Physics 131- Fundamentals of Physics for Biologists I

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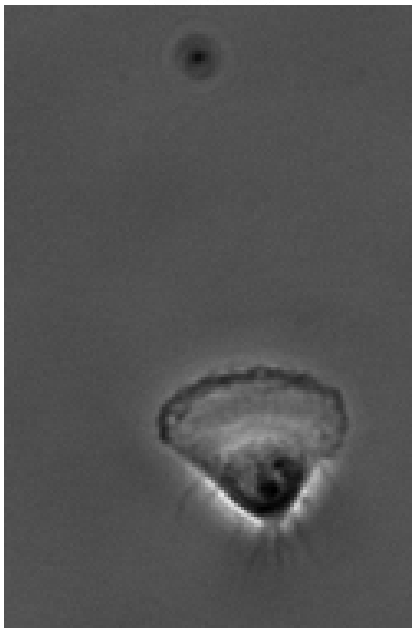
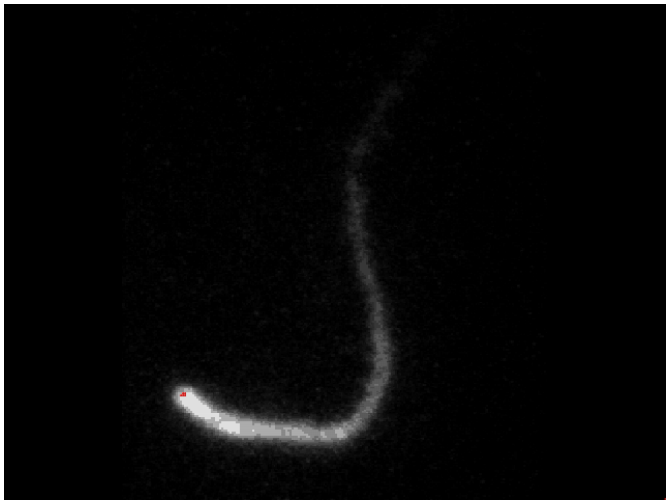




An exercise on how your brain processes information

- I will show you a slide with a list of color names
- Each word will be printed in a colored ink.
- Pair off in groups of twos.
- One of each pair will be the reader, the other the checker

- The reader will have 20 seconds to read out loud the **colors that the words are printed in.**
- The checker will count the number of words read, and the number correct.


RED GREEN BLUE YELLOW PINK
ORANGE BLUE GREEN BLUE WHITE
GREEN YELLOW ORANGE BLUE WHITE
BROWN RED BLUE YELLOW GREEN
PINK YELLOW GREEN BLUE RED

Checkers: how many colors did your partner name?

A. 0-5

B. 6-10

C. 11-15

D. 16-20

E. 21-25

Checkers: how many colors did your partner get right?

A. 0-5

B. 6-10

C. 11-15

D. 16-20

E. 21-25


RED GREEN BLUE YELLOW PINK
ORANGE BLUE GREEN BLUE WHITE
GREEN YELLOW ORANGE BLUE WHITE
BROWN RED BLUE YELLOW GREEN
PINK YELLOW GREEN BLUE RED

What did we learn from these exercises?

Our brains will connect what we see to what we know

You can take advantage of this in learning science!

- If you have prior knowledge, your brain will connect this prior knowledge when carrying out a task
  → **foothold principles**

- Do not rely on the first recollection or intuition that comes to your mind. Active thinking is required!

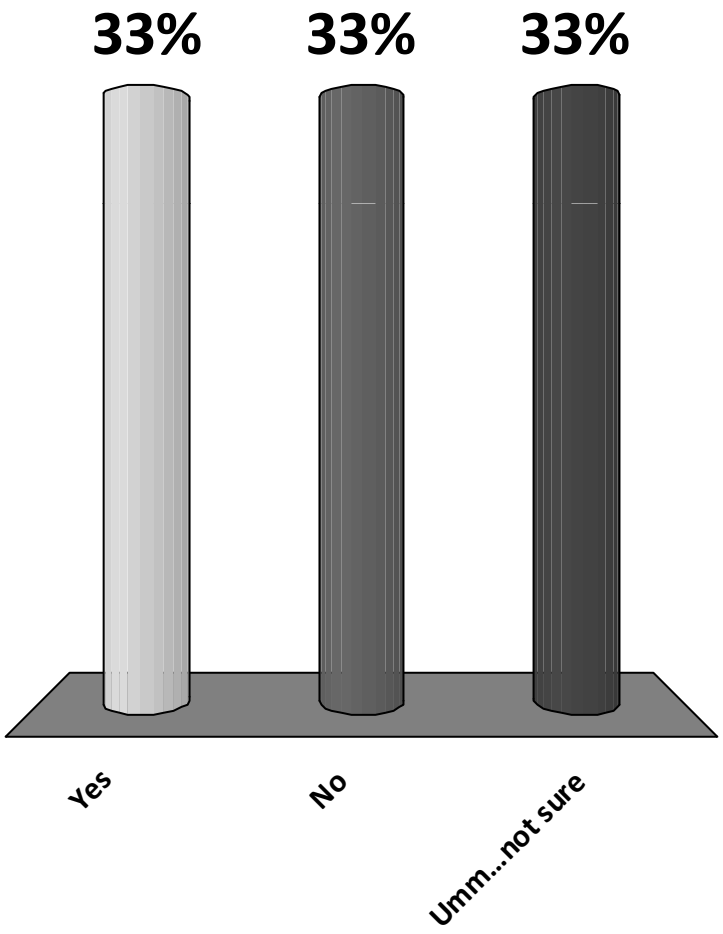
NEW in the Course (1)
Focus on Sense-making

NEW in the Course (2)

Physics Topics relevant to living systems

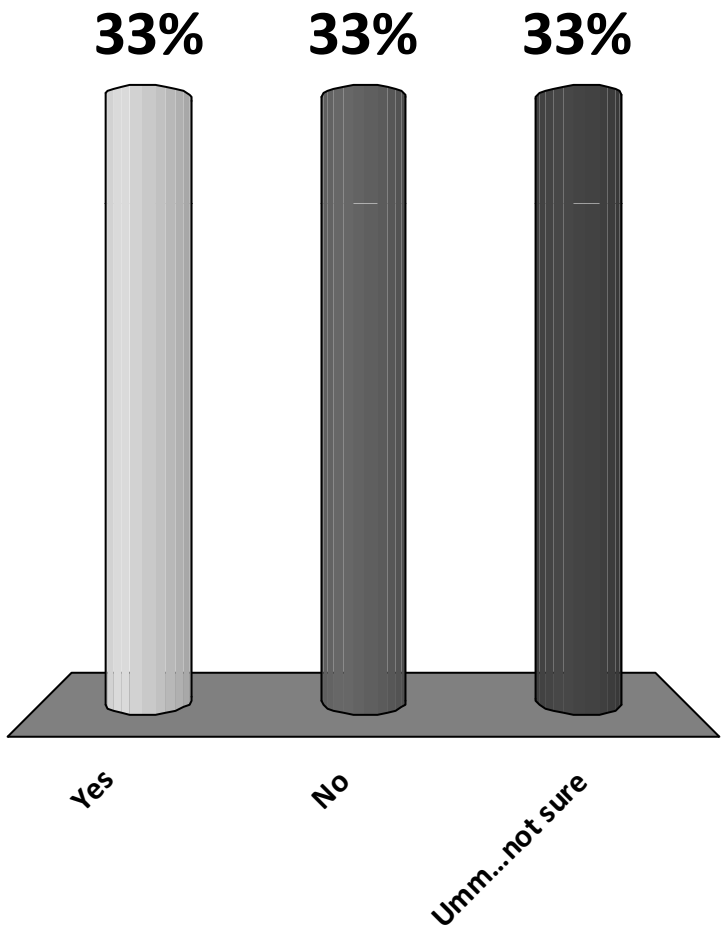
Do Newton's Laws always hold?

A. Yes
B. No
C. Umm…not sure



Is "Conservation of Energy" Always Right?

A. Yes
B. No
C. Umm…not sure



What is Physics?

Physics provides a framework for understanding **basic principles of nature**

e.g. **motion, forces, light**

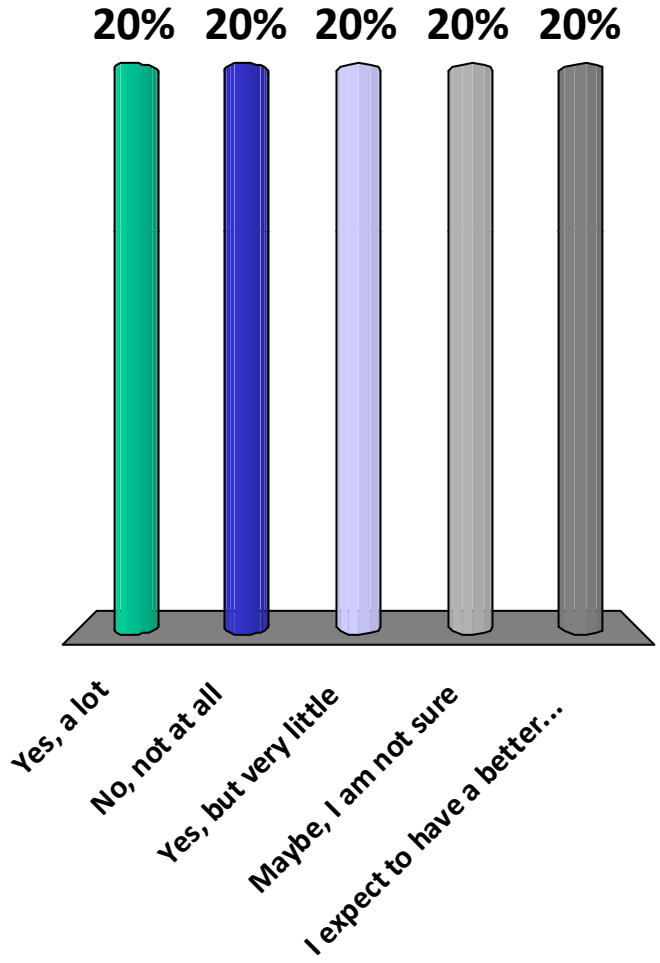
Physics uses **models** and **Math** to describe basic principles of nature

Based on insights from models and math, physicists sometimes discover novel ways of controlling natural processes

- Light → lasers → Modern microscopes
- Electric charges → transistors → CPUs

Can Physics contribute to Biology and Medicine

A. Yes, a lot
B. No, not at all
C. Yes, but very little
D. Maybe, I am not sure
E. I expect to have a better answer after this course!



What can Physics contribute to Biology and Medicine?

- Whiteboards: write down your ideas!
- Groups of 3 – discuss topics
  - Teaching Assistant and Learning Assistant will be in Lecture hall to participate in these discussions
- Pick one to talk about

- Discuss with another group of 3
- Share with Class

Some of your responses

Better ways to model disease
Diffusion across membrane
Metastasis of cancer
Bioengineering, Biotechnology
Size shape of life
Speed of reactions delivery of medication
Optics
Artificial sensory organs, Prosthetics
Biomed technologies
Fluids
Understand physiology
Fluids
Light, visual perceptions
Imaging technologies

How can Physics contribute to Biology and Medicine?

Experimental Tools for Cell Biology

- Super-resolution imaging (breaking the diffraction barrier)
- Optical traps and Magnetic traps to apply small forces

Experimental Tools for Diagnosis and Therapy

- MRI for high resolution imaging
- Proton therapy to eliminate diseased cells

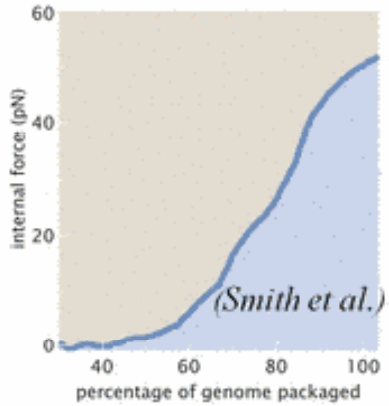
Physics approaches: Quantitative Approaches to Complexity & Information

Physical principles: Forces and Motion

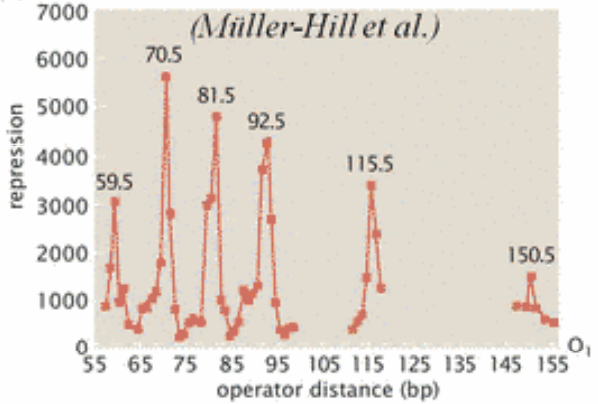
Experiments to change your life for: A serious role for theory in biology

- ***Often, biological data reports on functional relationships like those that are the lifeblood of physics.***
- ***Data of this variety imposes much stricter demands on biological theory. No amount of words or cartoons suffice to describe such data.***
- ***This approach allows us to see things that we can't see with words and cartoons alone (i.e. Darwin's sixth sense).***

Genome Management



Gene regulation



- ***How can we even know if these results are surprising?***

Rob Phillips, Caltech

Beyond the traditional approach

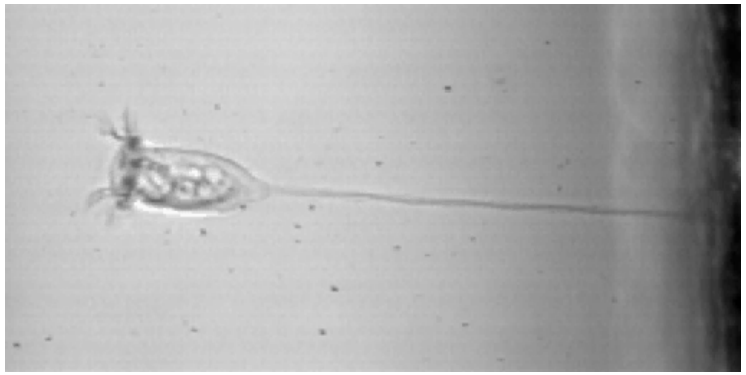
Biologists approach:

Look for the important molecules
Perturb them to find important interactions

Physicists approach:

Underlying physical mechanisms
Models or theories based on the physics of the system
Can go beyond molecular details and unearth generic principles

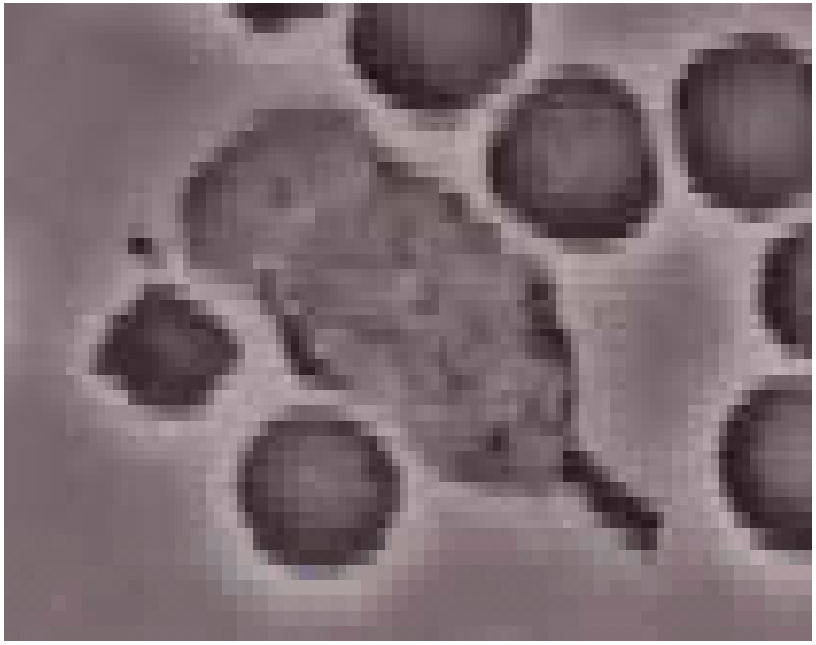
Cells in motion



Vorticella: 10 cm/s

Biological spring

(David Rogers)



Neutrophil : 0.1 μm/s

White blood cell chasing a bacteria

Chemical energy converted to mechanical energy and movement

Cells change shape, cells exert forces, cells compute

How many times faster is the Vorticella (10 cm/s) compared to the Neutrophil (0.1 μm/s) ?

A. 10
B. 10^2
C. 10^3
D. 10^4
E. 10^5
F. 10^6
G. 10^7

Forces in Living Systems

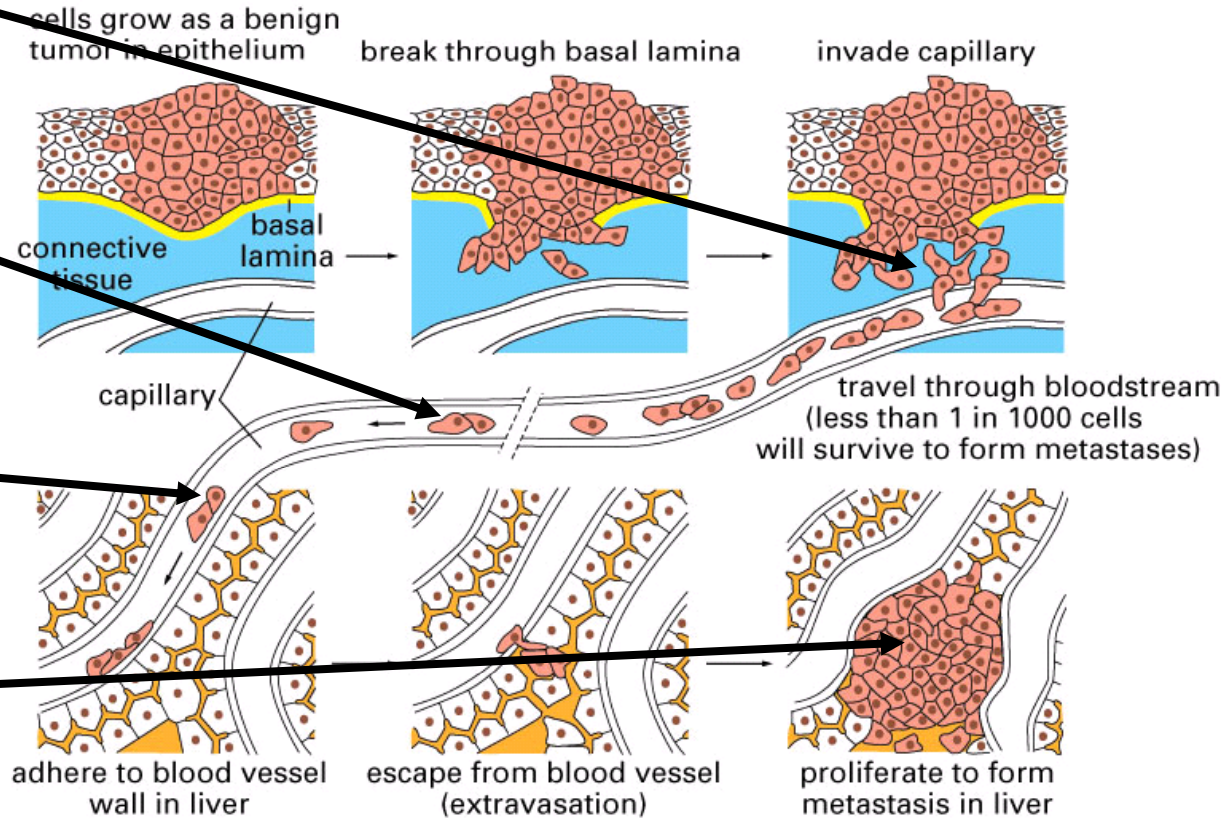
Example: The role of forces in Cancer, or development of the embryo

Cells generate forces to migrate

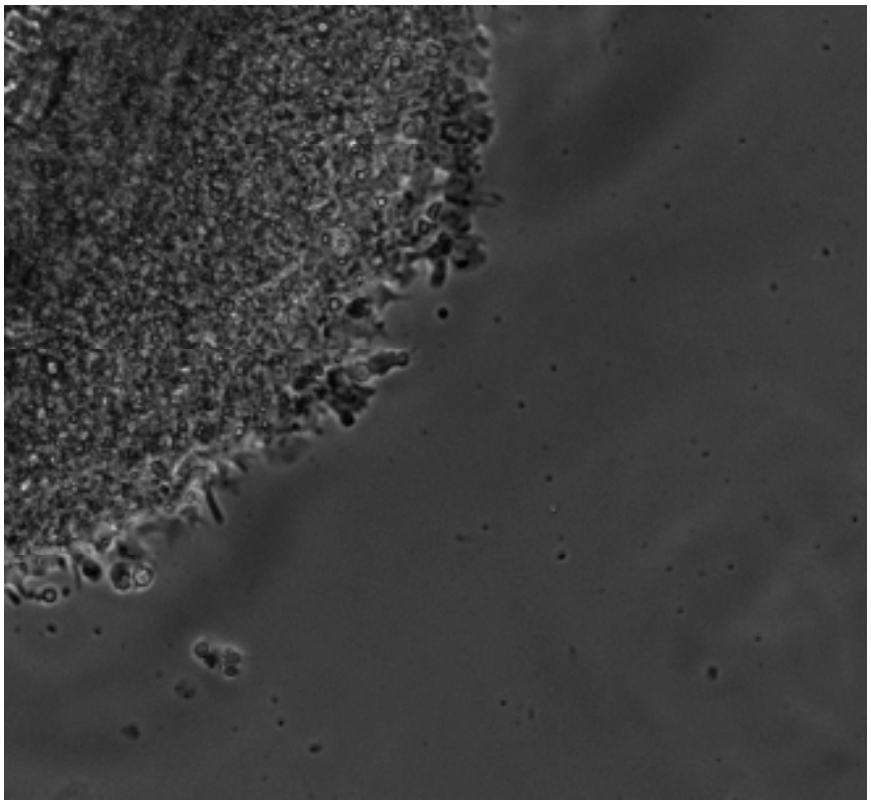
Cells are deformed by fluid forces

Cells adhere to new tissue

Cells grow in tissue with different stiffness



Cells interact with their physical environment



Cell sheets from chick embryo (neural crest cells)

80 µm
6 h

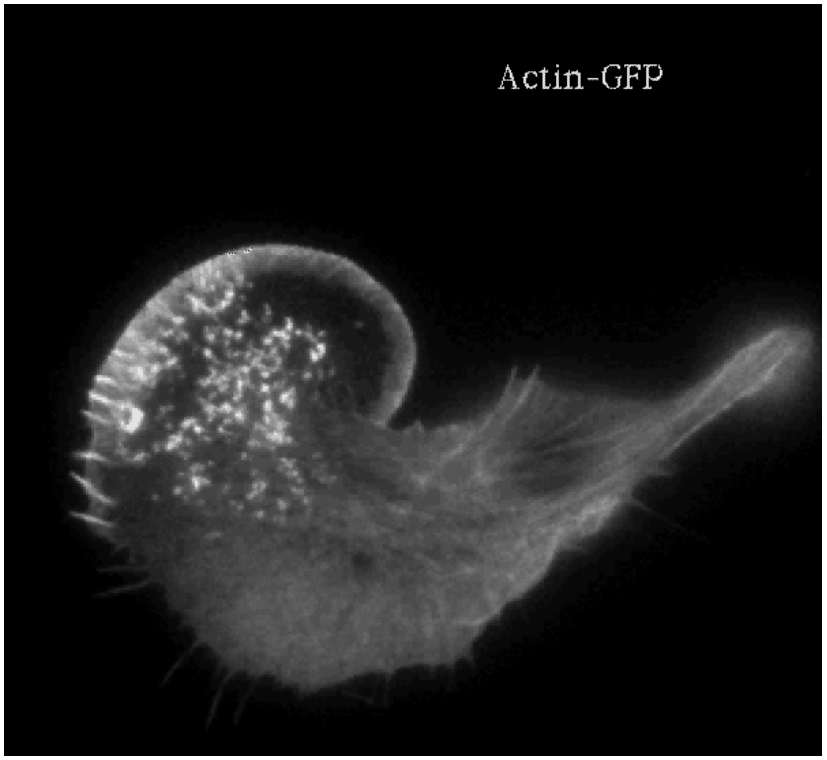
Forces in living systems

Forces generated by cells

Forces between cells

Christy Ketchum, Shen Li, 2013
Upadhyaya lab, Taneyhill lab, UMD

What powers the cellular engine?



Cancer cell

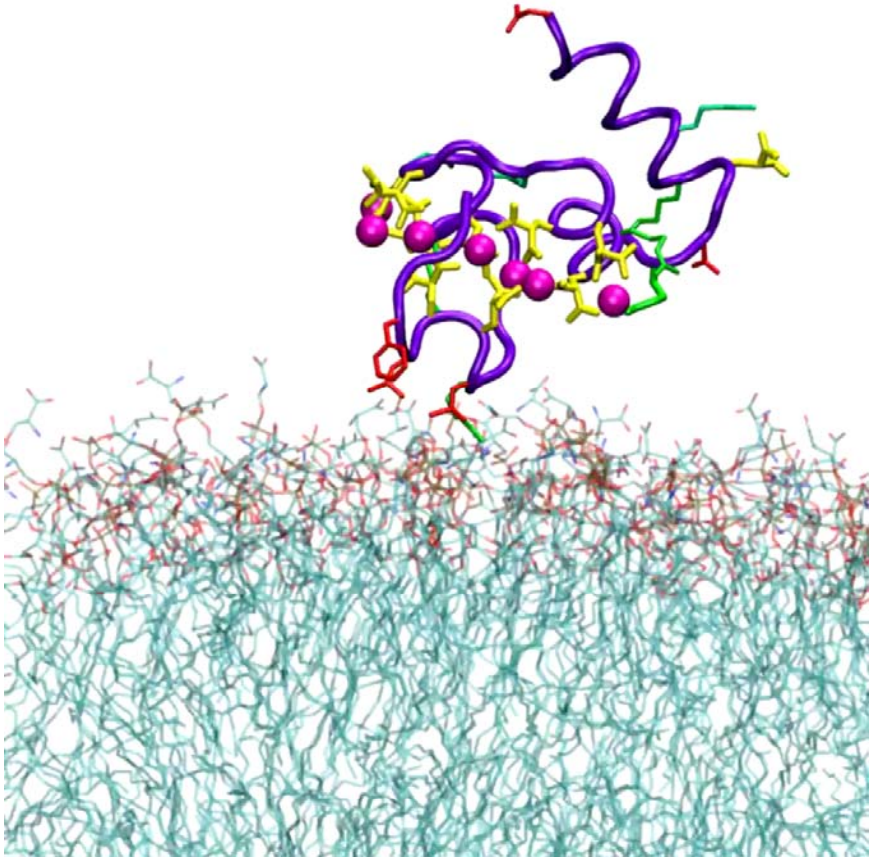
Immune cell (T cell)

Molecular origin of forces:
Actin dynamics + motors
(a biopolymer)

Physics of Living Systems is DIFFERENT from the Physics taught in traditional Intro Courses

Example:

Forces and Motion on the scale of proteins



Blood Clotting Protein on Membrane, Molecular Dynamics Simulation
Ohkubo & Tajkhorshid, *Structure* 2008.

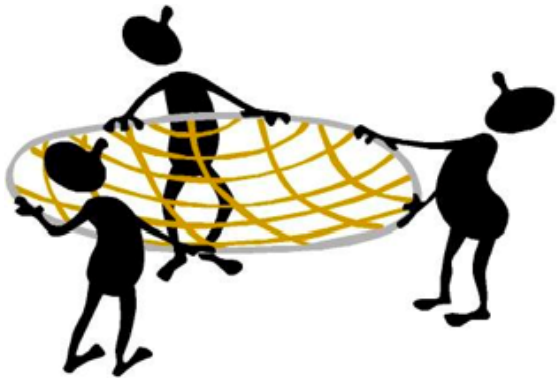
NEW in the Course: (2) Physics Topics relevant to living systems

Example: We will study random forces and motion. You will also learn how directed forces affect random motion.

Random (Forces/Motion)	⟷	Directed (Forces/Motion)
"Brownian Motion"		*Fluid Flow* *Electrical Forces*

Knowing-how-you-know icon: Coherence – Your safety net

- We will be establishing fundamental principles that we can (almost) always trust as "**stakes in the ground**."
- The links among the different views creates a "**safety net**" that protects us against errors of recalled or reconstructed memory.
- We will use our coherence to "**reconcile**" what we know about the world with a coherent physics picture.



Topics

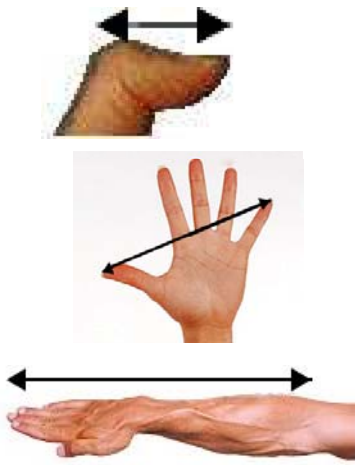
- Estimation
- Modeling the world
- Math in science
- Units and dimensions
- Scaling

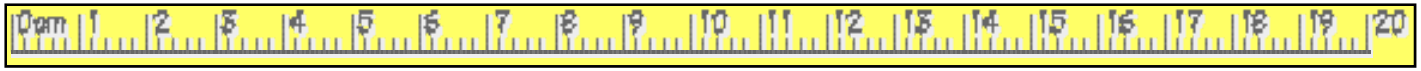
Foothold Ideas:
Estimation – Quantifying experience

- **Measure your body parts**
- **Don't** look up data online or get it from friends!
- **Don't** use your calculator! Use 1-digit arithmetic
- **Do** figure out your estimations by starting with something you can plausibly know and scale up or down
- **Do** check your answer to see if it's reasonable
- **Do** learn a small number of Useful numbers

My personal scales

	inches	centimeters
First digit of thumb		
Open handspan		
Forearm (cubit)		
Full height		





Useful numbers (people)

Numbers	
Number of people on the earth	~7 billion (7×10^9)
Number of people in the USA	~ 300 million (3×10^8)
Number of people in the state of Maryland	~ 5 million (5×10^6)
Number of students in a large state university	~30-40 thousand (3×10^4)

Useful numbers (distances)

Macro Distances	
Circumference of the earth	~24,000 miles (1000 miles/time zone at the equator)
Radius of the earth*	$2/\pi \times 10^7$ m
Distance across the USA	~3000 miles
Distance across DC	~10 miles

Useful numbers (bio)

Bio Scales	
Size of a typical animal cell	~10-20 microns (10^{-5} m)
Size of a bacterium, chloroplast, or mitochondrion	~1 micron (10^{-6} m)
Size of a medium-sized virus	~0.1 micron (10^{-7} m)
Thickness of a cell membrane	~5-10 nm (10^{-8} m)

Length scales – powers of ten

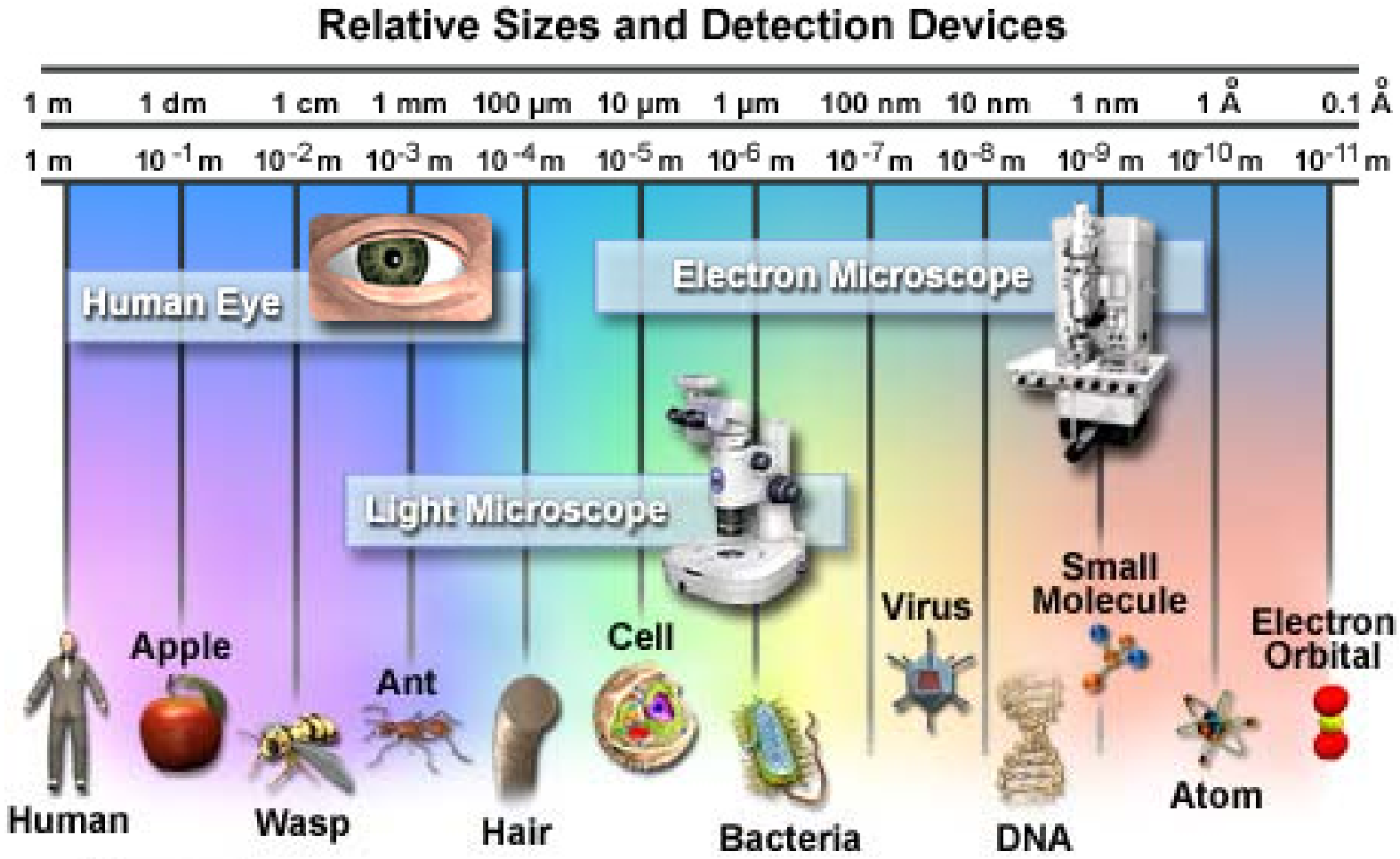


Figure 1

Guess the thickness of a page in a textbook. (Quickly! No talking!)

A. 10^{-0} m

B. 10^{-1} m

C. 10^{-2} m

D. 10^{-3} m

E. 10^{-4} m

F. 10^{-5} m

G. 10^{-6} m

H. 10^{-7} m

I. 10^{-8} m

J. 10^{-9} m

Estimate the thickness of a page in a textbook. (Take your time – talk to your neighbors)

A. 10^{-0} m
B. 10^{-1} m
C. 10^{-2} m
D. 10^{-3} m
E. 10^{-4} m
F. 10^{-5} m
G. 10^{-6} m
H. 10^{-7} m
I. 10^{-8} m
J. 10^{-9} m