Visualizations and visual illusions: how the mind tricks us

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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^-6: threshold for vision
- 10^-4: outdoor, starlight
- 10^-2: outdoor, full moon
- 10^0: streetlight
- 10^2: indoors, lit room
- 10^4: outdoor, cloudy
- 10^6: outdoor, bright sun
- 10^8: eye damage

Outdoor scene
What color?
luminance (cd/m^2)

- eye damage
- outdoor, bright sun
- outdoor, cloudy
- indoors, lit room
- streetlight
- outdoor, full moon
- outdoor, starlight
- threshold for vision

- white
- black

A
What the retina does:

• Spatial compression

• Adjust luminance range to nerve S/N

• Extract reflectance
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

DARK

baseline rate
Retinal cell response

Center excites above baseline rate
Retinal cell response

Surround inhibits below baseline rate
Retinal cell response

Full illumination same as no illumination
Center-surround antagonism

Cells respond to differences in intensity
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

- retina
- edge detection
Visual pathways

parallel pathways

visual cortex

color/luminance
left/right
top/bottom
Visual pathways

higher visual areas

WHERE

WHAT
Visual pathways

higher visual areas

WHERE

color blind
fast
low acuity
high contrast sensitivity

motion perception
depth perception
spatial organization
figure/ground segregation
Visual pathways

higher visual areas

color selective
slow
high acuity
low contrast sensitivity

object recognition
face recognition
color perception

WHAT
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?
“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

Types:
- Abstract
- Realistic
Visualization types

- illustration
- abstract
- realistic
- animation

constant velocity

by you, on crate

by floor, on crate
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

\[ y = v_{0y}t - \frac{1}{2} gt^2 = h - \frac{1}{2} gt^2 \]

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

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?)
People look at

- Parabolic motion of ball
- Carts
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

- Horizontal position (m):
  - Frames: 0, 10, 20, 30, 40
  - Values: 0, 0.2, 0.4, 0.6, 0.8

- Vertical position (m):
  - Frames: 0, 10, 20, 30, 40
  - Values: 0, 0.2, 0.4, 0.6, 0.8

- Horizontal velocity (m/s):
  - Frames: 0, 10, 20, 30, 40
  - Values: 0, 0.2, 0.4, 0.6, 0.8

- Vertical acceleration (m²/s²):
  - Frames: 0, 10, 20, 30, 40
  - Values: 0, 5, 10, 15, 20
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
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