Part III Visual Encoding

Marks and Channels

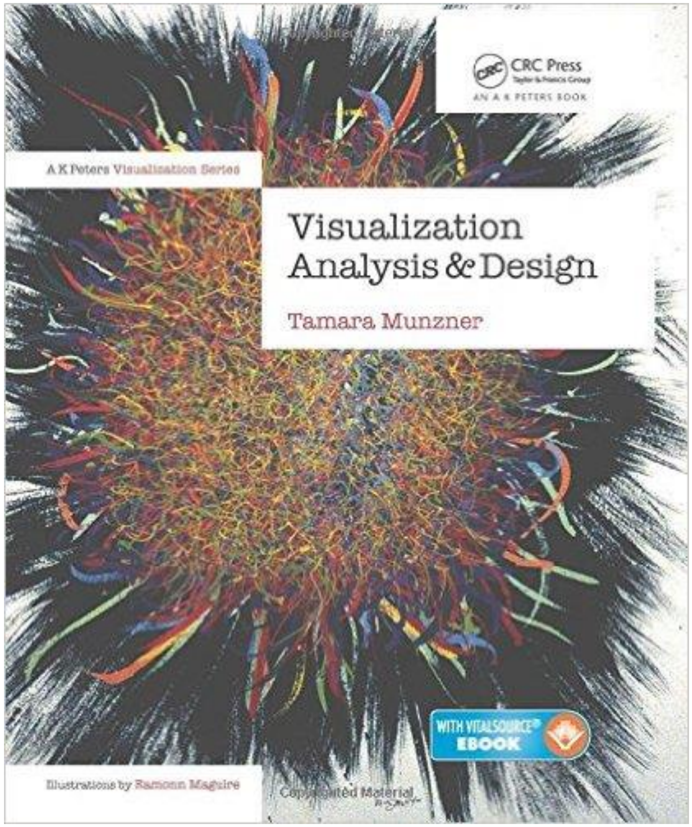
The question of whether computers can think is just like the question of whether submarines can swim

Fall 2020

Edsger W. Dijkstra

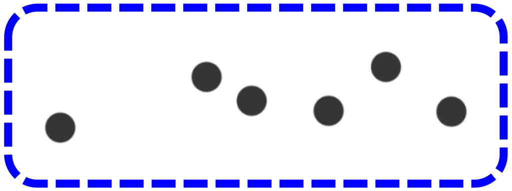
Source of This Unit

- **Material of this unit is based on Chapter 5 of Tamara Munzner, *Visualization Analysis and Design*, AK Peters/CRC Press, 2014.**



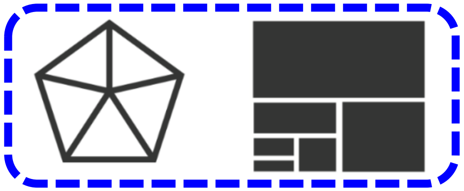
Definitions: Marks

- A **mark** is a basic graphical element in an image.
- Marks are geometric primitives classified according to the number of dimensions they require.
- Examples: points (0D), lines (1D), areas (2D) and volumes (3D).
- Volume marks are not commonly used.



Points – 0D

Lines – 1D

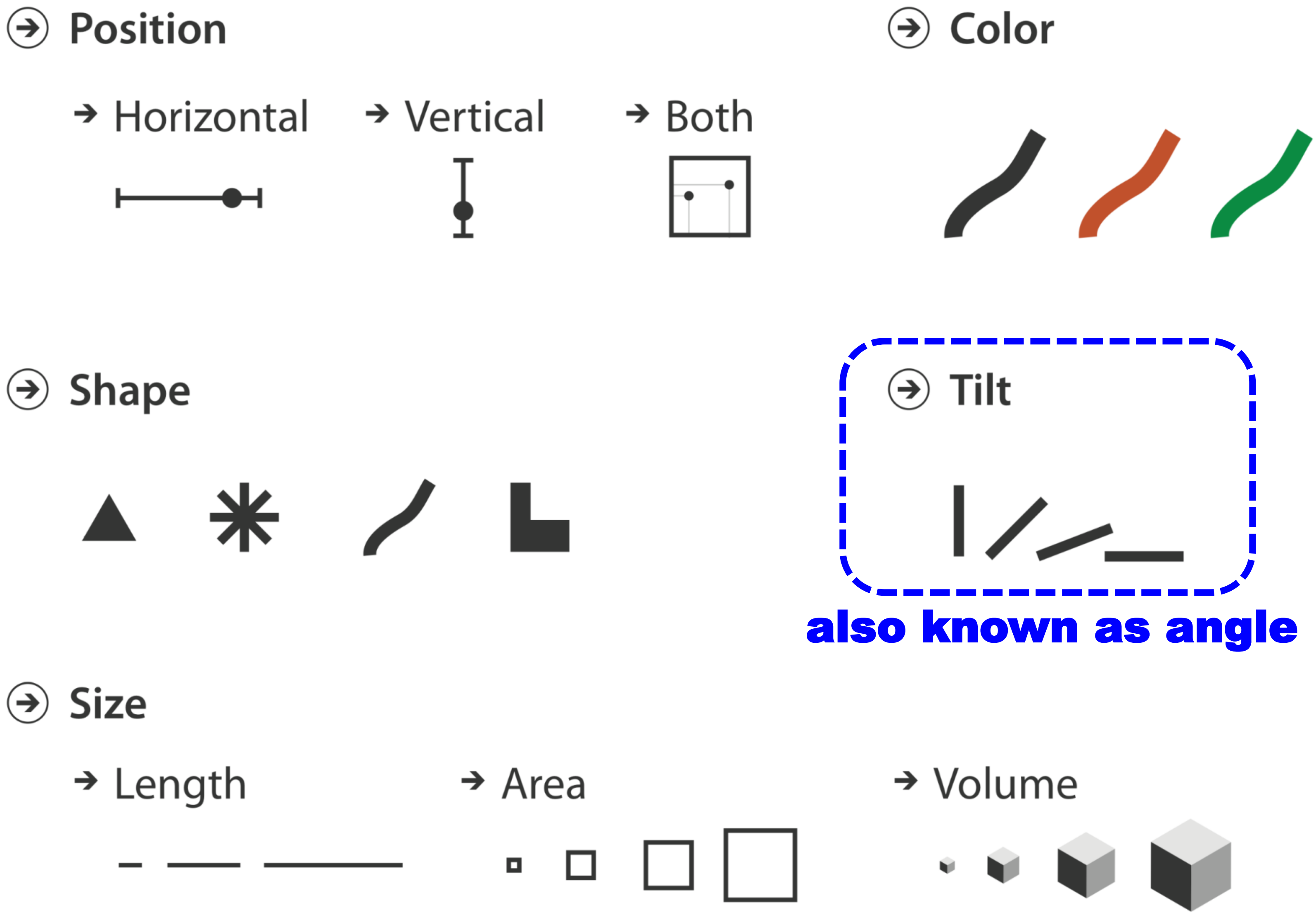


Areas – 2D

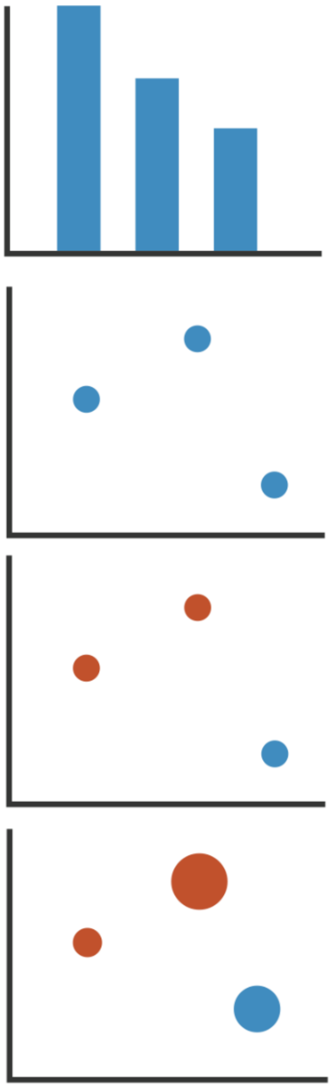
Definitions: Channels 1/2

- **A visual channel is a way to control the appearance of marks, independent of the dimensionality of the geometric primitives.**
- **There are some commonly seen channel types: position, color, shape, tilt and size.**
- **See next slide for examples.**
- **There are other possible channels such as depth, luminance, saturation, curvature, etc.**

Definitions: Channels 2/2



Notes: 1/3



Bar charts show two attributes,
but only one is quantitative (vertical)
and the other is categorical

A second quantitative attribute can be
encoded by using the visual channel
of horizontal spatial **position**.
We have a 2D scatterplot.

One more categorical attribute may be added
by using the visual channel of **hue** (i.e., color)

The visual channel of **size** may be used
to add yet another quantitative attribute

Notes: 2/3

- **In these examples, each attribute is encoded with a single channel.**
- **Multiple channels can be combined to redundantly encode the same channel; however, this approach uses more channels so that not as many attributes can be encoded in total.**
- **Usually, the size and shape channels cannot be used on all types of marks. For example, higher-dimensional mark types may have built-in constraints from their definitions.**

Notes: 3/3

- An **area** mark has both dimensions of its size constrained as part of its shape. For example, an area mark denoting a state within a country on a geographic map already has a certain size.
- A **line** mark that encodes a quantitative attribute using length in one direction can be size coded by changing its width; however, it cannot be sized in its length dimension.
- A **point** mark can be **size** coded for its quantitative attribute and **shape** coded for its categorical attribute.

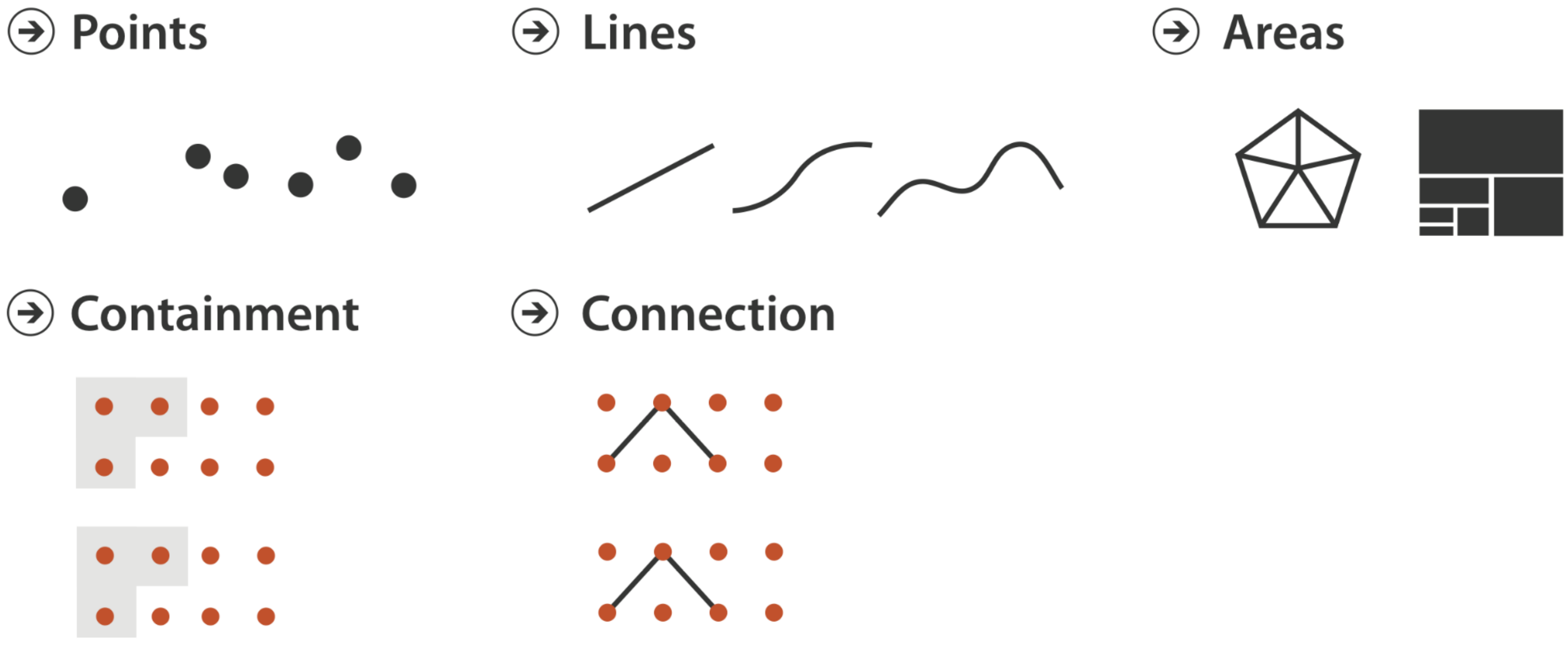
Channel Types

- **The human perceptual system has two fundamentally different kinds of sensory modalities.**
- **The *identity* channels tell us information about *what* something is or *where* it is. *Examples*: circles, triangles, colors, in motion, inside/outside of an area, etc.**
- **The *magnitude* channels tell us *how much* of something there is. *Examples*: longer/shorter, larger/smaller, brighter/darker, etc.**

Mark Types: 1/2

- **In a table dataset, a mark always represents an item. For a network database, a mark may be an item (i.e., node) or a link.**
- **There are two link marks: connection and containment.**
- **A connection mark shows a pairwise relationship between two items, using a *line*.**
- **A containment mark shows hierarchical relationships using areas, and connection marks may be nested within each other at multiple levels.**

Mark Types: 2/2



Using Marks and Channels

- **The use of marks and channels in visualization idiom design should be guided by the principles of expressiveness and effectiveness.**
- **These ideas can be combined to create a ranking of channels according to the type of data that is being visually encoded.**
- **Those attributes indentified as the most important ones should be encoded with the highest ranked channel.**

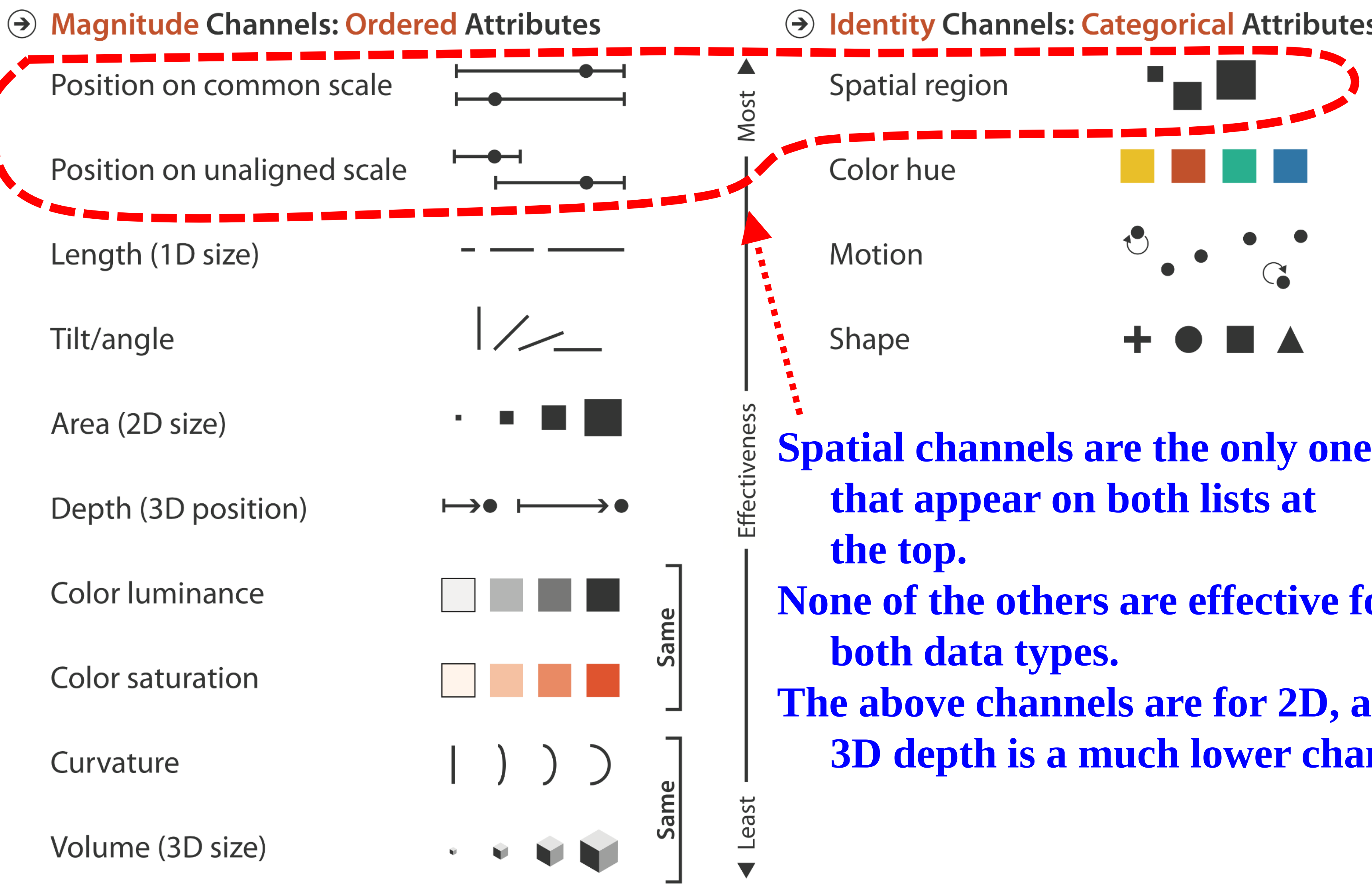
Expressiveness and Effectiveness: 1/2

- The **expressiveness** principle states that the visual encoding should express all of, and only, the information in the dataset attributes.
- Ordered data should be shown in a way that our perceptual system senses as ordered. Unordered data should not be shown in a way that perceptually implies an ordering.
- The **identity** channels are the correct match for unordered categorical attribute, and the **magnitude** channels are good matches for ordered (i.e., ordinal and quantitative) attributes.

Expressiveness and Effectiveness: 2/2

- The **effectiveness** principle states that the importance of the attribute should match with the **salience** (i.e., noticeability) of the channel.
- The most important attributes should be encoded with the most effective channels in order to be most noticeable.
- Less important attributes can be matched with less effective channel.

Channel Ranking



Spatial channels are the only ones that appear on both lists at the top.

None of the others are effective for both data types.

The above channels are for 2D, and 3D depth is a much lower channel.

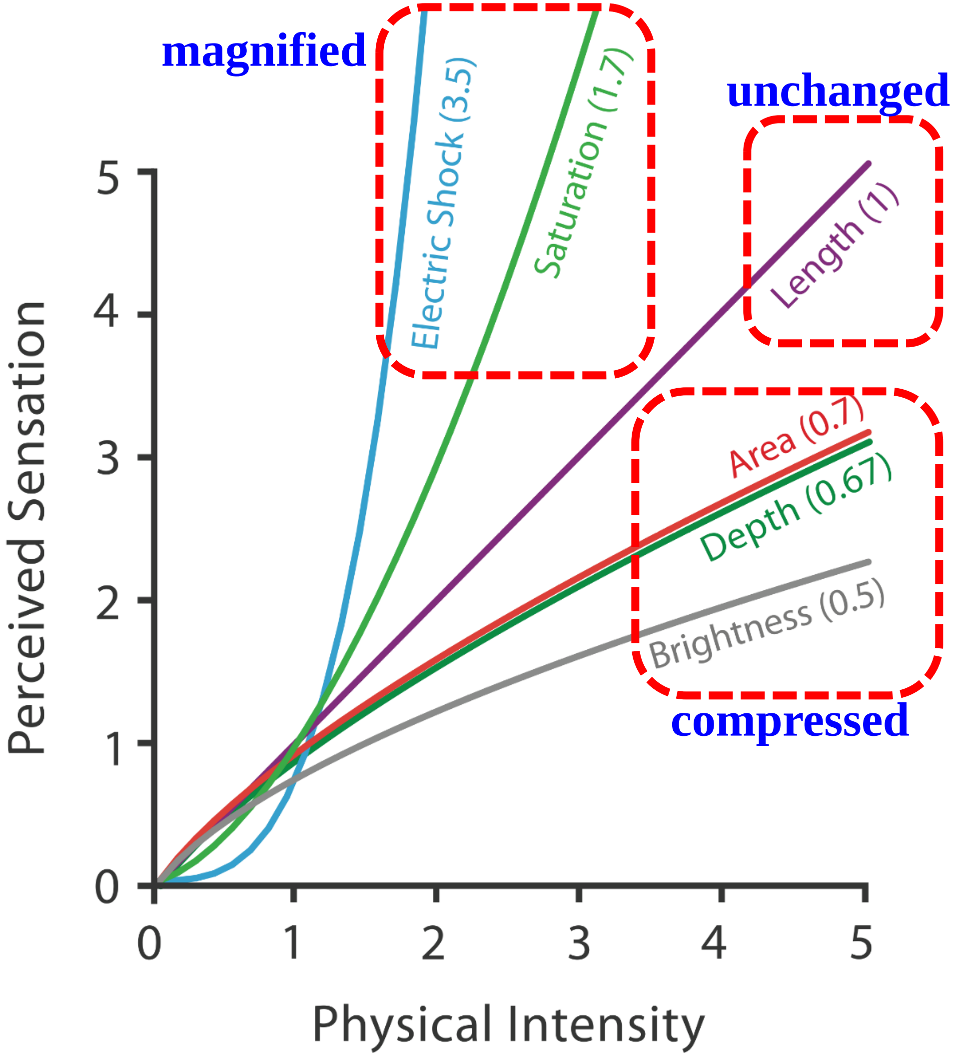
Channel Effectiveness

- **How do we identify the effectiveness of a channel?**
- **This can be analyzed according to the criteria of accuracy, discriminability, separability, the ability to provide visual popout, and the ability to provide perceptual grouping.**

Accuracy: 1/4

- **Accuracy: How close is human perceptual judgment to some objective measurement of the stimulus.**
- **Human perceive different visual channels with different levels of accuracy; they are not all equally distinguishable.**
- **Our responses to the sensory experience of magnitude are characterized by power laws. Most stimulus are magnified or compressed, with few remaining unchanged.**

Accuracy: 2/4



Stevens' Psychophysical law:

$S = I^n$,

where

S is the perceived sensation and

I is the physical intensity

n > 1 – magnified

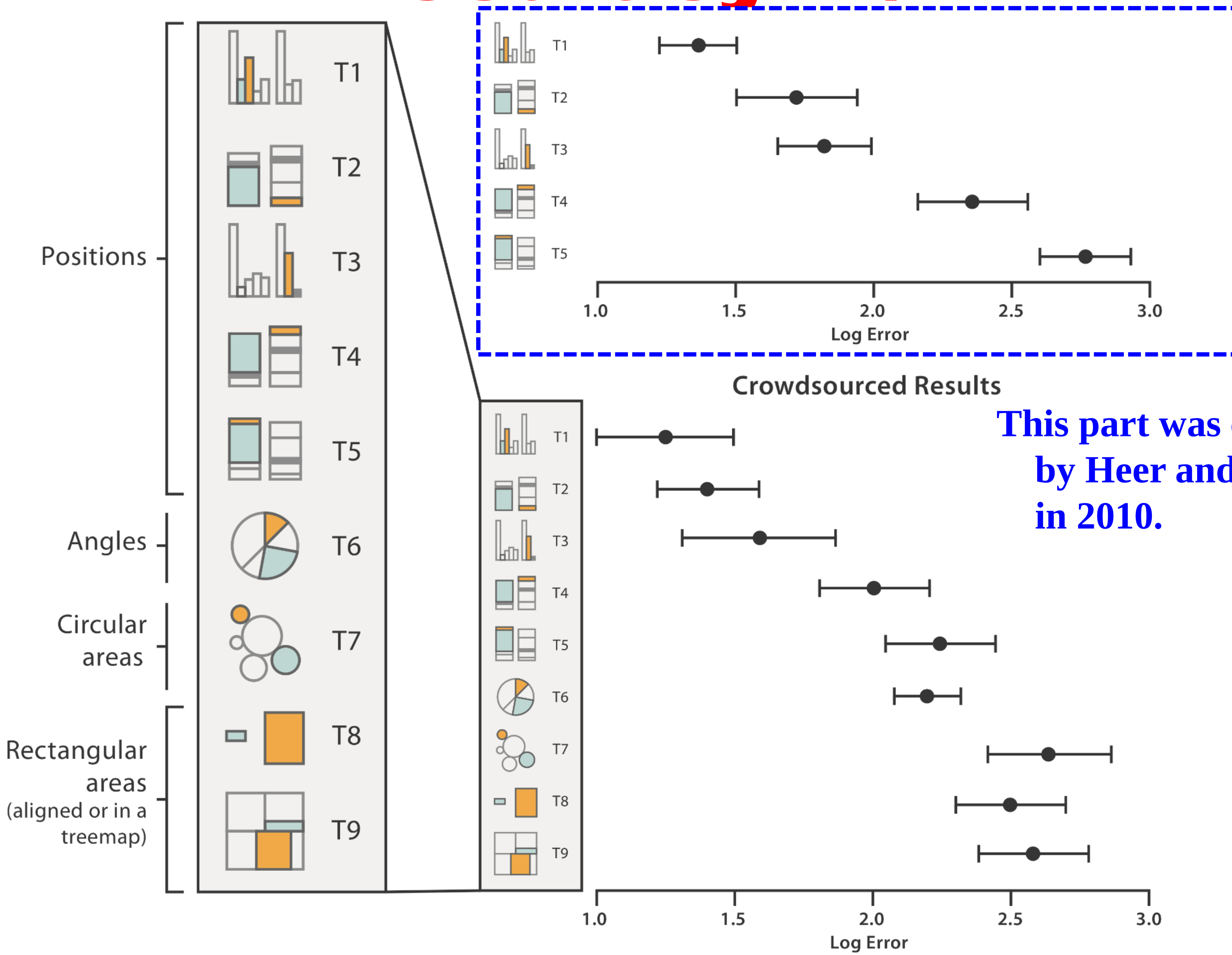
n < 1 – compressed

n = 1 - unchanged

Accuracy: 3/4

- **Cleveland and McGill (1984) conducted experiments on the magnitude channels and found the following, from most accurate to less accurate:**
  1. **aligned position against a common scale**
  2. **unaligned position against an identical scale,**
  3. **length**
  4. **angled**
  5. **area judgments being notably less accurate**

Accuracy: 4/4



This part was confirmed by Heer and Bostock in 2010.

Discriminability: 1/4

- **Discriminability: If a data attribute is encoded using a particular visual channel, are the differences between items (of this attribute) perceptible to the human as intended?**
- **The characterization of visual channel should quantify the number of bins that are available for use within a visual channel, where each bin is a distinguishable step or level from the other.**

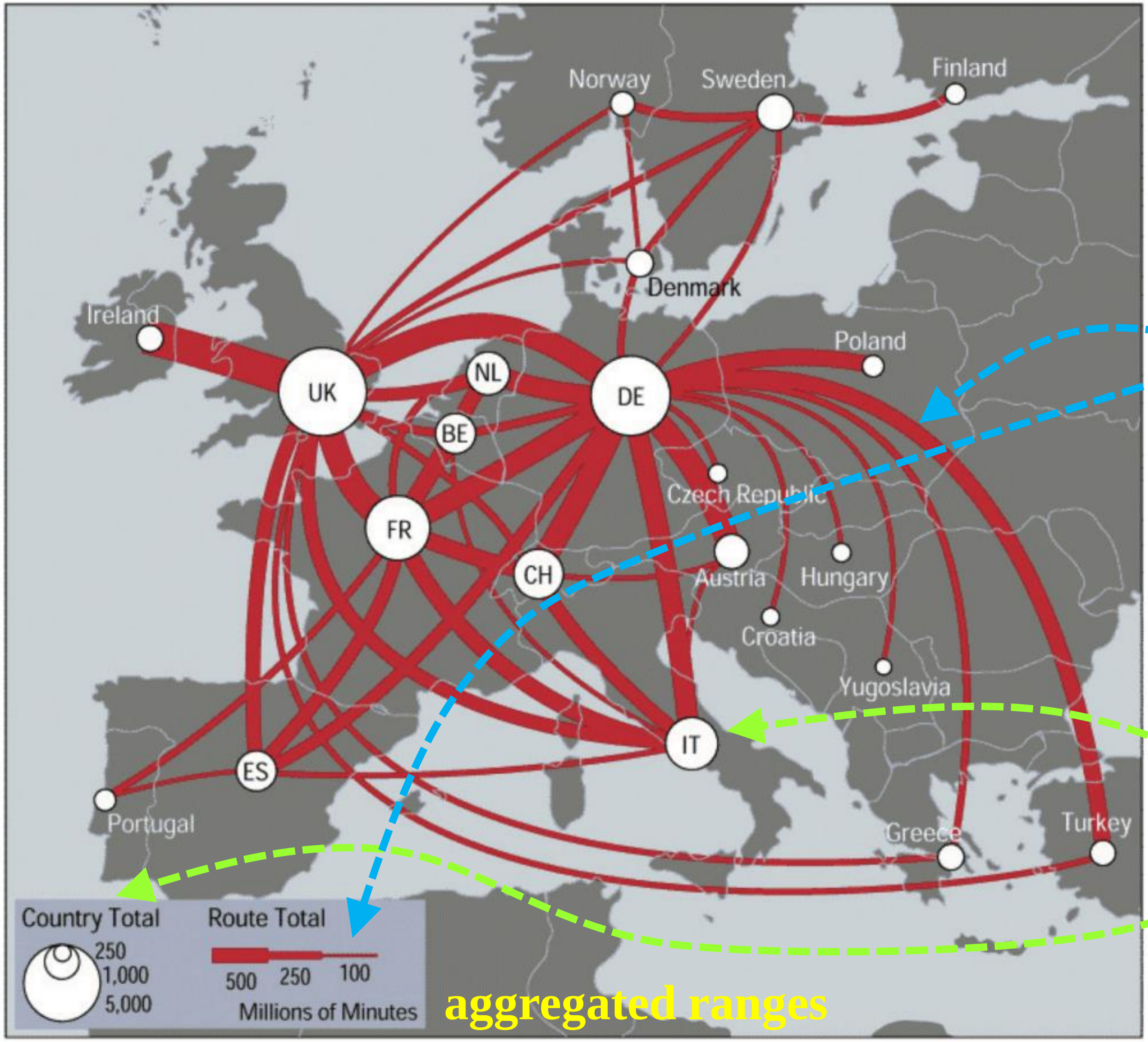
Discriminability: 2/4

- The characterization of a visual channel should quantify the number of **bins** that are available for use within a visual channel, where each **bin** is a distinguishable step or level from the other.
- **Example**: Some channels have a very limited number of bins. For example, changing line width past certain limit may be perceived as an area rather than a line mark.
- Line width may be very usable for a small number of different values but would be a poor choice for dozens or hundreds of values.

Discriminability: 3/4

- **Matching the ranges of the data with the possible sizes of a channel (i.e., the available bins).**
- **If it is not possible, aggregate the attribute into meaningful bins or use a different visual channel.**

Discriminability: 4/4



sized line:
only 3 sizes

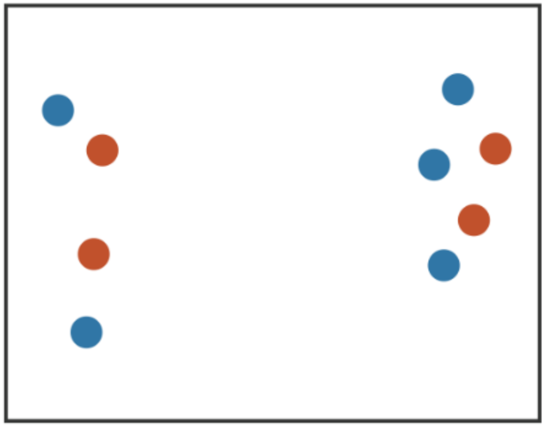
sized point:
only 3 sizes

aggregated ranges

Separability: 1/6

- **Visual channels are not completely independent from each other, because some have dependencies and interactions with other.**
- **Consider potential interaction between visual channels, ranging from the orthogonal and independent separable channels to the inextricably combined integral channels.**
- **Visual encoding separable channels is straightforward but encoding different information in integral channels will fail.**

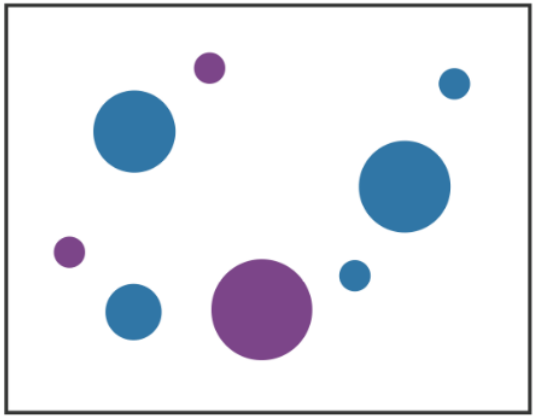
Separability: 2/6



- **The right plot shows a scatter plot of 8 points using position and hue channels.**
- **It is easy to see two categories for spatial position, left and right.**
- **We also separately notice their hues and distinguish the red from blue.**
- **It is also easy to see half the points fall into each of these categories for each of the two channels.**

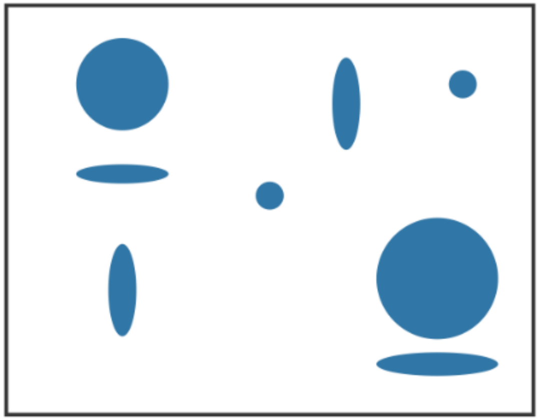
Separability: 3/6

- The right plot uses size and hue channels.
- It is easy to distinguish the larger half from the small half, but within the small half discriminating between the two colors is more difficult.
- Therefore, size interacts with many visual channels, including shape.



Separability: 4/6

- This is an integral pair channel.
- This plot encodes one variable with horizontal size and the other with vertical size. This is ineffective!
- Both channels are automatically fused into an integrated perception of area, yielding three groups: circles, flatten and tall ellipses.
- So, we have some significant interference between channels.



Separability: 5/6

- **This is the most inseparable channel pair, where the red and green channels are used.**
- **While we can tell there are four colors, even with an intensive effort it may still be difficult to recover the original information about high and low in each axis.**

Separability: 5/6

- **The red and green channels in the RGB color space used by computers is different from our perceptual system.**
- **Usually, the three color channels (i.e., red, green and blue), in particular red and green, may not be perceived separately.**
- **Hence, R, G and B may not be perceptually separable.**

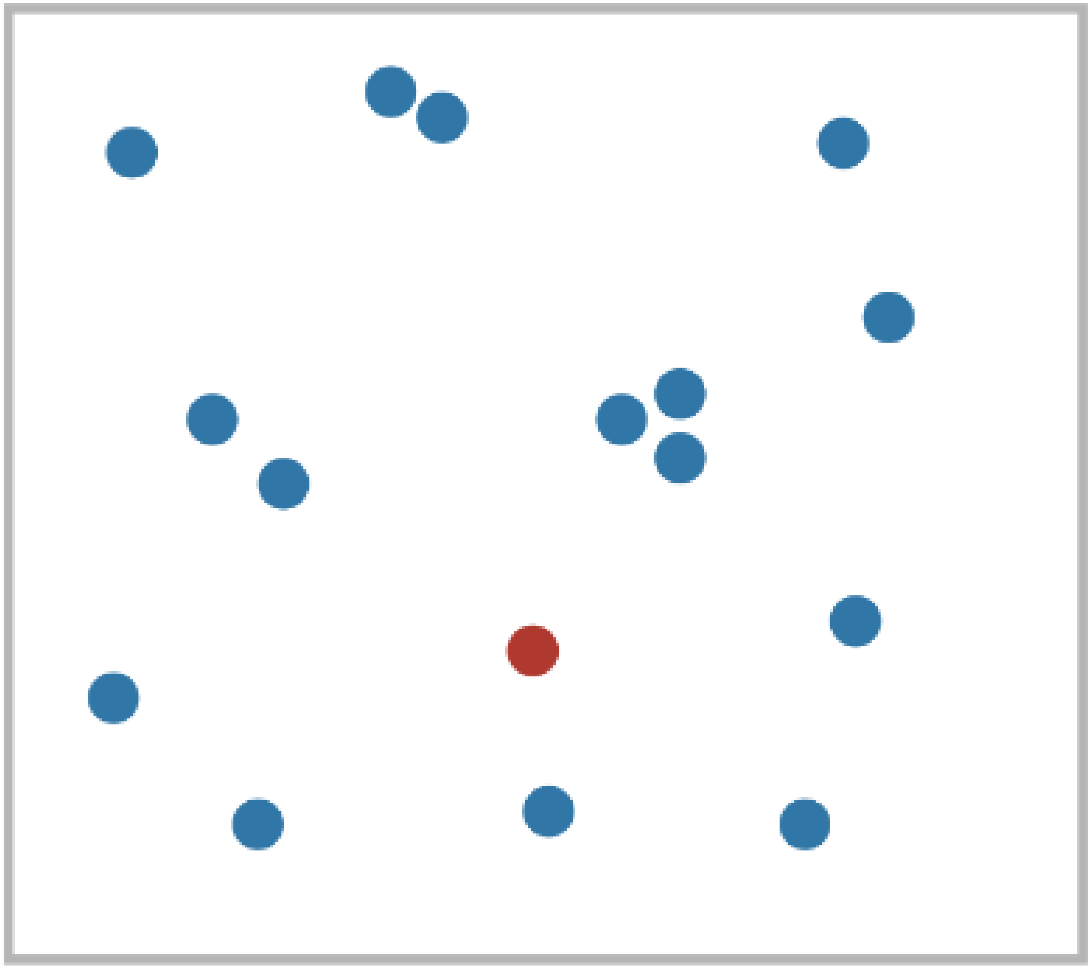
Separability: 6/6

- **Important: Match the characteristics of the channels to the information that is encoded.**
- **For two different attributes, either of which can be attended separately, then a separable channel pair of position and hue is good.**
- **If the goal is to show a single data attribute with three categories, then the integral channel pair of horizontal and vertical size is a reasonable, because it yields the three groups of small, flattened and large.**

Visual Popout: 1/14

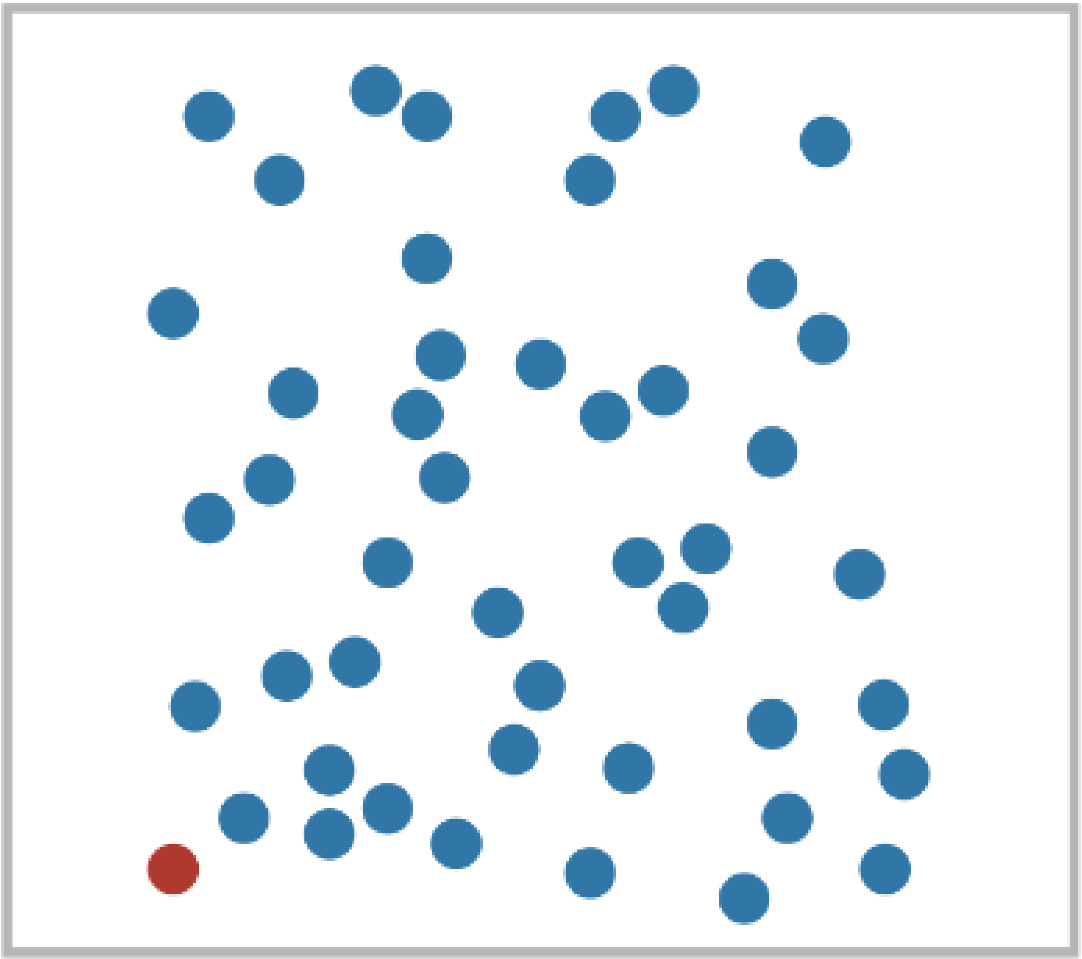
- **Visual Popout**: Making a distinct item stands out from many others immediately.
- **Popout** is also known as **preattentive processing** or **tunable detection**.
- Our low-level visual system can help spot in parallel the different objects from a large number of distracting objects, without the need for the viewer to consciously directly attention to the item one by one.
- In fact, this capability is independent of the number of distracting item.

Visual Popout: 2/14



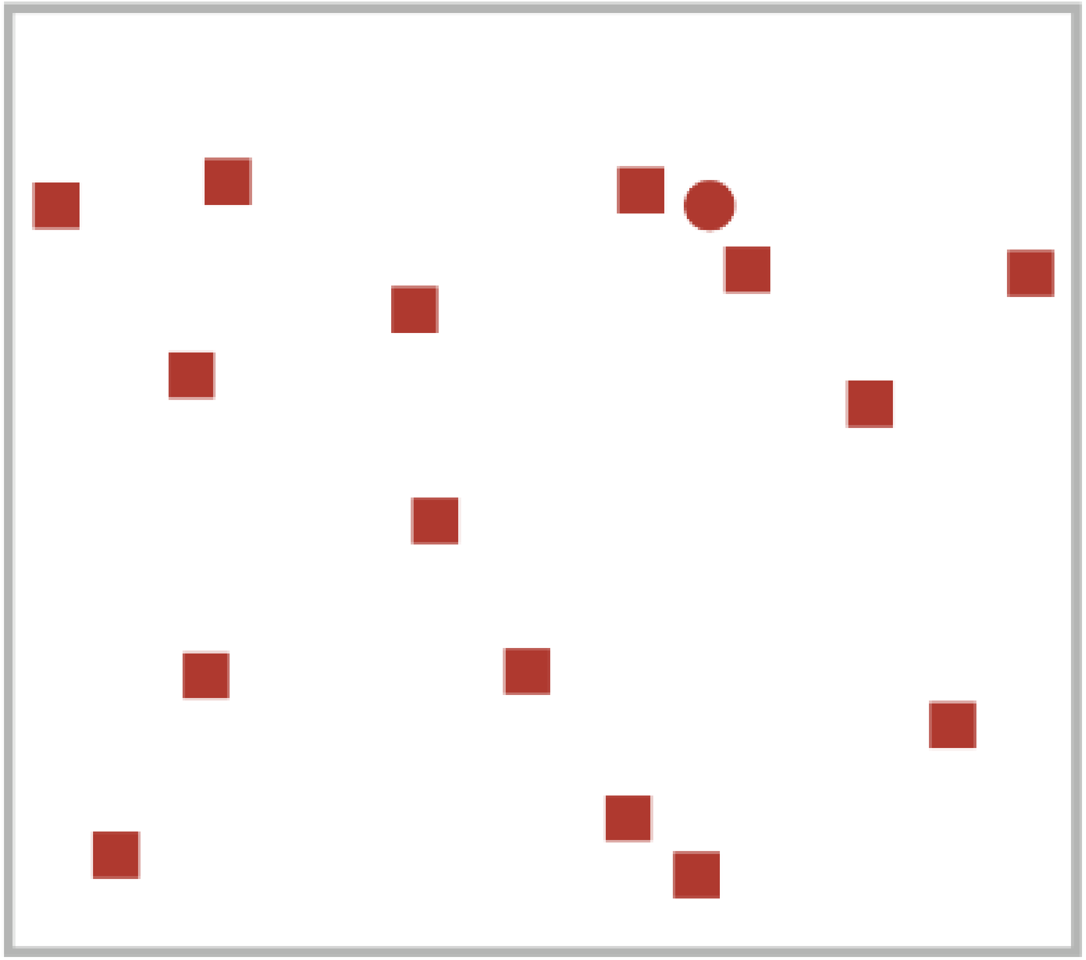
The red circle pops out from a small set of blue circles. We recognize this instantly.

Visual Popout: 3/14



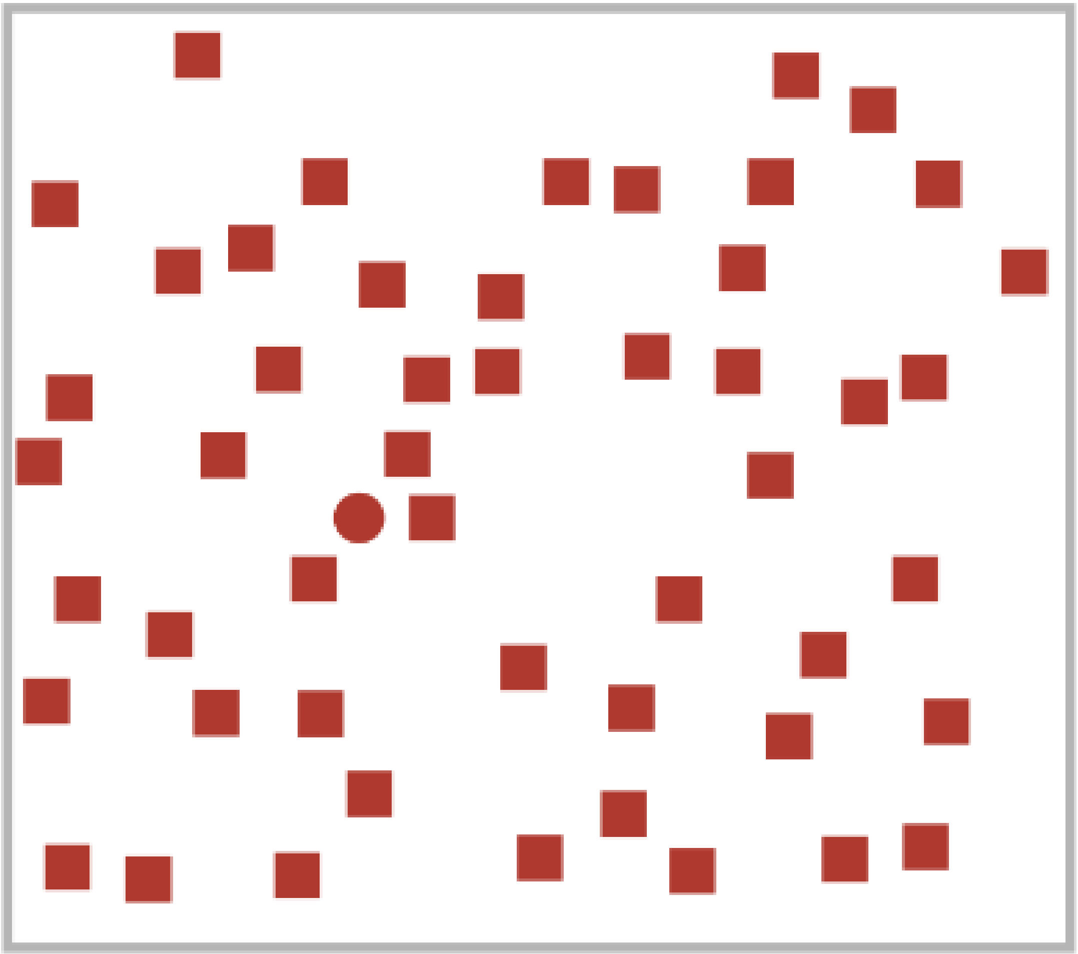
The red circle pops out from a large set of blue circles.
We still can recognize this instantly.

Visual Popout: 4/14



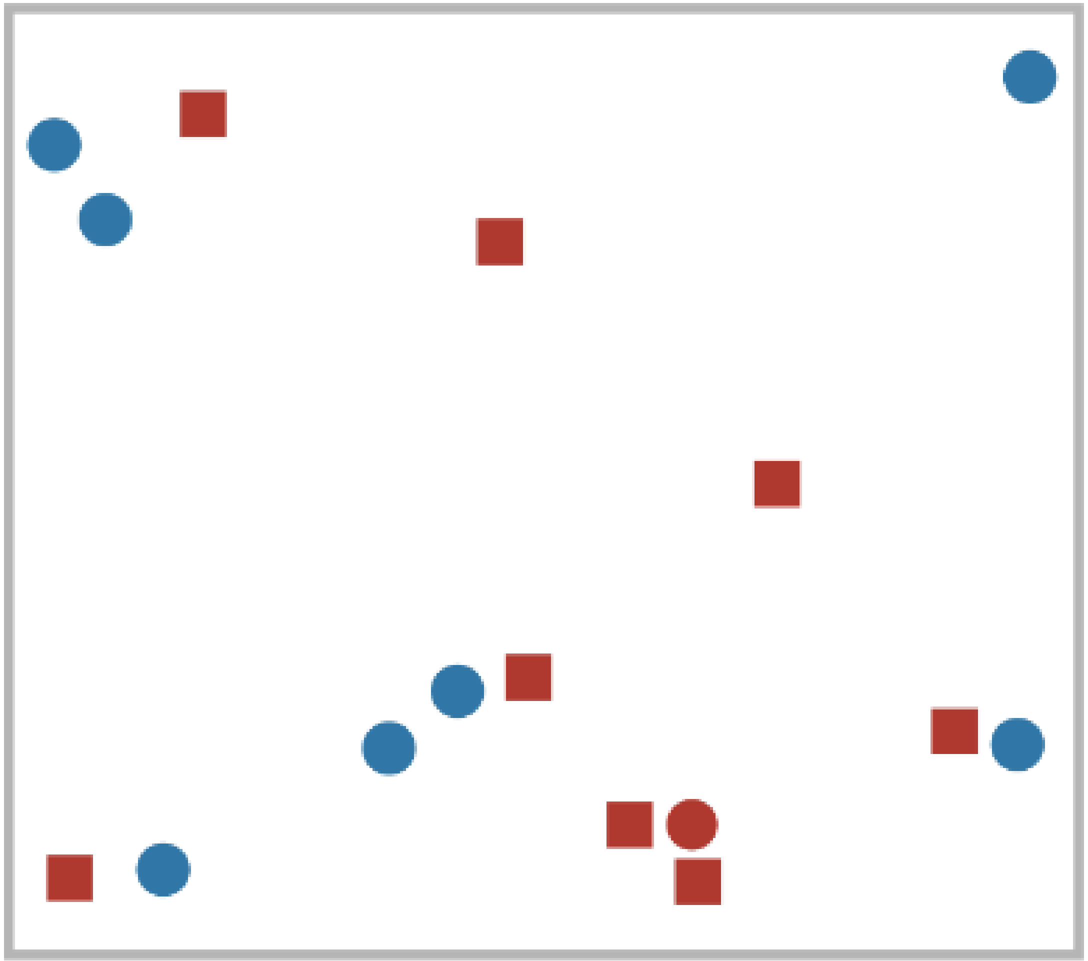
The red circle pops out from a small number of squares.
It is a bit slower than with color, though.

Visual Popout: 5/14



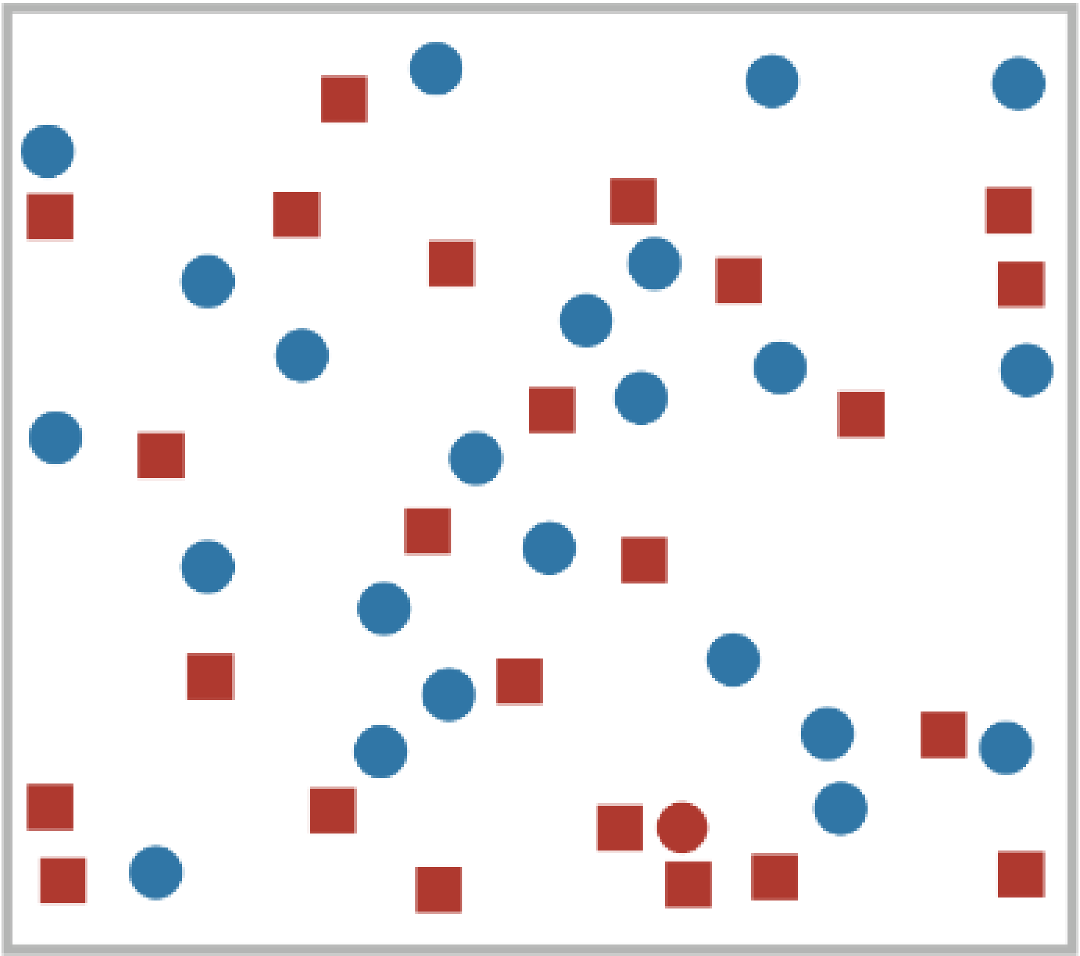
The red circle also pops out from a large number of squares. It is again a bit slower than with color.

Visual Popout: 6/14



The red circle also pops out from a small set of mixed shapes and colors.

Visual Popout: 7/14

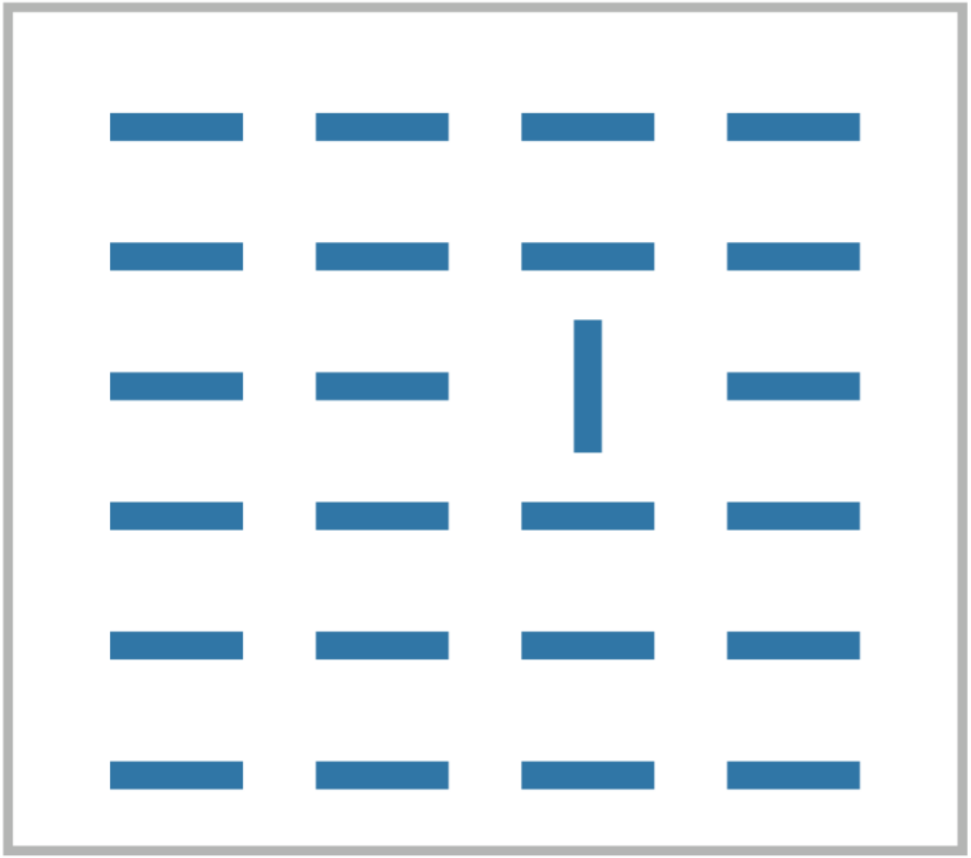


The red circle does not pop out from a large number of red squares and blue circles. It can only be found by searching one by one through all the objects.

Visual Popout: 8/14

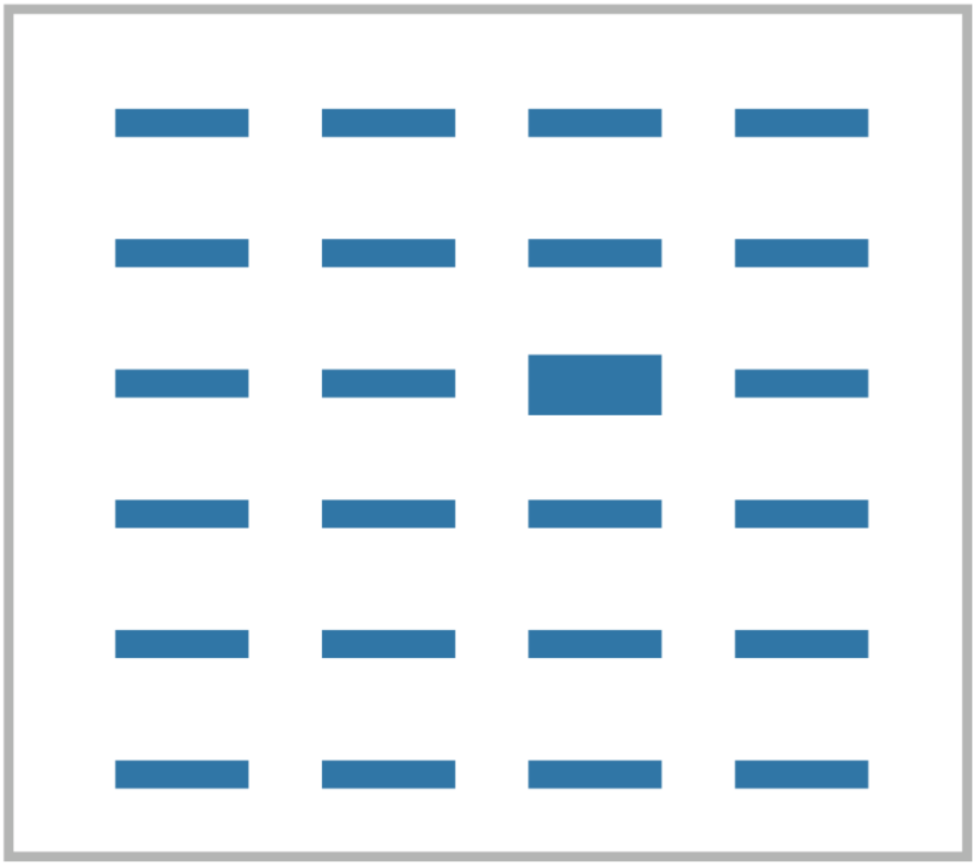
- **Popout depends on both the channel itself and how different the target item is from its surroundings.**
- **The difference between red and blue on the color hue channel is larger than the difference in shape between filled circles and filed squares.**
- **Most pairs of channels do not support popout, but a few pairs do, such as (space, color) and (motion, shape).**
- **Use one popout for a single channel at a time.**

Visual Popout: 9/14



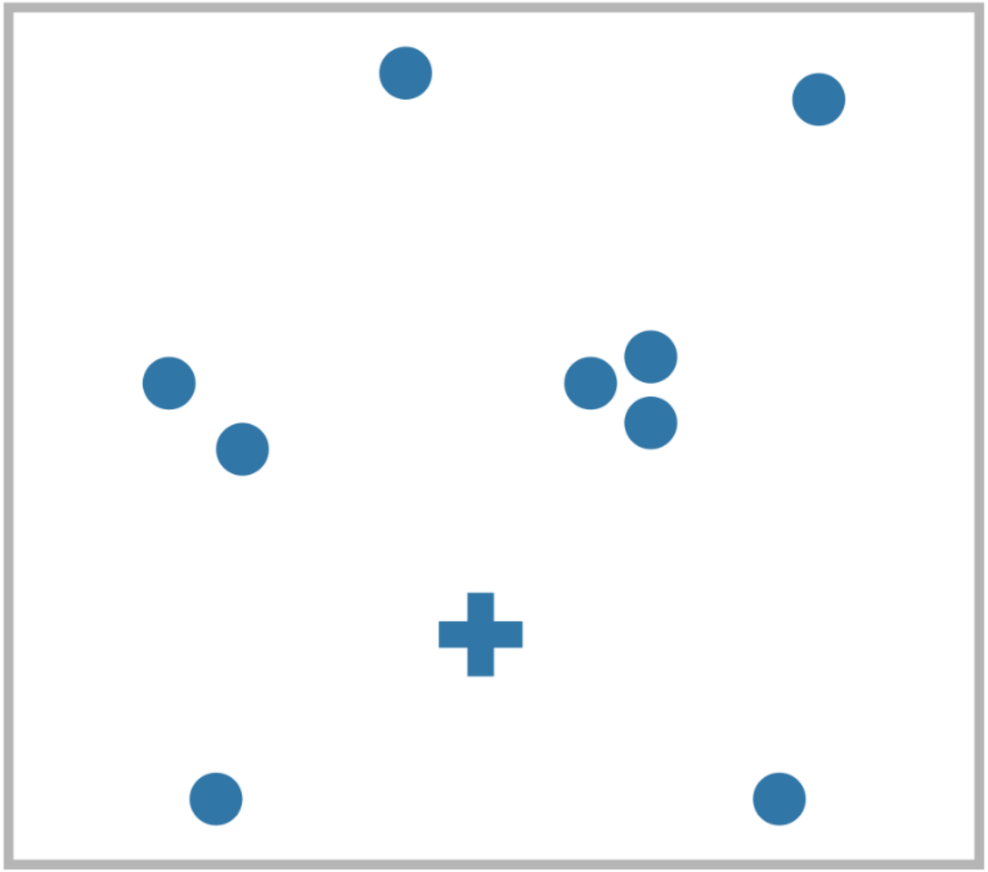
Many channels support visual popout: **Tilt**

Visual Popout: 10/14



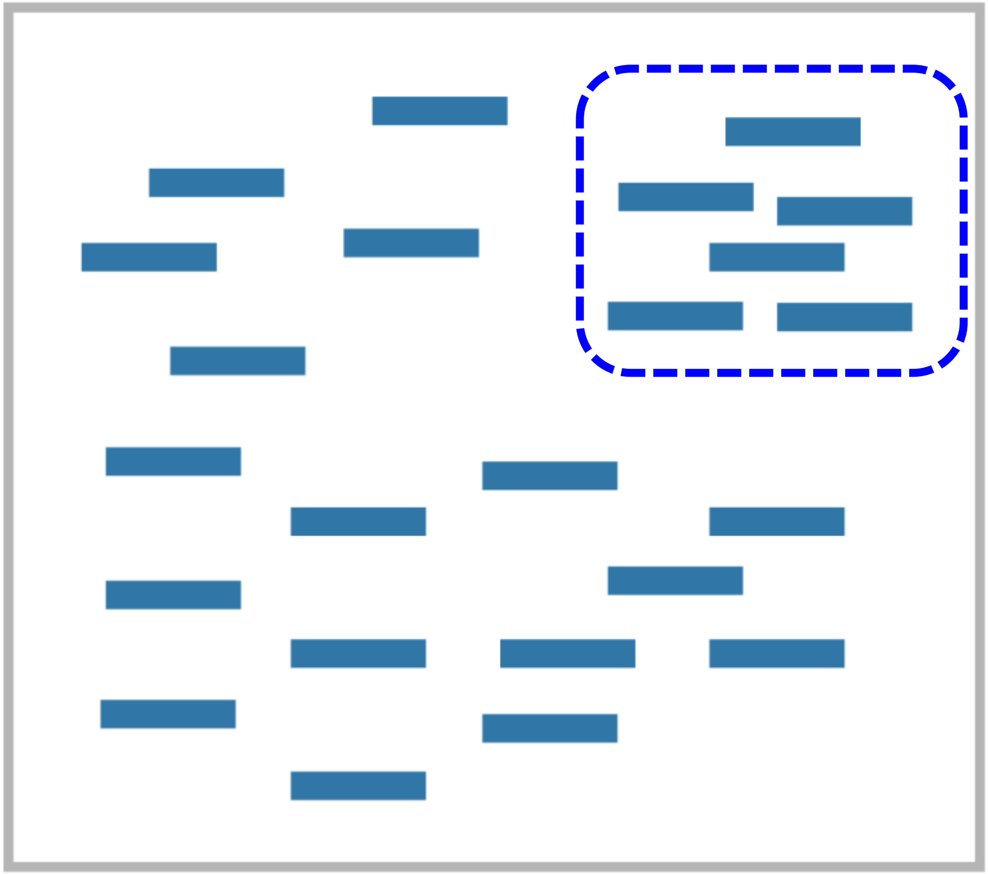
Many channels support visual popout: **Size**

Visual Popout: 11/14



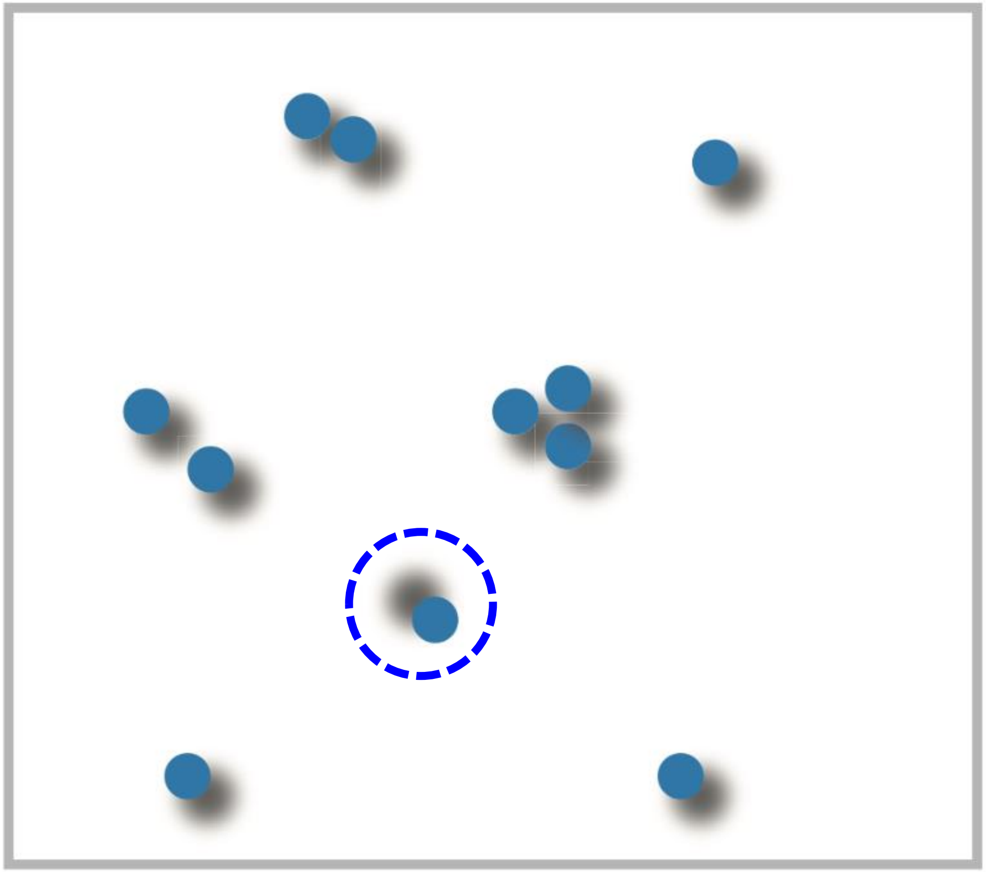
Many channels support visual popout: **Shape**

Visual Popout: 12/14



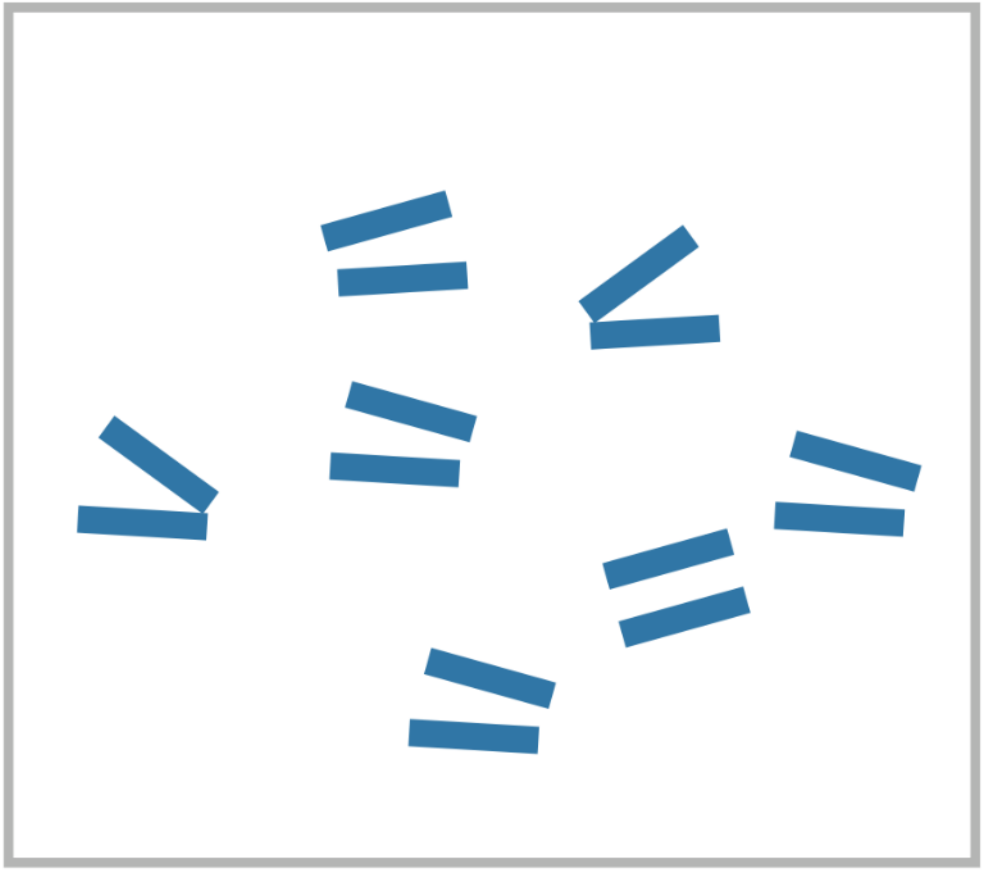
Many channels support visual popout: **Proximity**

Visual Popout: 13/14



Many channels support visual popout: **Shadow Direction**

Visual Popout: 14/14



Parallel line pairs do not popout from a set of slightly tilted line pairs.
It has to be detected through a serial search.

Visual Grouping: 1/3

- **Visual Grouping** can arise from either the use of link marks or from the use of identify channels to encode categorical attributes.
- **Approach 1**: Containment is the strongest cue for grouping, with connection coming in second.
- **Approach 2**: Encode categorical data with identity channels:
  - All of the items that share the same level of the attribute can be perceived by simply directing attention to that level selectively.
  - Strong as the use of containment and connection.

Visual Grouping: 2/3

- **Approach 3**: Use **proximity**, placing items within the same spatial region, because the highest ranked channel for encoding categorical data is spatial region.
- **Approach 4**: Use **similarity** with the other categorical channels of hue and motion, and also shape if chosen carefully.
  - Proximity is similar to similarity; however, from a perceptual point of view the effect of the spatial channel is so much stronger than the effect of the others that it is useful to consider them separately.

Visual Grouping: 3/3

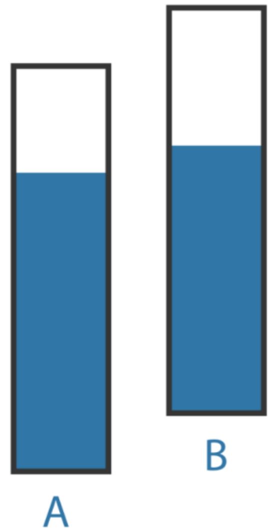
- **Approach 4 Example**: The categorical attribute of animal type with three levels of cat, dog and deer can be encoded with the three hue bins of red, green and blue, respectively.
- Use the shape channel with care, because, for example, C and Ɔ may not be automatically perceived as selectable groupings. On the other hand, circle versus star do!
- Also, a set of moving objects against a static background is salient cue, multiple levels of motion all happening at once is overwhelming.

Relative vs. Absolute Judgments: 1/7

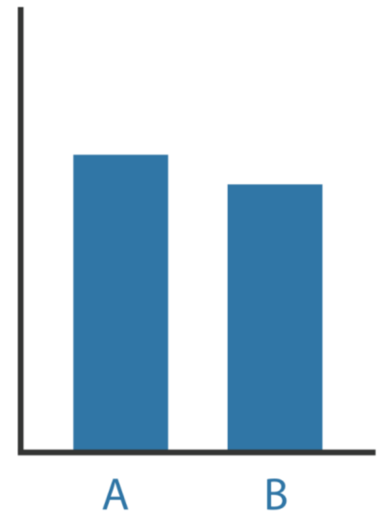
- **The human perceptual system is fundamentally based on relative judgments, not absolute ones.**
- **Weber's Law: The difference in stimulus intensity *I* is a fixed percentage *K* of the object magnitude: $\delta I/I = K$.**
- **Weber's Law tells us why position along a scale can be more accurately perceived than a pure length judgment of position without a scale. See next slide.**

Relative vs. Absolute Judgments: 2/7

The lengths of unframed, unaligned rectangles of slightly different sizes are hard to compare



Adding a frame allows us to compare the very different sizes of the unfiled rectangles between the bars and frame tops

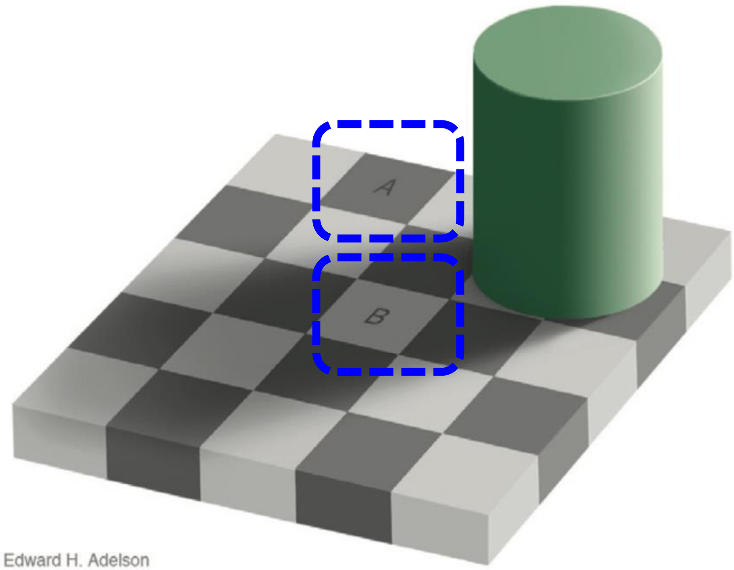


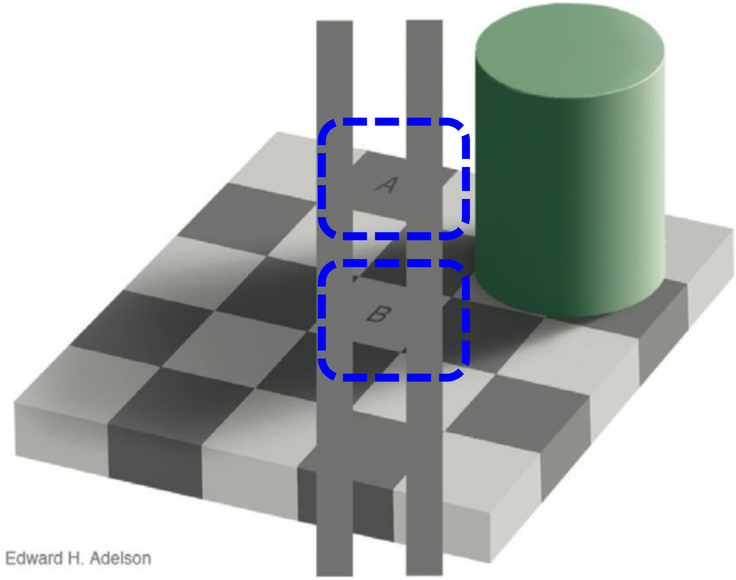
Aligning the bars also makes the judgment easier.

Relative vs. Absolute Judgments: 3/7

- **Our perception of color and luminance is completely contextual, based on the contrast with surrounding colors.**
- **Again, this is relative.**
- **See the next slide.**

Relative vs. Absolute Judgments: 4/7



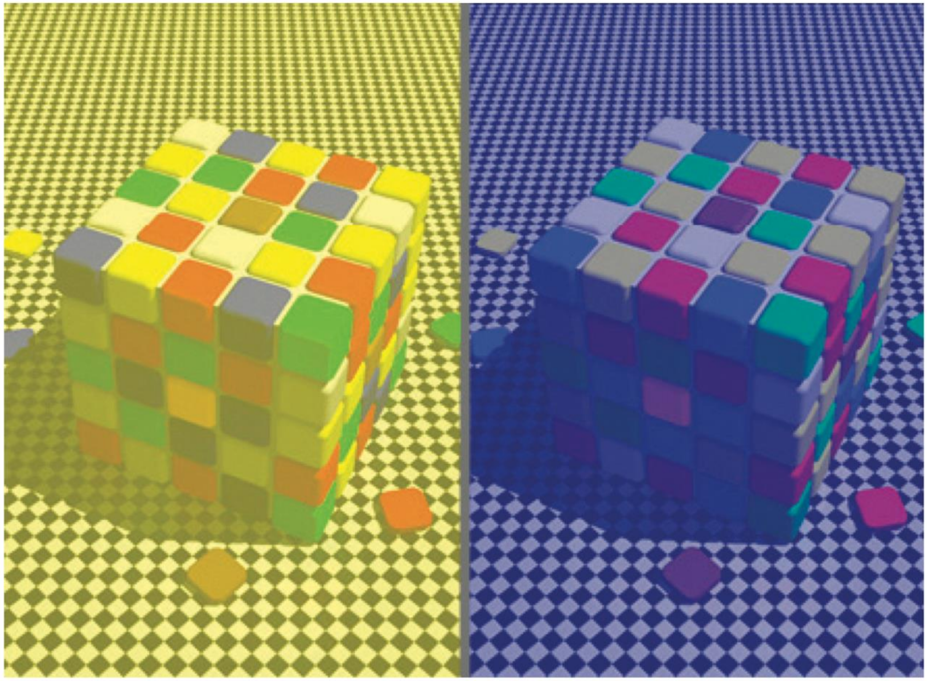


The two squares A and B appear very different!

Superimposing a gray mask on the image shows that they are in fact almost identical

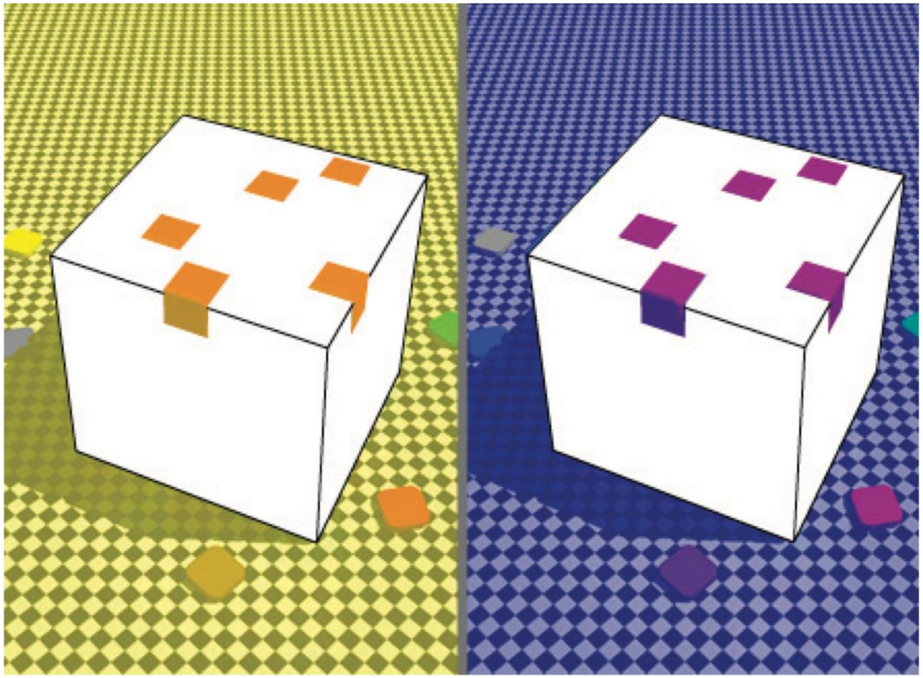
Relative vs. Absolute Judgments: 5/7

- **Color perception is also relative to surrounding colors and depends on context.**
- **In the images below, both cubes have tiles that appear to be red.**



Relative vs. Absolute Judgments: 6/7

- Masking the intervening context shows that the colors are very different: with yellowish lighting, they are orange; with bluish lighting, they are purple.



Relative vs. Absolute Judgments: 7/7

- **Our visual system can provide color constancy so that the same surface is identifiable across a broad set of illumination conditions, even though a physical light meter would yield very different readings**
- **While the visual system works well in natural environments, many of its mechanisms work against simple approaches to visually encoding information with color.**
- **Think about the white balance mechanism in your digital cameras.**

The End