

CSCI 1377

Tools for Thought

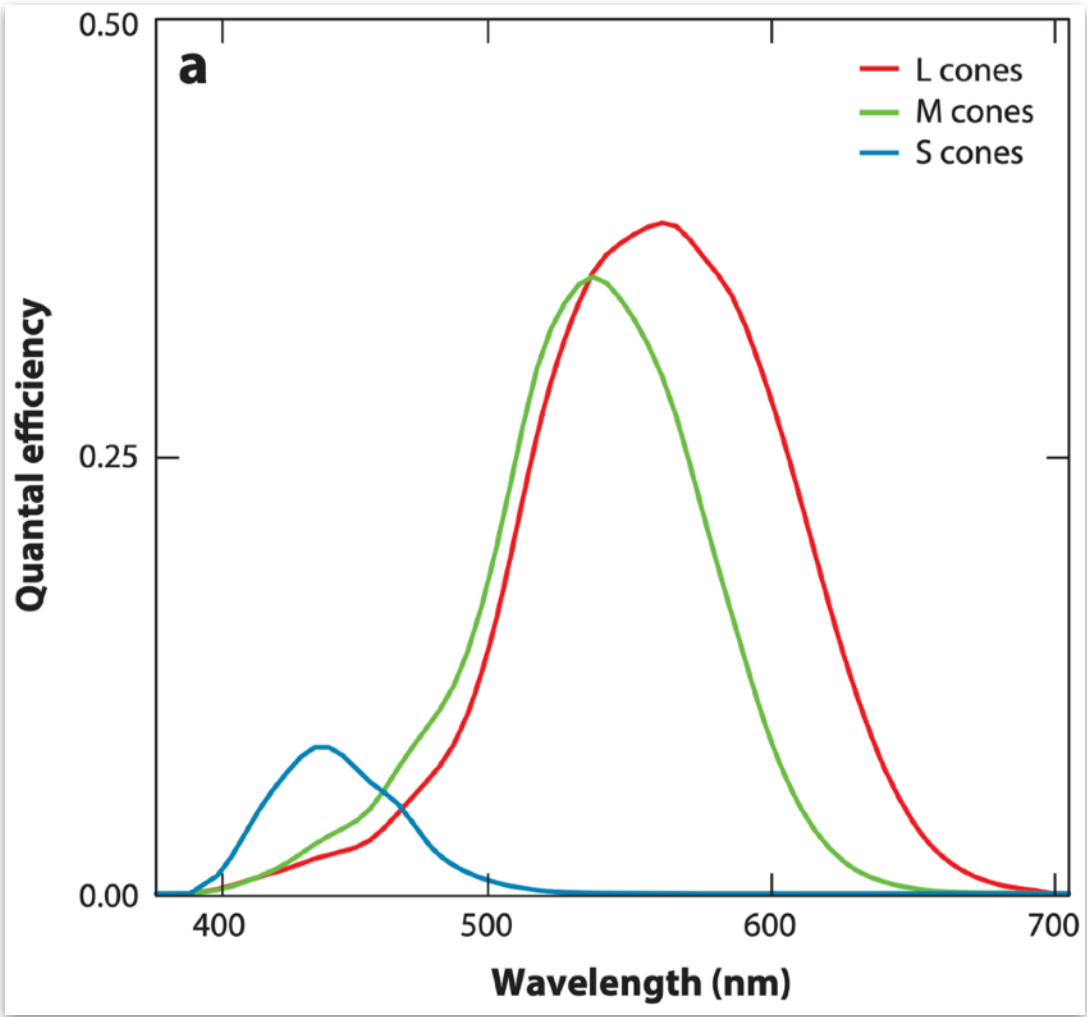
Visualization I

Principles of Perception

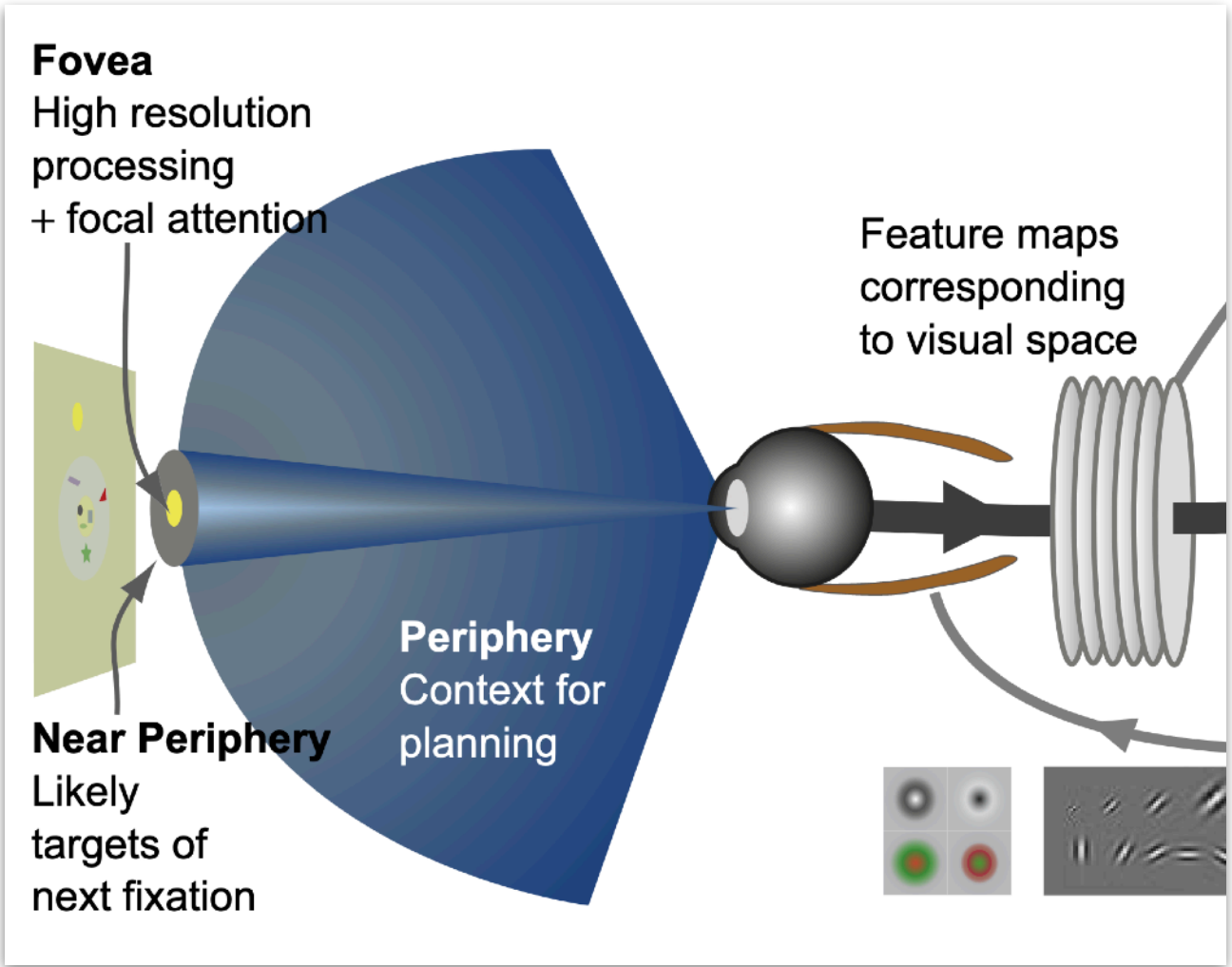
“Little effort is expended in seeing the structure once the right visualization method is used, so we are misled into thinking nothing exciting has occurred.”

— William Cleveland, *Visualizing Data* (1993)

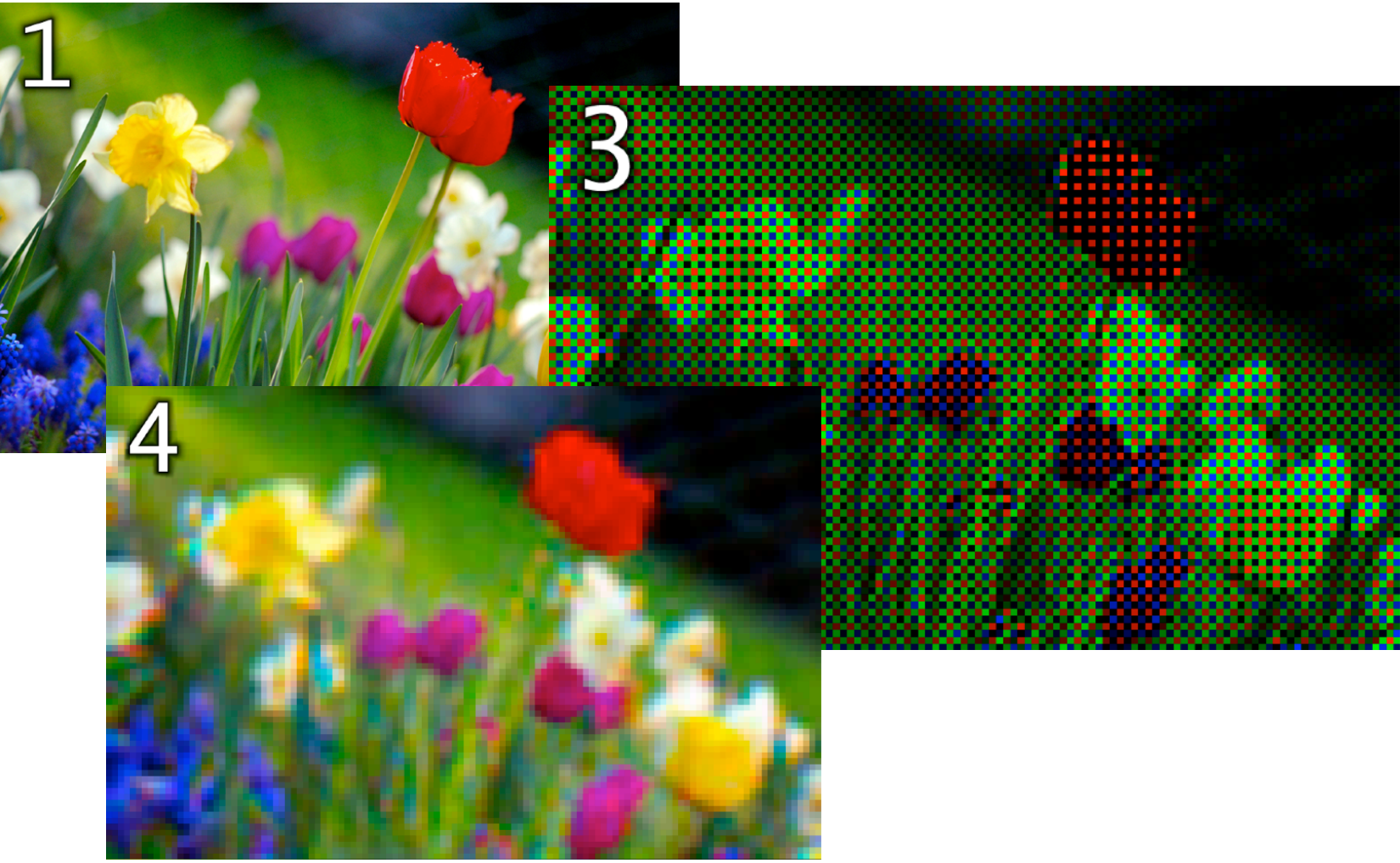
Charts



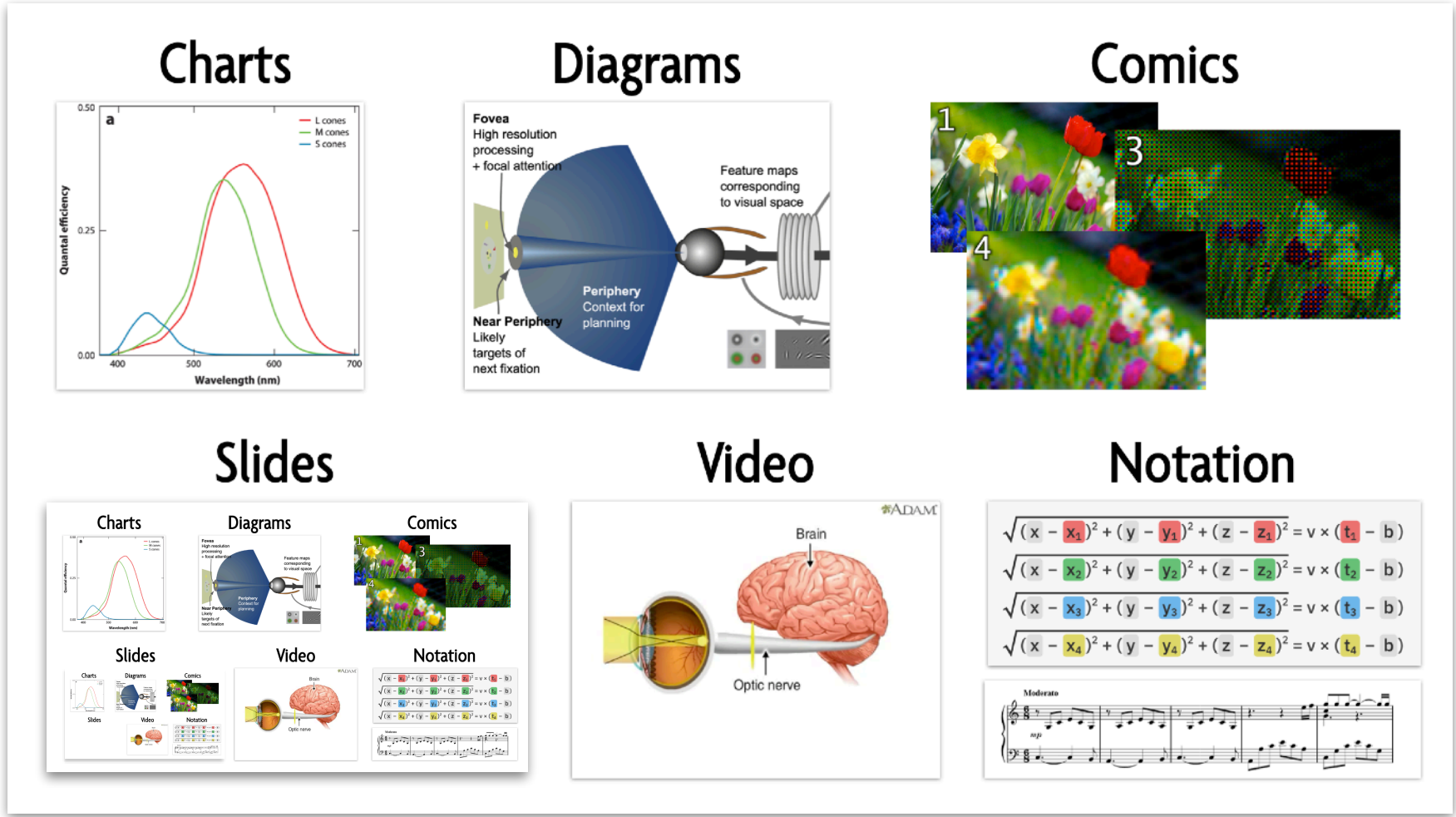
Diagrams



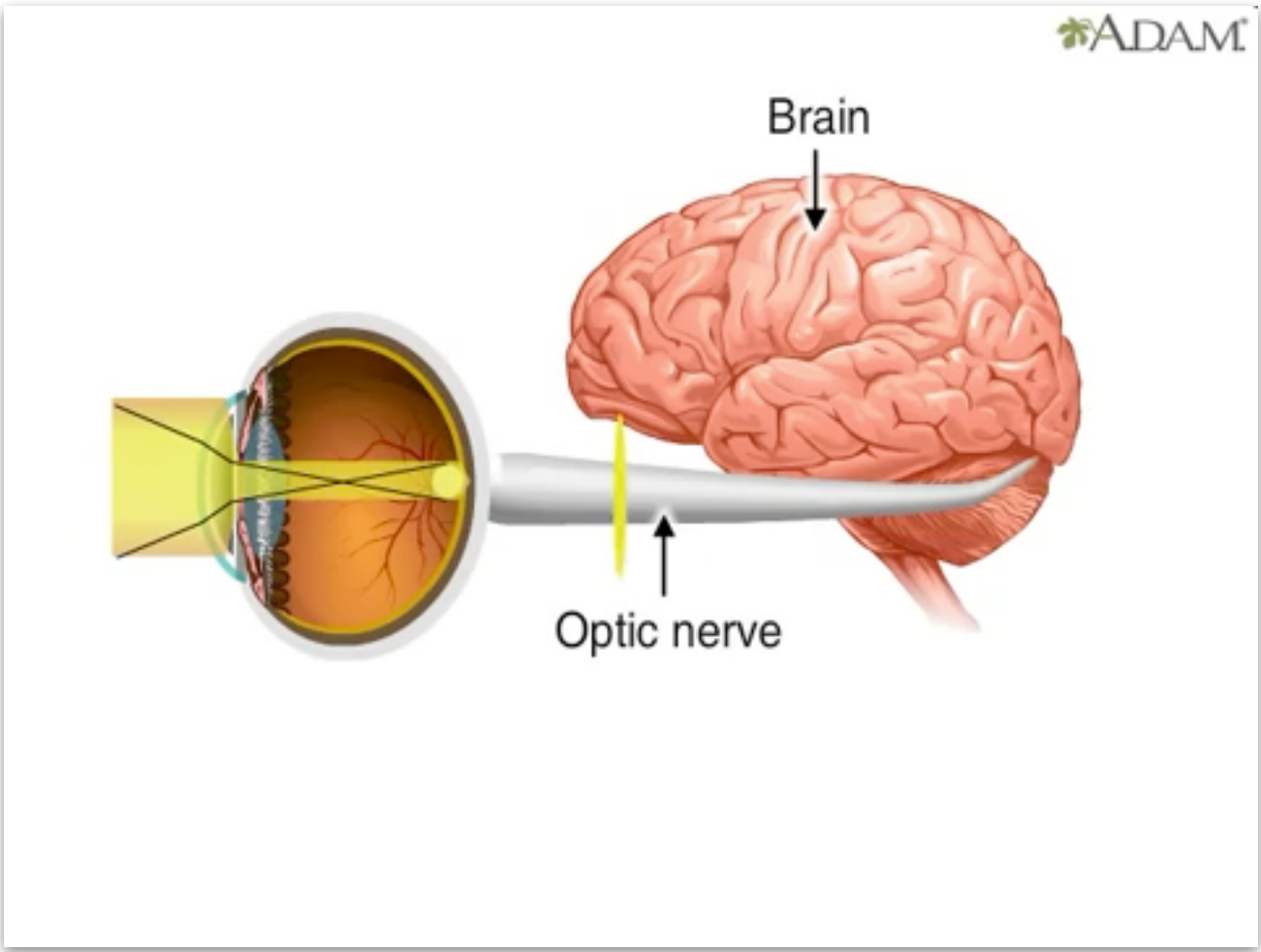
Comics



Slides



Video



Notation

$$\sqrt{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2} = v \times (t_1 - b)$$
$$\sqrt{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2} = v \times (t_2 - b)$$
$$\sqrt{(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2} = v \times (t_3 - b)$$
$$\sqrt{(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2} = v \times (t_4 - b)$$

Moderato

mp

Visualization can* improve cognitive efficiency

- **Externalization:** visualizations take information out of your head into the world
 - A check list exists as a durable bag of symbols rather than a fragile mnemonic entity
- **Parallelism:** brain performs limited processing of visual field
 - c.f. serial processing: you can't easily overlay multiple sounds and pick just one out
 - But you still can't read an entire paragraph at once!
- **Permanence:** static visualizations persist in time, allowing one to revisit, scan, annotate, rehearse
 - c.f. sound and video: information is gone as soon as it's made

Visualization can* improve cognitive efficiency

- **Spatiality:** visualizations exist in 2 (sometimes 3) dimensions, enabling sequential processing of non-linear information
 - e.g. spotting the trend in data you can see vs. is spoken aloud to you
 - e.g. reading through a diagram along multiple pathways
- * only if the visualization is carefully designed!
 - Visualizations can be cognitively inefficient or actively misleading
 - Much of visualization design is knowing what not to do

Consider how our games compare on each axis

1 2 3 4 5 6 7 8 9

- Externalization

- Parallelism

- Permanence

- Spatiality

8	1	6
3	5	7
4	9	2

Mental imagery is important for thought, but its connection to visualization is a WIP

“The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be “voluntarily” reproduced and combined. [...] this combinatory play seems to be the essential feature in productive thought before there is any connection with logical construction in words or other kinds of signs which can be communicated to others.”

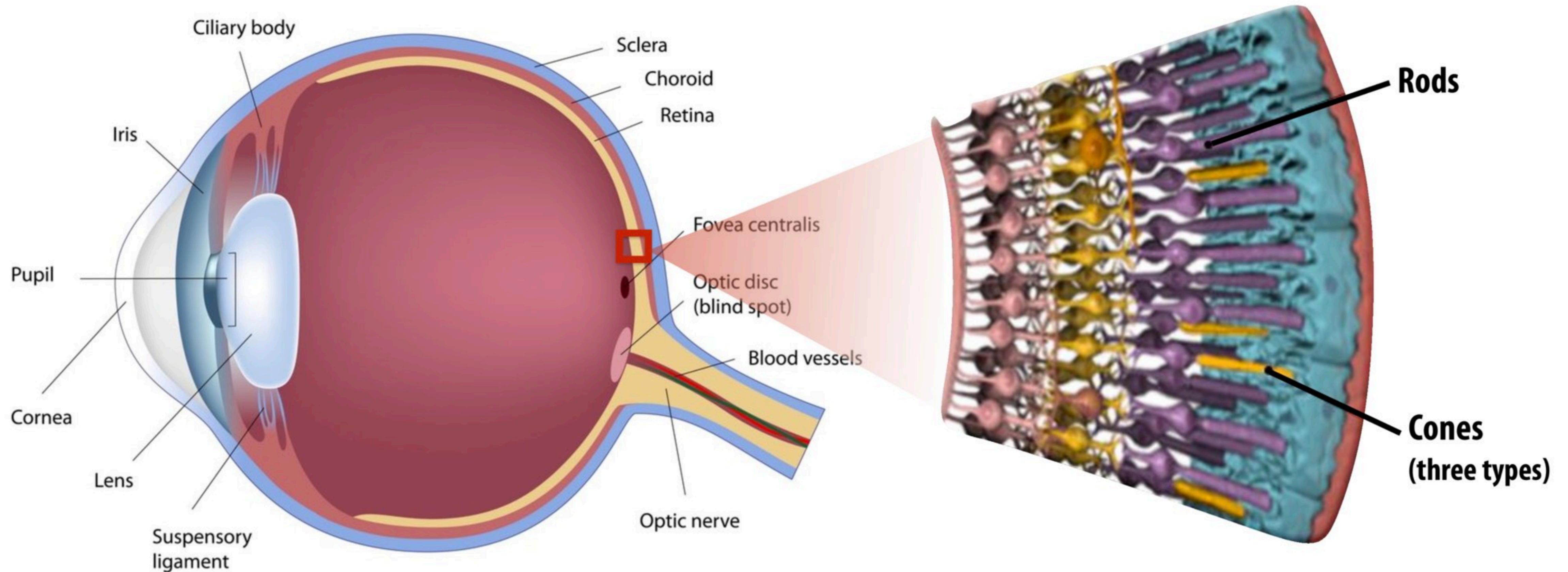
— Albert Einstein, in correspondence to Jacques Hadamard, 1945

“Although it seems clear that perceptual processes are involved in visual imagery to some degree, the degree to which the mechanisms of visual imagery are the same as the mechanisms of visual perception remains an open question.”

— John Anderson, *Cognitive Psychology*, 2020

**This lecture: introduction to the
science of perception**

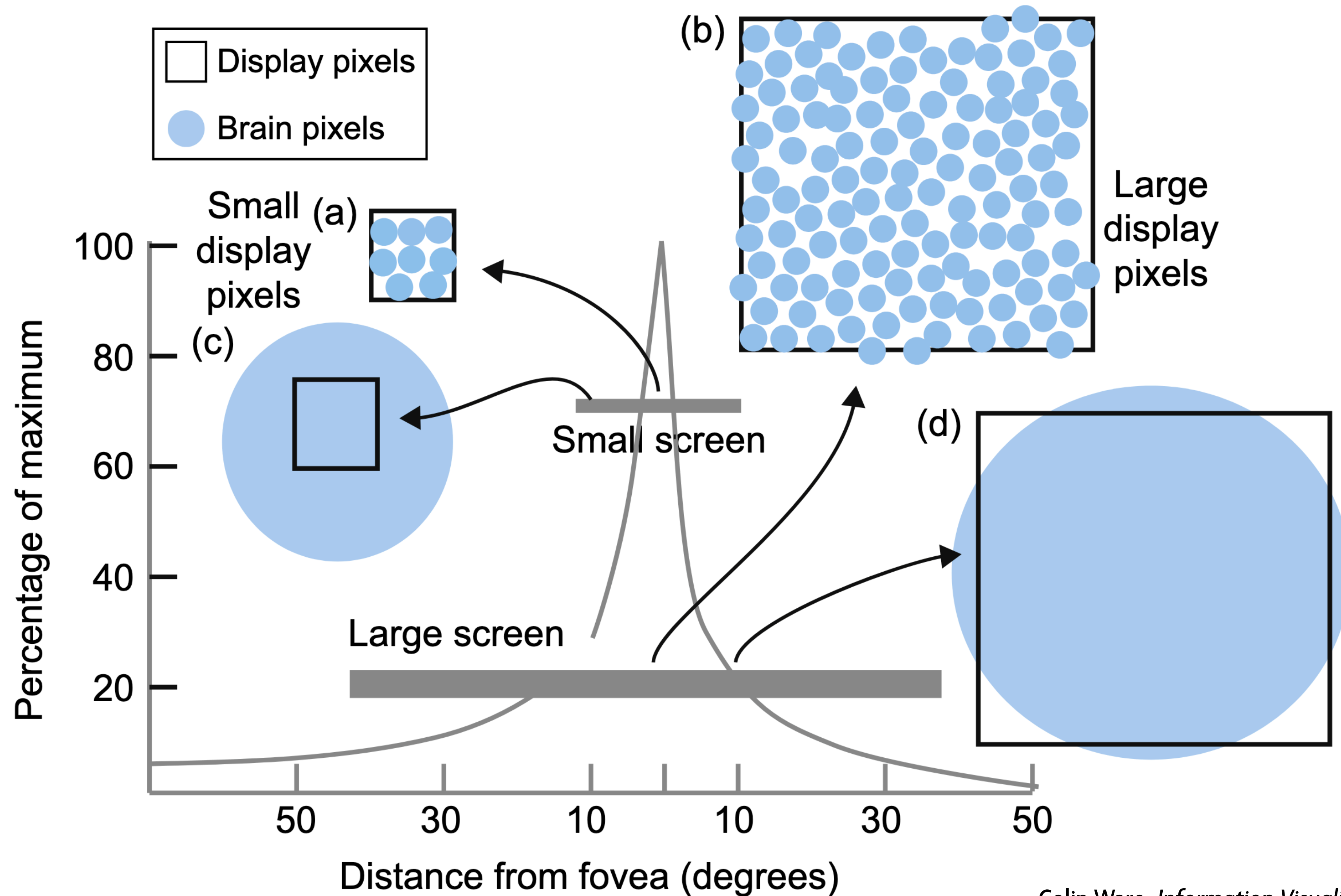
Eye contains rods and cones concentrated in fovea



Rods (~100 mil): light intensity receptors for night vision

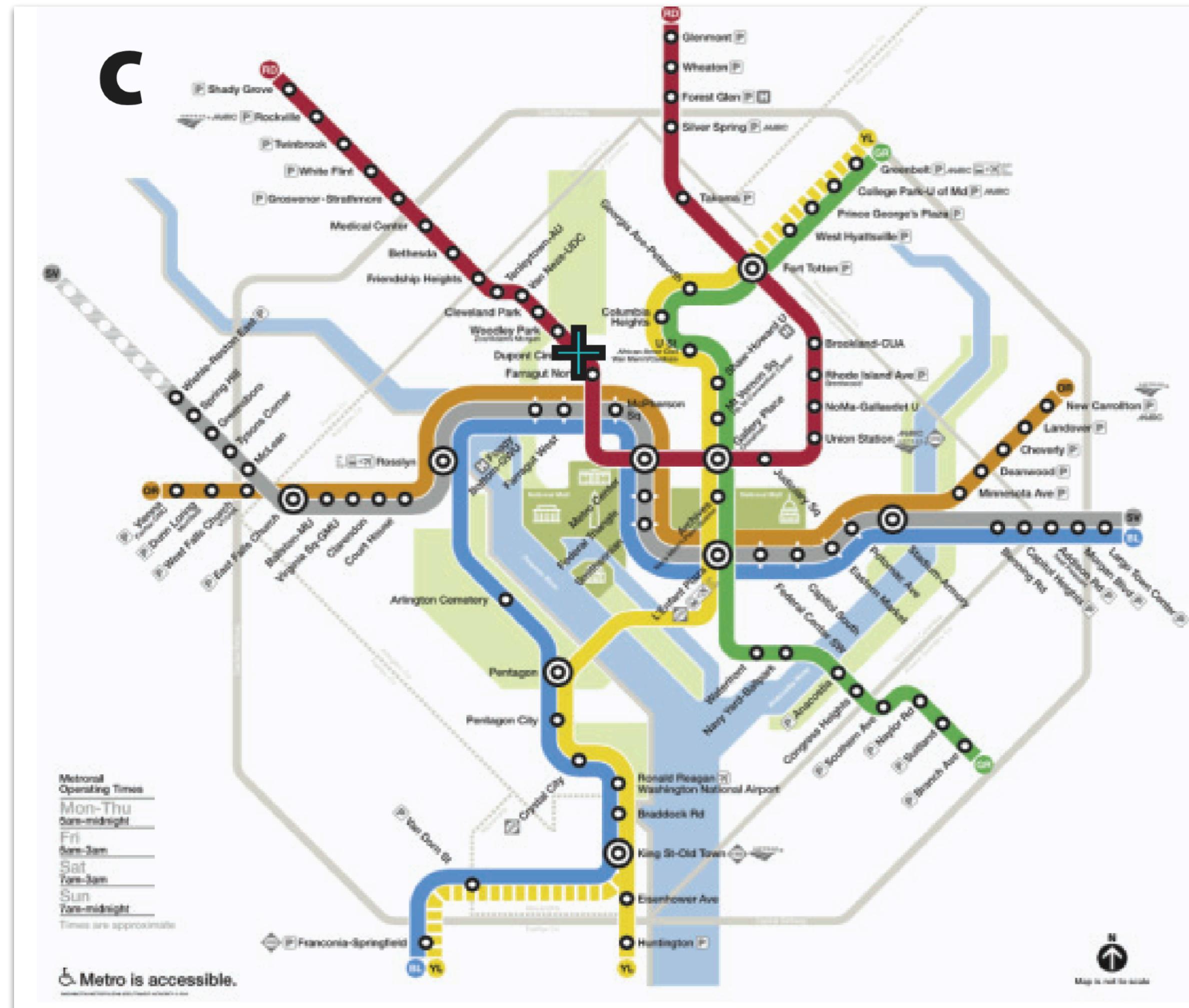
Cones (~6 mil): color receptors for day vision

Visual acuity outside fovea drops quickly



Periphery contains a coarse view of the world

True image



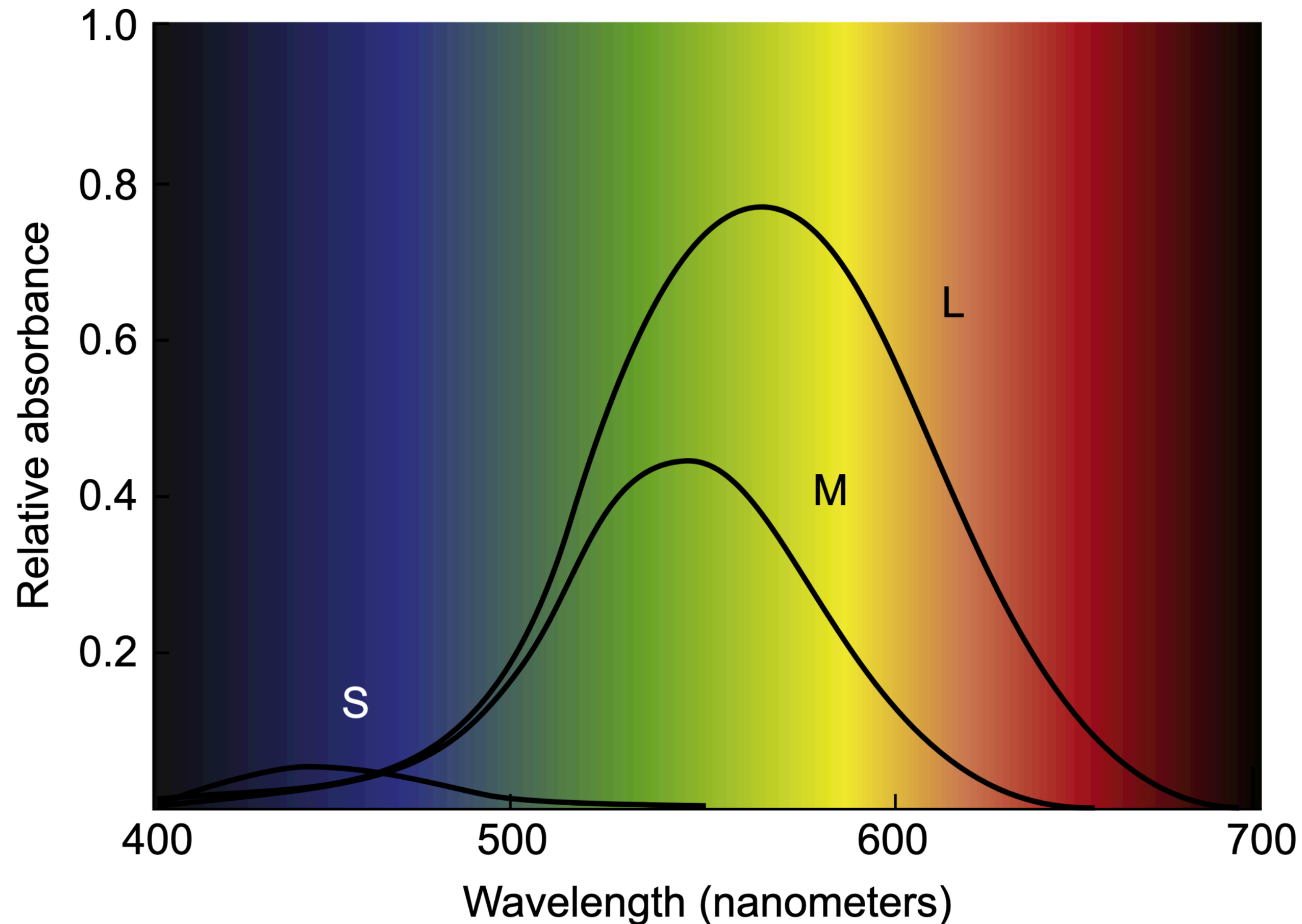
Model of perceived image



**Foveated rendering reduces render time by
rendering at lower quality outside foveal region**

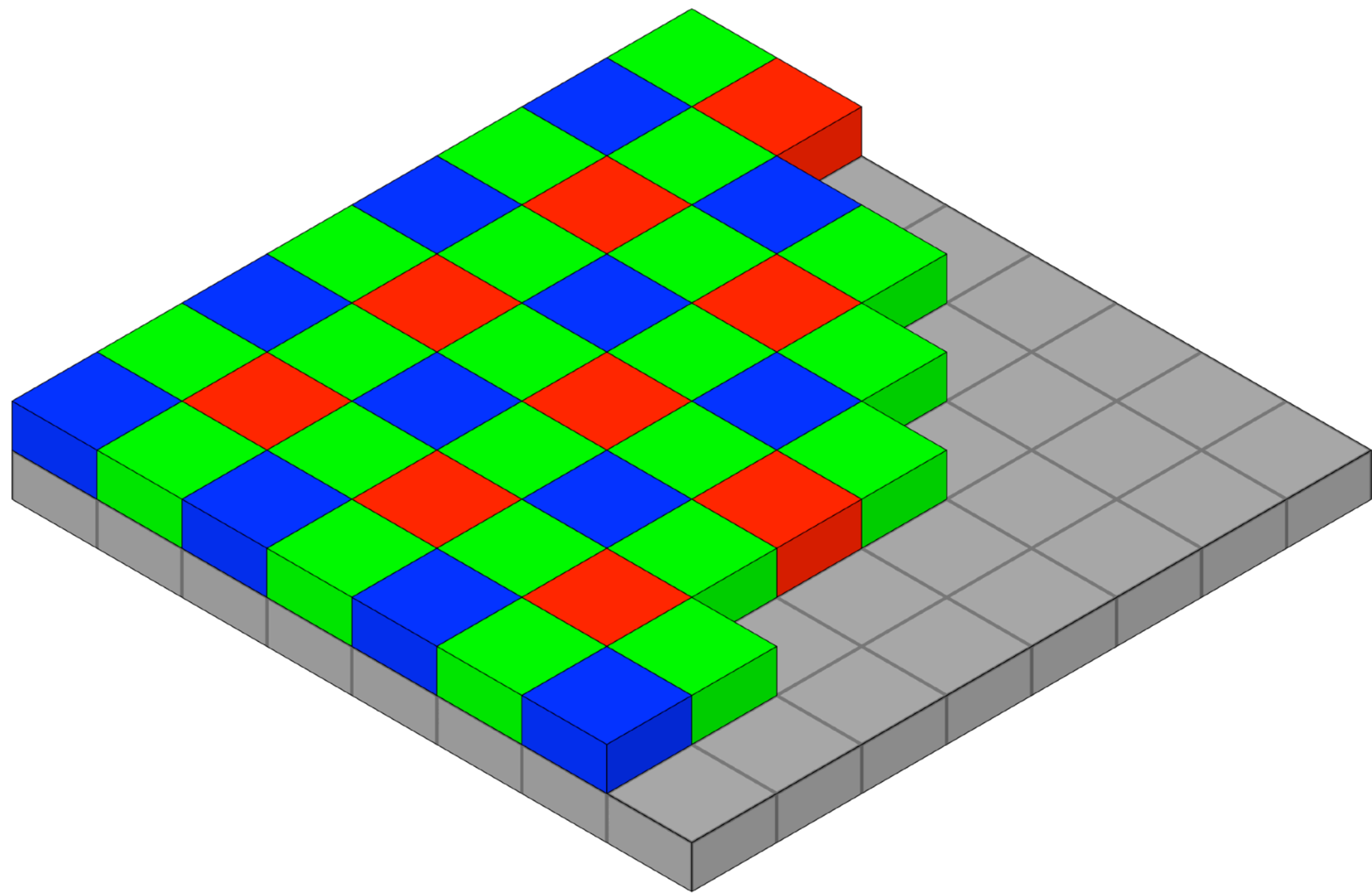
<https://youtu.be/OUjhJqpJjEo>

Different cones types detect different wavelengths

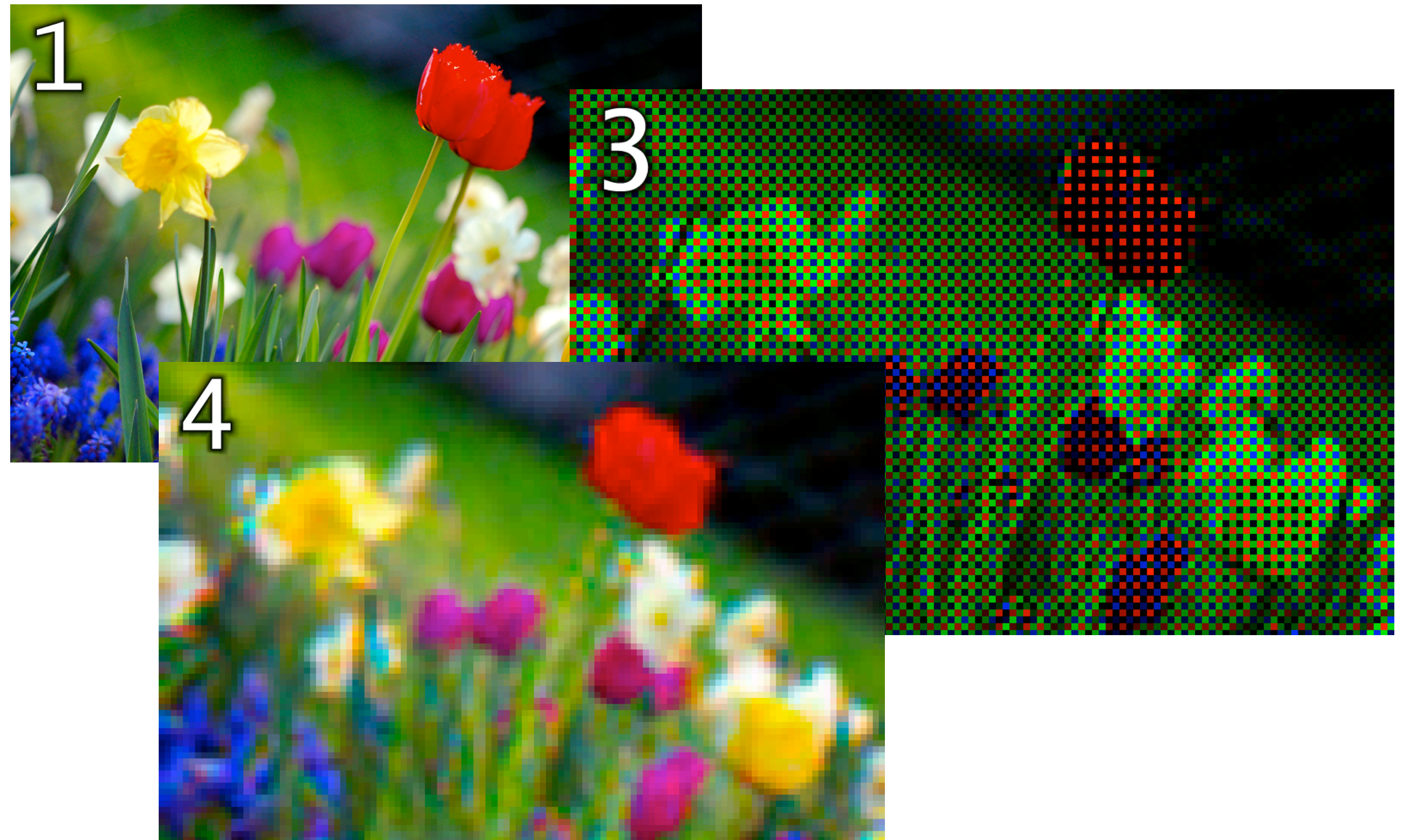


Cones disproportionately detect green, so cameras are designed to pick up more green

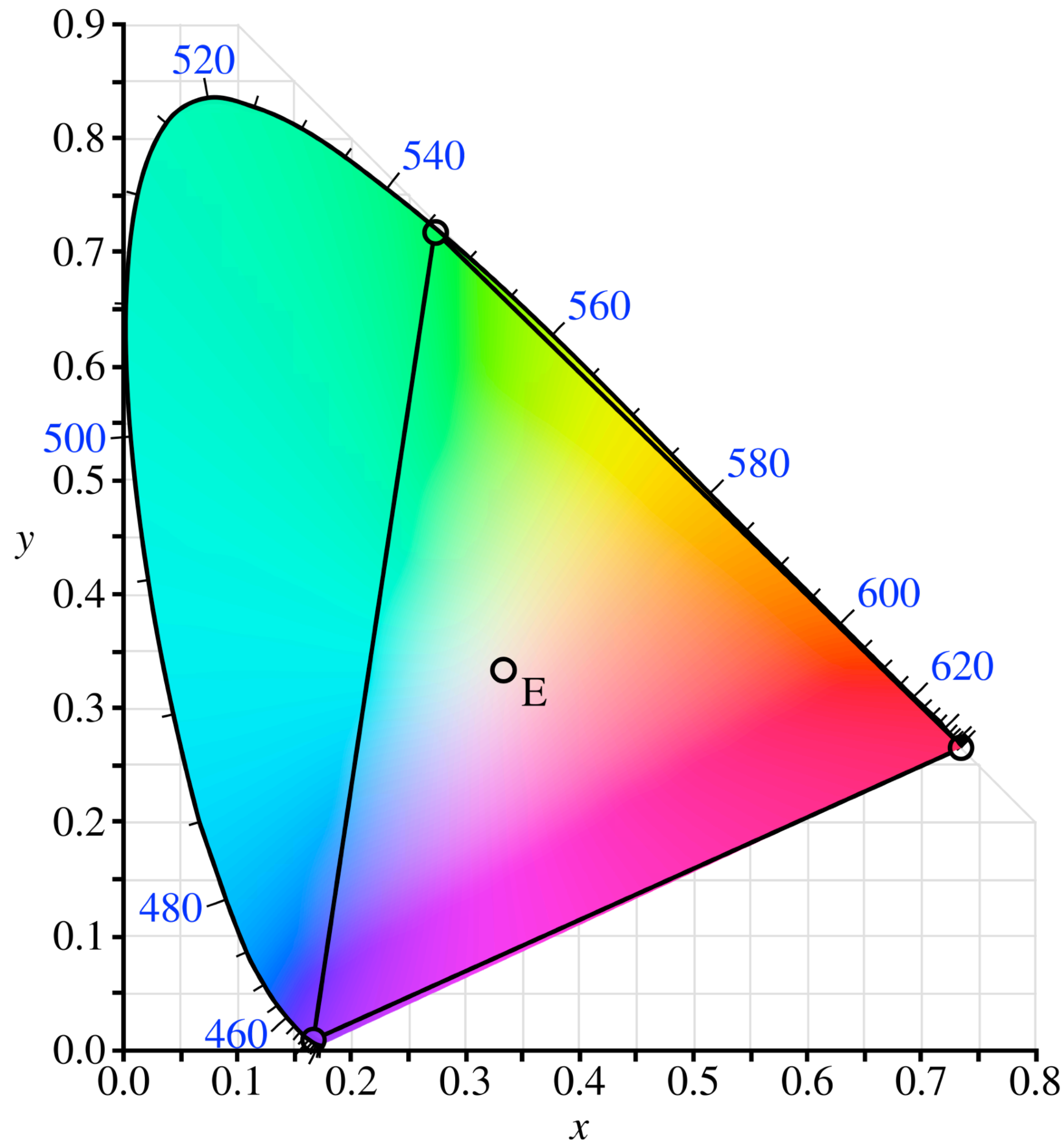
Bayer mosaic



Demosaicking

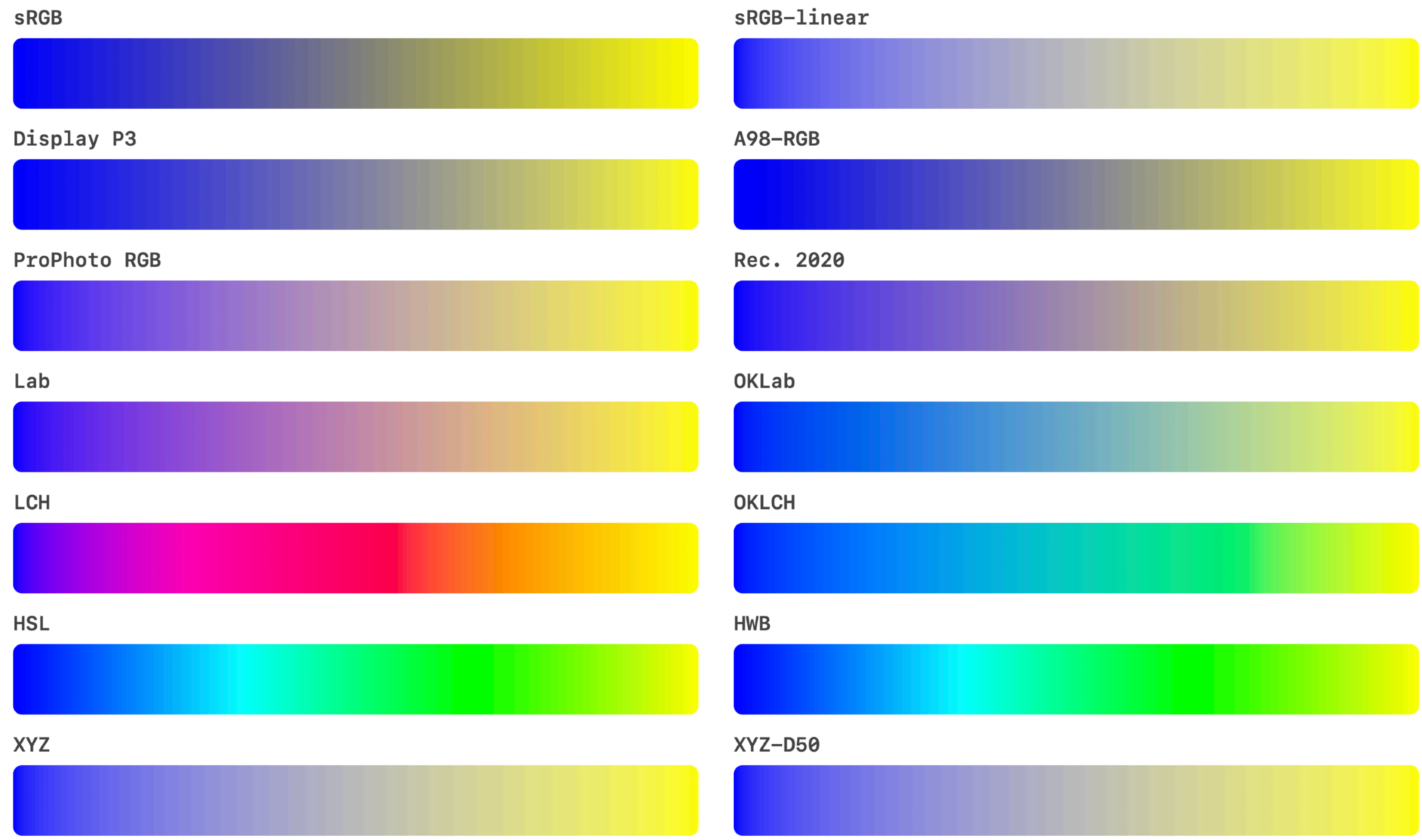


Color spaces represent color as vectors



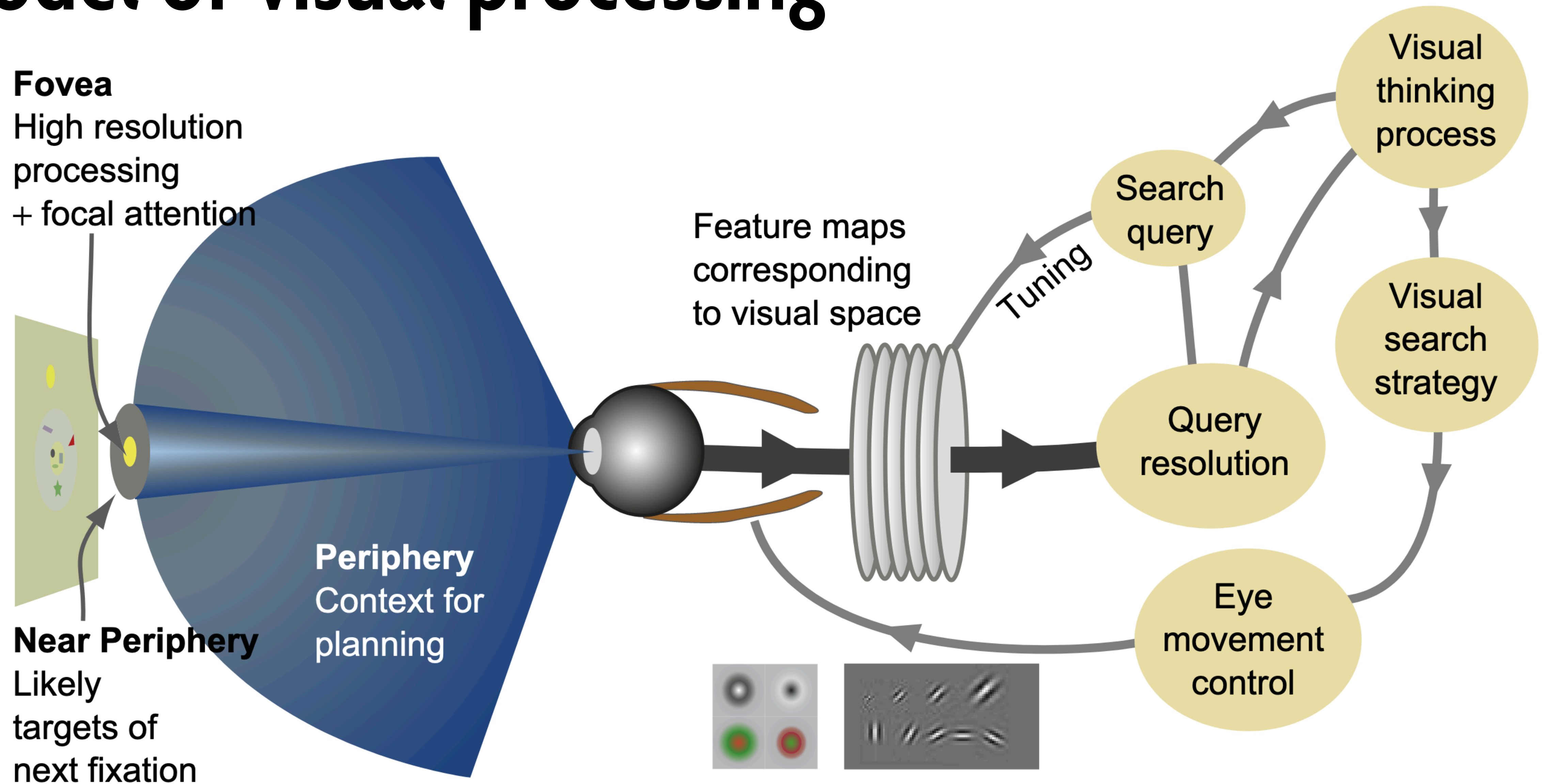
CIE XYZ color space

There's many color spaces to pick from!



background: linear-gradient(in <color space> to right, blue, yellow)

Model of visual processing



Signal Detection

Discriminability: how easy is it to tell two things apart?

Magnitude Estimation

Accuracy: how correctly can we read off values?

Preattentive Processing

Pop out: how easy is it to spot some values from the rest?

Selective Attention

Separability: how much interaction occurs between attributes

Signal Detection

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Separability: how much interaction occurs between attributes

Which is brighter?



`rgb(128, 128, 128)`



`rgb(144, 144, 144)`

Which is brighter?



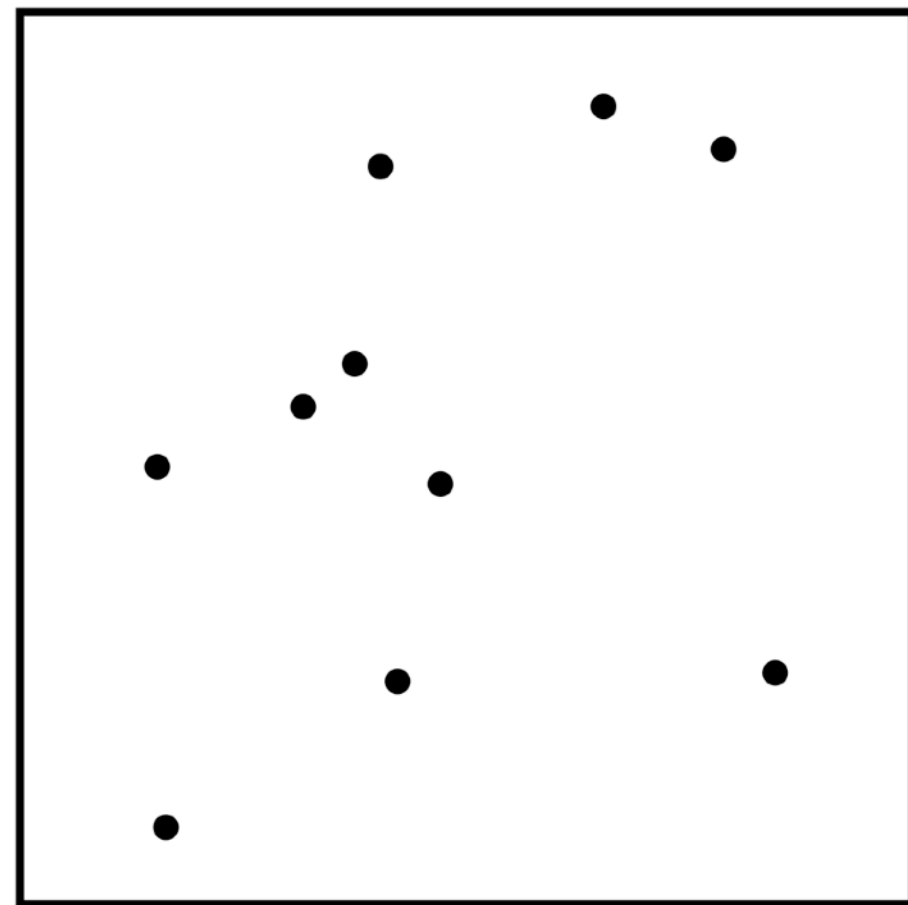
`rgb(134, 134, 134)`



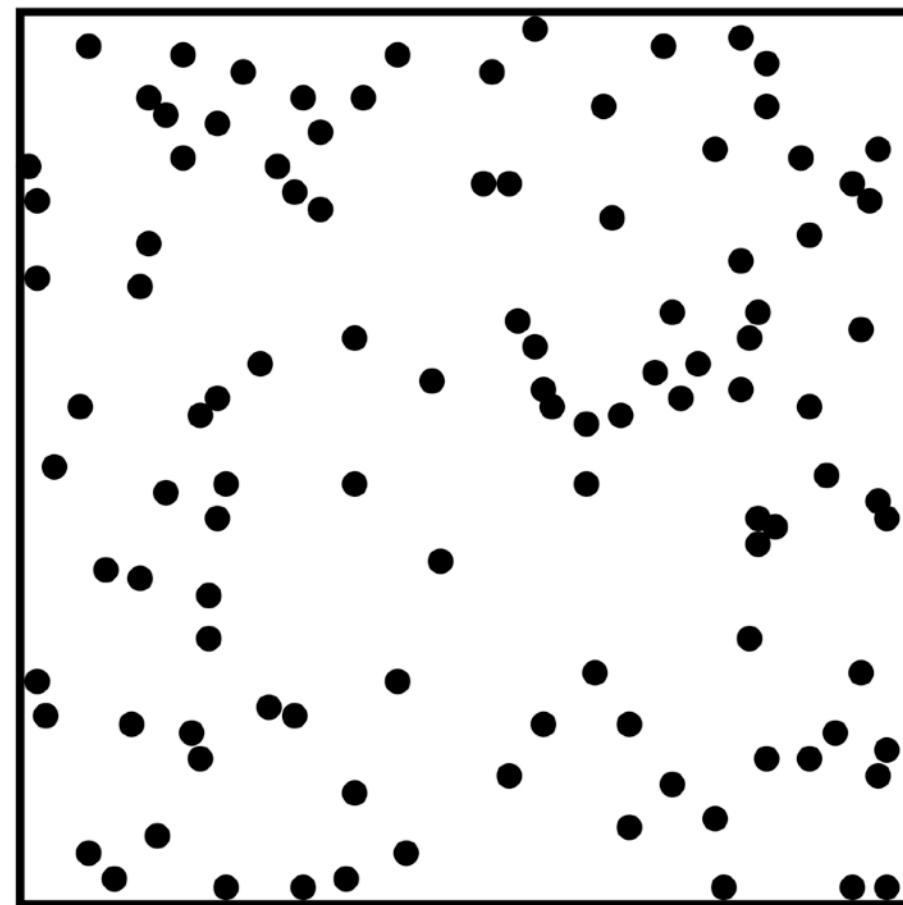
`rgb(128, 128, 128)`

**[https://www.keithcirkel.co.uk/
whats-my-jnd/](https://www.keithcirkel.co.uk/whats-my-jnd/)**

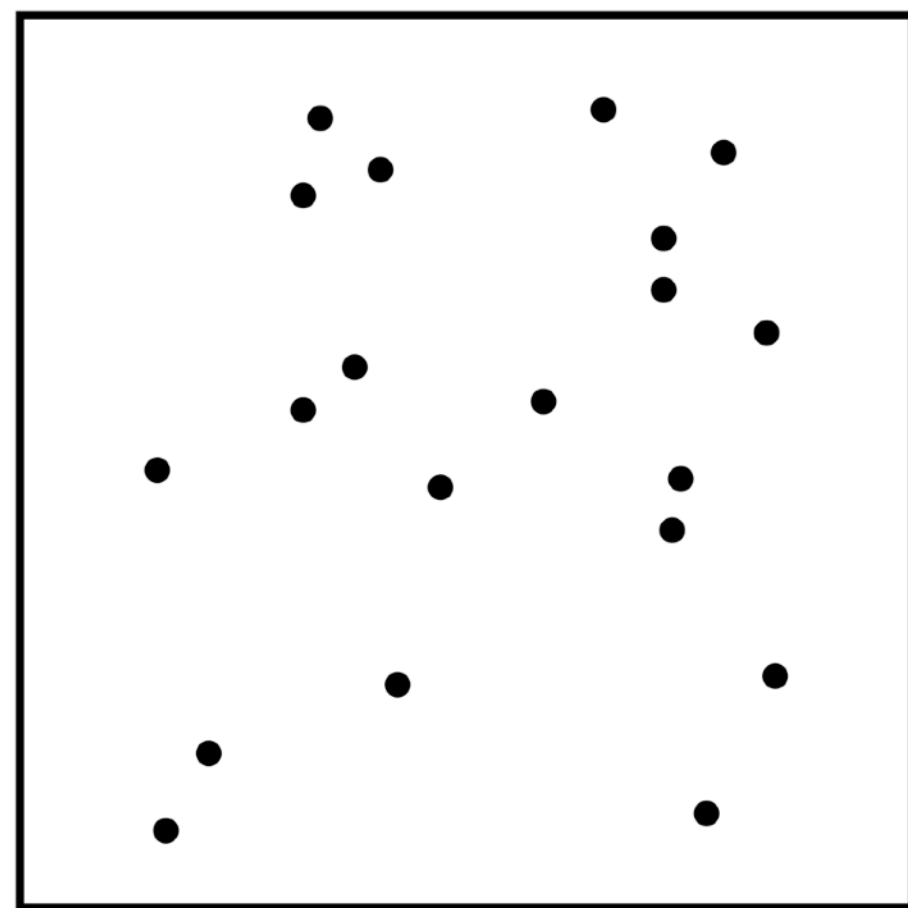
Increases are less perceptible with larger stimuli



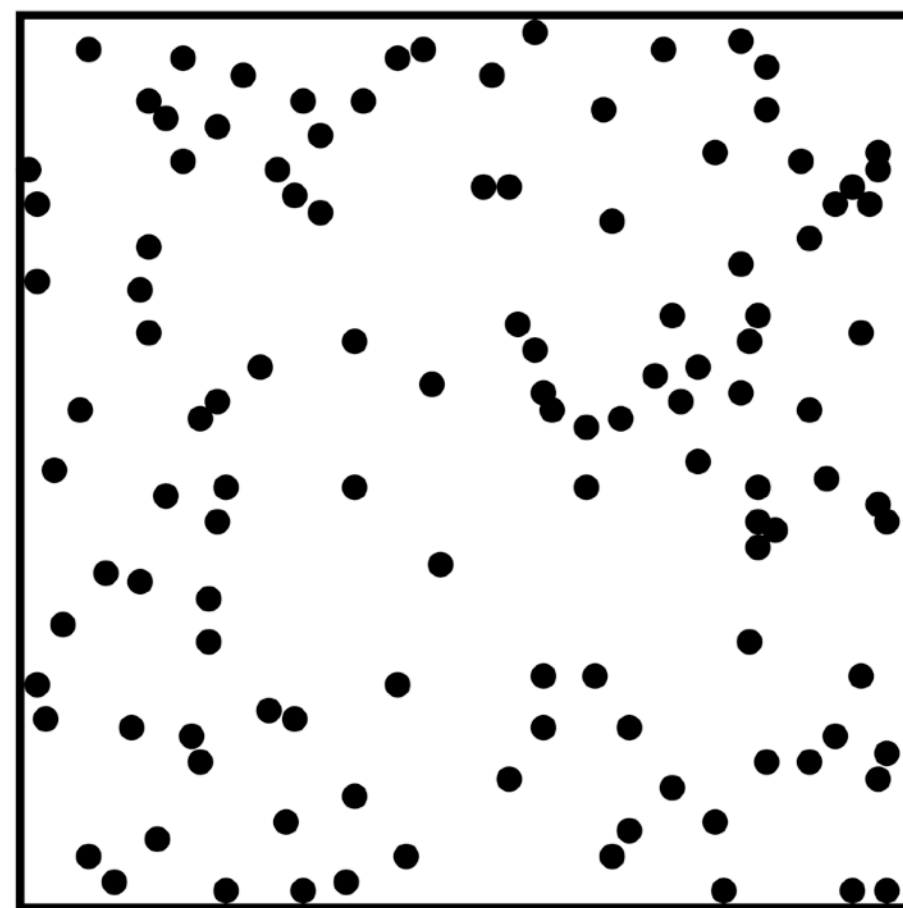
10



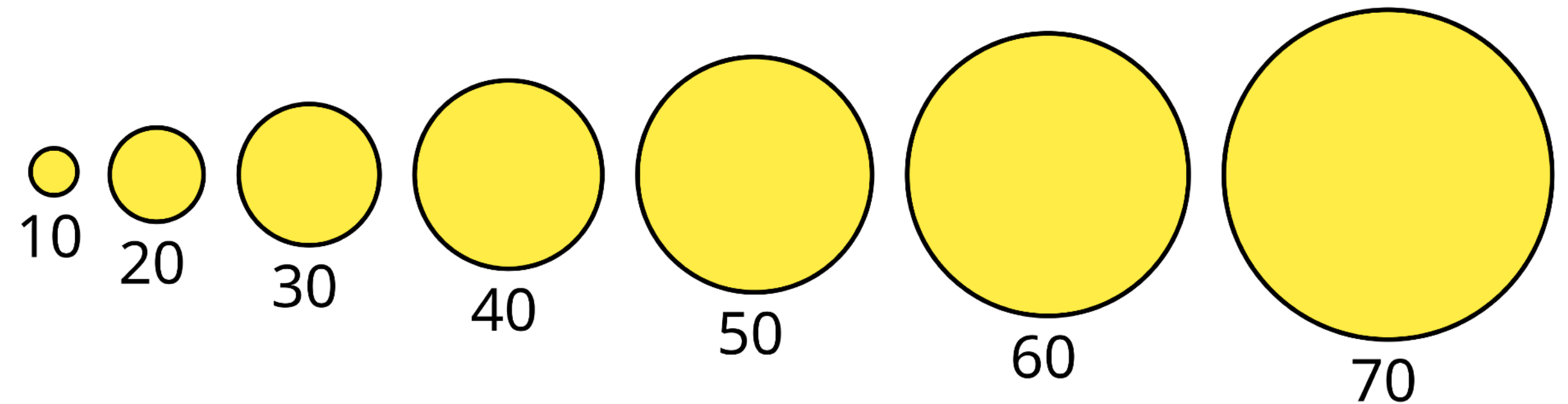
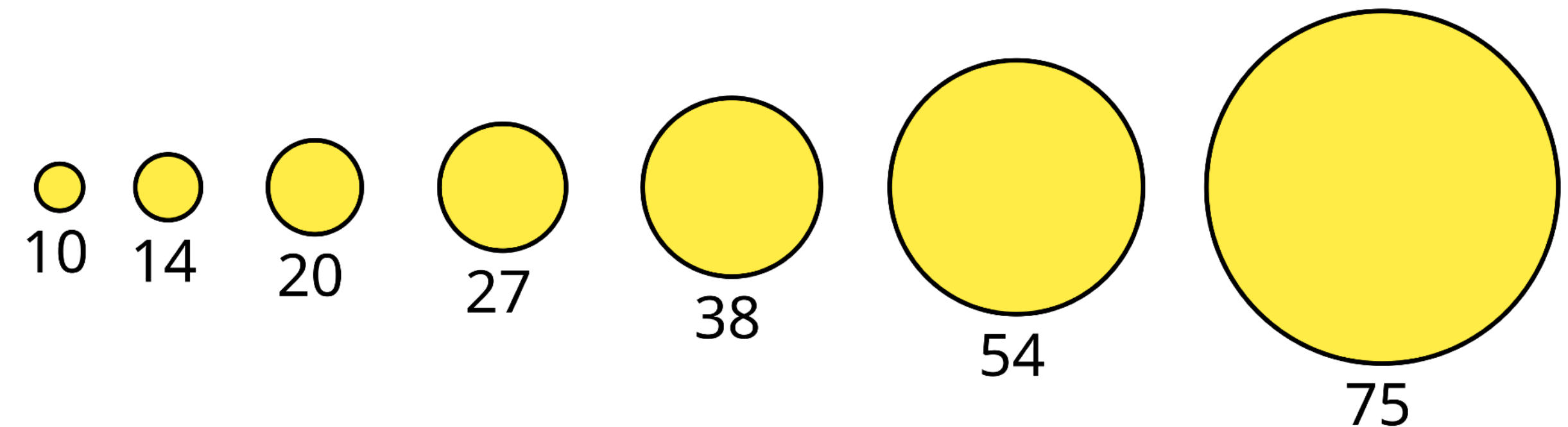
110



20



120



Weber's law: “just noticeable difference” depends on the stimulus magnitude

$$\Delta S = k S$$

JND threshold

Scale factor

Stimulus magnitude

Ex: $k = \frac{1}{10}$

$$S = 10 \implies \Delta S = 1$$

$$S = 100 \implies \Delta S = 10$$

Signal Detection

Discriminability: how easy is it to tell two things apart?

Magnitude Estimation

Accuracy: how correctly can we read off values?

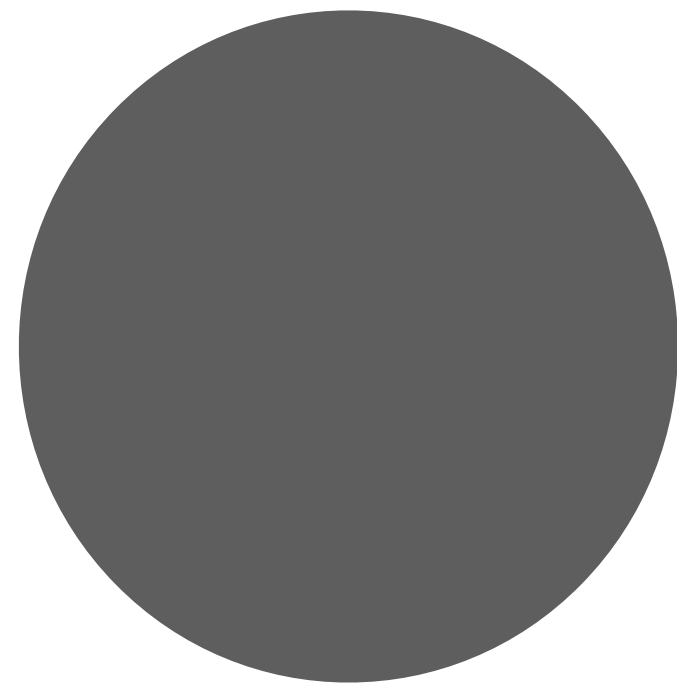
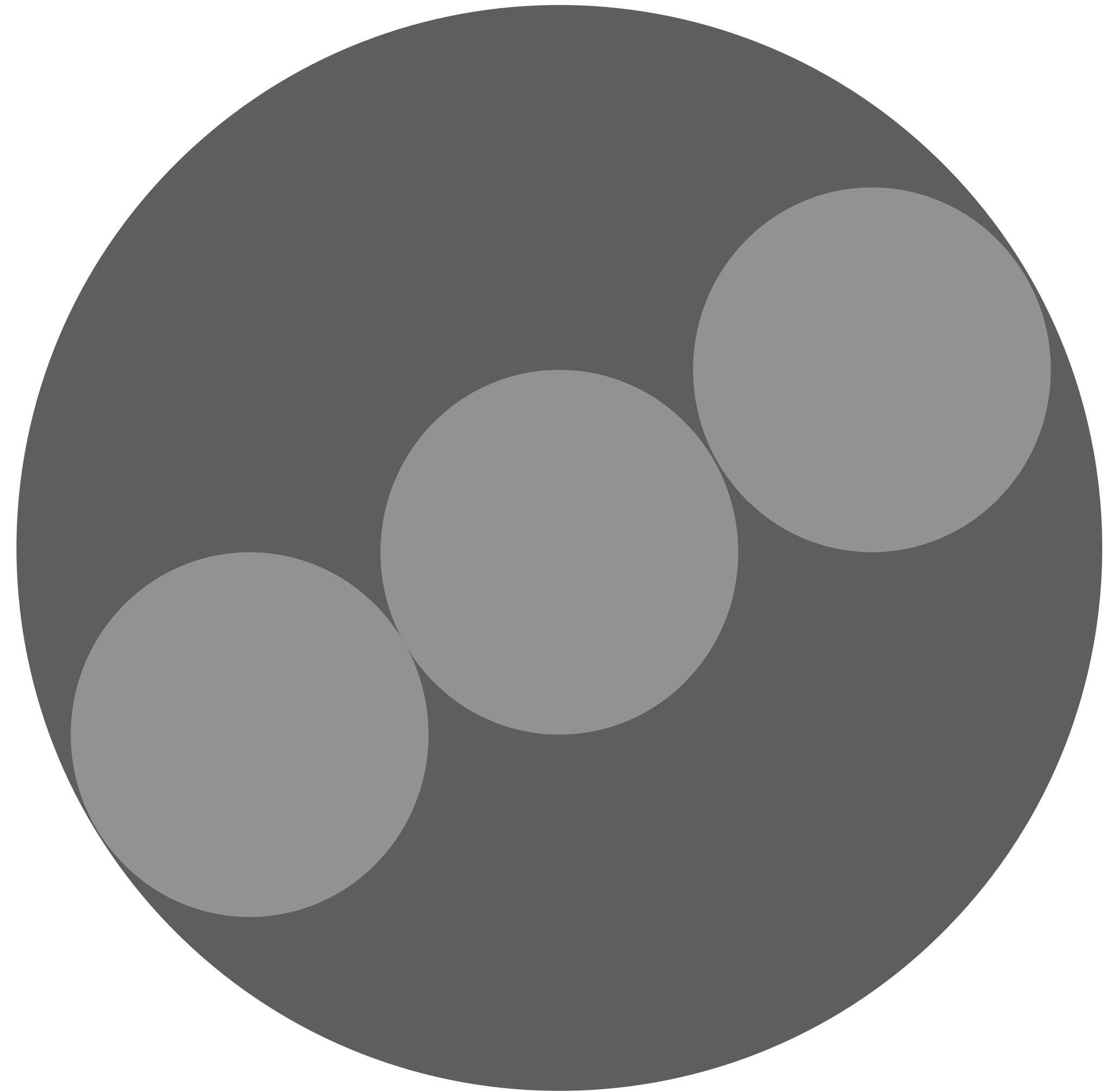
Preattentive Processing

Pop out: how easy is it to spot some values from the rest?

Selective Attention

Separability: how much interaction occurs between attributes

How much larger is the area of the big circle?



How much longer is the big bar?



Two competing theories of absolute perceptual magnitude

Perceived intensity Scale factor Stimulus magnitude

Fechner's law (1860): $\psi = k \log(S)$

Perception is a **logarithmic** function of intensity

Steven's law (1957): $\psi = k S^\alpha$ Sensory-specific exponent

Perception is a **power** function of intensity

Decibel puts units on a logarithmic scale

dB
= decibel
= 1/10 bel

$$X \text{ bel } Y = 10^X \times Y$$

$$X \text{ decibel } Y = 10^{\frac{X}{10}} \times Y$$

$$10 \text{ dB} = 10 \times [\text{something}]$$

$$20 \text{ dB} = 100 \times [\text{something}]$$

$$30 \text{ dB} = 1000 \times [\text{something}]$$

SPL = sound pressure level = 20 μPa

$$20 \text{ dB SPL} = 100 \times 20 \mu\text{Pa}$$

Decibels are used for image compression quality



PSNR = 40 dB



PSNR = 30 dB



PSNR = 20 dB

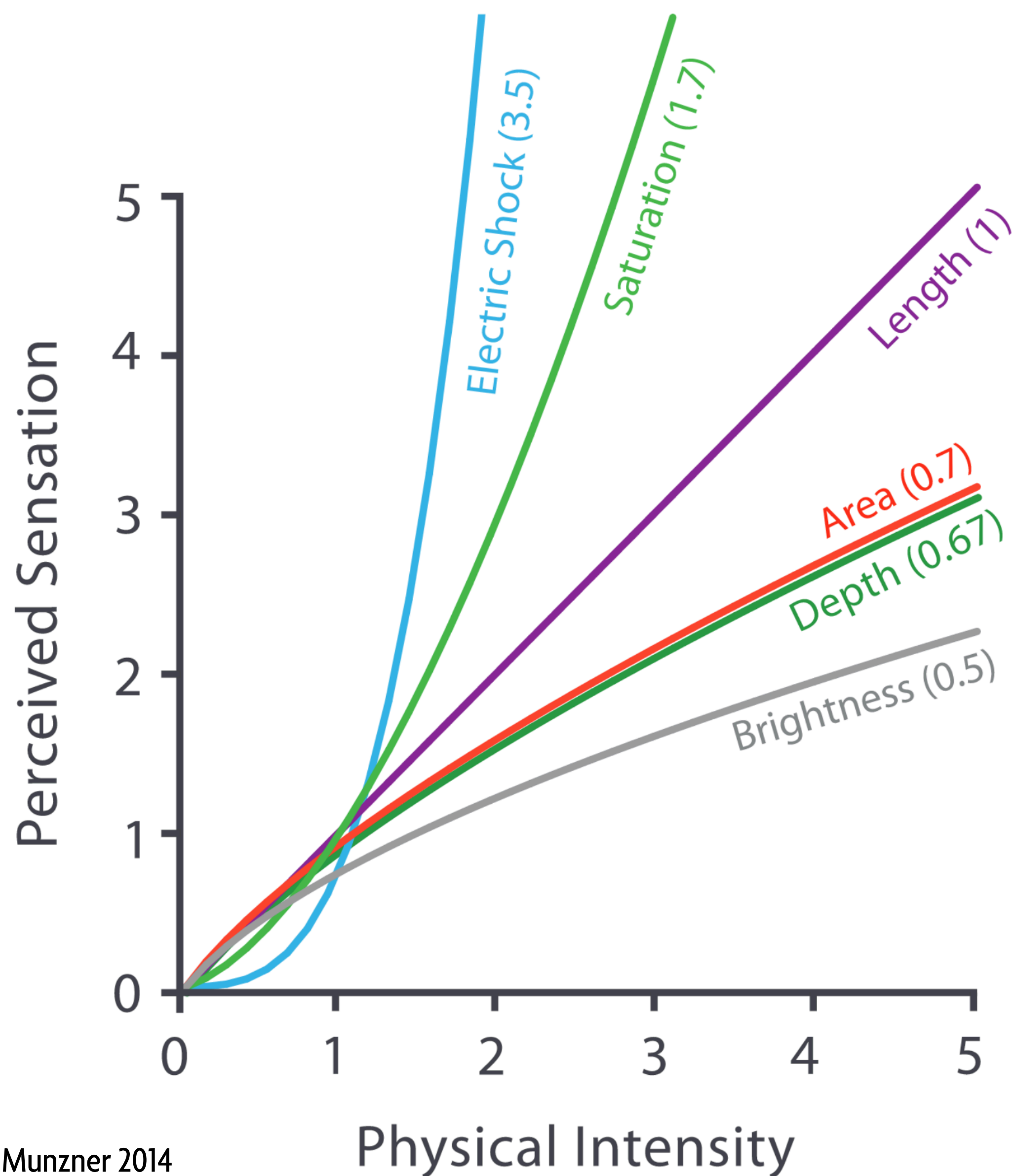
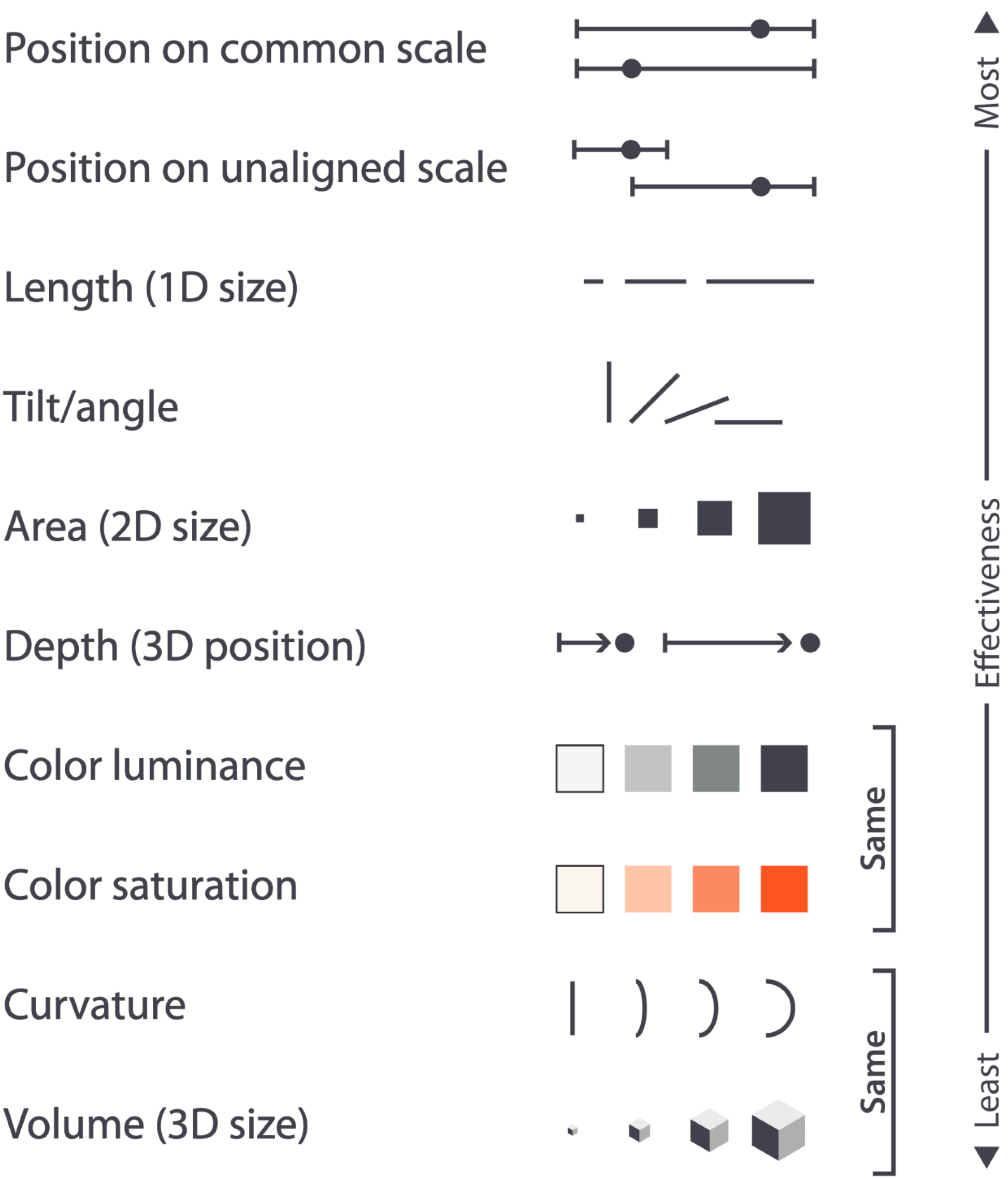


PSNR = 10 dB



PSNR = 0 dB

Stevens' law suggests encodings of quantity



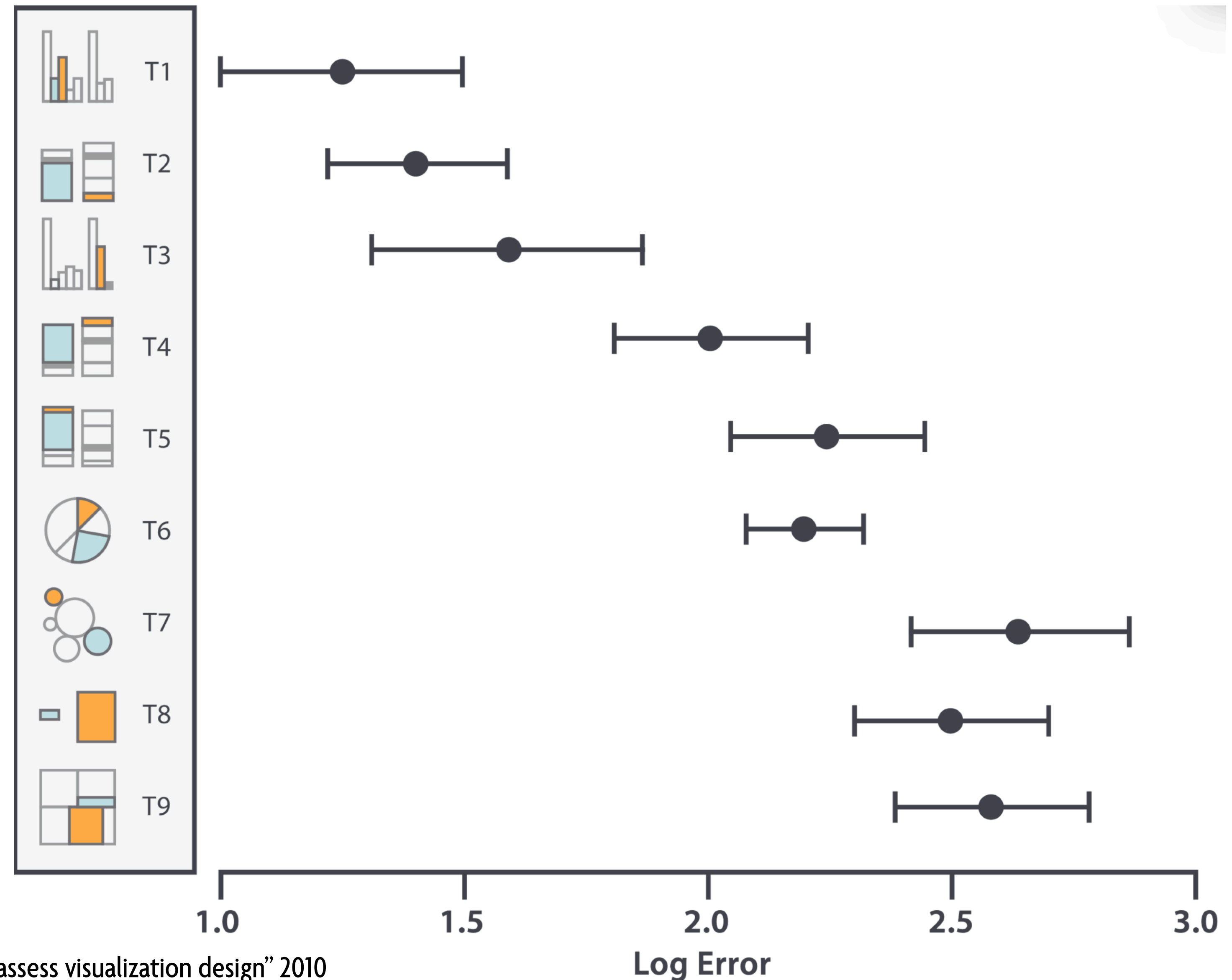
Stevens' law predictions hold up experimentally

Materials

Nine visual encodings of quantity $\times 10$ charts per encoding

Procedure

Ask participants snap judgment about relative size of areas



Signal Detection

Discriminability: how easy is it to tell two things apart?

Magnitude Estimation

Accuracy: how correctly can we read off values?

Preattentive Processing

Pop out: how easy is it to spot some values from the rest?

Selective Attention

Separability: how much interaction occurs between attributes

How many 3's?

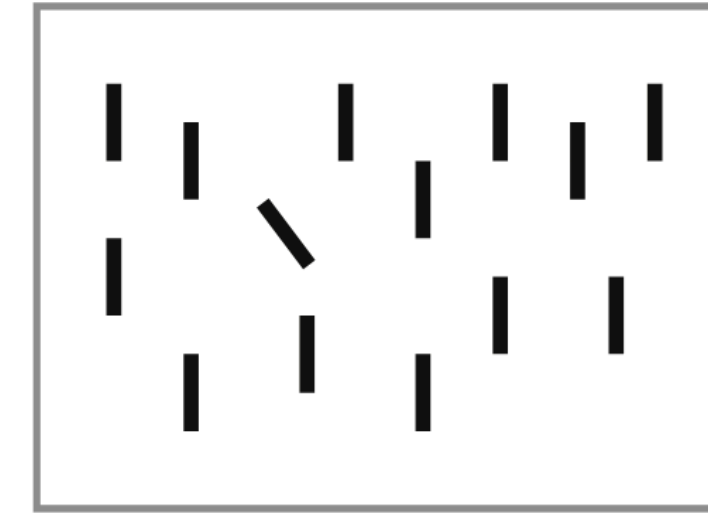
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27107462144654207079014738109743897010971
43907097349266847858715819048630901889074
25747072354745666142018774072849875310665

459290780597720987759726556651100498**3**6645
271074621446542070790147**3**810974**3**897010971
4**3**907097**3**492668478587158190486**3**0901889074
25747072**3**54745666142018774072849875**3**10665

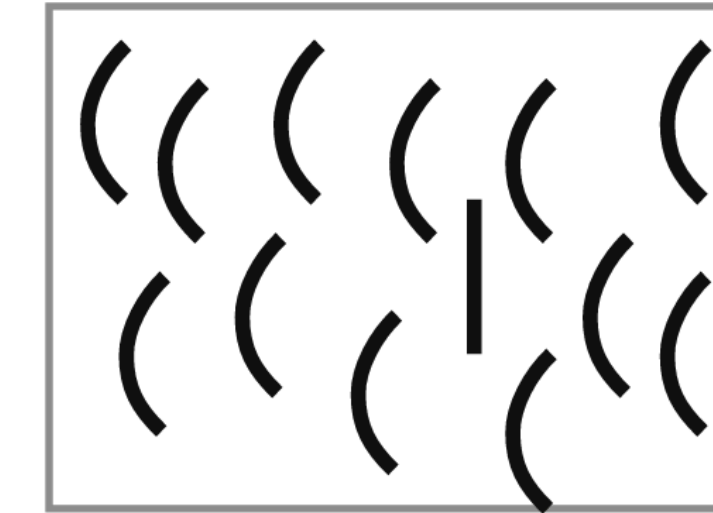
Preattentive processing

is the phenomenon where certain visual features appear to be processed automatically, facilitating effortless visual search against distractors.

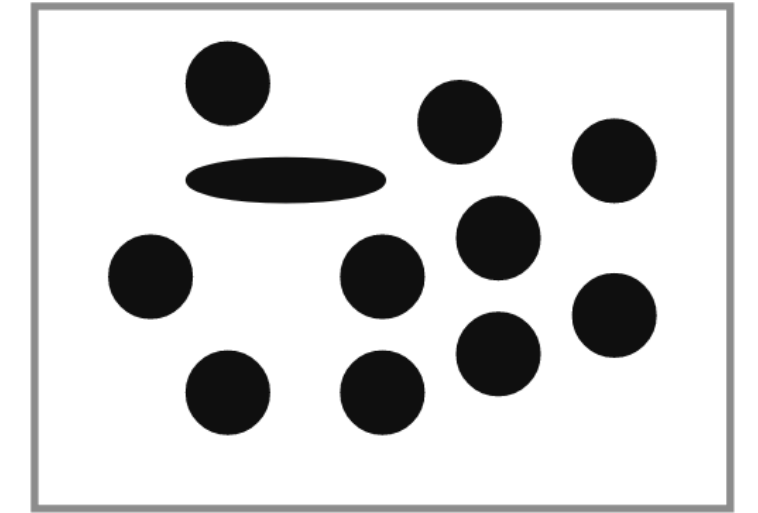
Orientation



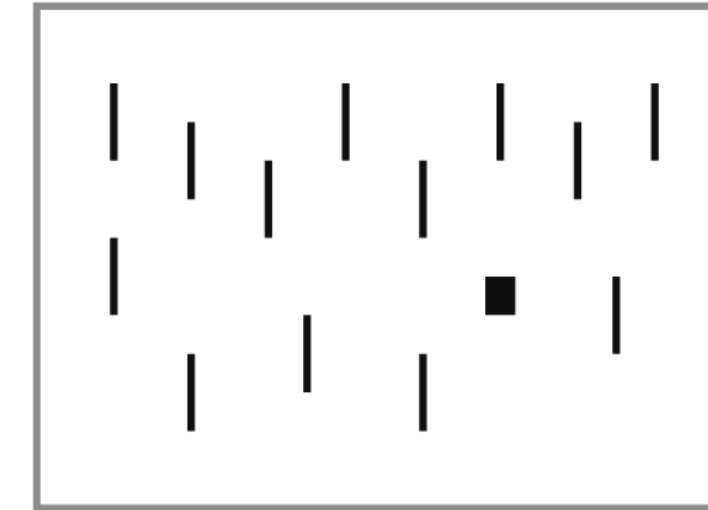
Curved straight



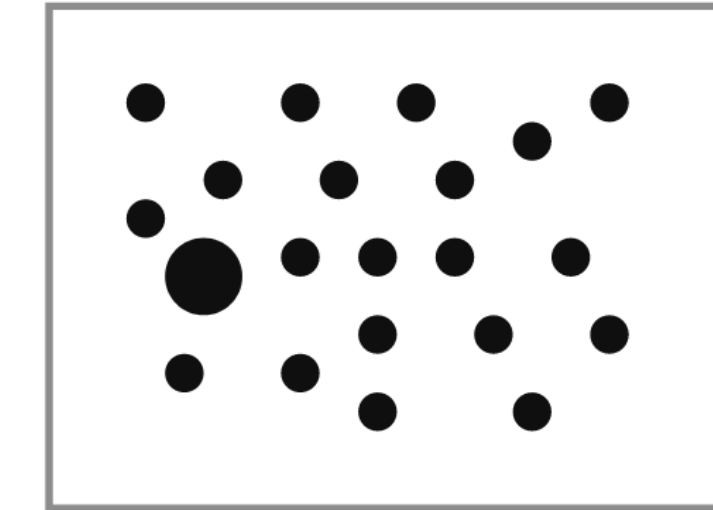
Shape



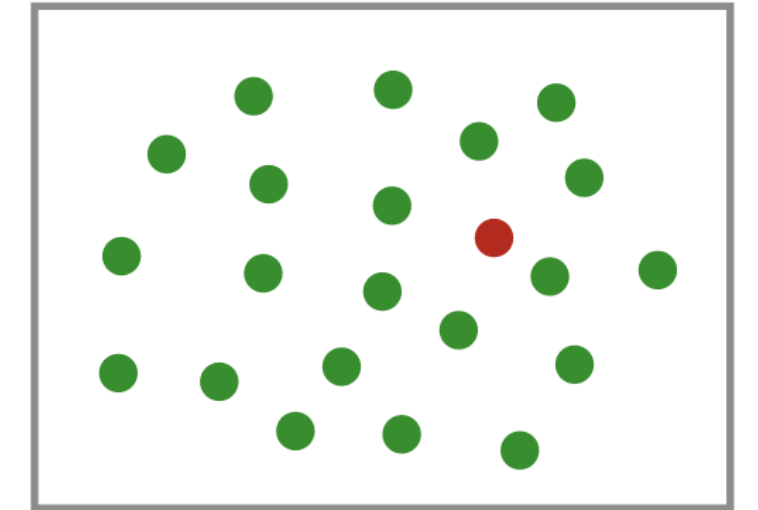
Shape



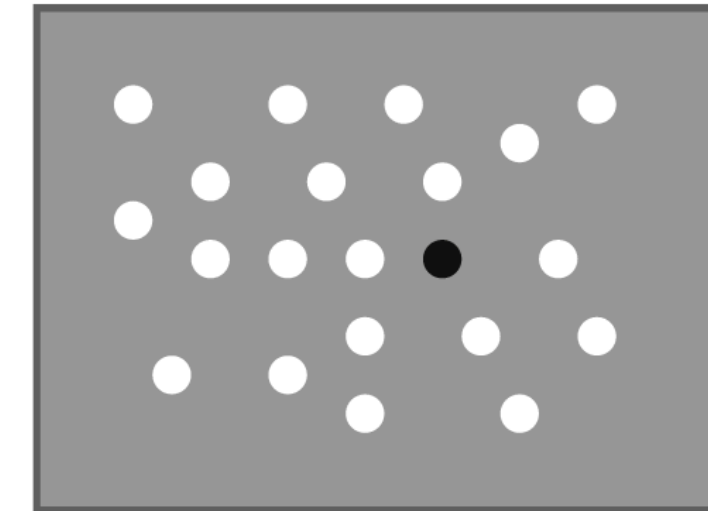
Size



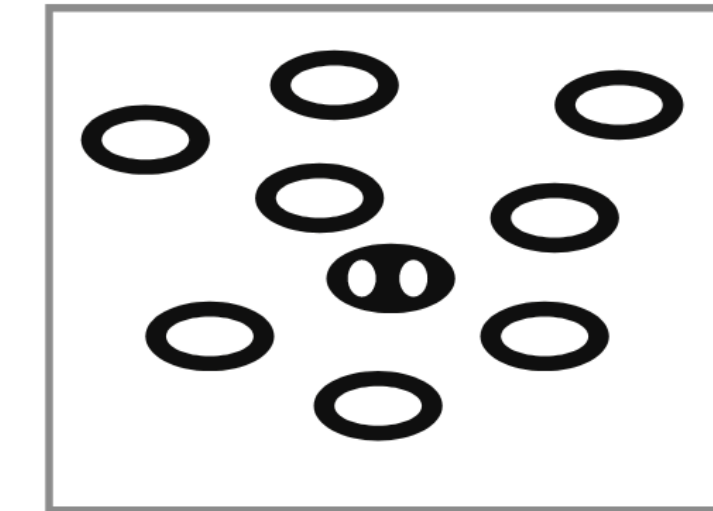
Color



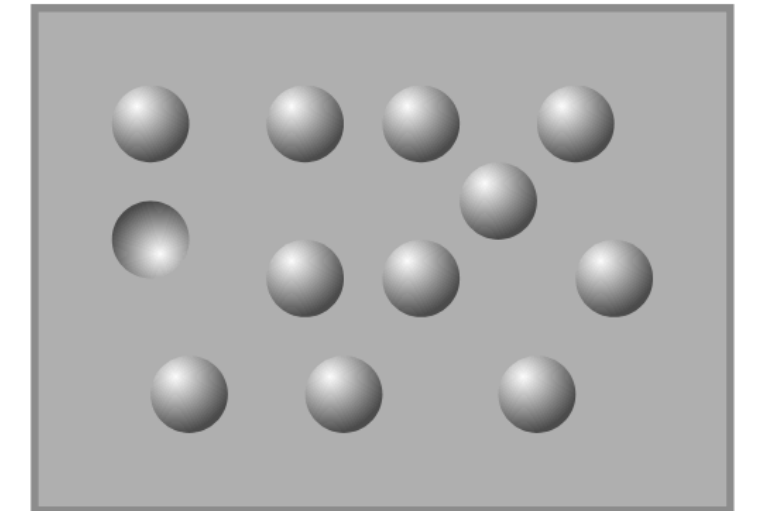
Light/dark



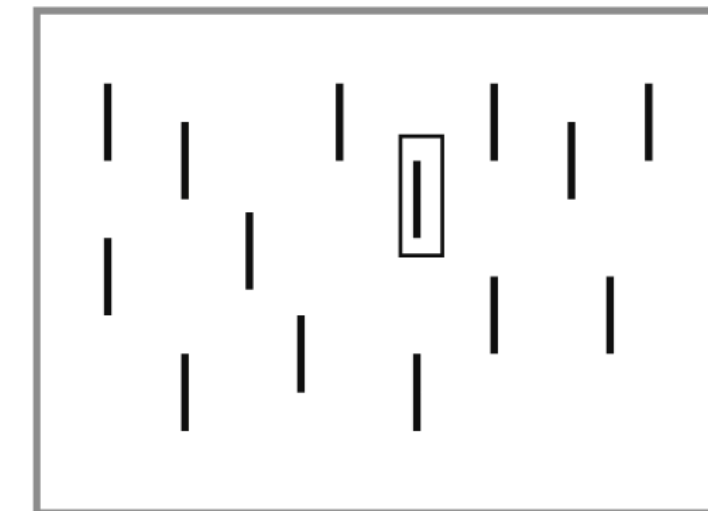
Topology (or count)



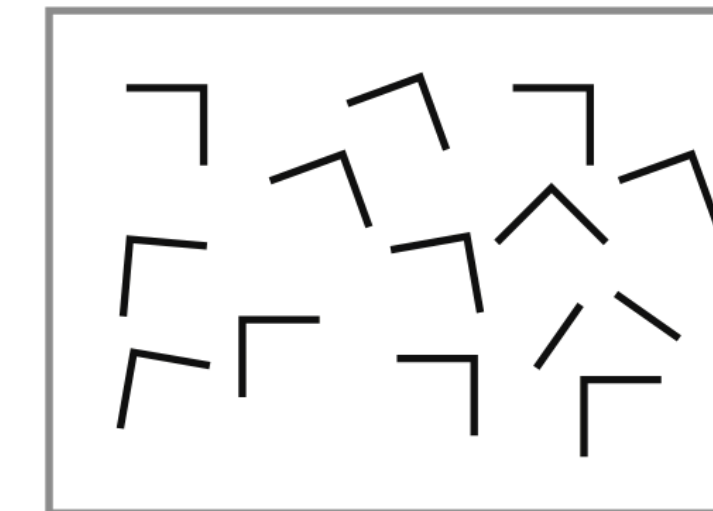
Convex/concave



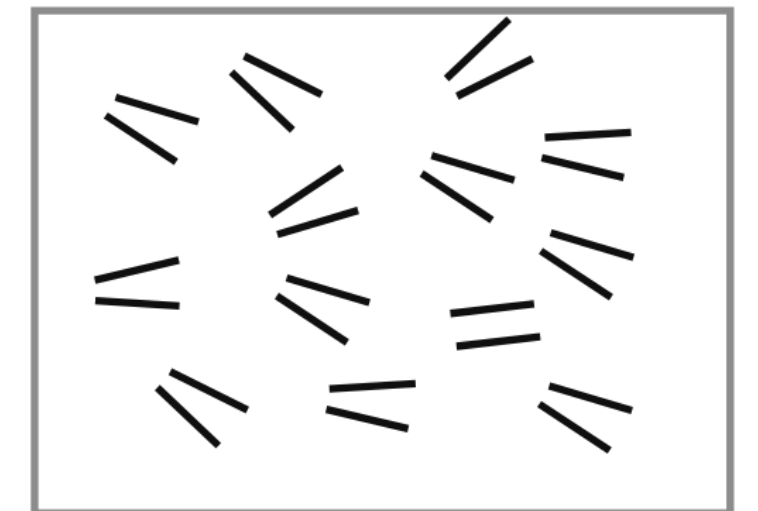
Addition



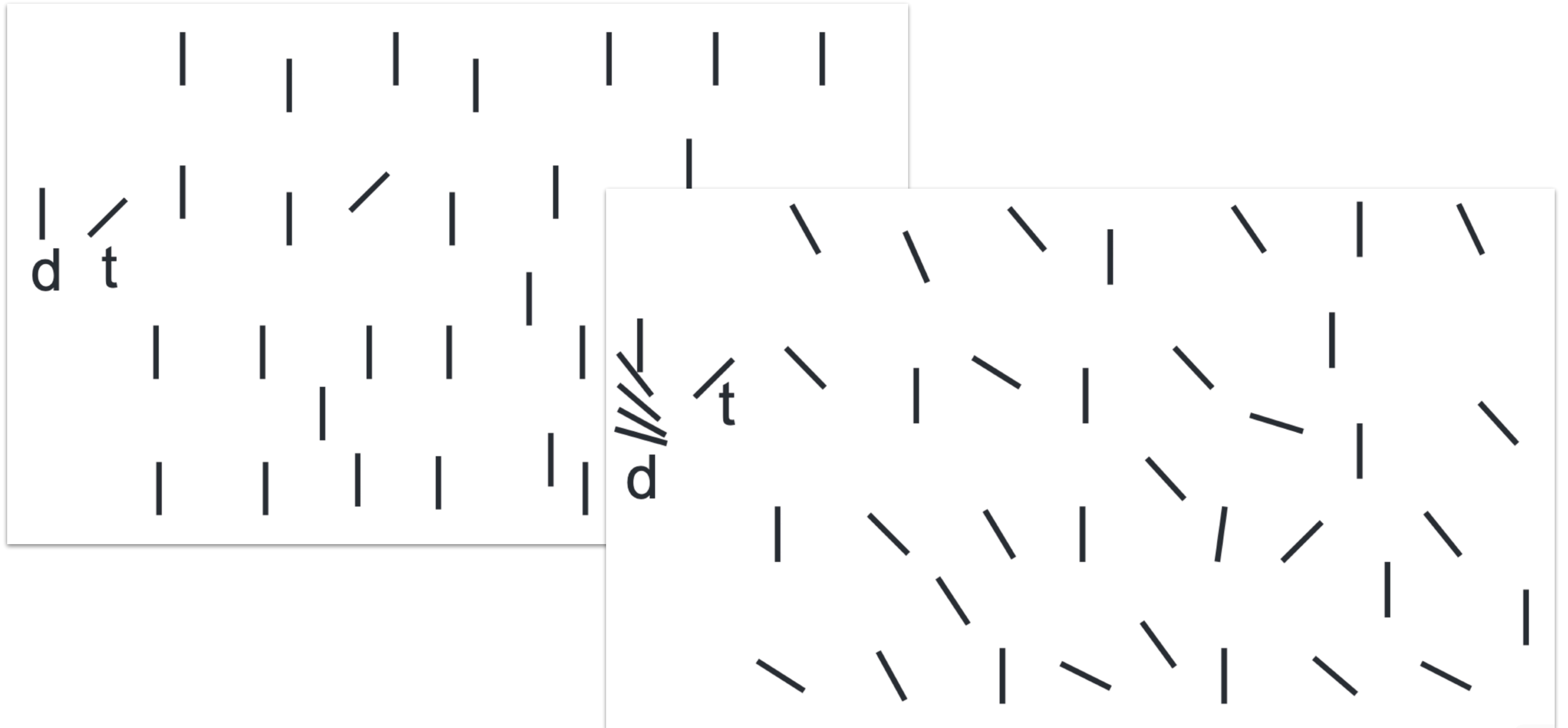
Juncture (not pre-att)



Parallelism (not pre-att)

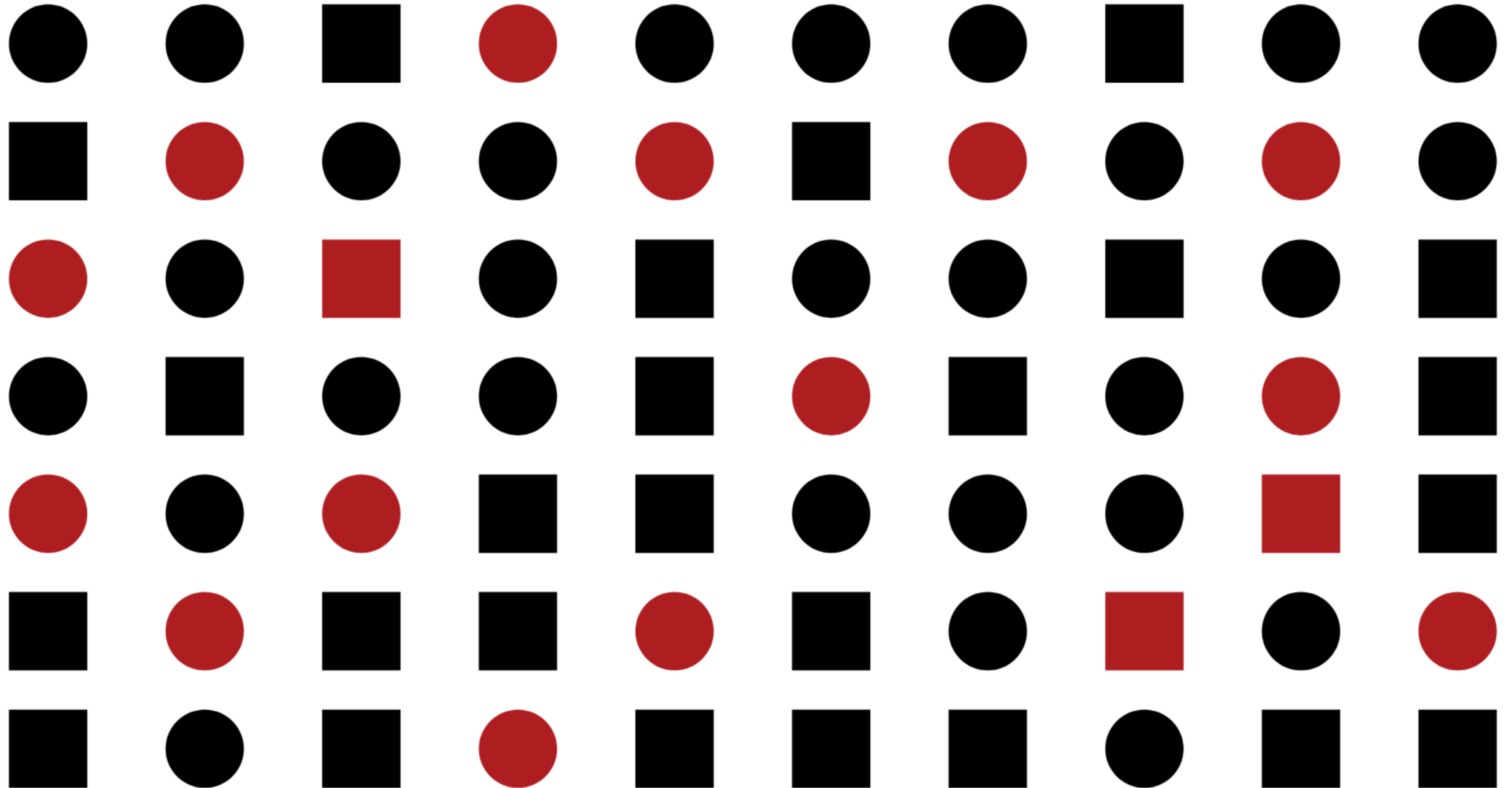


Preattention cues should be asymmetric



Conjunctions are not preattentive

Find the
red circles

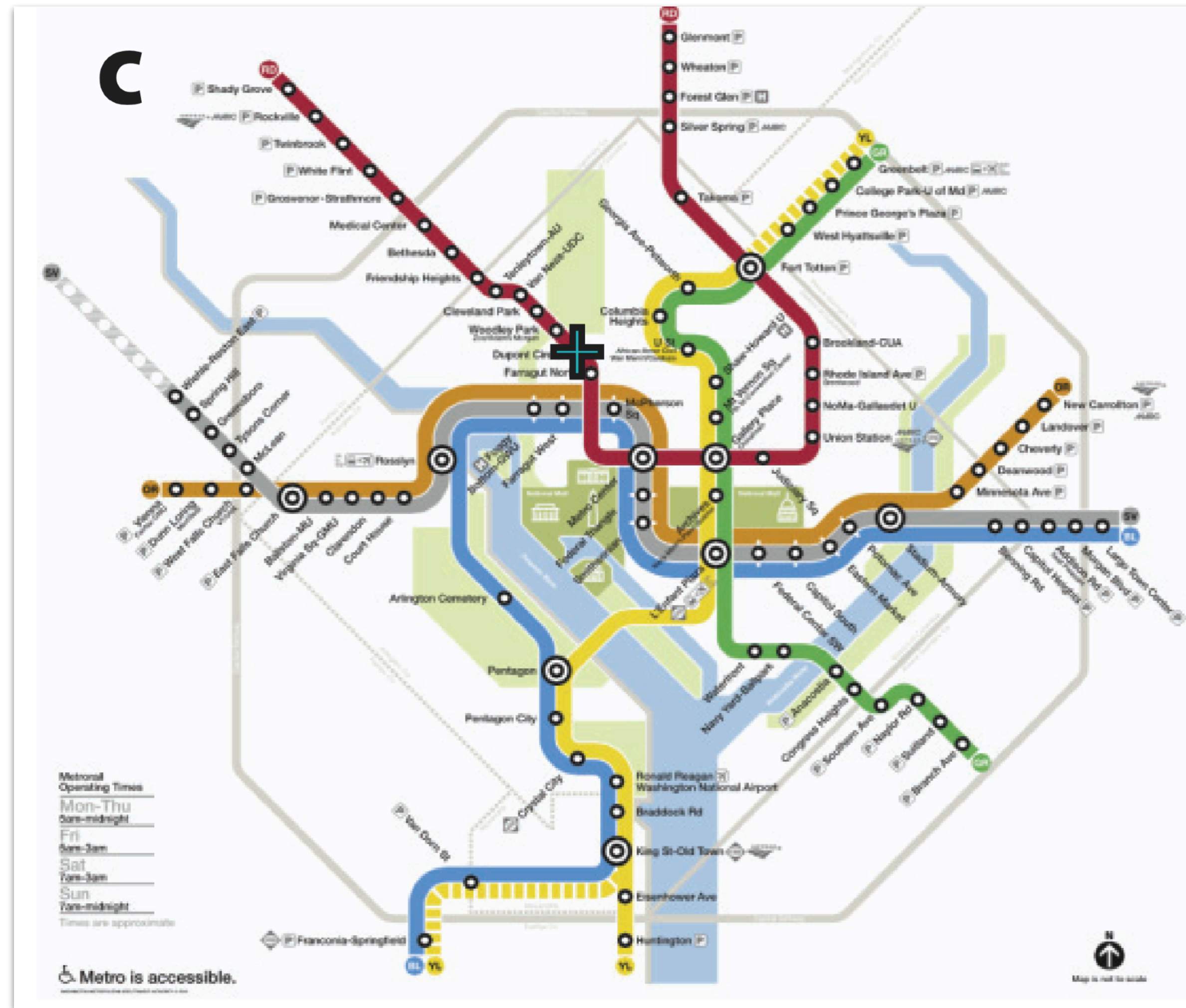


Vision scientists are still debating the precise nature of preattention

- Treisman and Gelade 1980: early vision can only access simple feature maps of color, orientation, or motion
- However, could not explain experiments where people quickly perceive the gist of an entire scene at a glance
- Rosenholtz 2025: early vision computes summary statistics on the periphery which guide attention

Periphery contains a coarse view of the world

True image



Model of perceived image



Signal Detection

Discriminability: how easy is it to tell two things apart?

Magnitude Estimation

Accuracy: how correctly can we read off values?

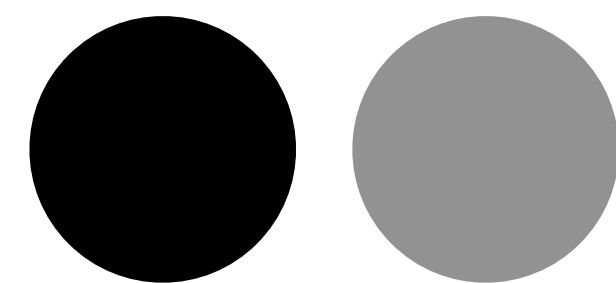
Preattentive Processing

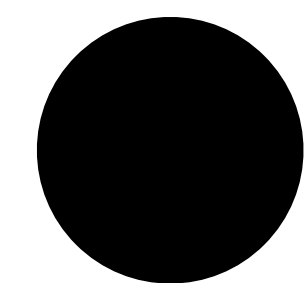
Pop out: how easy is it to spot some values from the rest?

Selective Attention

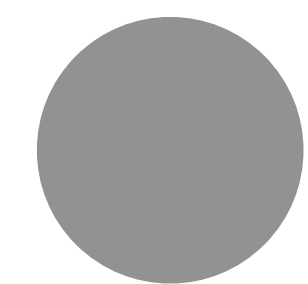
Separability: how much interaction occurs between attributes

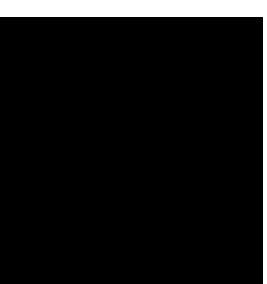
One-dimensional: lightness

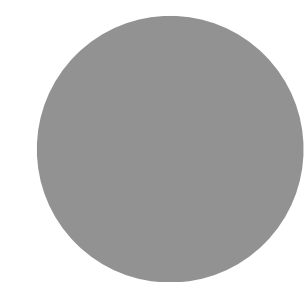


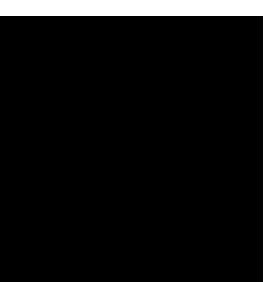
 Black

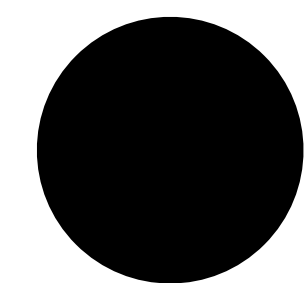
 Gray

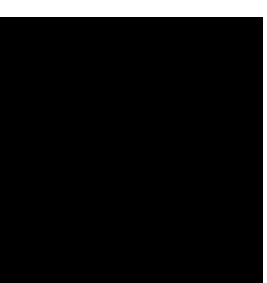
 Gray

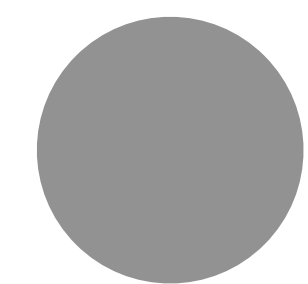
 Black

 Gray

 Black

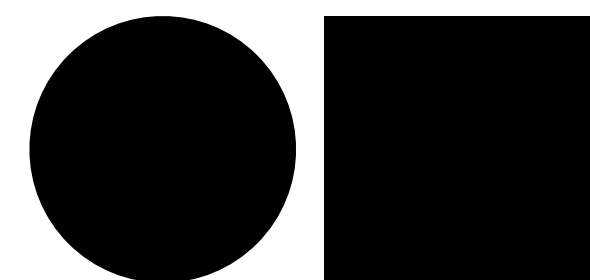
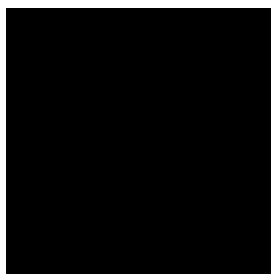
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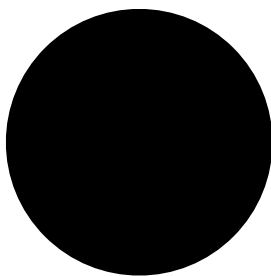
 Gray

 Gray

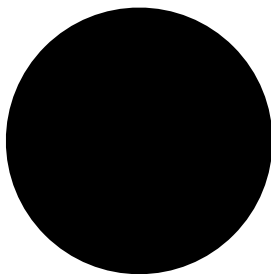
One-dimensional: shape



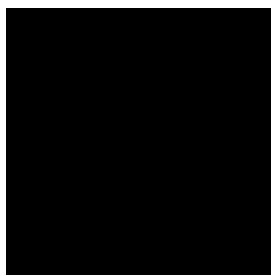
Square



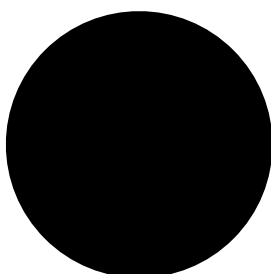
Circle



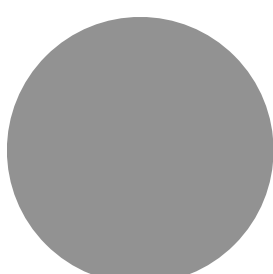
Circle



Square



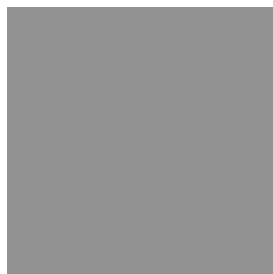
Circle



Circle



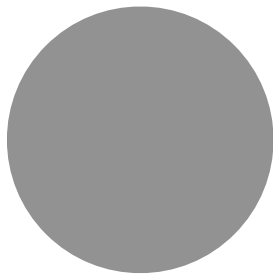
Square



Square

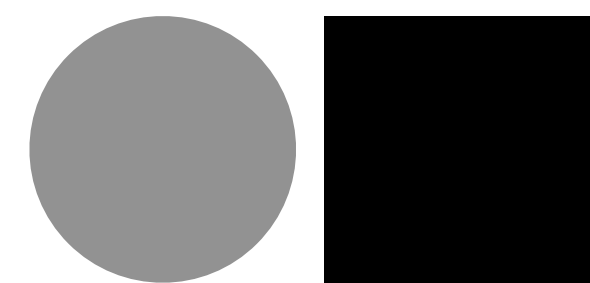
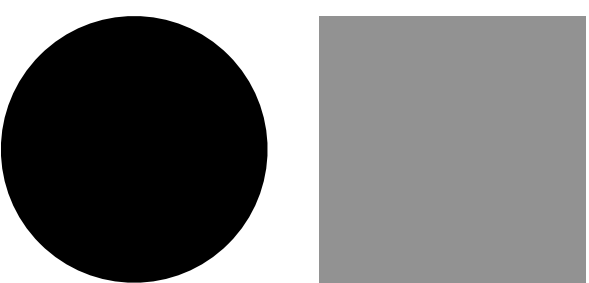
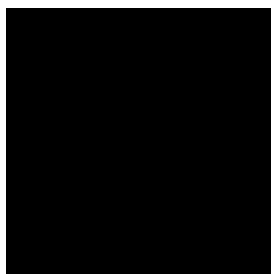


Square

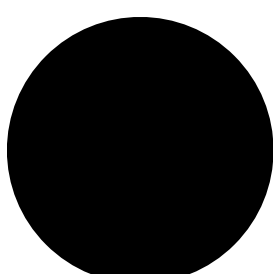


Circle

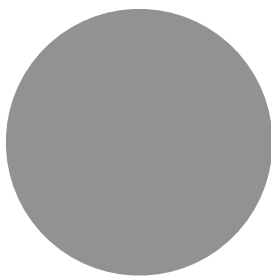
Redundant: shape & lightness



Black



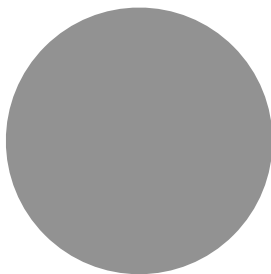
Circle



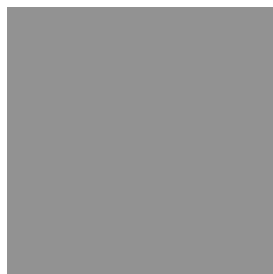
Gray



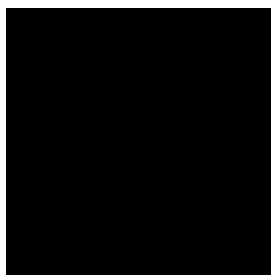
Square



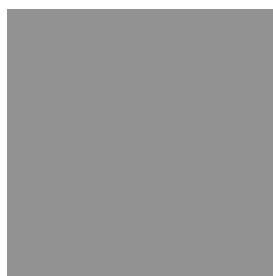
Gray



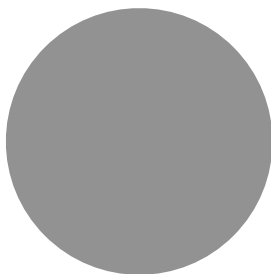
Square



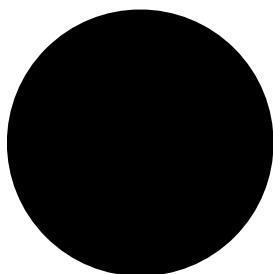
Black



Square

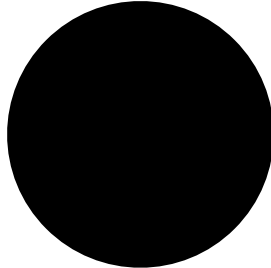
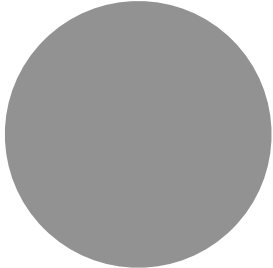
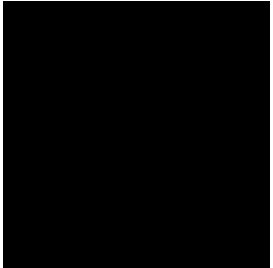
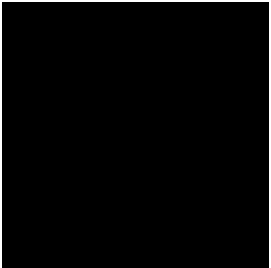
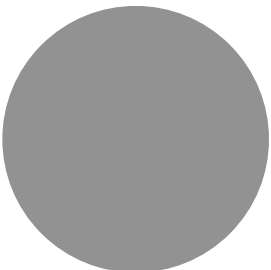
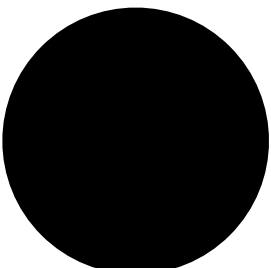
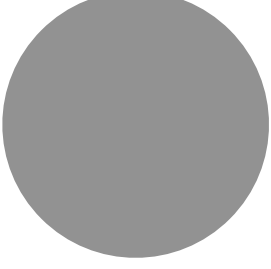


Gray



Circle

Orthogonal: shape & lightness

			
	Black + square		
	Gray + circle		
	Black + circle		
	Gray + square		
	Gray + circle		

Attribute pairs vary in their separability

