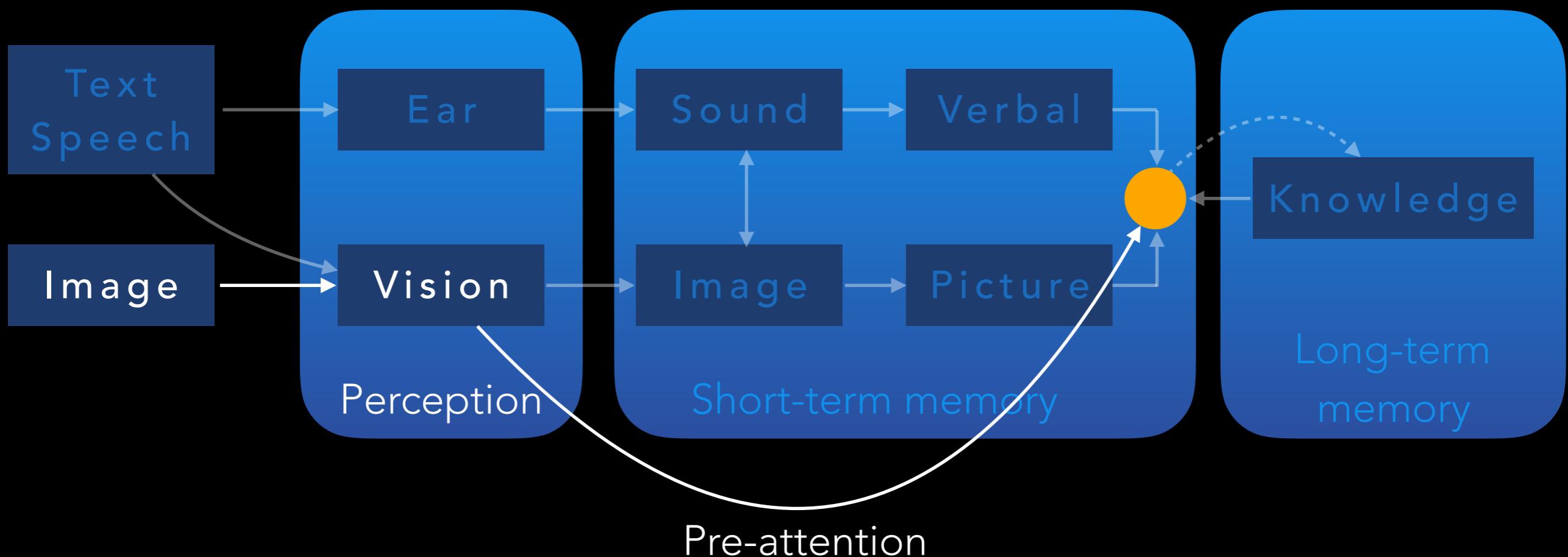


- **Pre-attentive perception**

# PRE-ATTENTIVE PERCEPTION

[Treisman &amp; Gormican, 1988]

- Some visual features are processed pre-attentively,  
e.g. without focusing attention
- Low-level (unconscious) cognitive processes
- Reduced reaction time: <200ms  
(eyes movement > 200ms)
- Witness of our evolutionary story



# PRE-ATTENTIVE PERCEPTION

[Treisman & Gormican, 1988]

- Some visual features are processed pre-attentively,  
e.g. without focusing attention

## Implications for Information Visualisation

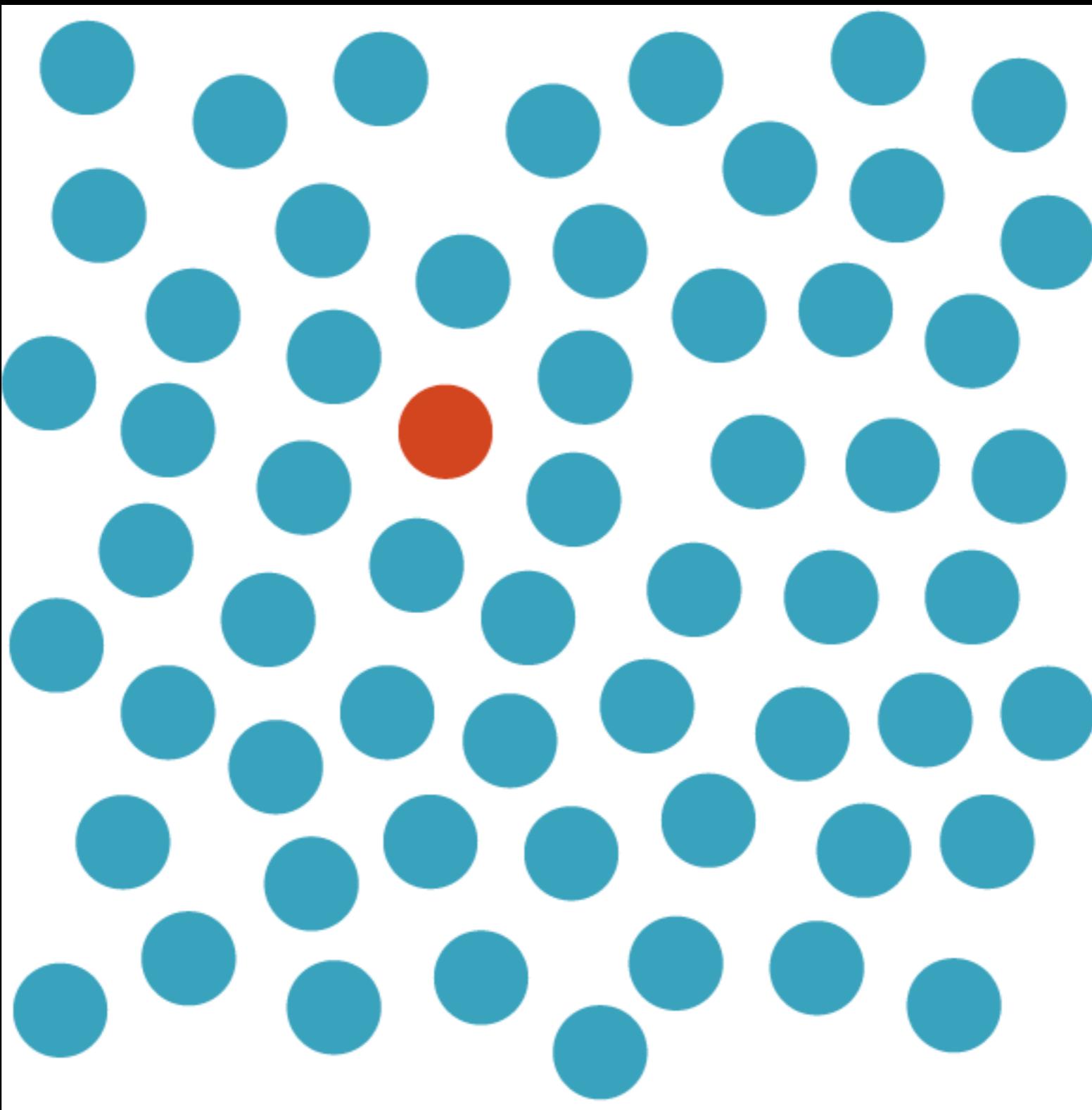
- No cognitive load
- Direct processing : what must be perceived immediately

Perception

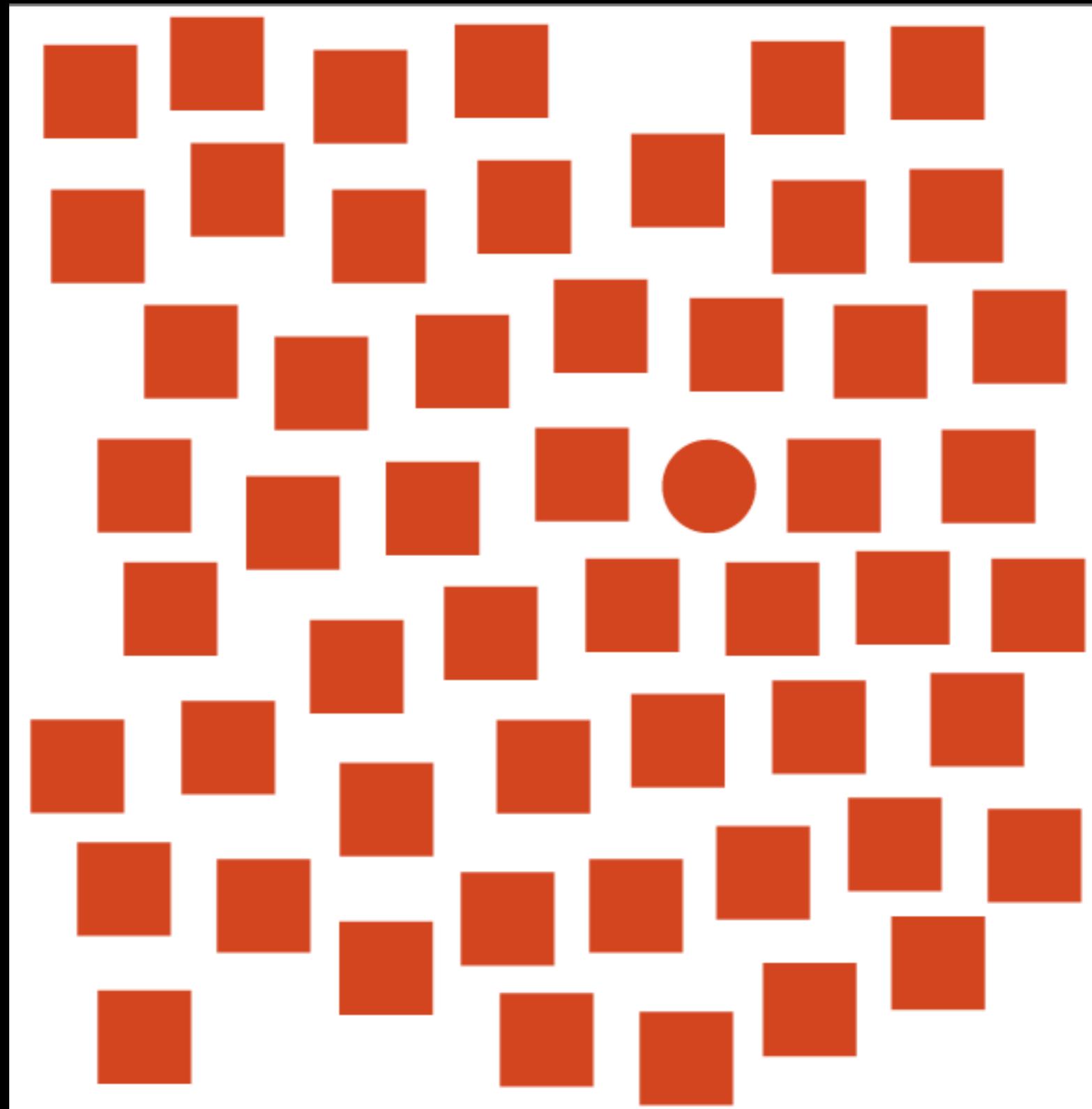
Short-term memory

Long-term  
memory

Is there a red circle?

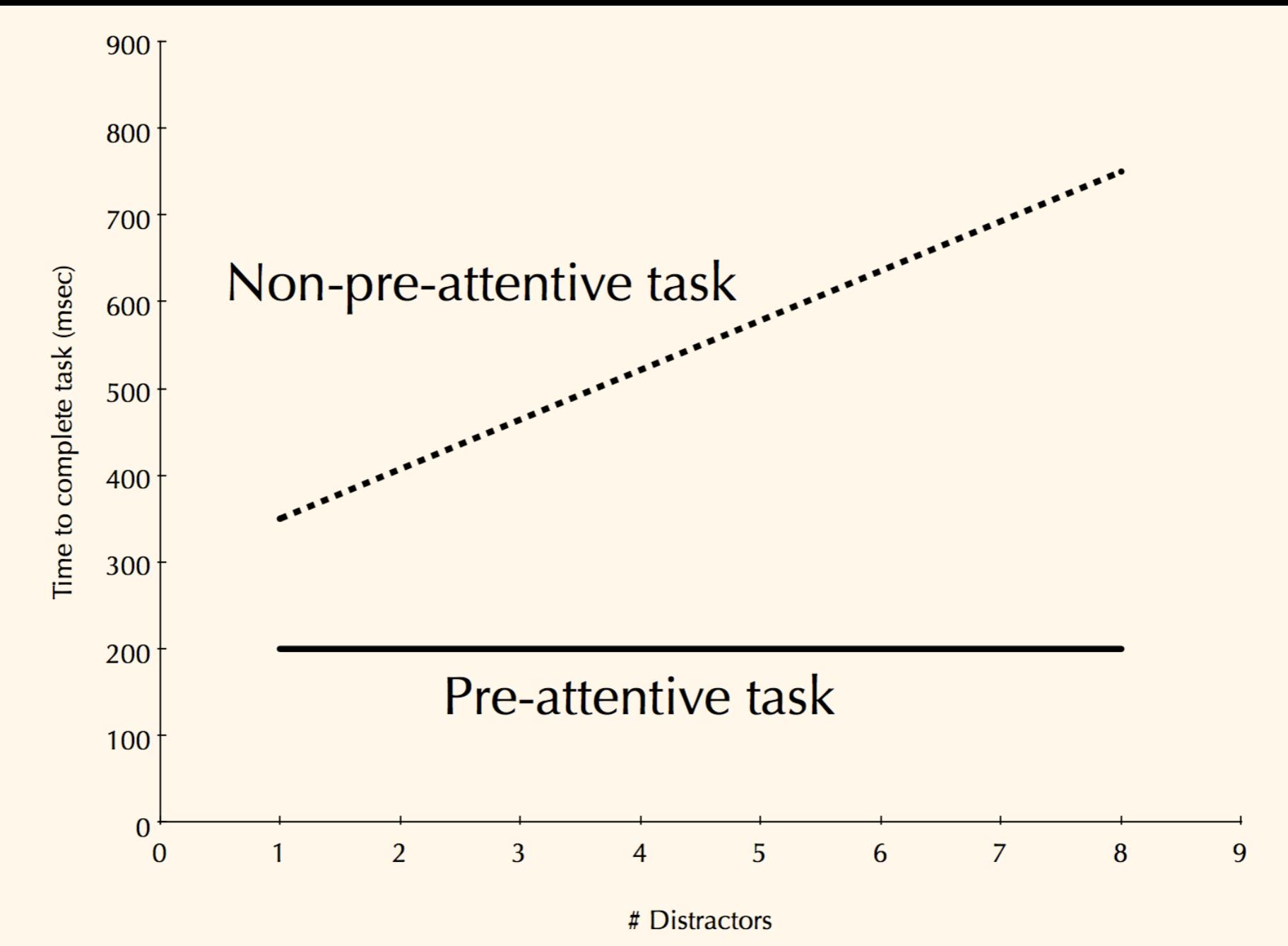


Is there a red circle?



# PRE-ATTENTIVE PERCEPTION

Takes the same amount of time, regardless of the number of distractors



Find the 3's

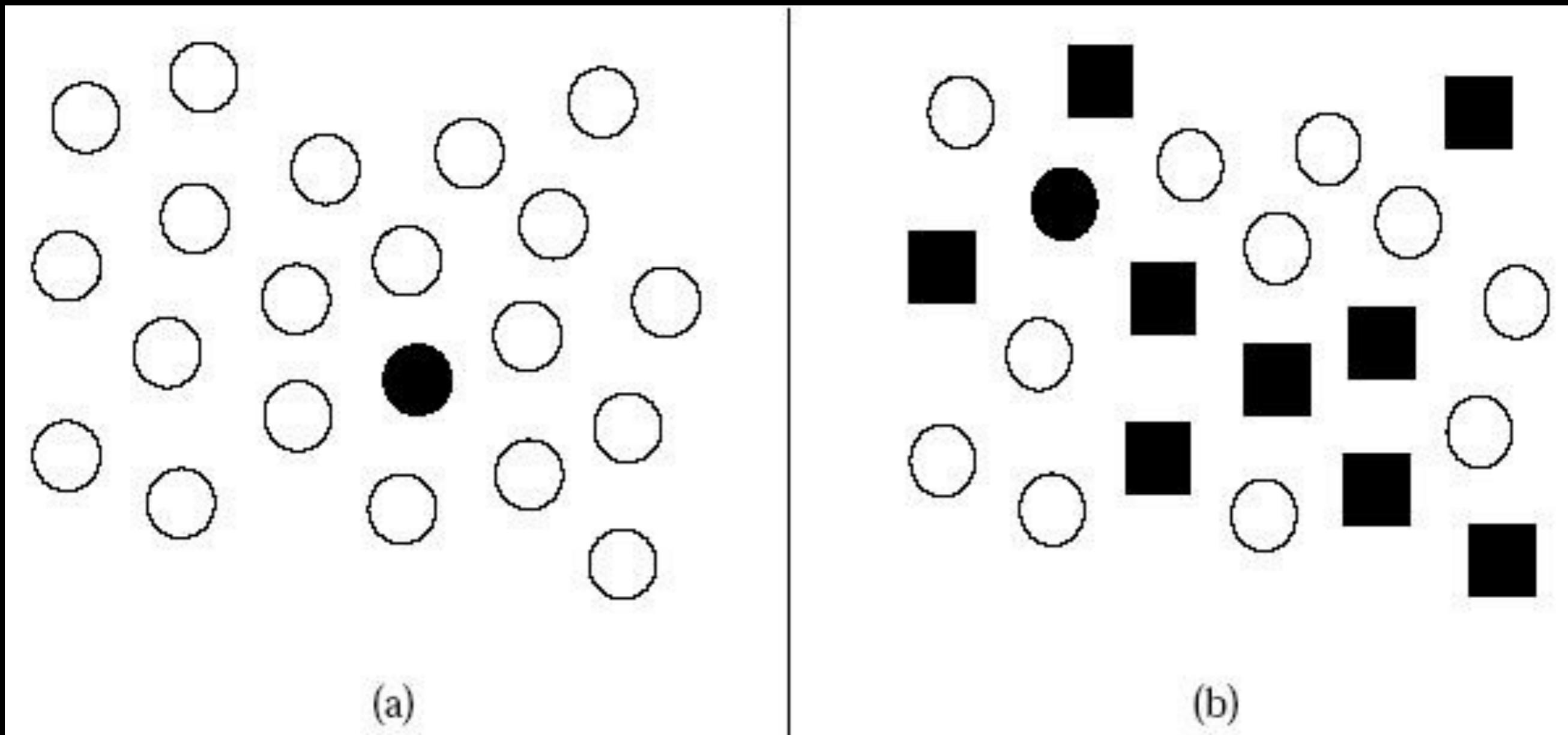
142416496357598475921765968474891728482  
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608365416496457590643980479248576960781  
285960799918712845268101495969124567781  
874241649645757659608149596912456701285  
960799164964575127879918712845298496912  
223591649645759588198250963576596080596

Find the 3's

142416496**3**57598475921765968474891728482  
285958819829450968504850695847612124044  
074674898985171495969124567659608020860  
608**3**6541649645759064**3**980479248576960781  
285960799918712845268101495969124567781  
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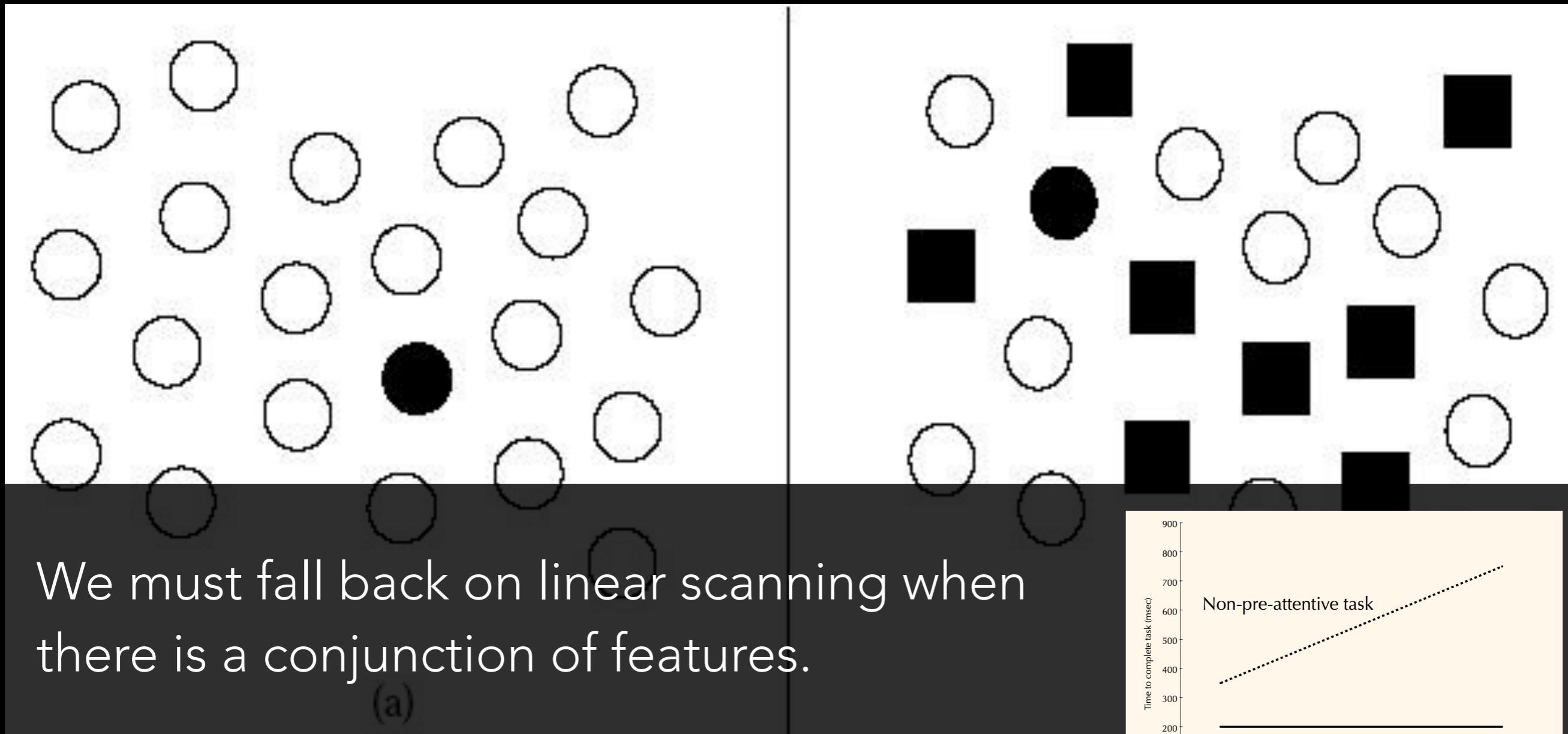
# PRE-ATTENTIVE PERCEPTION

Only works when the distractors differ from one feature:

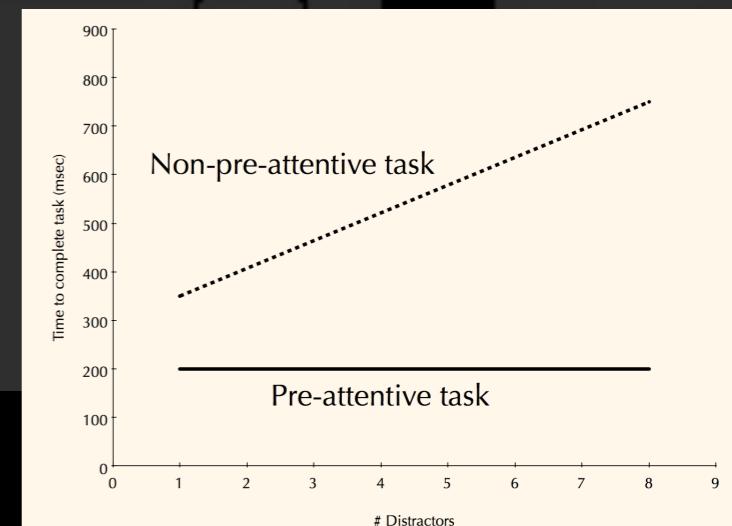


# PRE-ATTENTIVE PERCEPTION

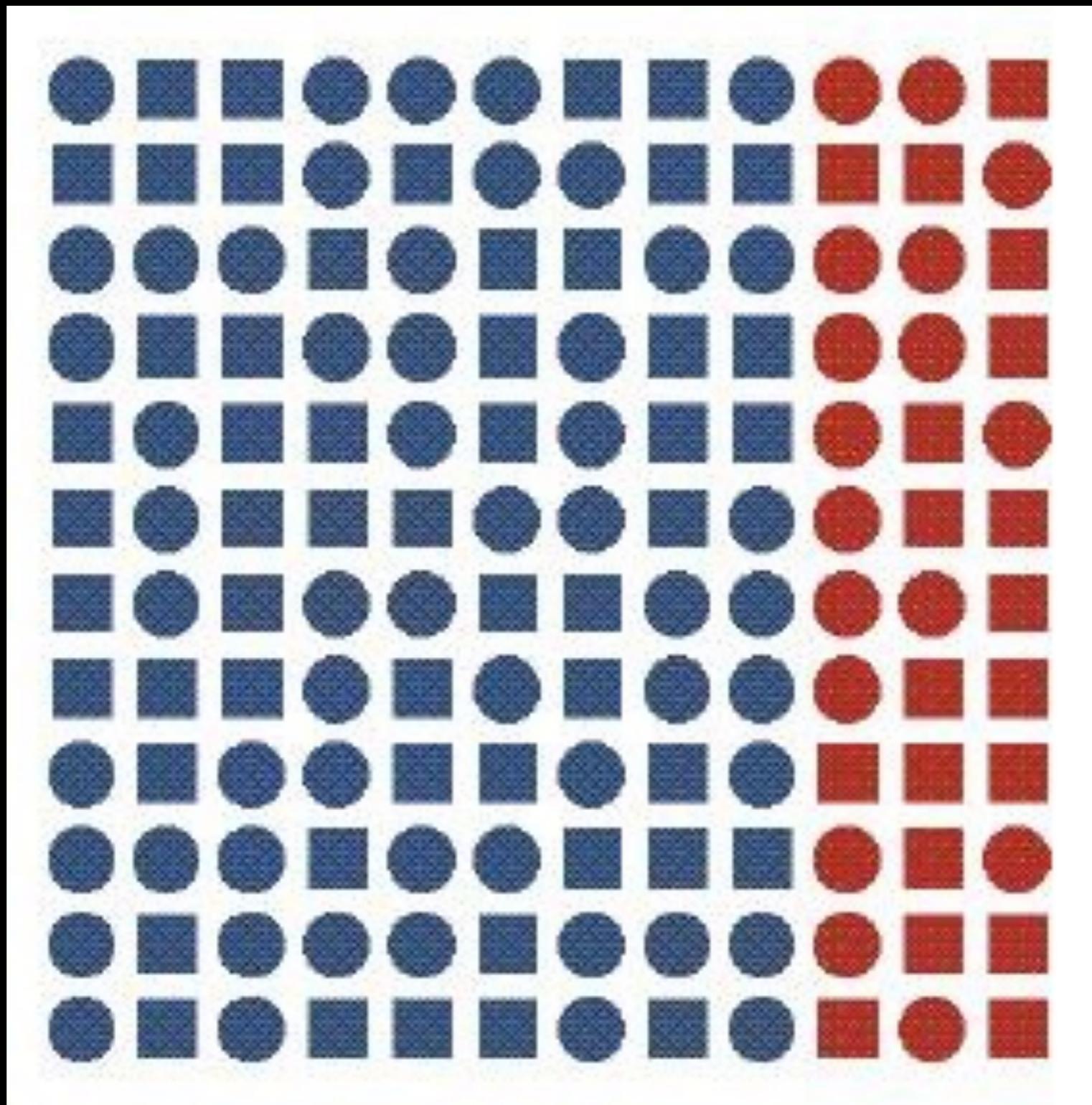
Only works when the distractors differ from one feature:



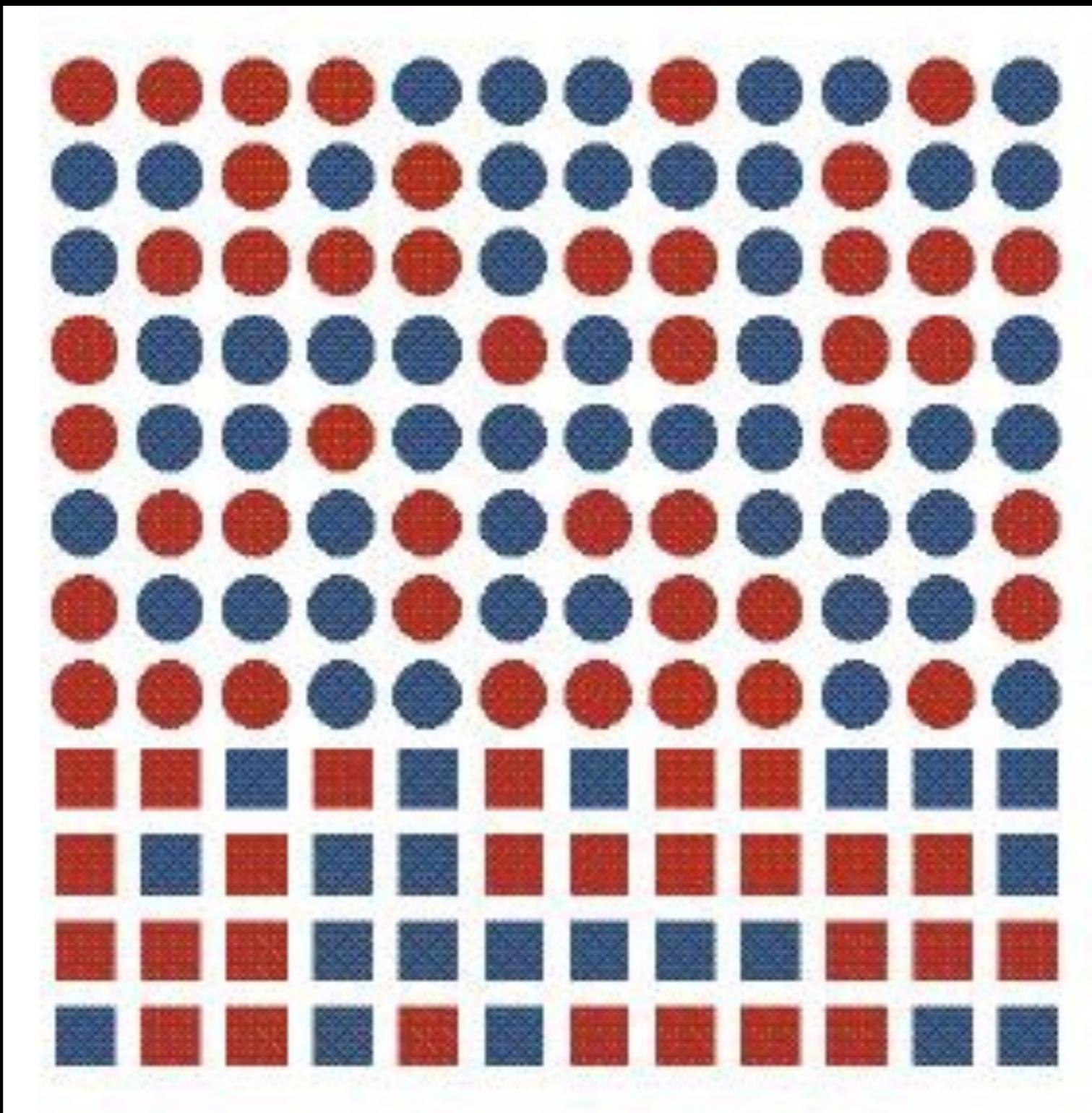
We must fall back on linear scanning when there is a conjunction of features.



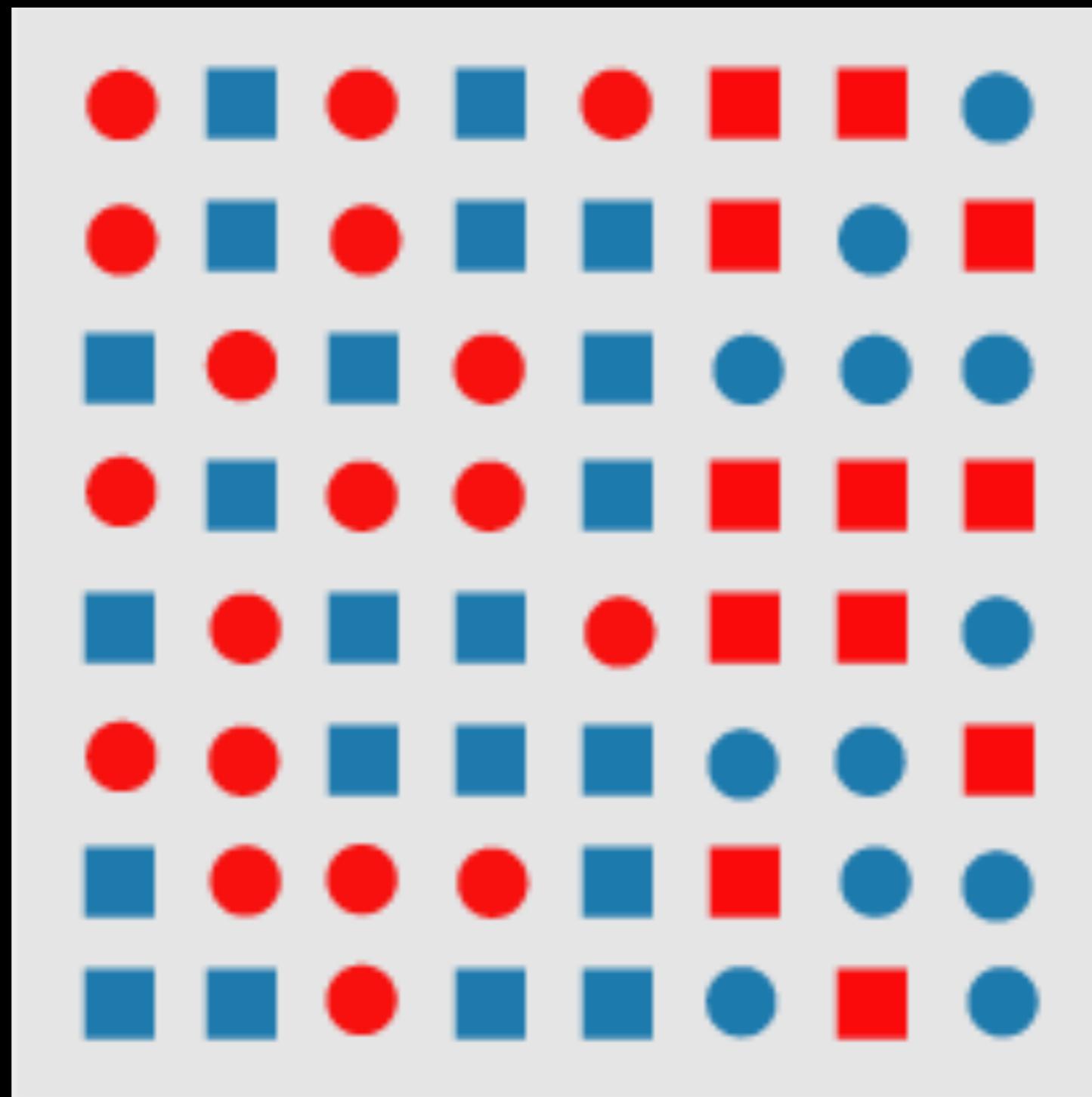
Is there a boundary?



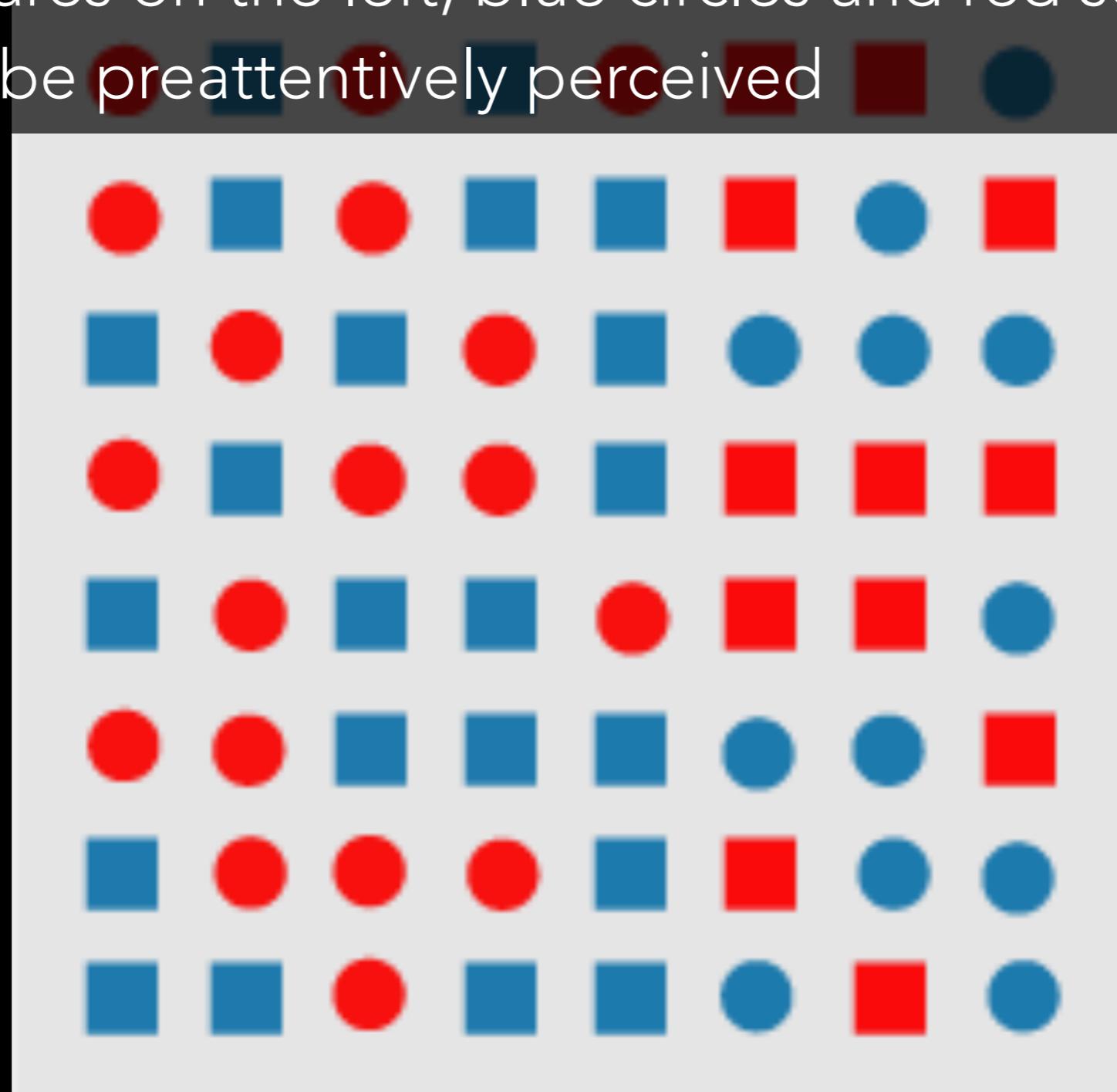
Is there a boundary?



Is there a boundary? (hint: YES!)



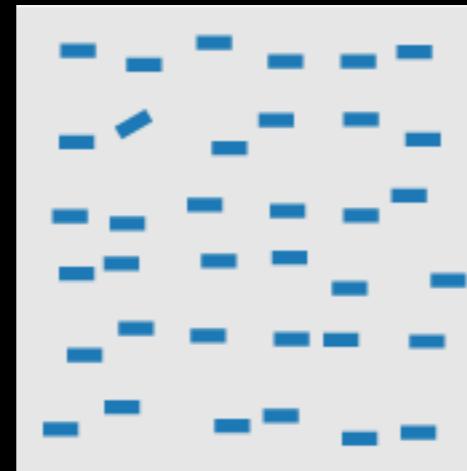
a boundary defined by a conjunction of features (here red circles and blue squares on the left, blue circles and red squares on the right) cannot be preattentively perceived



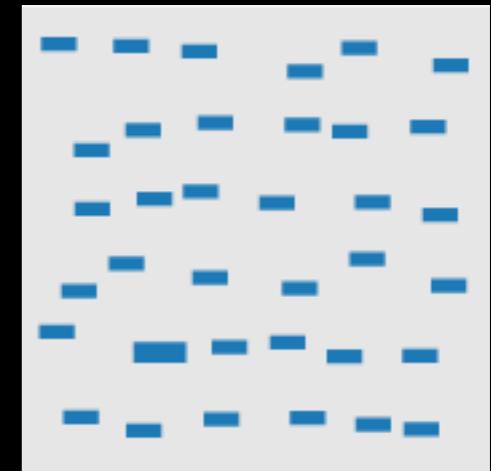
## (SOME) PRE-ATTENTIVE VISUAL FEATURES

**orientation**

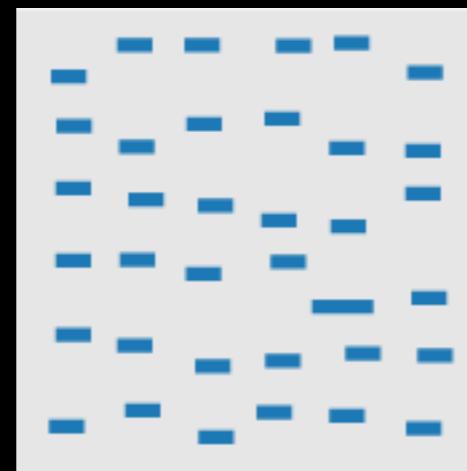
[Julész & Bergen 83]  
 [Sagi & Julész 85]  
 [Wolfe et al. 92]  
 [Weigle et al. 2000]

**size**

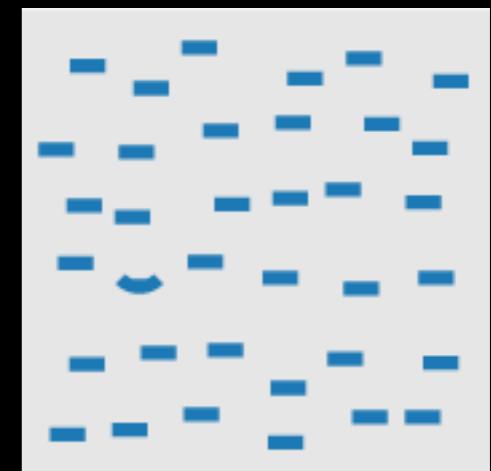
[Treisman & Gelade 80]  
 [Healey & Enns 98]  
 [Healey & Enns 99]

**length, width**

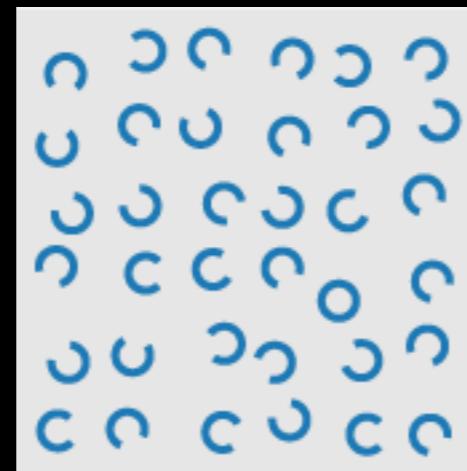
[Sagi & Julész 85]  
 [Treisman & Gormican 88]

**curvature**

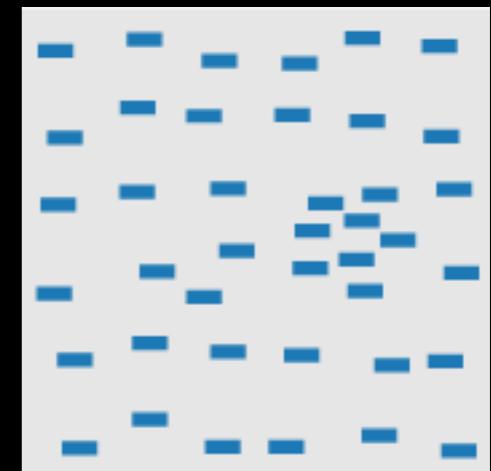
[Treisman & Gormican 88]

**closure**

[Julész & Bergen 83]

**density, contrast**

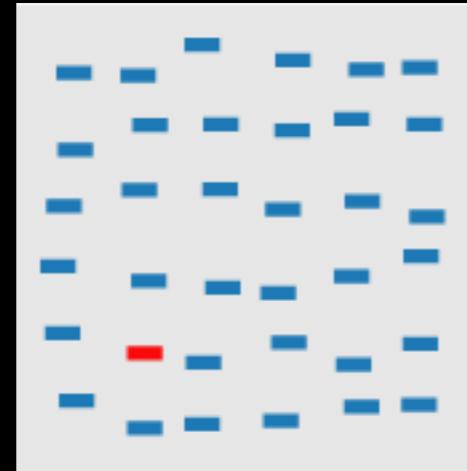
[Healey & Enns 98]  
 [Healey & Enns 99]



# (SOME) PRE-ATTENTIVE VISUAL FEATURES

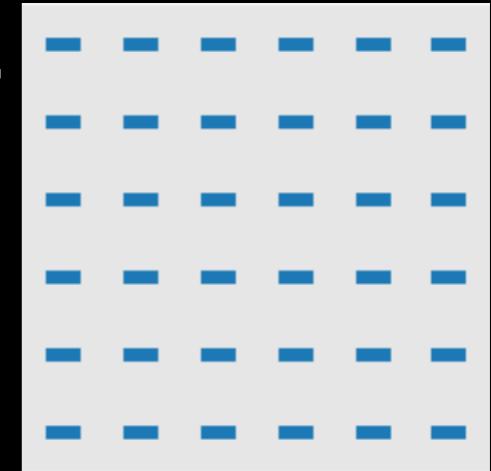
## color, hue

Nagy & Sanchez 90; Nagy et al. 90; D'Zmura 91;  
Kawai et al. 95; Bauer et al. 96; Healey 96; Bauer et al. 98; Healey & Enns 99



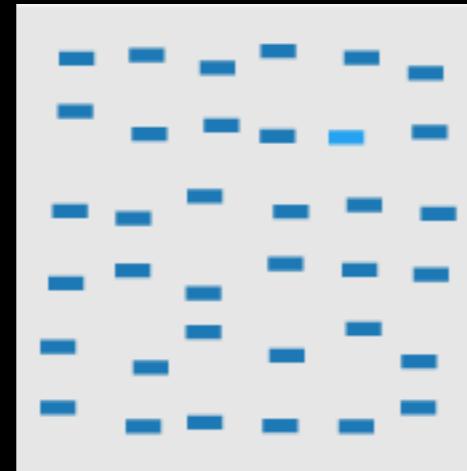
## flicker

[Gebb et al. 55; Mowbray & Gebhard 55; Brown 65; Julész 71]  
[Huber & Healey 2005]



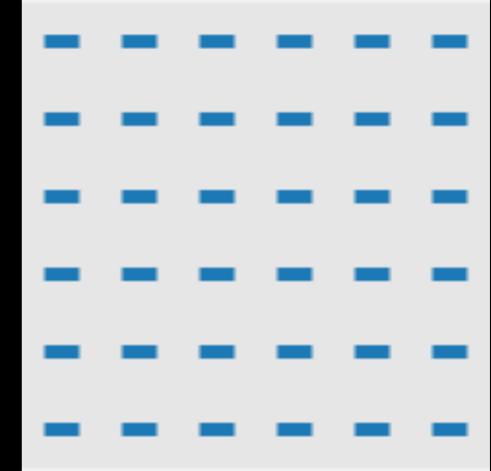
## intensity

[Beck et al. 83]  
[Treisman & Gormican 88]  
[Wolfe & Franzel 88]



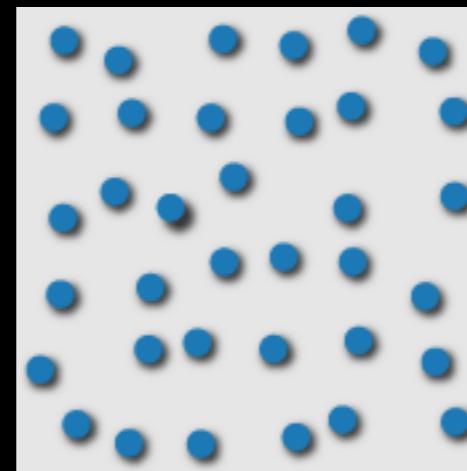
## direction of motion

[Nakayama & Silverman 86; Driver & McLeod 92; Huber & Healey 2005]



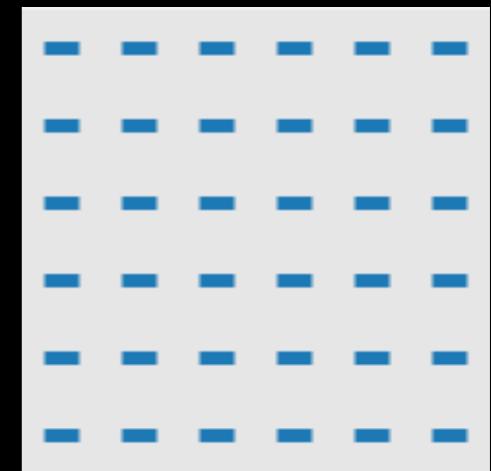
## 3D depth cues

[Enns 90b; Nakayama & Silverman 86]

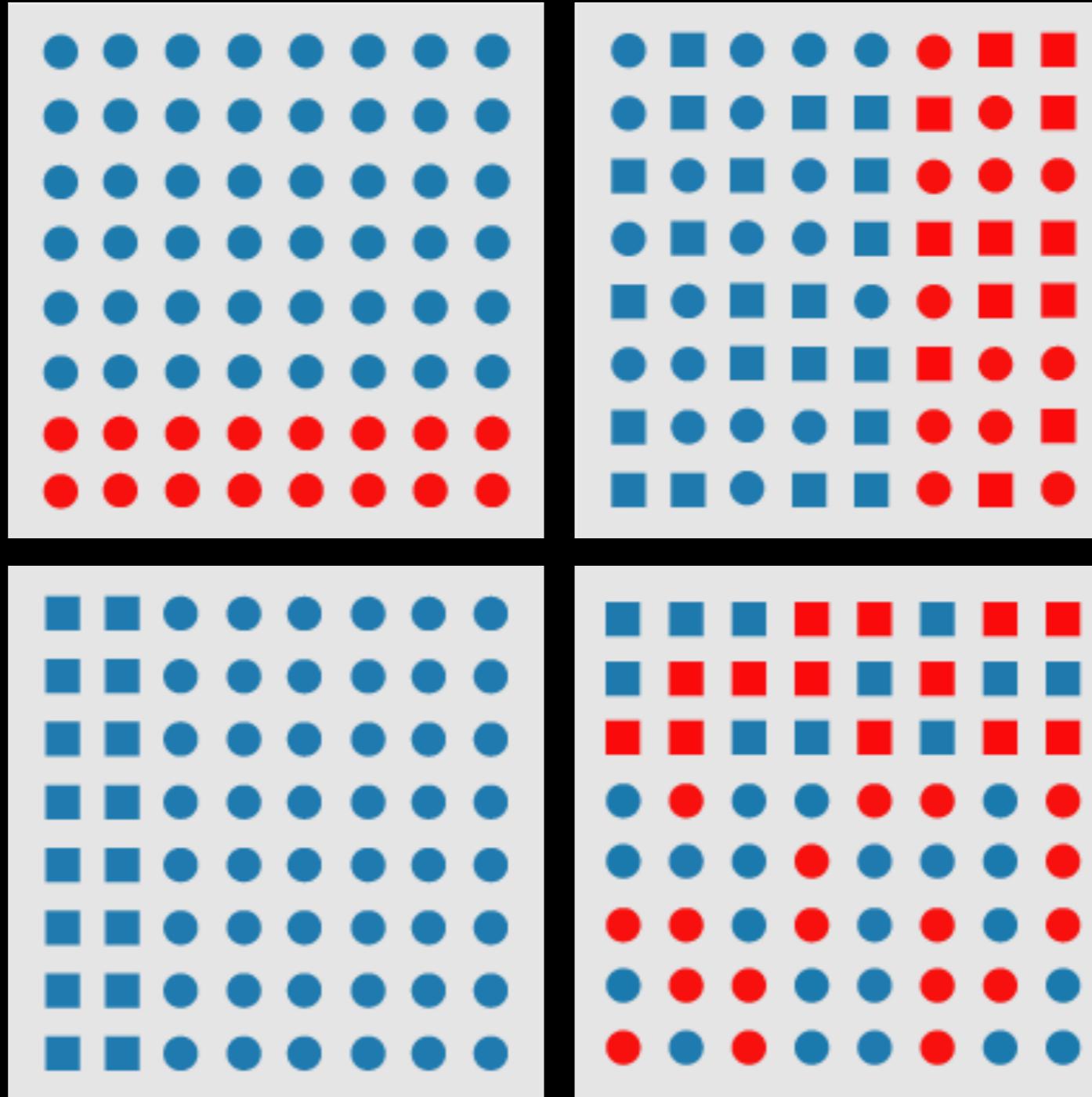


## velocity of motion

[Tynan & Sekuler 82; Nakayama & Silverman 86; Driver & McLeod 92; Hohnsbein & Mateeff 98; Huber & Healey 2005]



Note that these various features are not created equal!



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

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*

*Region tracking*

*Boundary detection*

*Counting (estimation)*

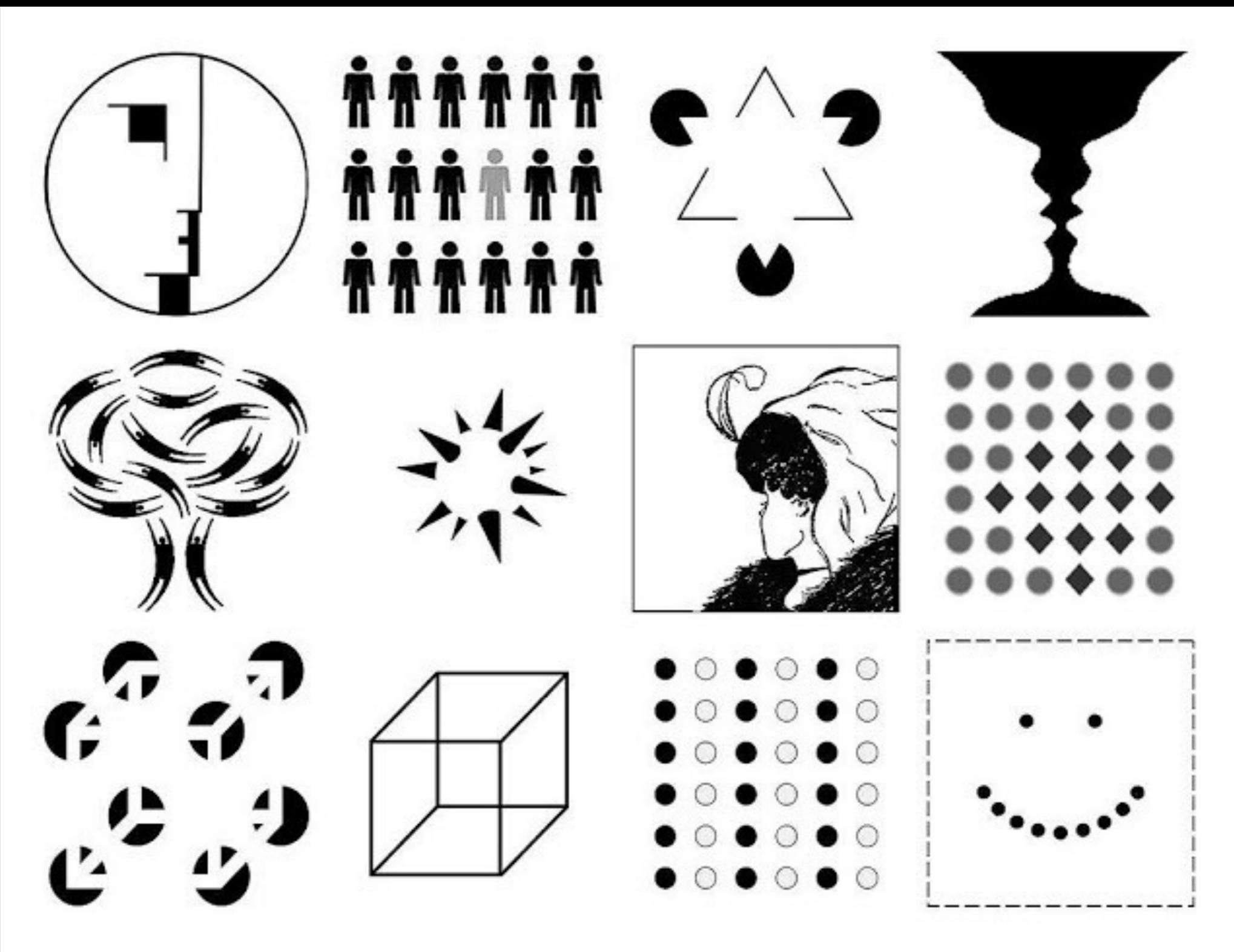
2. The more of our story we can tell using pre-attentive features, the faster and better our viewer will “get it”.

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

*Many of the things that make a bad visualisation "bad" can be traced back to problems relative to pre-attentive processing.*



# GESTALT PSYCHOLOGY



## DEFINITION

The Gestalt psychology is a **theory of perception** that is often summed up by:

*“The whole is other than the sum of the parts”*  
— Kurt Koffka (1922)

## 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  
**optimised for.**

The Gestalt psychology notably describes the **perception of forms** by the visual system.

It relies on four **principles**:

- Emergence
- Reification
- Multistability
- Invariance

It also describes our visual perceptions by a set of **laws**.

# EMERGENCE

The **global perception** can **not** be explained by the **sum of its parts**.

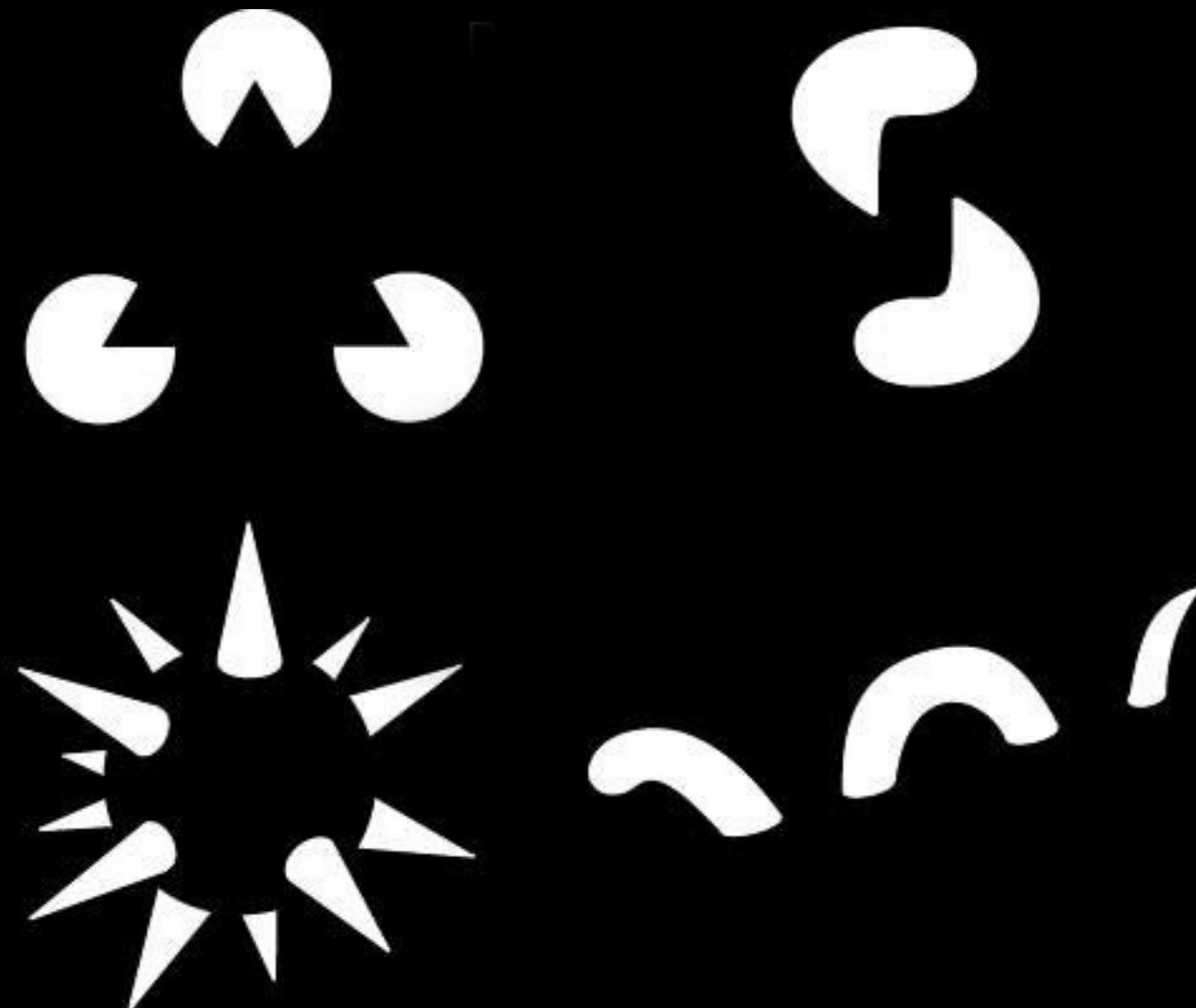
# EMERGENCE



# REIFICATION

The **perception** contains **more spatial information than the stimulus** on which it is based: **part of the perception is generated.**

# REIFICATION



# MULTISTABILITY

**Ambiguous stimuli** can generate **different perceptions** but they **can not coexist** simultaneously.

# MULTISTABILITY

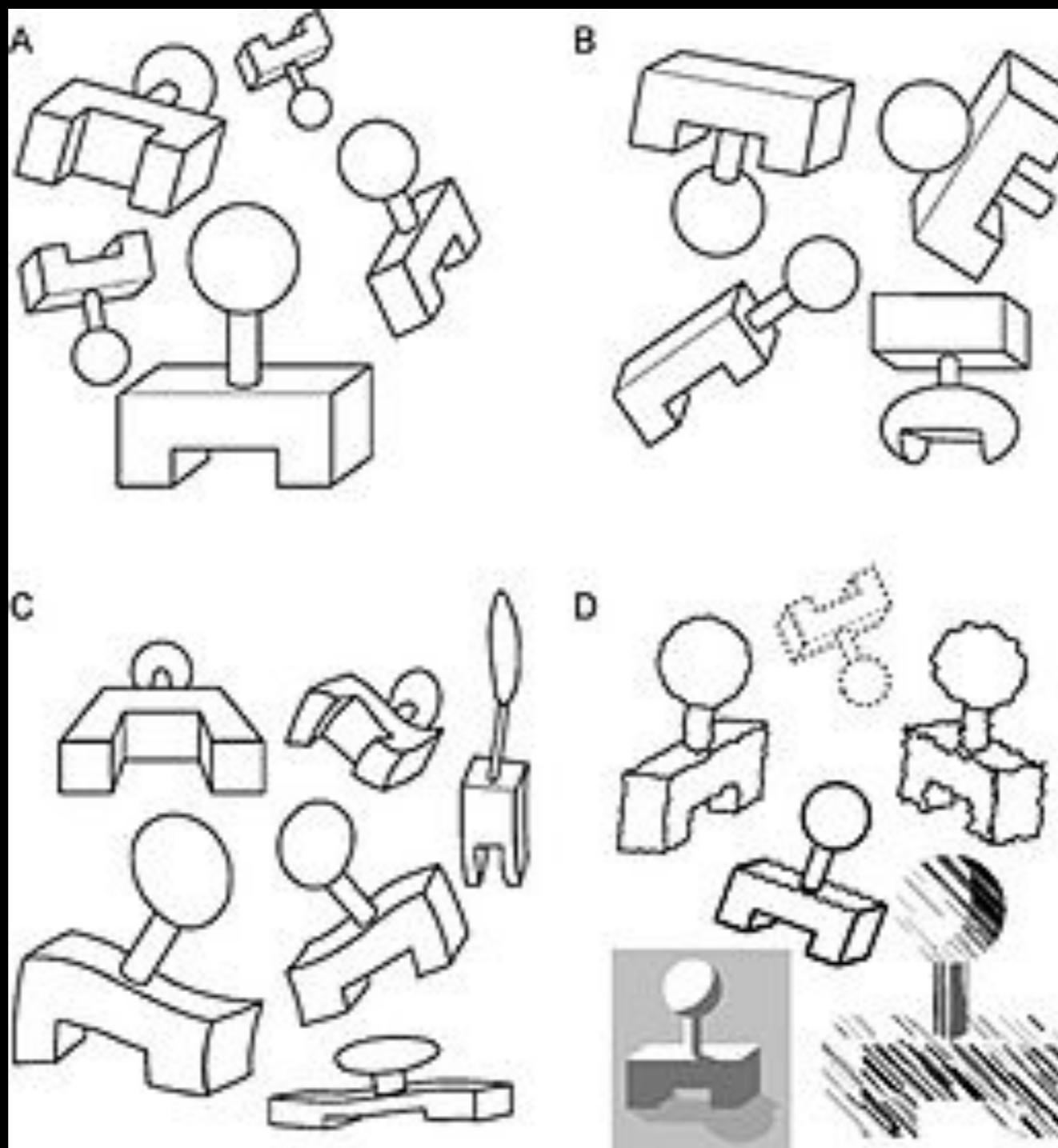


"My wife and my mother-in-law." (1915)

# INVARIANCE

Objects are **recognized independently of various variations**, such as geometrical transformations, lighting, etc.

# INVARIANCE



# GESTALT LAWS OF GROUPING



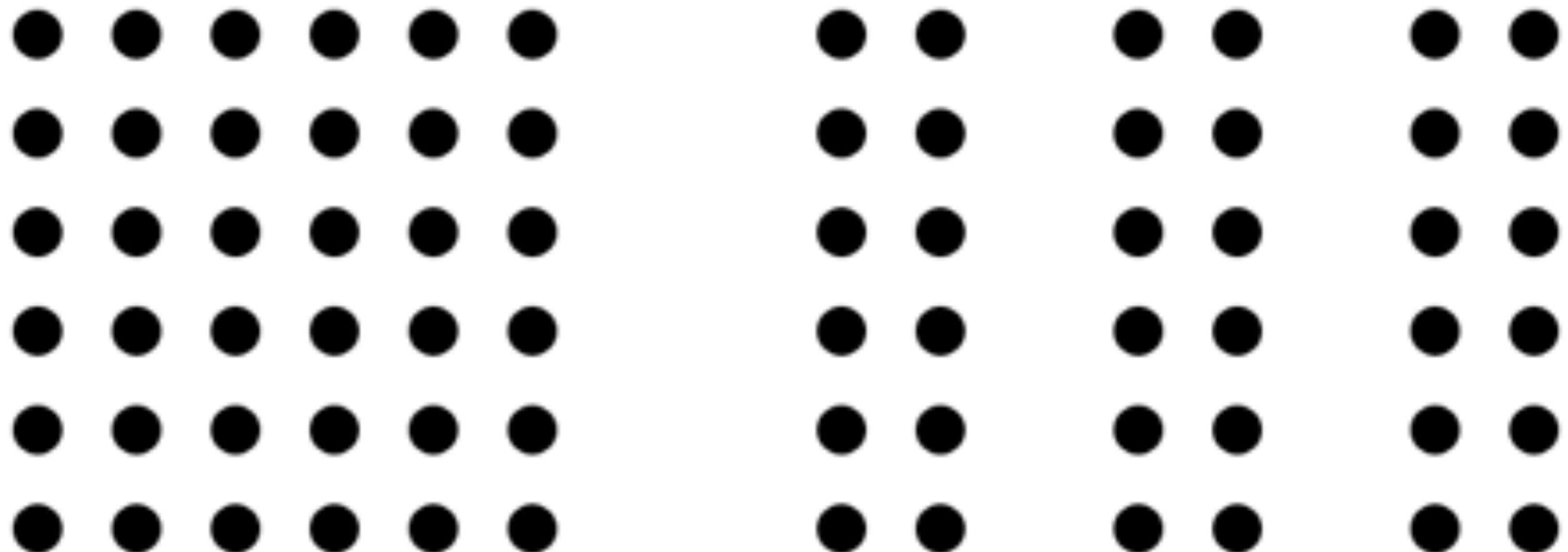
The **laws of grouping** state how **low-level perceptions** are **grouped** into higher-level objects.

Good Gestalt (Prägnanz)

We tend to order our experience in a manner that is regular, orderly, symmetric, and simple.

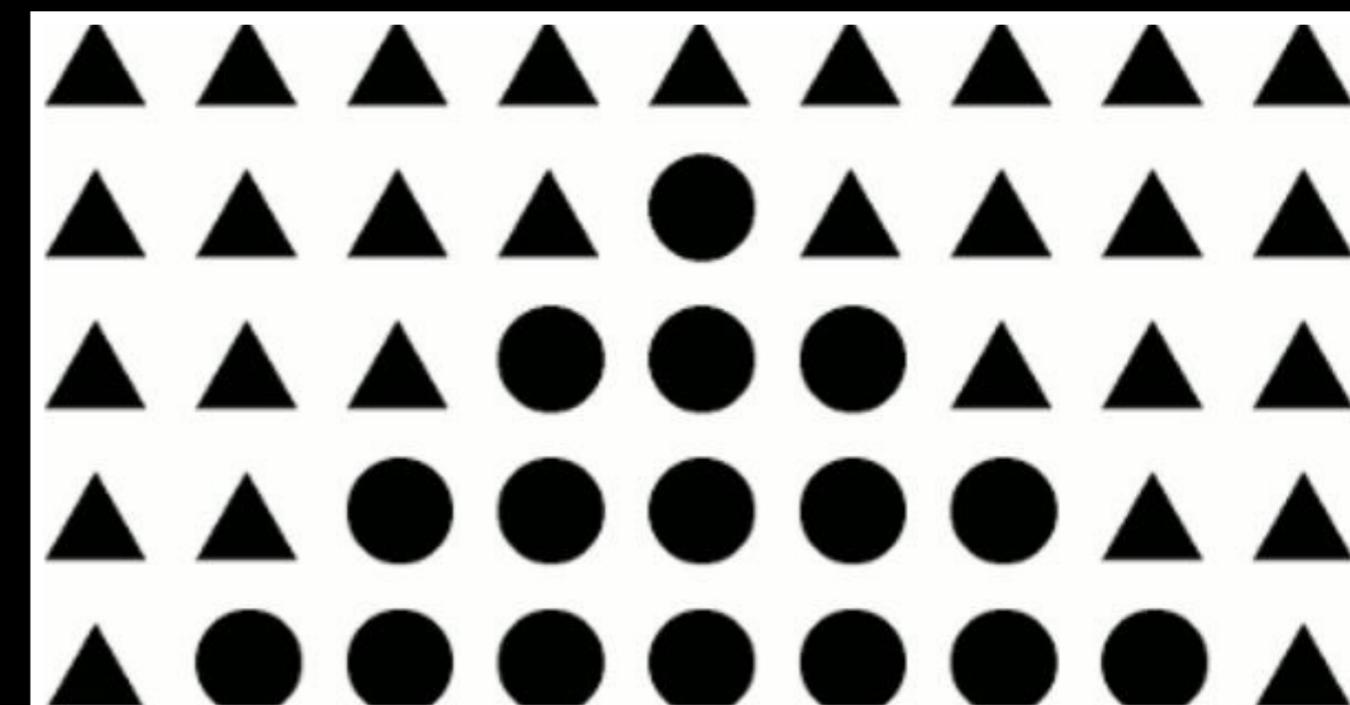
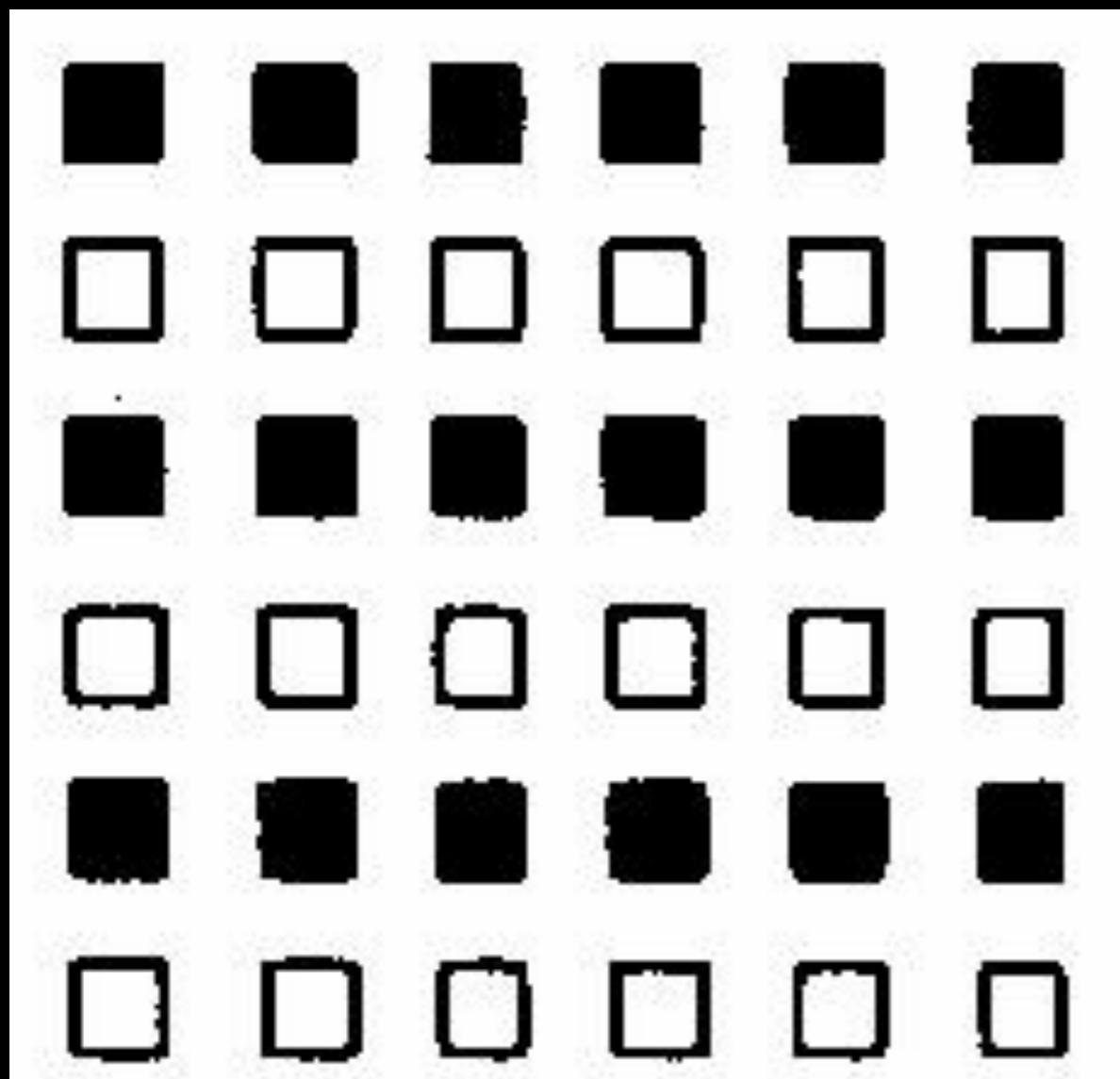
## LAW OF PROXIMITY

Objects that are close tend to be perceived as a group.



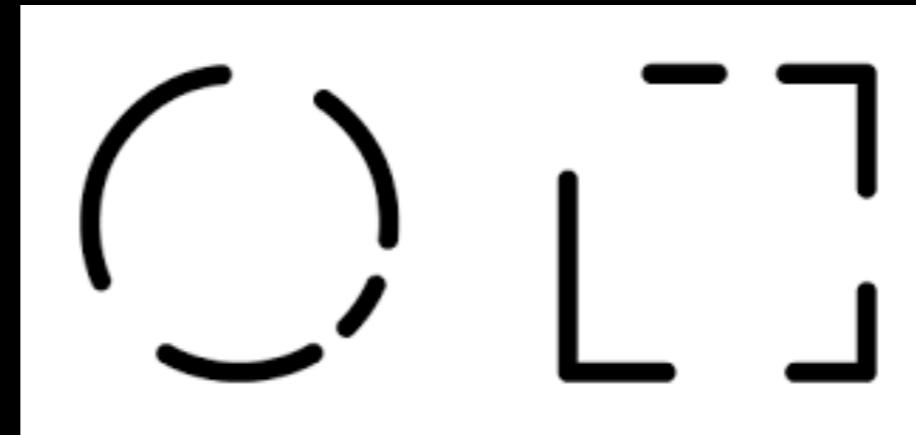
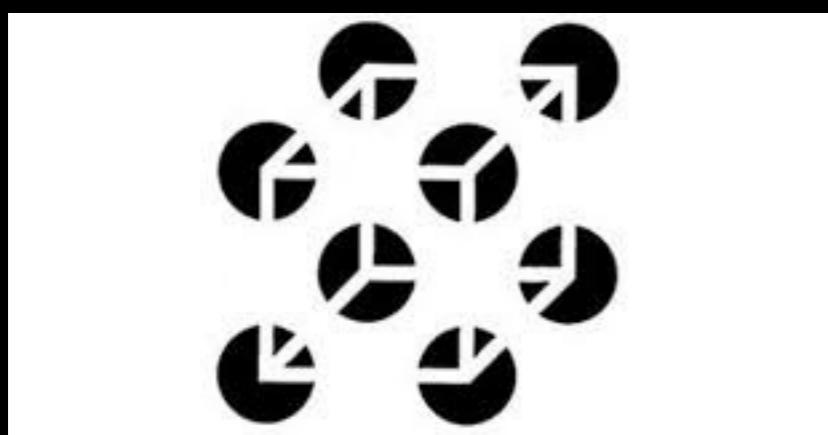
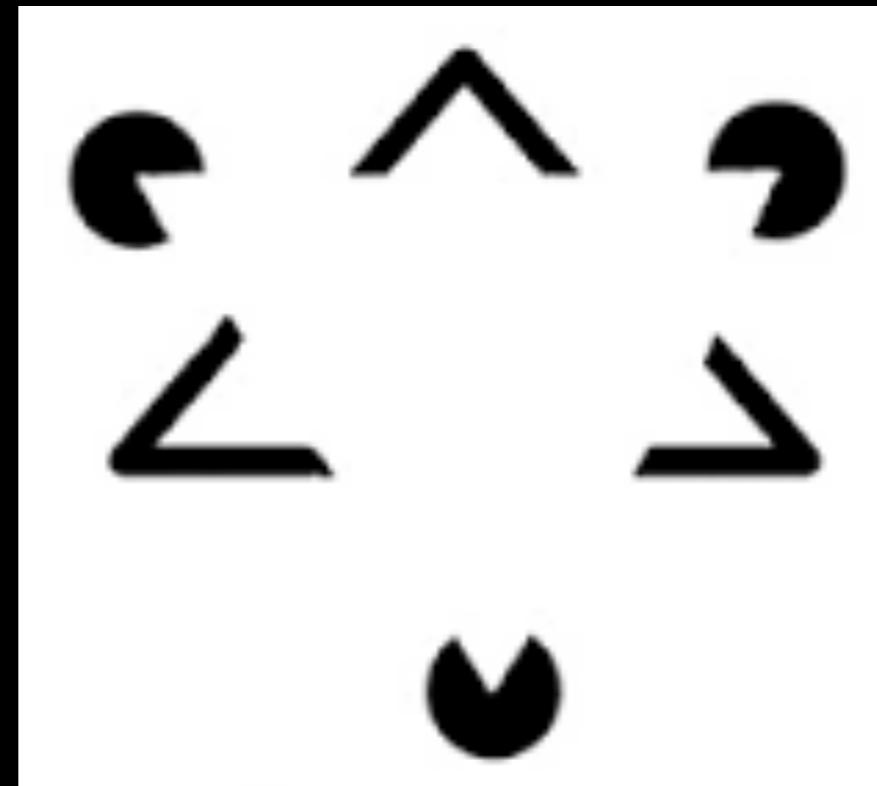
# LAW OF SIMILARITY

Objects that are similar (in shape, color, shading, etc.) tend to form a group.



# LAW OF CLOSURE

The perception fills gaps in stimuli.



# LAW OF SYMMETRY

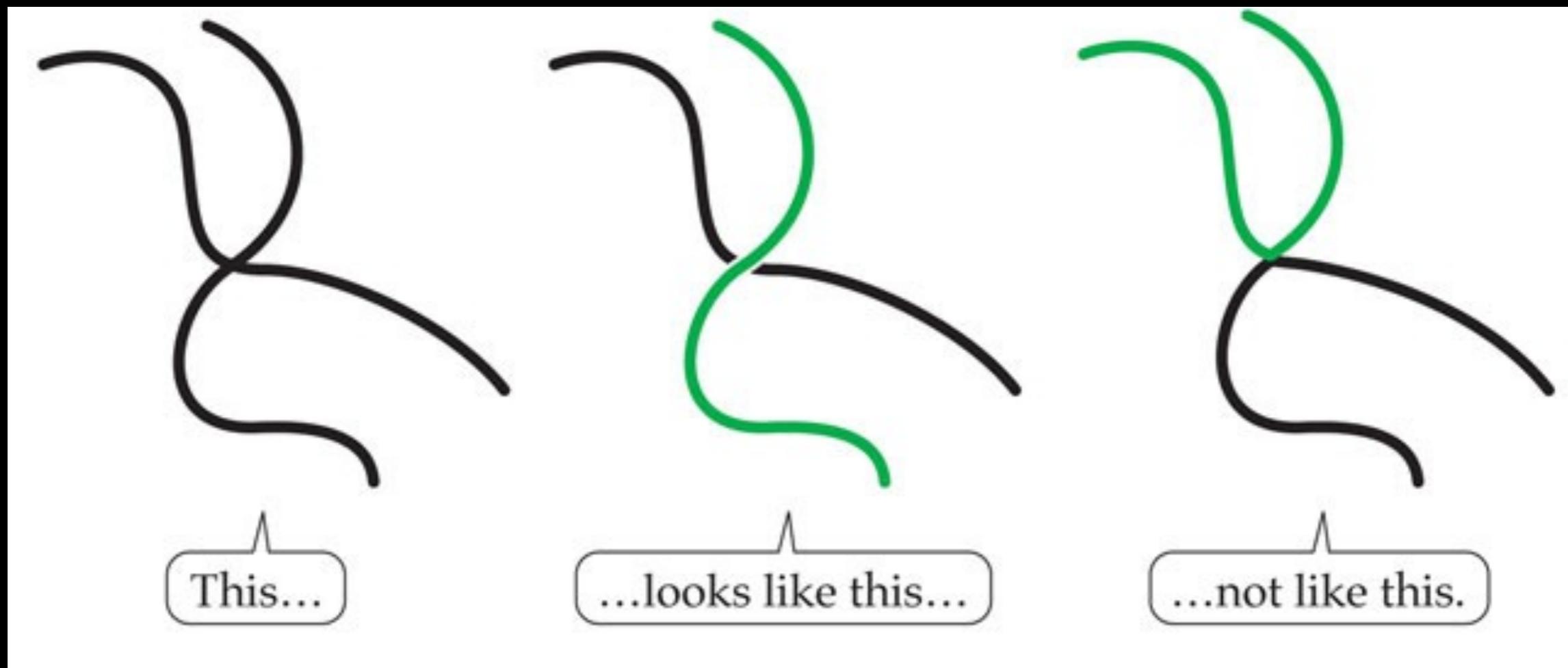
Objects with symmetric disposition tend to be perceived as forming a whole.

[                  ] {                  } [                  ]

How many groups of elements are there?

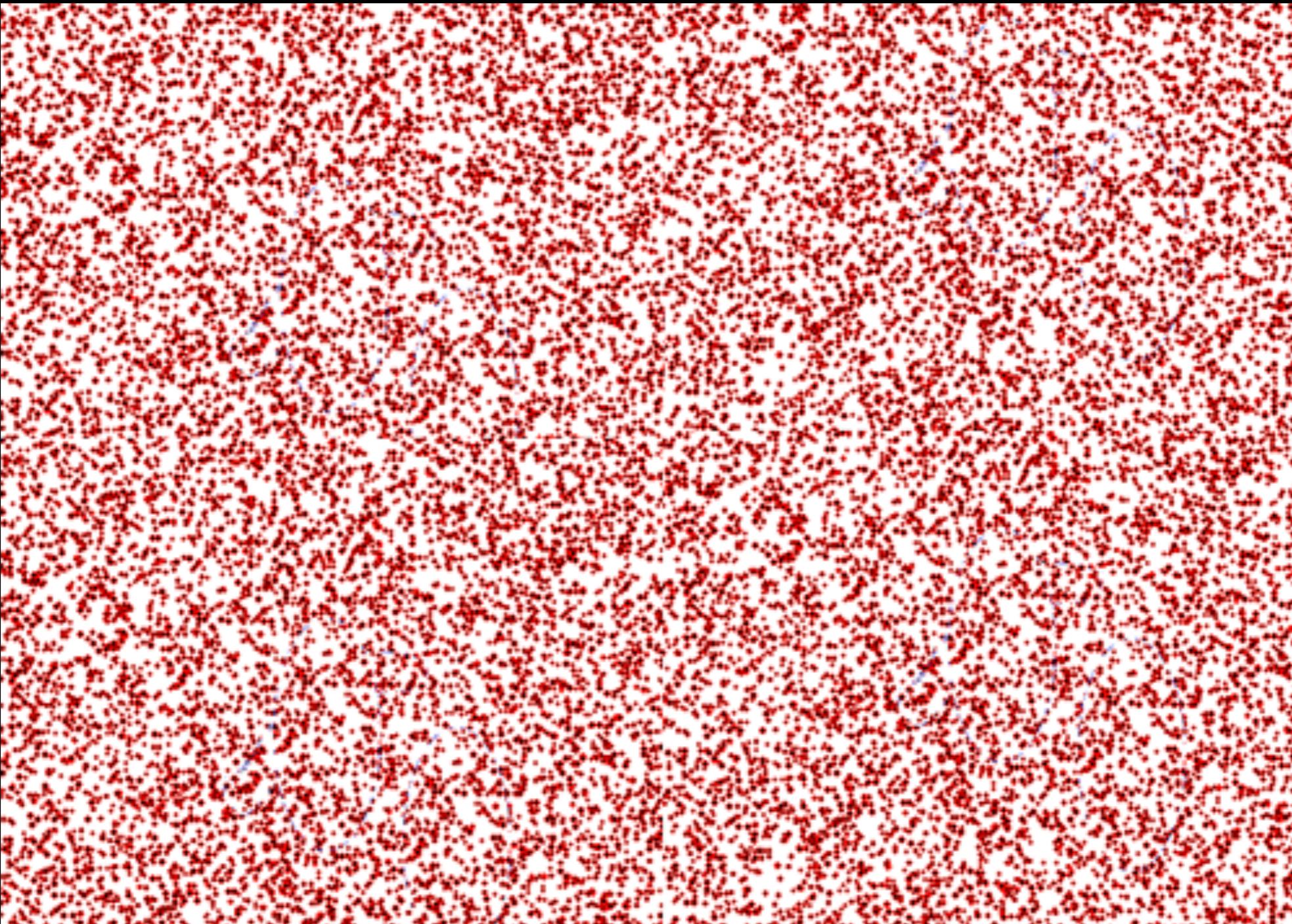
# LAW OF CONTINUITY

Ambiguous stimuli are perceived preferentially with the interpretation that is the most continuous.



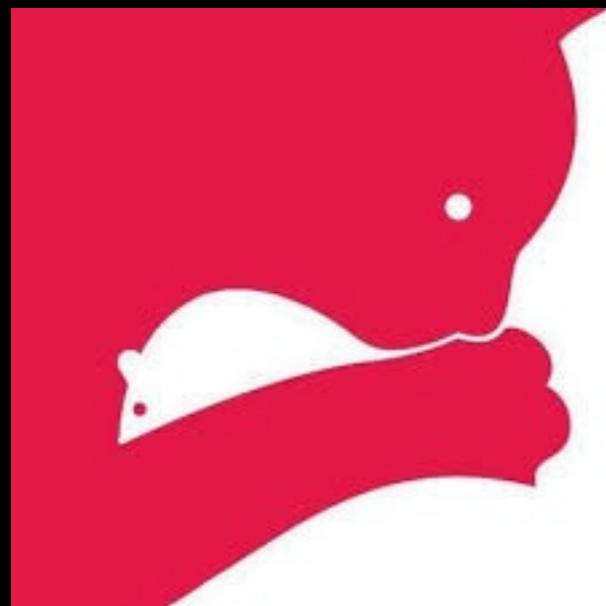
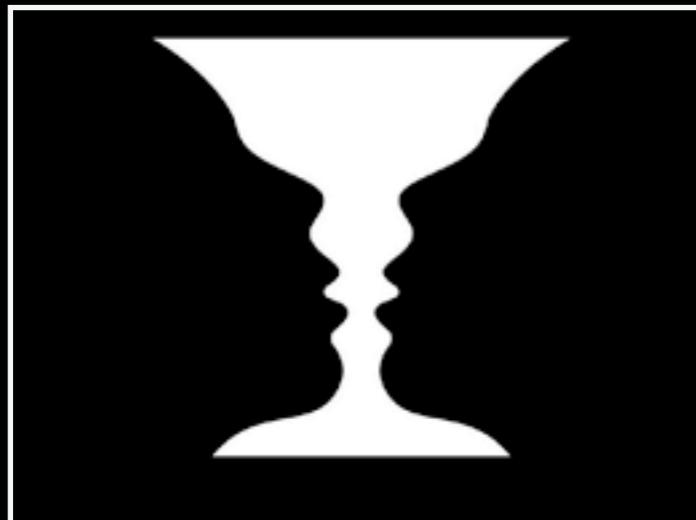
# LAW OF COMMON FATE

Objects evolving together are perceived as a group.



# LAW OF FIGURE & GROUND

Elements are perceived as either a **figure** (element of focus) or **ground** (background on which the figure sits)



# FIGURE & GROUND IN ART



Visual Perception & Cognition

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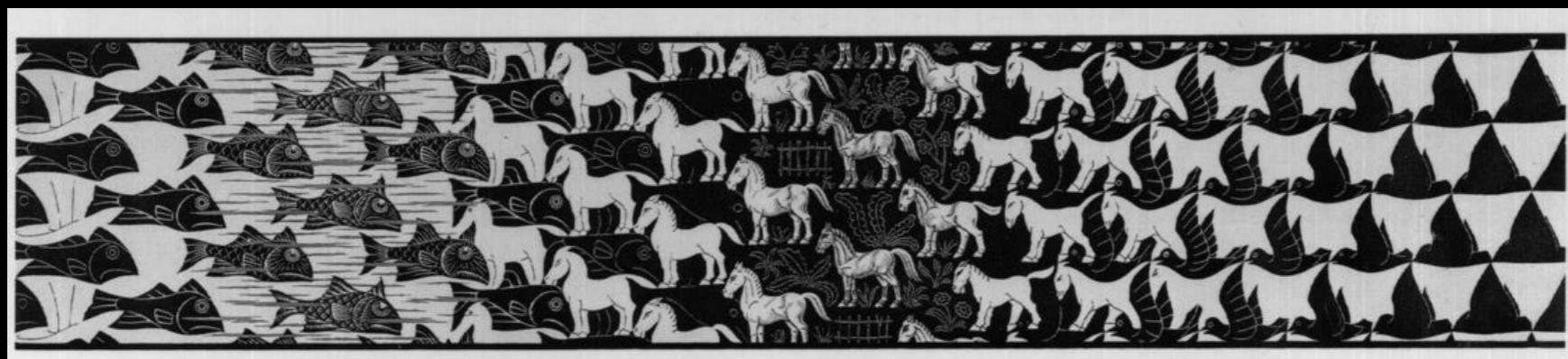
Visualization

ooooooooooooo

# FIGURE & GROUND IN DESIGN



# FIGURE & GROUND: BEFORE GESTALT

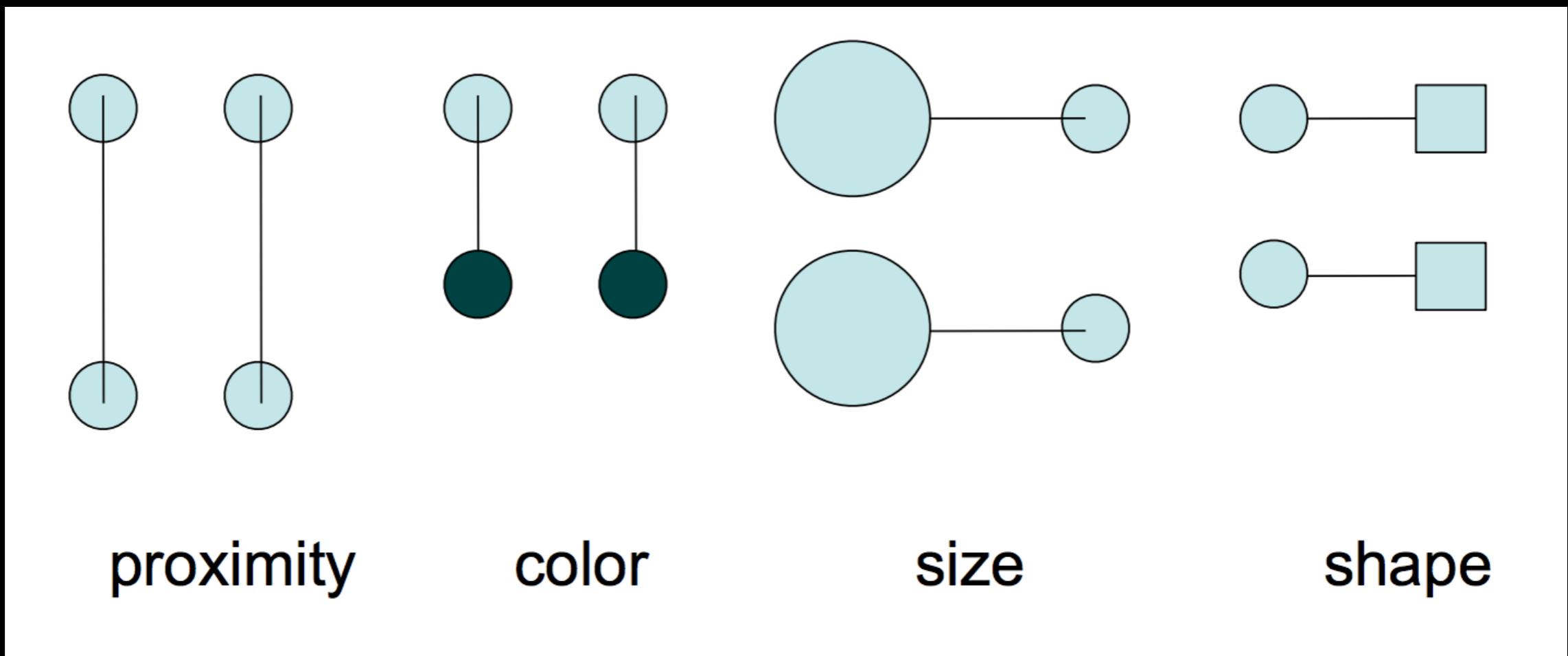


Escher's Metamorphosis

# MORE LAWS!

## LAW OF CONNECTEDNESS

Things that are linked are perceived as belonging to the same group.

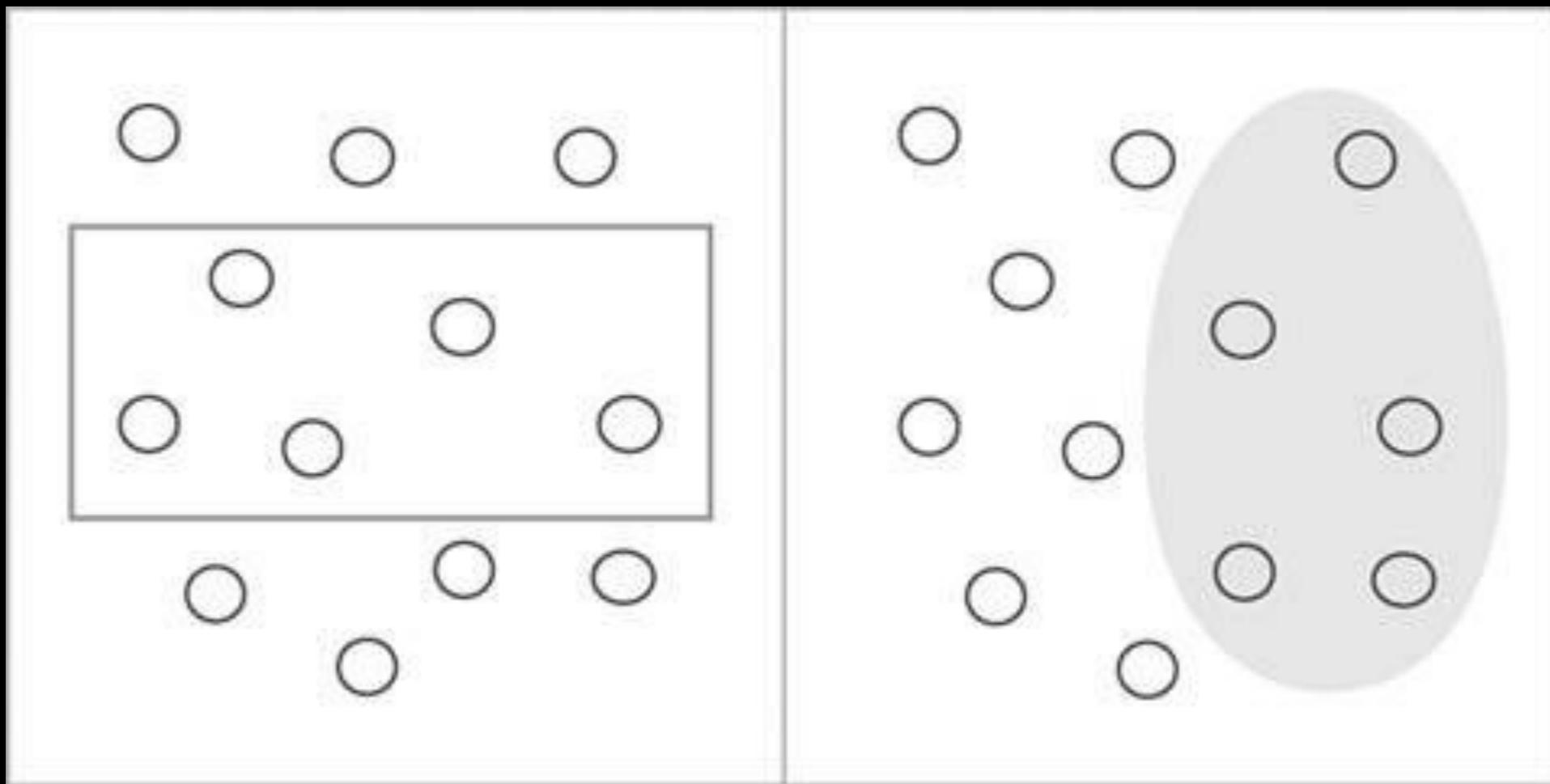


More powerful than proximity, color, size, shape...

# MORE LAWS!

## LAW OF ENCLOSURE

Objects that are enclosed are perceived as a group



Again, more powerful than proximity, color, size, shape...

## IN SUMMARY

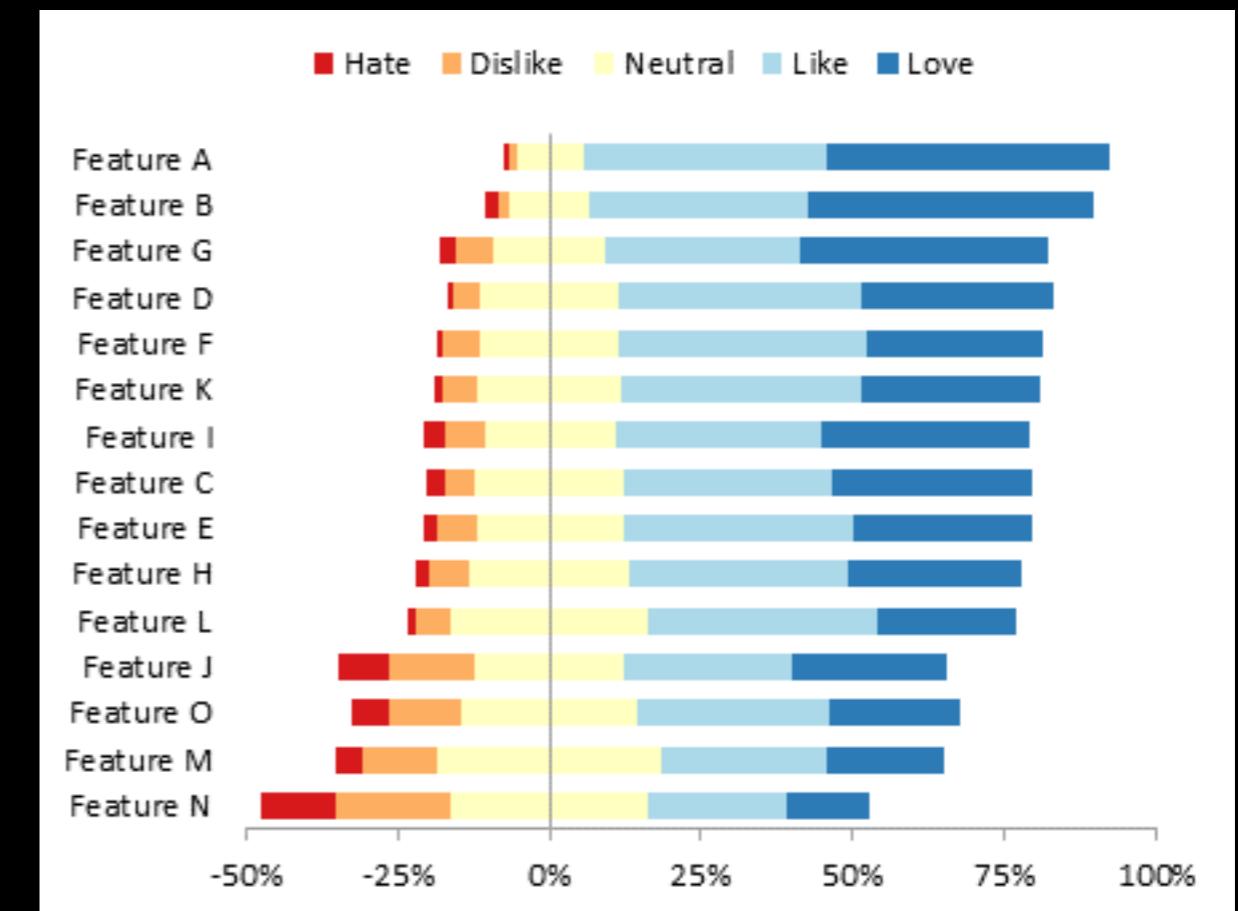
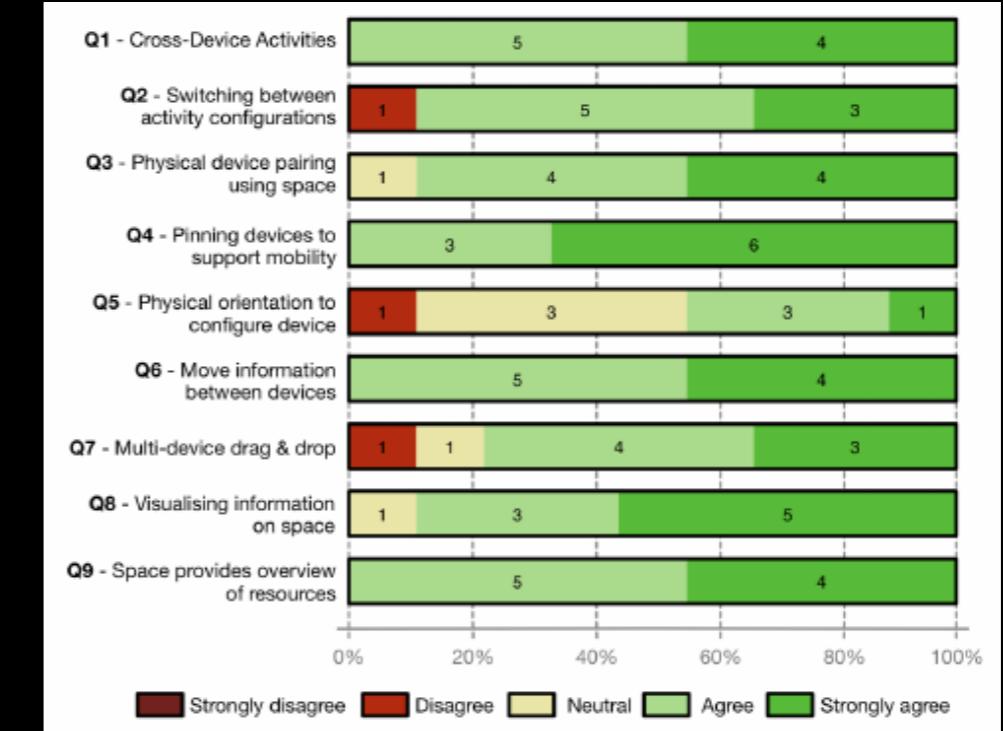
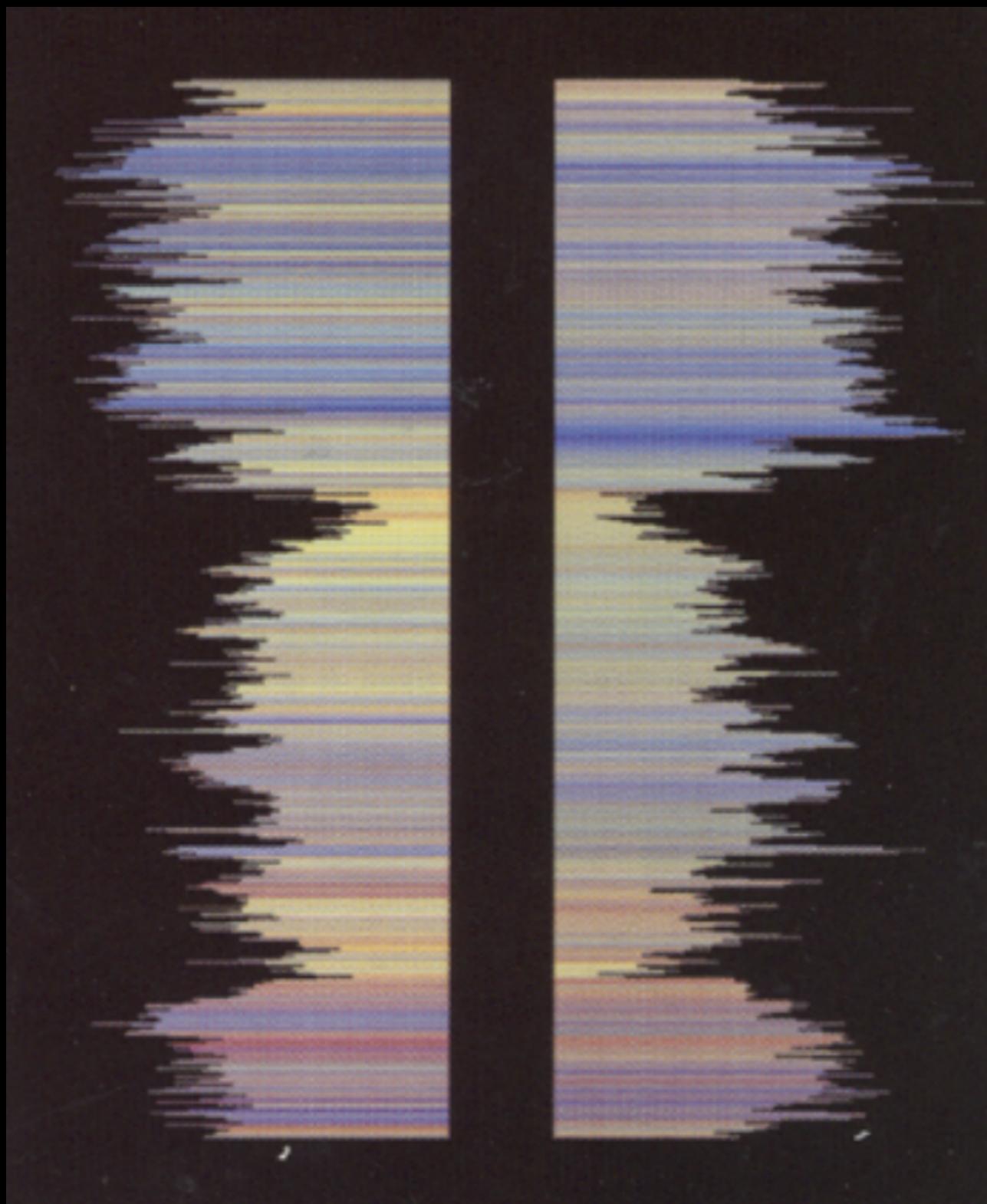
Our brains take lots of perceptual “shortcuts”...

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

It is not enough to simply show something, we need to pay attention when and how it is shown.

**A GOOD UNDERSTANDING OF PERCEPTUAL AND COGNITIVE PROCESSES IS CRITICAL!**

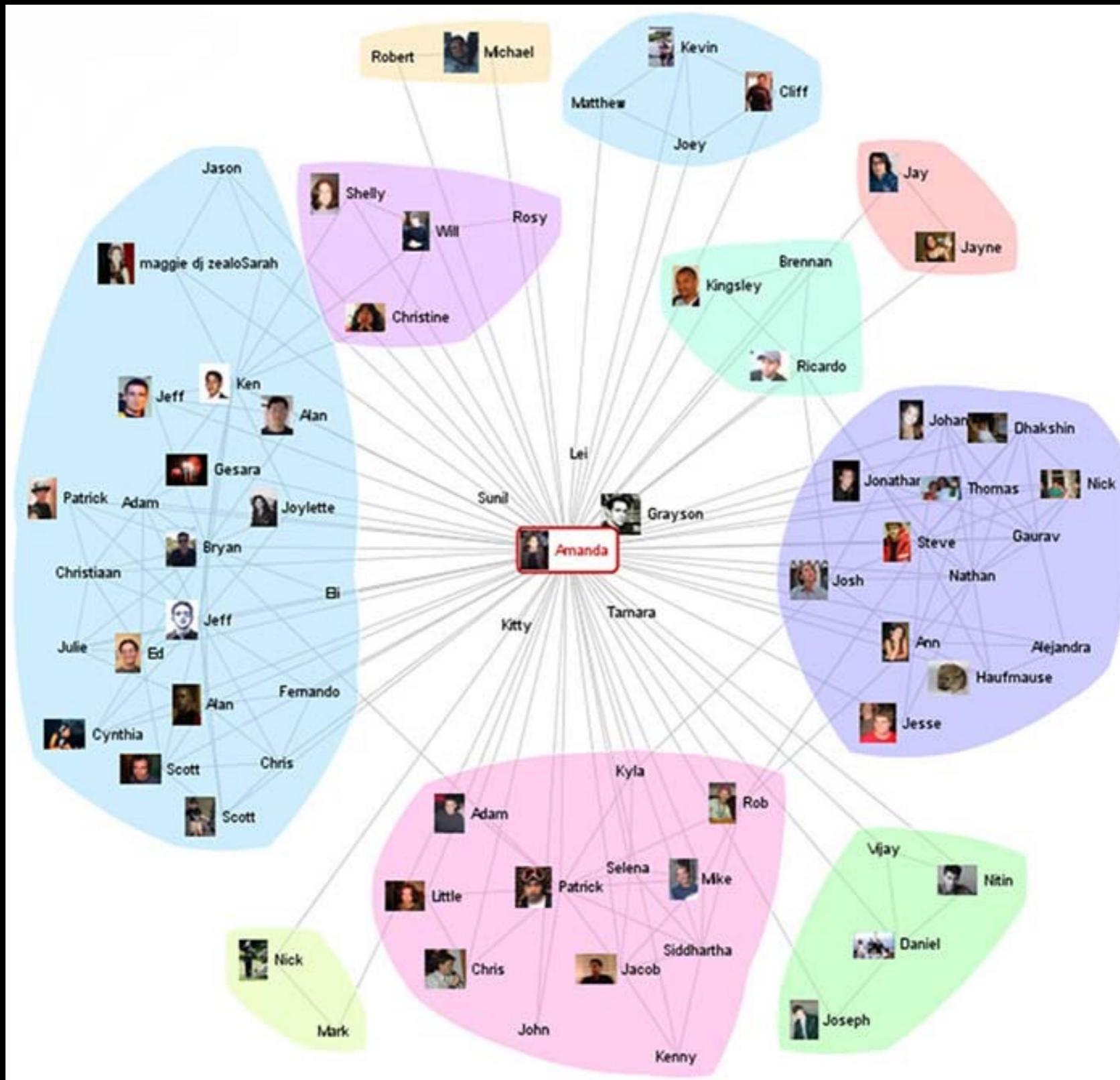
# IMPLICATIONS FOR INFOVIS



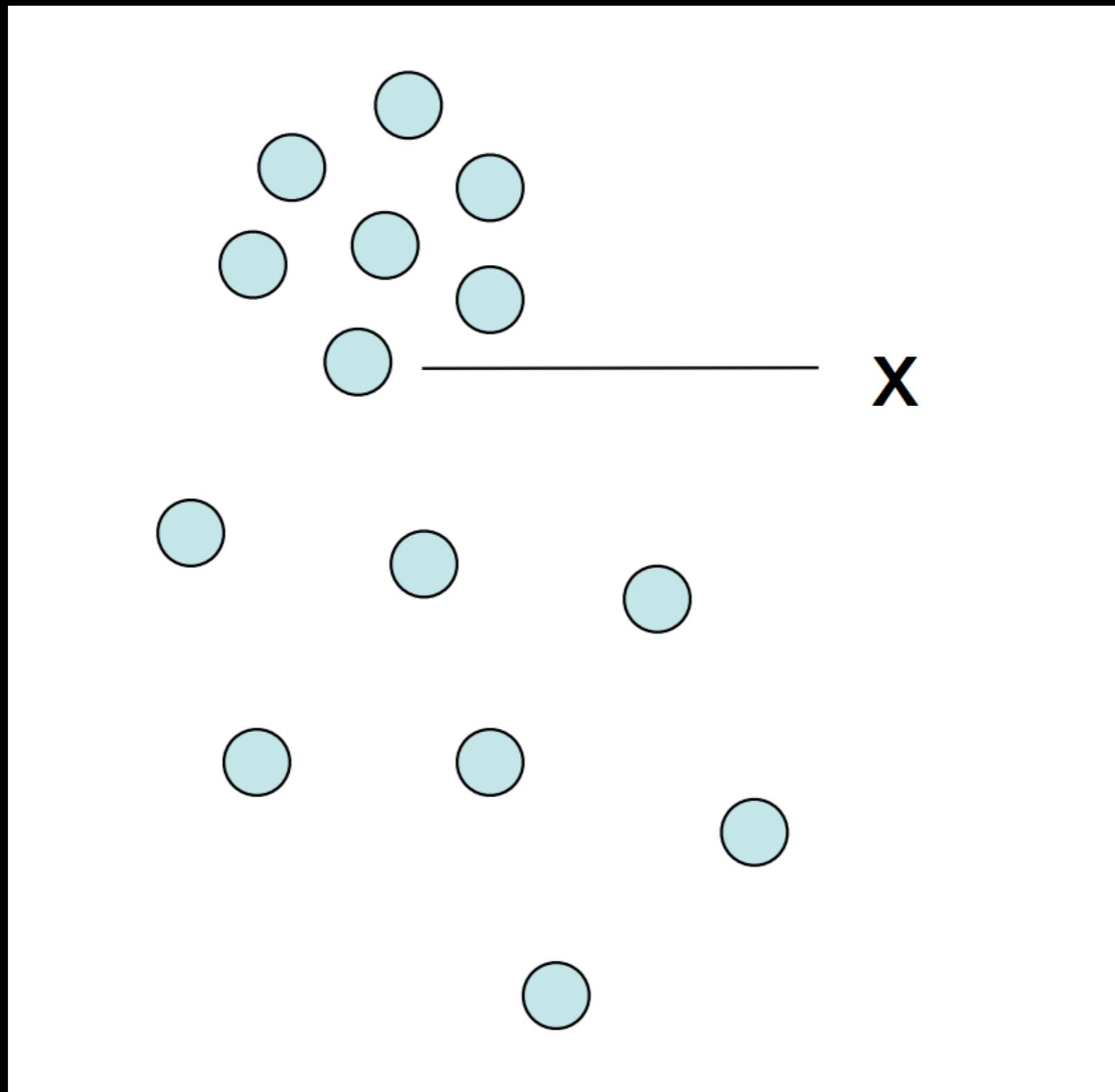
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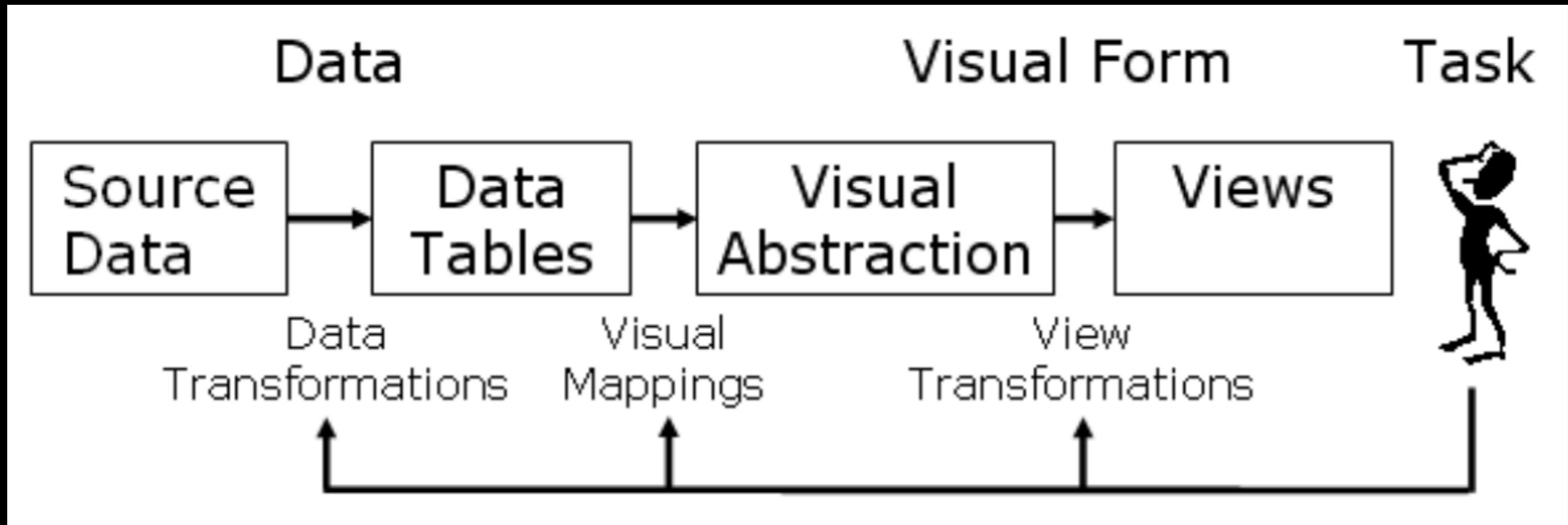
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FROM DATA TO VISUAL REPRESENTATIONS

# VISUALIZATION BUILDING BLOCKS

# THE INFOVIS REFERENCE MODEL

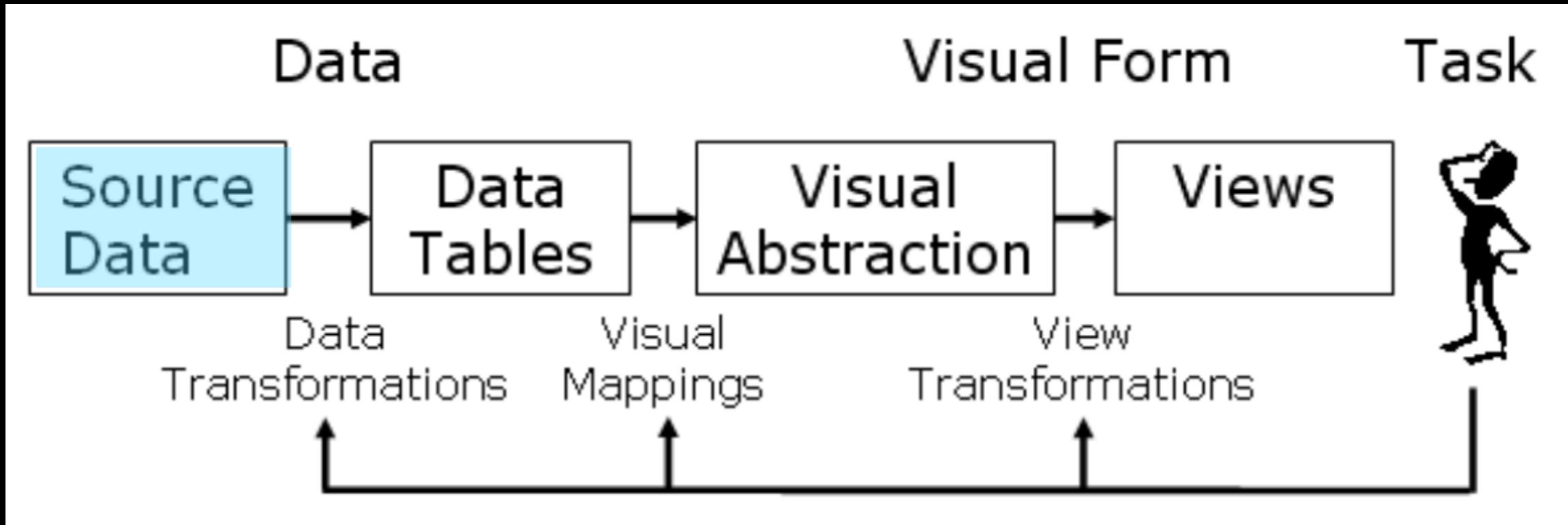
aka infovis pipeline, data state model [Chi99]



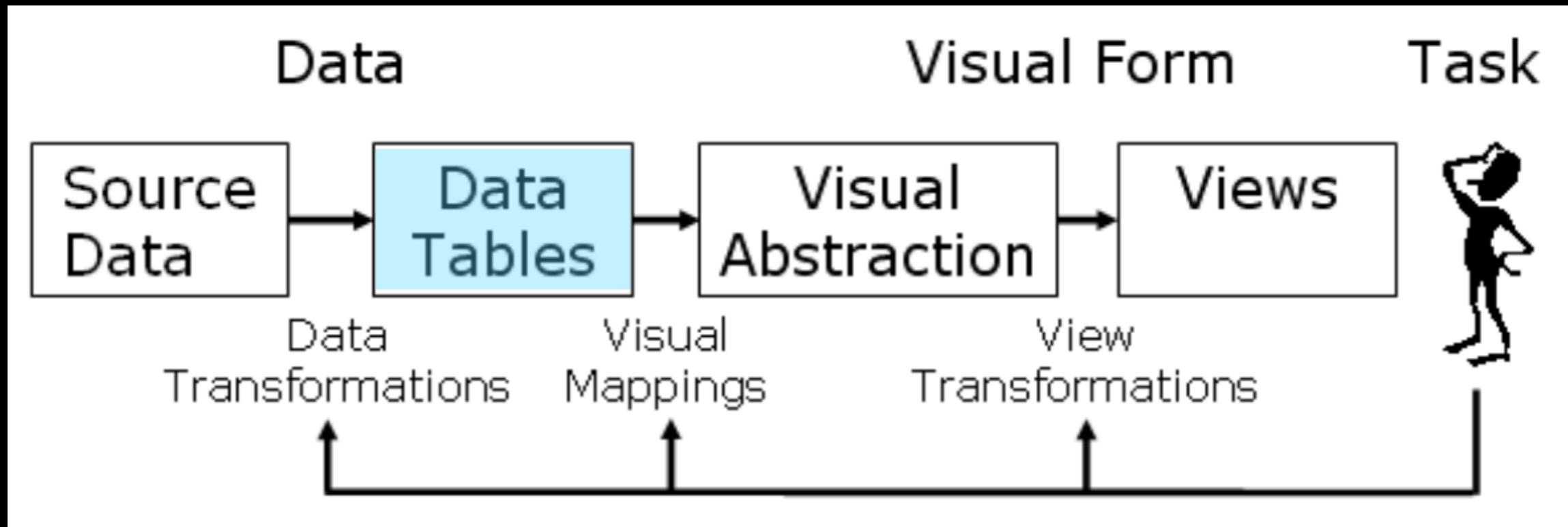
Ed Chi. A Framework for Information visualisation spreadsheets.  
PhD Thesis, University of Minnesota, 1999.

Image from: Card, Mackinlay, and Shneiderman. Readings in Information Visualization: Using Vision To Think, Chapter 1. Morgan Kaufmann, 1999

# THE INFOVIS REFERENCE MODEL

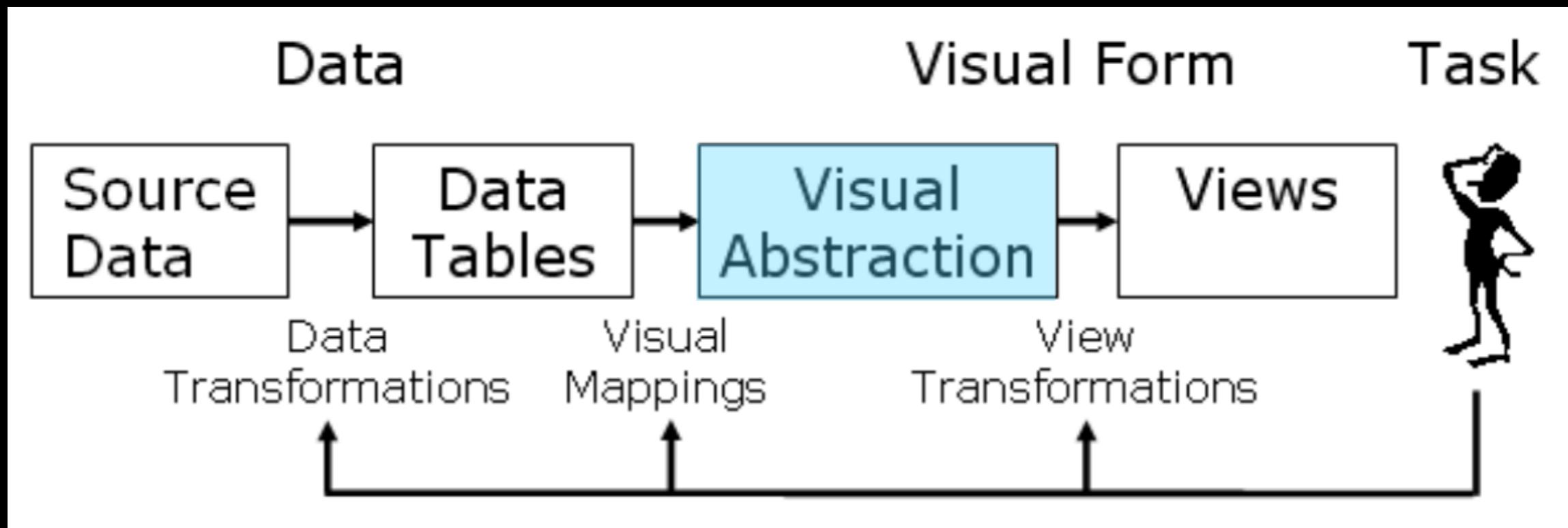


# THE INFOVIS REFERENCE MODEL



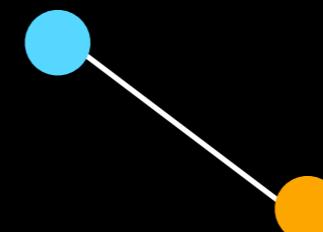
Fanny, Thomas  
Fanny, Géry  
Fanny, Nicolas  
Fanny, Laurent  
Fanny, Bruno  
Fanny, Laëtitia  
Thomas, Géry  
Thomas, Nicolas  
Laëtitia, Laurent  
Laëtitia, Mathieu  
Laëtitia, Julie  
Bruno, Mathieu  
...

# THE INFOVIS REFERENCE MODEL

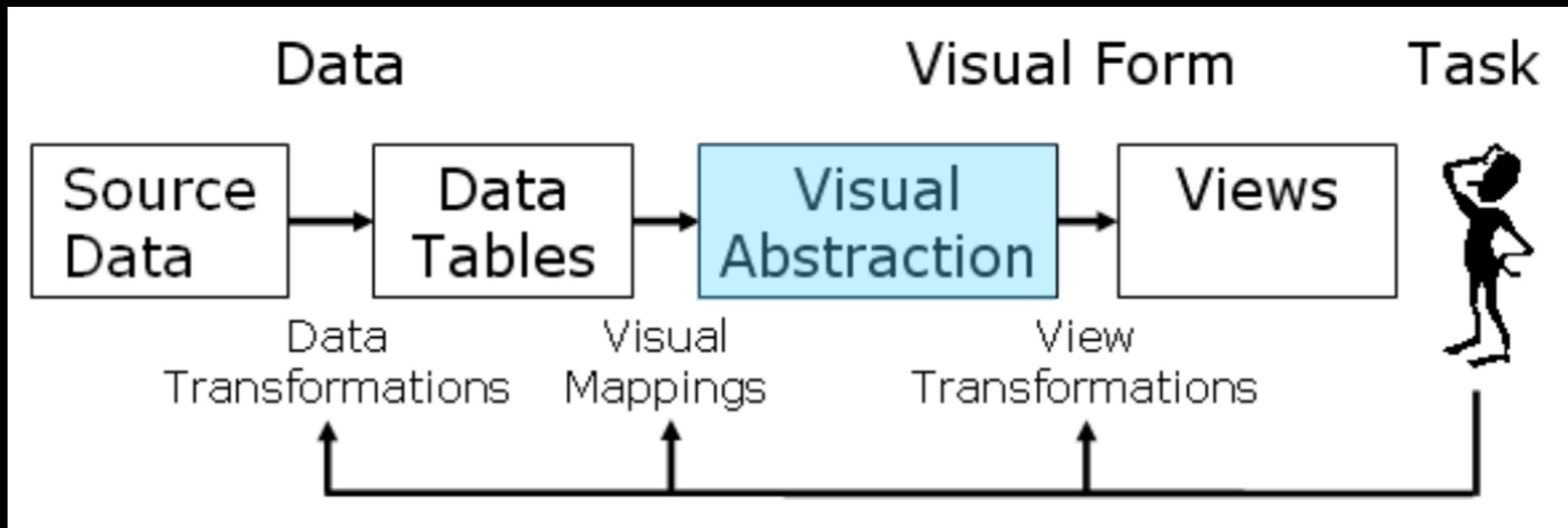


**Fanny, Thomas**

Fanny, Géry  
Fanny, Nicolas  
Fanny, Laurent  
Fanny, Bruno  
Fanny, Laëtitia  
Thomas, Géry  
Thomas, Nicolas  
Laëtitia, Laurent  
Laëtitia, Mathieu  
Laëtitia, Julie  
Bruno, Mathieu  
...

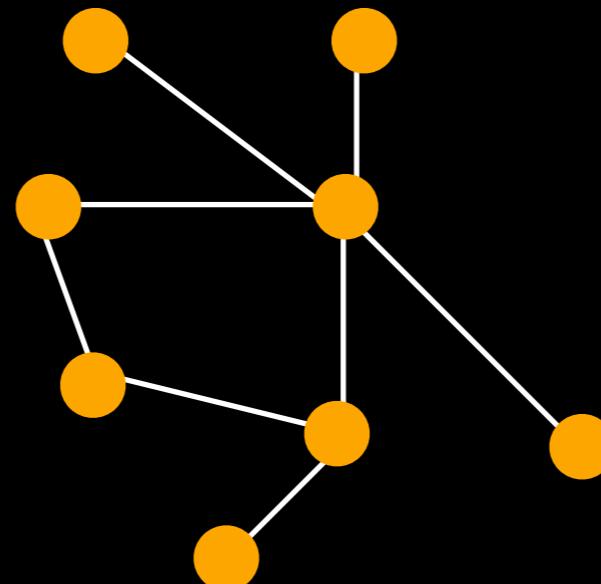


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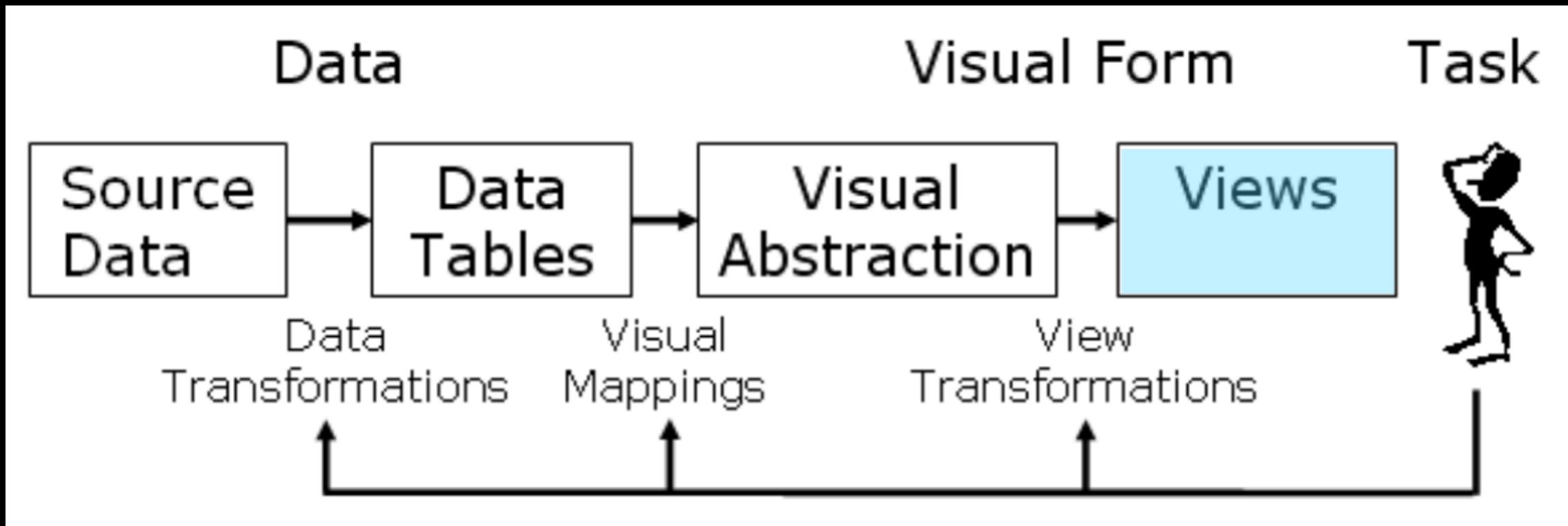


**Fanny, Thomas**

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Fanny, Laurent  
Fanny, Bruno  
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Thomas, Nicolas  
Laëtitia, Laurent  
Laëtitia, Mathieu  
Laëtitia, Julie  
Bruno, Mathieu  
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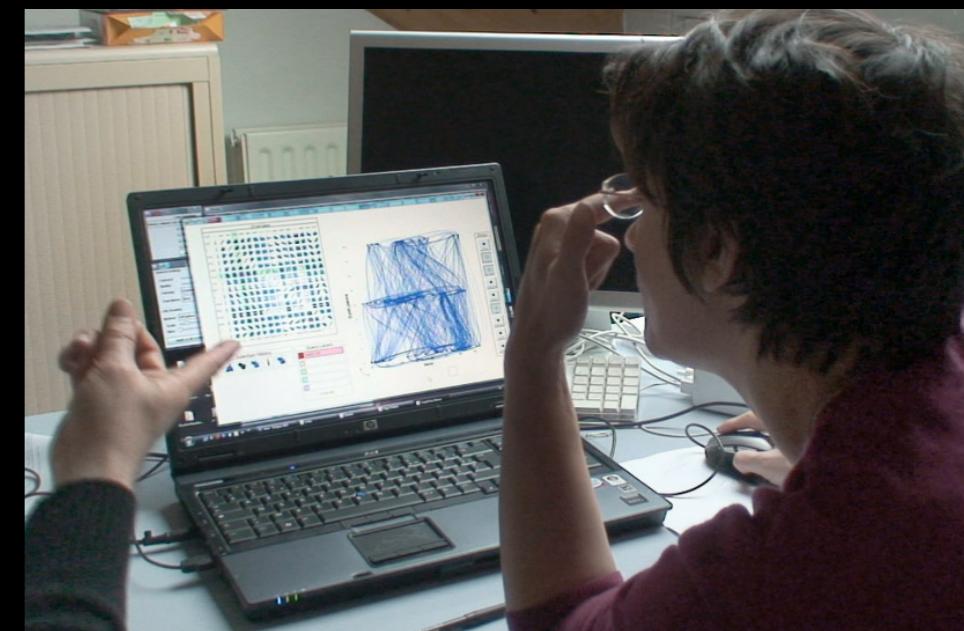
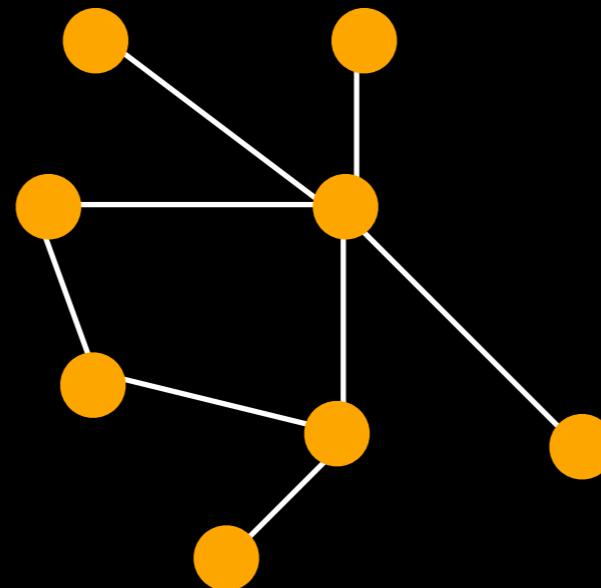


# THE INFOVIS REFERENCE MODEL

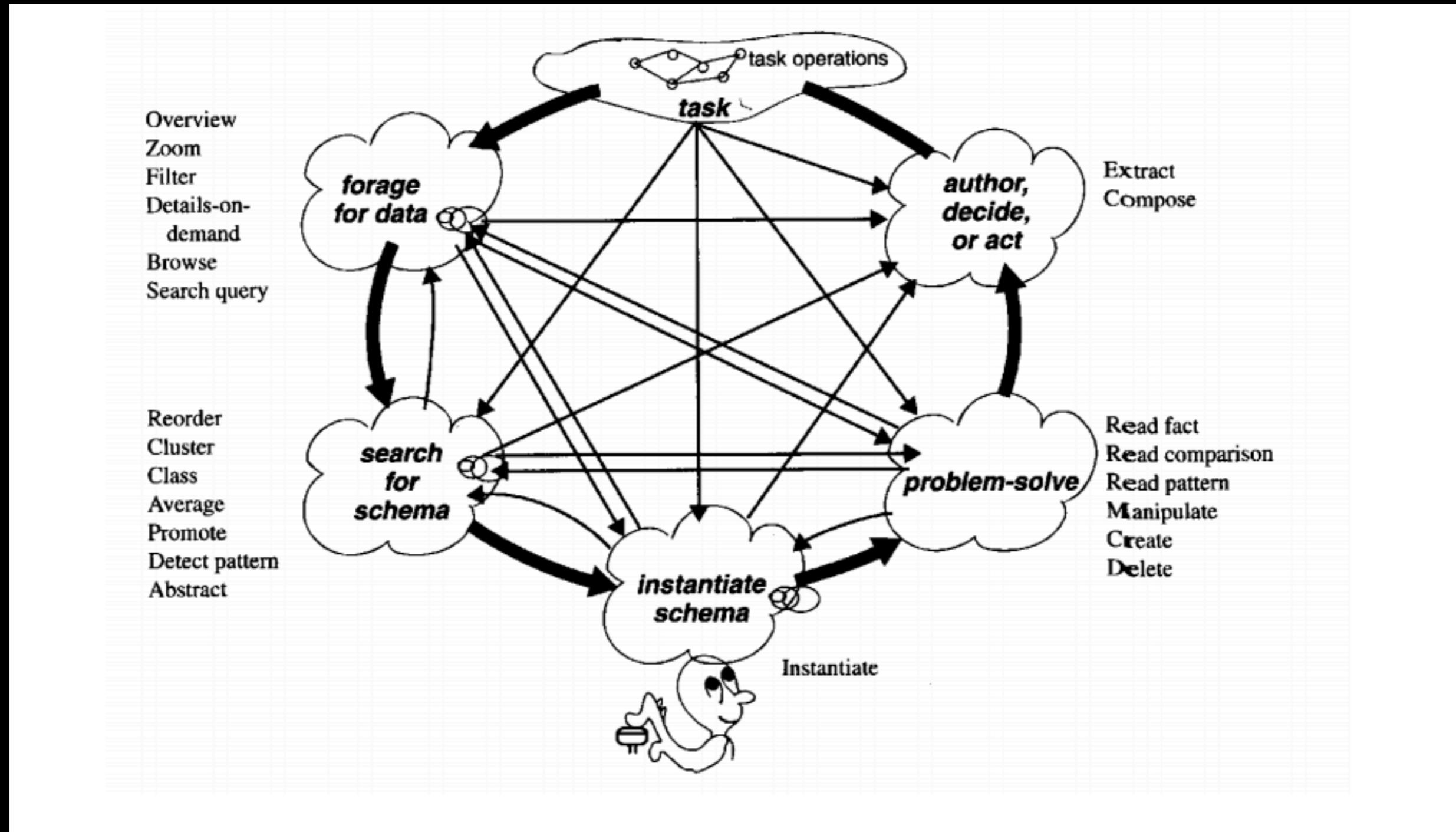


**Fanny, Thomas**

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 Thomas, Nicolas  
 Laëtitia, Laurent  
 Laëtitia, Mathieu  
 Laëtitia, Julie  
 Bruno, Mathieu  
 ...



# KNOWLEDGE CRYSTALIZATION PROCESS



**WORKING WITH VISUALIZATIONS IS NOT A LINEAR PROCESS**

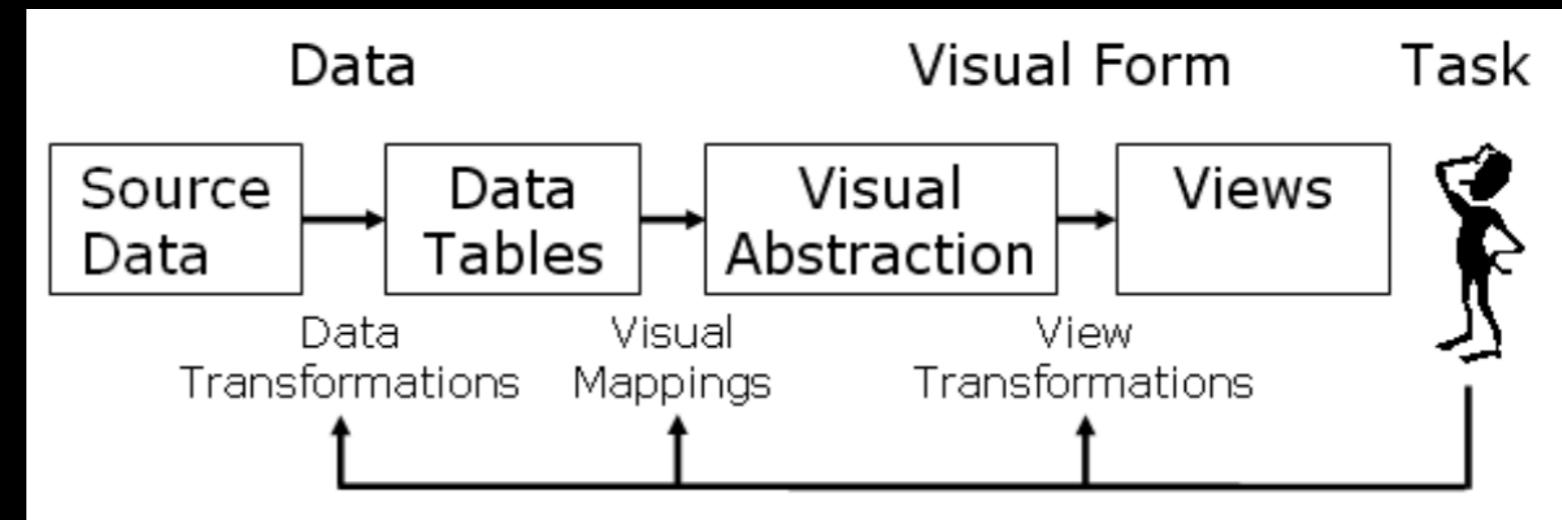
# THE VISUAL INFORMATION-SEEKING MANTRA

Overview first, Zoom and filter, then Details-on-demand.

Ben Shneiderman. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations.  
In Proc. Visual Languages, 336–343, 1996.



# CHALLENGES



- Collect the right data
- Choose the right data structure
- Not discard important data
- Choose the right representation
- Develop appropriate interaction mechanisms