

# How the mind tricks us: Visualizations and visual illusions



Public Lecture  
Questacon  
Canberra, Australia, 26 March 2009



# 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

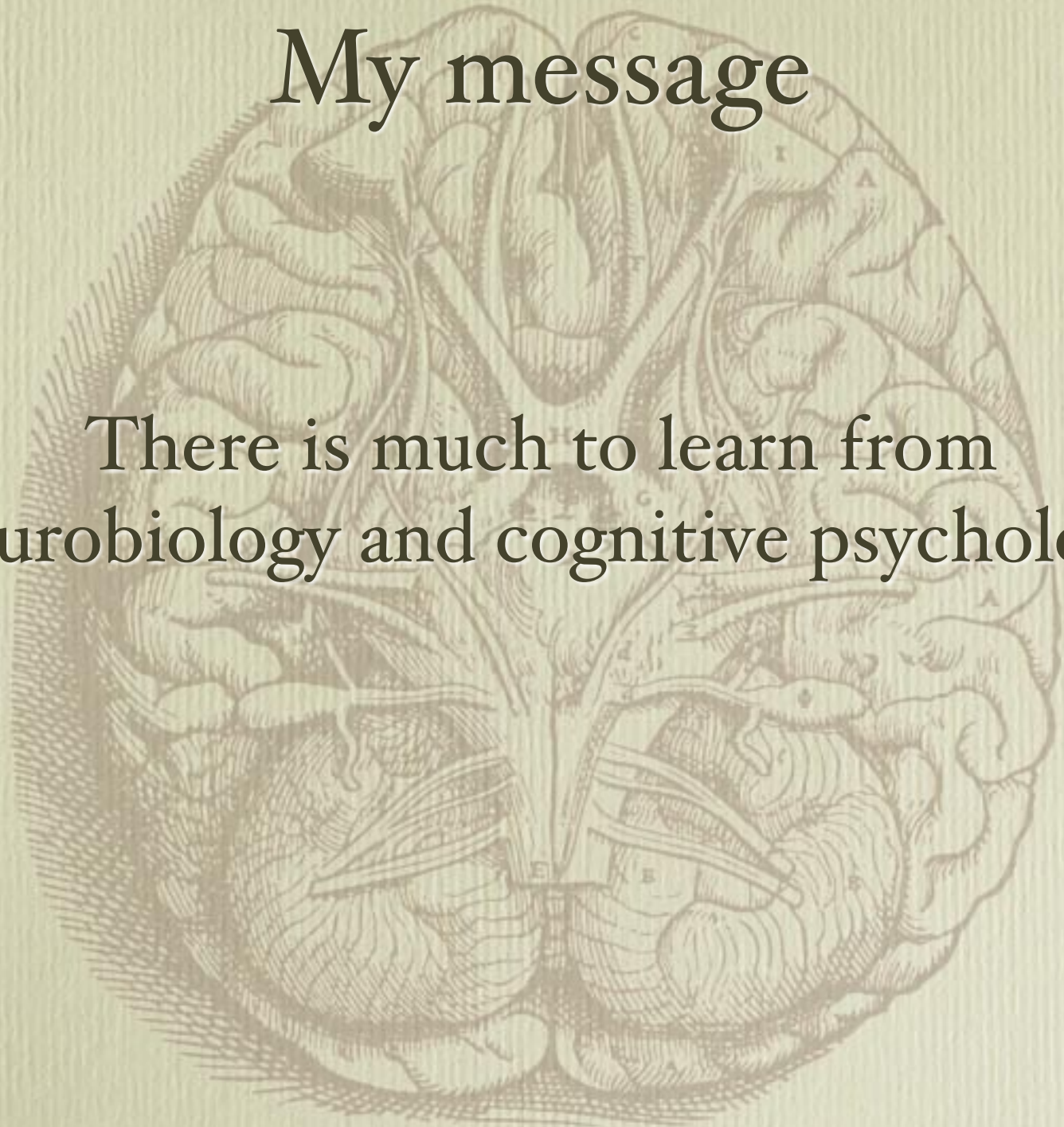
1 picture = 1000 words

*“Information can be transferred more quickly and more effectively visually than verbally”*

1 = disagree, 5 = agree

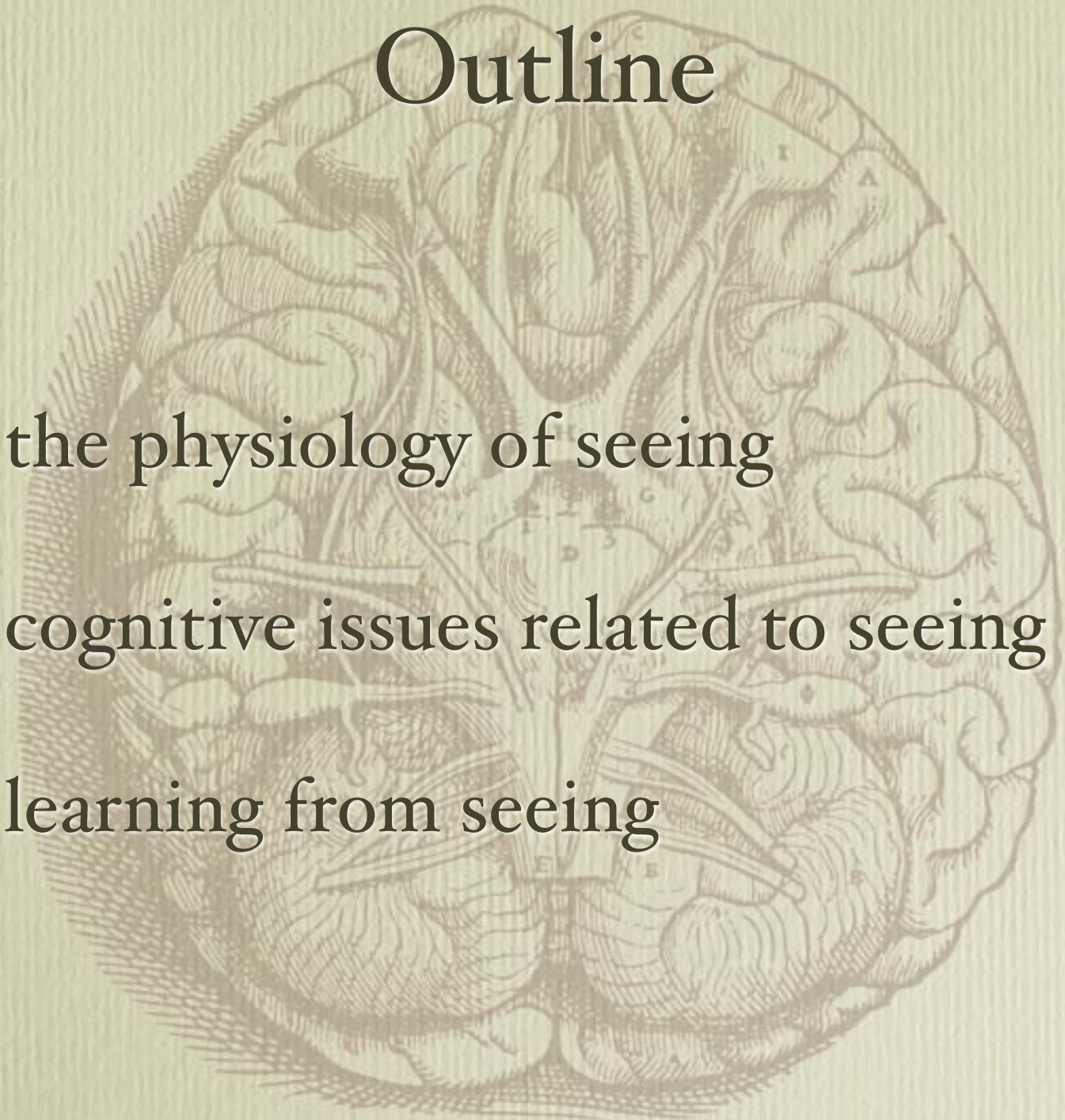
# My message

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

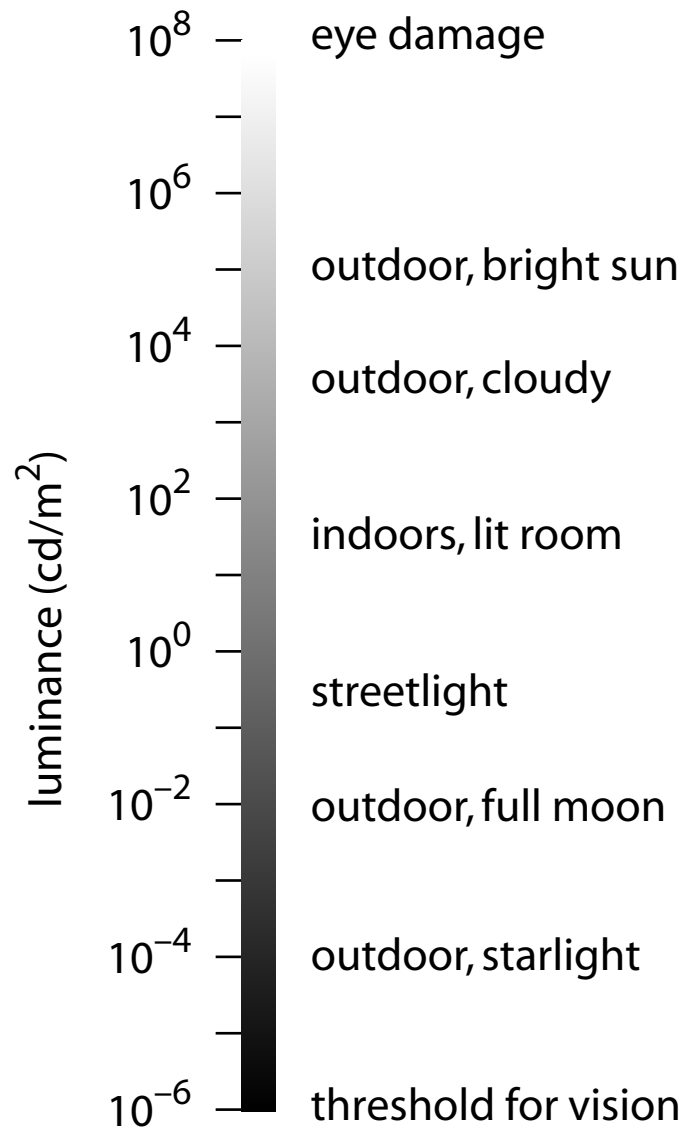


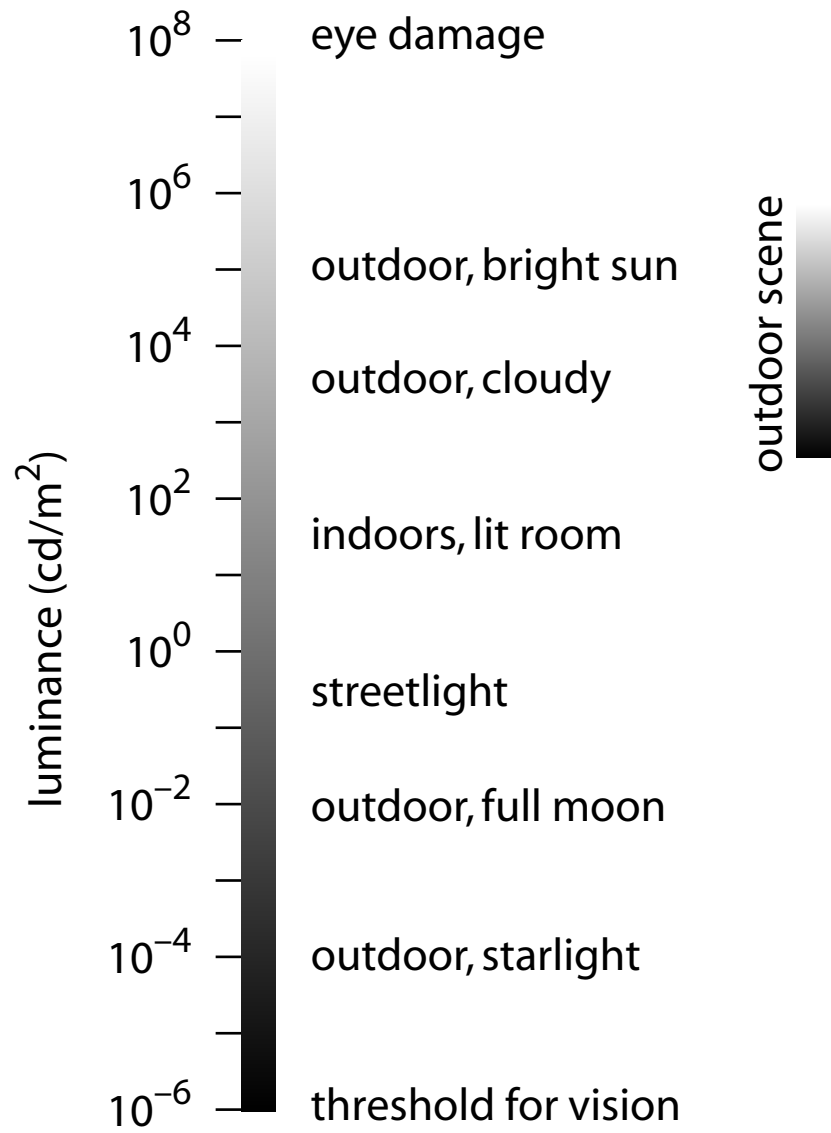
# Human vision

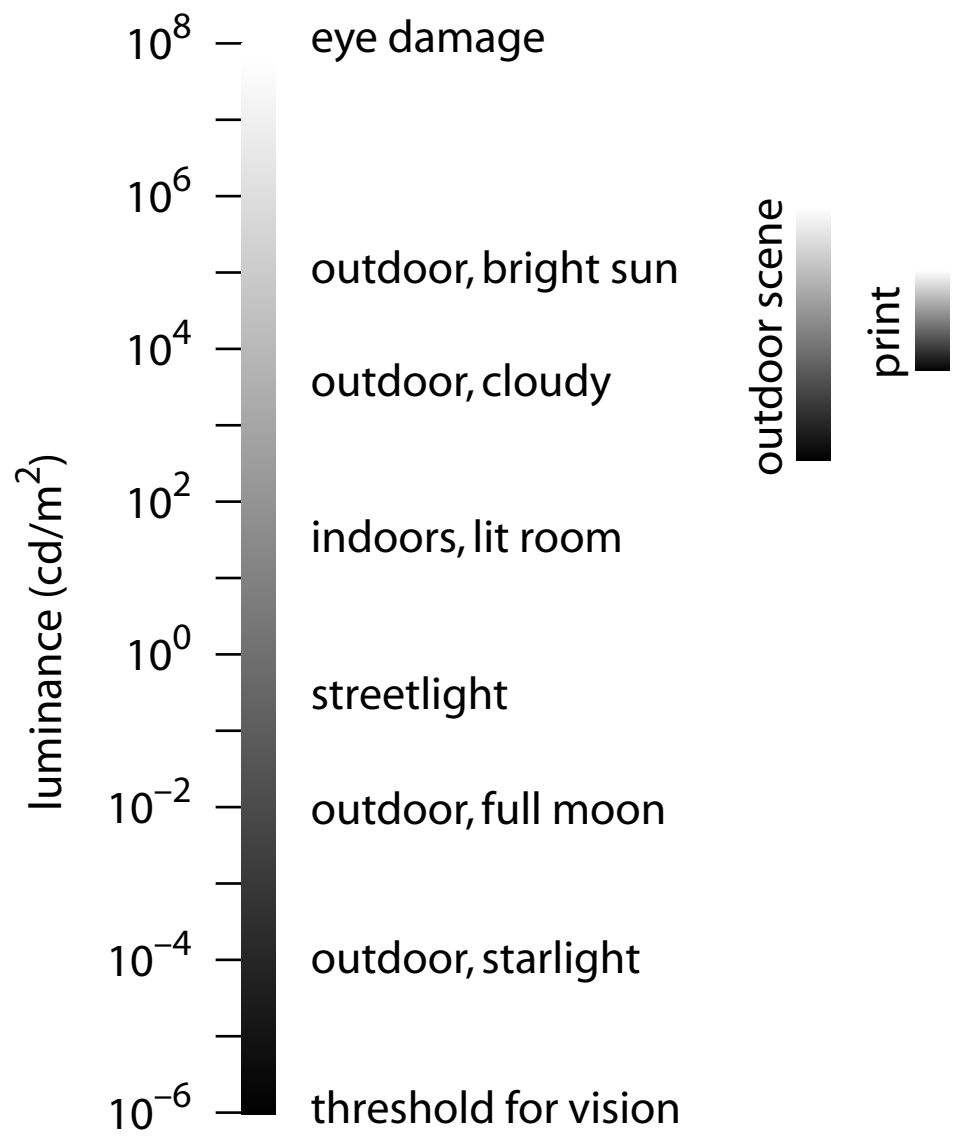
- Small frequency range
- Huge luminance range

# Luminance

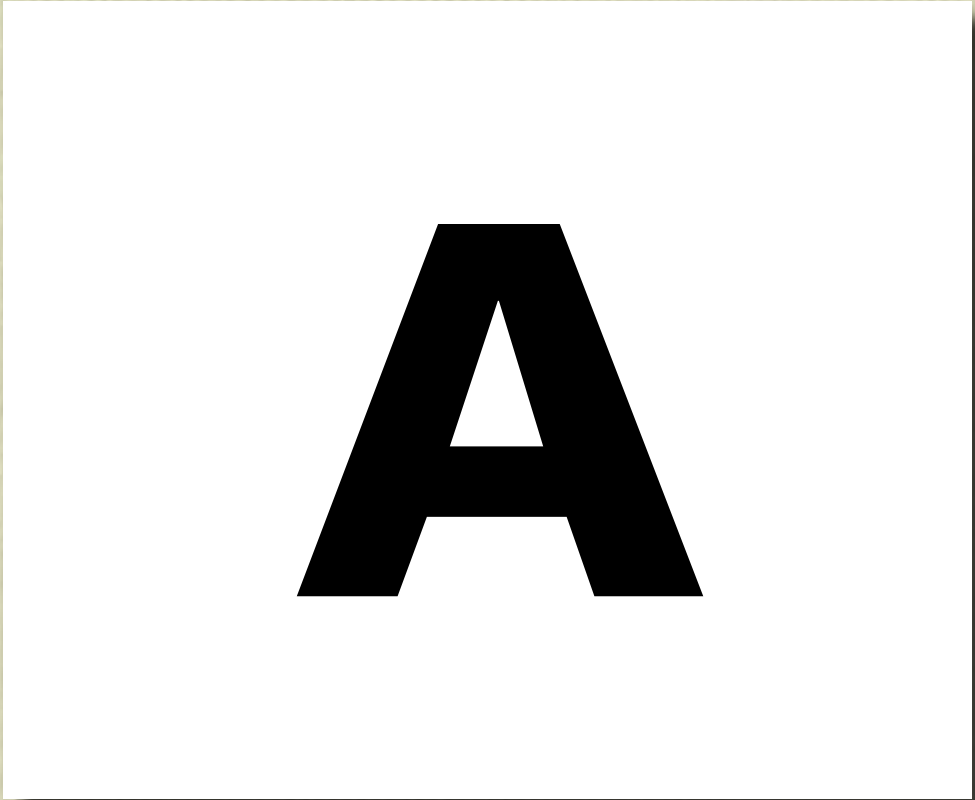
- Light energy radiated/reflected
- Determined by reflectance and illumination

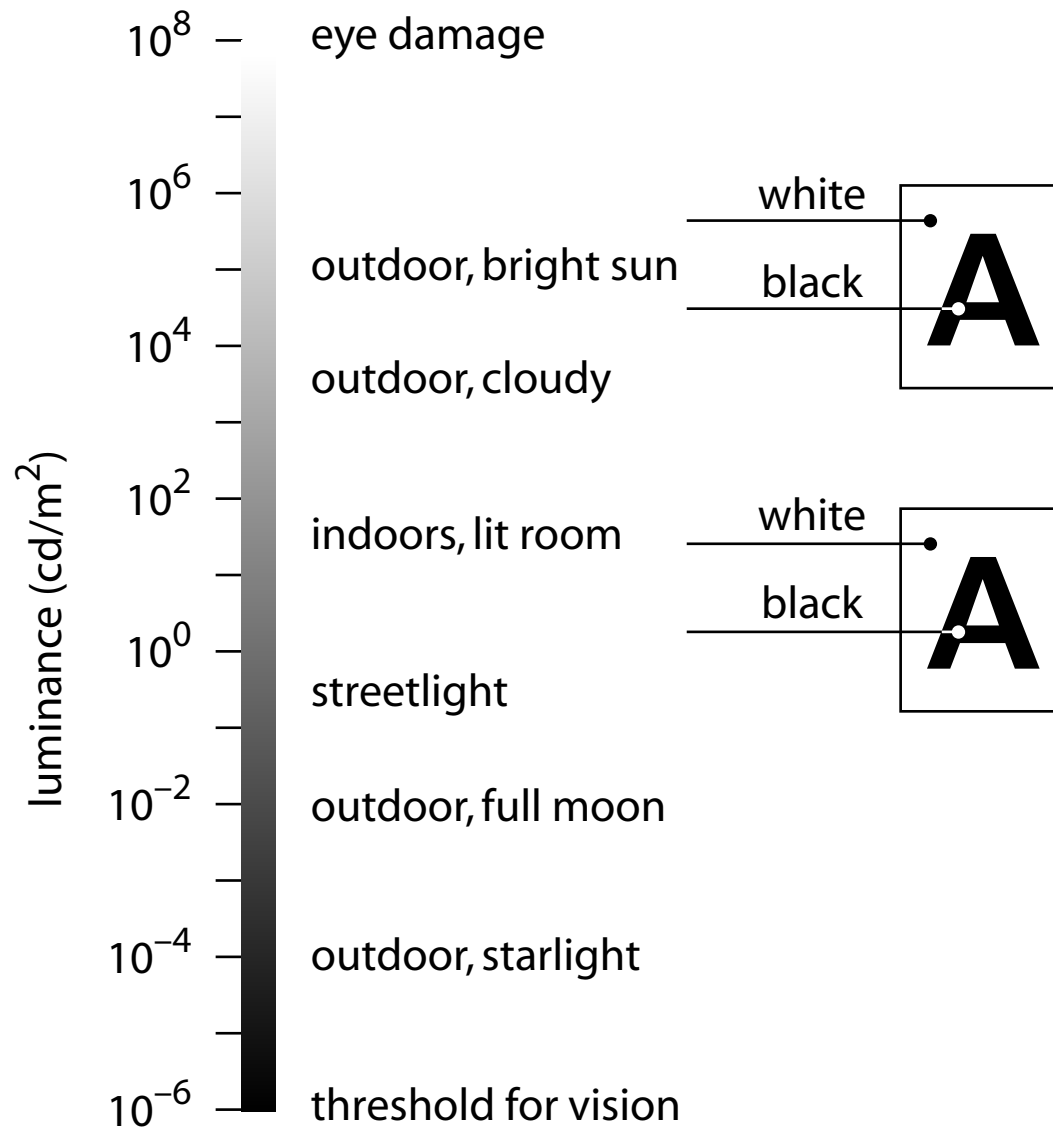






What color?

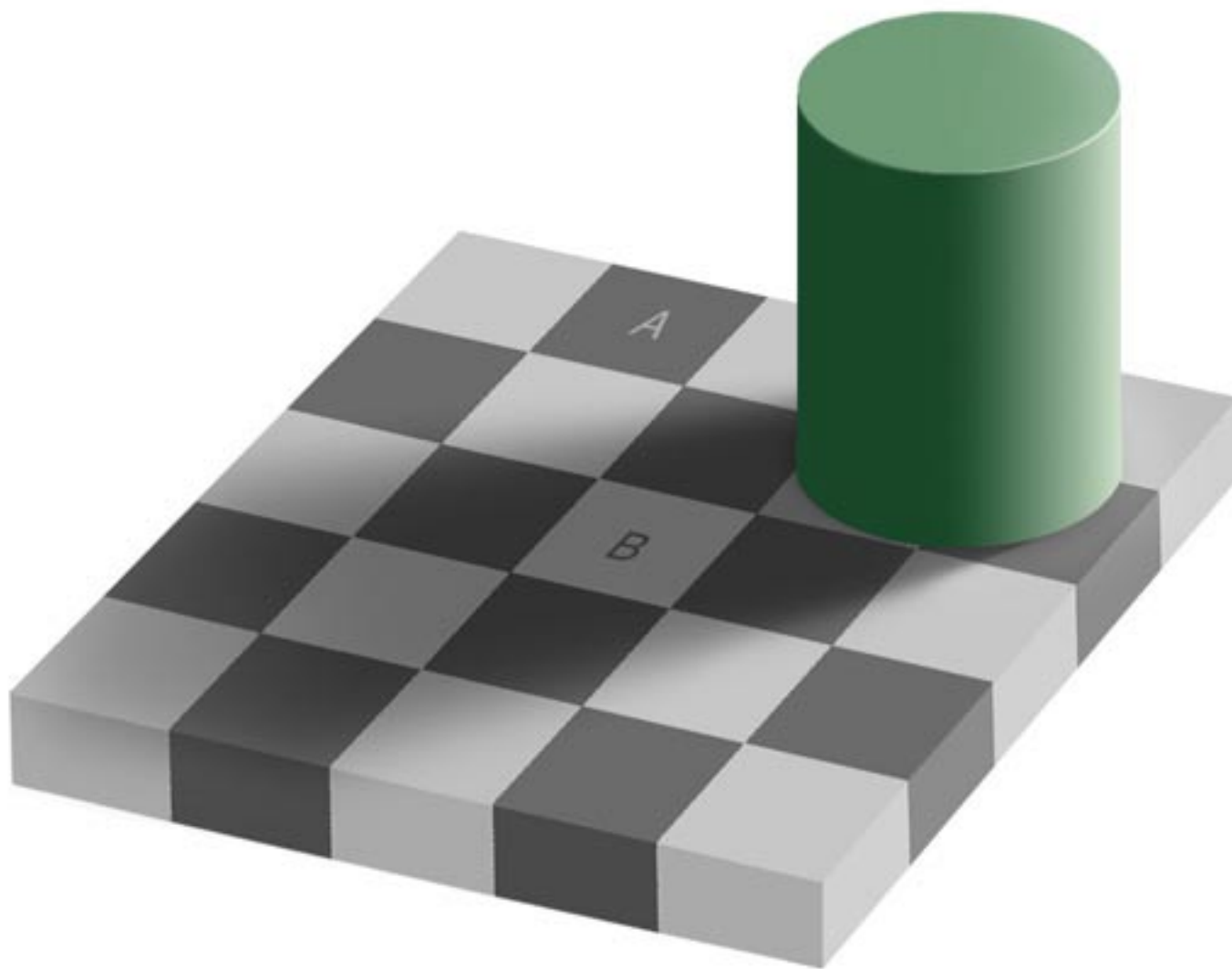
A large, bold, black capital letter 'A' is centered on a white square background. The white square is set against a light beige, textured background. The letter 'A' is composed of thick, solid black strokes.

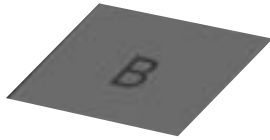
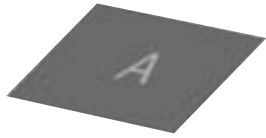


# What the retina does:

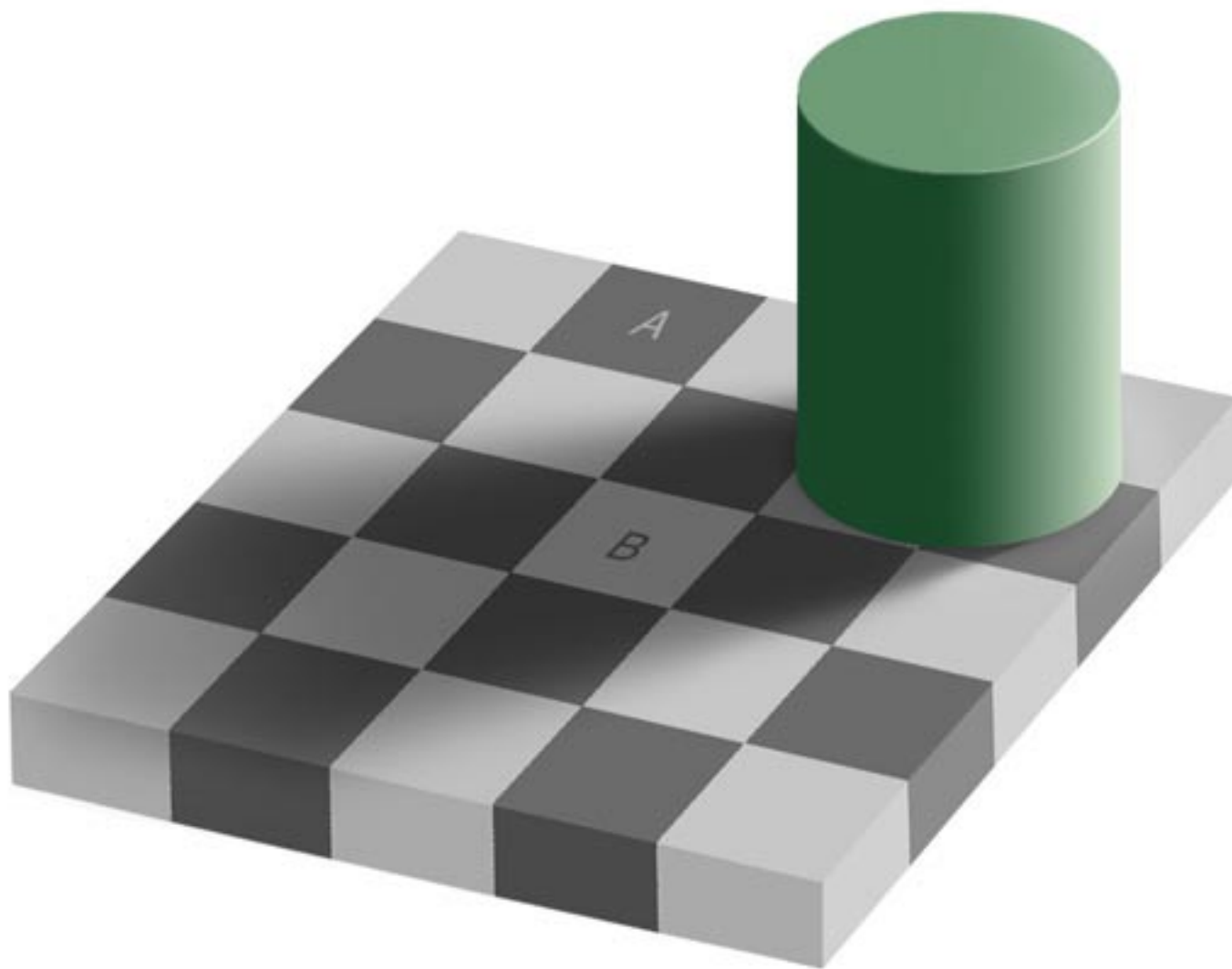
- Spatial compression
- Adjust luminance range to nerve S/N
- Extract reflectance

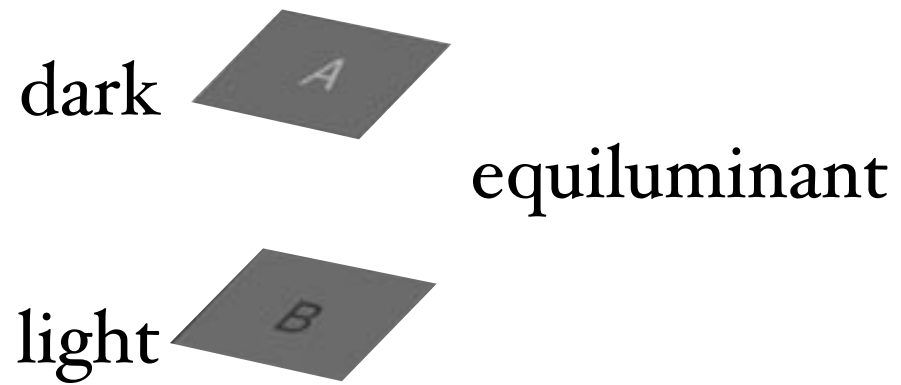








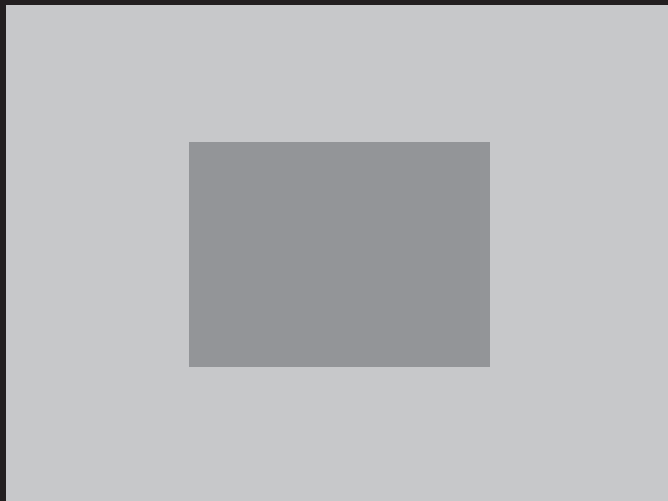




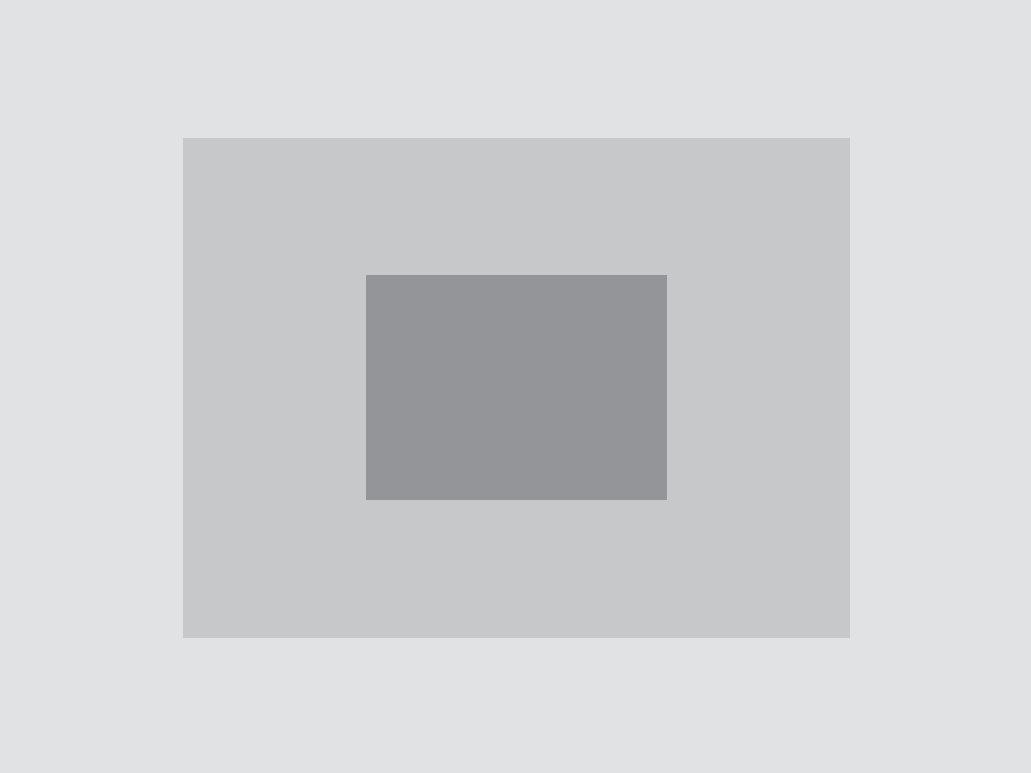
$\text{luminance} = \text{illumination} + \text{reflectance}$

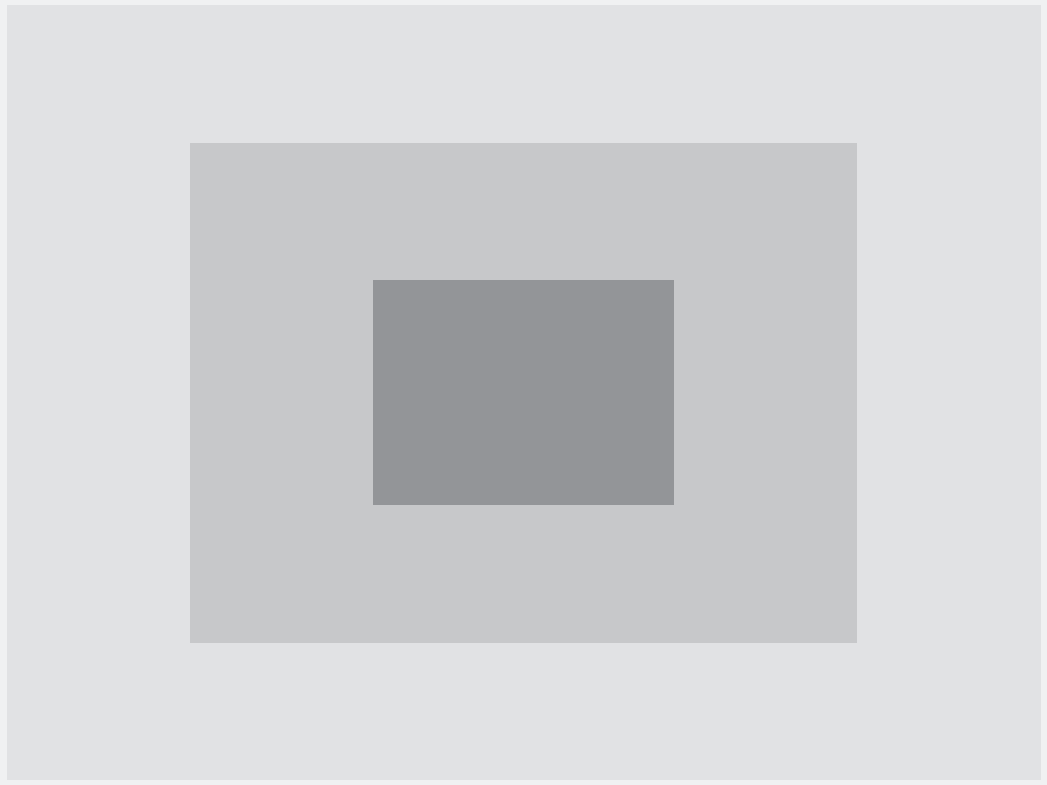


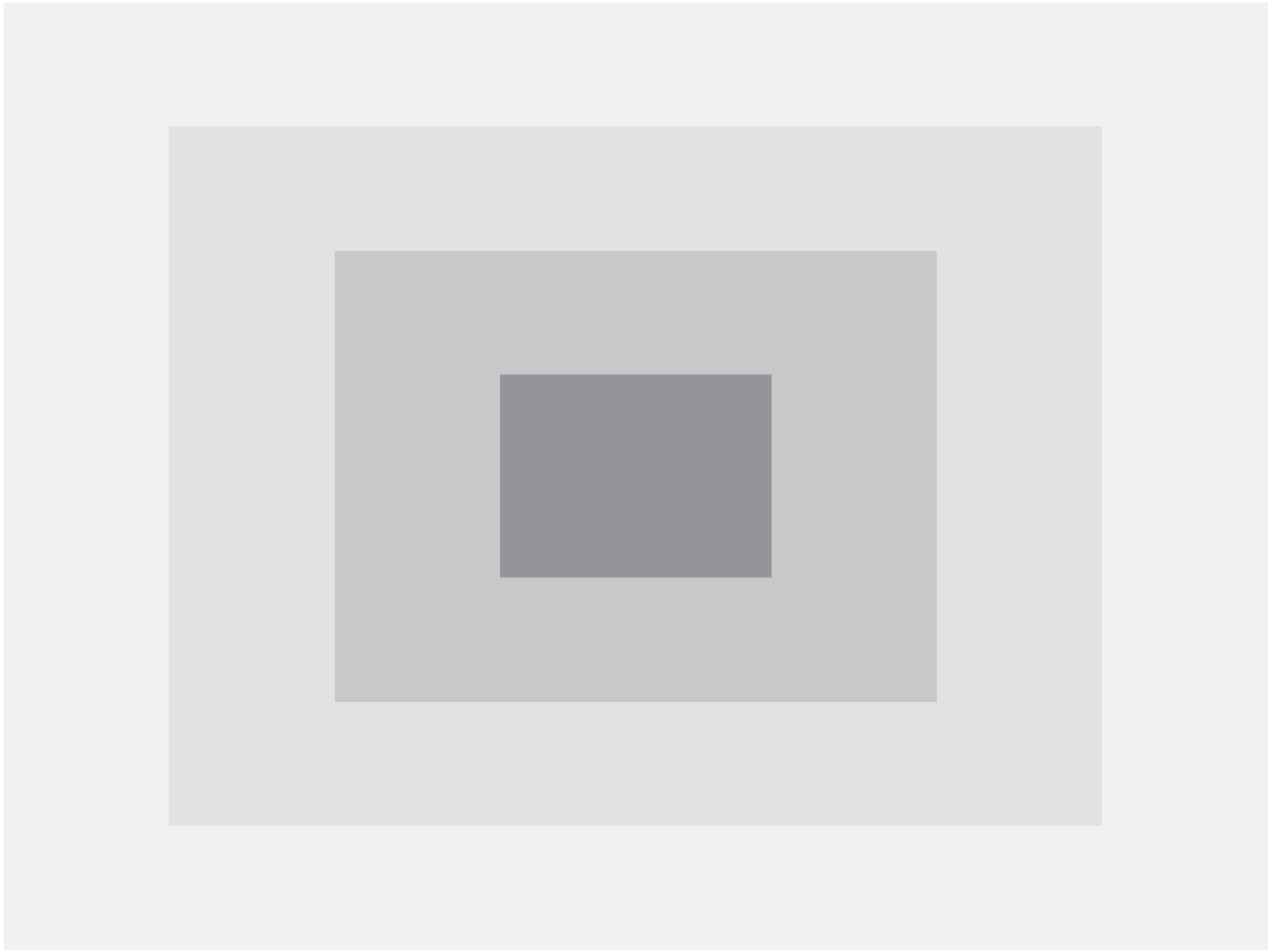










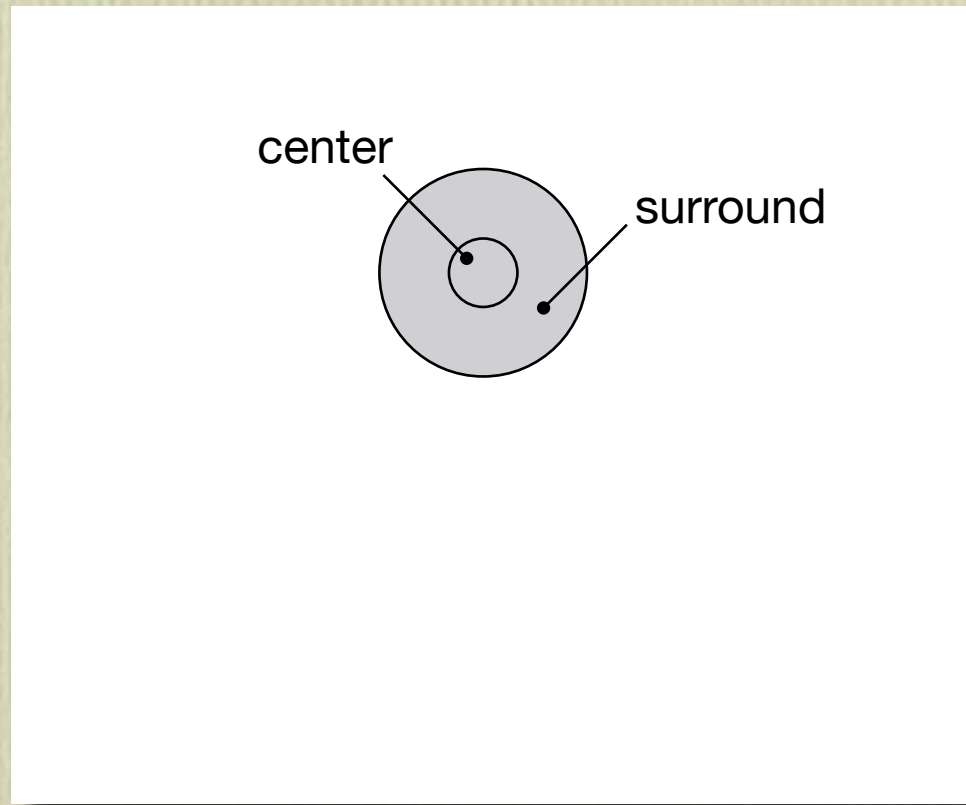


# Retinal cell organization

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

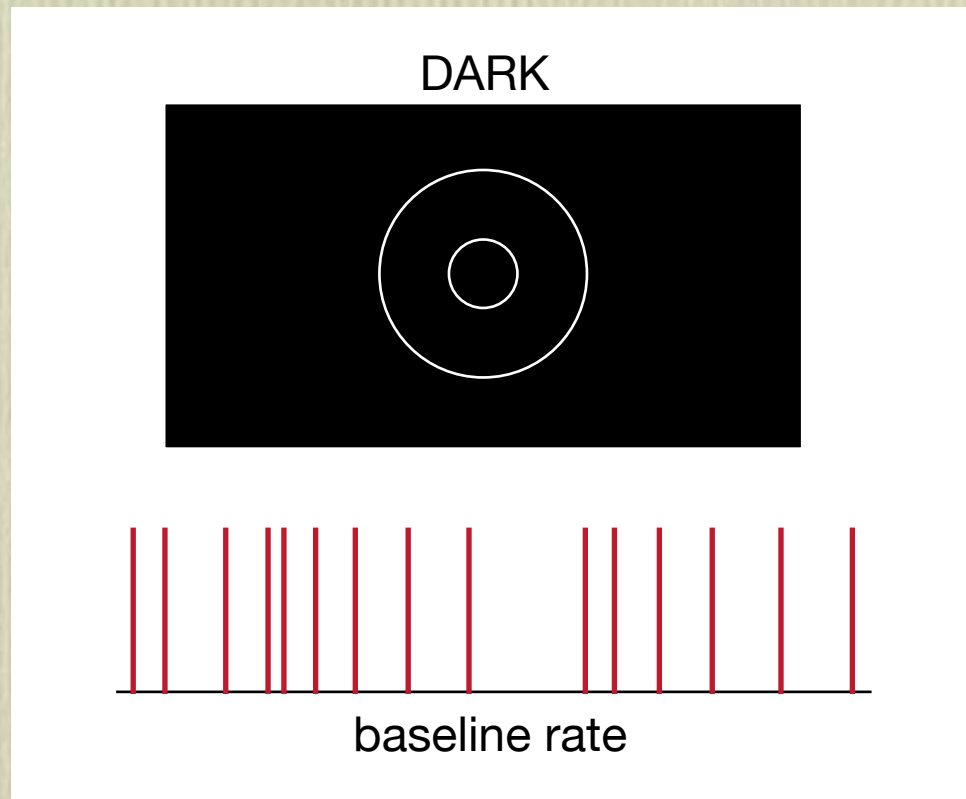
Each ganglion cell has a receptive field containing about 100 receptors

# Retinal cell organization

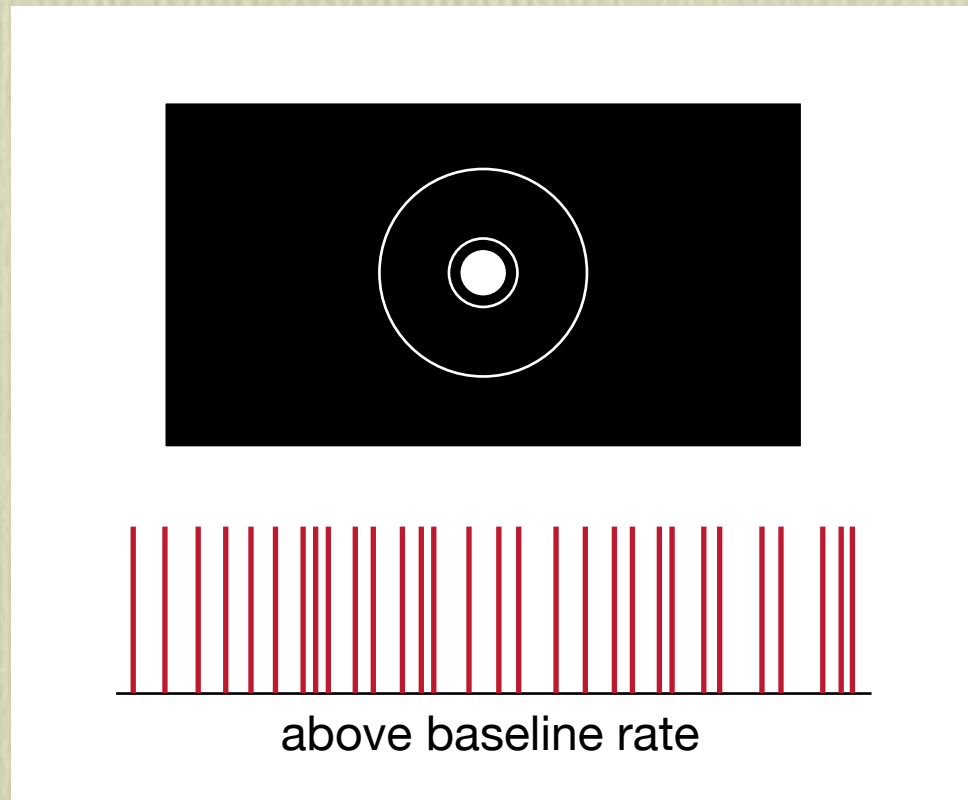


Receptive field divided into two regions

# Retinal cell response

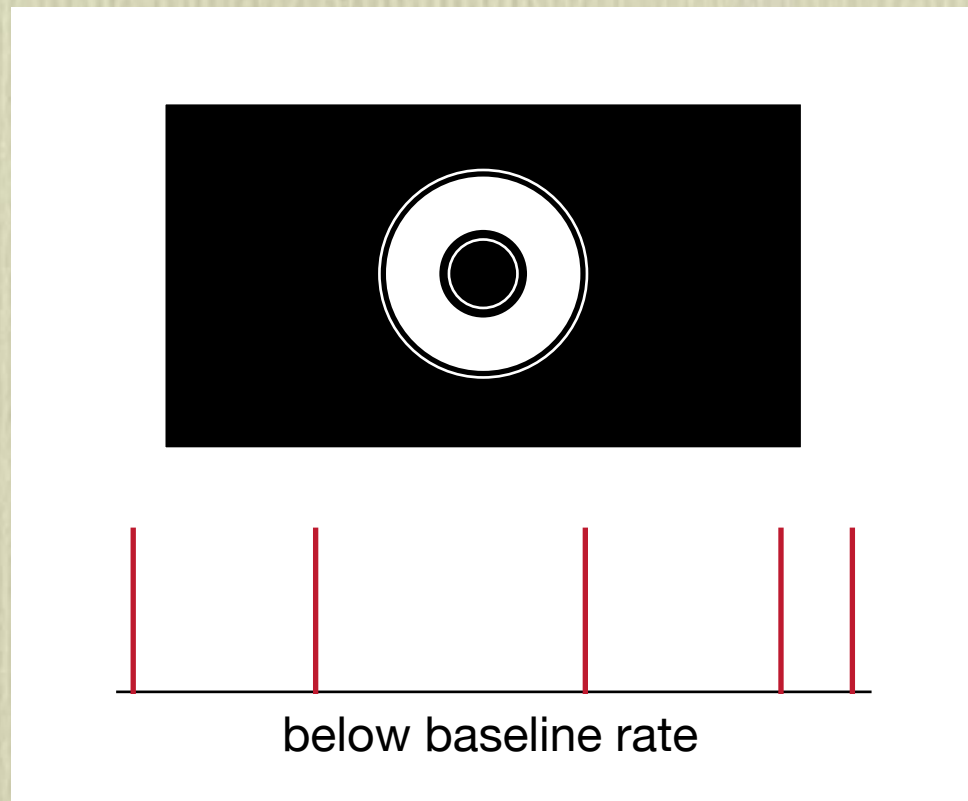


# Retinal cell response



Center excites

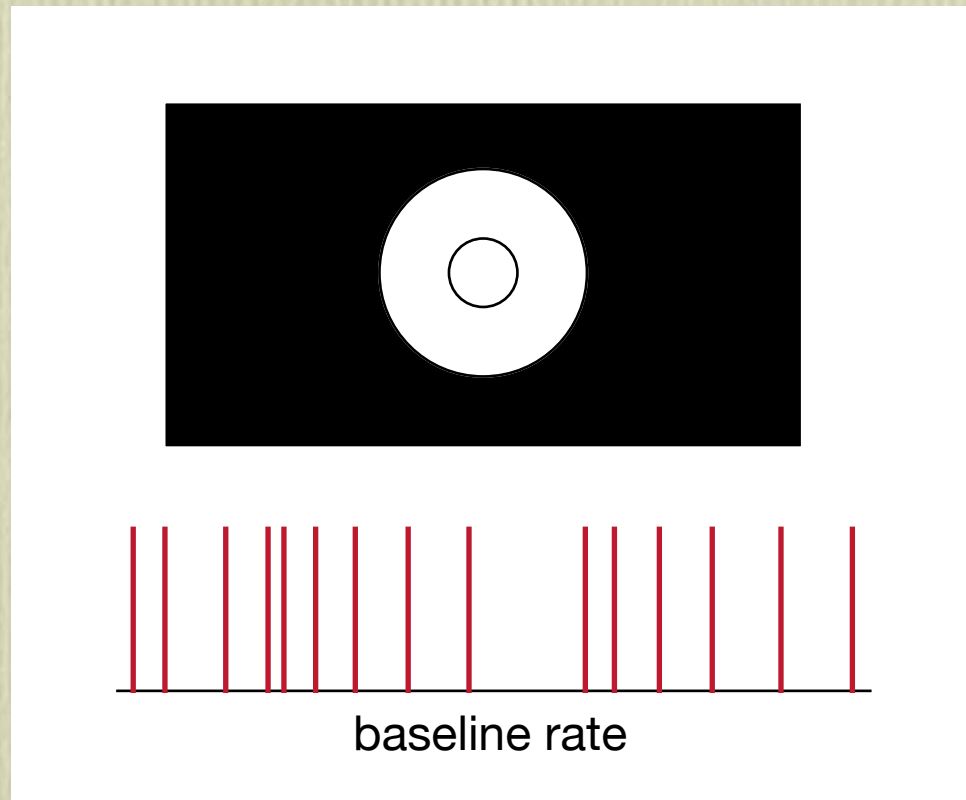
# Retinal cell response



Surround inhibits

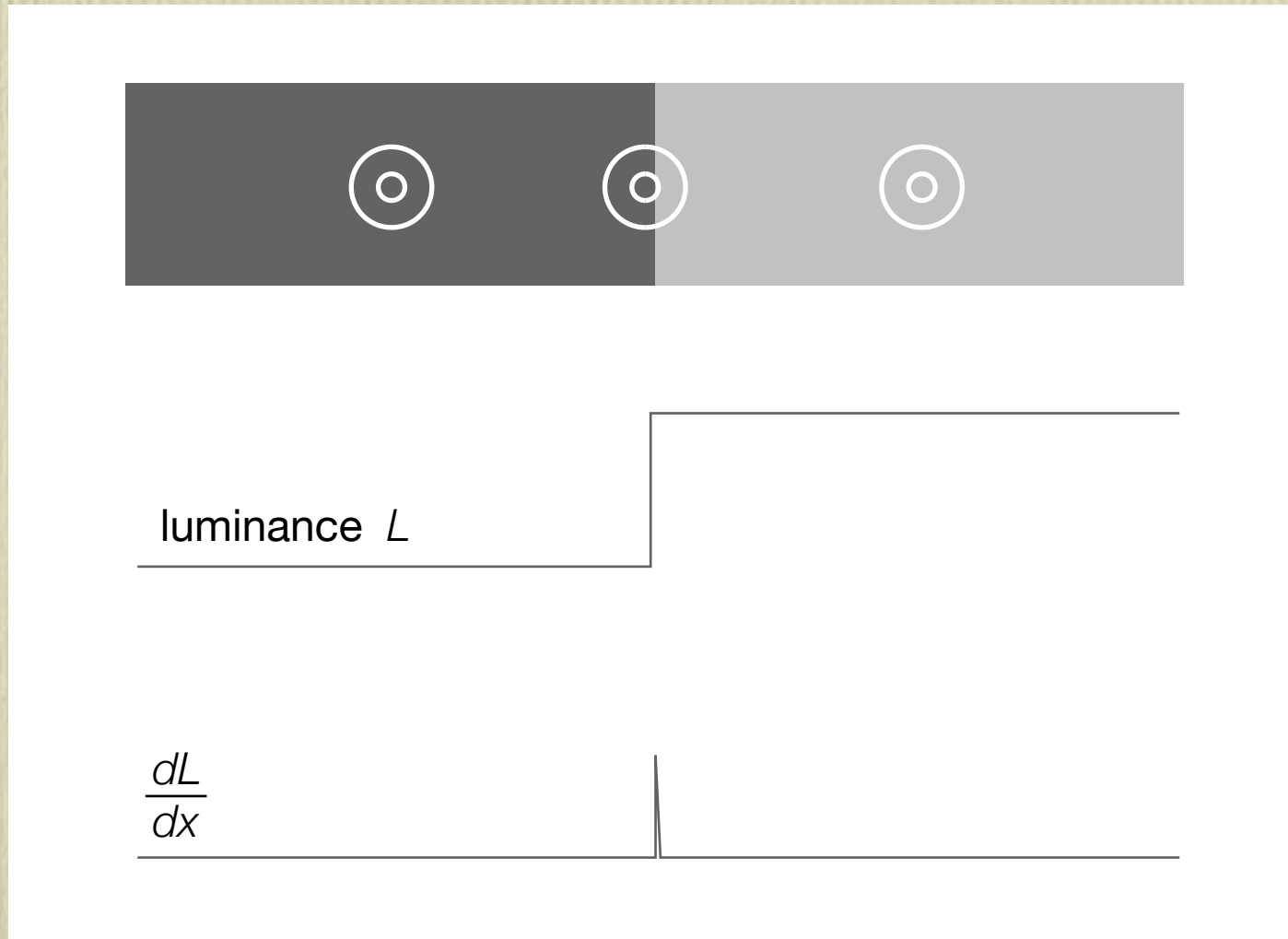


# Retinal cell response

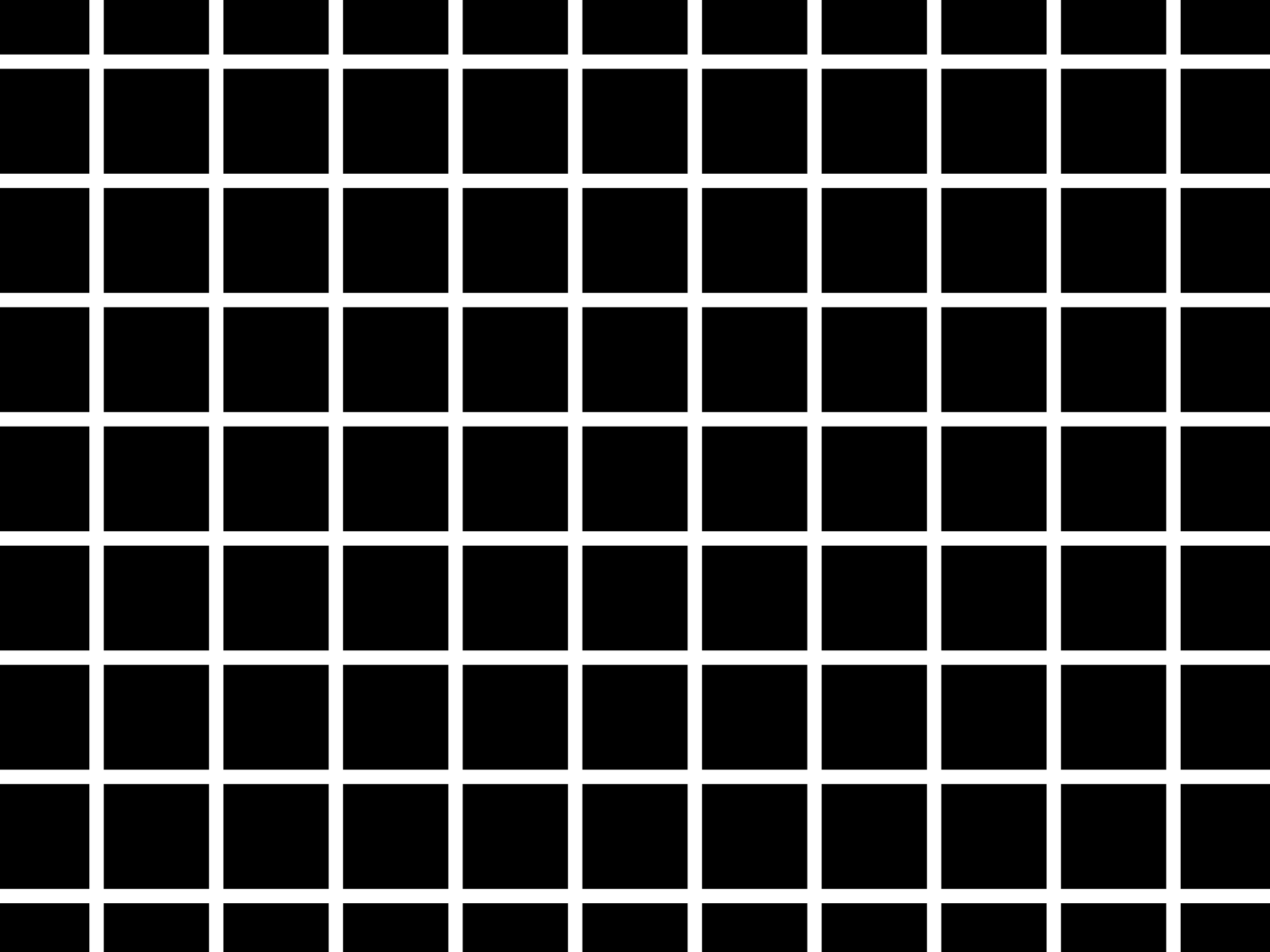


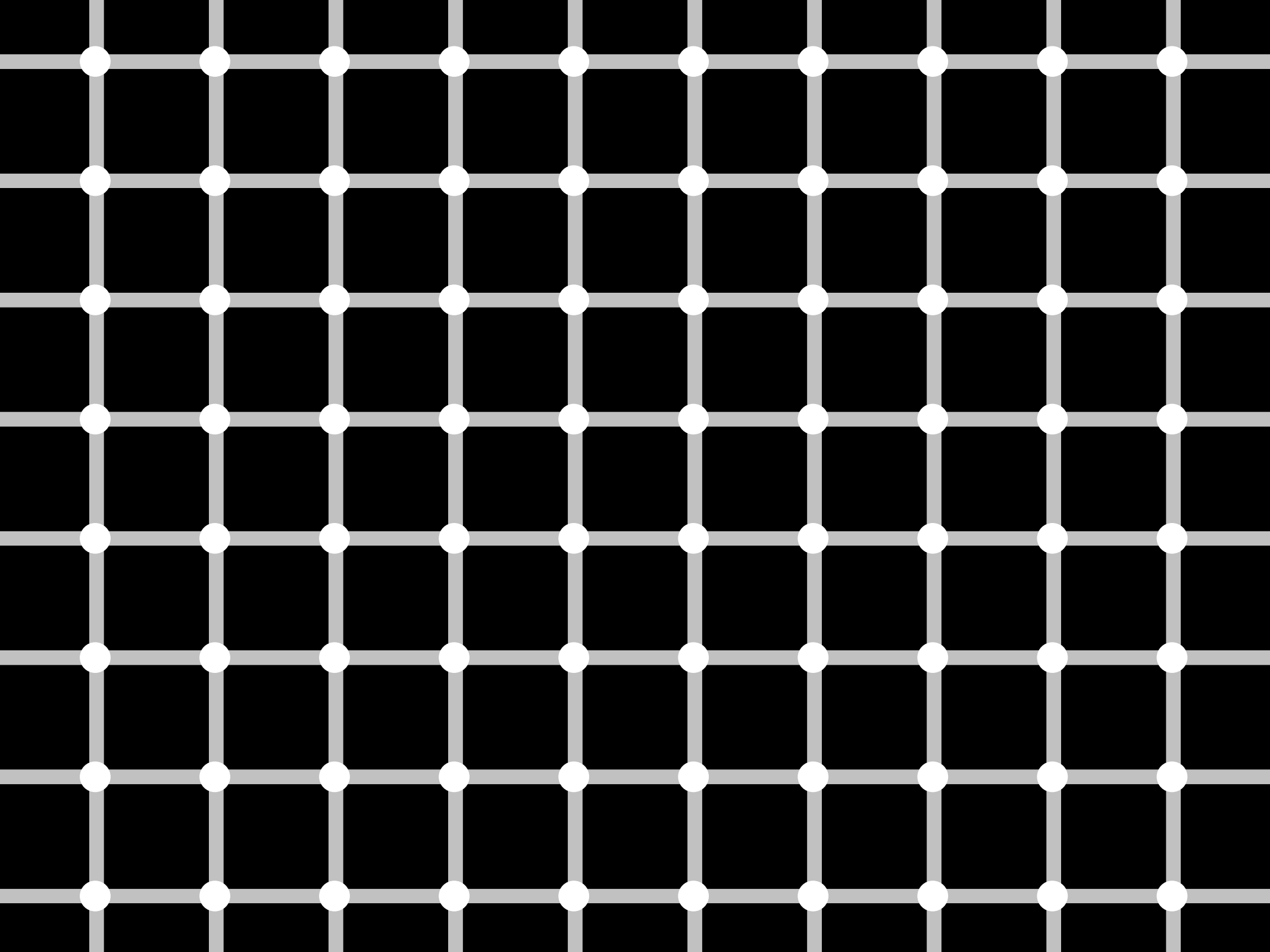
Full illumination same as no illumination

# Center-surround antagonism

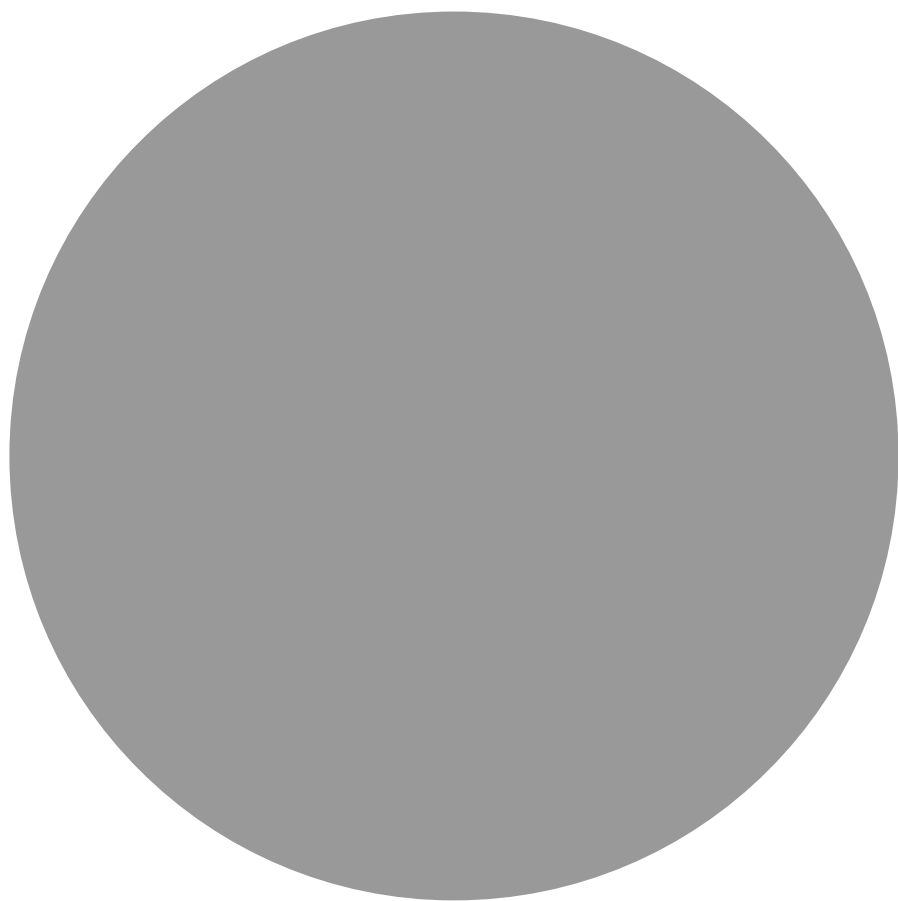


cells respond to *differences* in intensity

















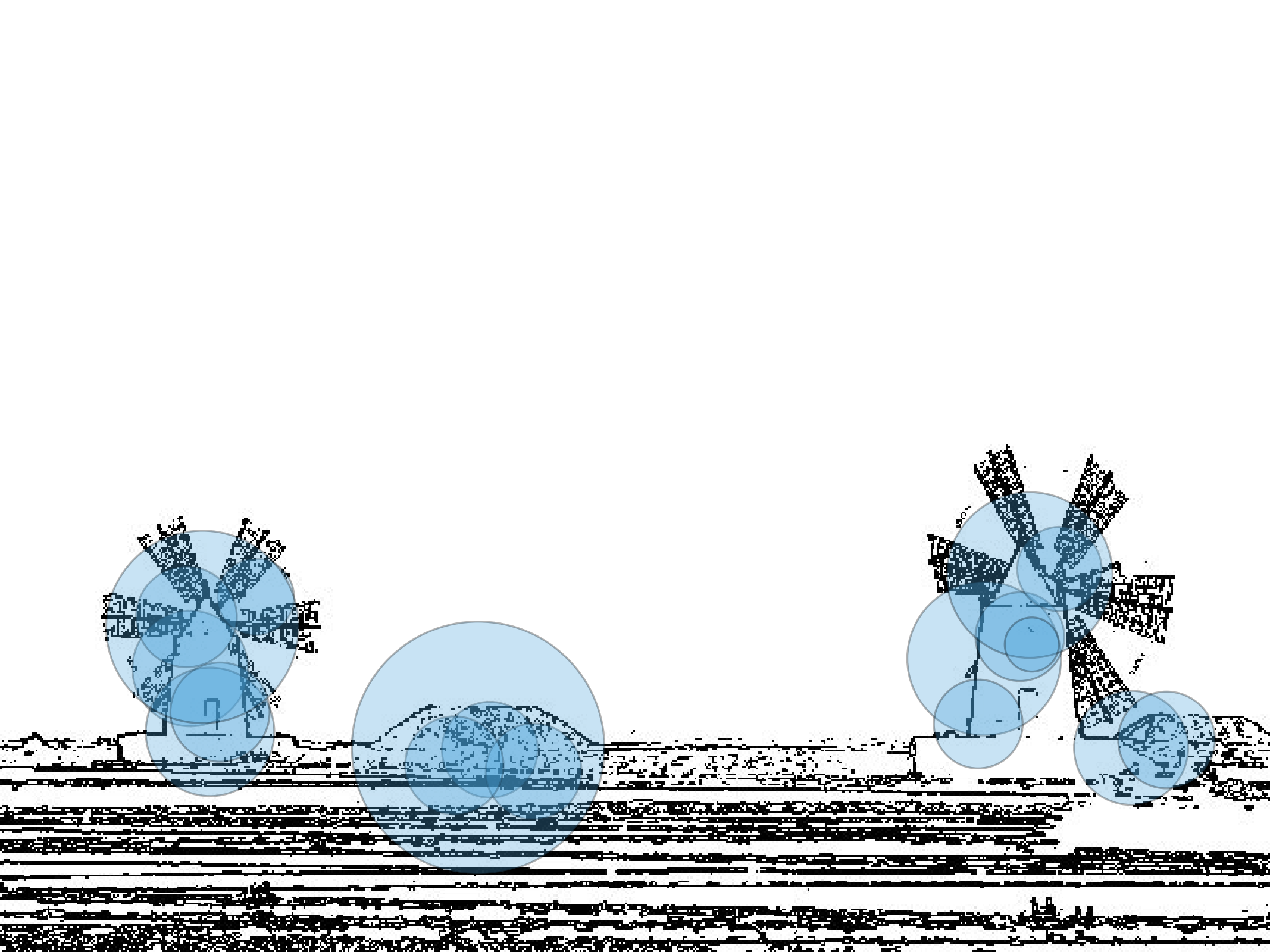


Sophie











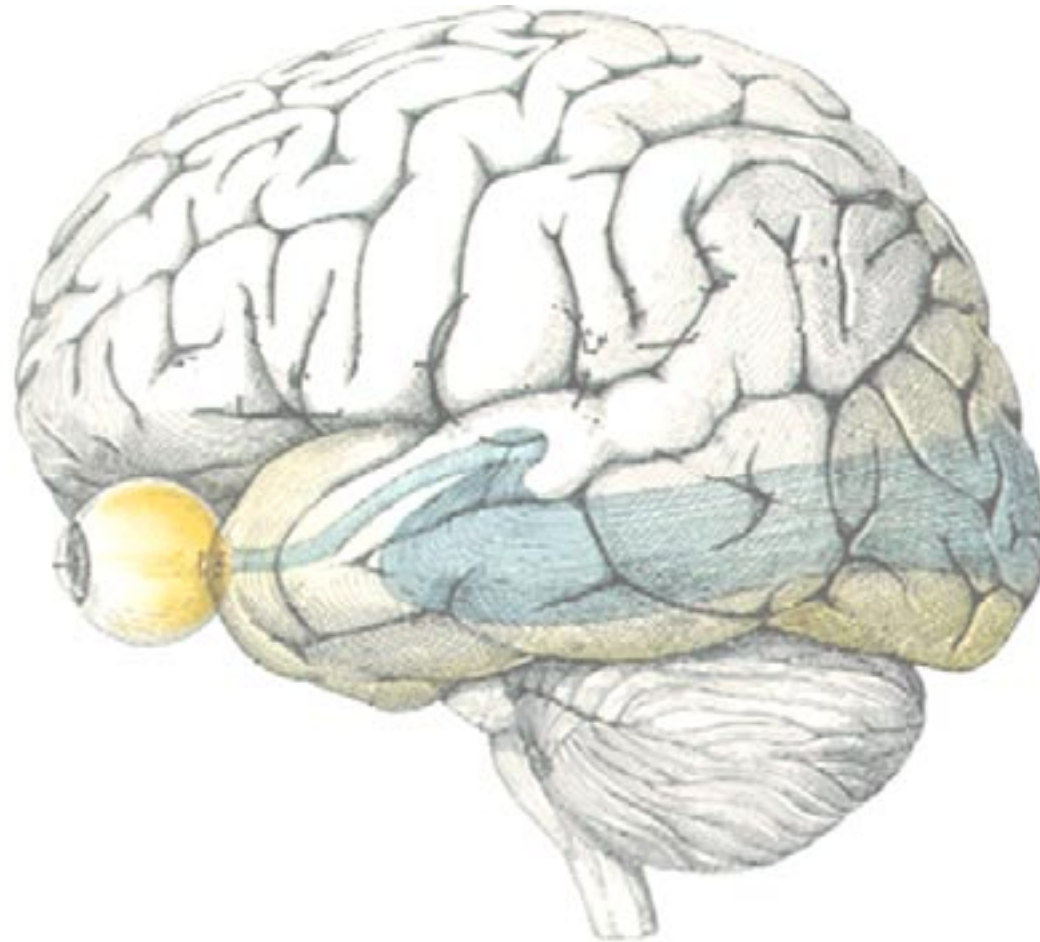
# Processing of visual information

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

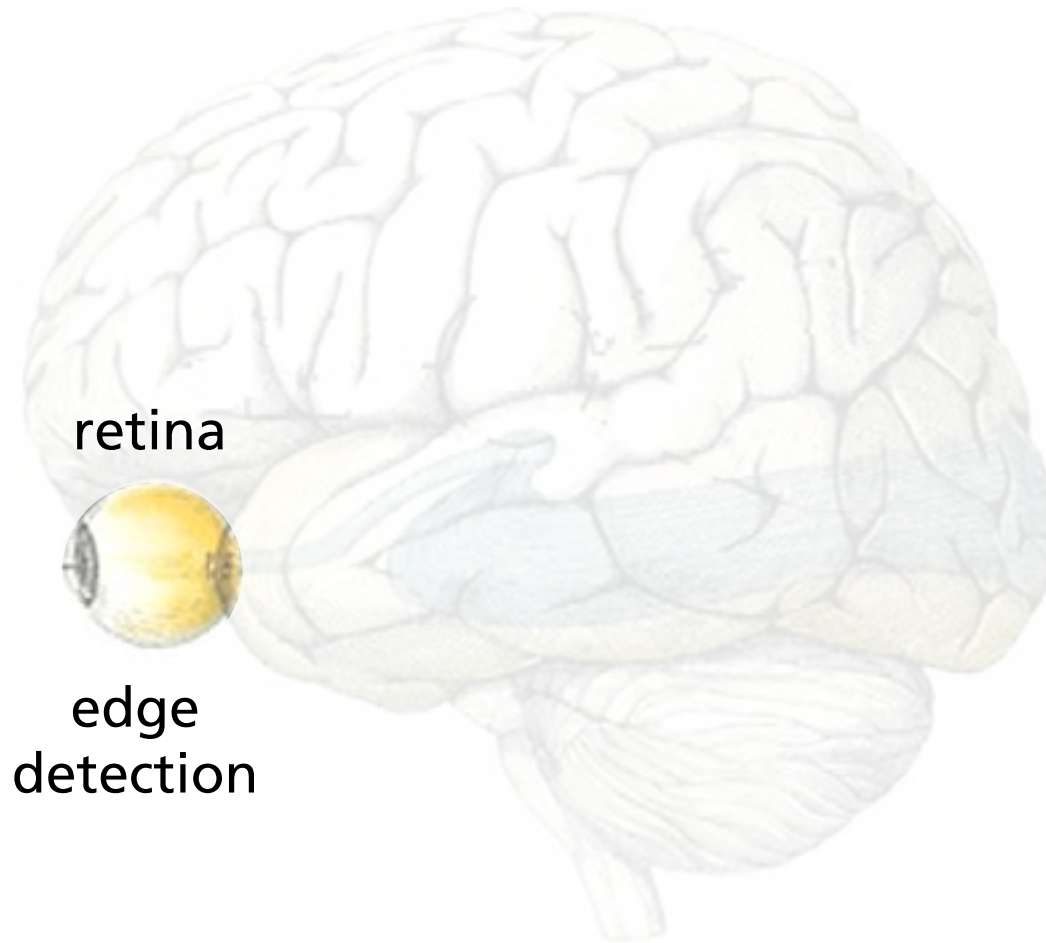
How do we *do* it?



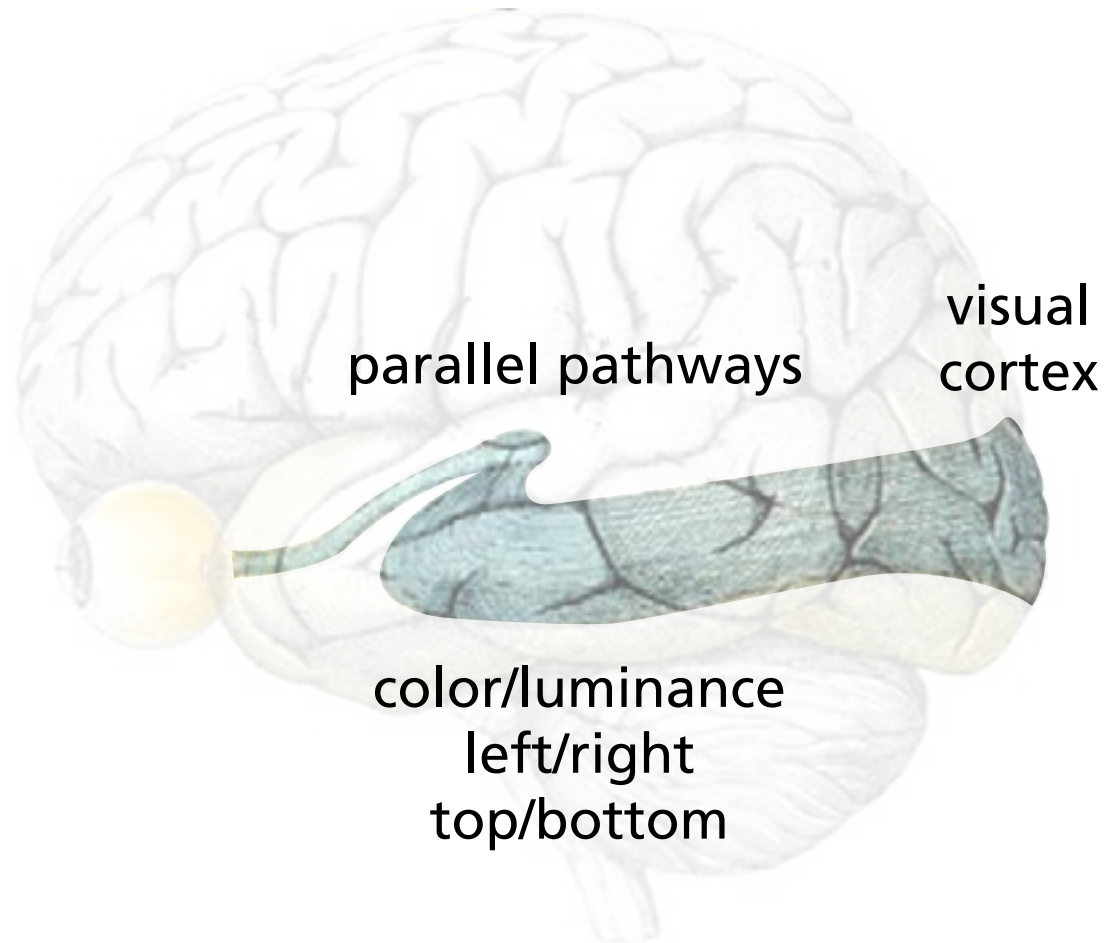
# Visual pathways



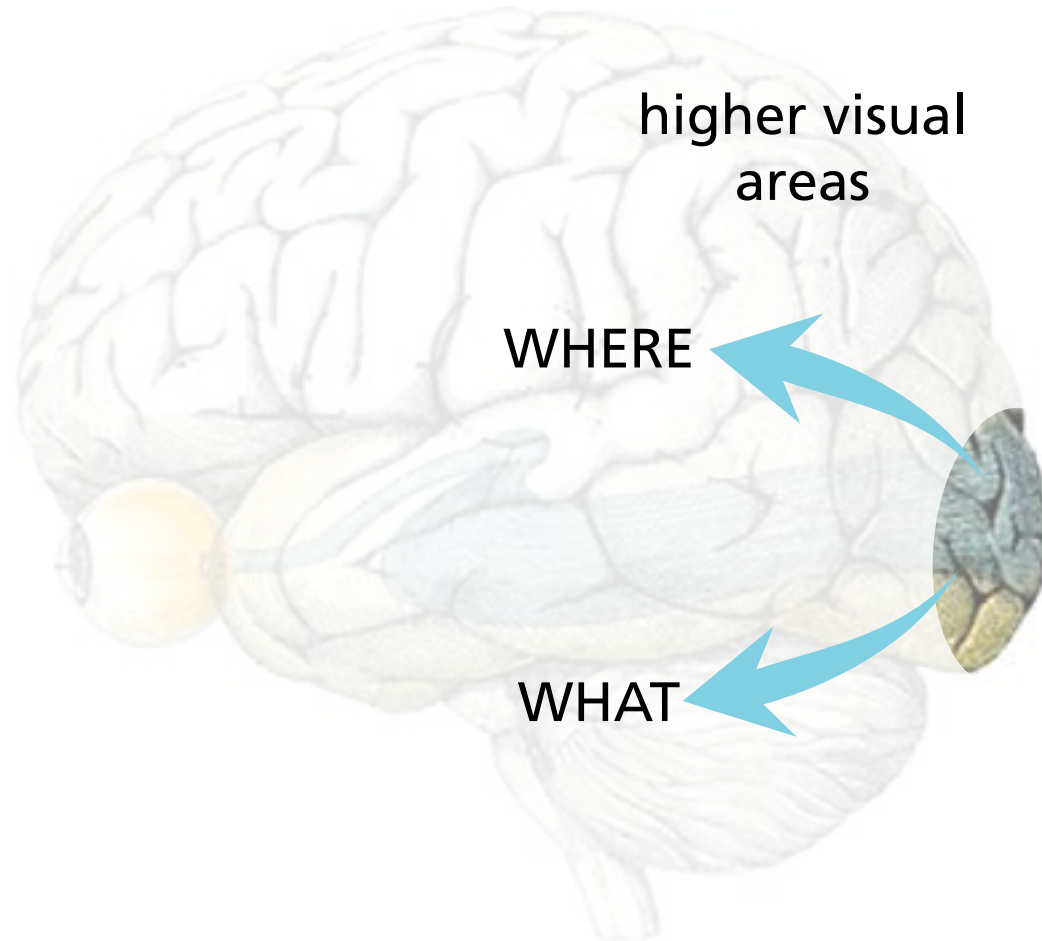
# Visual pathways



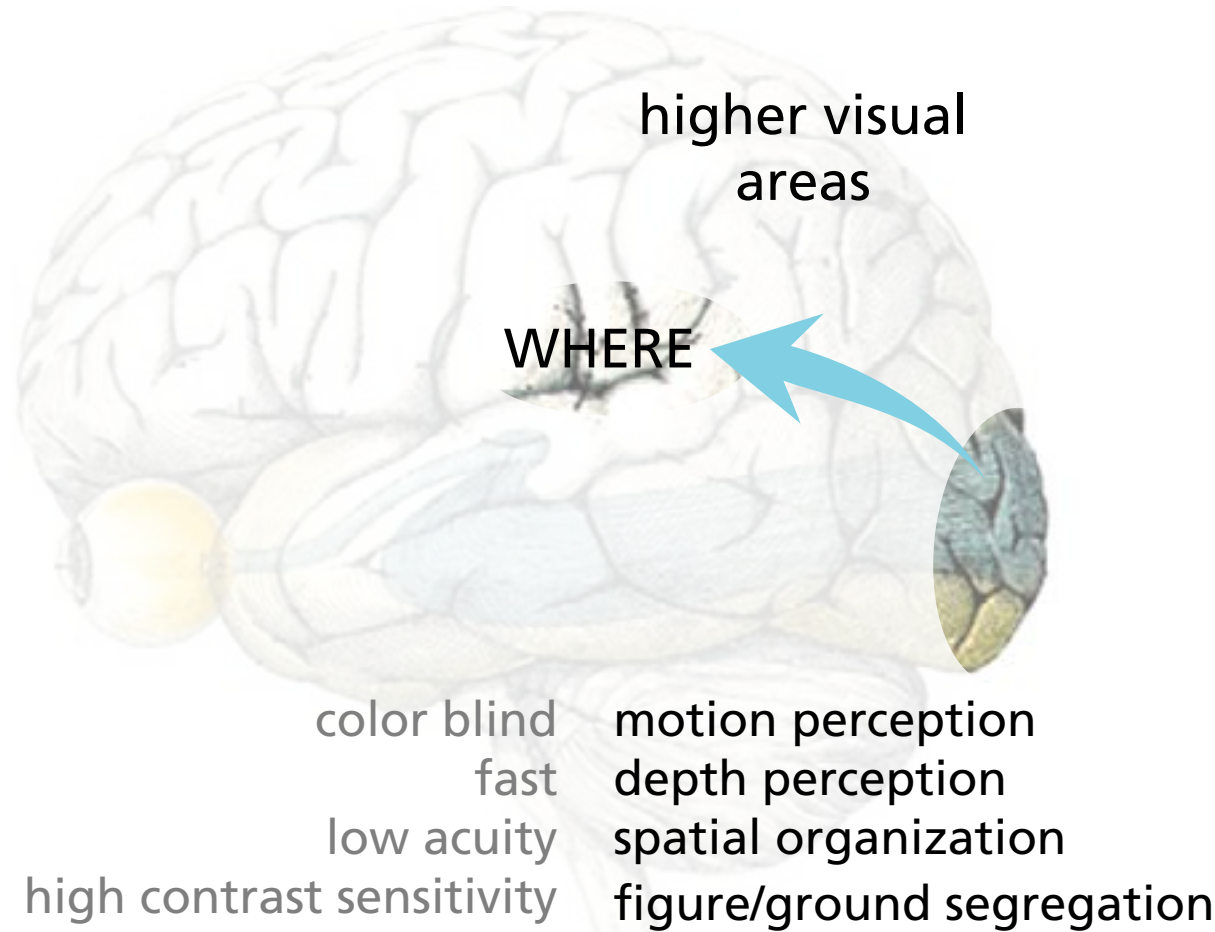
# Visual pathways



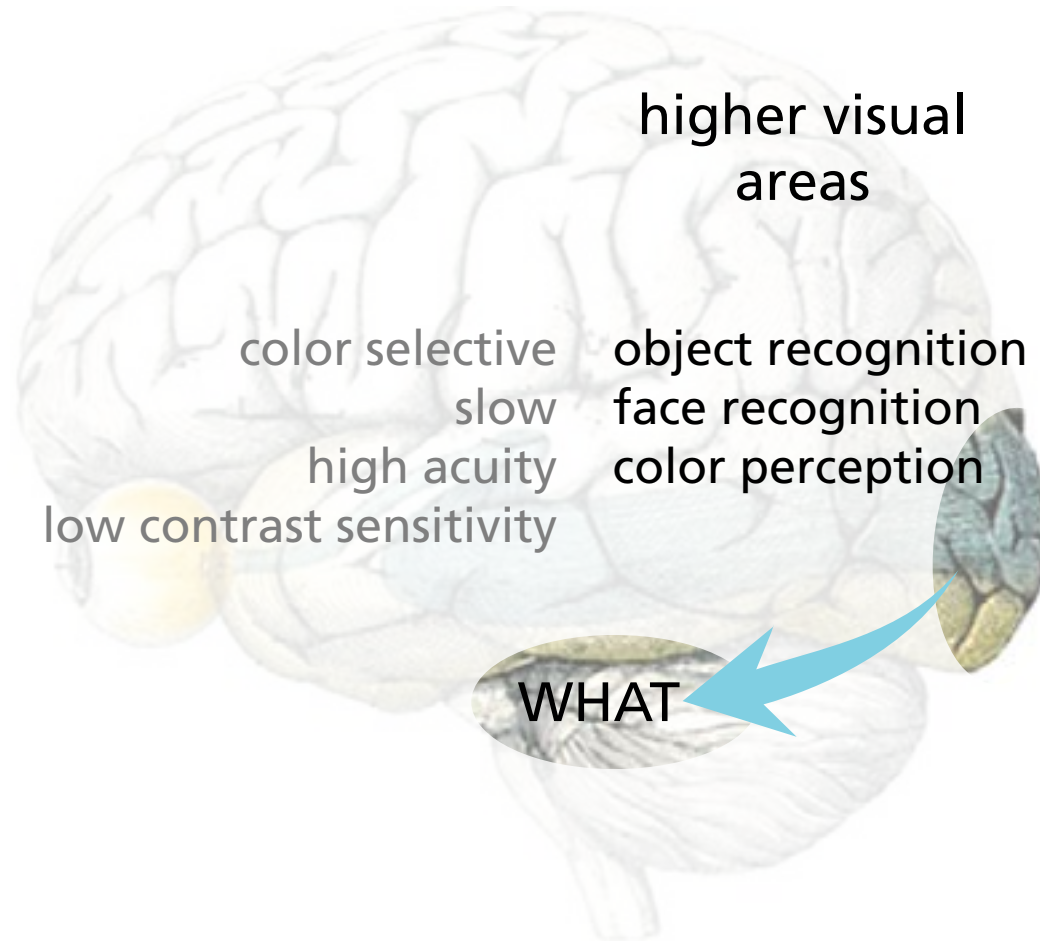
# Visual pathways



# Visual pathways



# Visual pathways











# Some points to keep in mind

Luminance:

- depth
- motion

Color:

- form
- function

# Cognitive issues related to seeing



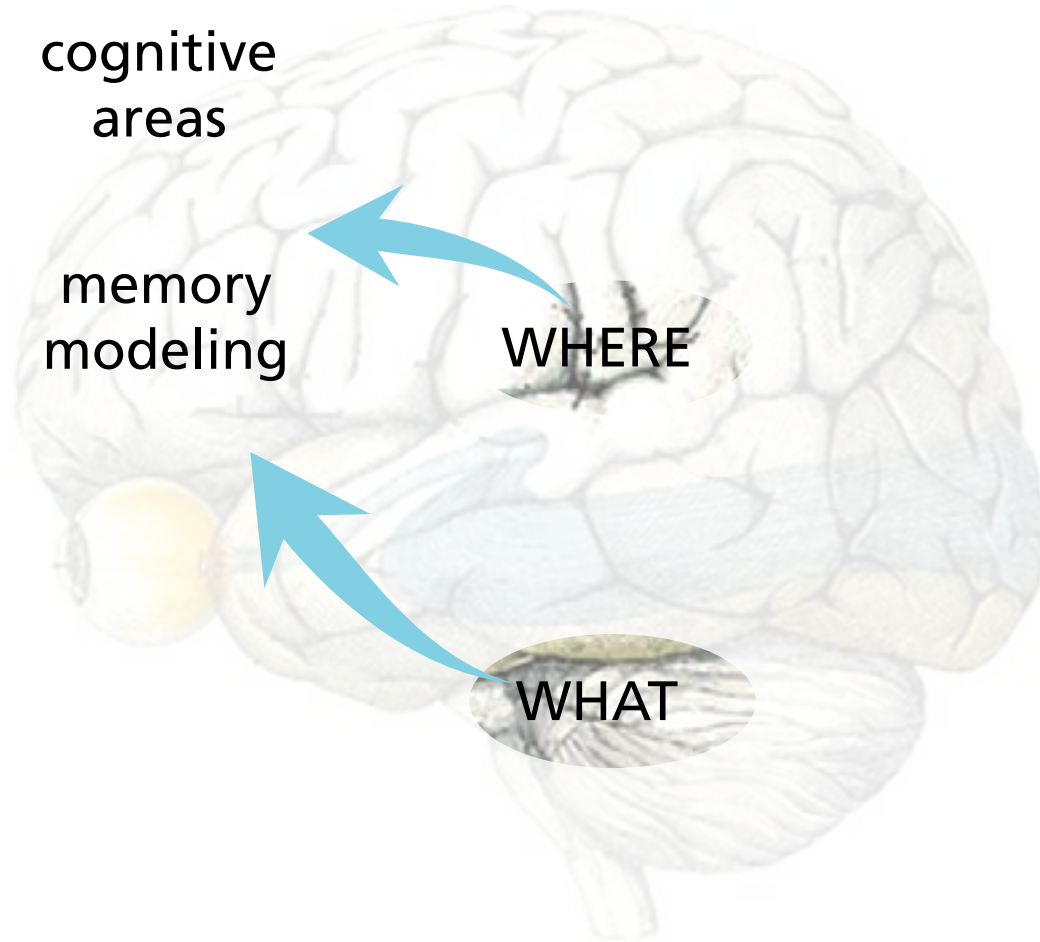
# Visual pathways

cognitive  
areas

memory  
modeling

WHERE

WHAT

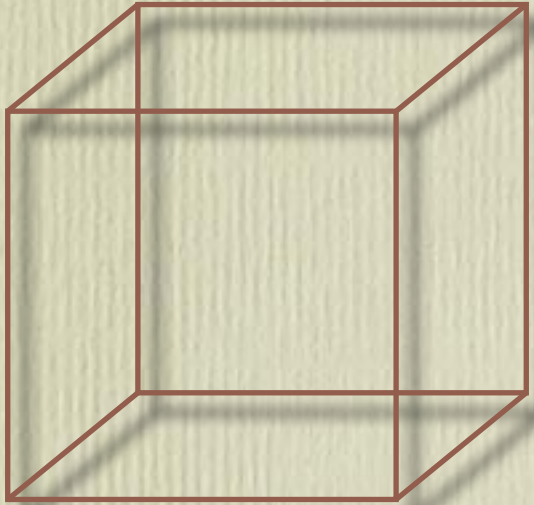


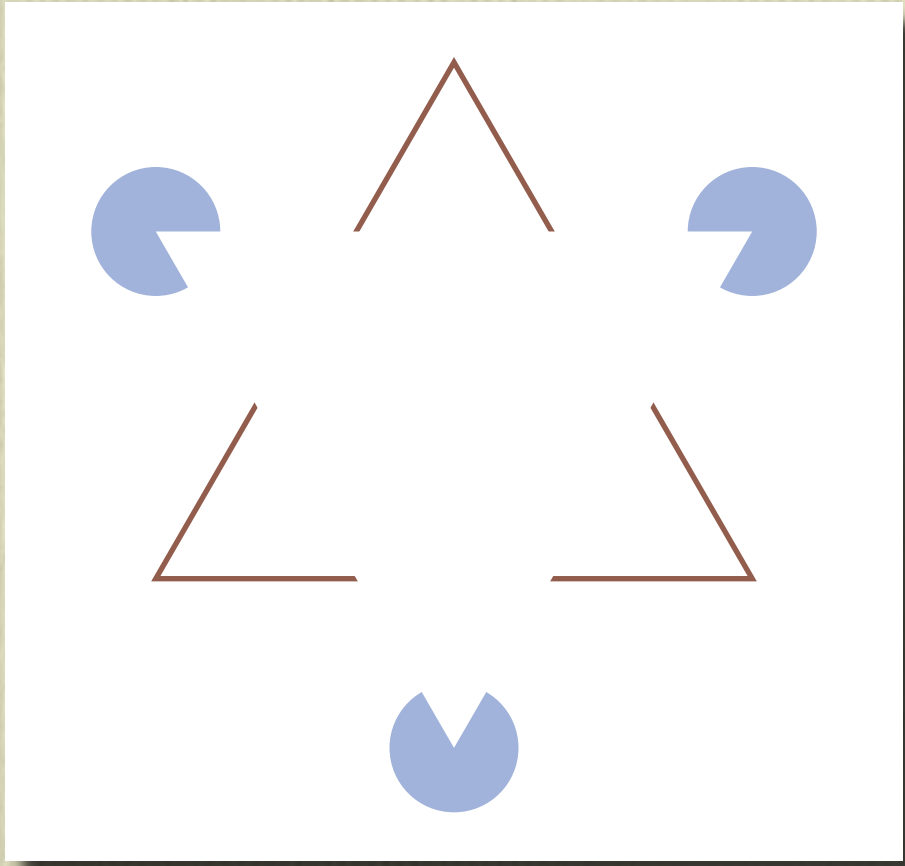
# Mental models

of behavior, events, workings are essential to

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

Mental models affect what we see







Mental tasks can prevent us from seeing

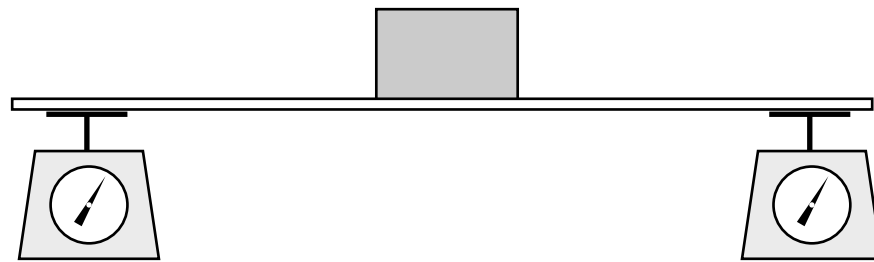


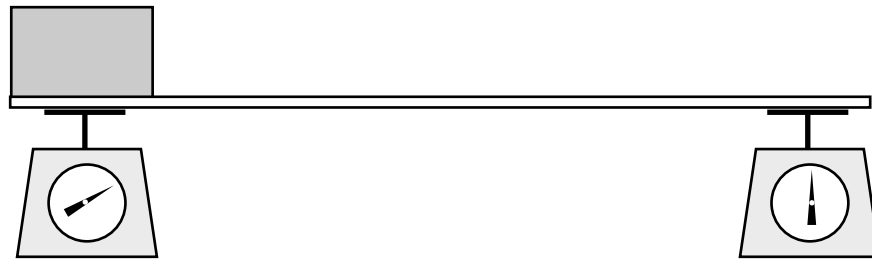






Mental models override visual memory







# 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!



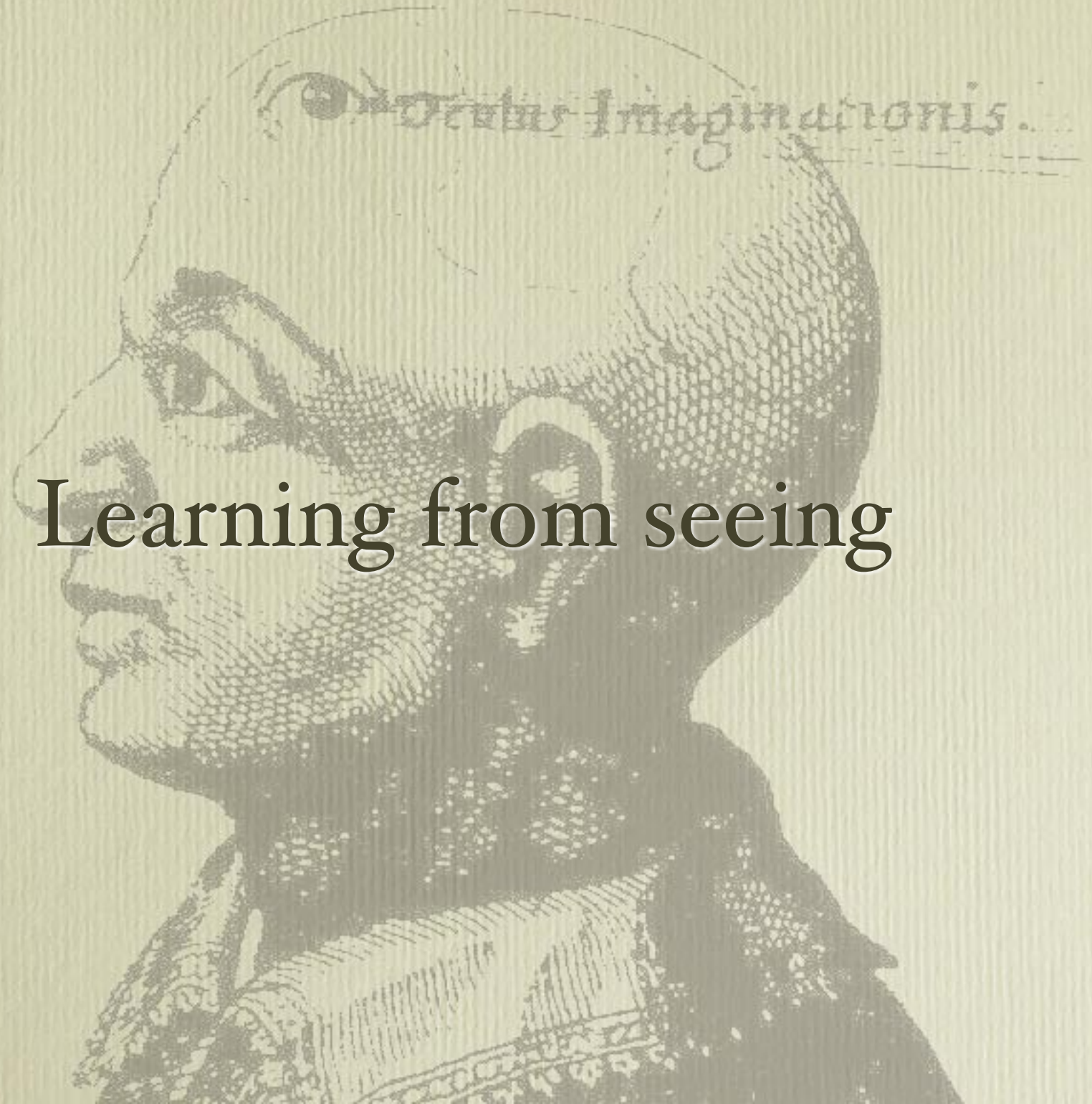
Must provide opportunity to revise model

# 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

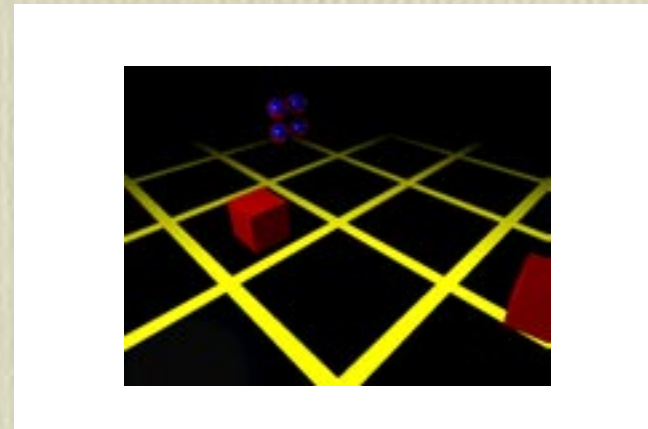
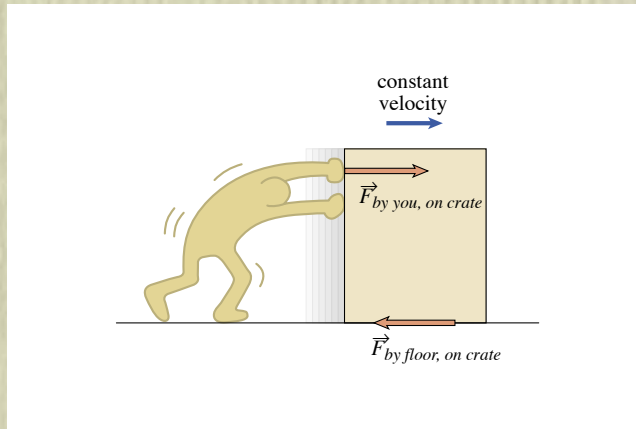
- Abstract: highlight model
- Realistic: connect to experience

# Visualization types

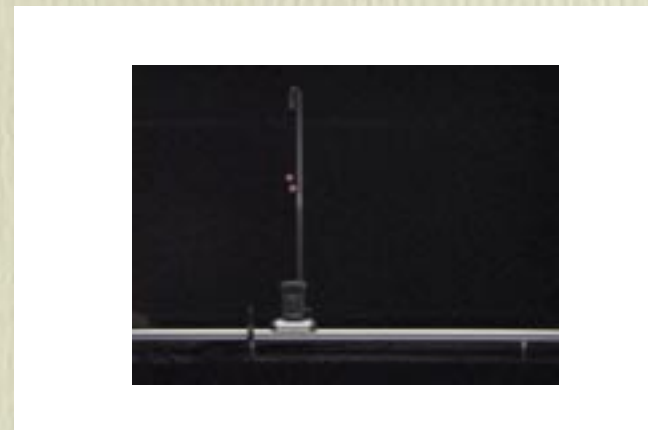
illustration

animation

abstract



realistic

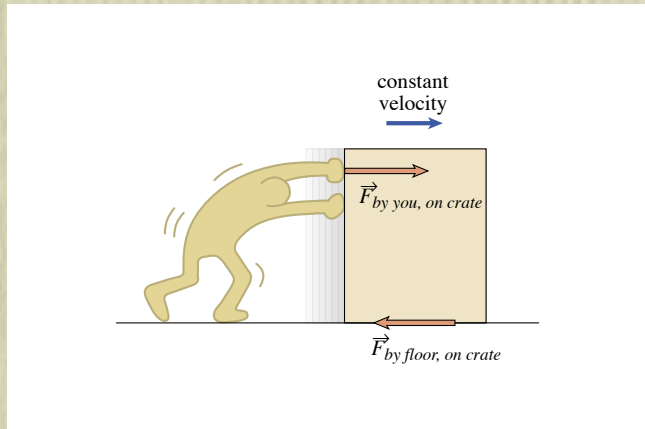


# Visualization types

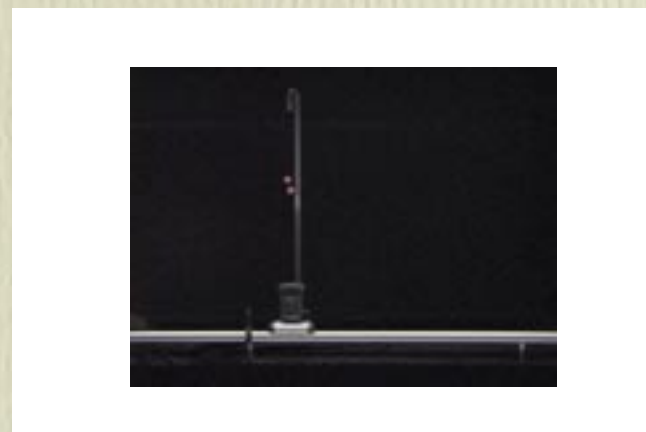
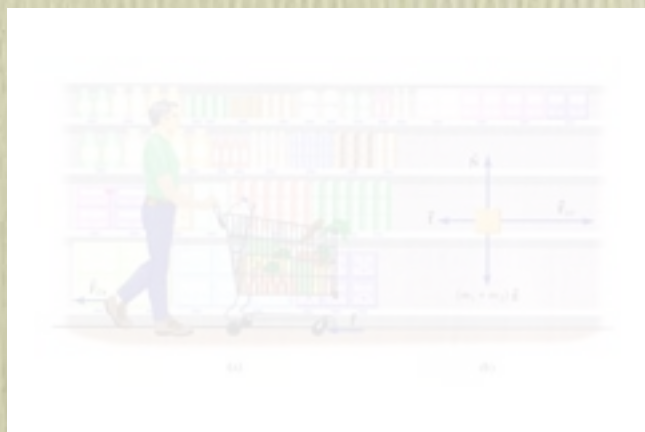
illustration

animation

abstract



realistic



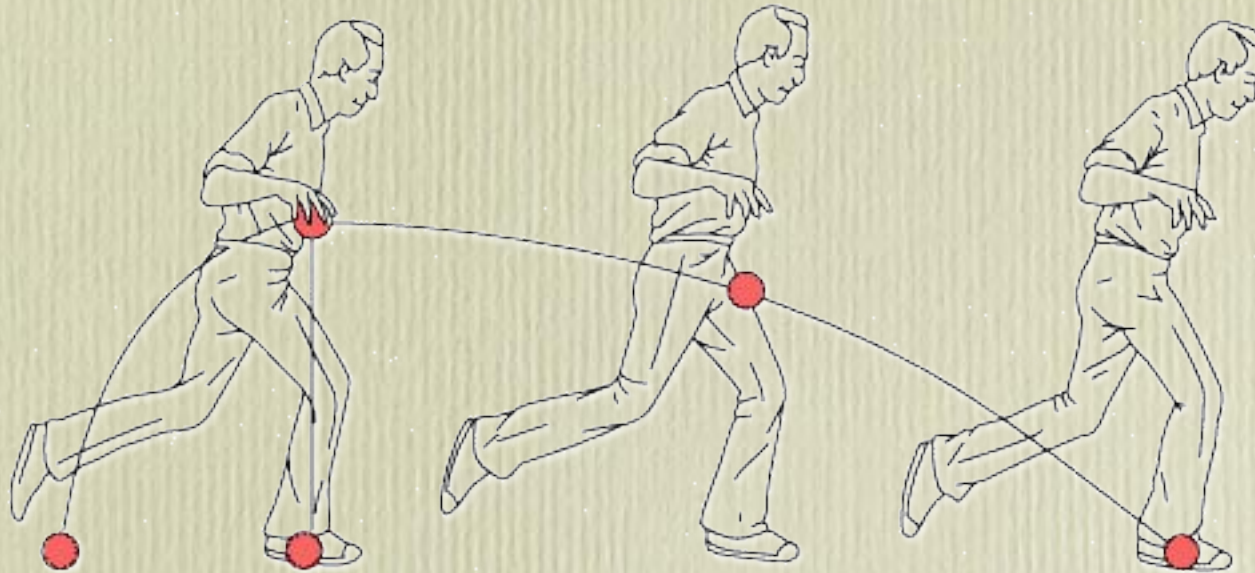
# Abstract versus realistic

Use:

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

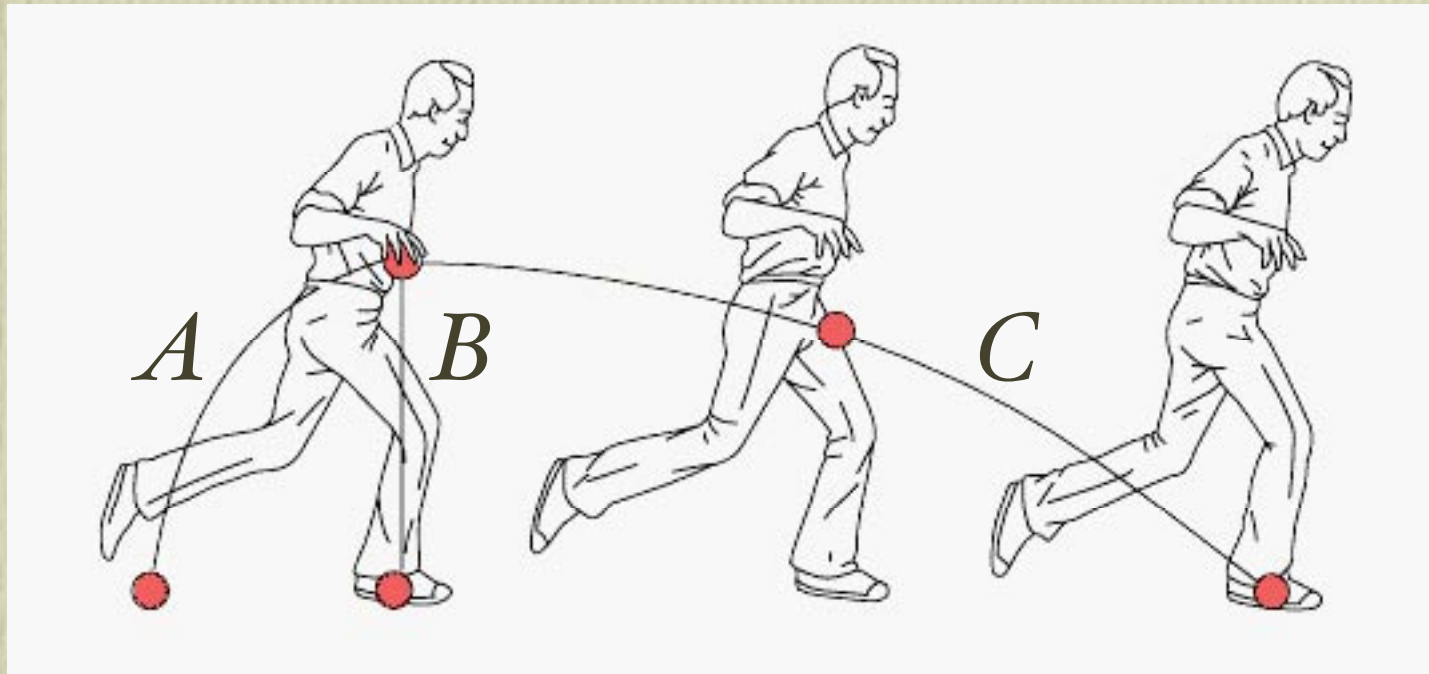
# Parabolic motion

# A quick quiz



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

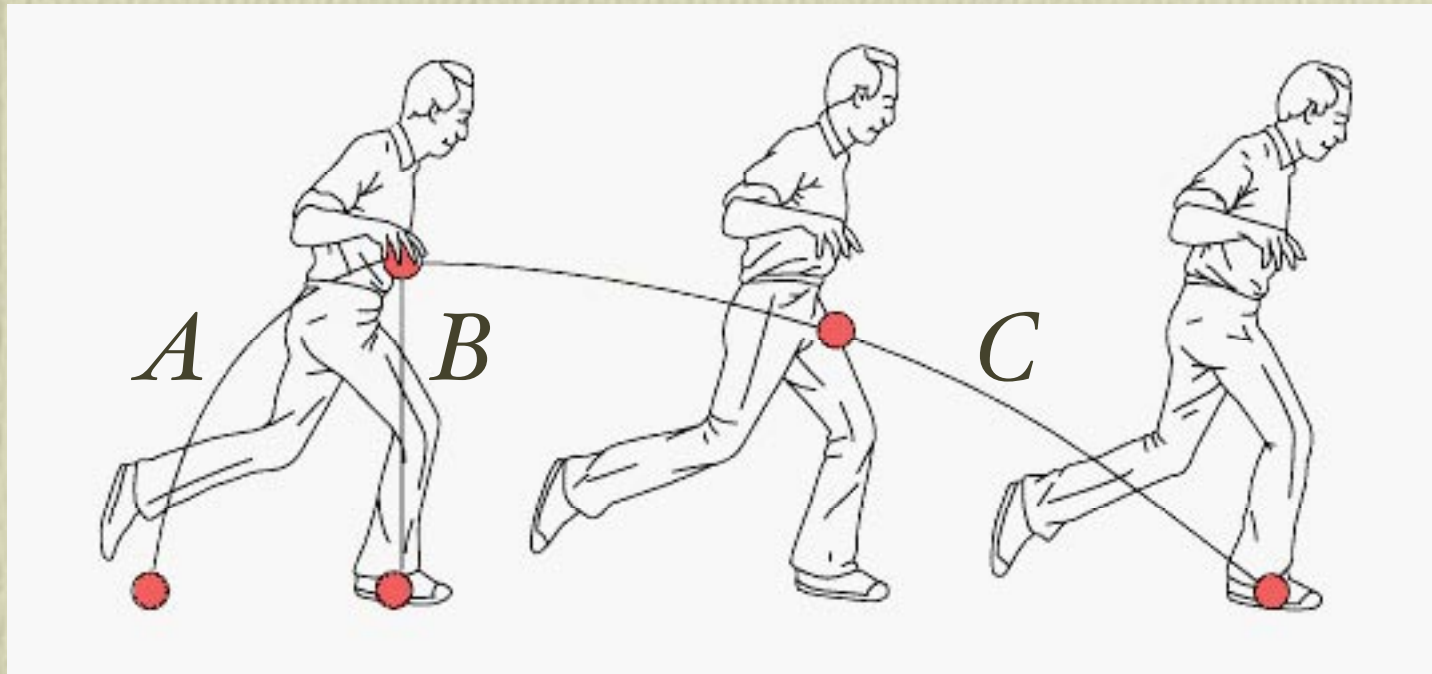
# A quick quiz



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

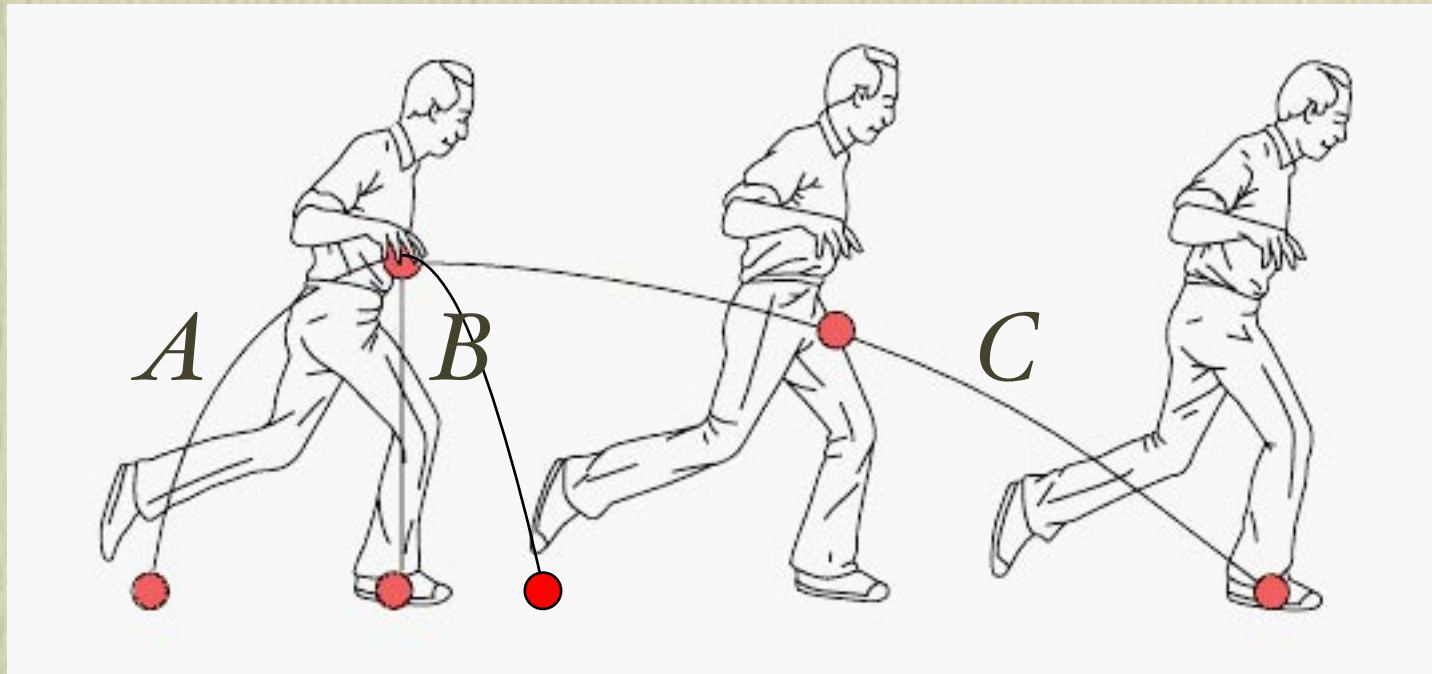


# A quick quiz



Answer: *B*

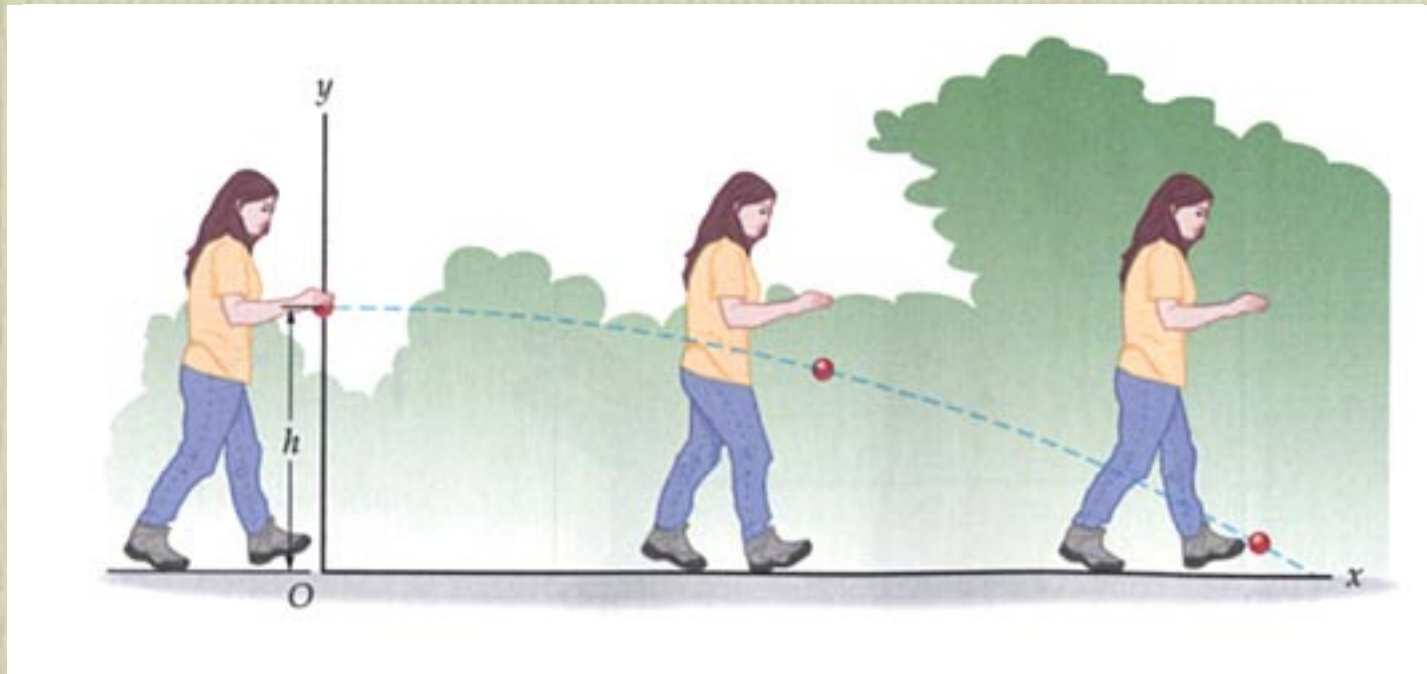
# A quick quiz



Answer: *B*

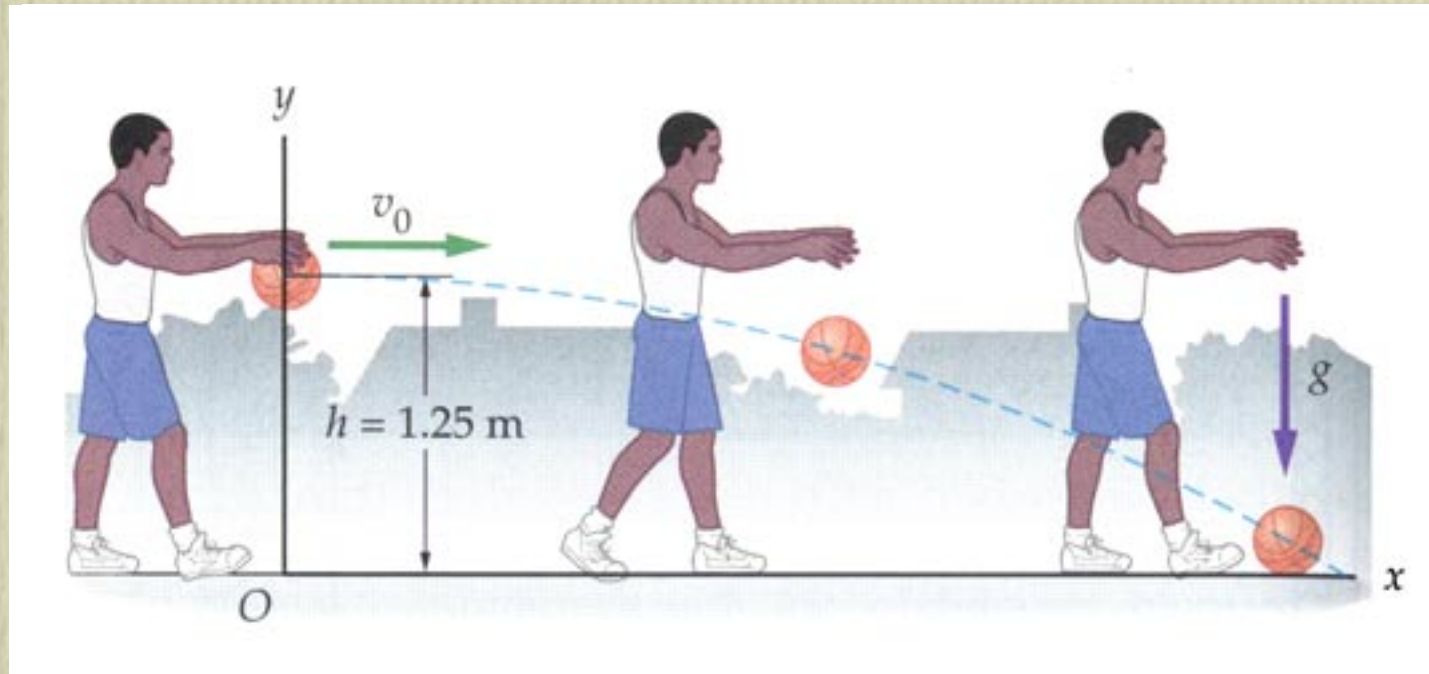
Even text book authors get the physics wrong!

# Microgravity



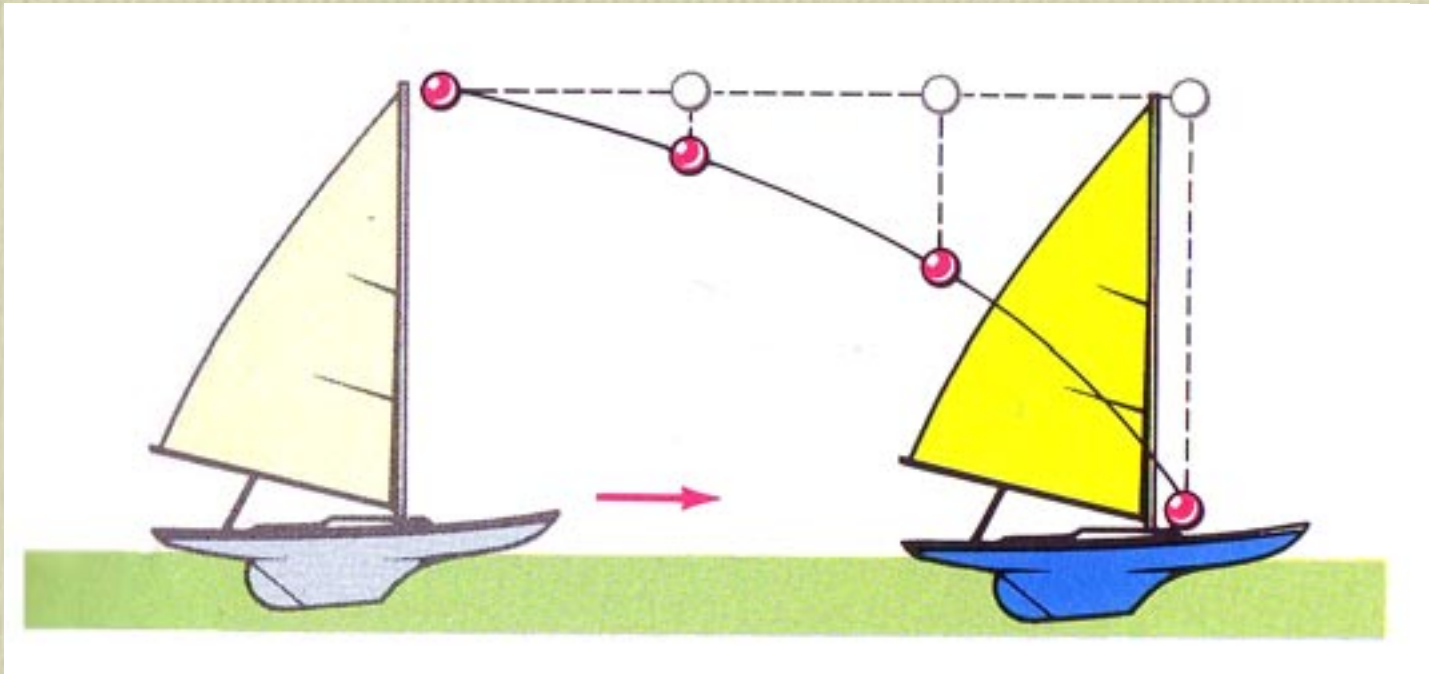
Walker, 2nd Ed. (Prentice Hall, 2004)

# Microgravity



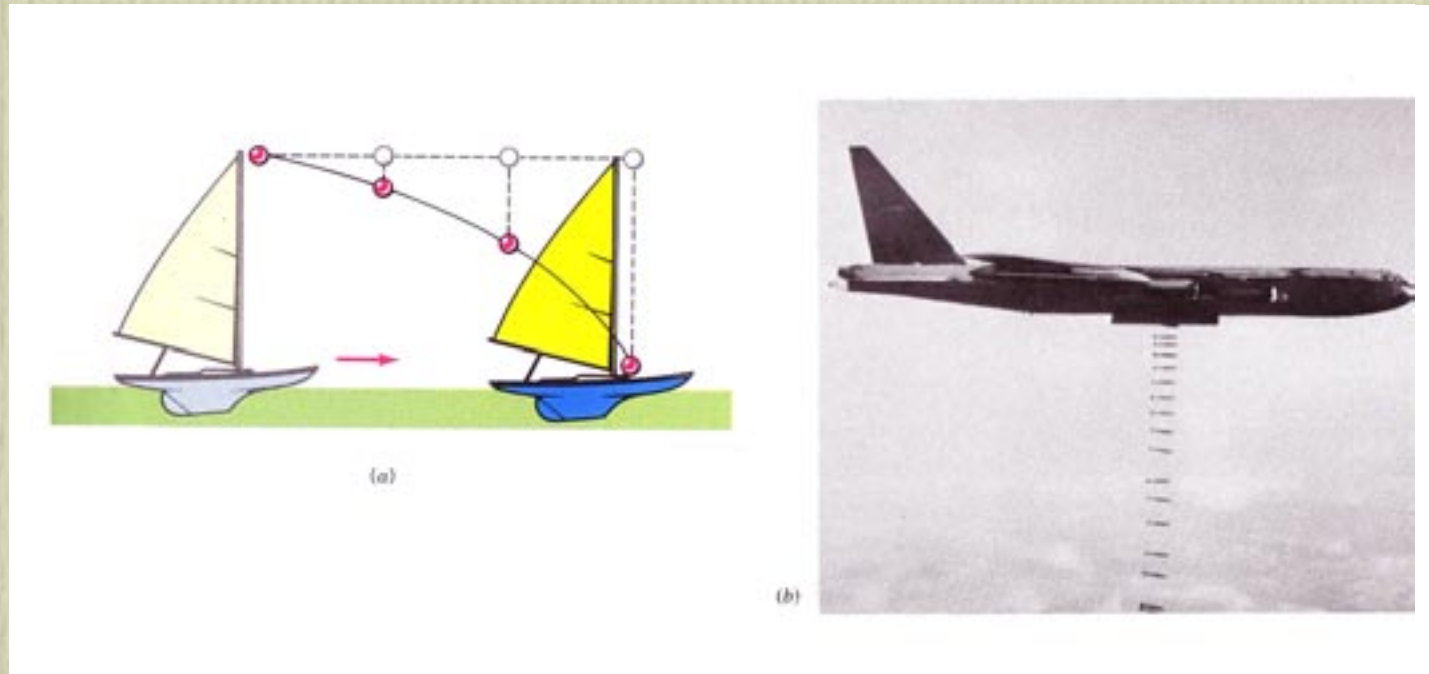
Walker, 2nd Ed. (Prentice Hall, 2004)

# Microgravity



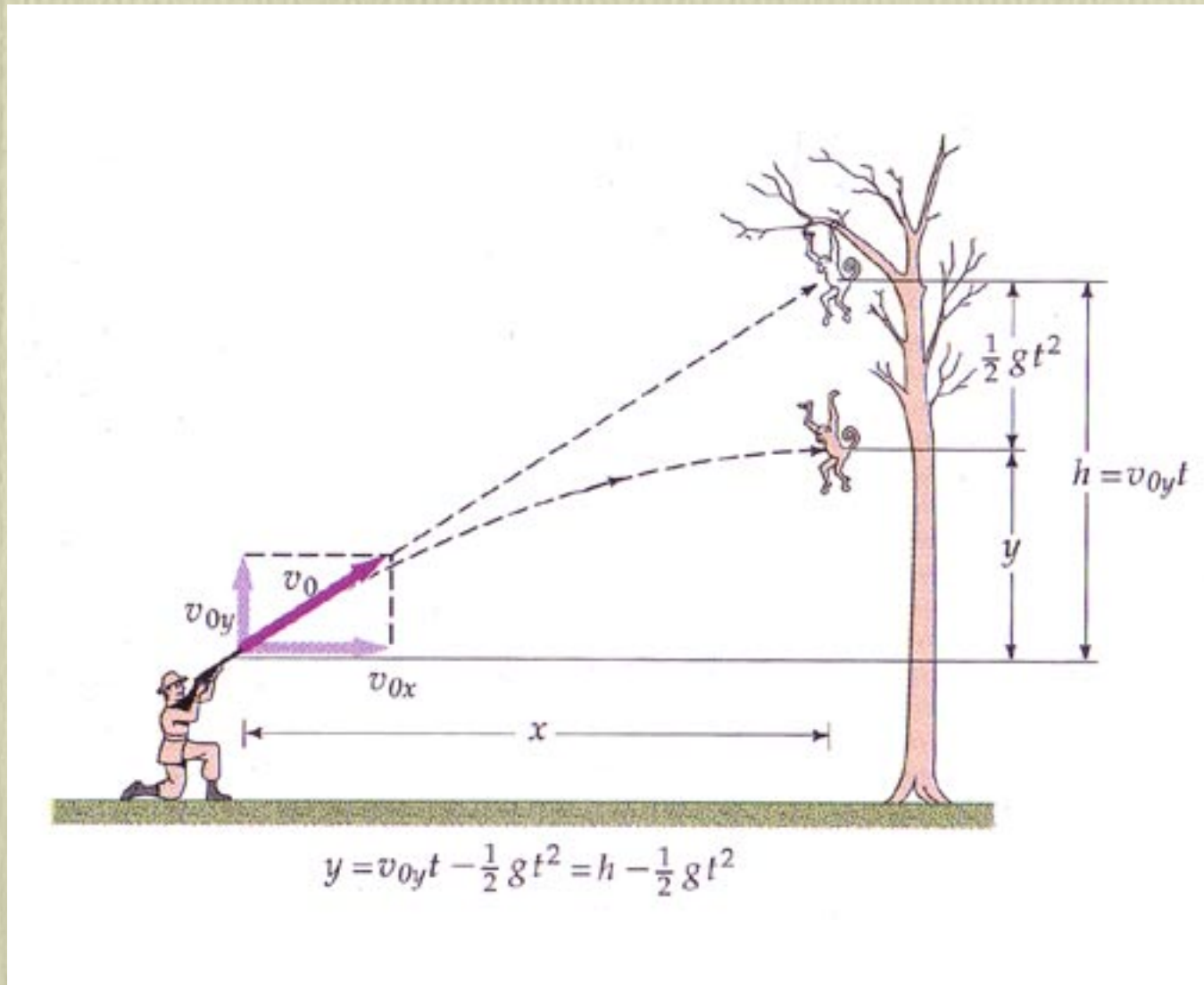
Benson (Wiley, 1991)

# Microgravity



Benson (Wiley, 1991)

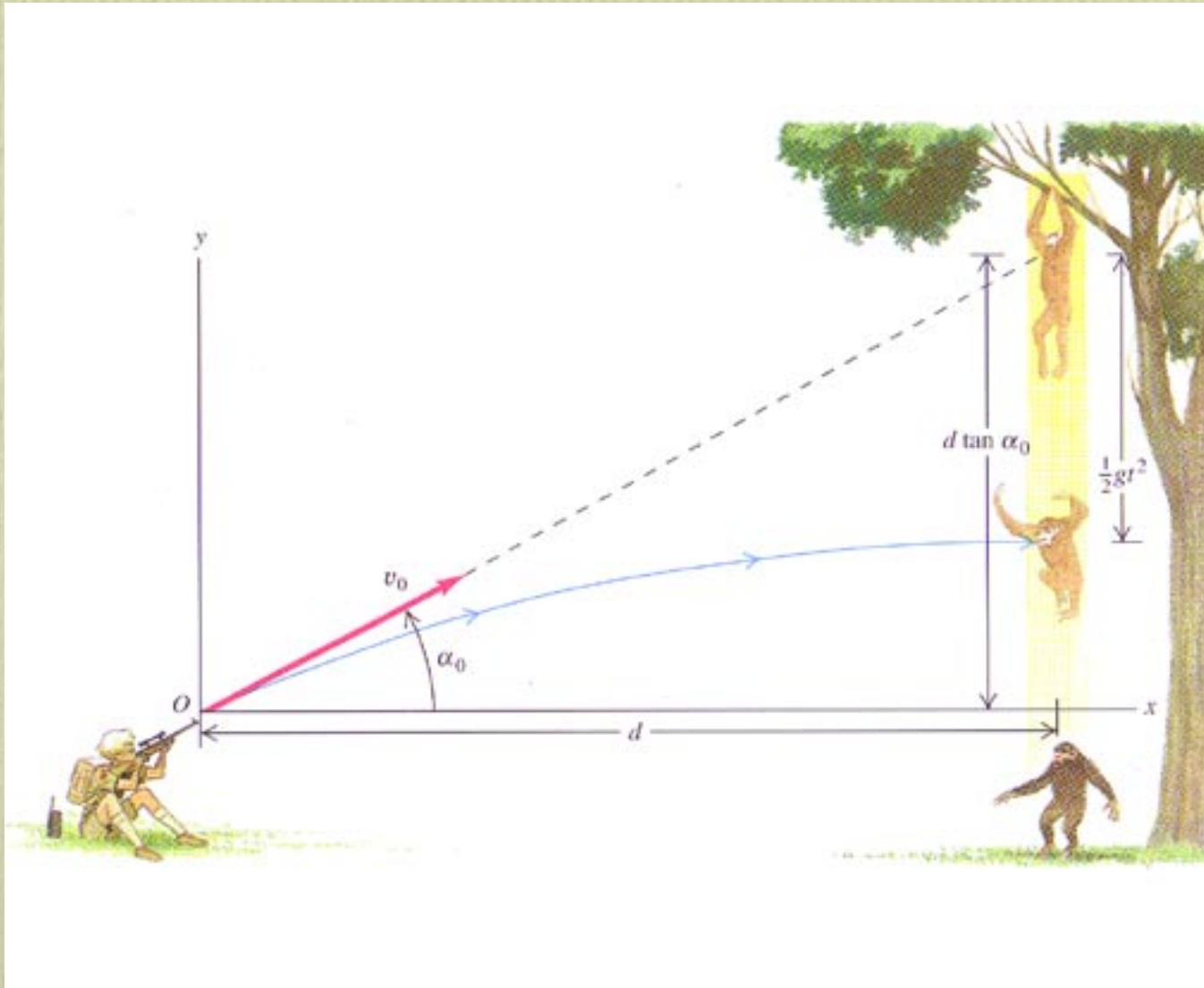
# Another classic



Tipler, 1st Ed. (Worth, 1971)

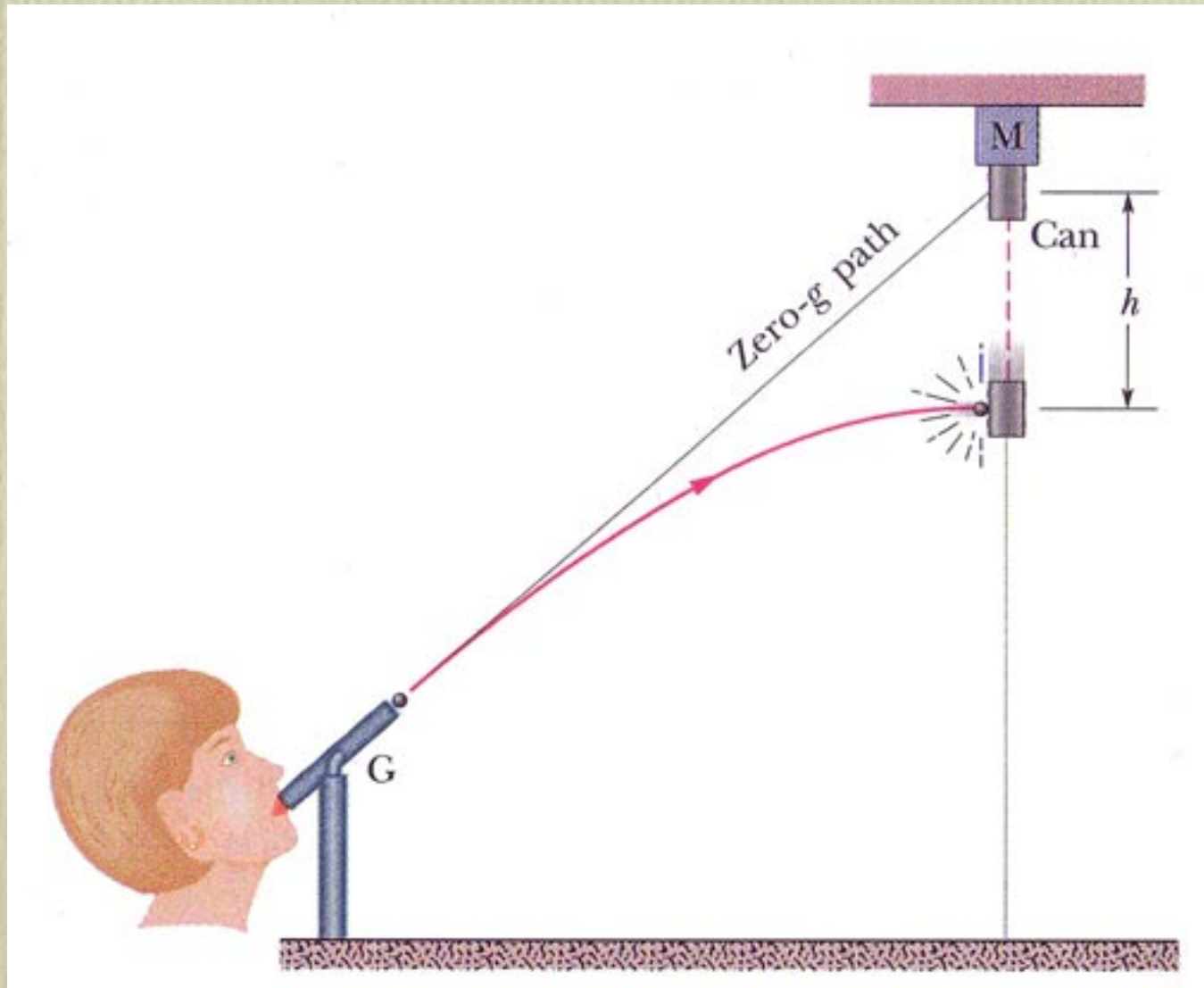


# How not to shoot a monkey



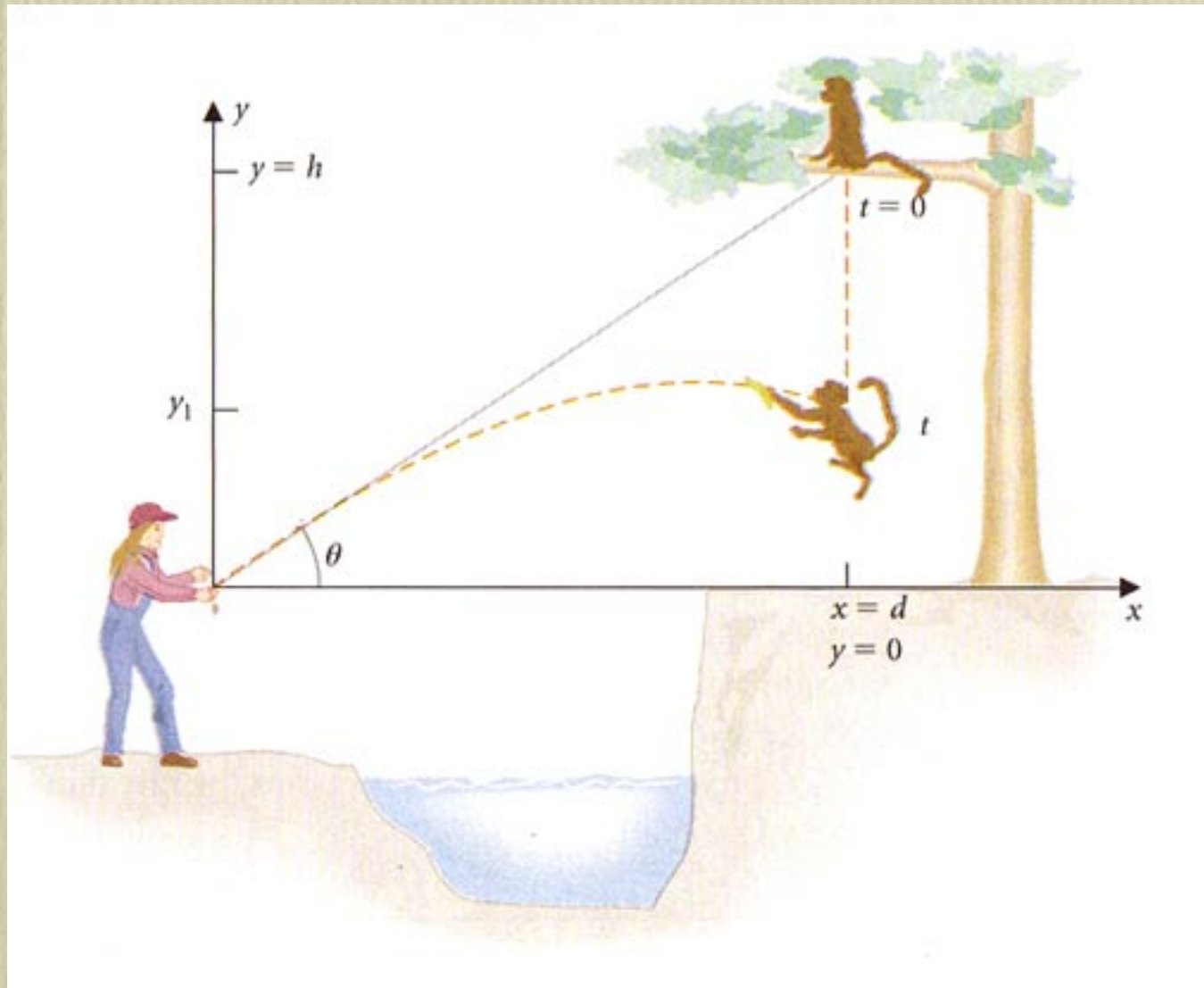
Sears and Zemansky, 10th Ed. (Addison Wesley, 2000)

# How not to shoot a monkey



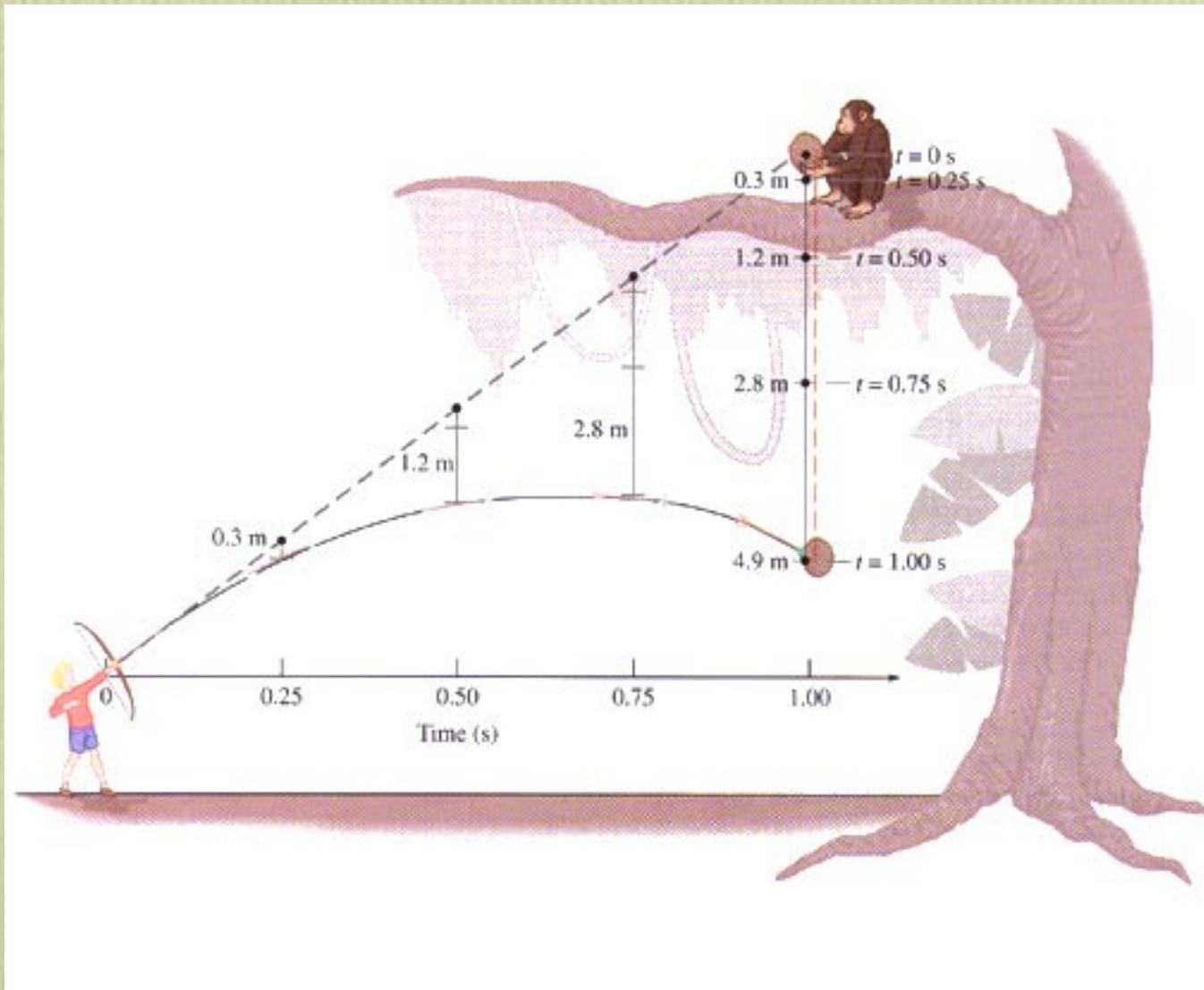
Haliday, Resnick, Walker, 5th Ed. (Wiley, 1997)

# How not to shoot a monkey



Lea and Burke (Brooks/Cole, 1997)

# How not to shoot a monkey



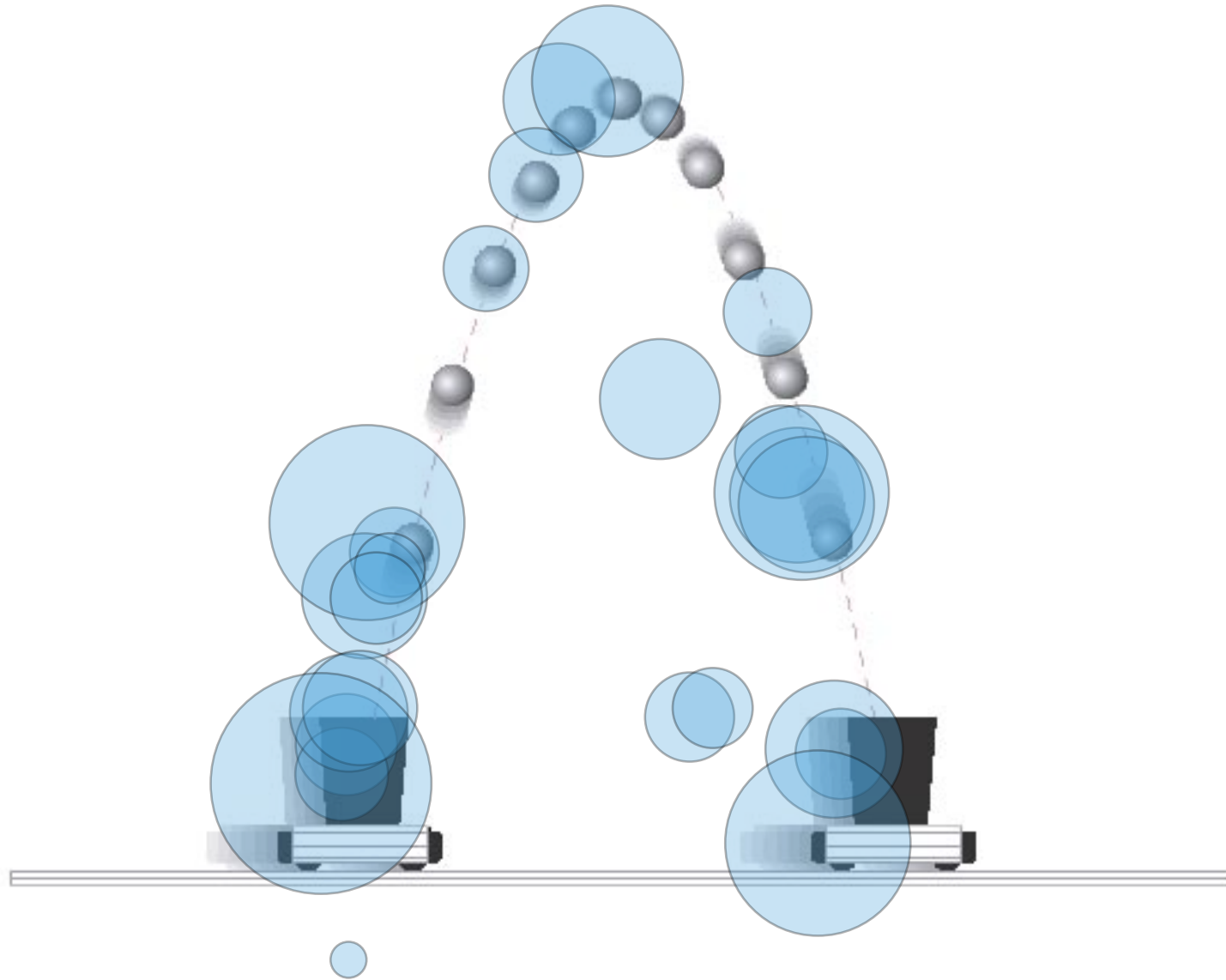
Giambattista, Richardson, Richardson (McGraw Hill, 2004)

# The Clutter!

What do people look at?

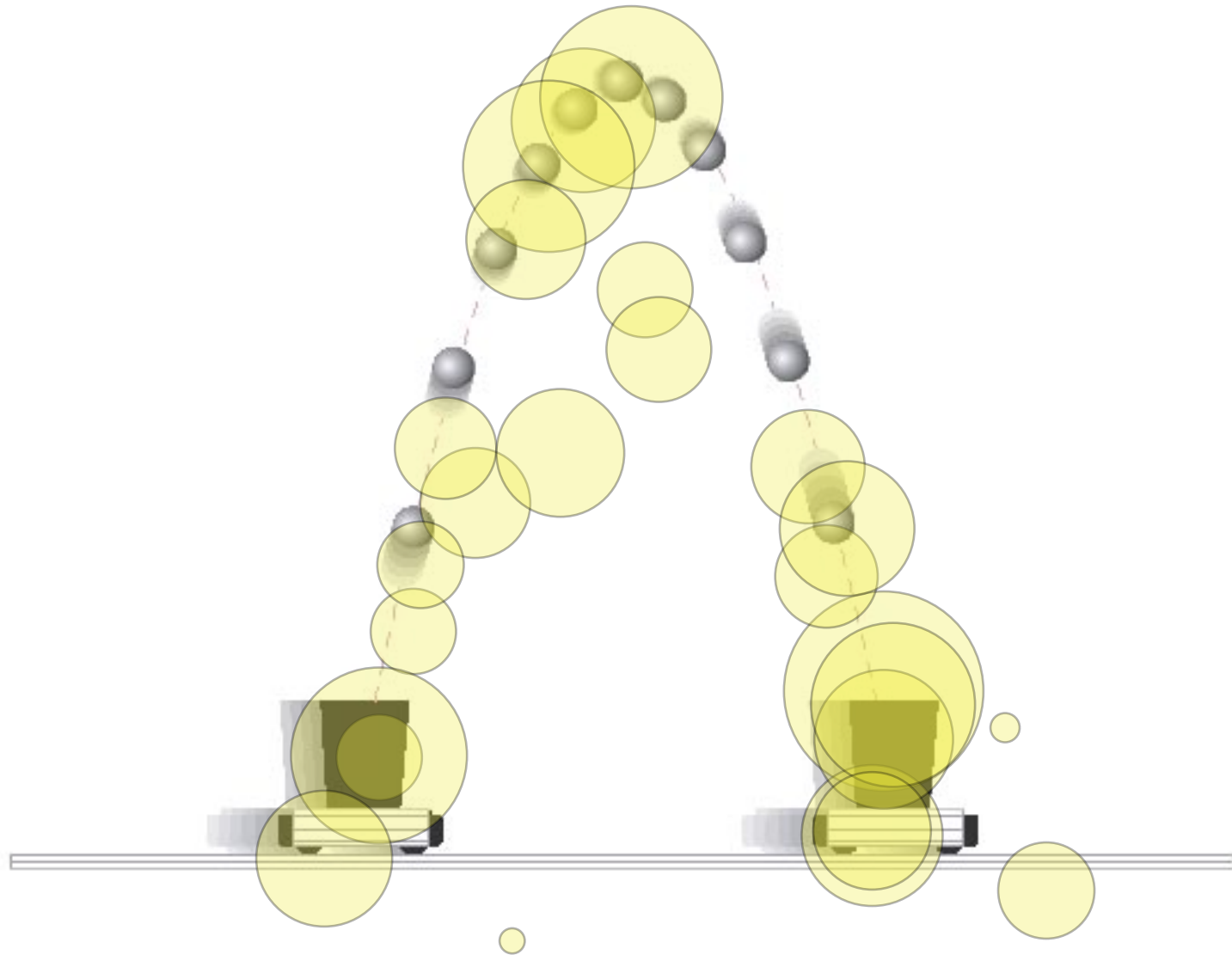


Mazur (Prentice Hall, 200?)



Mazur (Prentice Hall, 200?)

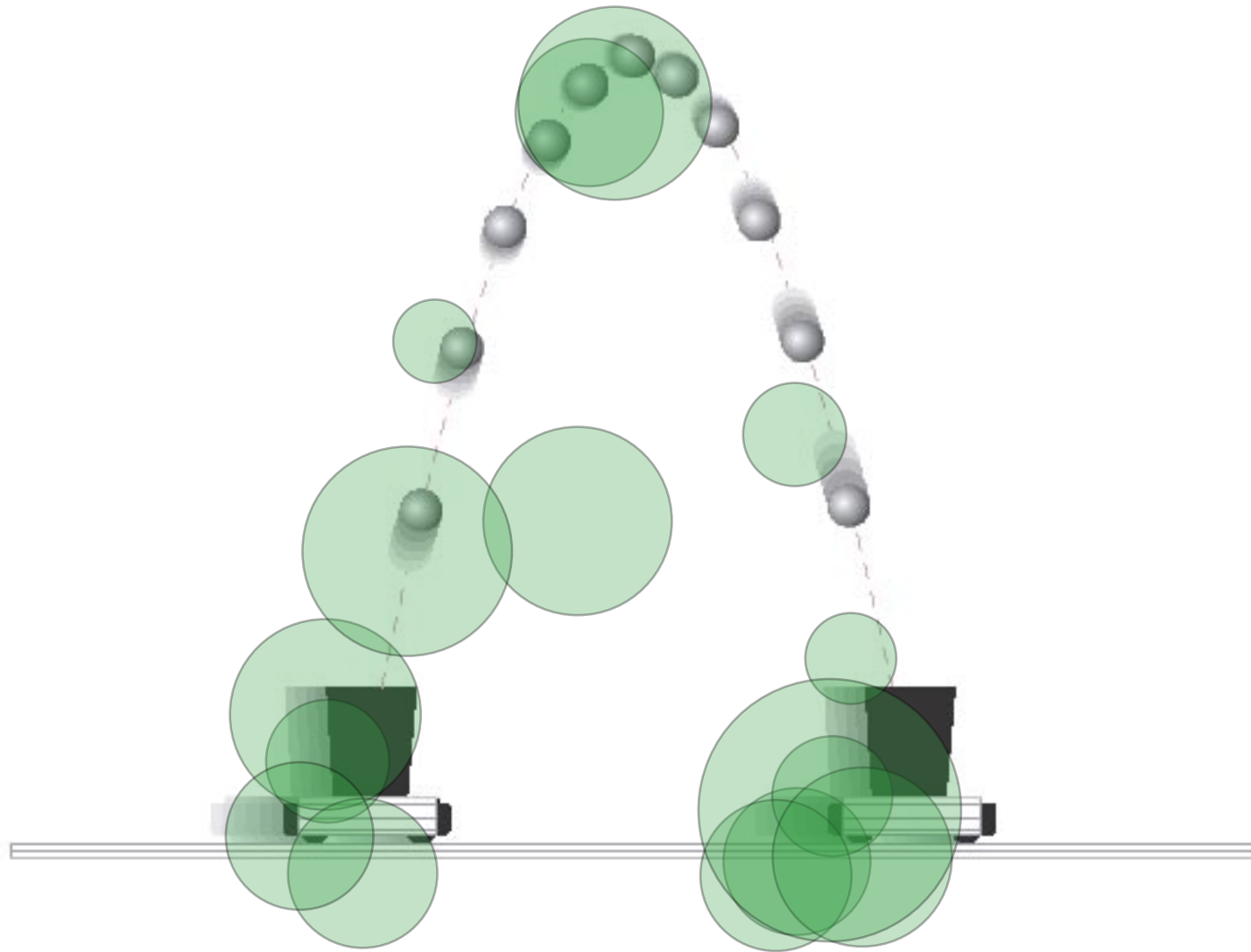




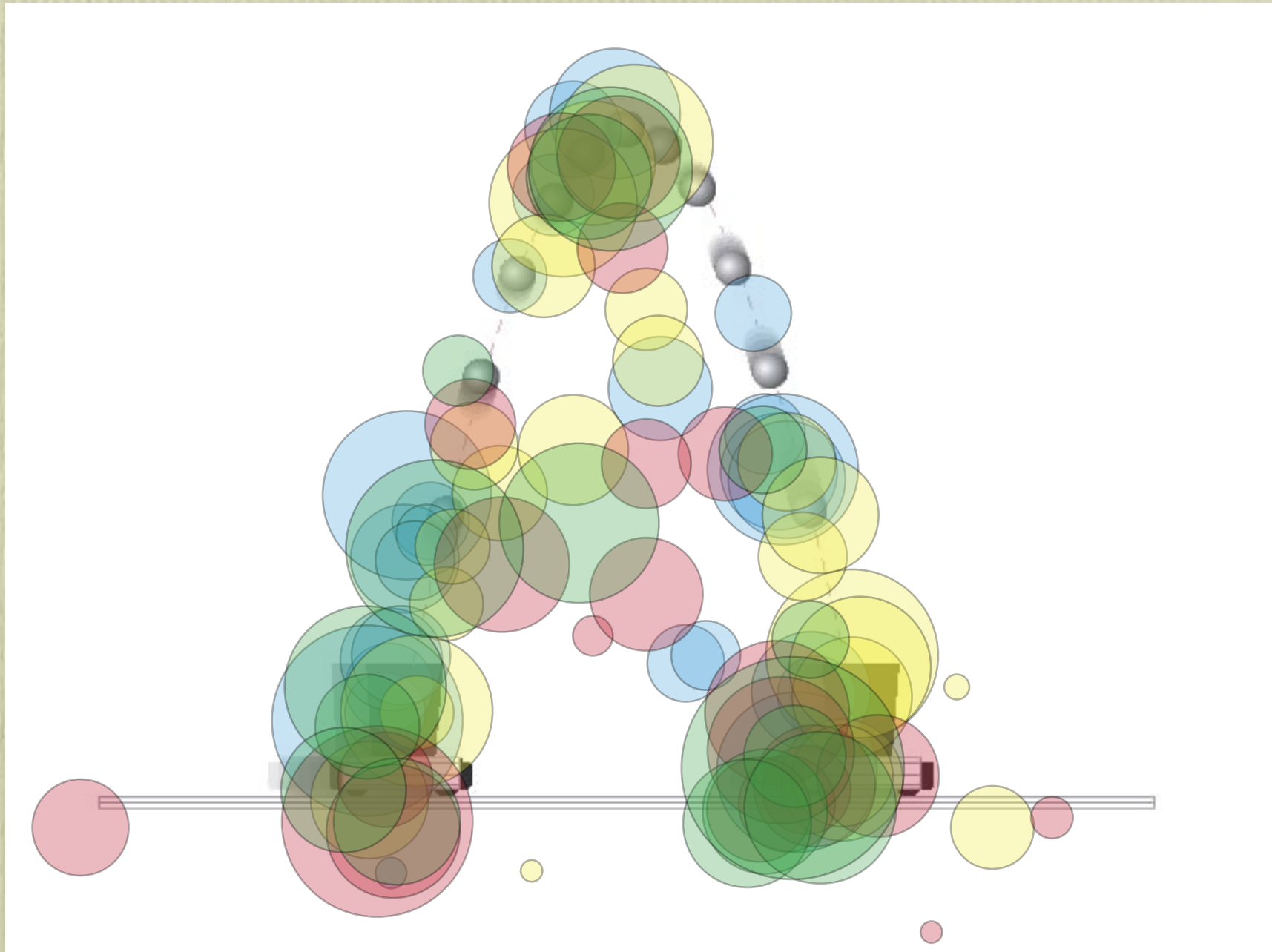
Mazur (Prentice Hall, 200?)



Mazur (Prentice Hall, 200?)



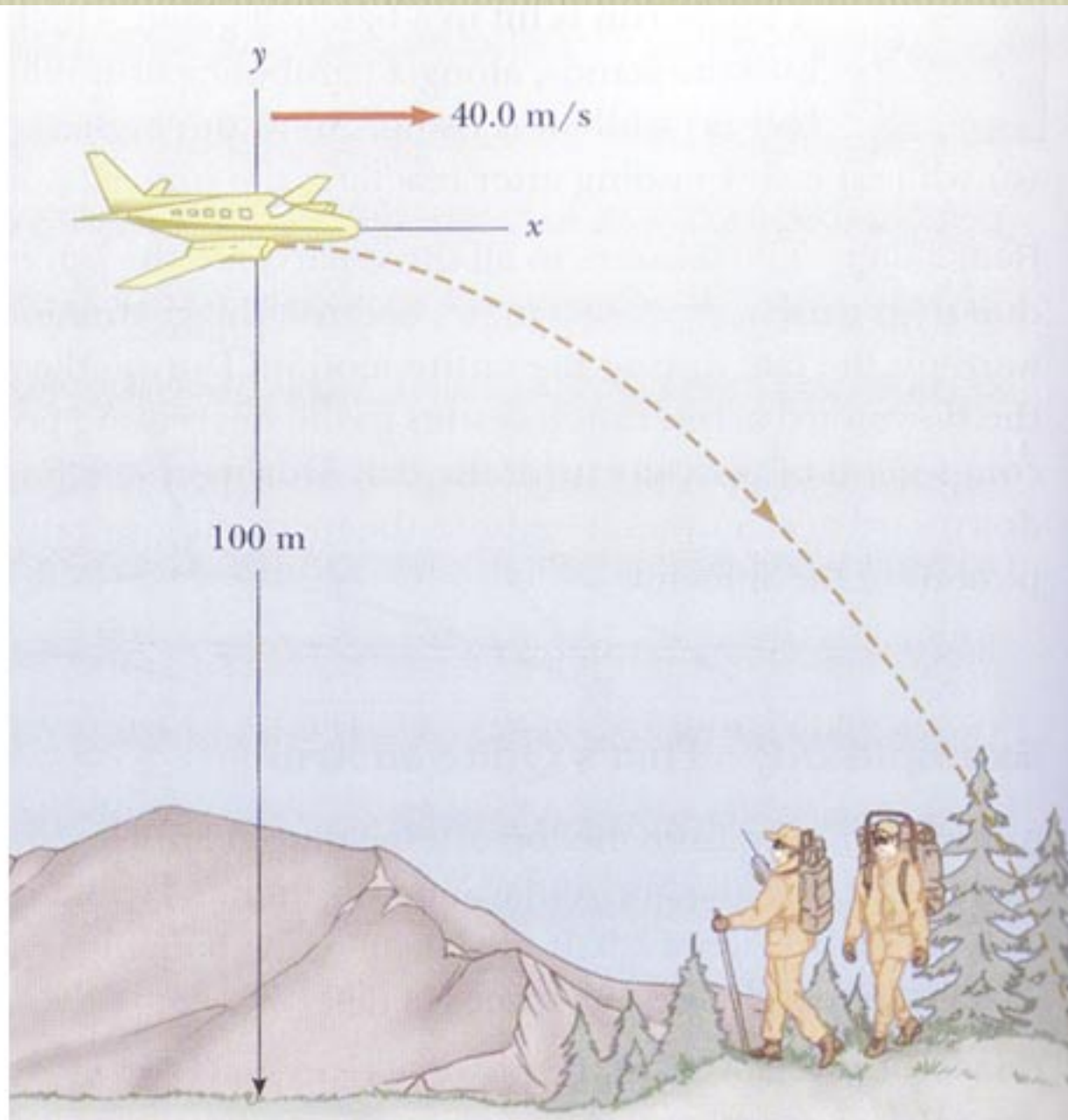
Mazur (Prentice Hall, 200?)



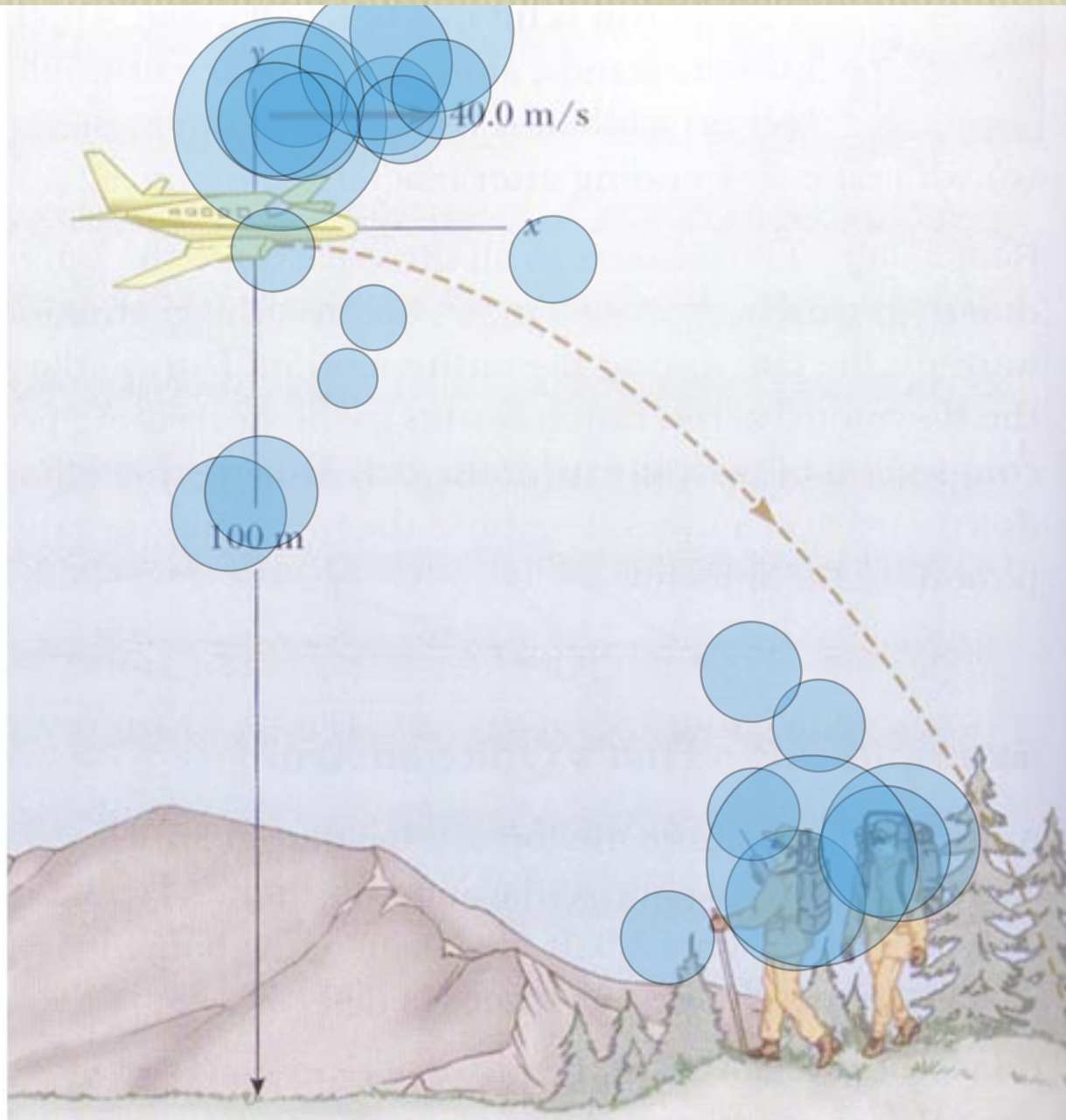
Mazur (Prentice Hall, 200?)

# People look at

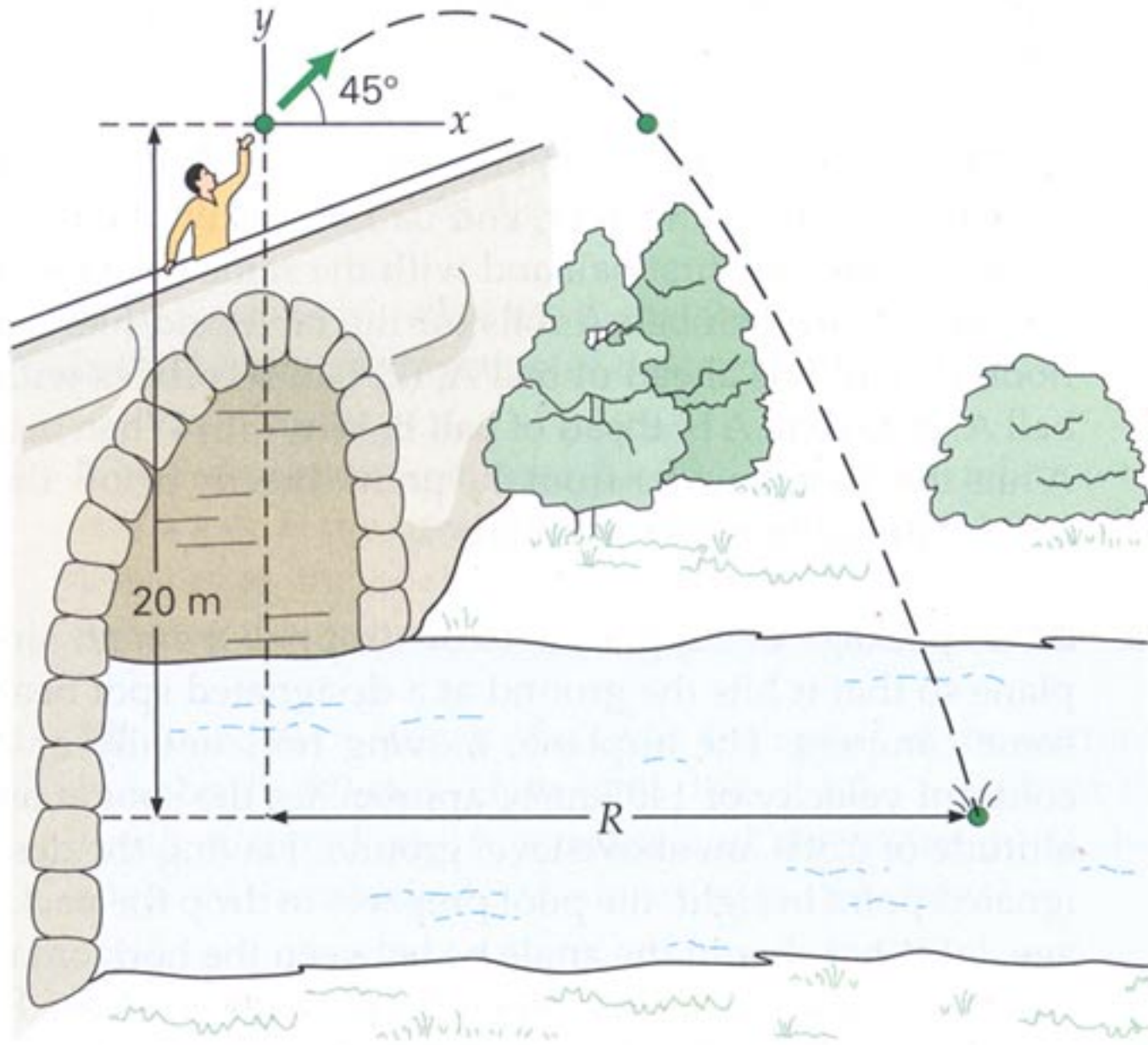
- Parabolic motion of ball
- Carts



Serway and Jewett (Harcourt, 2002)

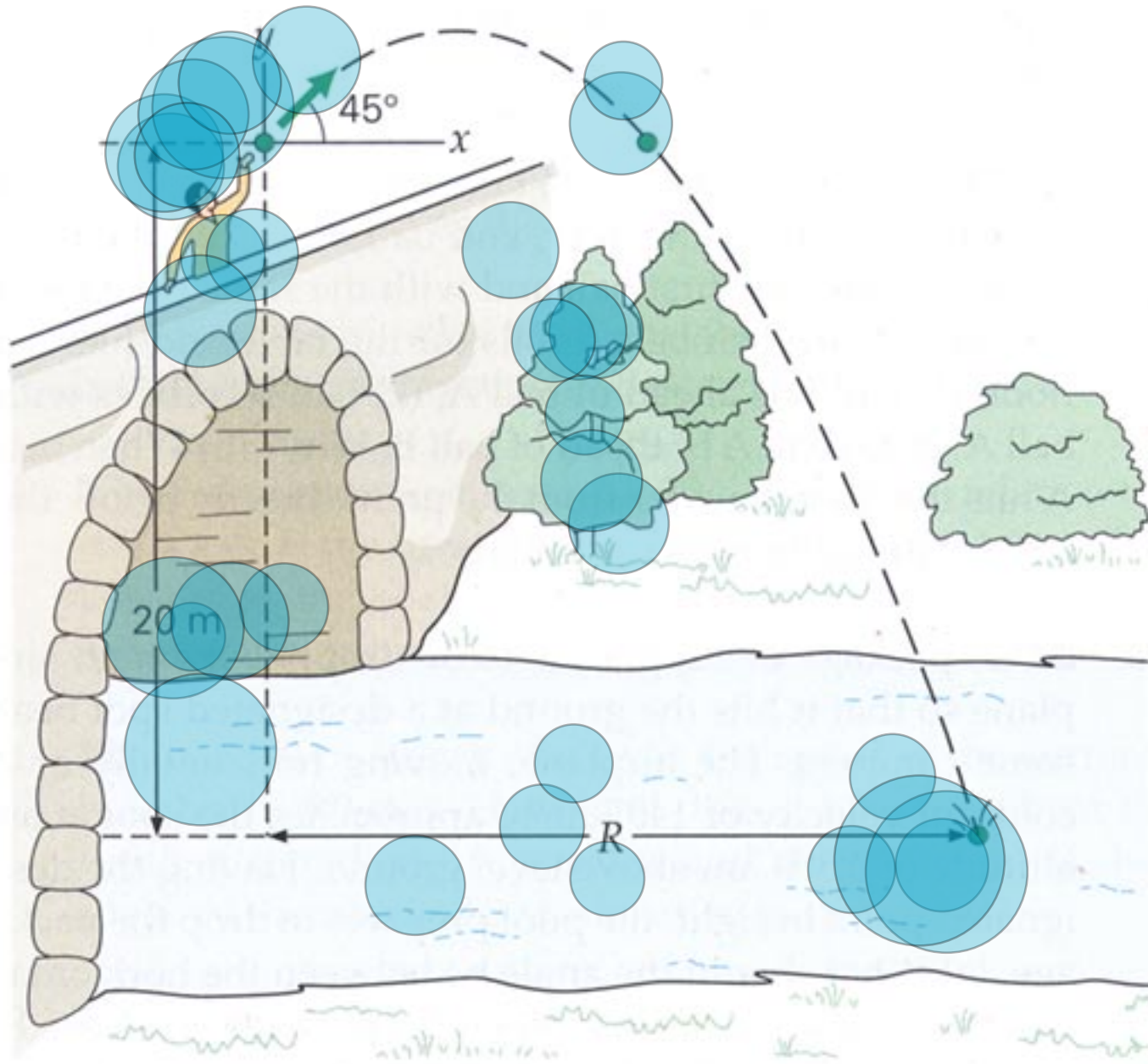


Serway and Jewett (Harcourt, 2002)

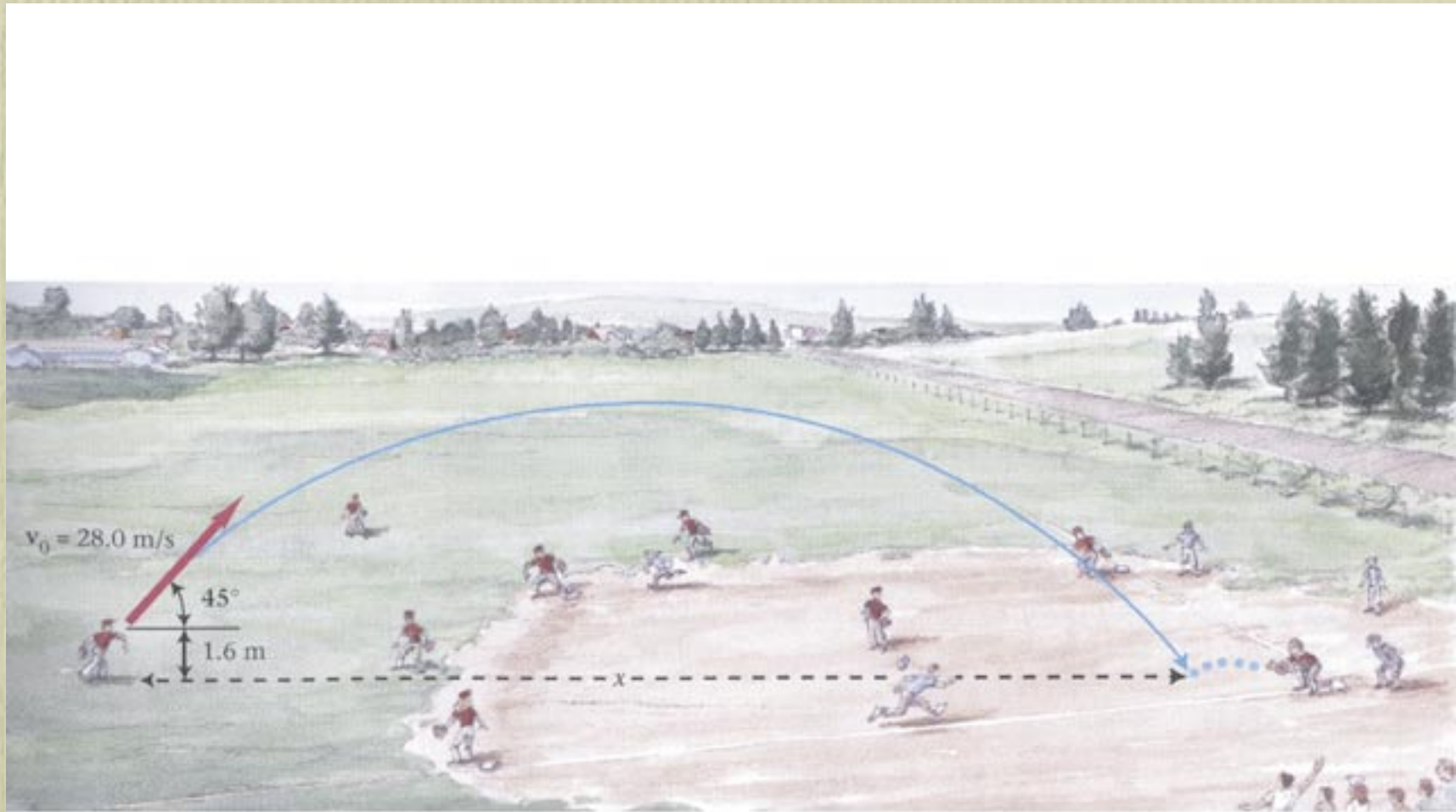


Wilson and Buffa, 5th Ed. (Prentice Hall, 2003)

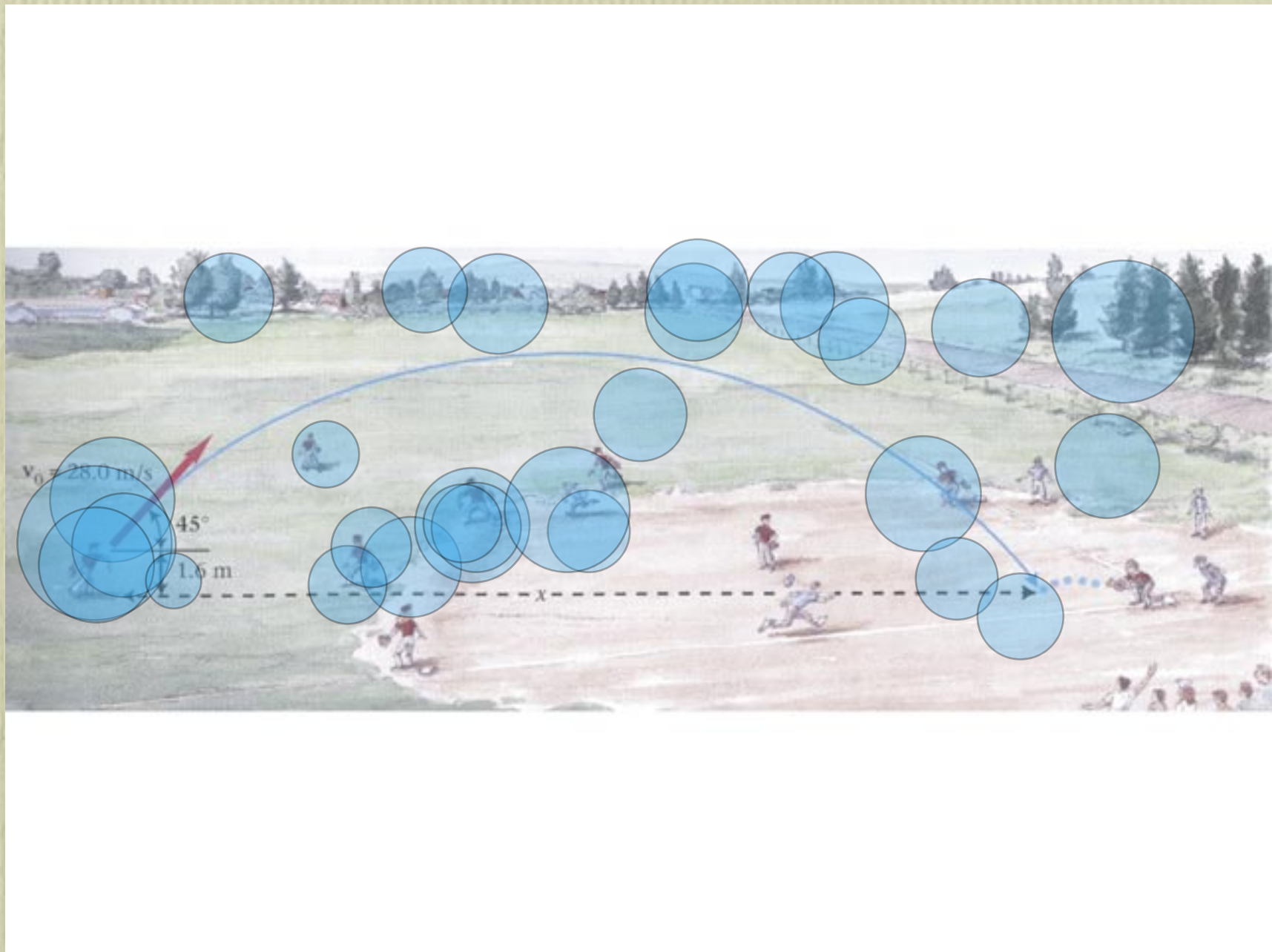




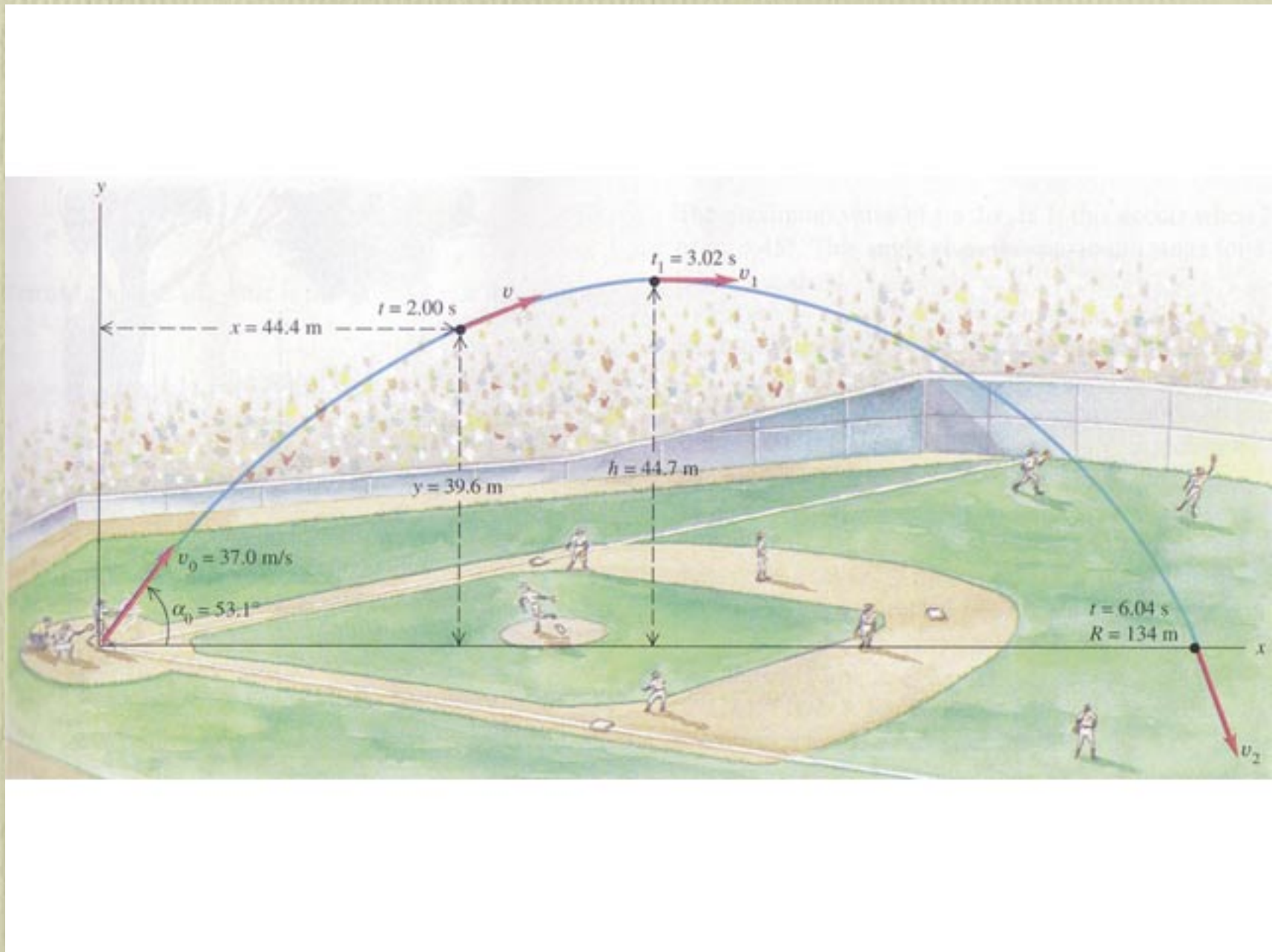
Wilson and Buffa, 5th Ed. (Prentice Hall, 2003)



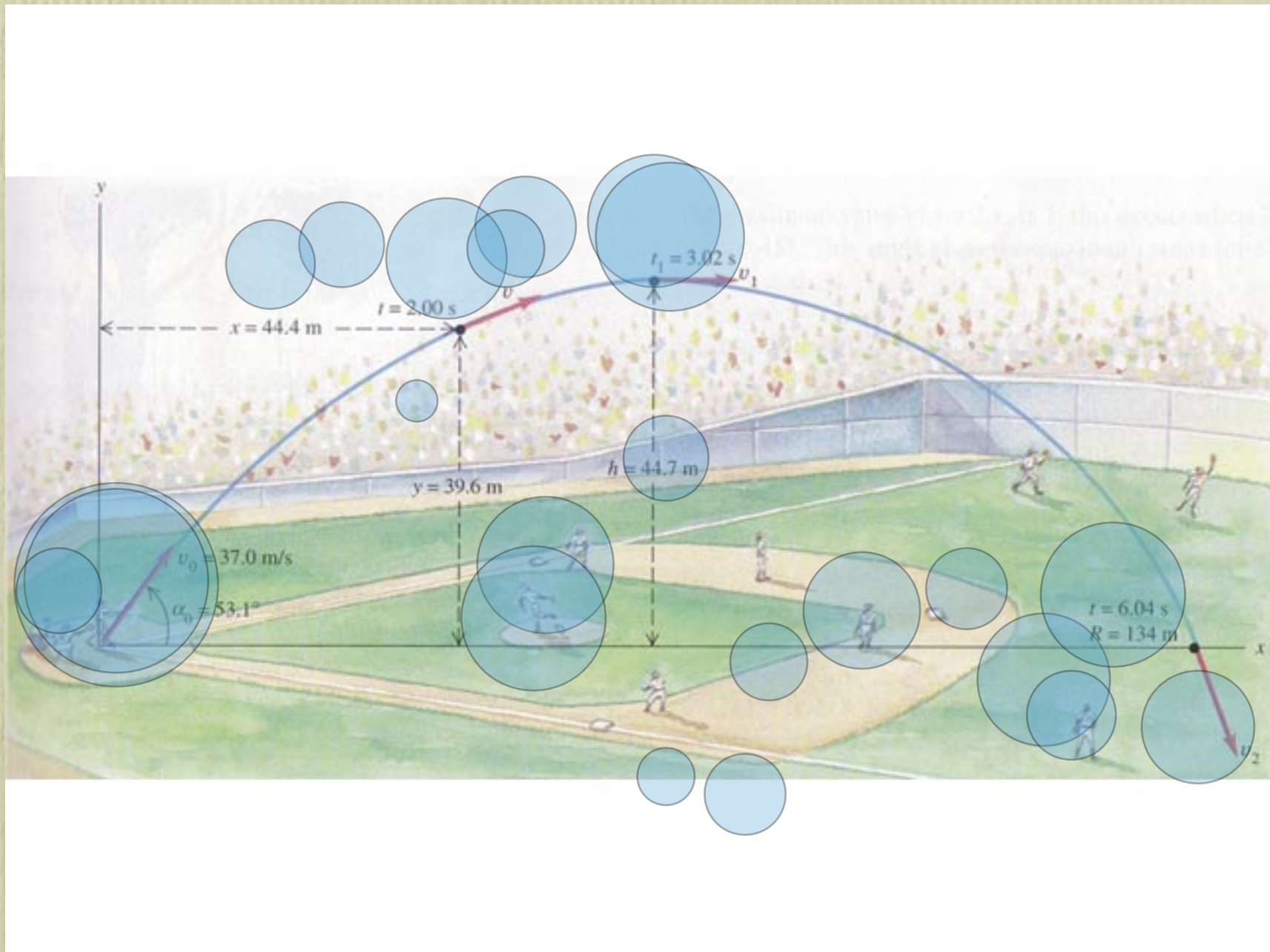
Jones and Childers, 3rd Ed. (McGraw Hill, 2001)



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?

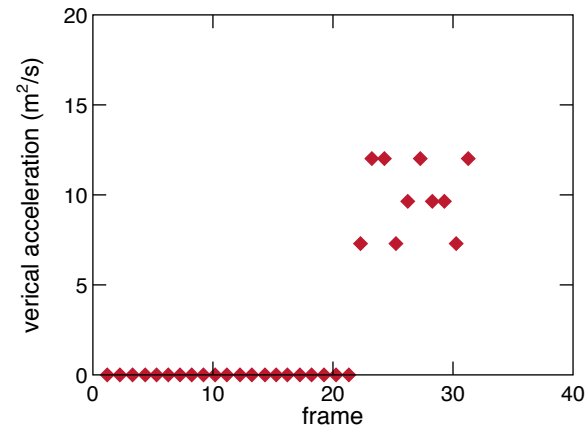
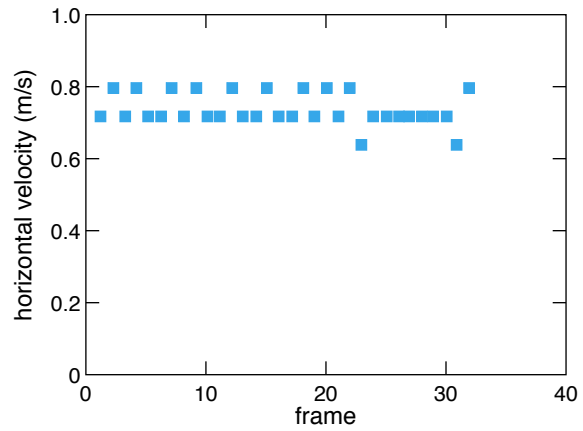
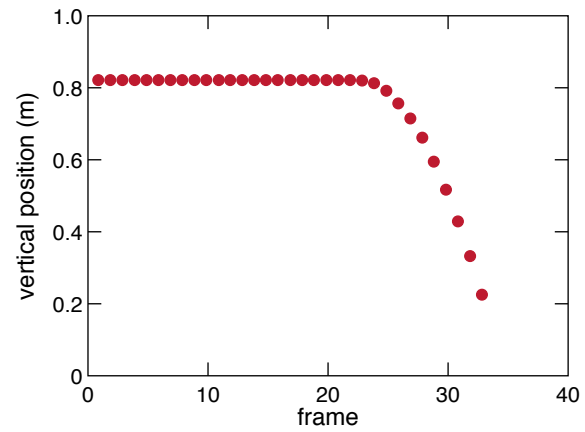
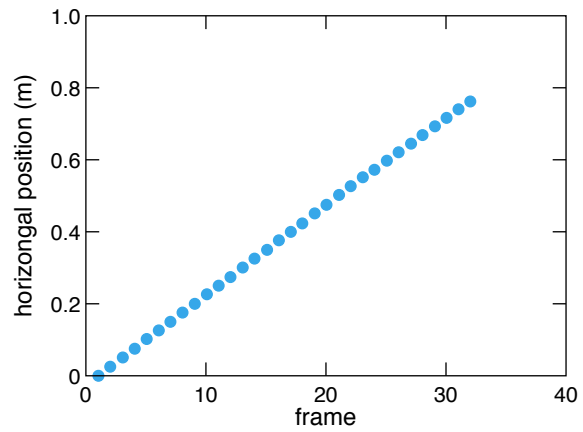








# Measurements







# 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

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Dr. Wolfgang Ruckner

Prof. Daniel Simons (UIUC)

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# Acknowledgments

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Rafael Gattass

Joanna Huey

Olof Jonmarker

Prof. Margaret Livingstone

Dr. Veronica McCauley

Dr. Wolfgang Ruckner

Prof. Daniel Simons (UIUC)

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