How the mind tricks us:
Visualizations and visual illusions

Phi Beta Kappa Public Lecture
University of Tennessee
Knoxville, TN, 3 April 2008

A Quick Survey:

- Three statements
- Disagree = 1, agree = 5
- Total & divide by 3

Seeing is believing

"Visual observations greatly help the understanding of material"

1 = disagree, 5 = agree

Visualization is important

"Memories of observations reinforce the retention of physical models"

1 = disagree, 5 = agree

1 picture = 1000 words

"Information can be transferred more quickly and more effectively visually than verbally"

1 = disagree, 5 = agree

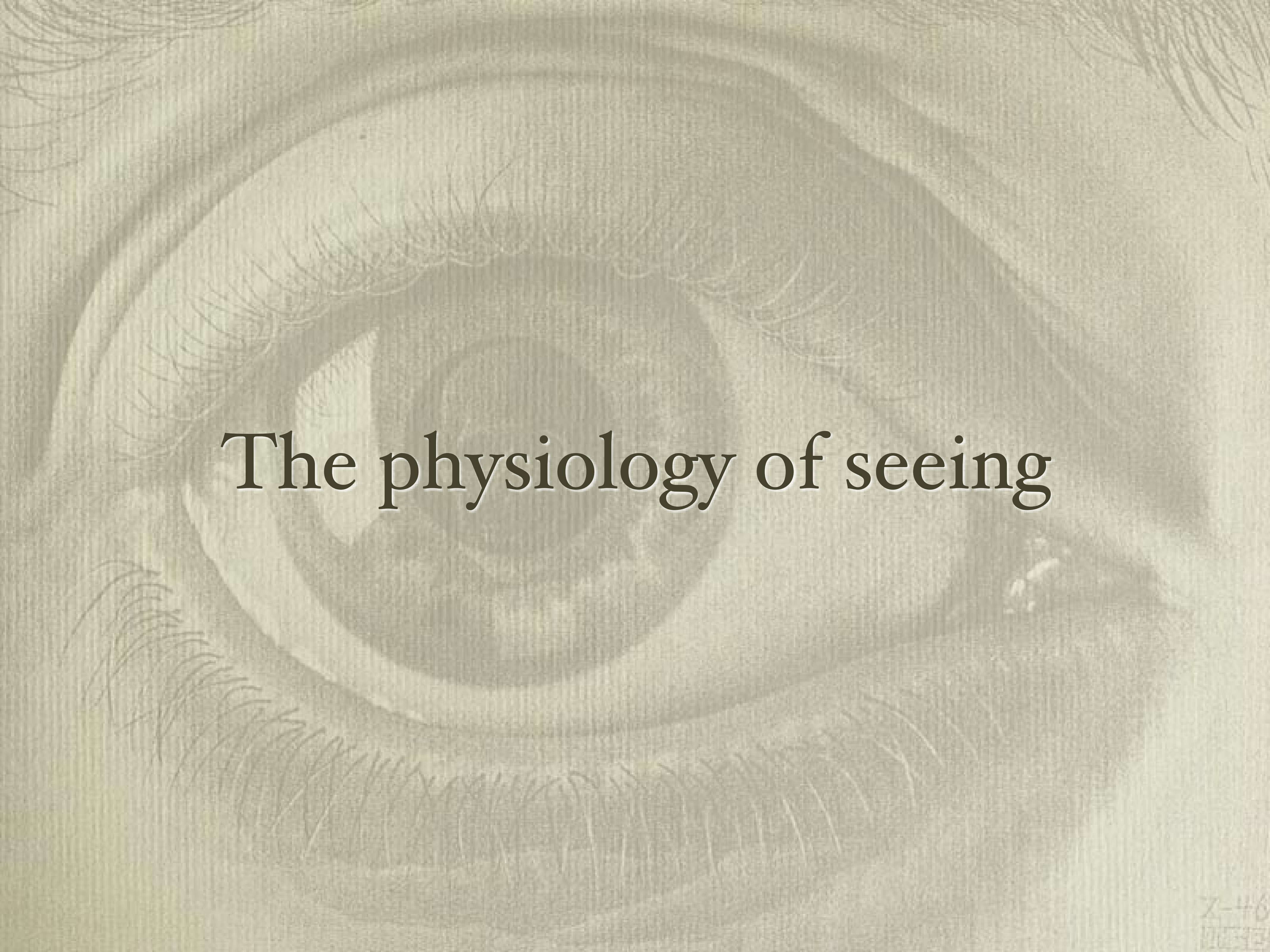
My message

There is much to learn from neurobiology and cognitive psychology

Outline

- the physiology of seeing
- cognitive issues related to seeing
- learning from seeing

The physiology of seeing

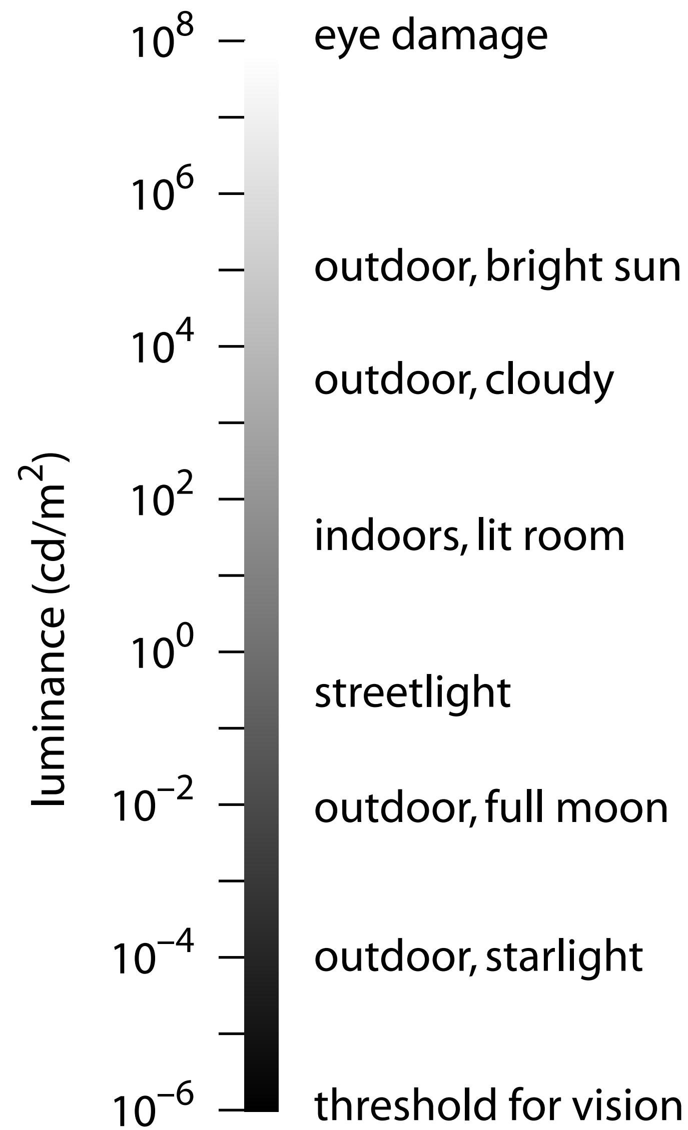


Human vision

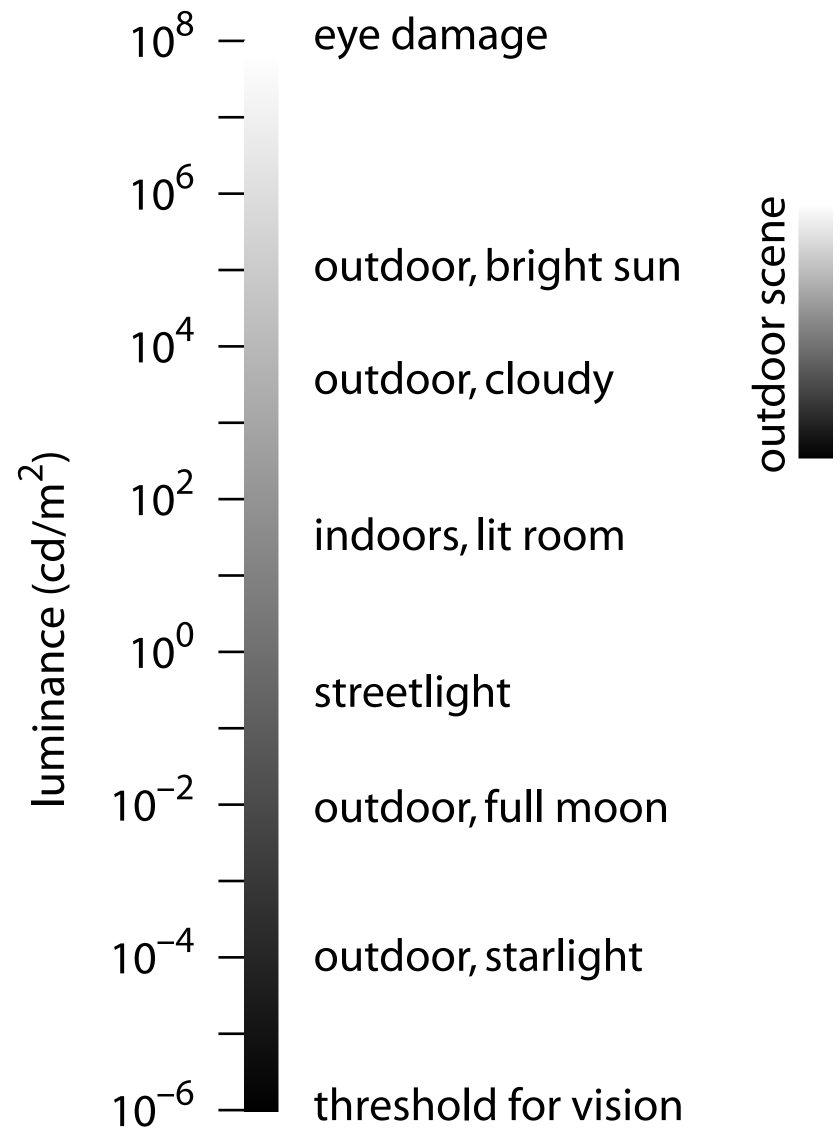
- Small frequency range
- Huge luminance range

Luminance

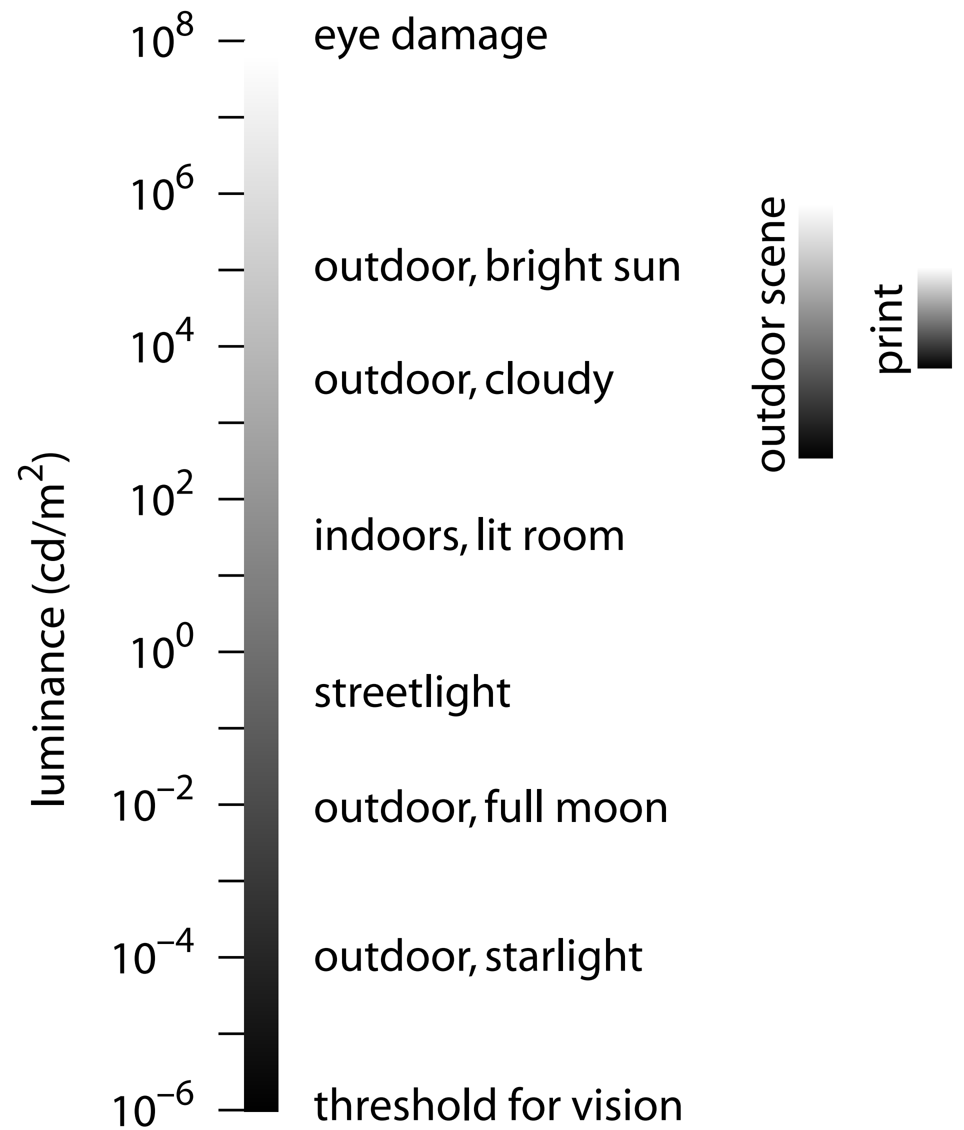
- Light energy radiated/reflected
- Determined by reflectance and illumination



luminance (cd/m²)
10^8
10^6
10^4
10^2
10^0
10^−2
10^−4
10^−6
eye damage
outdoor, bright sun
outdoor, cloudy
indoors, lit room
streetlight
outdoor, full moon
outdoor, starlight
threshold for vision



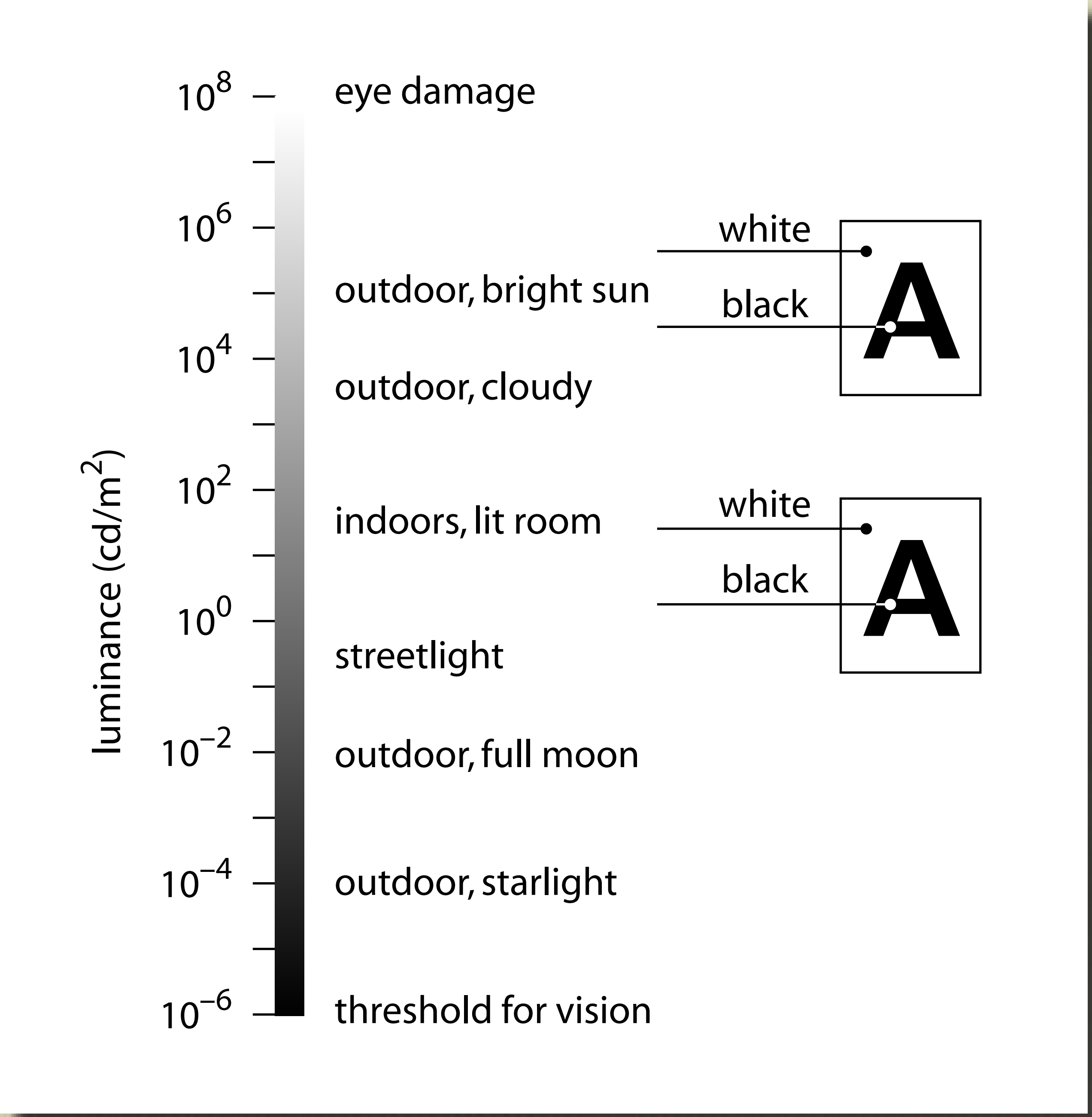
luminance (cd/m²)
10^8
10^6
10^4
10^2
10^0
10^−2
10^−4
10^−6
eye damage
outdoor, bright sun
outdoor, cloudy
indoors, lit room
streetlight
outdoor, full moon
outdoor, starlight
threshold for vision
outdoor scene



luminance (cd/m²)
10^8
10^6
10^4
10^2
10^0
10^−2
10^−4
10^−6
eye damage
outdoor, bright sun
outdoor, cloudy
indoors, lit room
streetlight
outdoor, full moon
outdoor, starlight
threshold for vision
outdoor scene
print

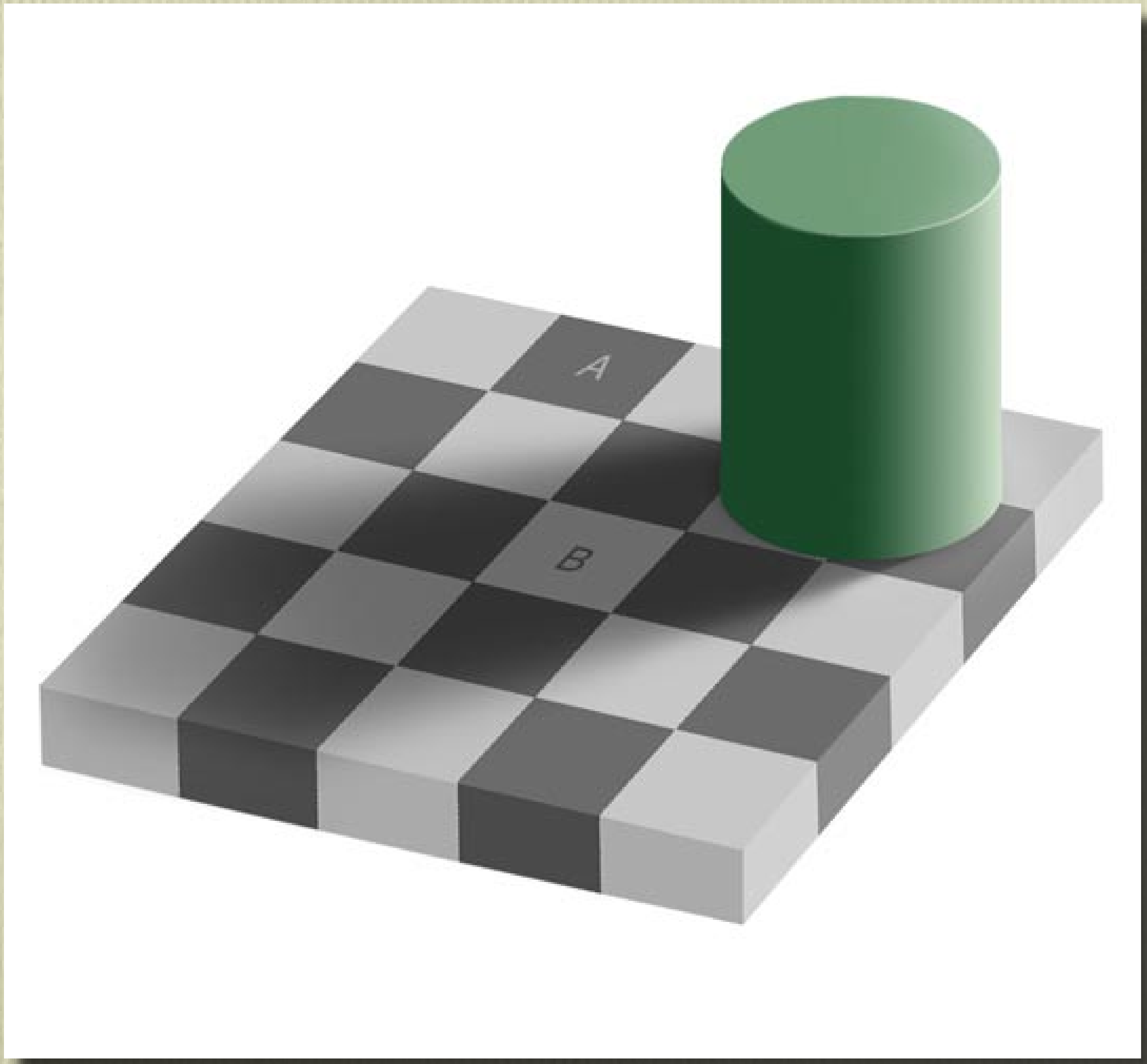
What color?

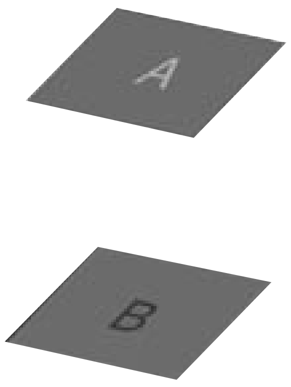
A

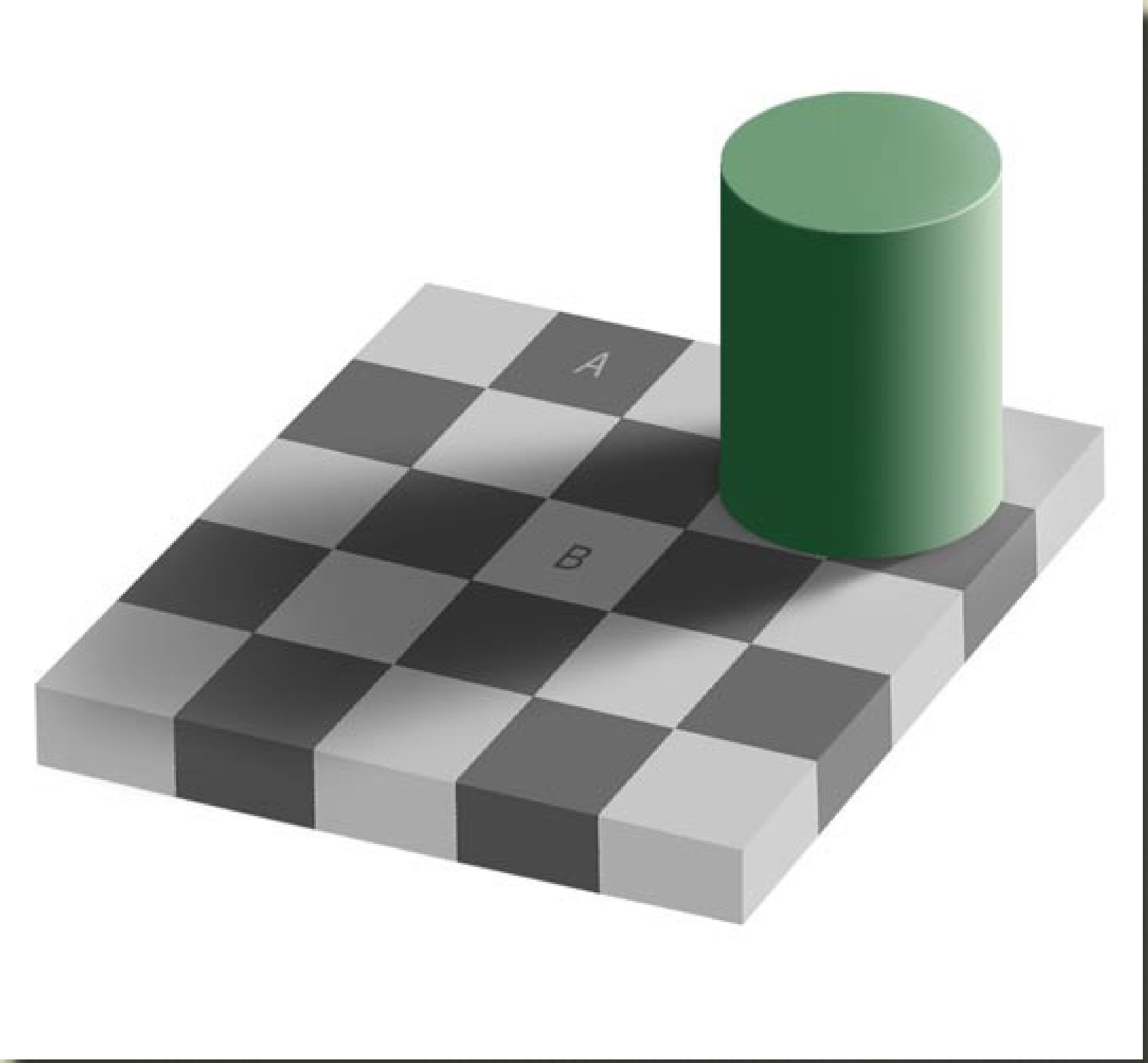

luminance (cd/m^2)
10^8
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
eye damage
outdoor, bright sun
outdoor, cloudy
indoors, lit room
streetlight
outdoor, full moon
outdoor, starlight
threshold for vision
white
black
A
white
black
A

What the retina does:

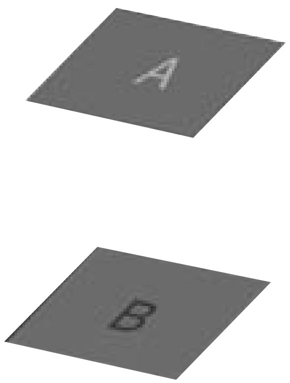
- Spatial compression
- Adjust luminance range to nerve S/N
- Extract reflectance


A
B


A
B


A
B

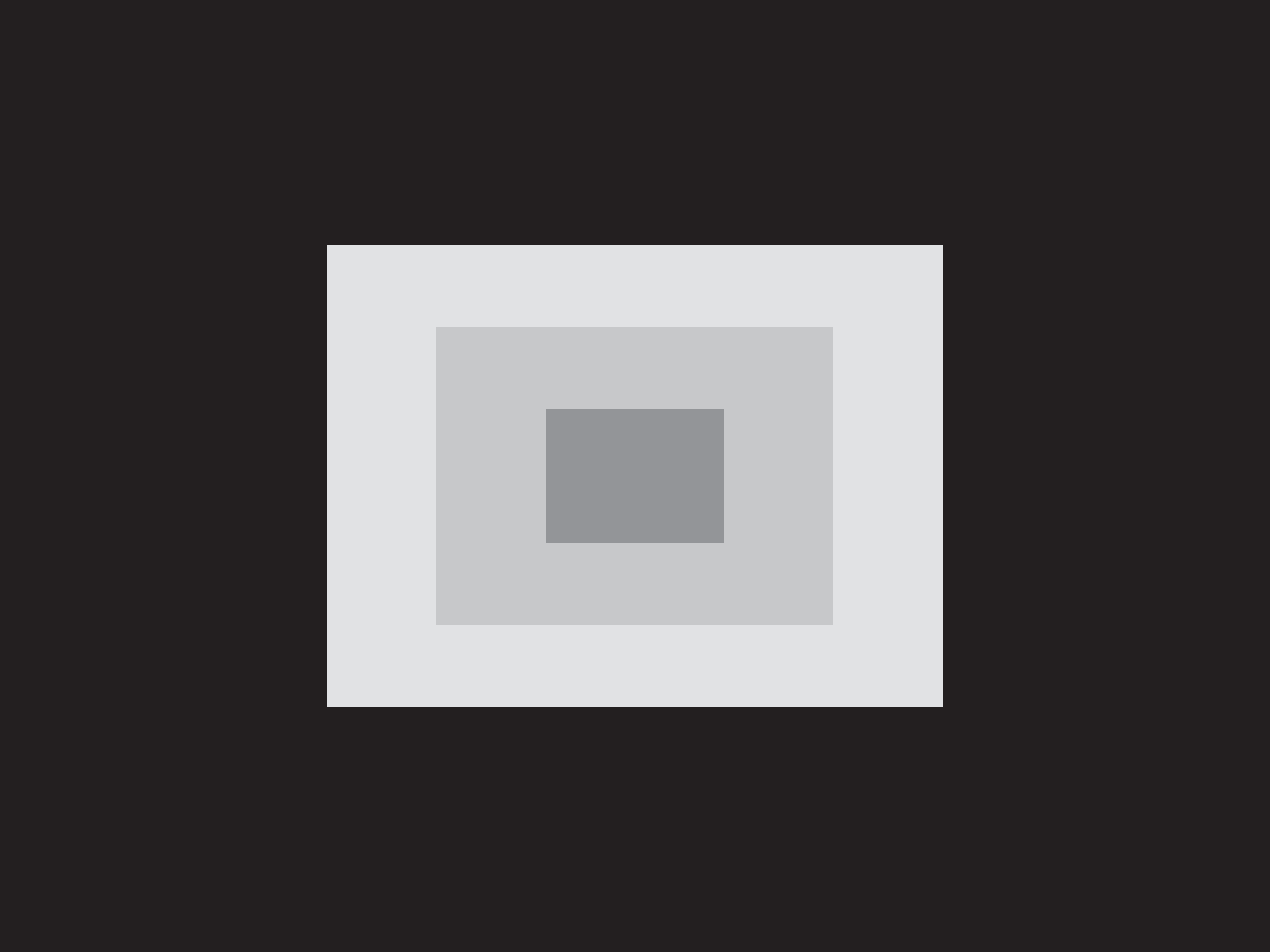
dark

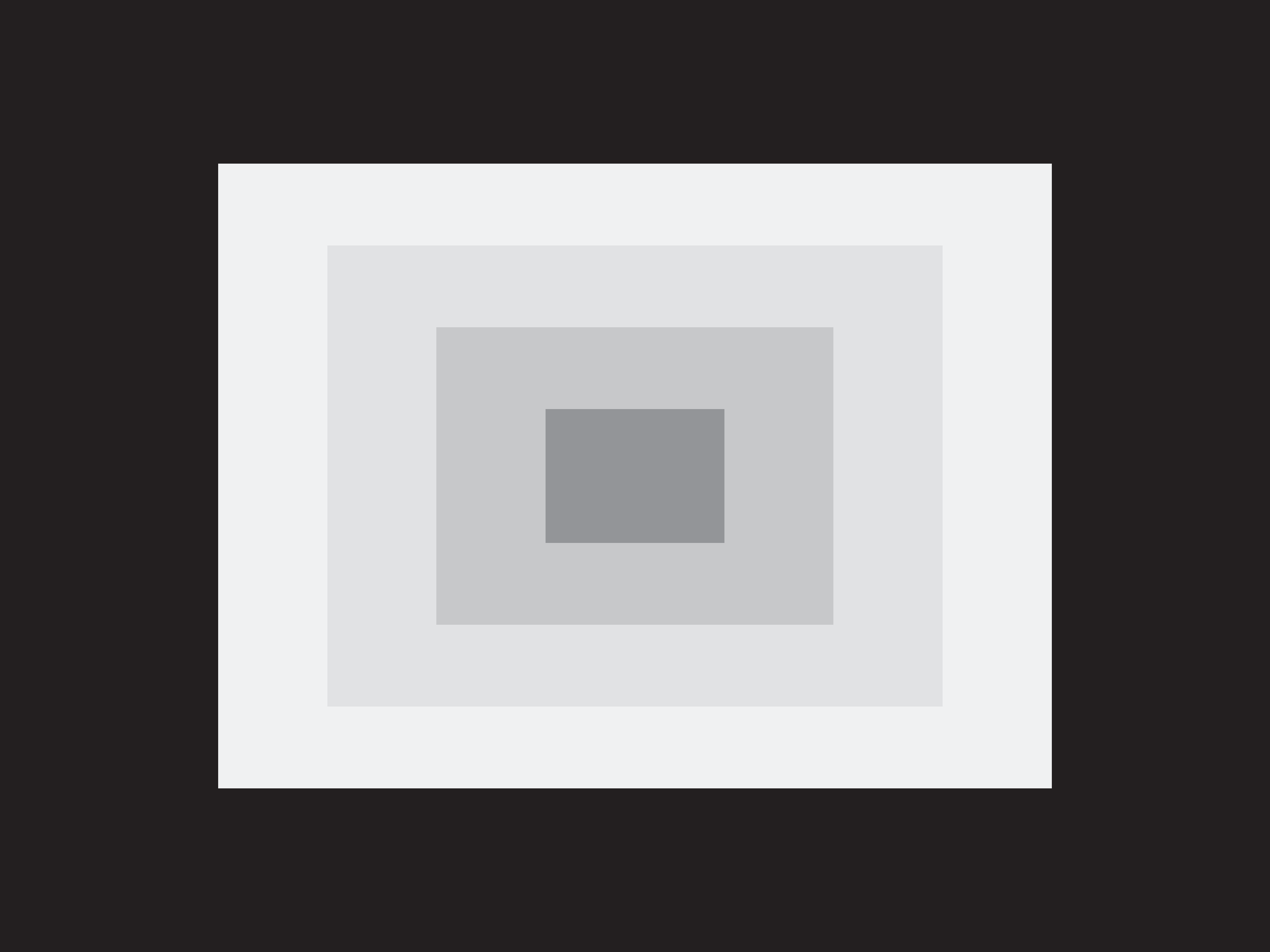


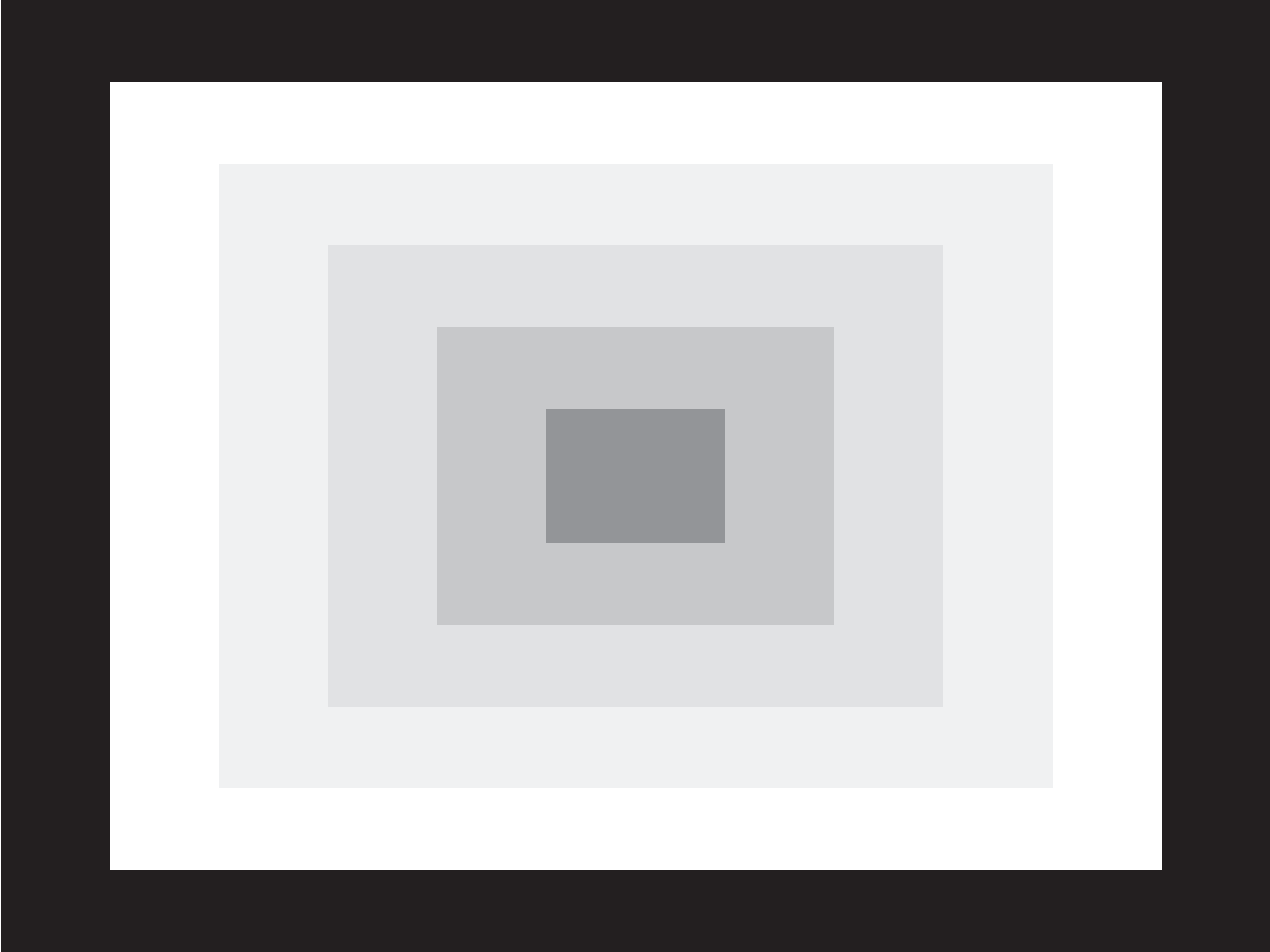
light

equiluminant

luminance = illumination + reflectance





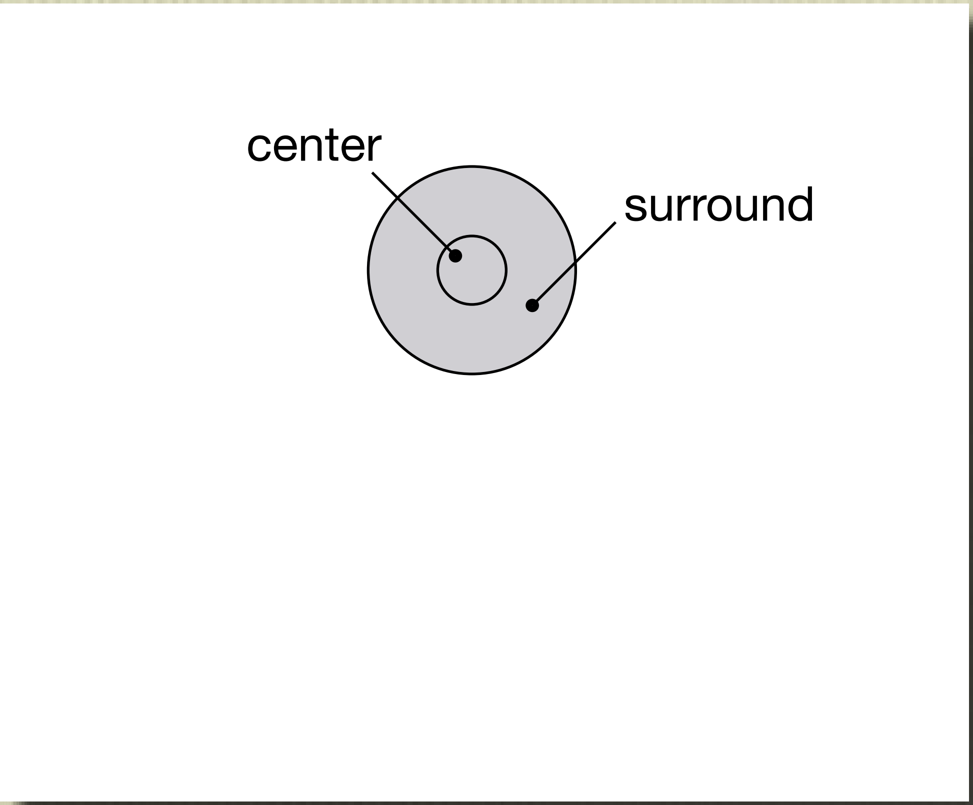


Retinal cell organization

- 10^8 receptors (rods and cones)
- 10^6 ganglion cells

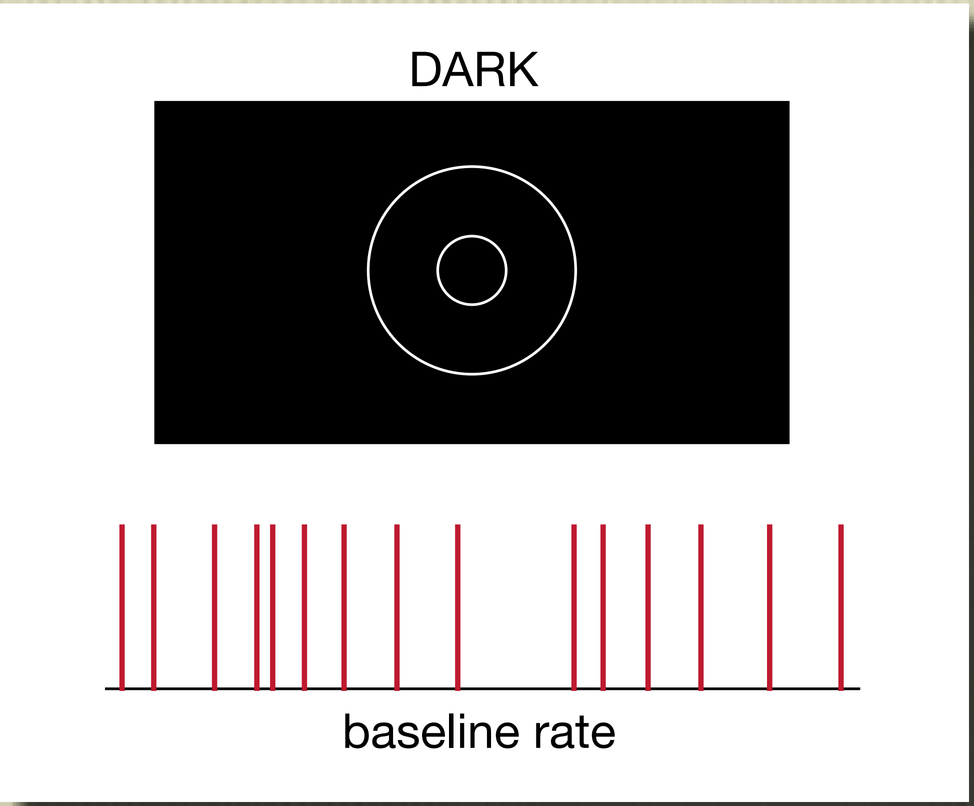
Each ganglion cell has a receptive field containing about 100 receptors

Retinal cell organization

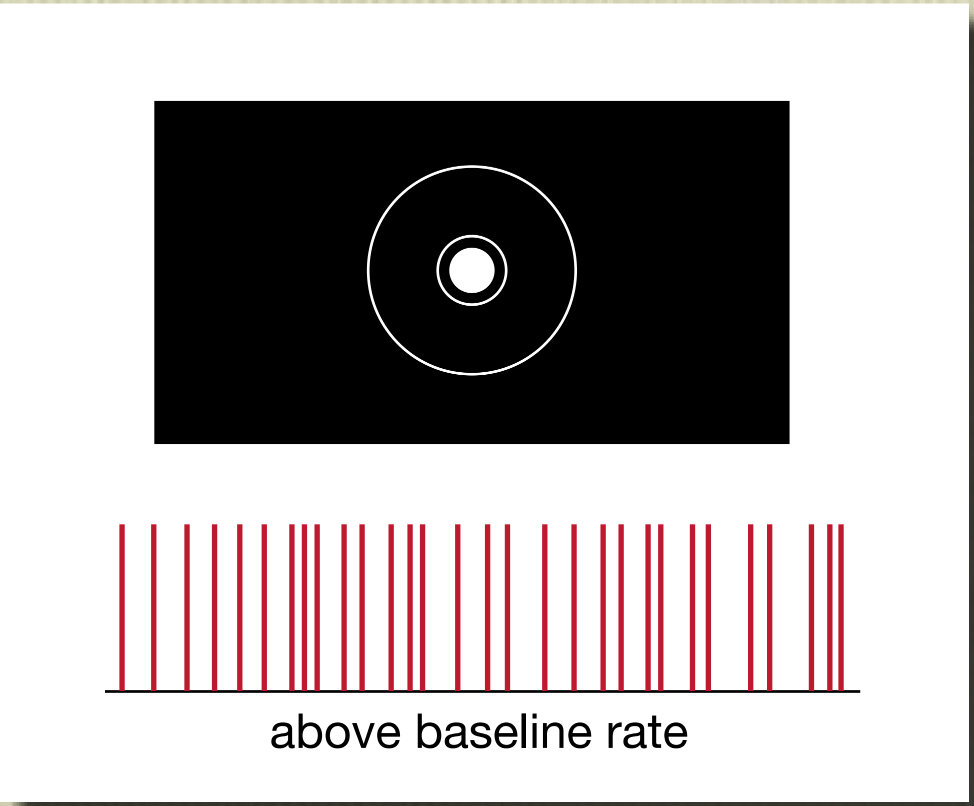


Receptive field divided into two regions

Retinal cell response

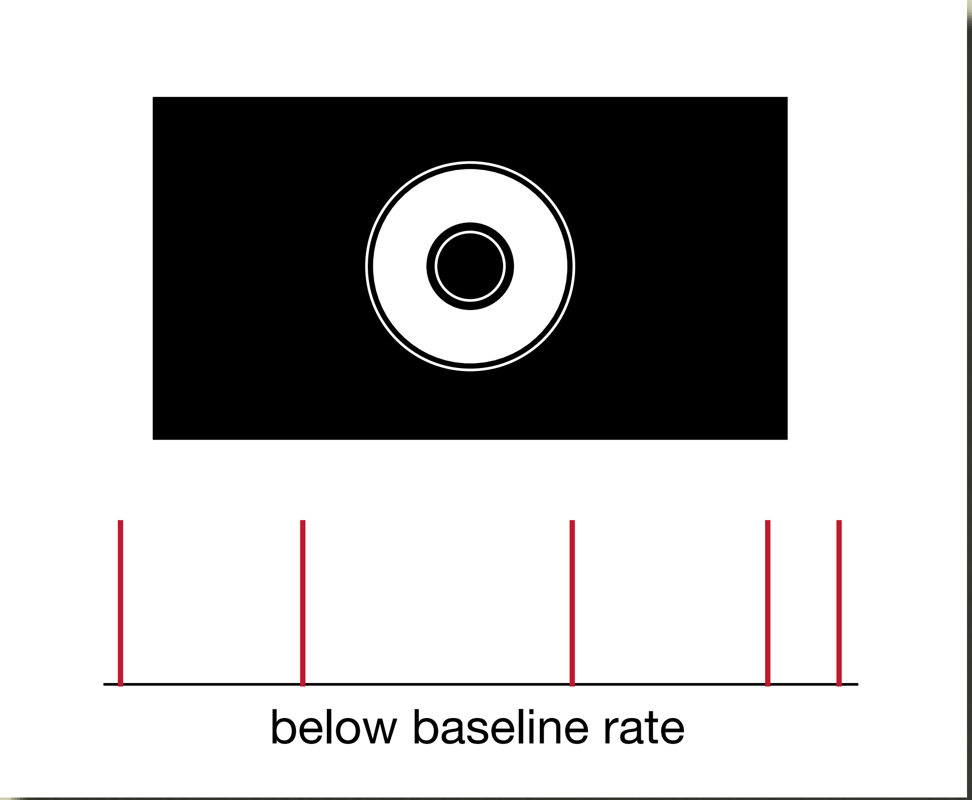


Retinal cell response



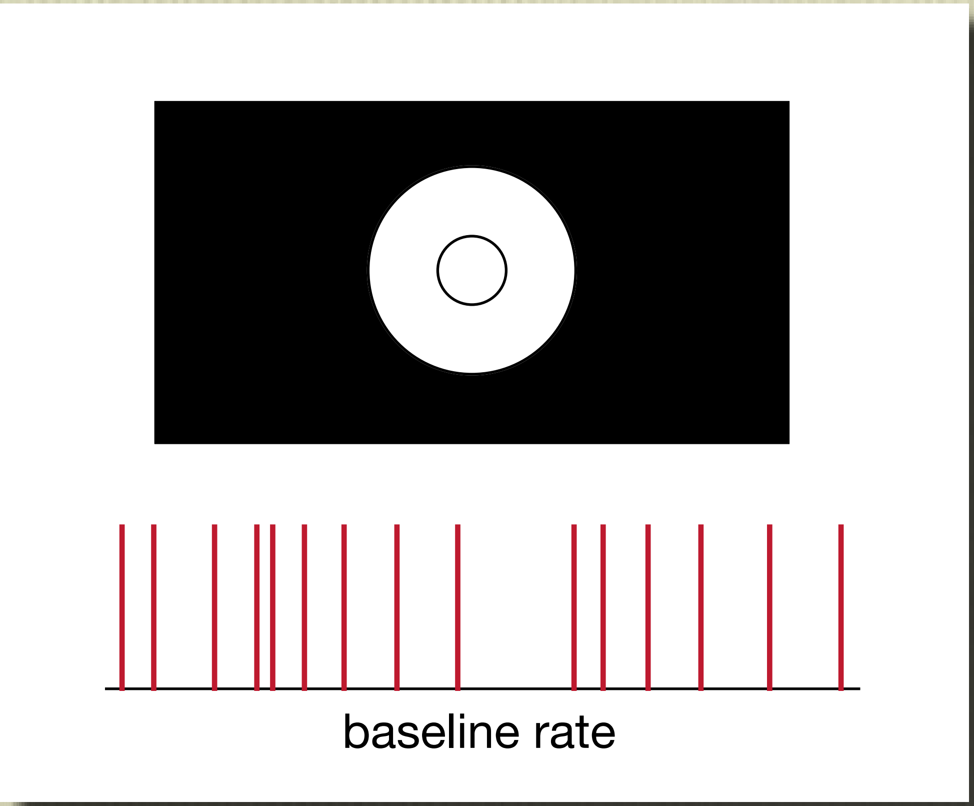
Center excites

Retinal cell response



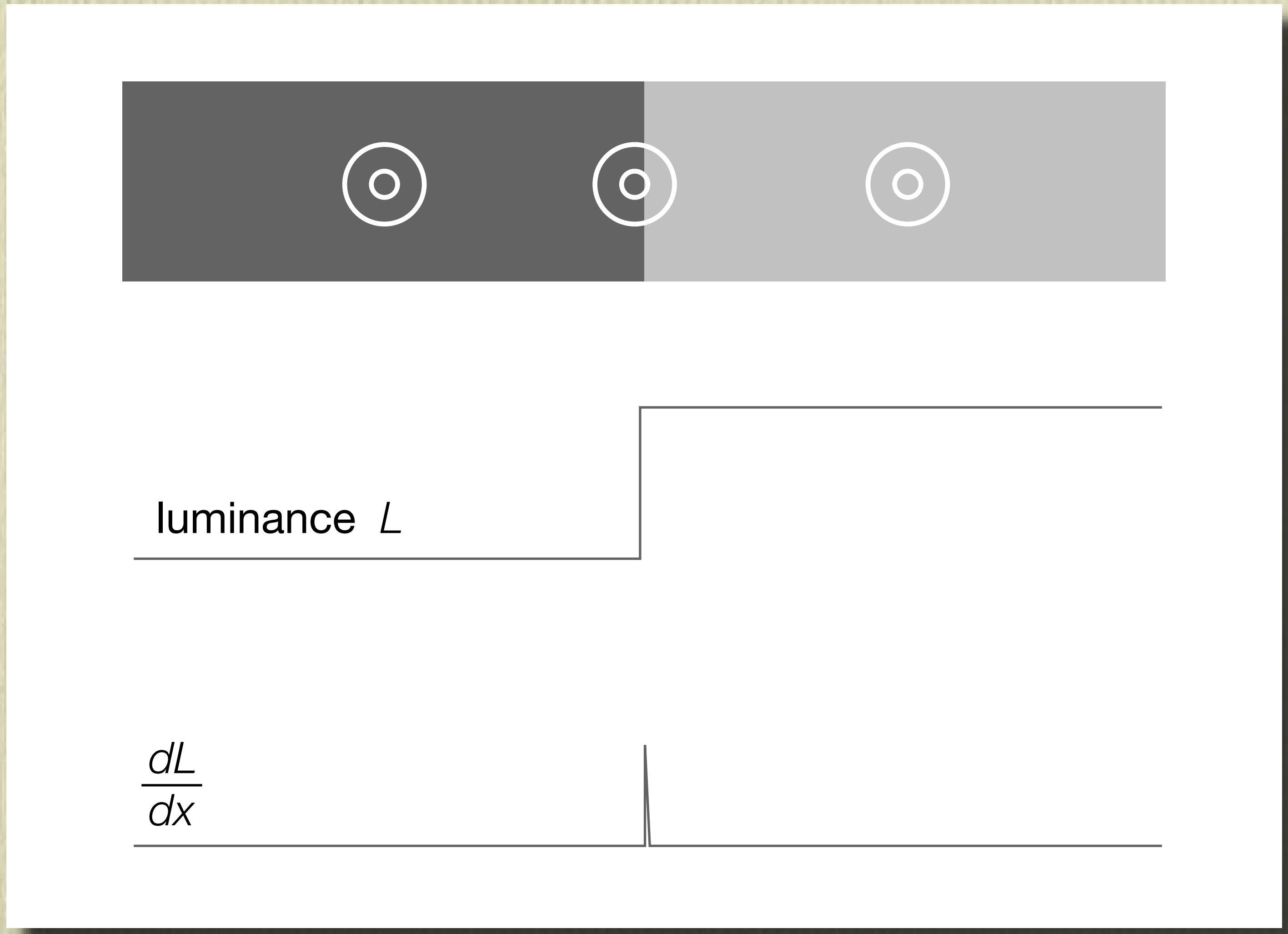
Surround inhibits

Retinal cell response

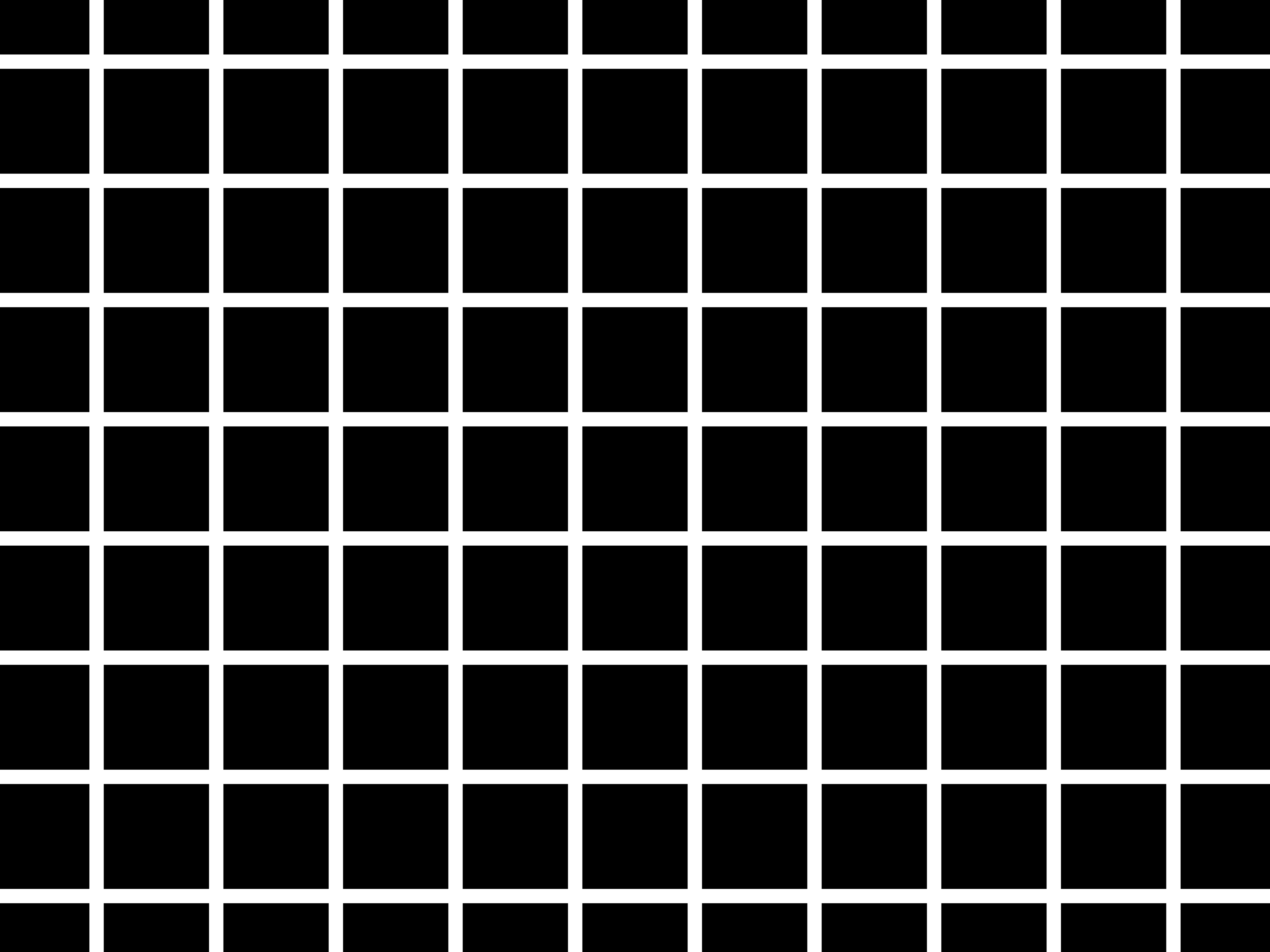


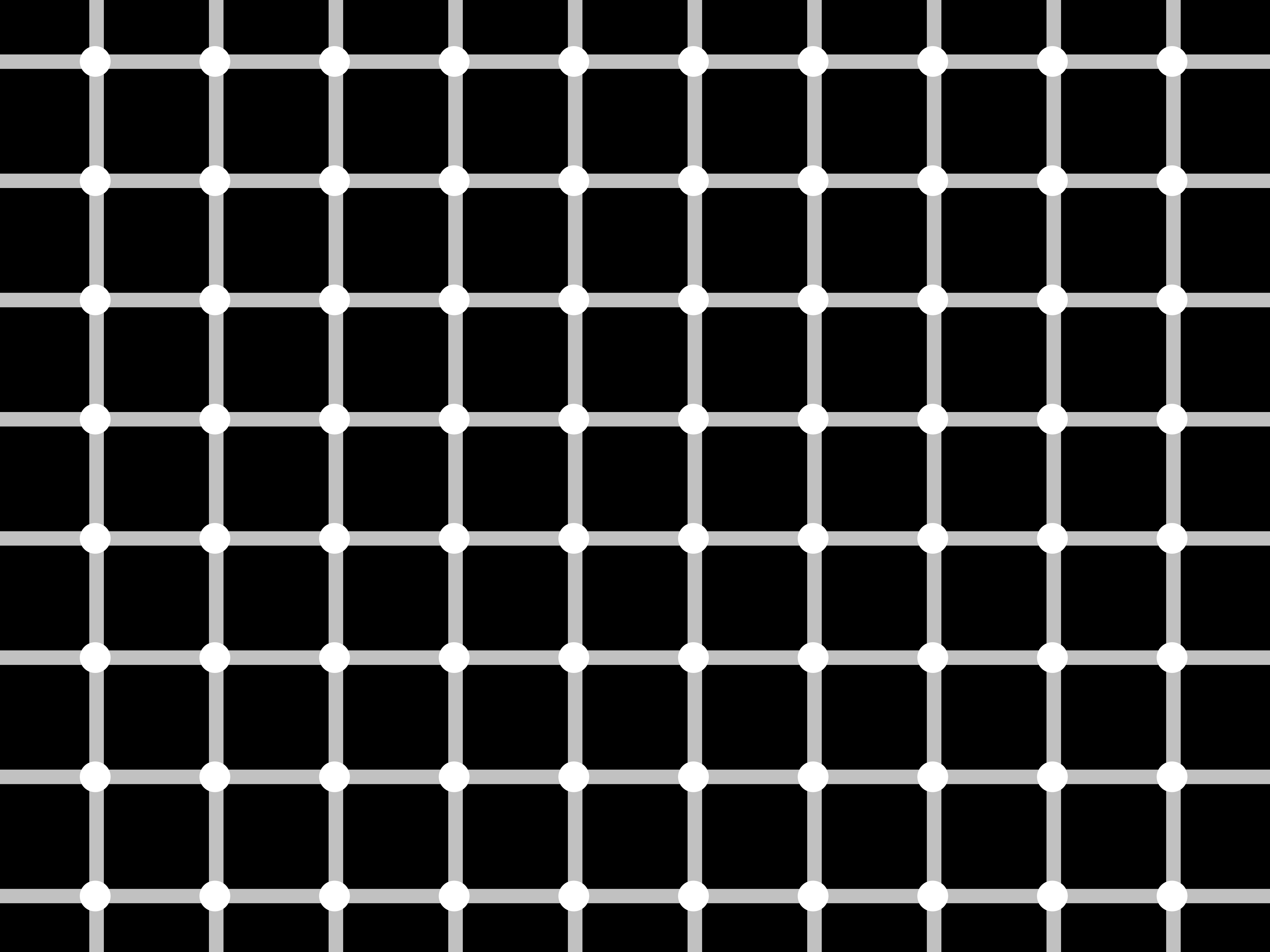
Full illumination same as no illumination

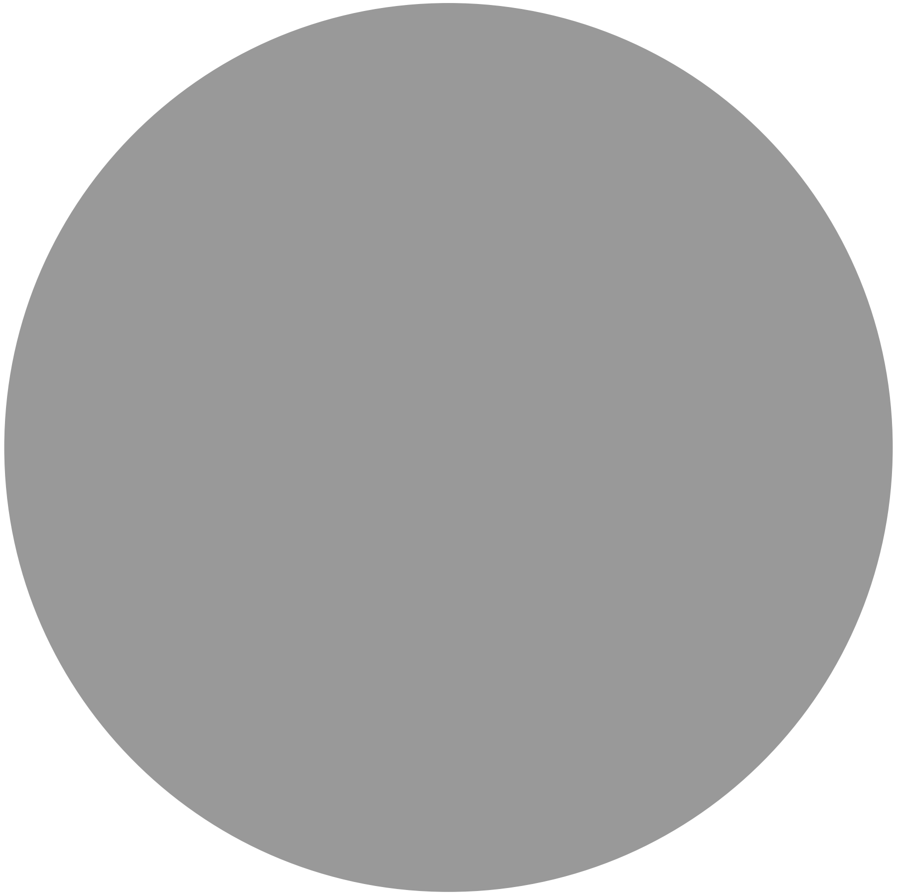
Center-surround antagonism

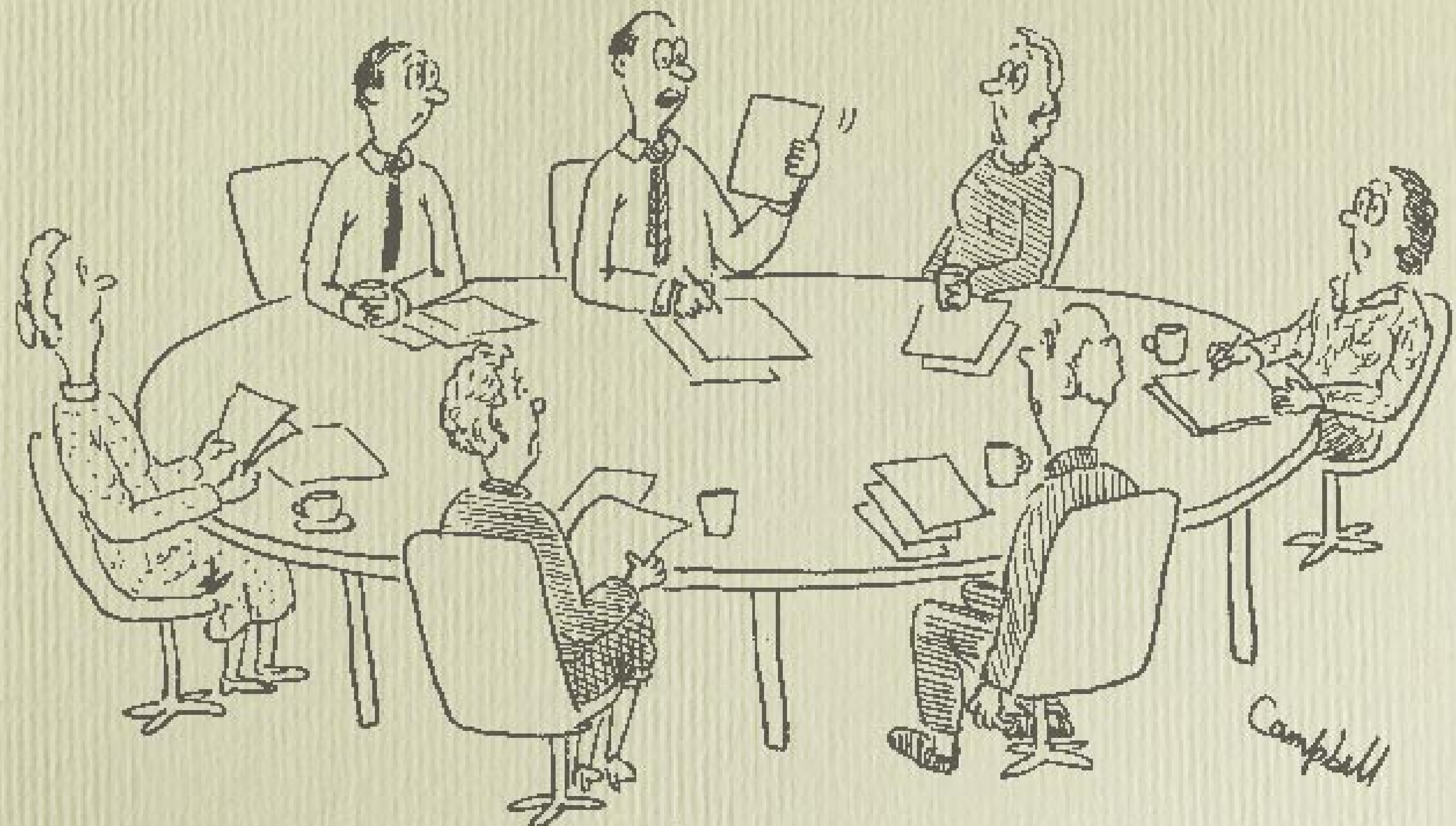


cells respond to *differences* in intensity

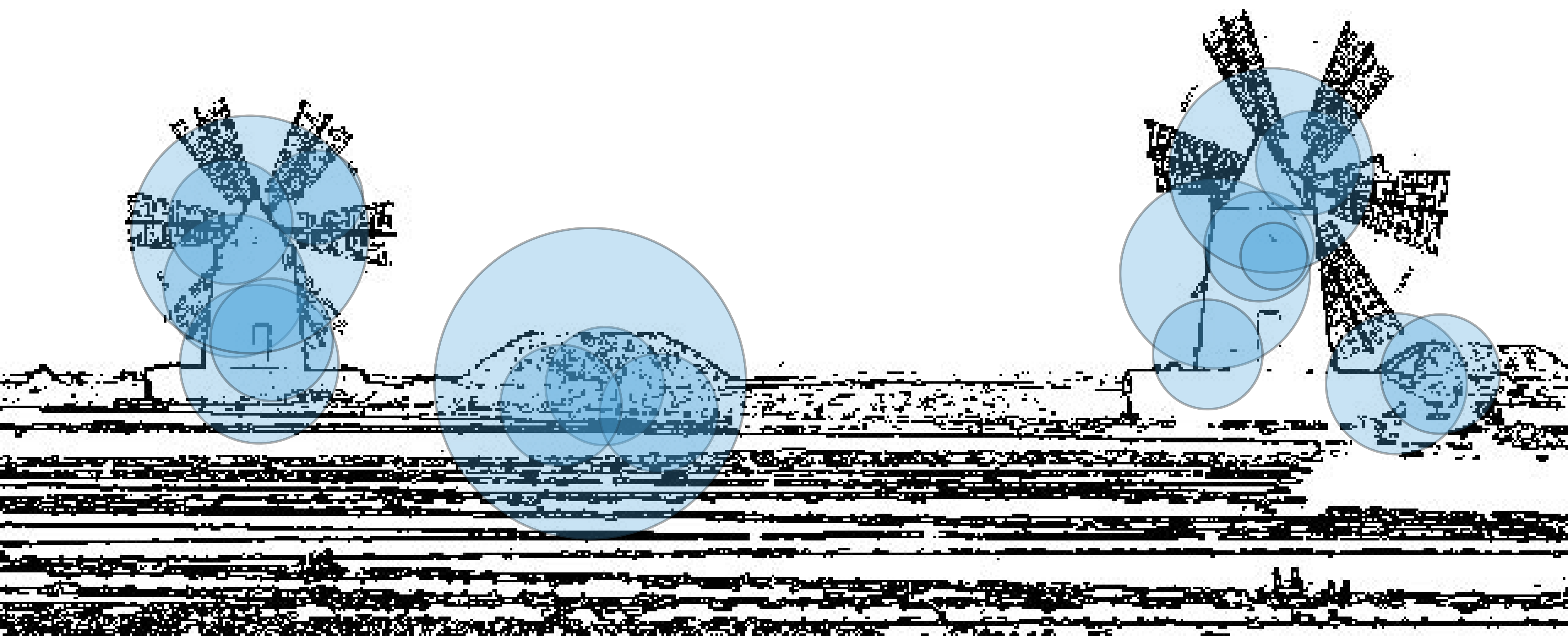







Campbell


Crayola
Crayola
Crayola
Sophie

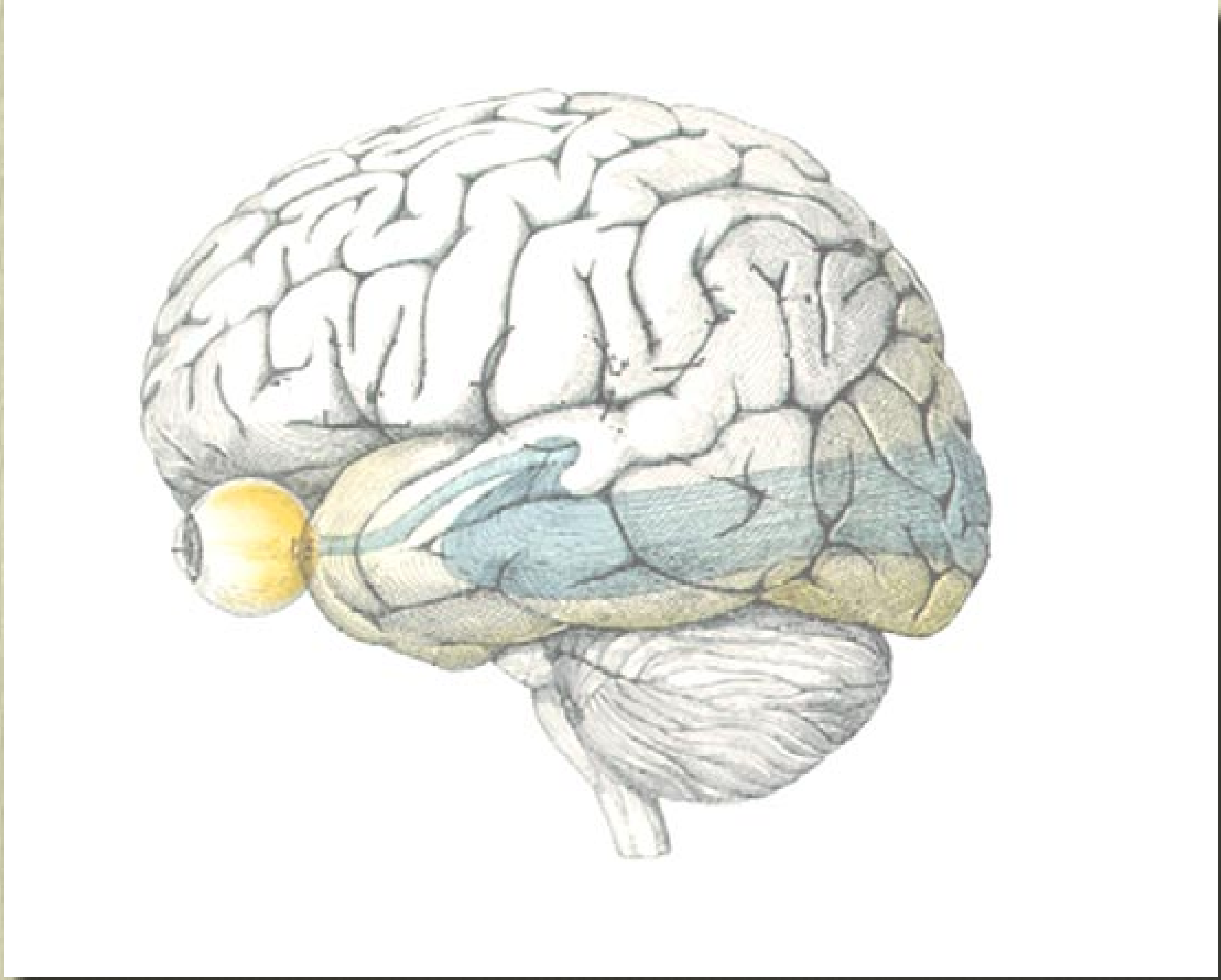


Processing of visual information

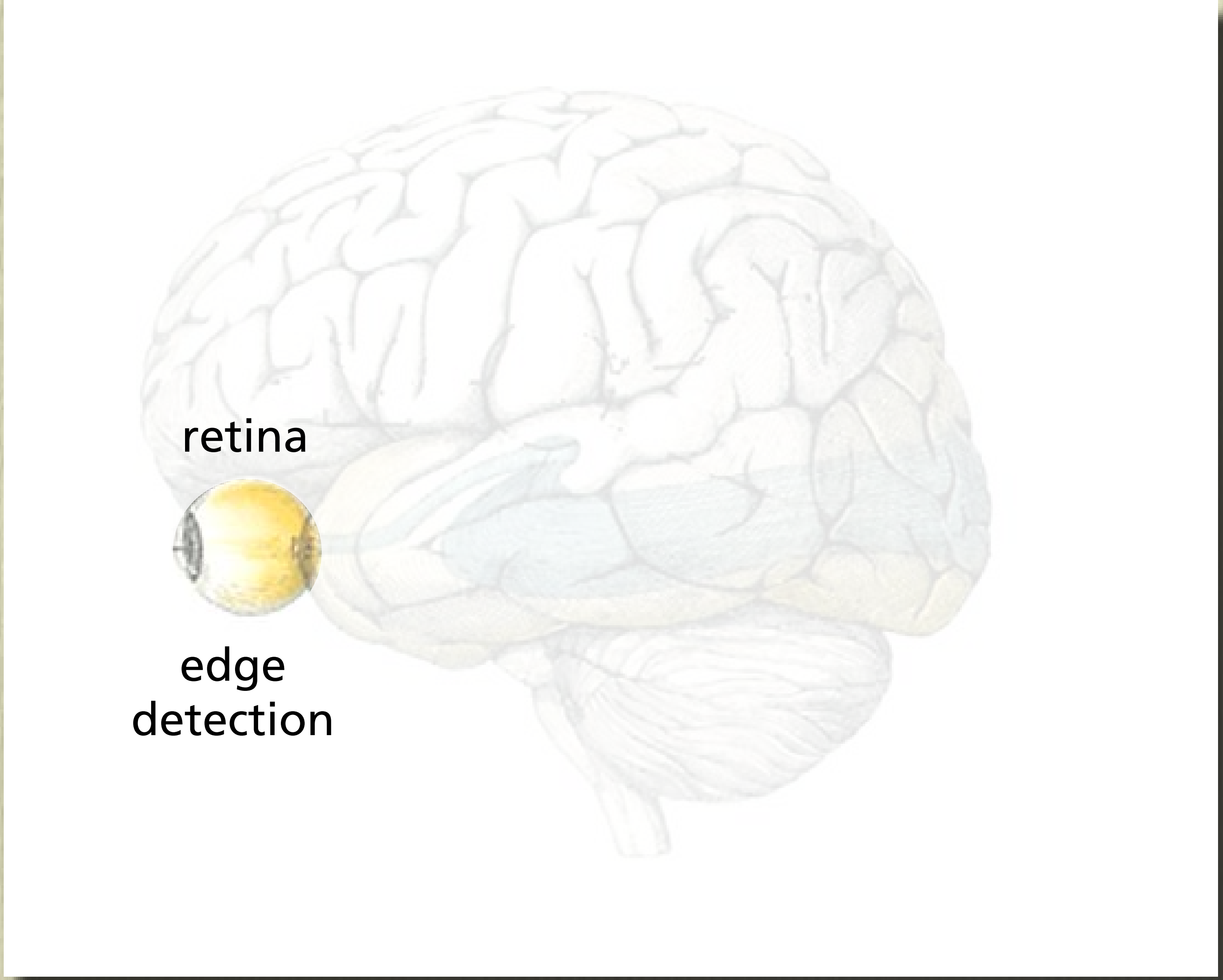
- 10^6 retinal ganglion cells
- 100 impulses/s
- that's about 10 MB/s!

How do we *do* it?

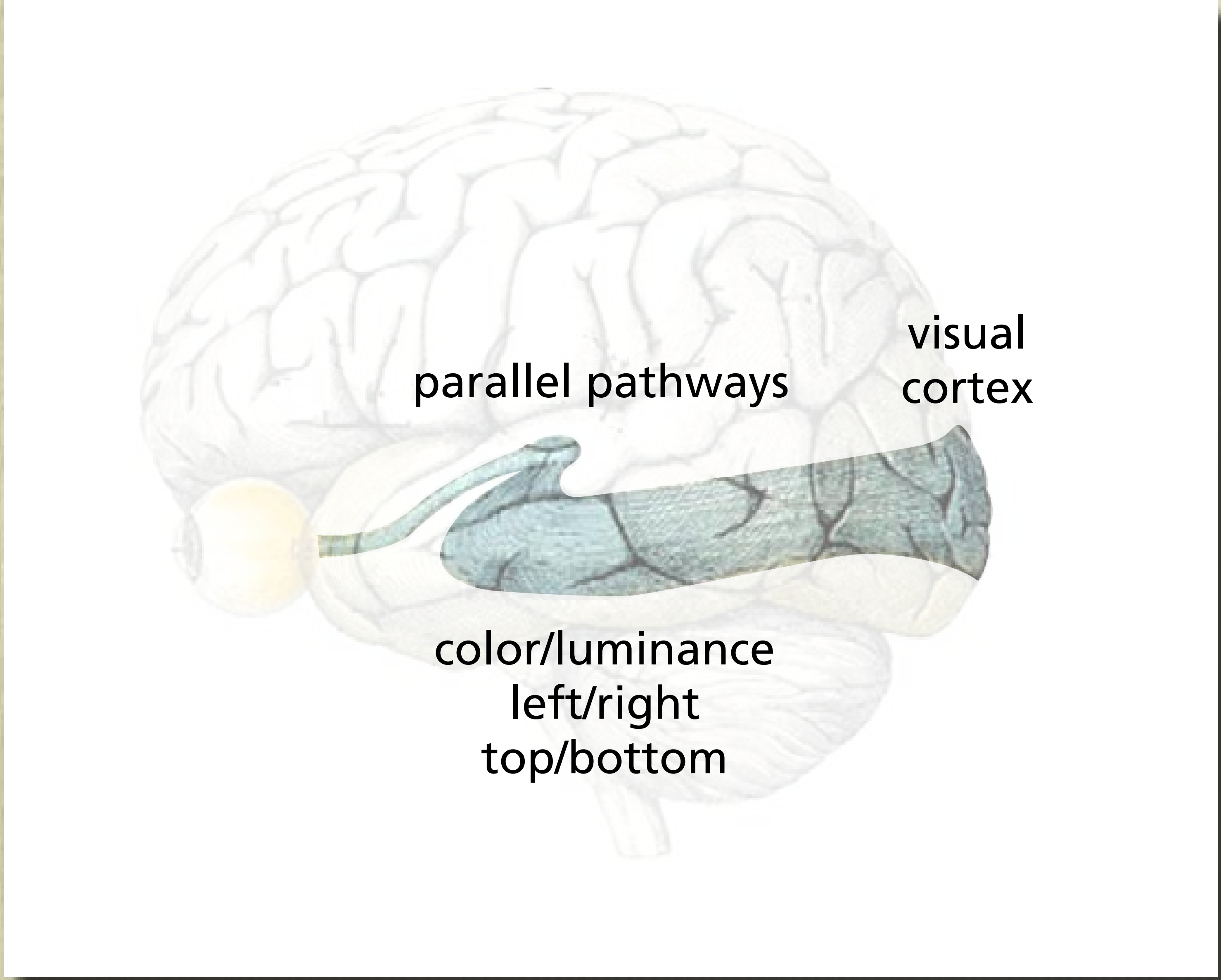
Visual pathways



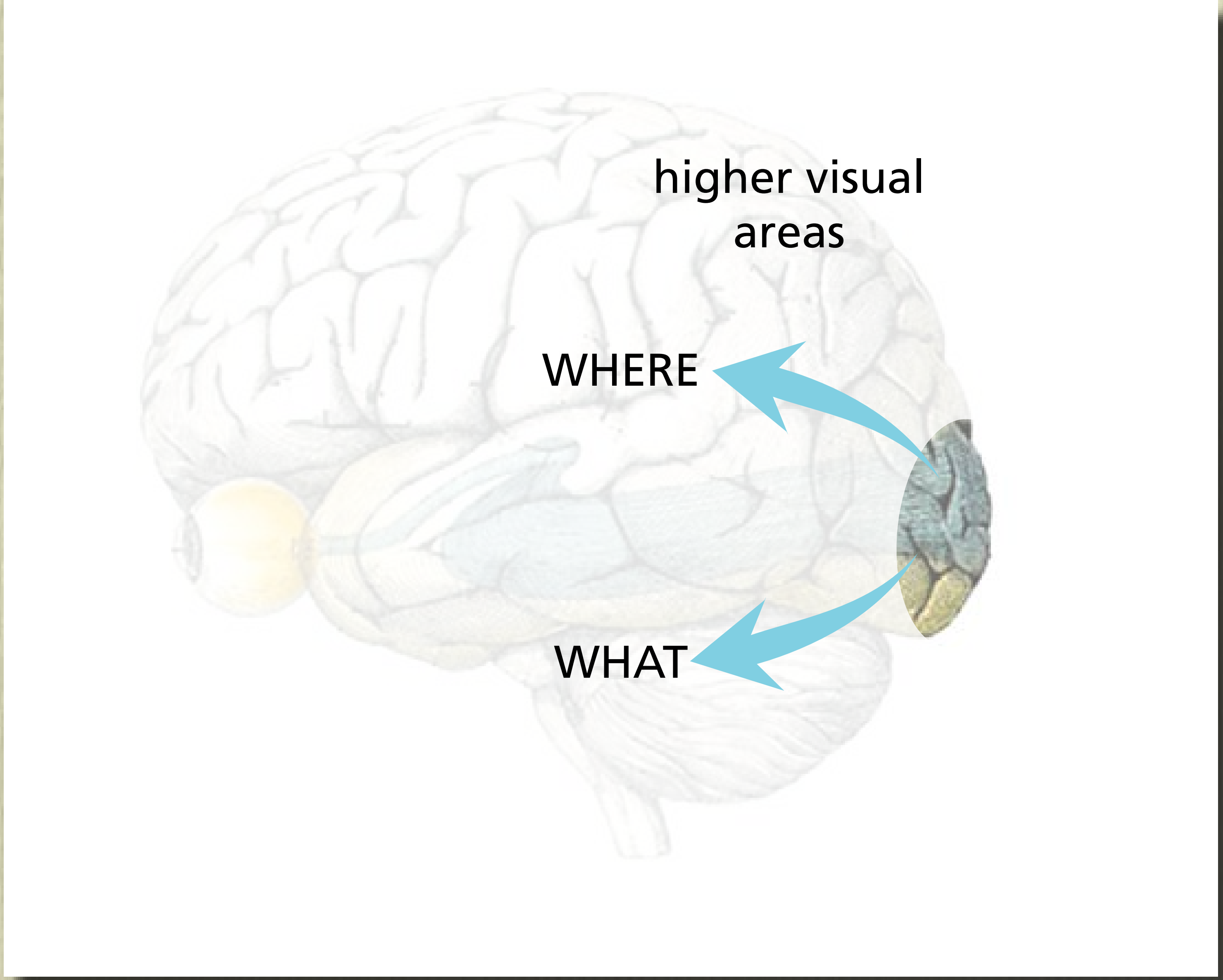
Visual pathways



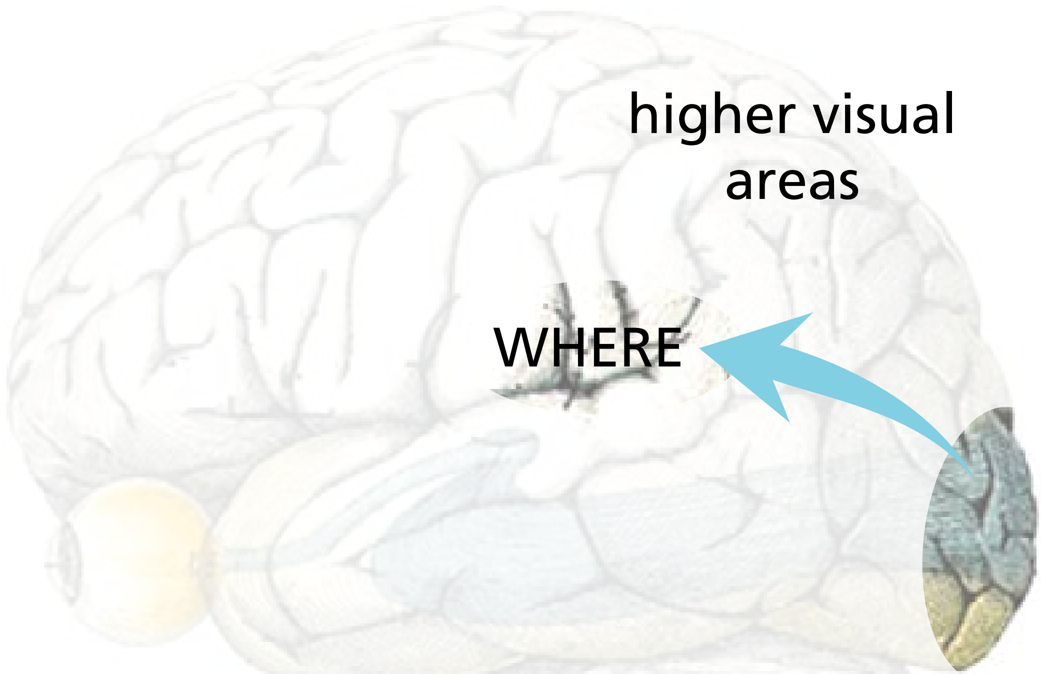
Visual pathways



Visual pathways

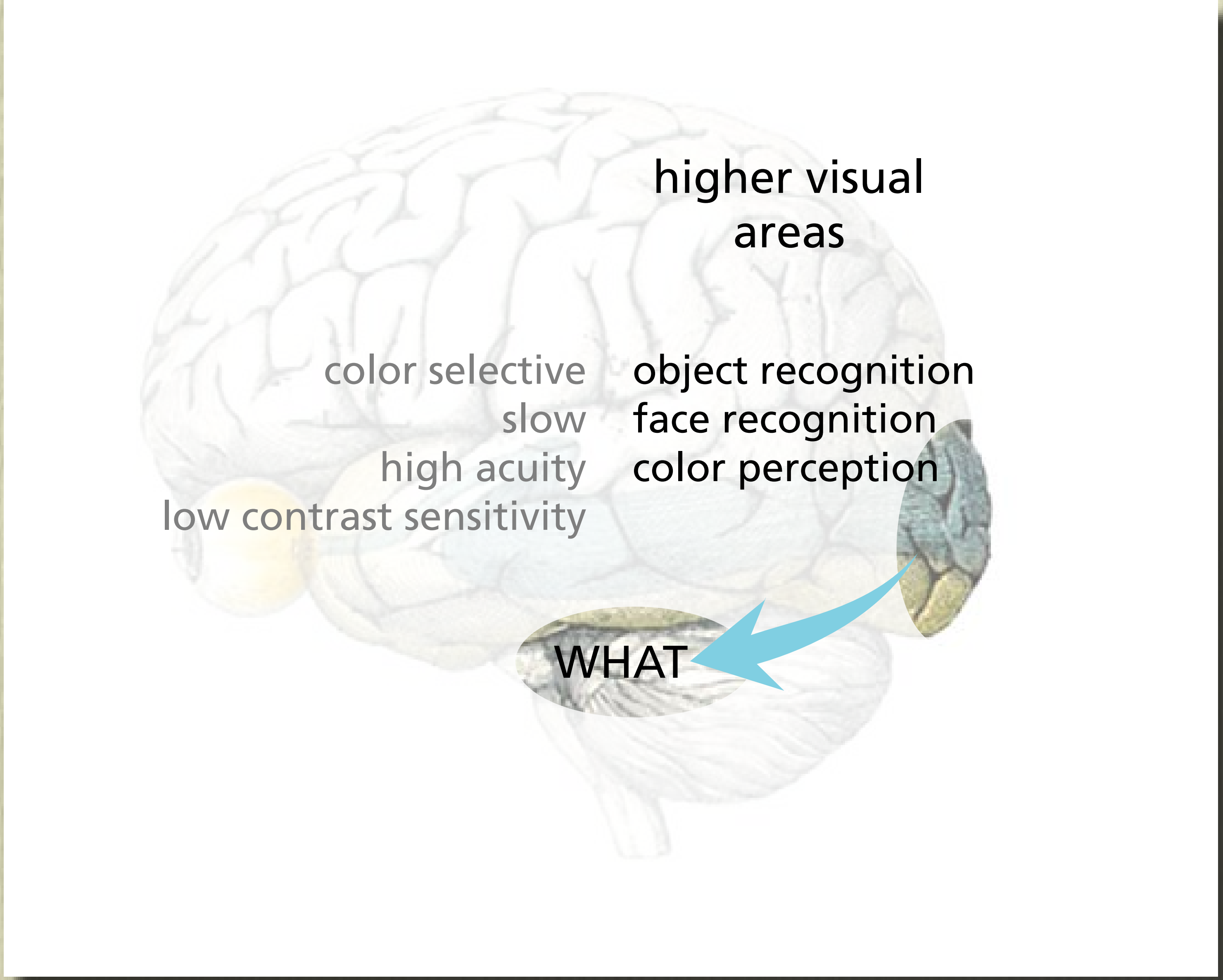


Visual pathways



color blind	motion perception
fast	depth perception
low acuity	spatial organization
high contrast sensitivity	figure/ground segregation

Visual pathways




visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization
visualization

Some points to keep in mind

Luminance:

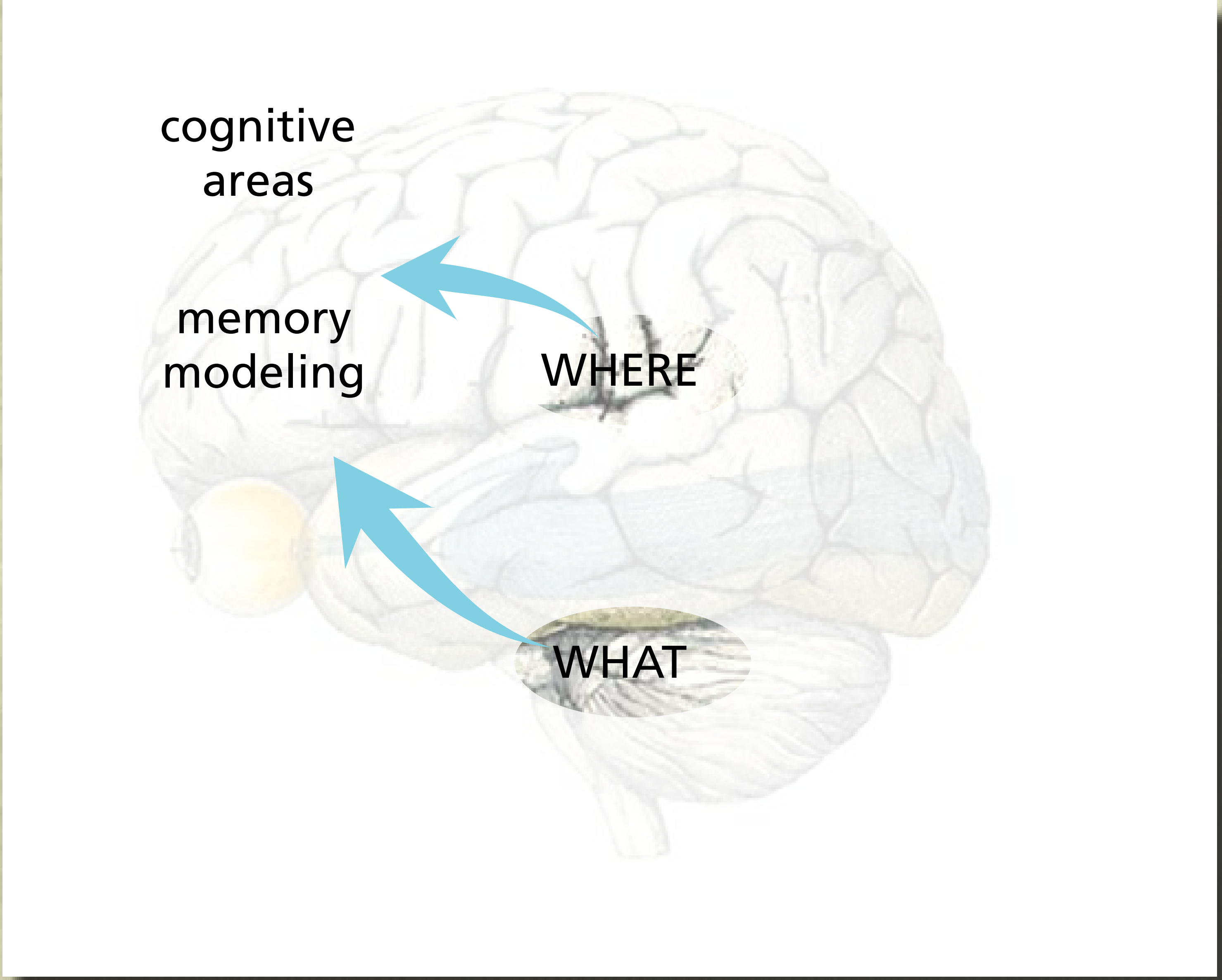
- depth
- motion

Color:

- form
- function

Cognitive issues related to seeing

Visual pathways

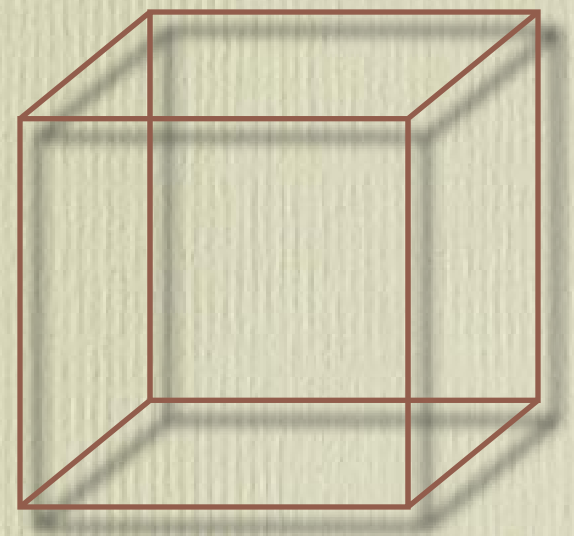


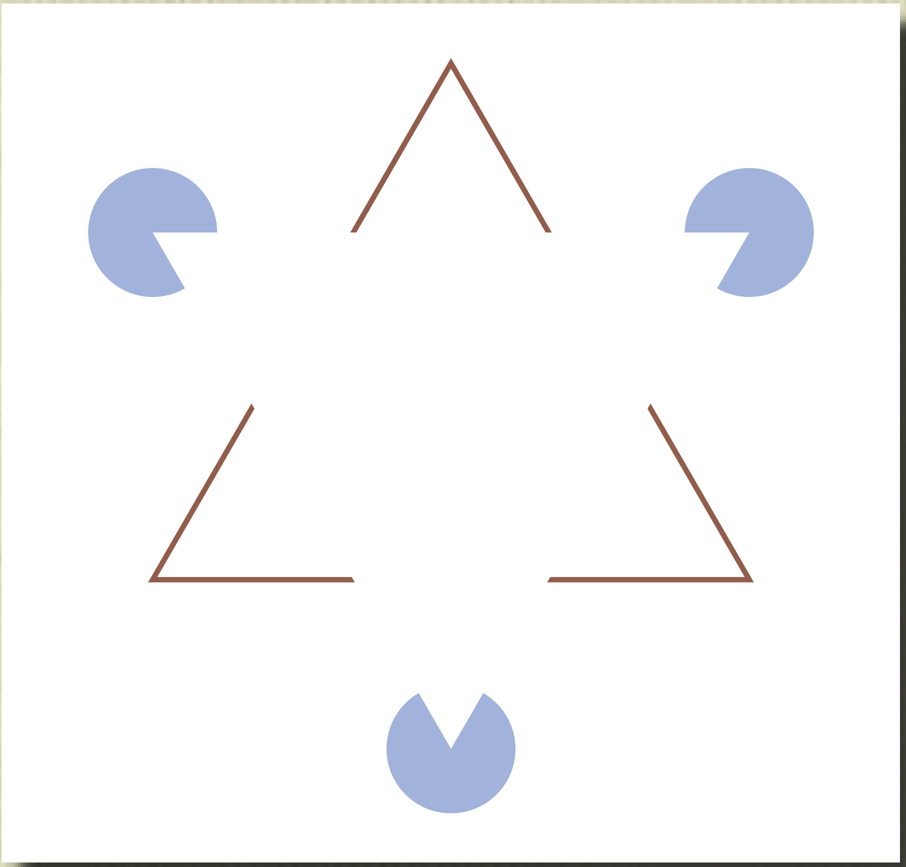
Mental models

of behavior, events, workings are essential to

- understand our experiences
- predict outcomes of our actions
- handle unexpected occurences

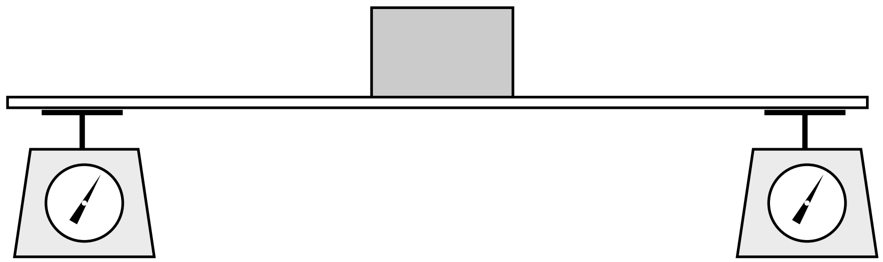
Mental models affect what we see

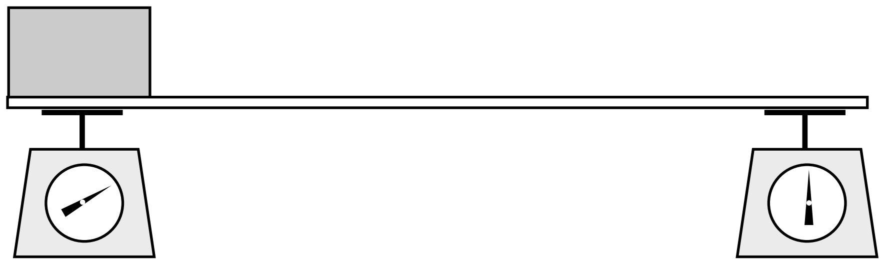




Mental tasks can prevent us from seeing

Mental models override visual memory





Common misconception

Plank evens out the load,
so scale reading doesn’t change

Can we correct this misconception
by showing the demonstration to students?

Presenting ineffective

"As demonstrated in lecture both scales will read 10 N regardless of where the center of mass is located. The platform and the metal block form one unit that is being measured, so the scales show two evenly distributed readings, no matter where the metal block is placed along the platform."

Observation can *reinforce* misconception!

Must provide opportunity to revise model

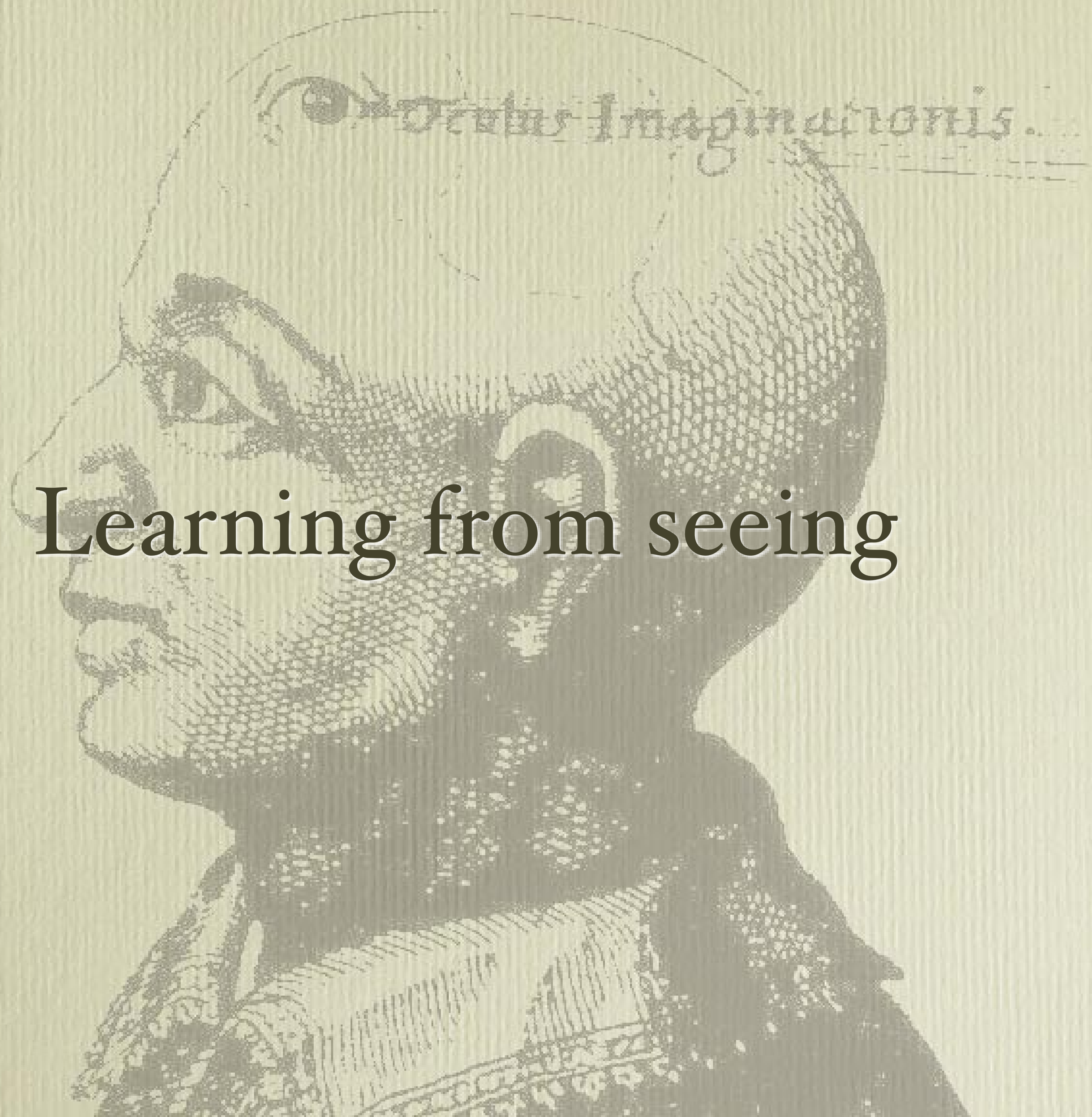
How?

- Predict outcome before observation
- Record observation
- Reconcile prediction with observation

Points to keep in mind

- Mental models affect what we see
- Mental tasks can prevent us from seeing
- Mental models override visual memory

Learning from seeing



Goal

Help build (correct) models

Abstract versus realistic

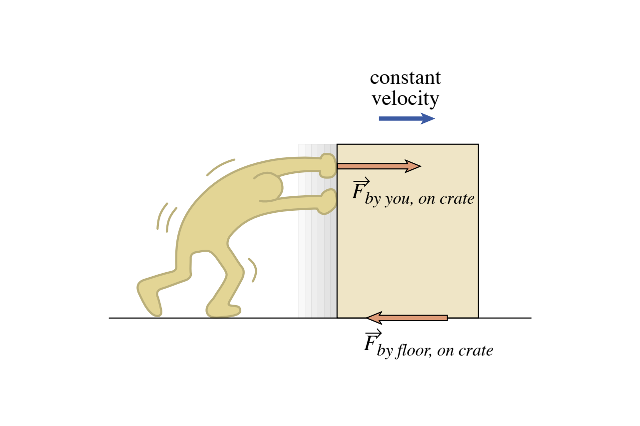
- Abstract: highlight model
- Realistic: connect to experience

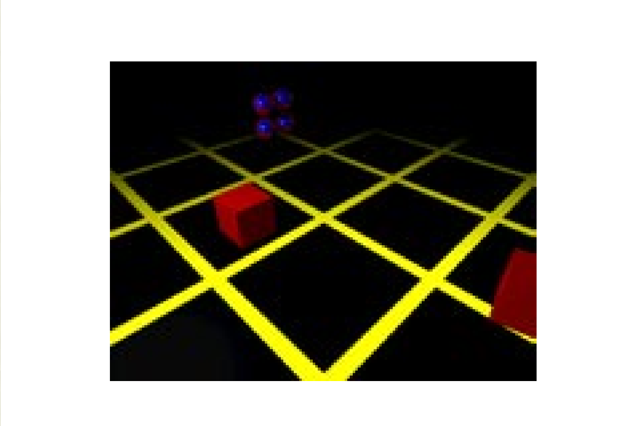
Visualization types

illustration

animation

abstract





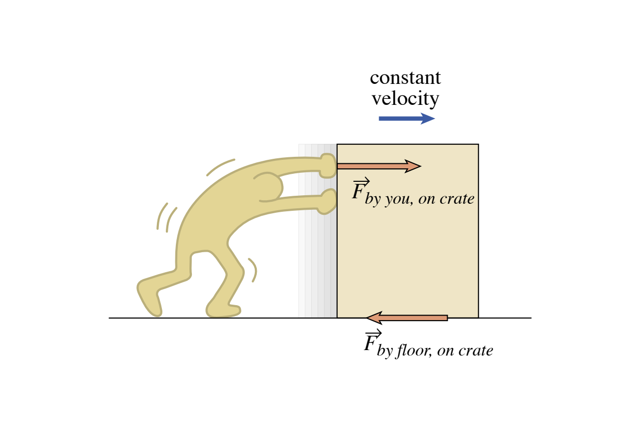
realistic

Visualization types

illustration

animation

abstract



realistic

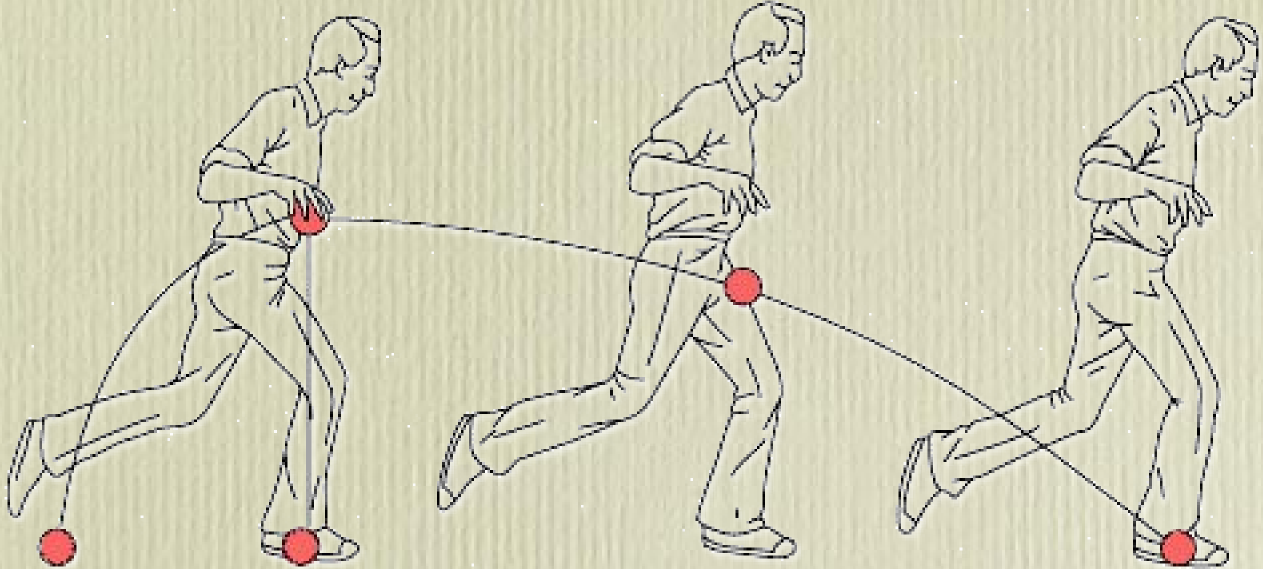
Abstract versus realistic

Use:

- photography/film when point can be observed directly
- abstract illustration/animation when phenomenon is an abstraction (*e.g.*, force or field)

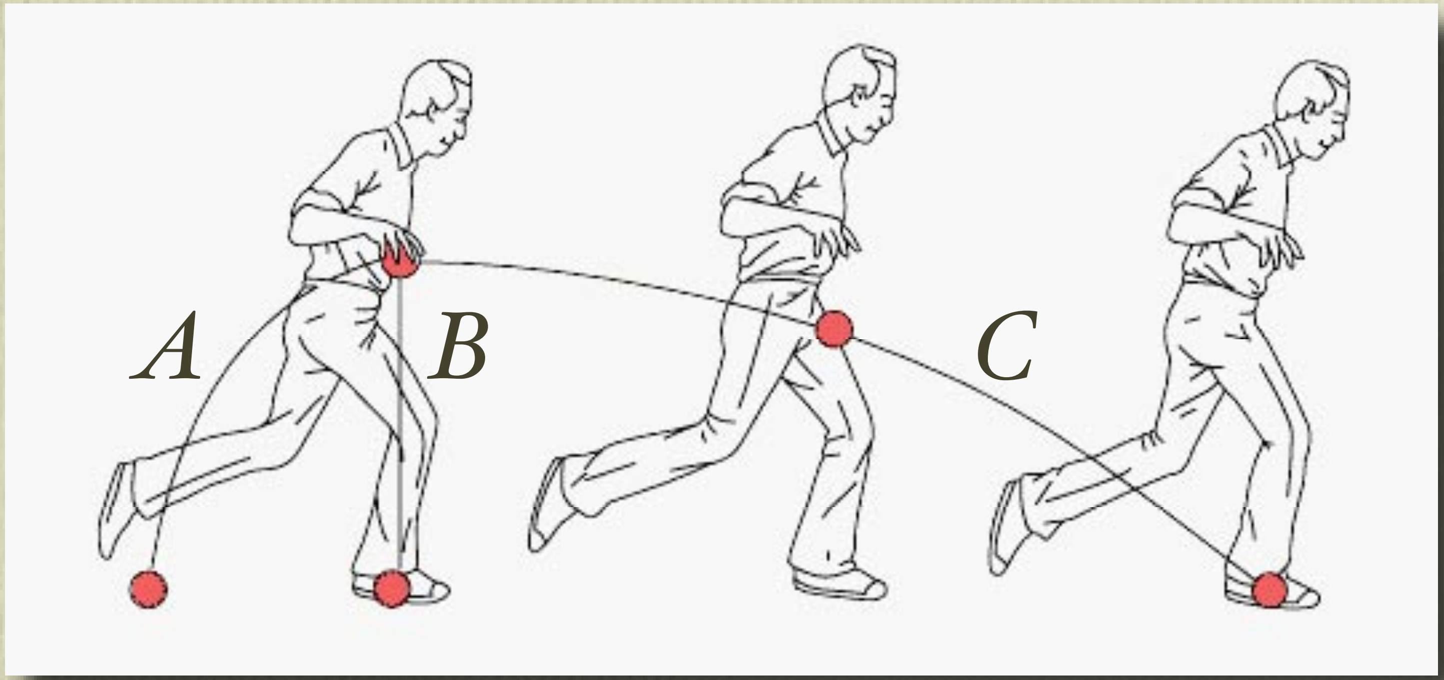
Parabolic motion

A quick quiz



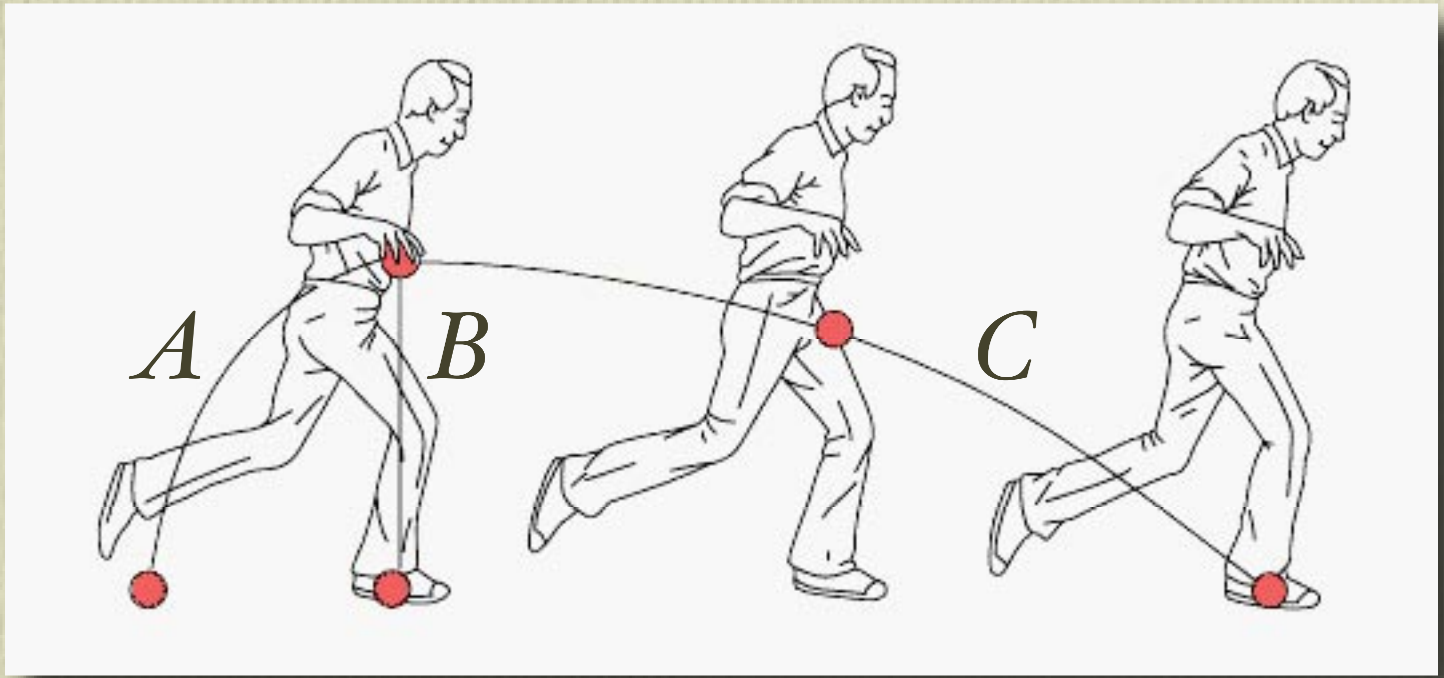
M. McCloskey, *Intuitive Physics*
Scientific American 248 (1983), pp. 122-130

A quick quiz



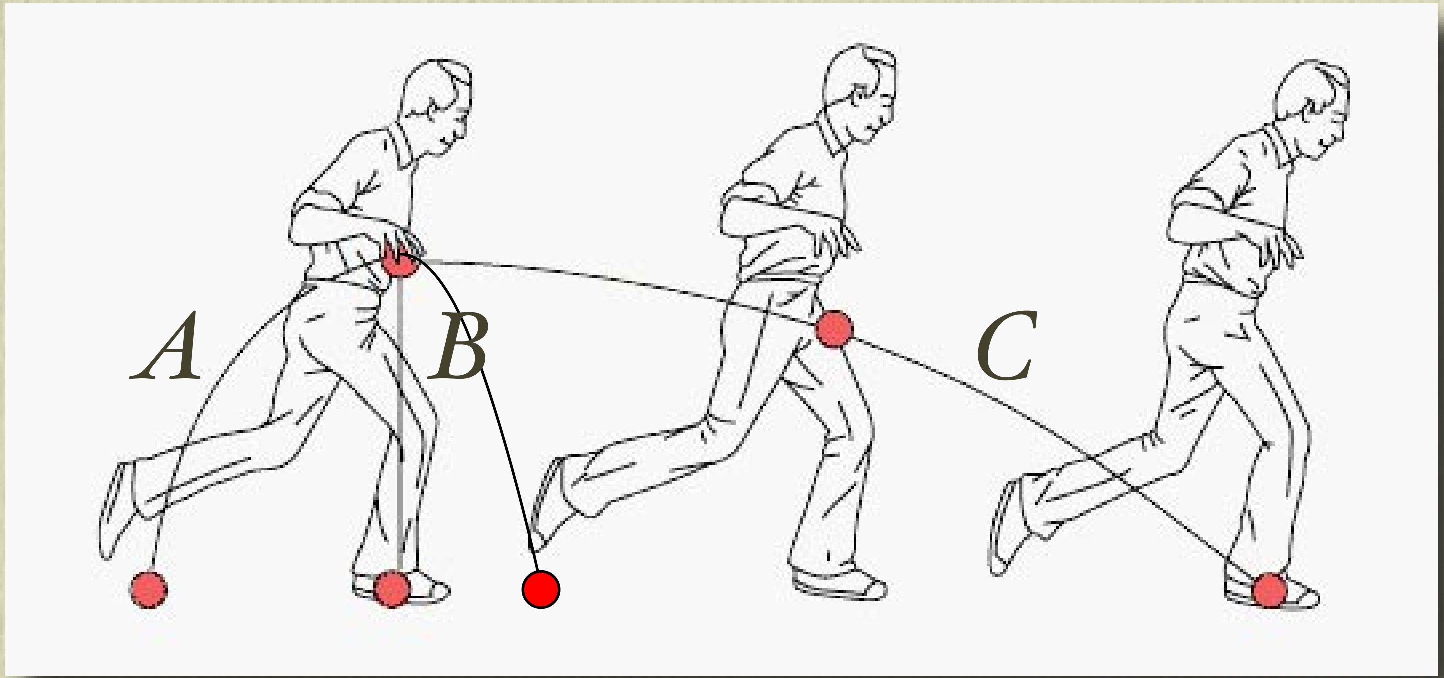
Which of the three paths shown (*A*–*C*) most closely resembles the path taken by the ball?

A quick quiz



Answer: *B*

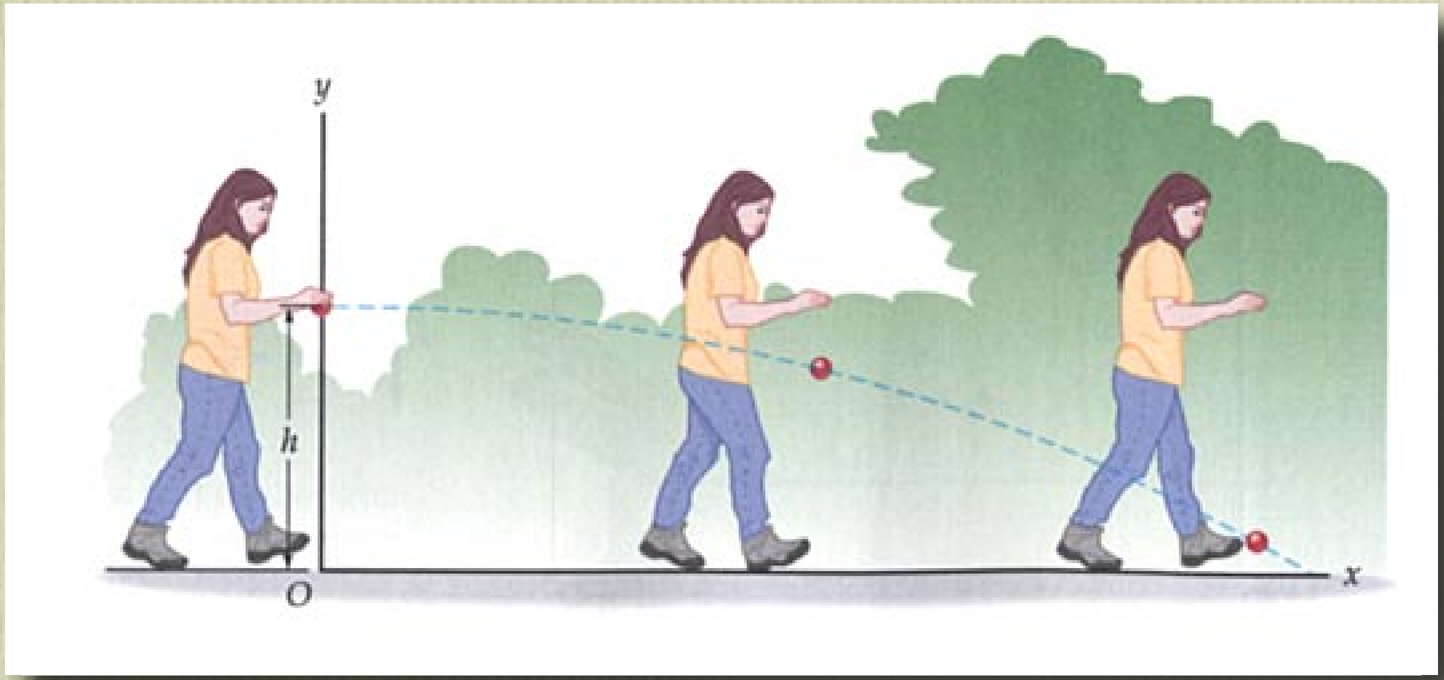
A quick quiz



Answer: *B*

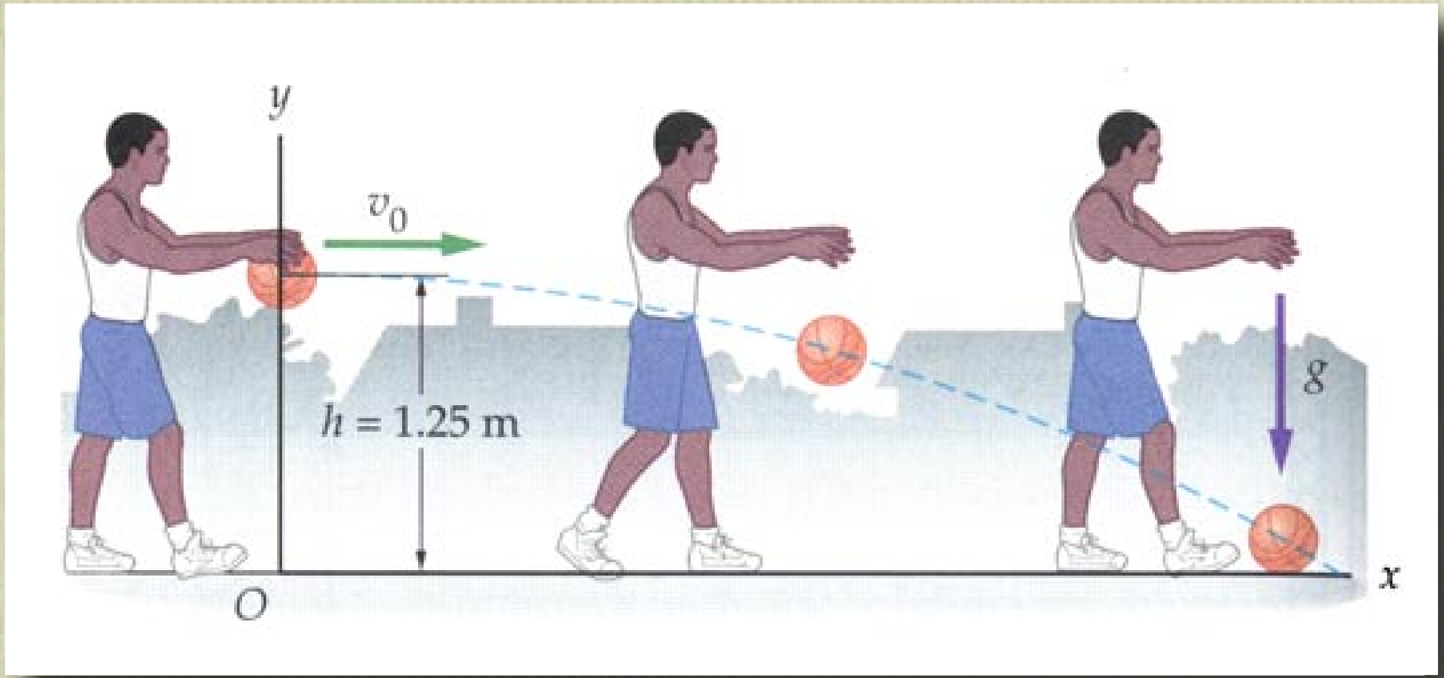
Even text book authors get the physics wrong!

Microgravity



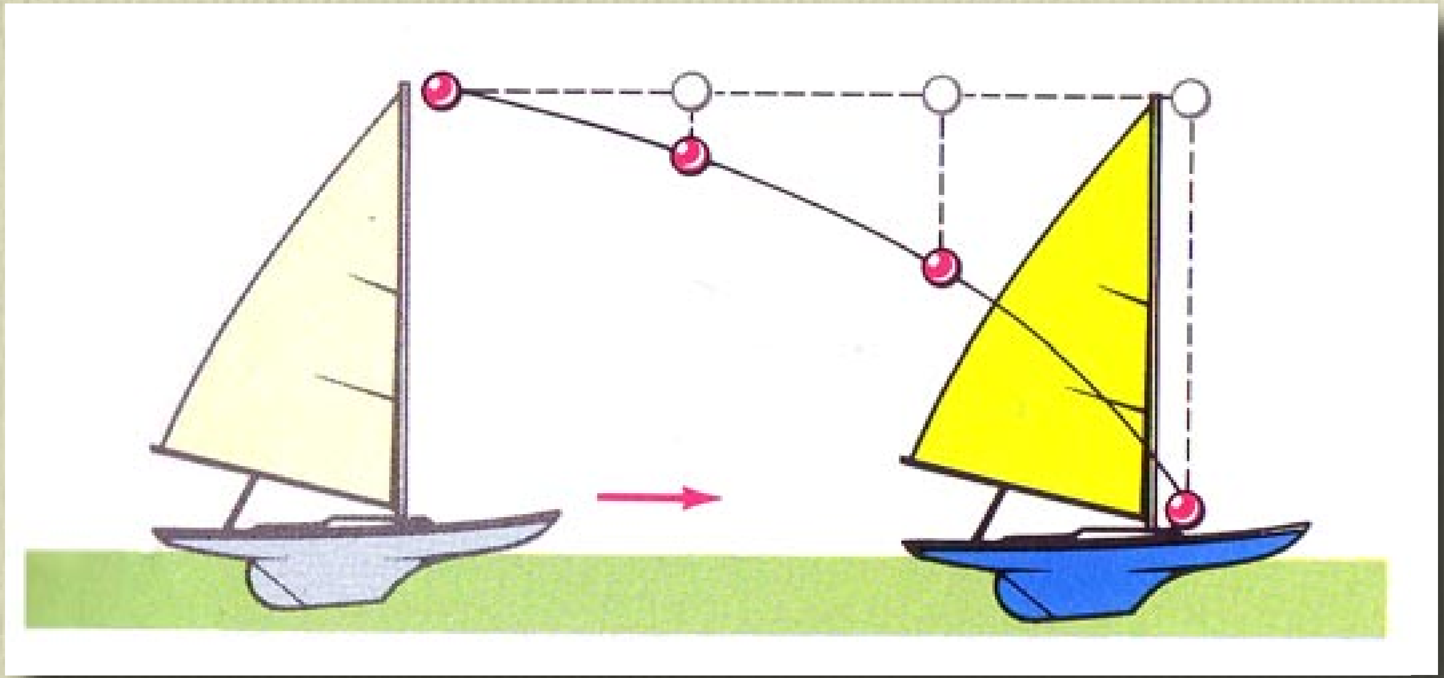
Walker, 2nd Ed. (Prentice Hall, 2004)

Microgravity



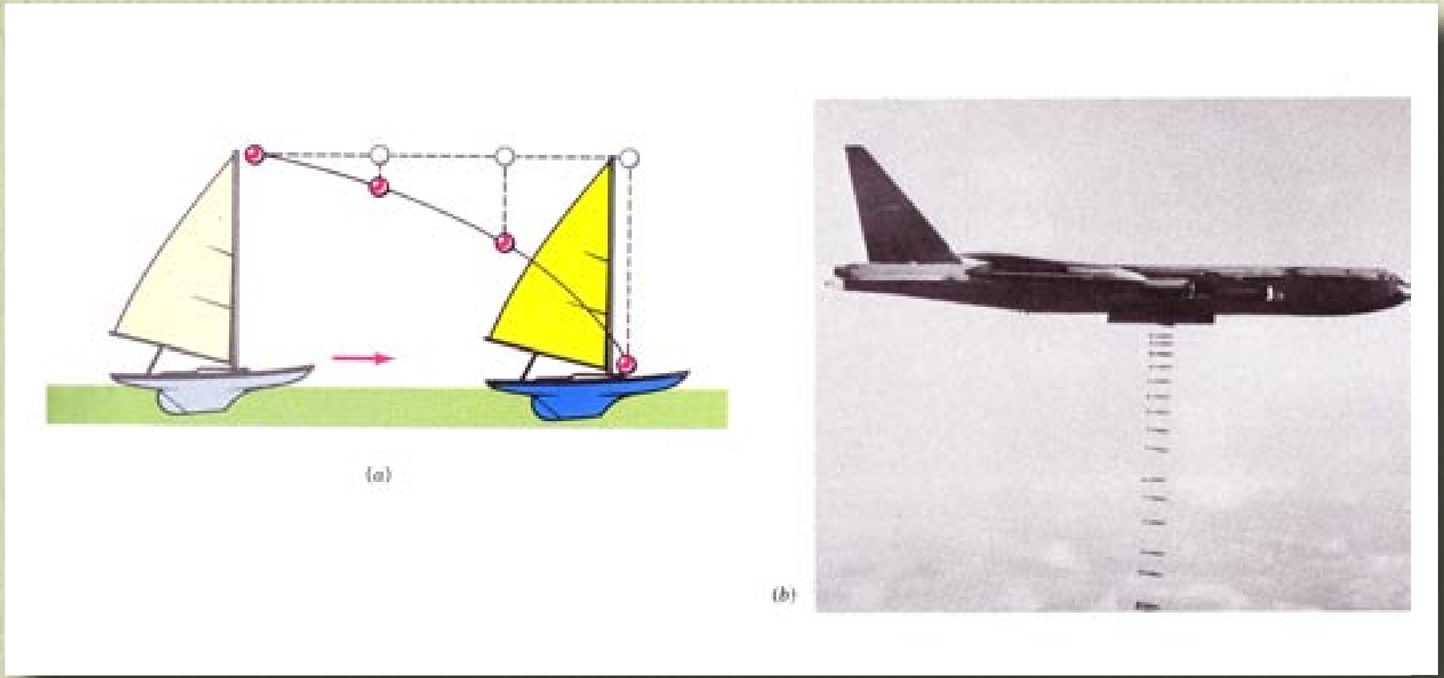
Walker, 2nd Ed. (Prentice Hall, 2004)

Microgravity



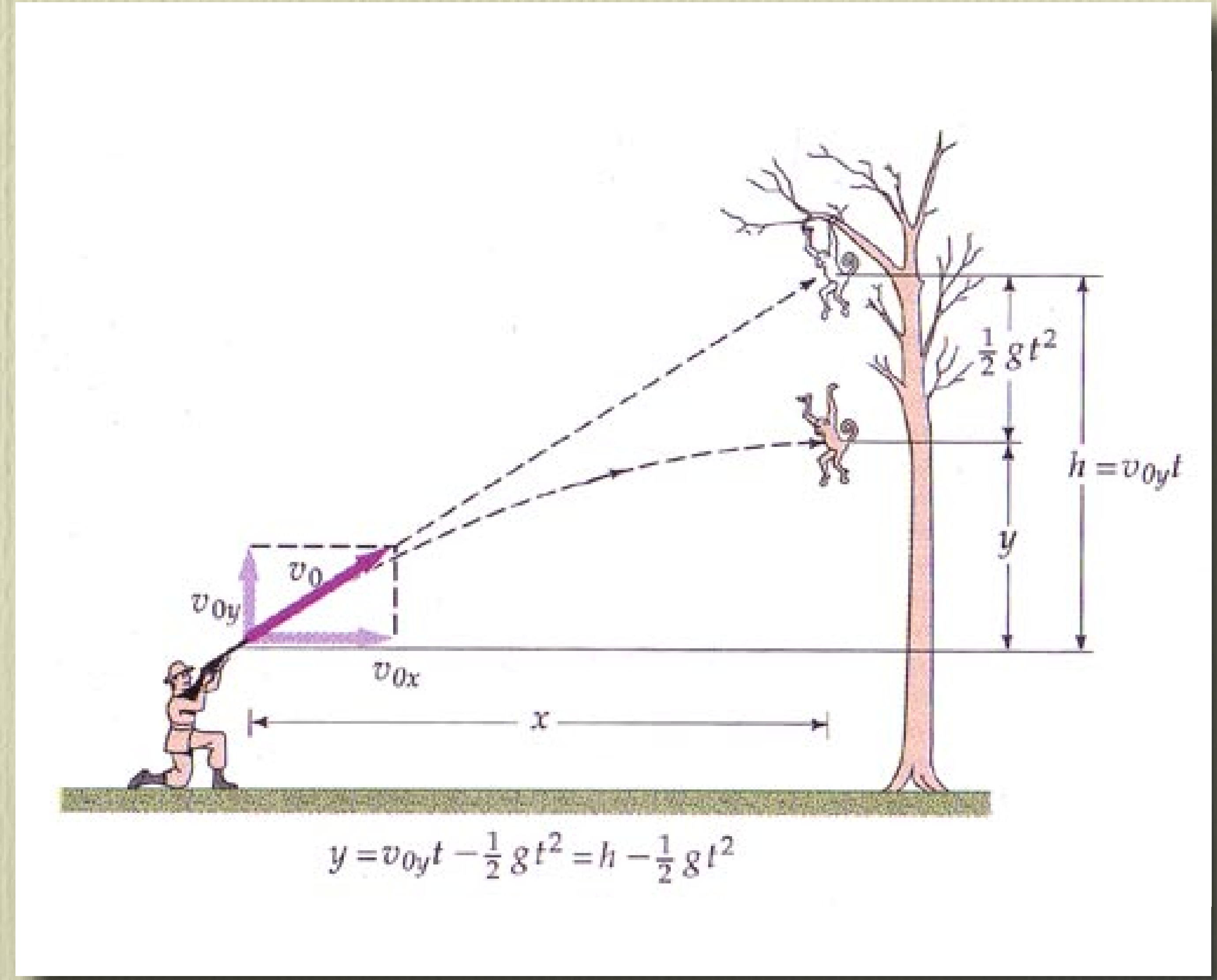
Benson (Wiley, 1991)

Microgravity



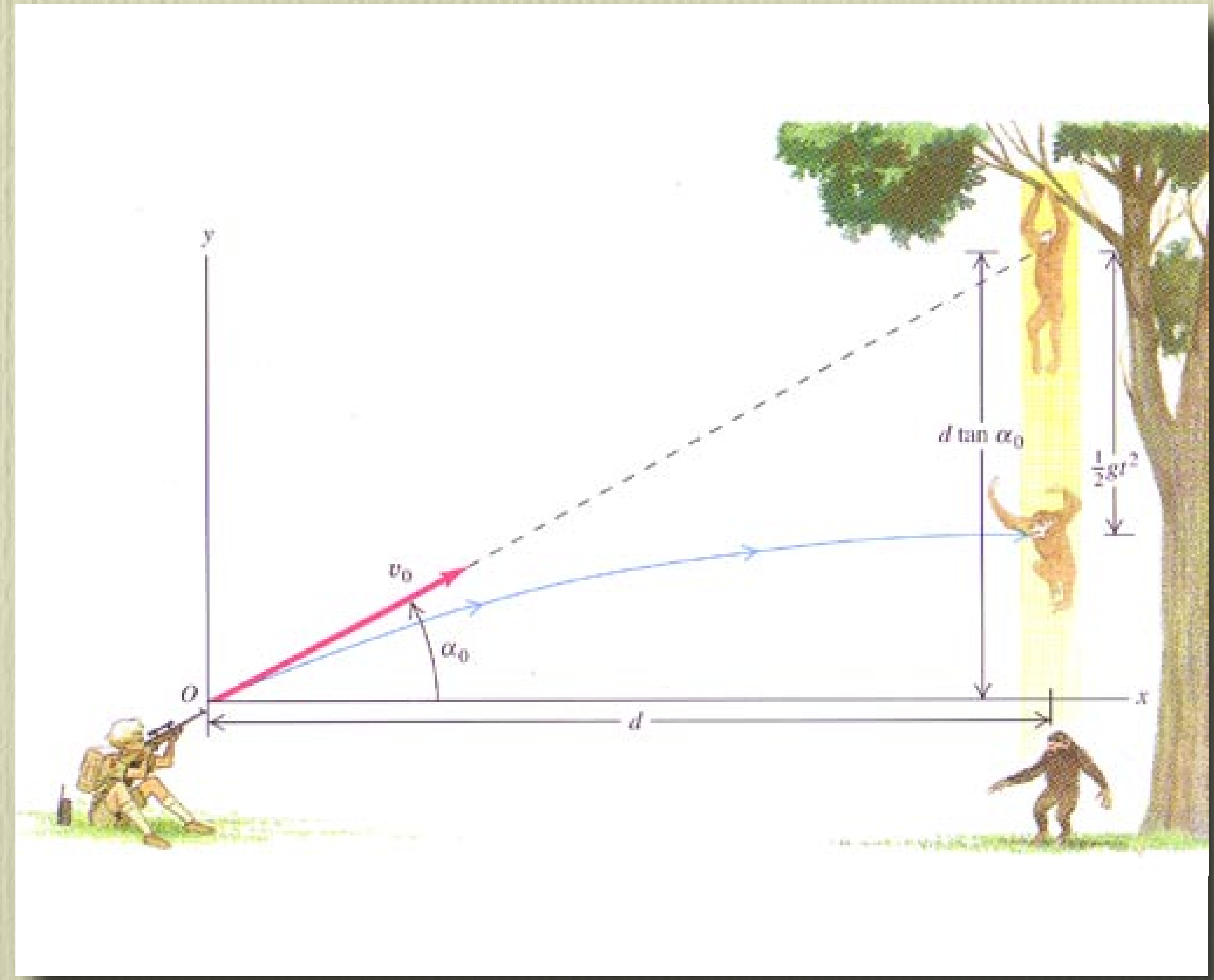
Benson (Wiley, 1991)

Another classic



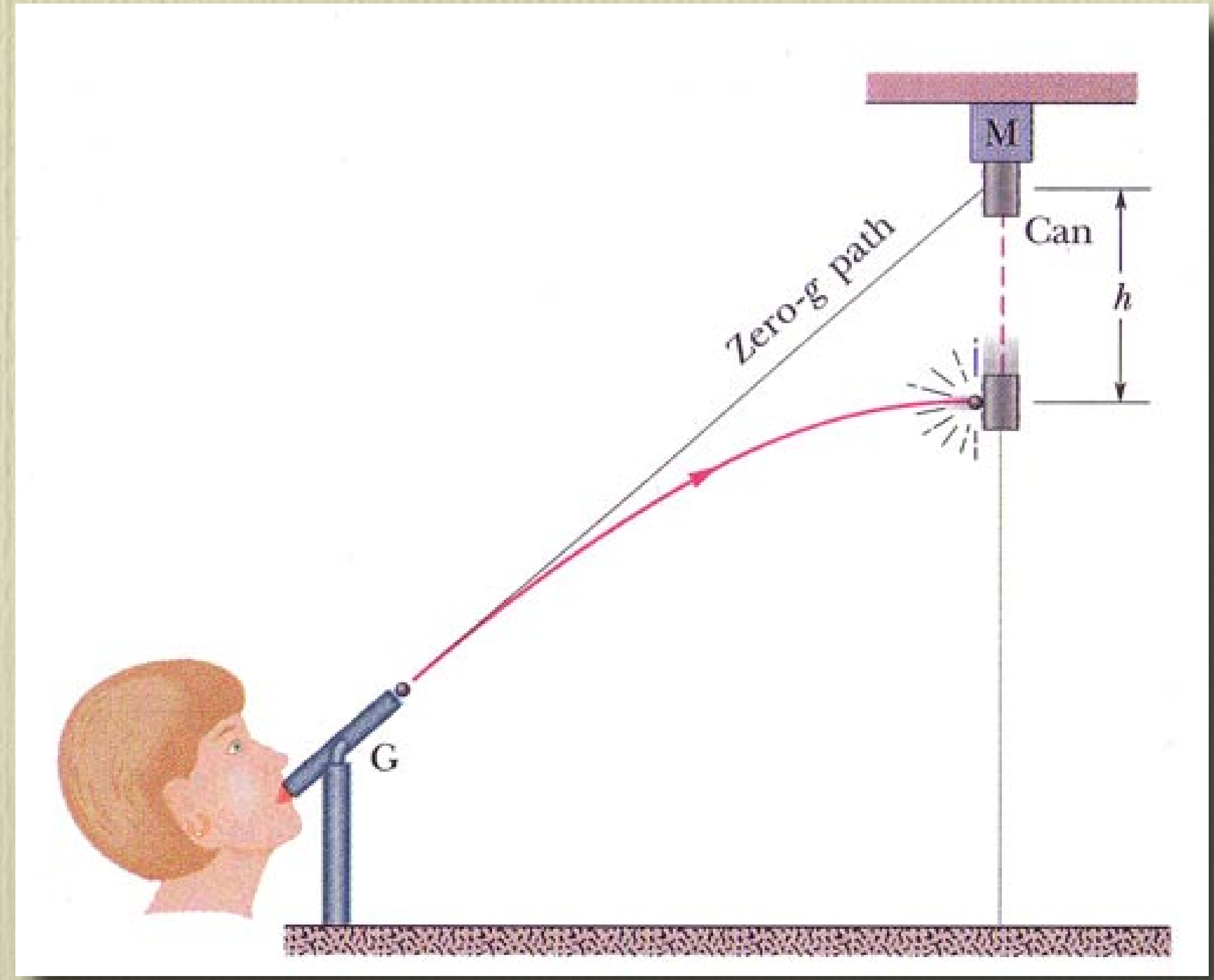
Tipler, 1st Ed. (Worth, 1971)

How not to shoot a monkey



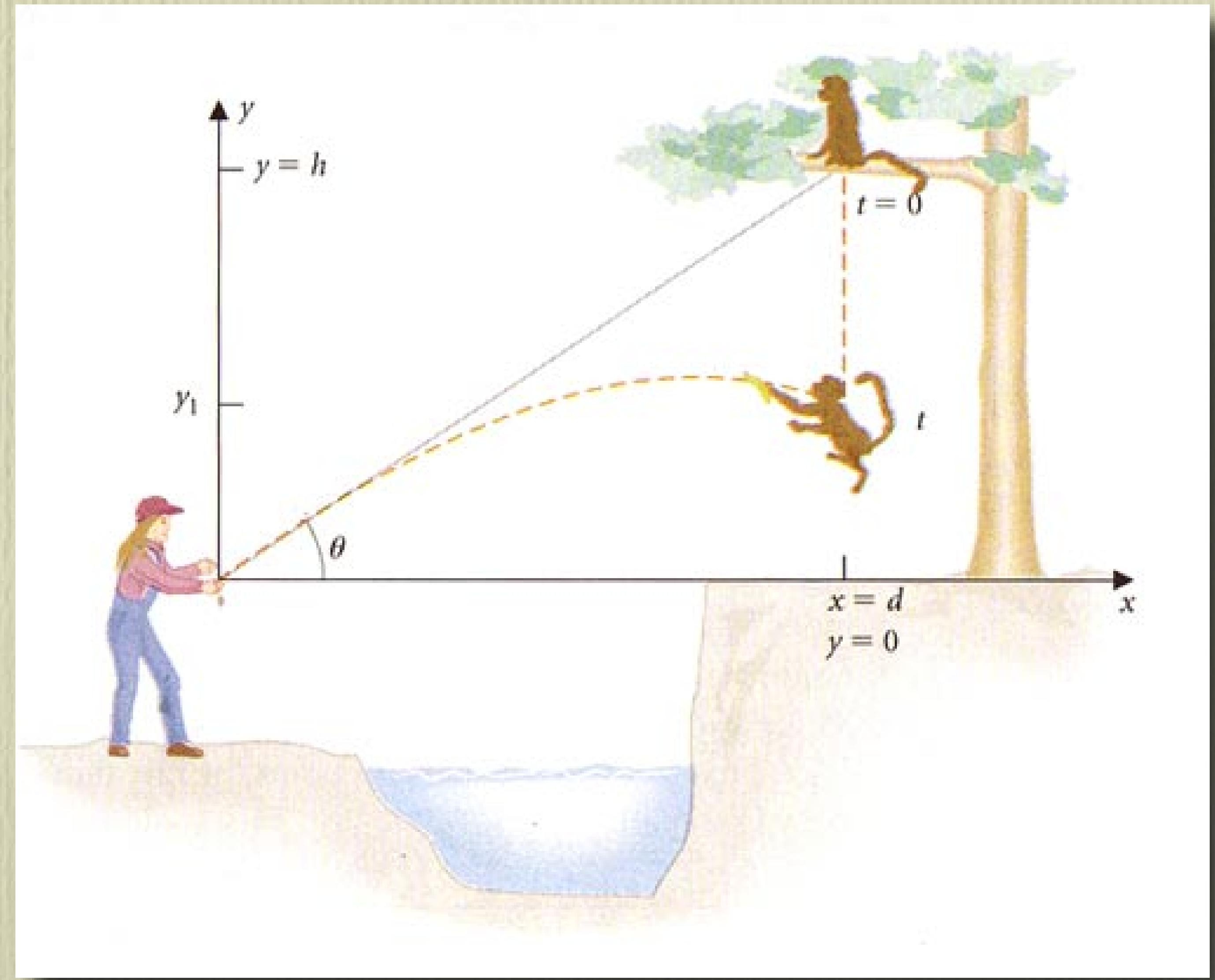
Sears and Zemansky, 10th Ed. (Addison Wesley, 2000)

How not to shoot a monkey



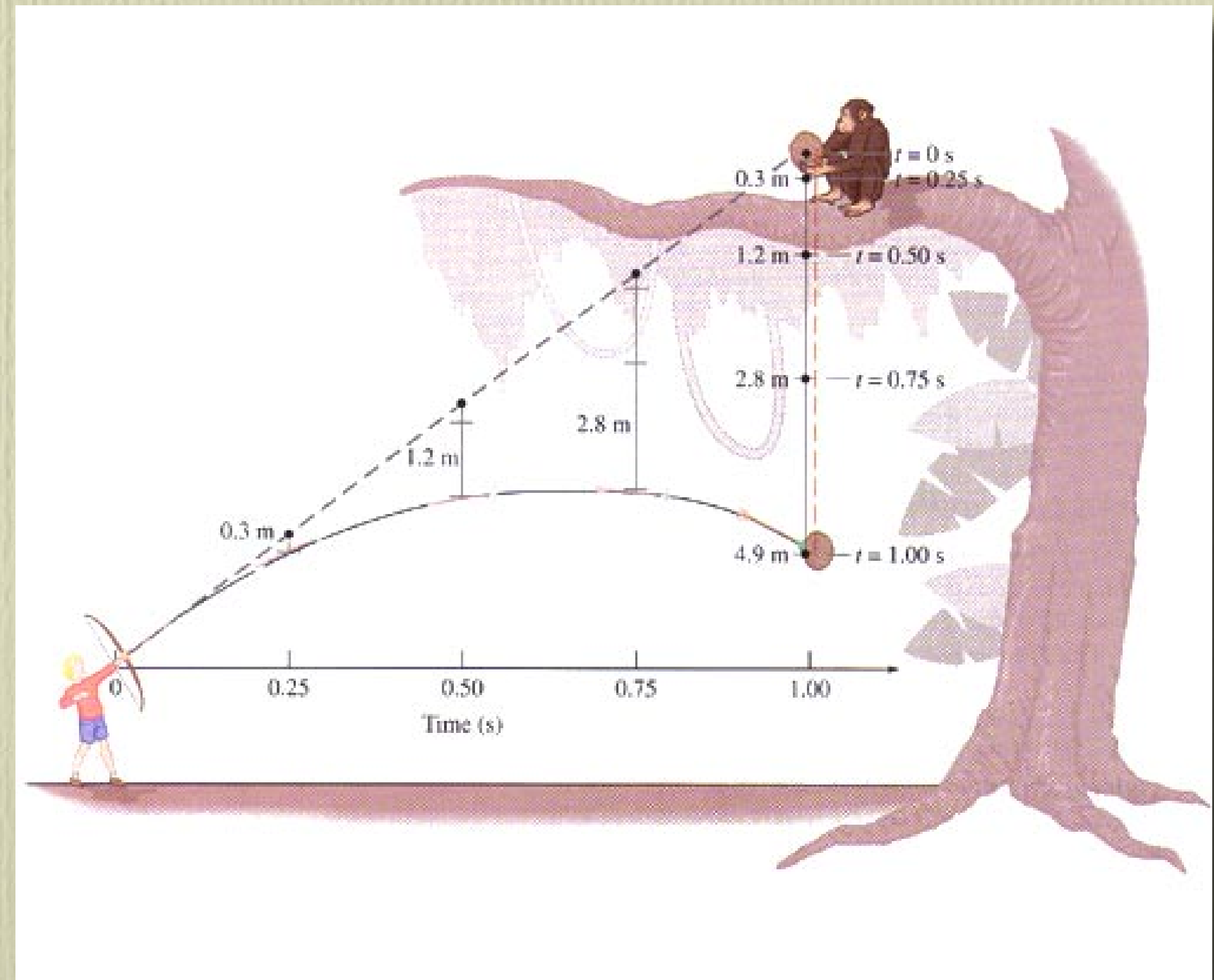
Haliday, Resnick, Walker, 5th Ed. (Wiley, 1997)

How not to shoot a monkey



Lea and Burke (Brooks/Cole, 1997)

How not to shoot a monkey

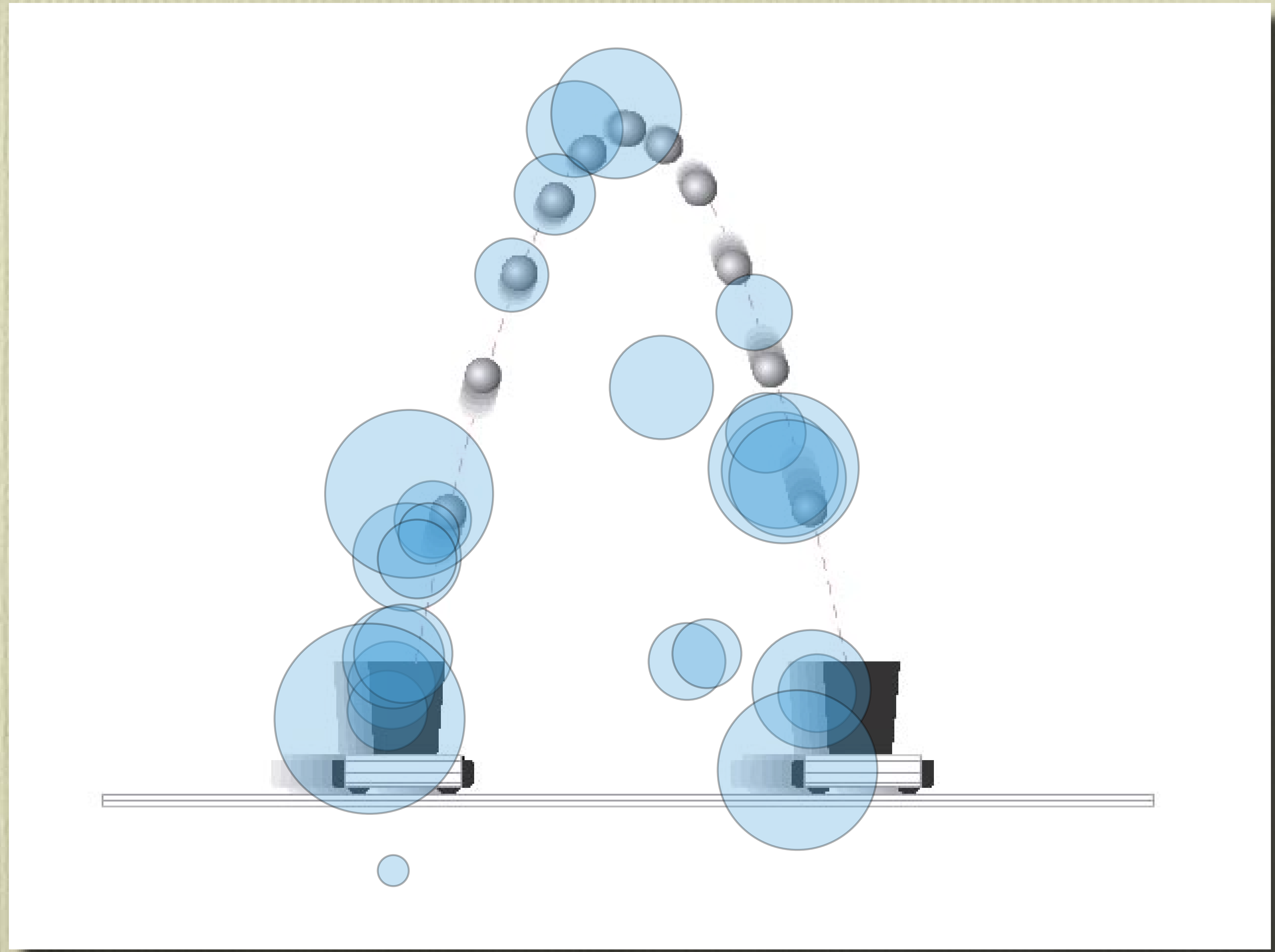


Giambattista, Richardson, Richardson (McGraw Hill, 2004)

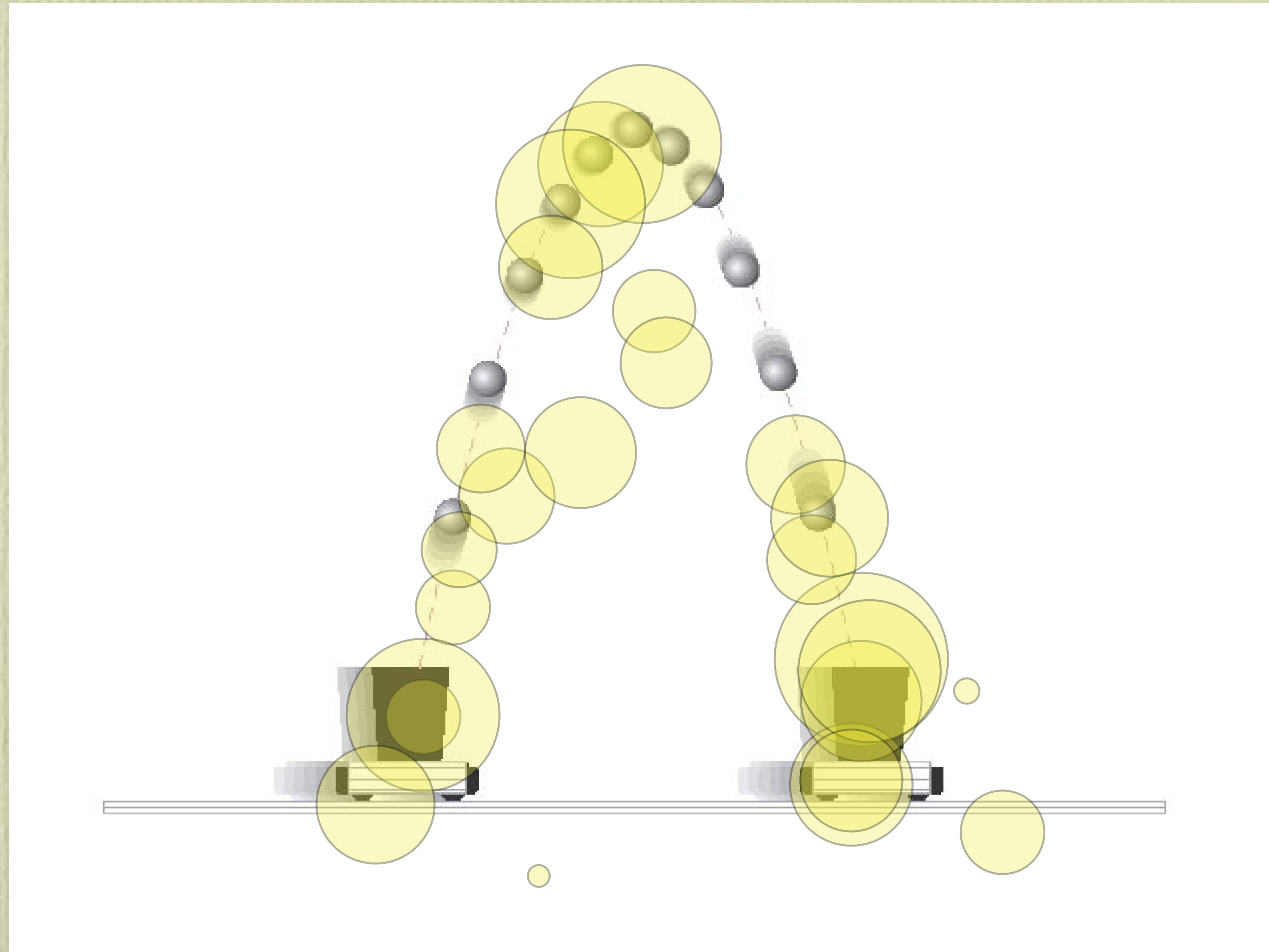
The Clutter!

What do people look at?

Mazur (Prentice Hall, 200?)

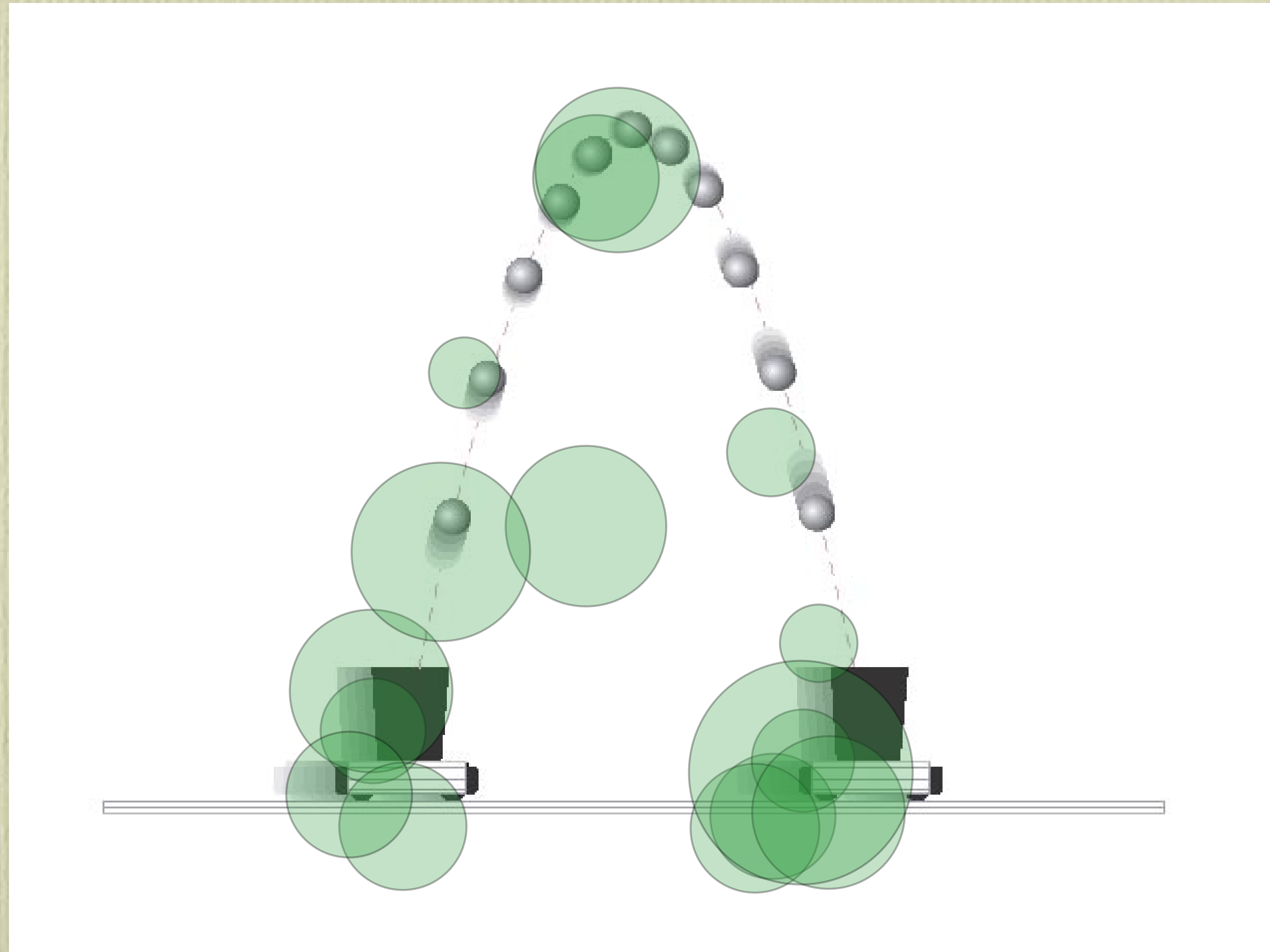


Mazur (Prentice Hall, 200?)

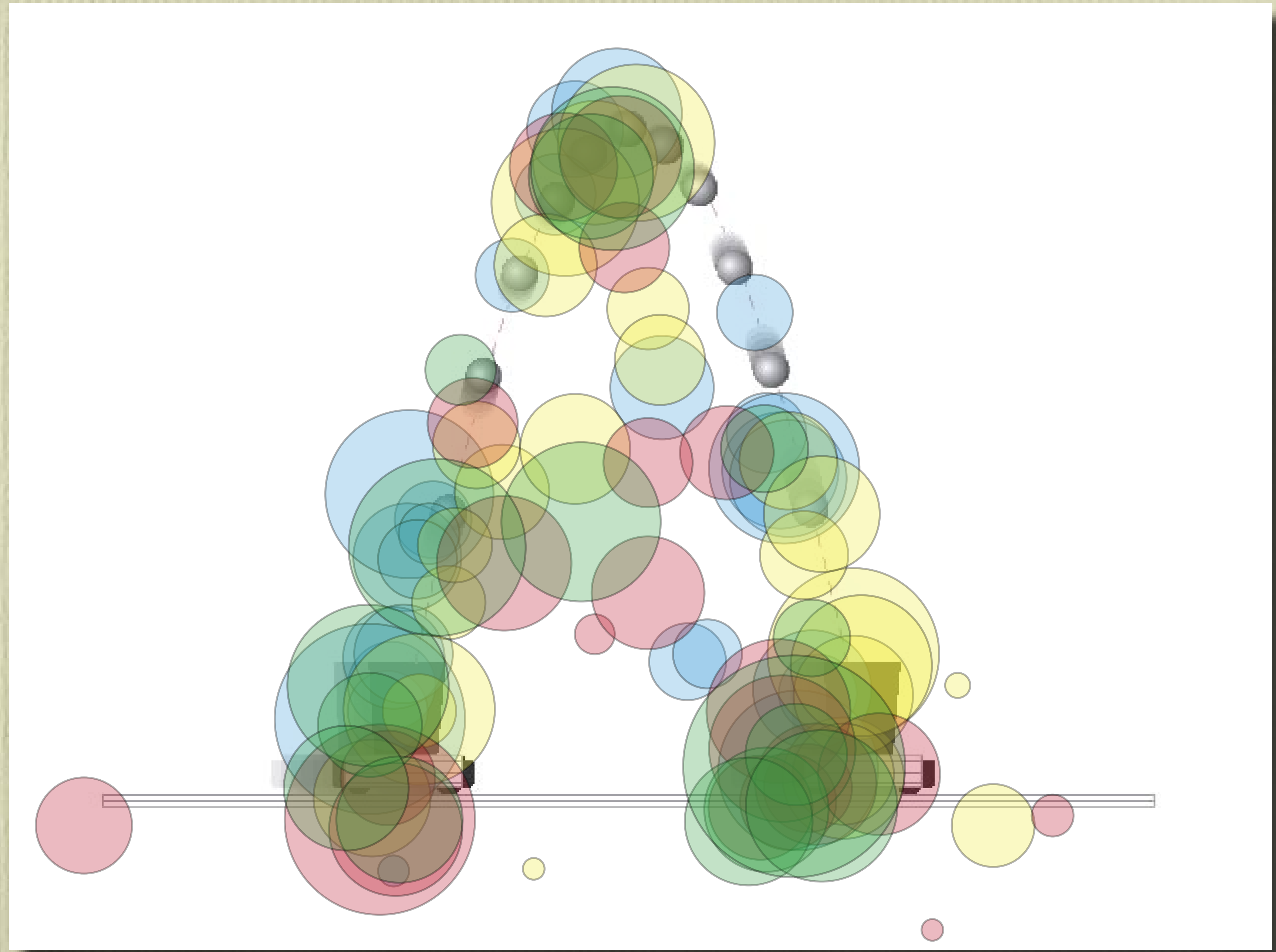


Mazur (Prentice Hall, 200?)

Mazur (Prentice Hall, 200?)



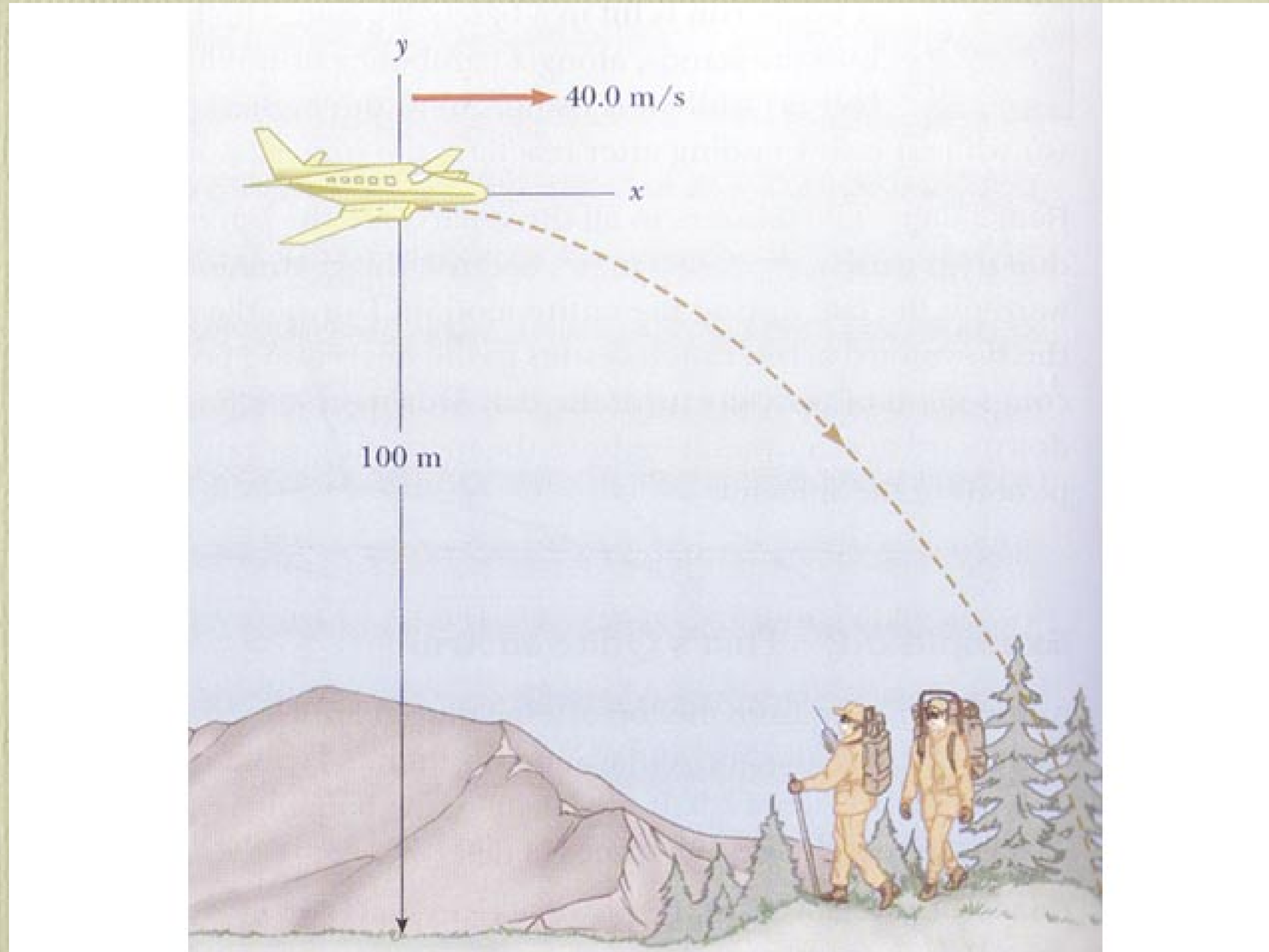
Mazur (Prentice Hall, 200?)



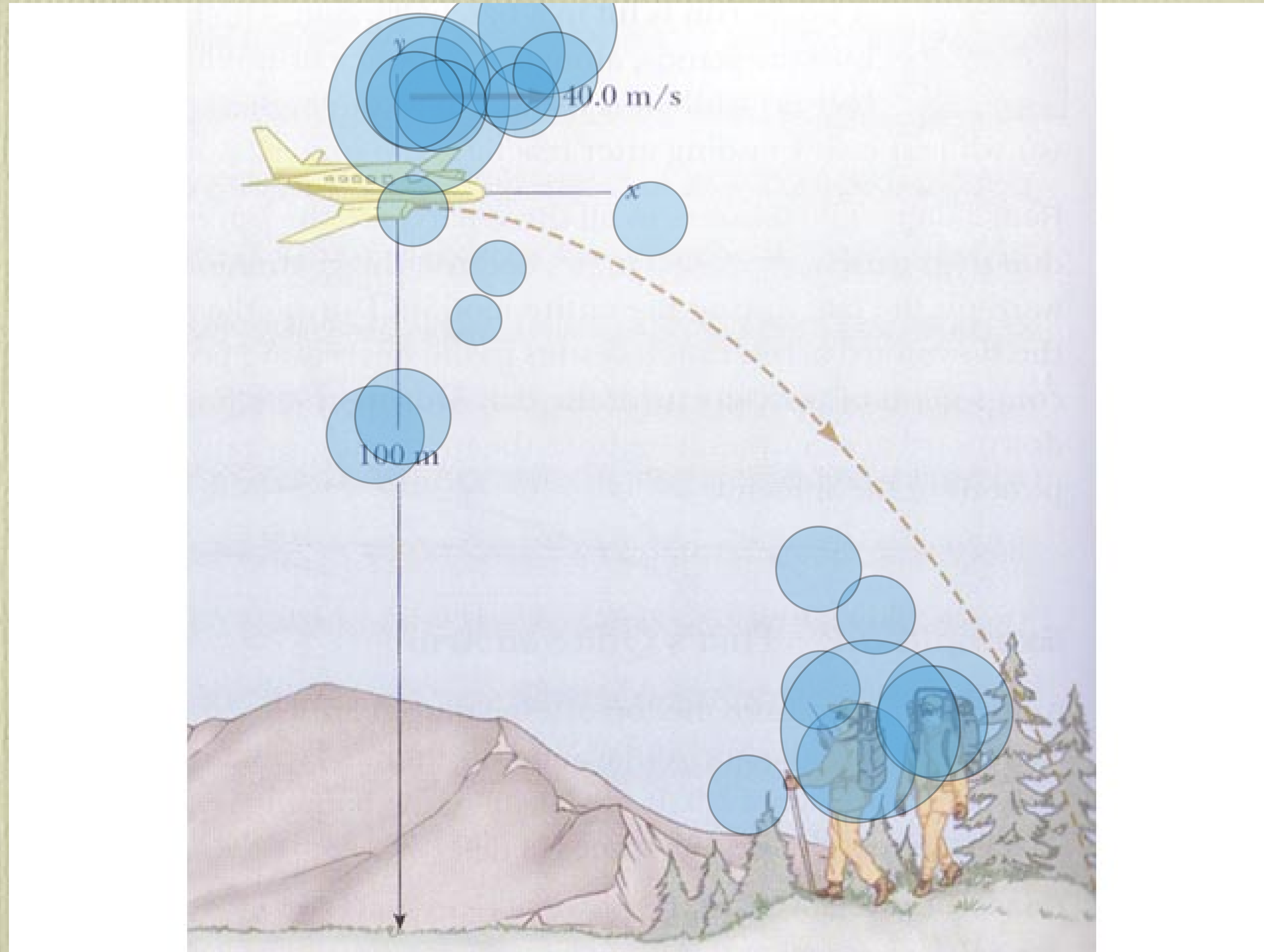
Mazur (Prentice Hall, 200?)

People look at

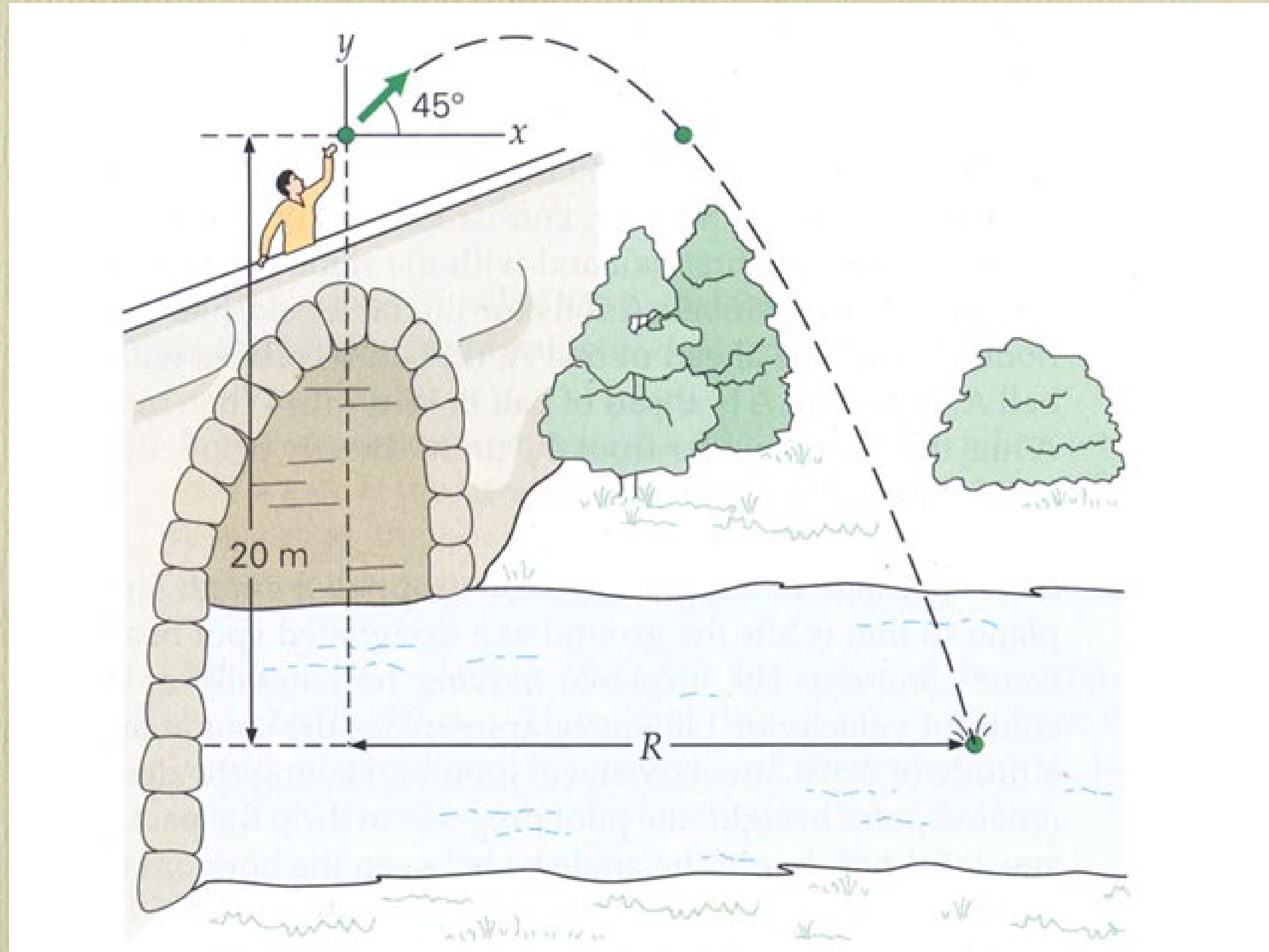
- Parabolic motion of ball
- Carts



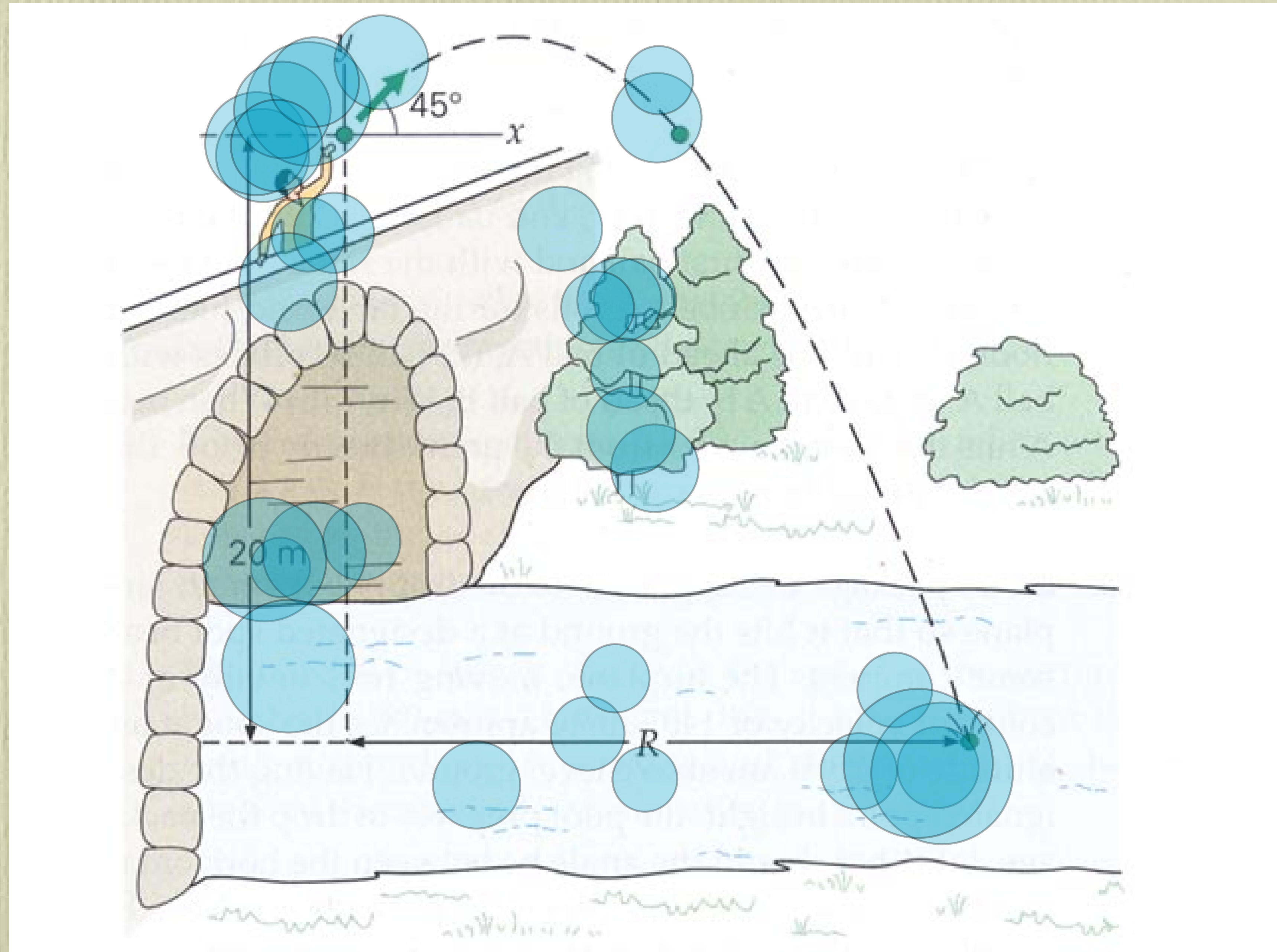
Serway and Jewett (Harcourt, 2002)



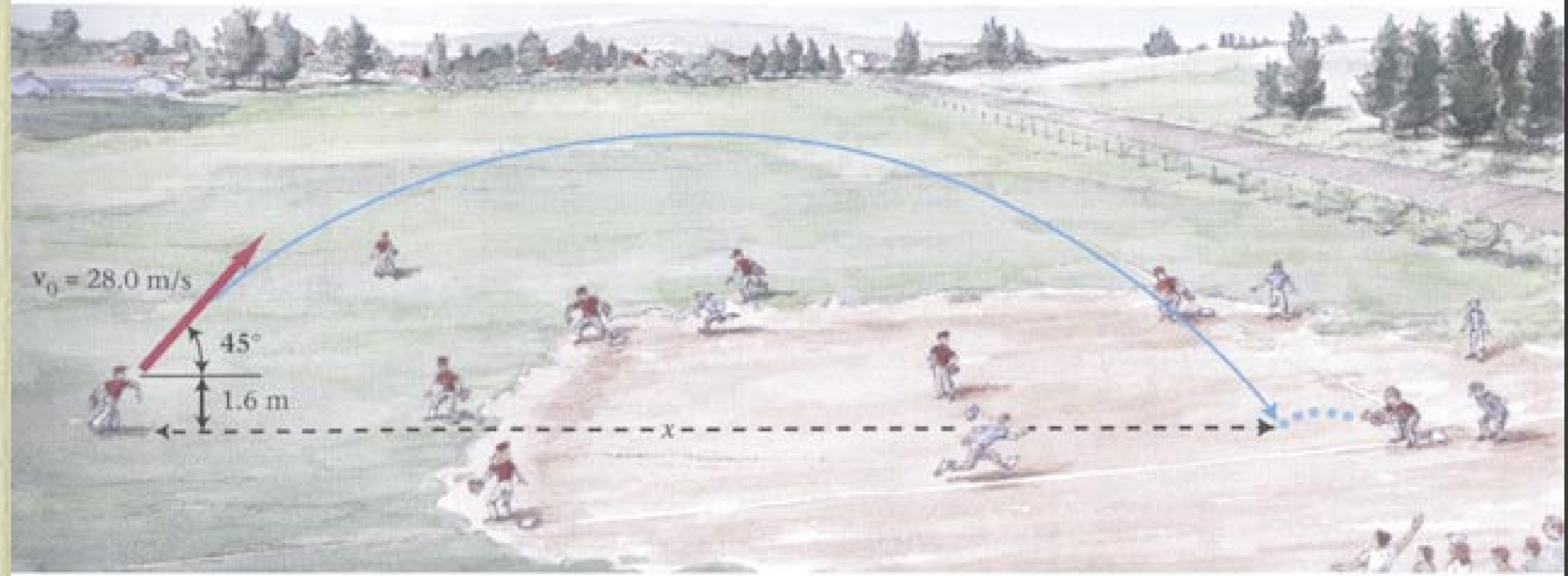
Serway and Jewett (Harcourt, 2002)



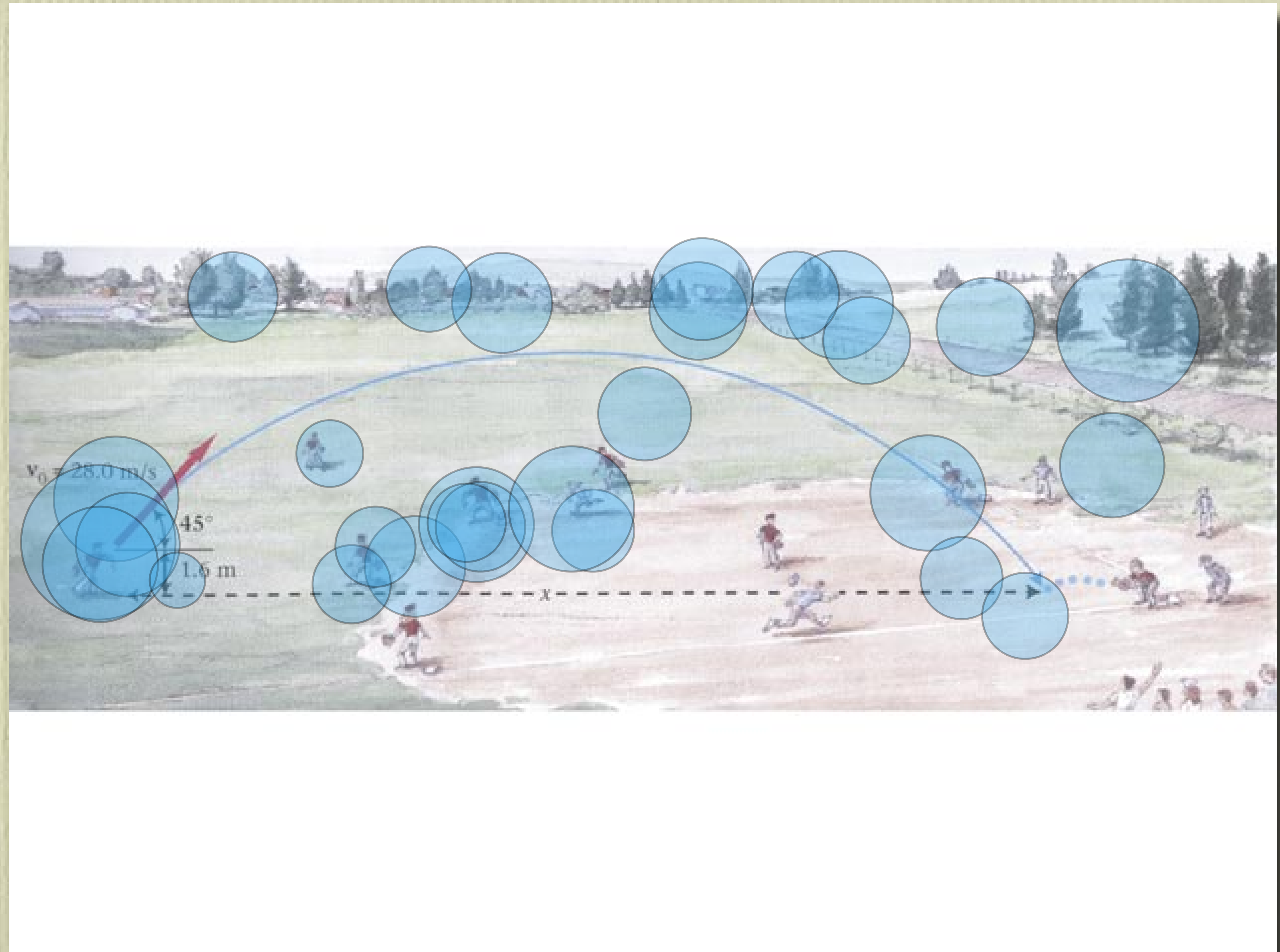
Wilson and Buffa, 5th Ed. (Prentice Hall, 2003)



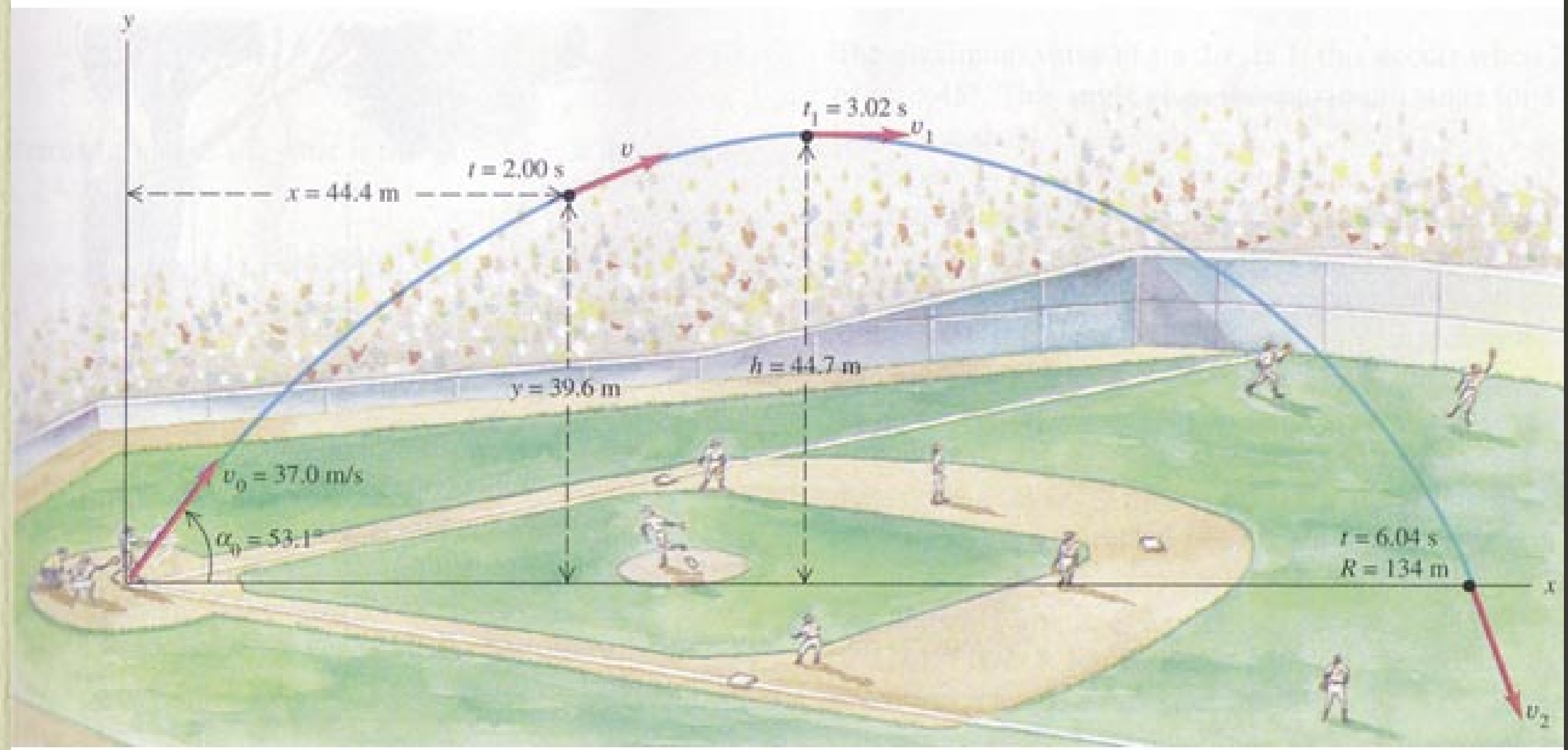
Wilson and Buffa, 5th Ed. (Prentice Hall, 2003)



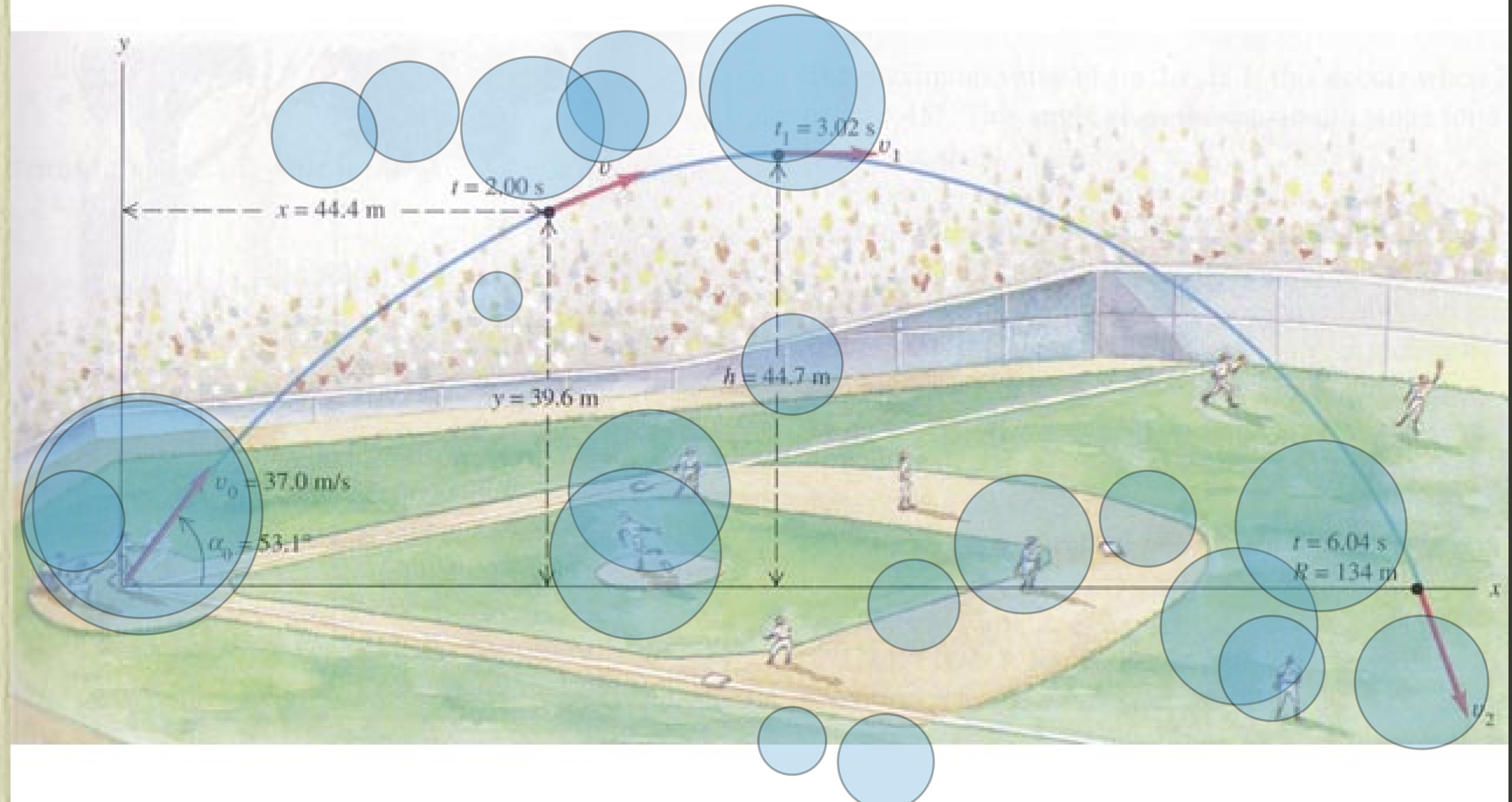
Jones and Childers, 3rd Ed. (McGraw Hill, 2001)



Jones and Childers, 3rd Ed. (McGraw Hill, 2001)



Sears and Zemansky (Addison Wesley, 2000)



Sears and Zemansky (Addison Wesley, 2000)

People look at

- People
- Text labels
- Other (distracting) elements

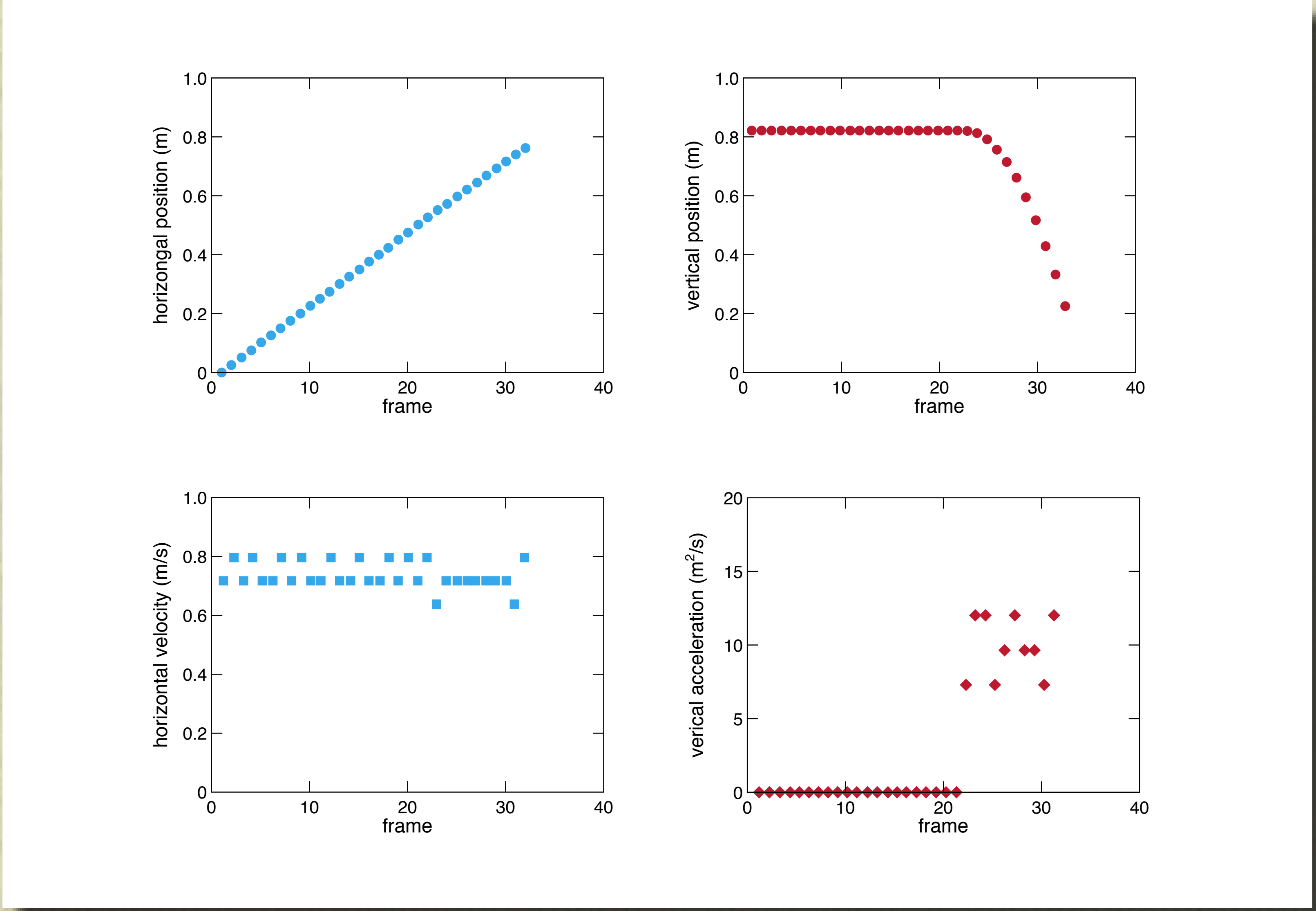
People look at

- People
- Text labels
- Other (distracting) elements

but not the parabolic motion!

How can we effectively teach parabolic motion?

Measurements



Summary

- Color and luminance processed separately
- Mental models & tasks affect what is seen
- Realism can be problematic

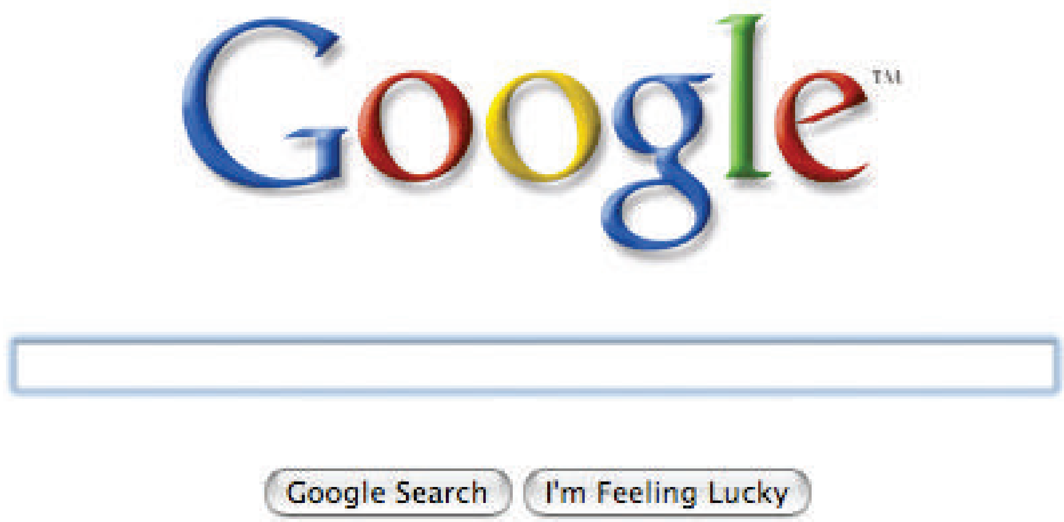
Good visualizations

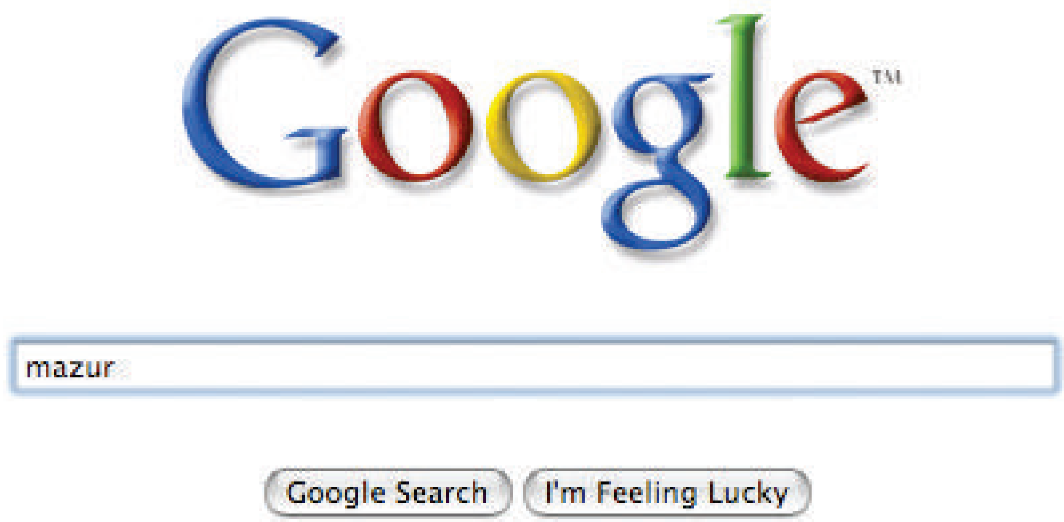
- Reduce information to a minimum
- Take into account how the brain processes information
- Are provided in an engaging context

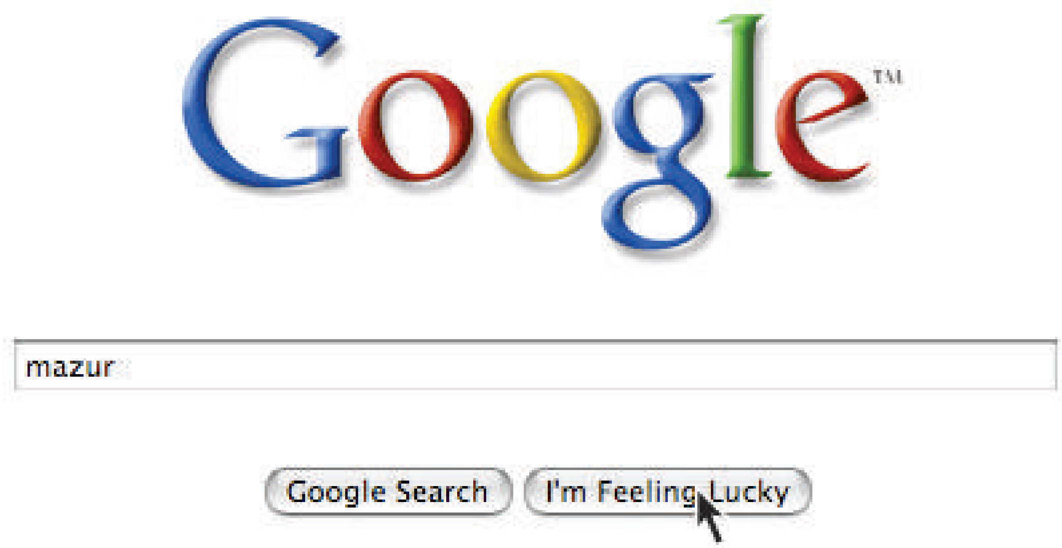
Acknowledgments

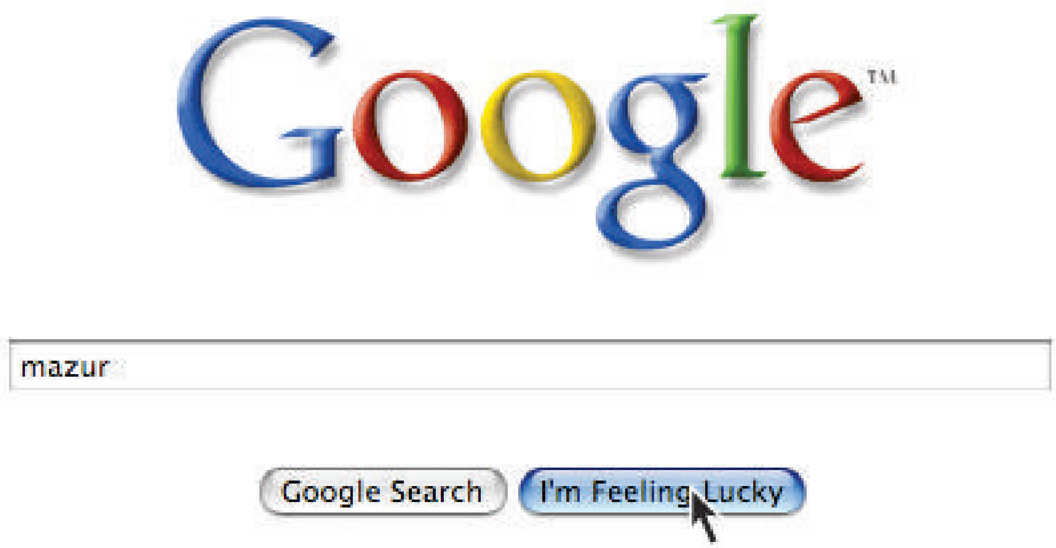
Prof. Mazharin Banaji
Prof. Patrick Cavanagh
Prof. Steven Franconeri (Northwestern)
Rafael Gattass
Joanna Huey
Olof Jonmarker
Prof. Margaret Livingstone
Dr. Veronica McCauley
Dr. Wolfgang Rueckner
Prof. Daniel Simons (UIUC)

for a copy of this presentation see:
http://mazur-www.harvard.edu


Google™
Google Search
I'm Feeling Lucky


Google™
mazur
Google Search
I'm Feeling Lucky


Google™
mazur
Google Search
I'm Feeling Lucky


Google™
mazur
Google Search
I'm Feeling Lucky

Acknowledgments

Prof. Mazharin Banaji
Prof. Patrick Cavanagh
Prof. Steven Franconeri (Northwestern)
Rafael Gattass
Joanna Huey
Olof Jonmarker
Prof. Margaret Livingstone
Dr. Veronica McCauley
Dr. Wolfgang Rueckner
Prof. Daniel Simons (UIUC)

for a copy of this presentation see:
http://mazur-www.harvard.edu