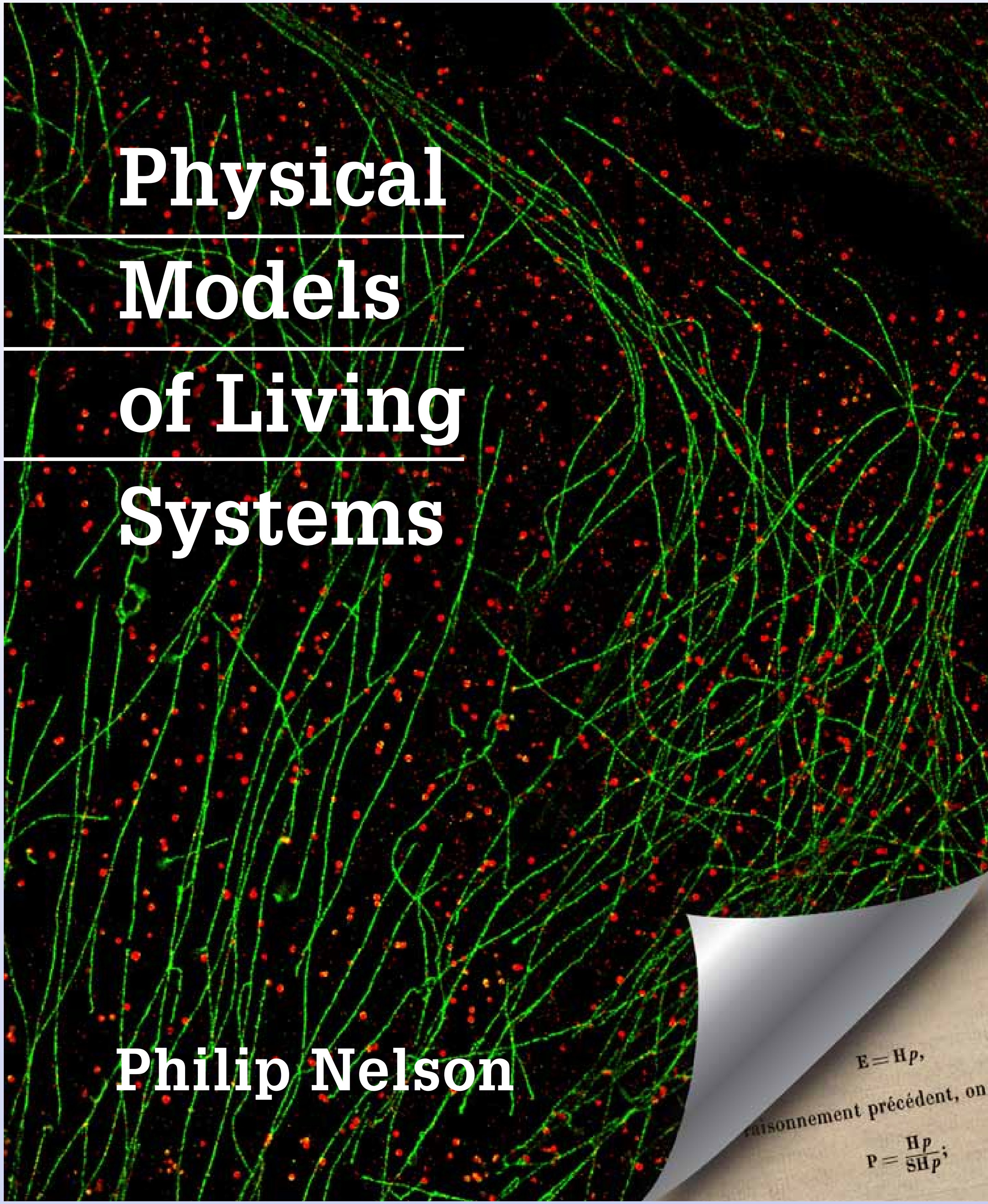
An intermediate-level course on...



Superresolution micrograph by Mark Bates.

These slides will appear at
www.physics.upenn.edu/~pcn
(or just google me)

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Well -- *skills and frameworks* still matter a lot. There is a big gap between information, for example that found on Wikipedia, and the competencies needed to obtain, integrate, and synthesize information, with the goal of making new knowledge that is relevant to important goals.

A class should help students get that -- in some specific context. ***Biological physics is an interesting context for that purpose***, regardless whether a student goes on in that field.

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Any science or engineering student benefits from explicit, repeated exposure to these ideas.
(And at my institution, at least some Physics majors are graduating without exposure to *any* of them.)

2: Biological Payoff: Beyond the diffraction limit

Framing: “How Life Does Those Tricks” -- that’s interesting. But “How Instruments Work” -- that’s interesting too.

Hey, how did A. Yildiz et al. measure the steps taken by a molecular motor using visible light? The diffraction-limited spot is at least 200 nm wide! In fact, *Everything interesting* in cells is below the diffraction barrier!

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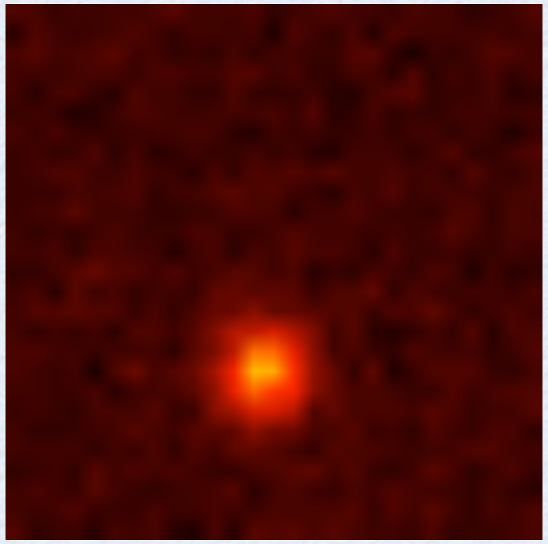

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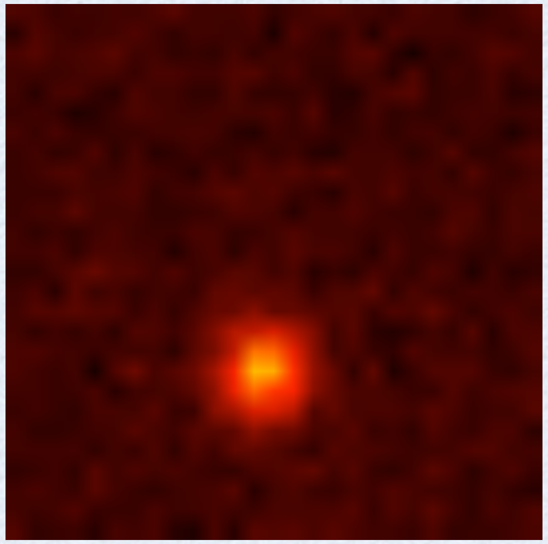

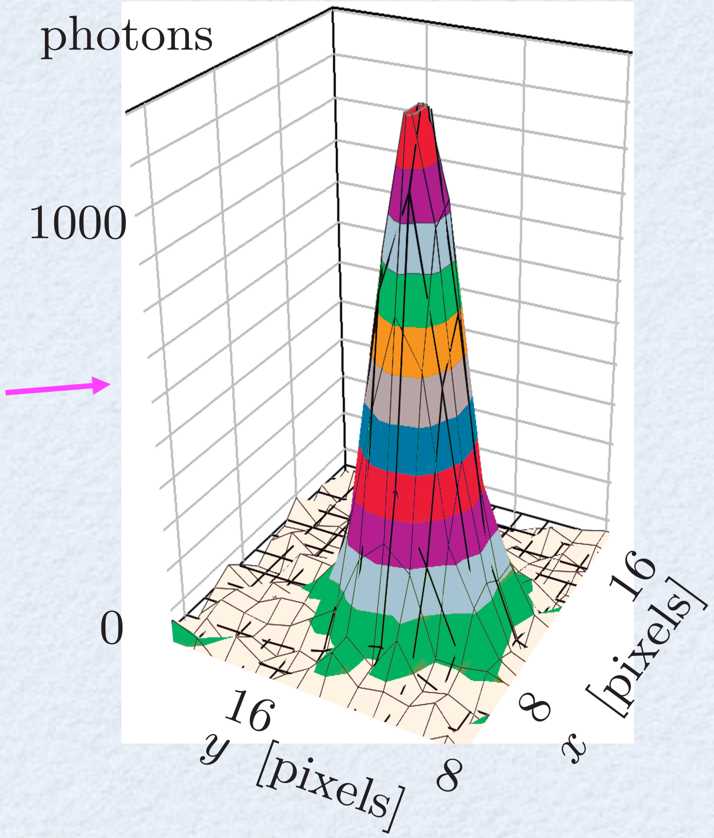

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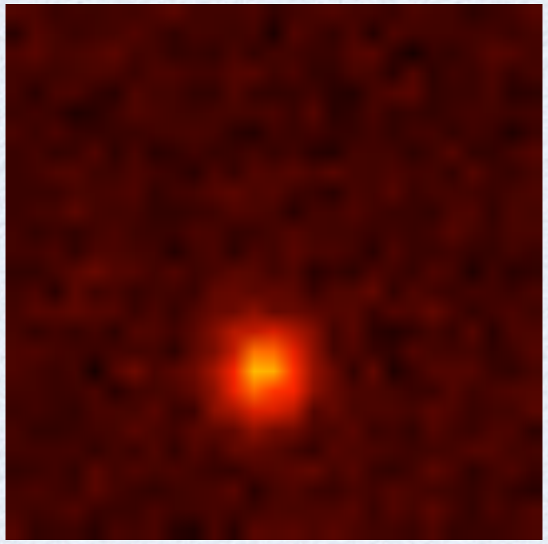

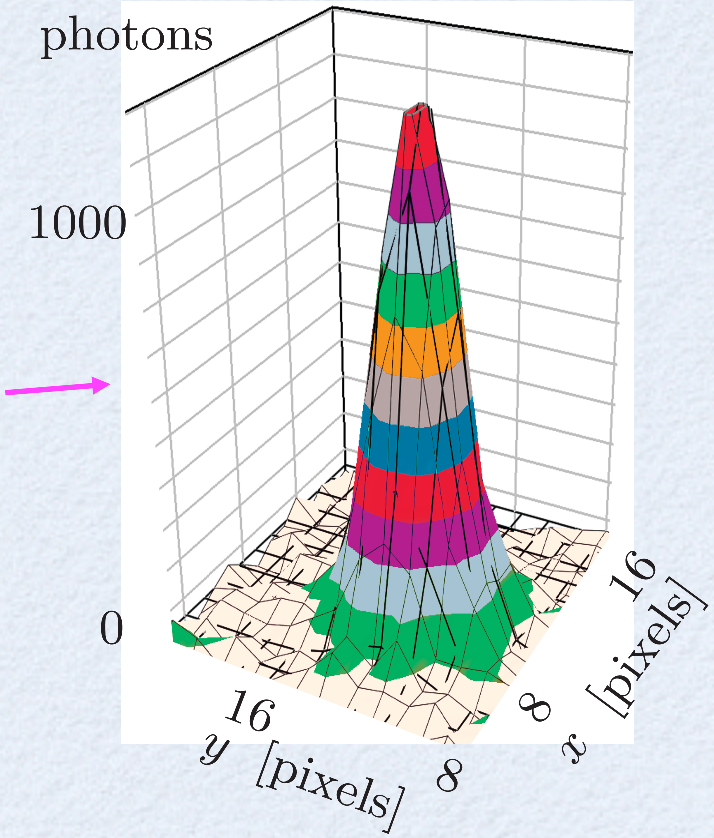

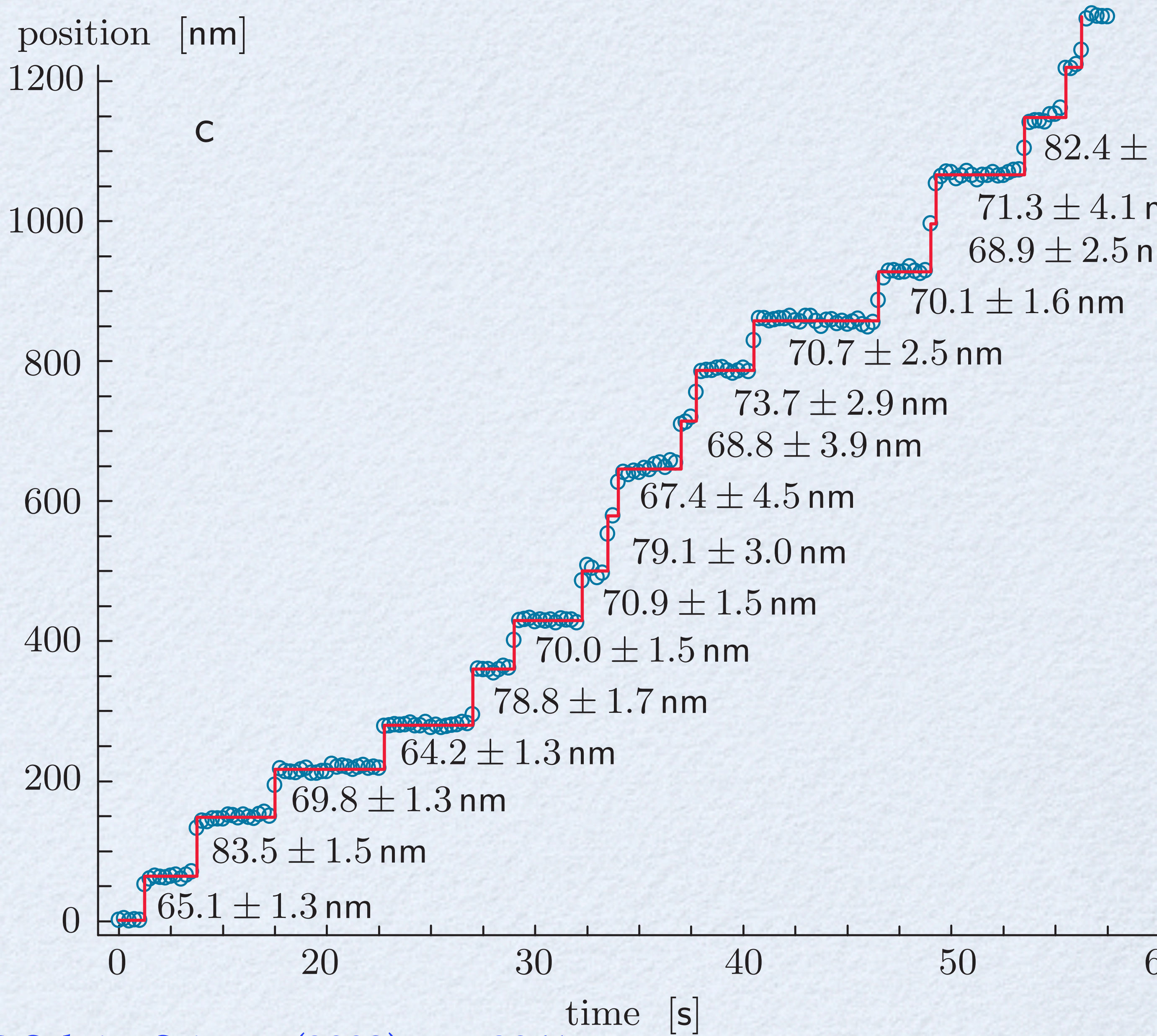

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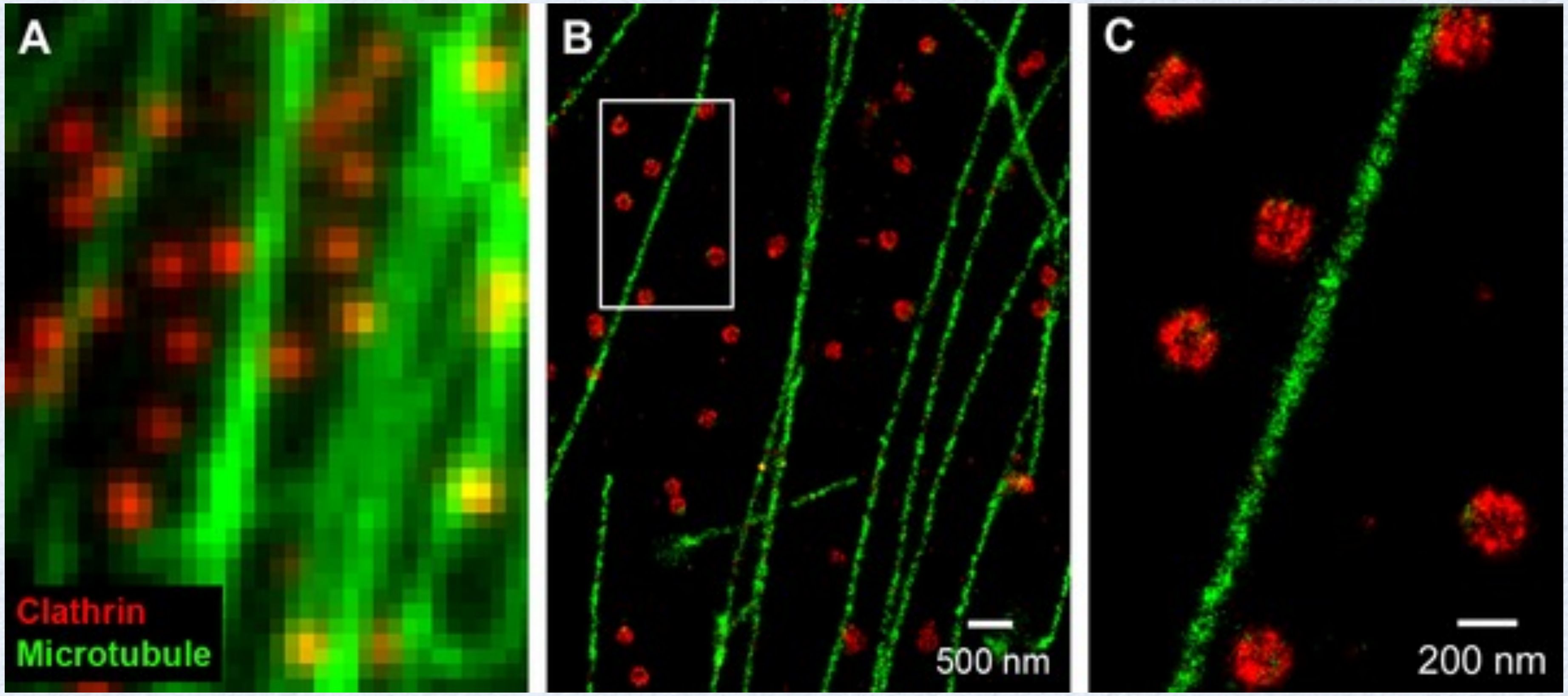
Conventional: Superresolution: Detail:



Introducing a *physical model* (the lumpy, statistical character of light), and applying maximum-likelihood, led to microscopy methods like PALM/STORM.

Images: Bo Huang, Mark Bates, Xiaowei Zhuang. Annu Rev Biochem (2009) vol. 78 pp. 993-1016.

3: Skills/frameworks: Feedback control

A 21st century frontier: synthetic biology

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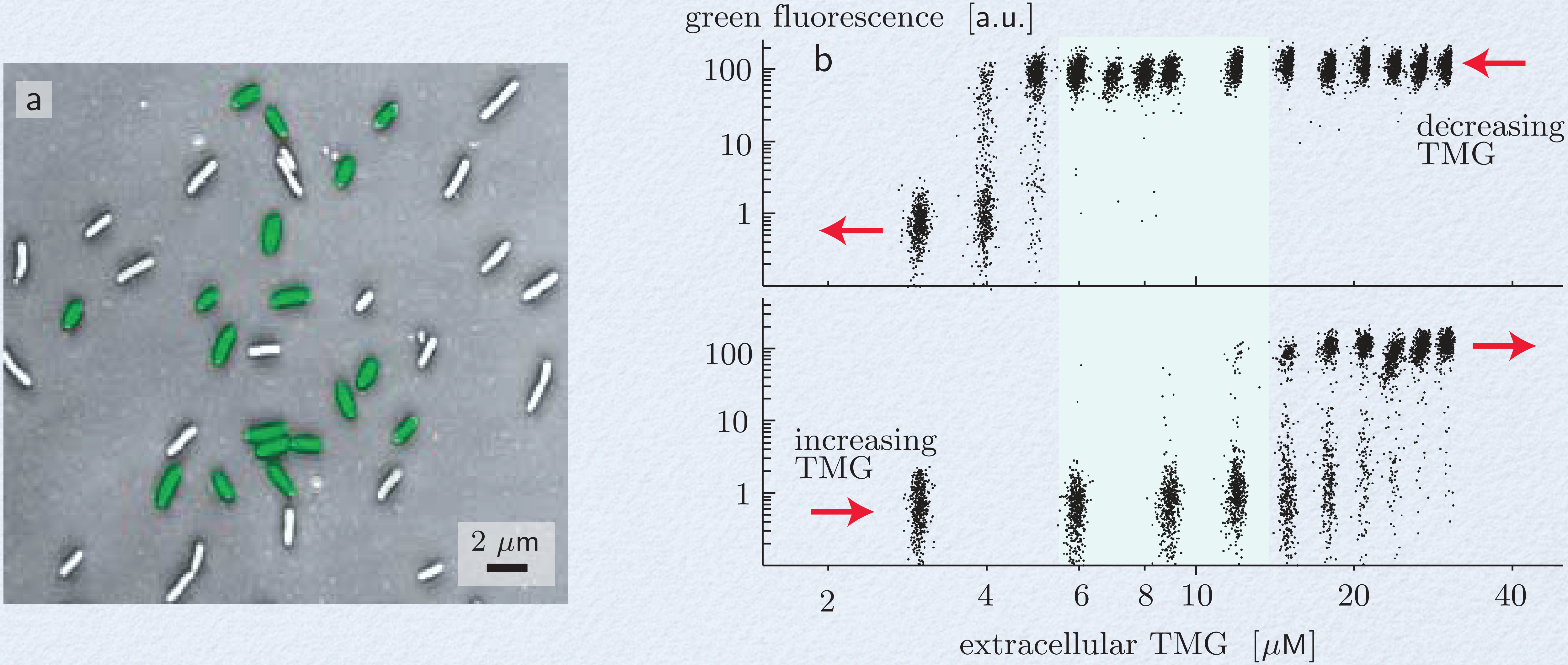
- Natural living systems also employ feedback control.

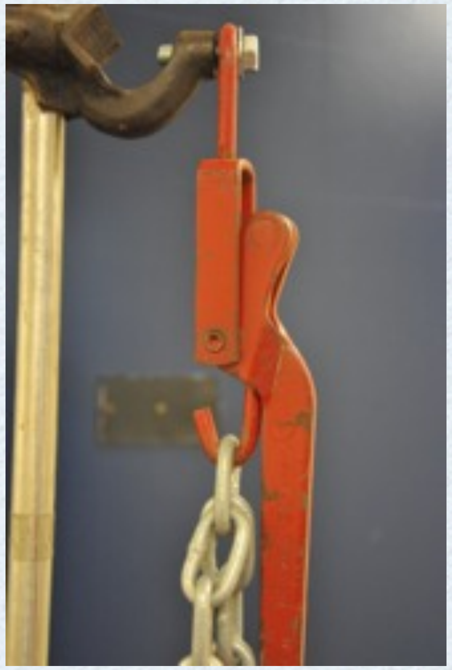
Biological problem: Switch response

Framing: How do you make decisions without a brain?



From P Nelson, *Physical models of living systems* (WH Freeman, 2015). Data and image from: Ozbudak et al., Nature (2004) vol. 427 (6976) pp. 737-740.

Physical analogy: the Toggle



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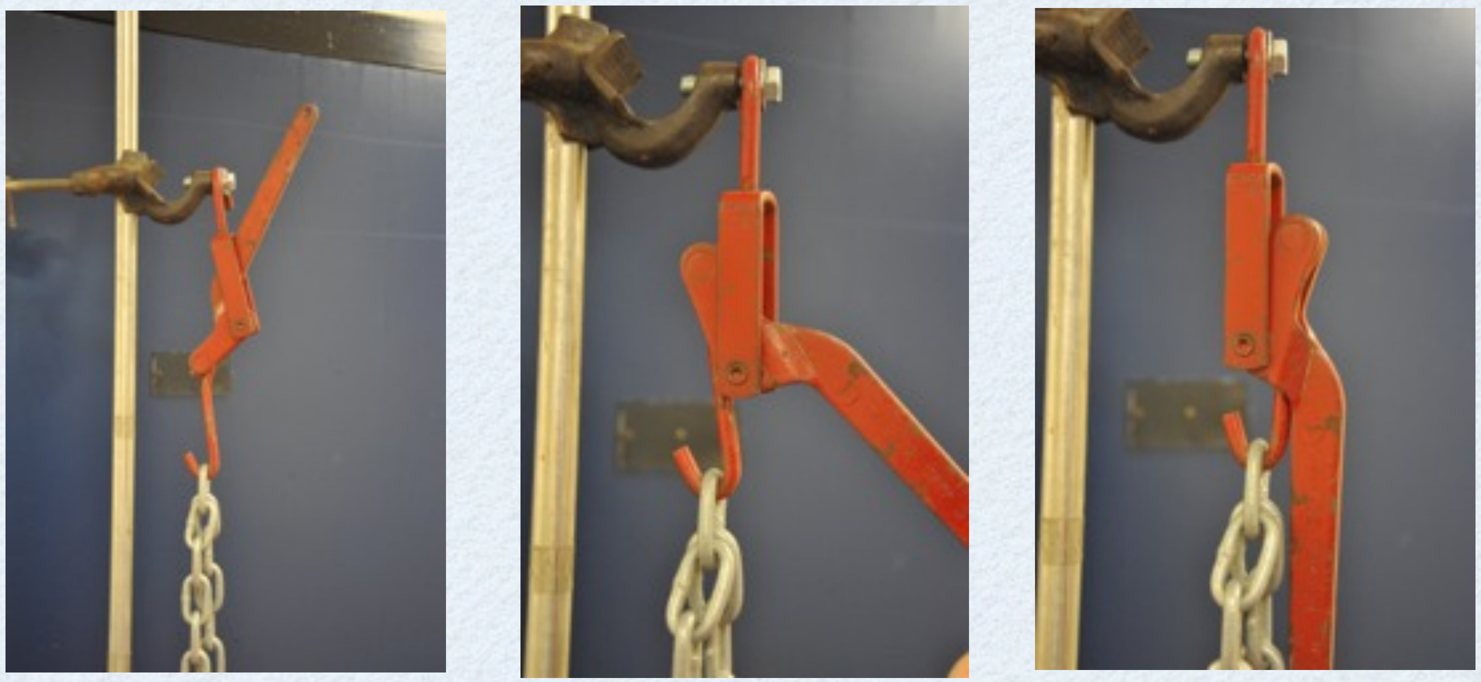

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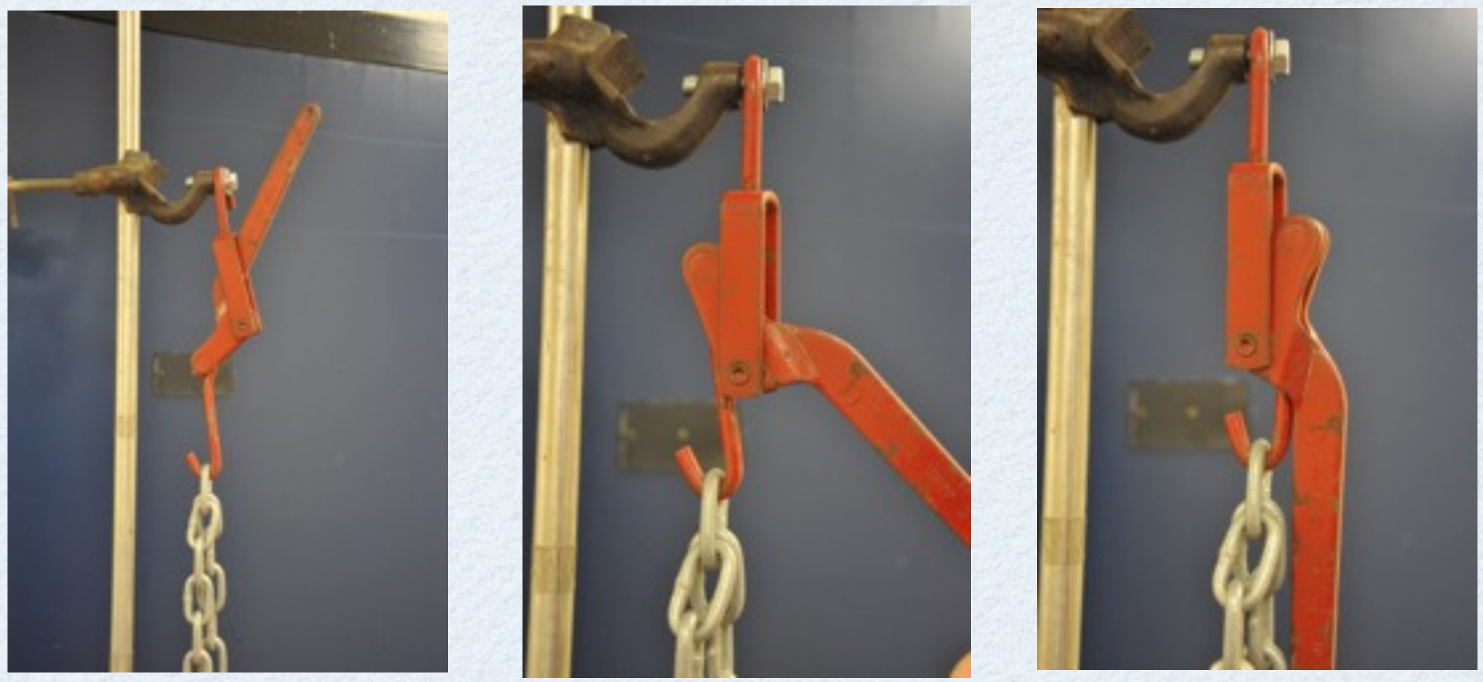

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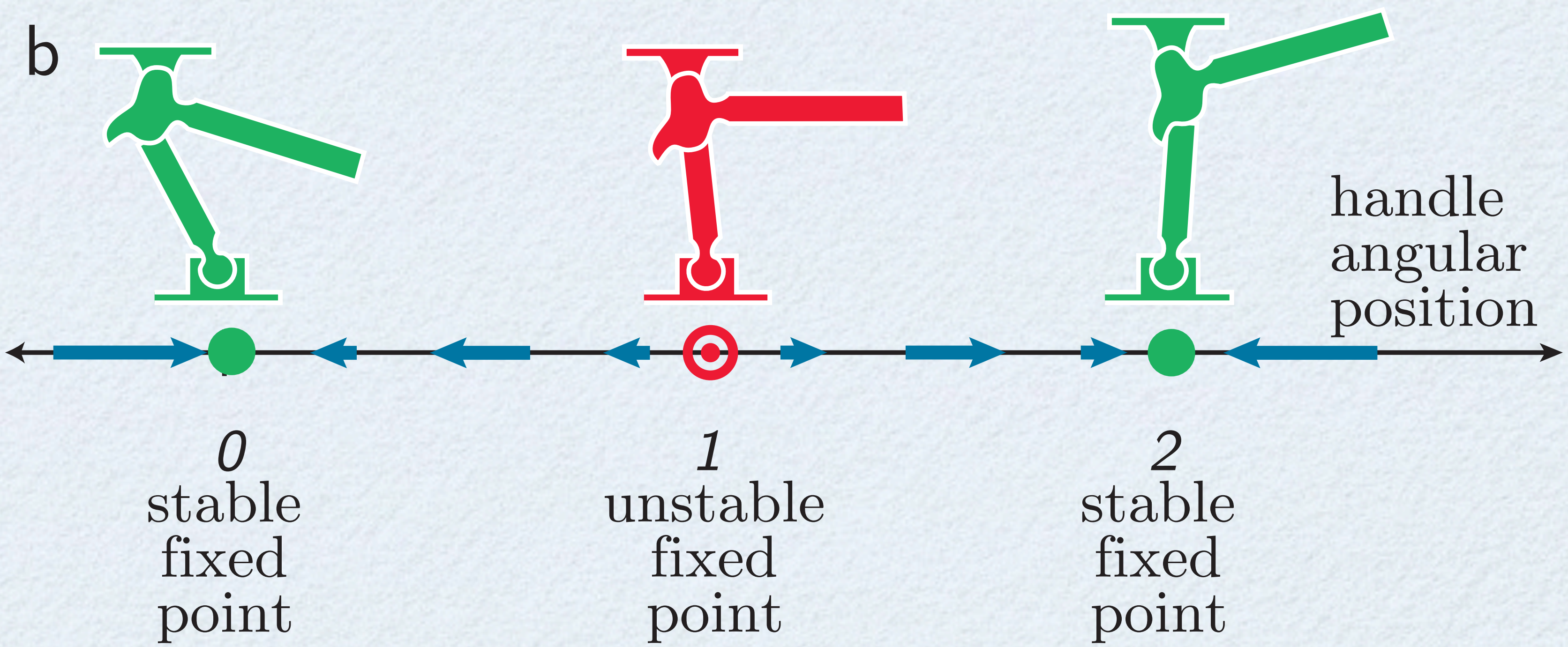

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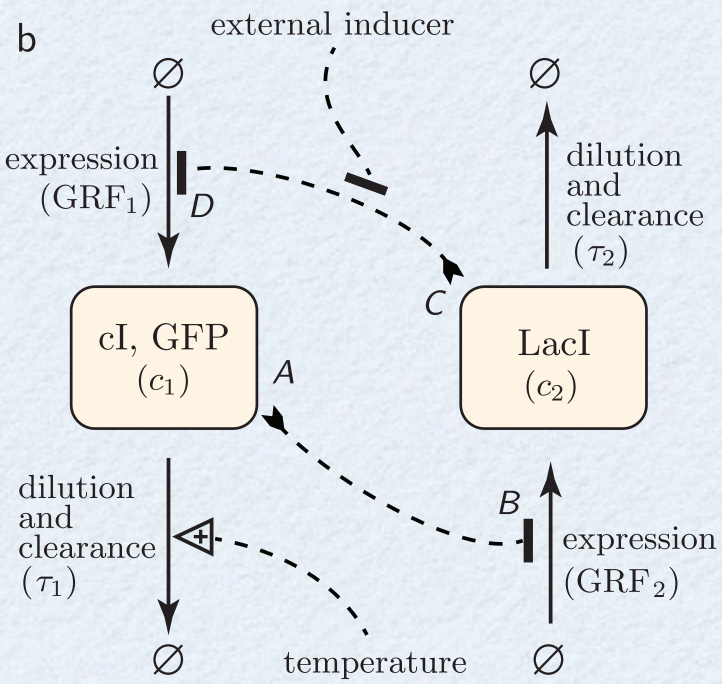
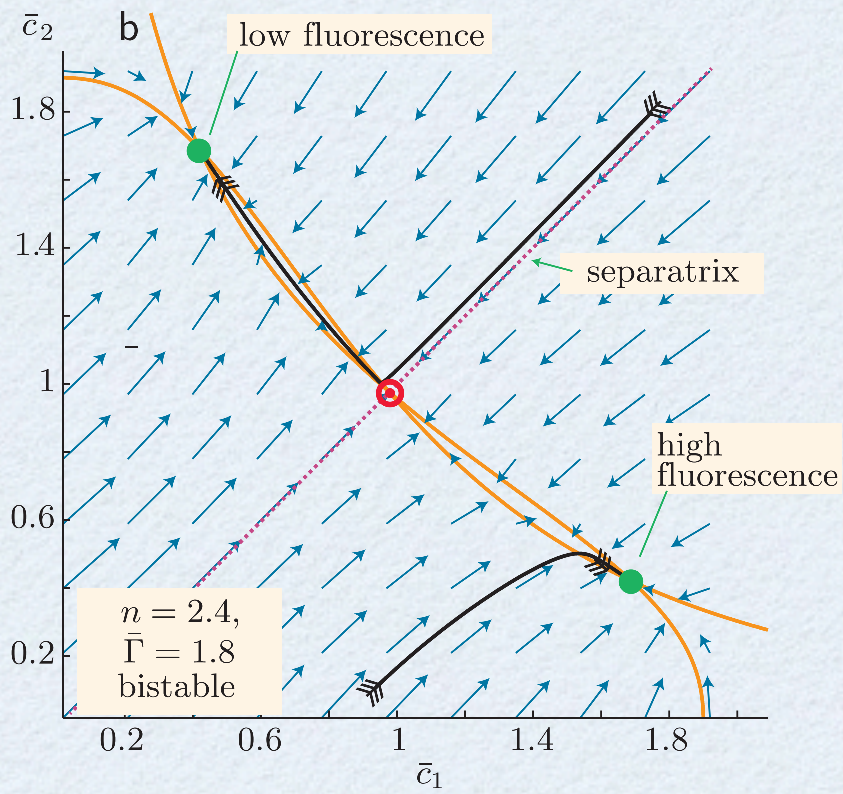
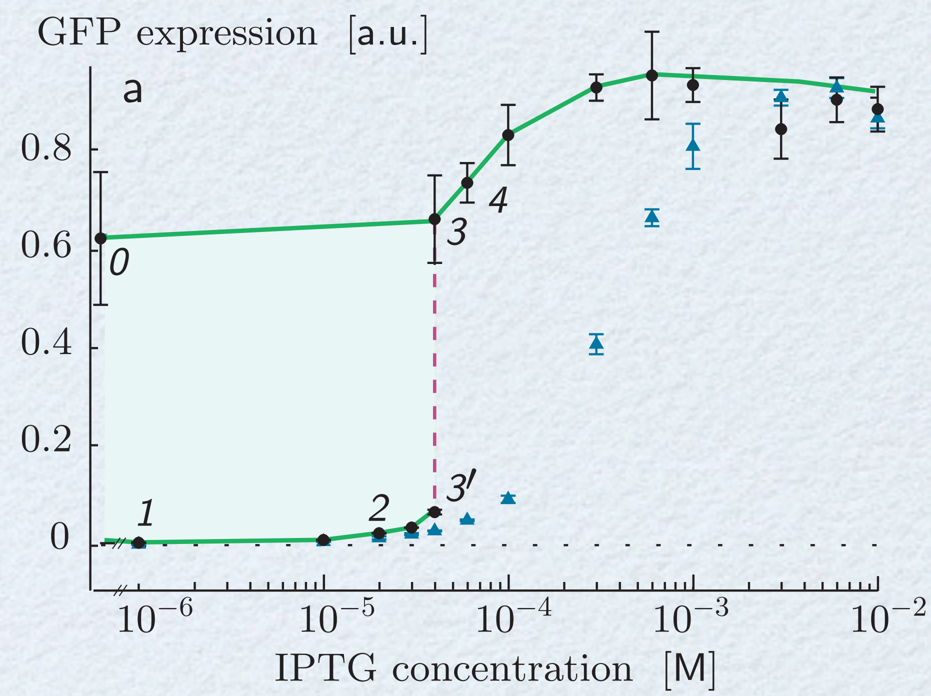
Synthetic biology: Two-gene switch







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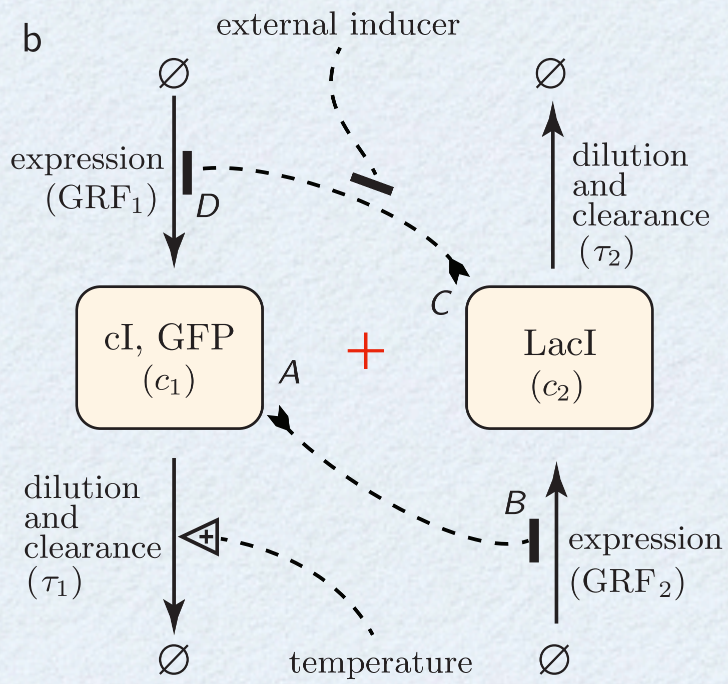

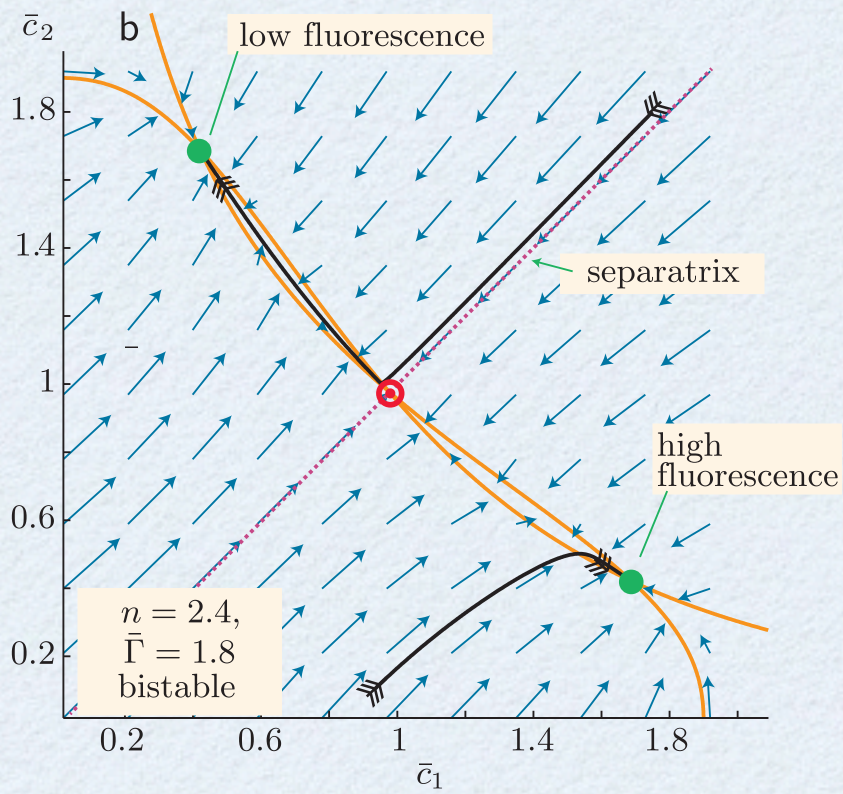

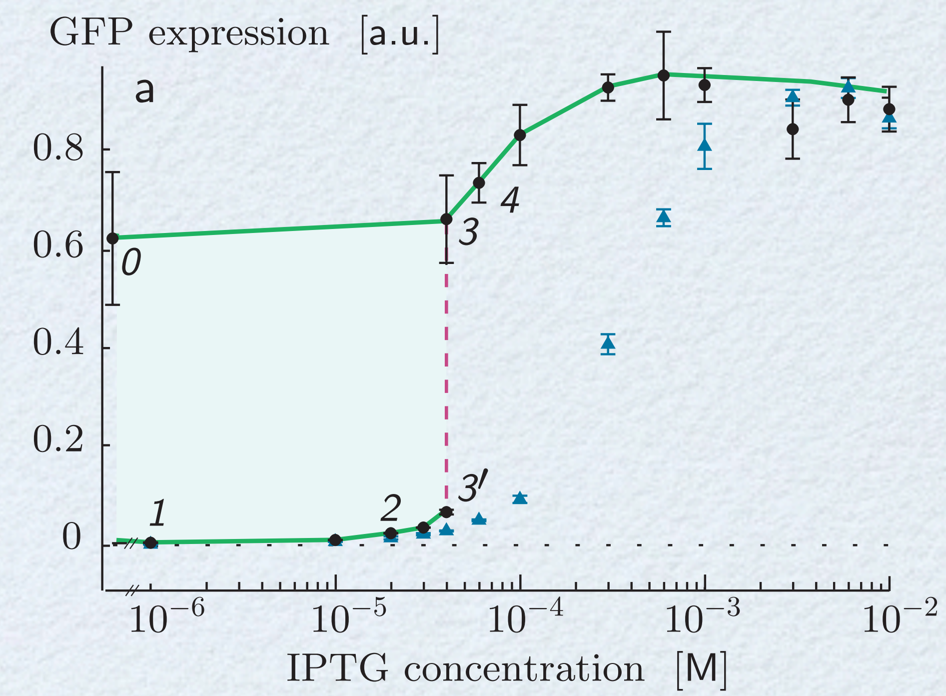

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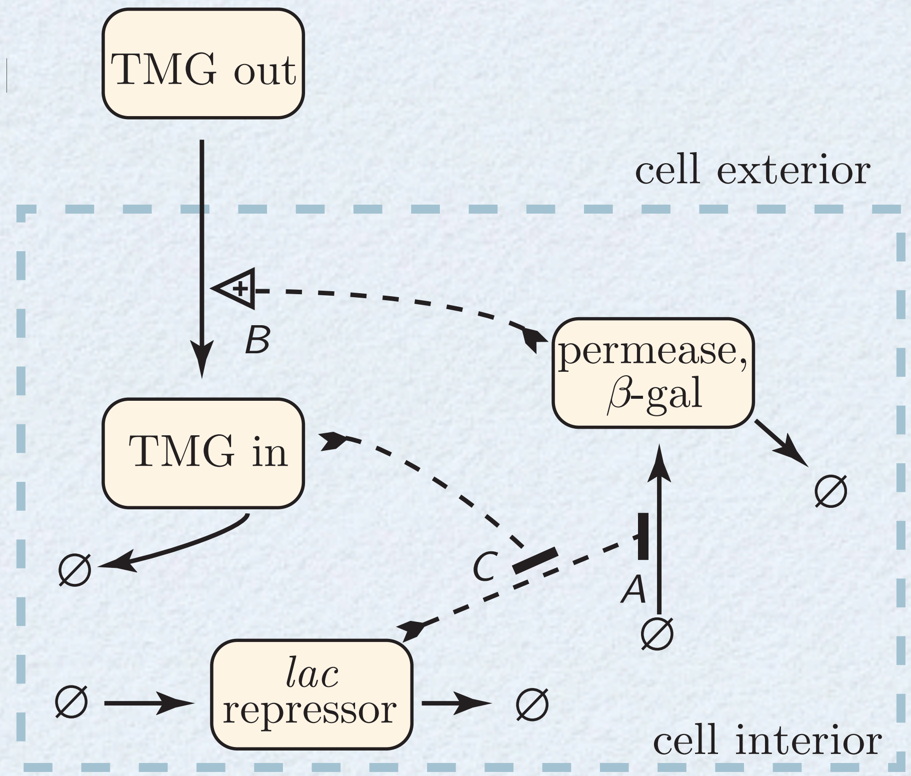

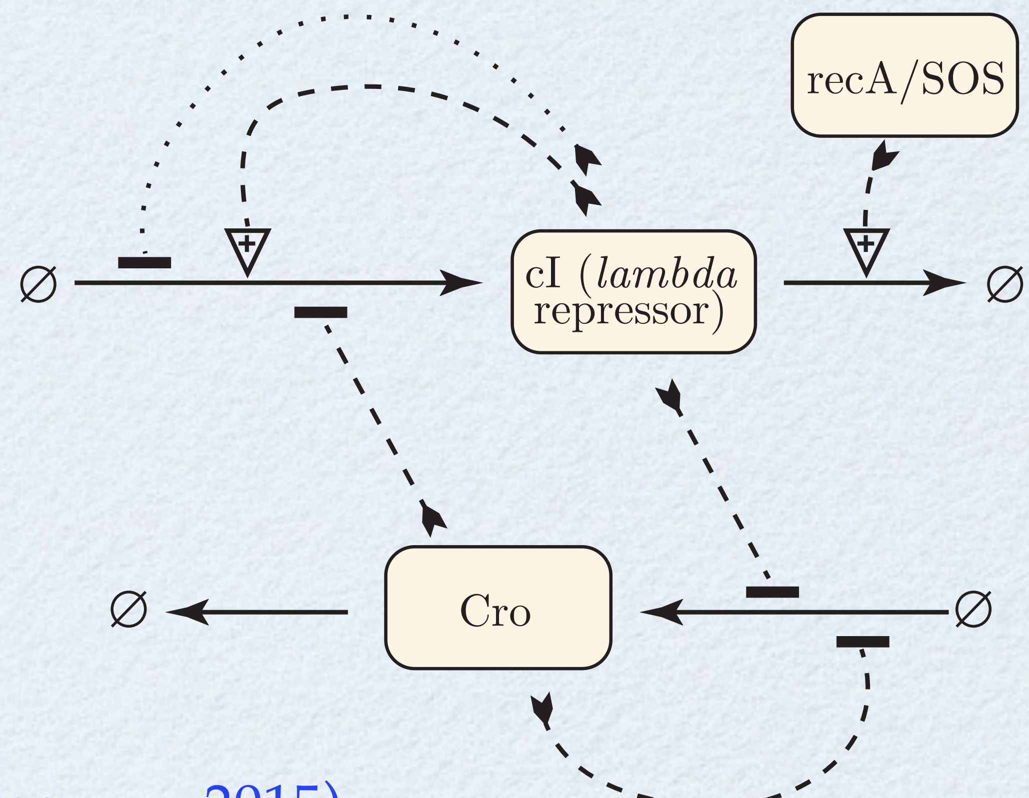

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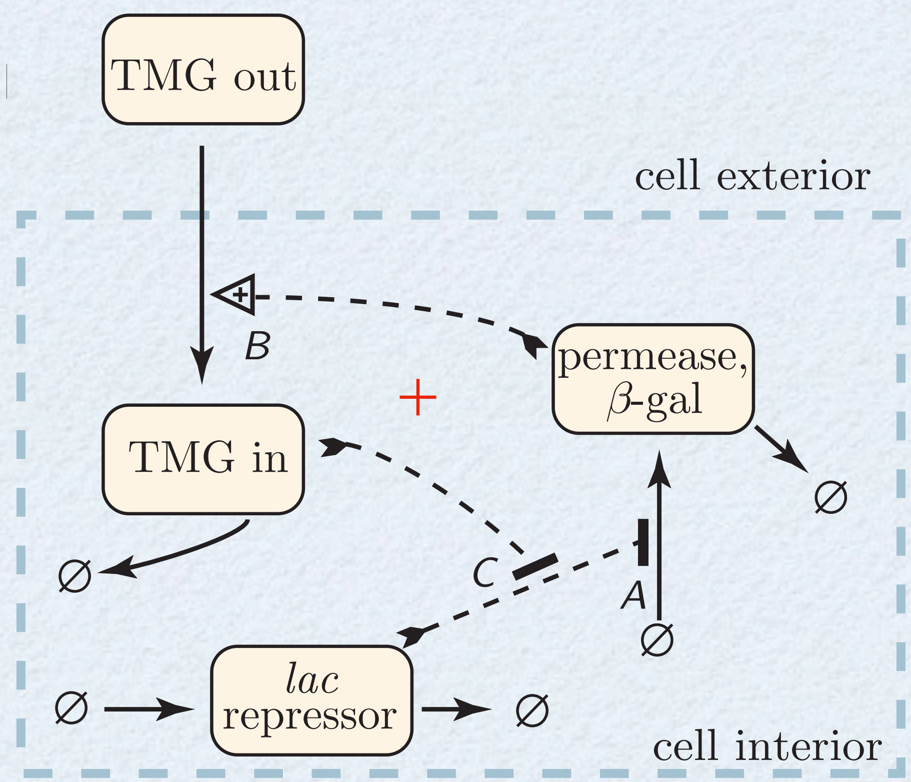

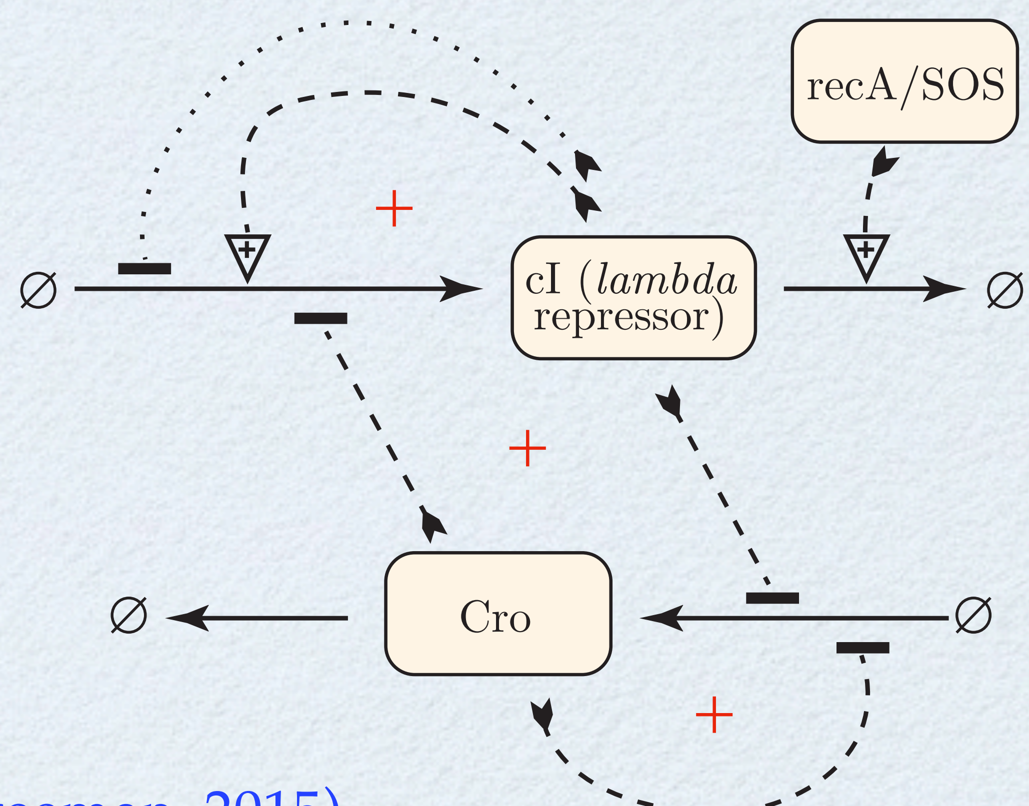

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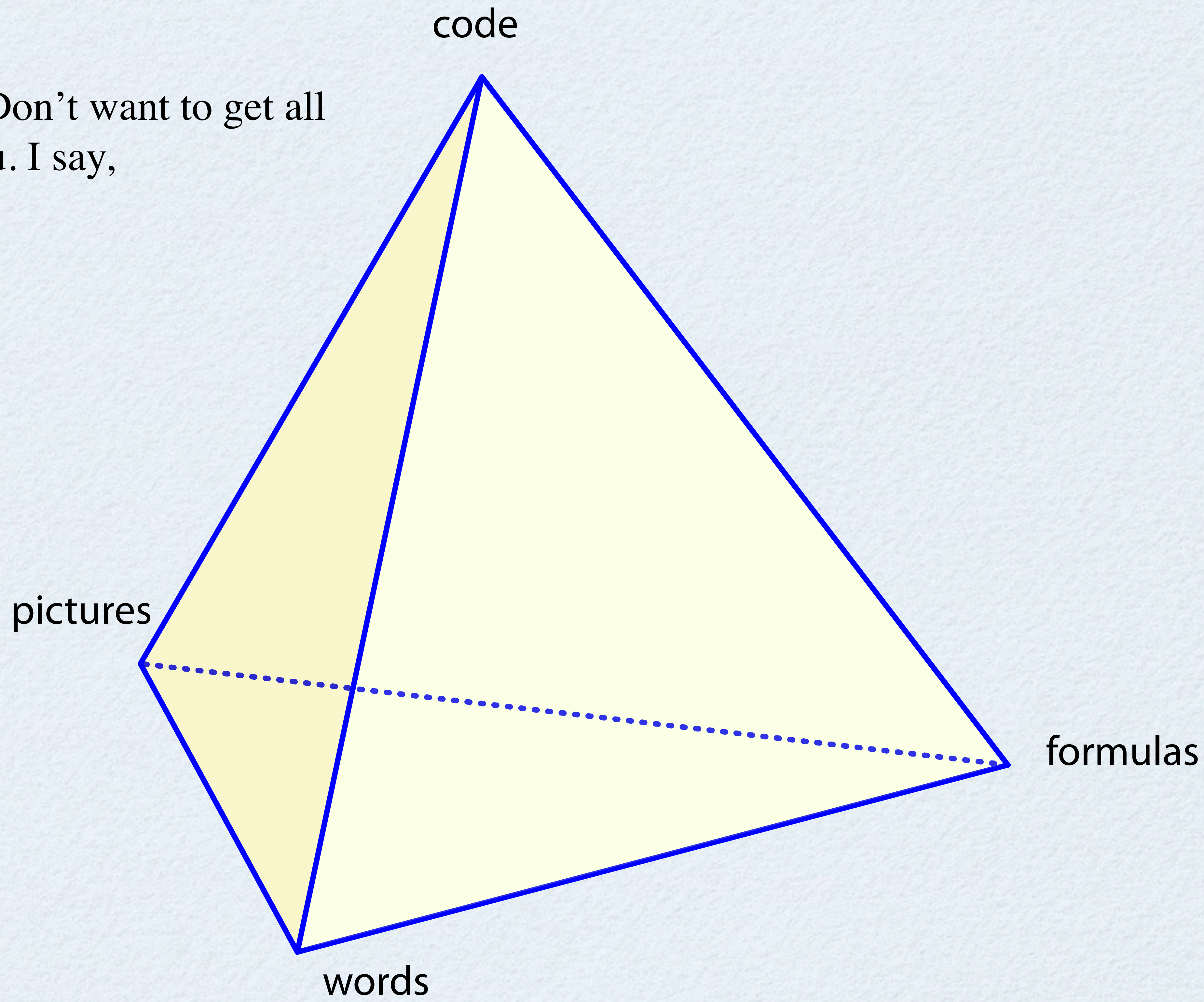
“Excuse me, but...”

What is a “physical model” anyway?

What is modeling? Don't want to get all philosophical on you. I say,

It's a Tetrahedron:



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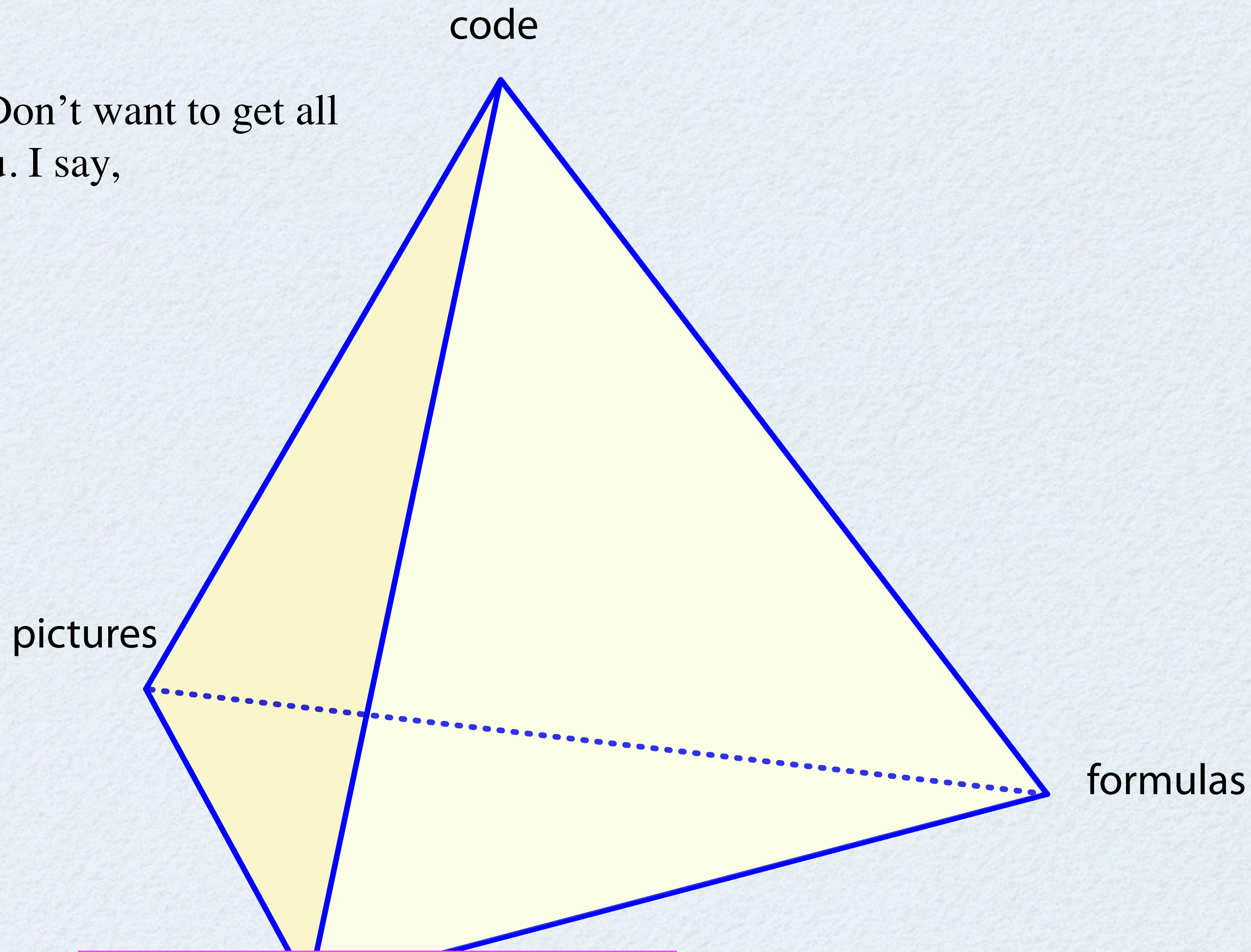

“Yadda, yadda... feedback, yadda... bistability, hysteresis, yadda,... bifurcation...

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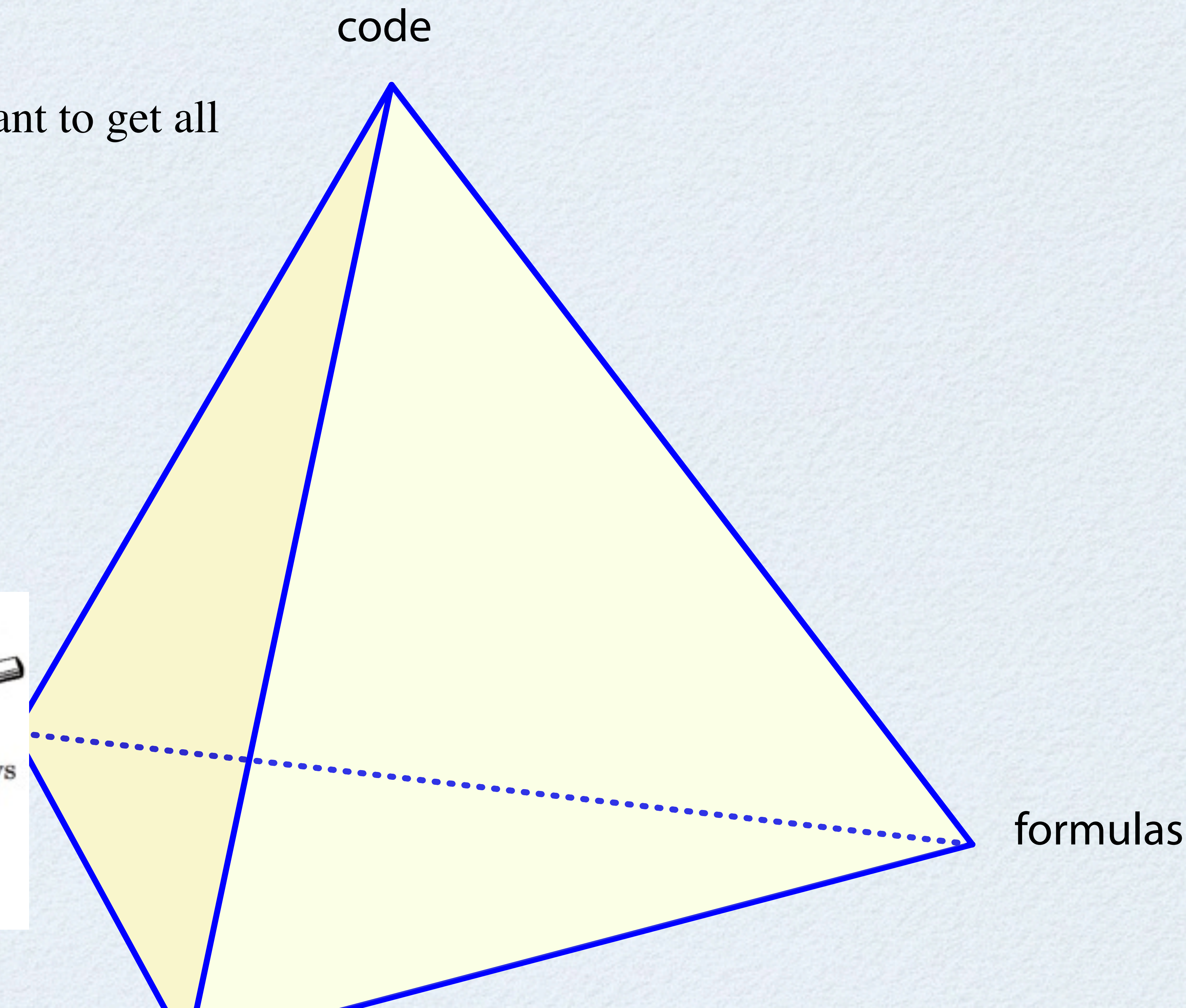

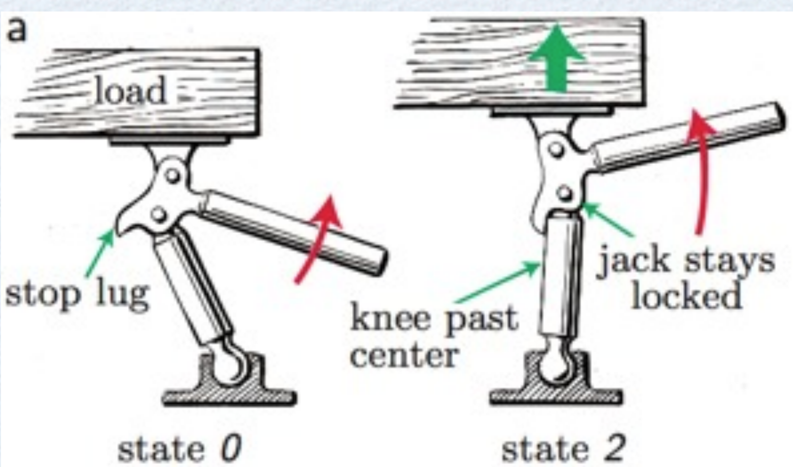

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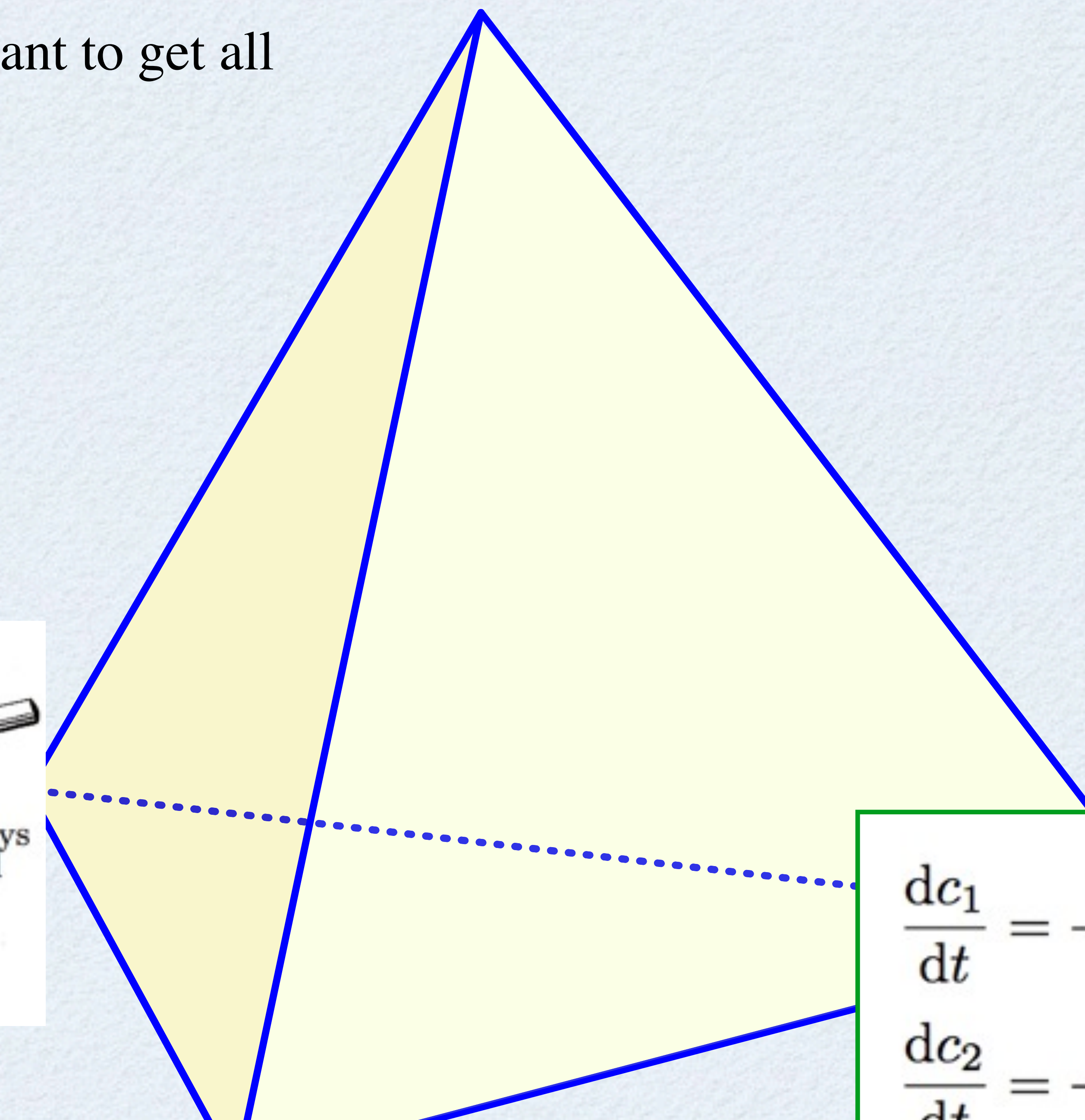

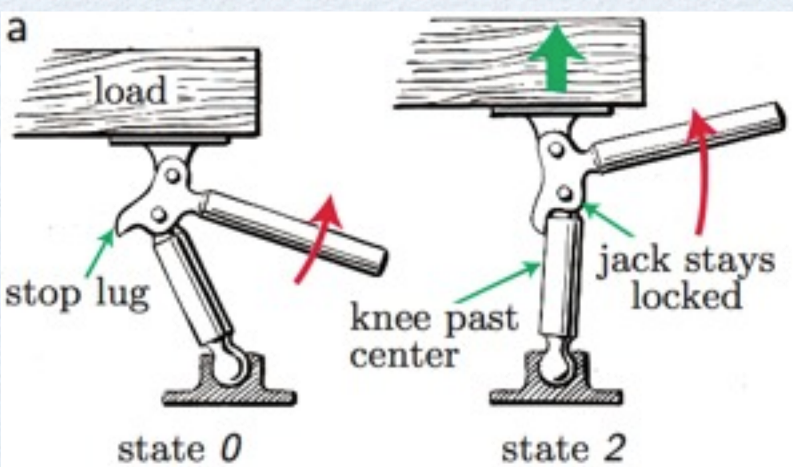

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hold on;
smalltg = [-1.2:.02:1.2];
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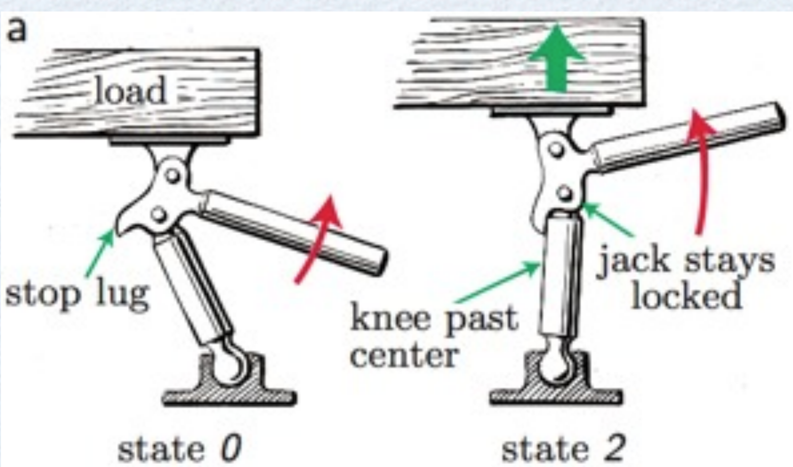

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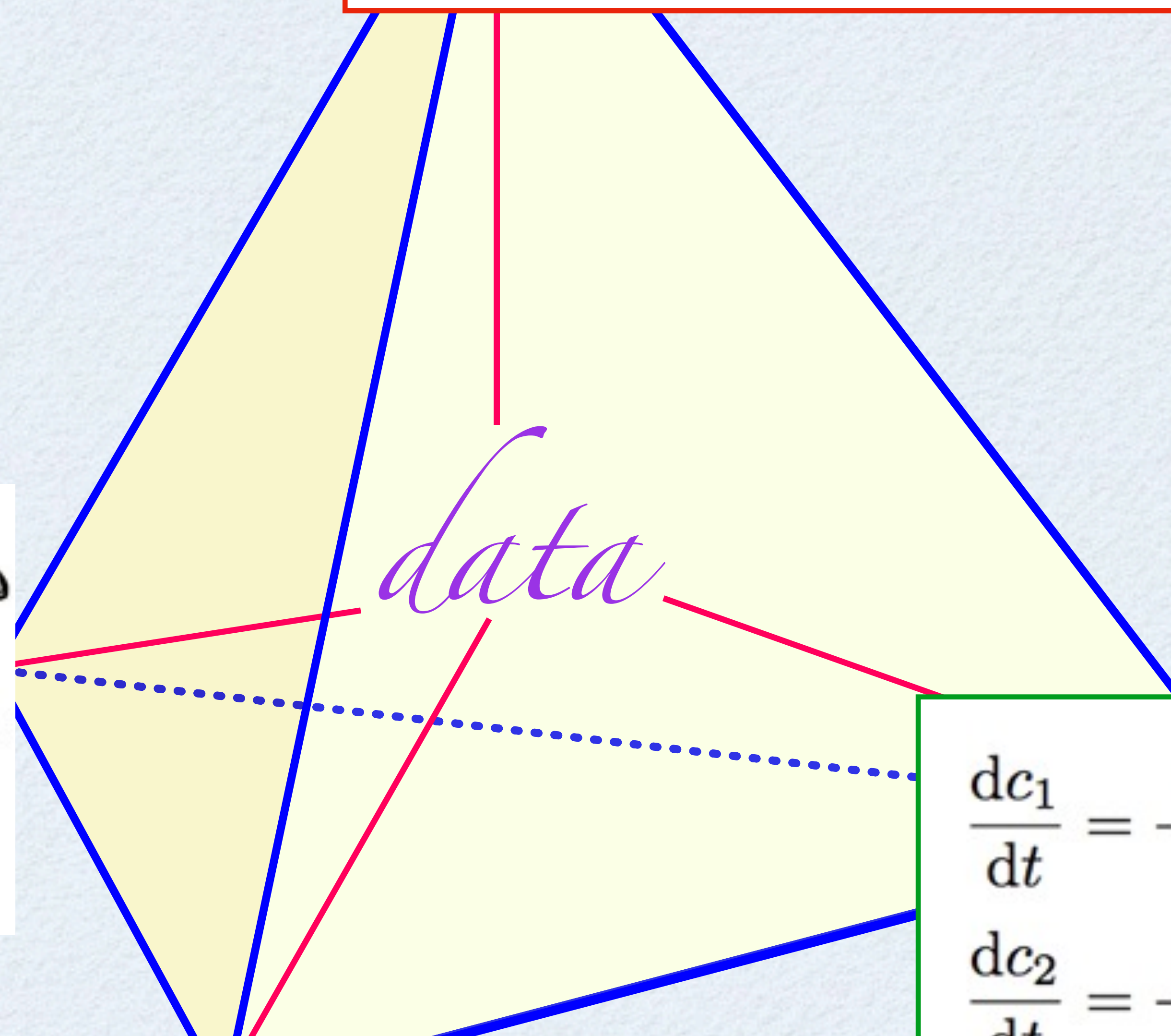

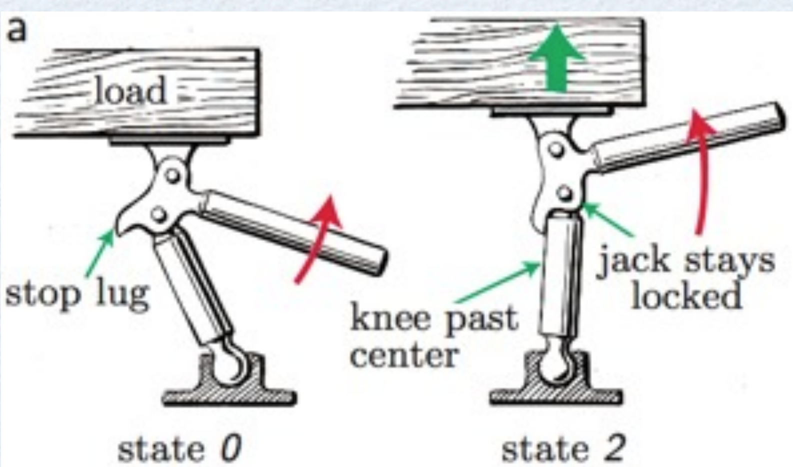

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4: And now a word from our sponsor

These courses aren't for most premeds. But there is a growing cadre of mathematically adept premeds who can handle them. What will they get?

Hilborn. Physics and the revised Medical College Admission Test. Am. J. Phys. (2014) vol. 82 (5) pp. 428-433

From Preview Guide for the MCAT ^{2015} Exam

The *Biological and Biochemical Foundations of Living Systems* and the *Chemical and Physical Foundations of Biological Systems* sections are designed to:

- target **basic research methods and statistics concepts** described by many baccalaureate faculty as important to success in introductory science courses; and
- require you to demonstrate your scientific inquiry and reasoning, research methods, and statistics skills as applied to the natural sciences.

Understanding the processes unique to living organisms, such as growing and reproducing, **maintaining a constant internal environment, acquiring materials and energy, sensing and responding to environmental changes, and adapting,** is important to the study of medicine.

Foundational Concept 2*B*. ***The structure, growth, physiology, and genetics of prokaryotes and viruses***

Foundational Concept 3: **Complex systems of tissues and organs sense the internal and external environments of multicellular organisms, and through integrated functioning, maintain a stable internal environment within an ever-changing external environment**

Foundational Concept 4: ***Complex living organisms transport materials, sense their environment,***
process signals, and respond to changes using processes understood in terms of physical principles.
4D. How light interacts with matter
4E. Atoms, nuclear decay, electronic structure, and atomic chemical behavior

Skill 1: Knowledge of Scientific Concepts and Principles

- Recognizing correct scientific principles
- Identifying the relationships among closely-related concepts
- Identifying the **relationships between different representations of concepts (e.g., verbal, symbolic, graphic)**
- Identifying examples of observations that illustrate scientific principles
- **Using mathematical equations to solve problems**

Skill 2: Scientific Reasoning and Problem-solving

- Reasoning about scientific principles, theories, and models
- Analyzing and evaluating scientific explanations and predictions
- Evaluating arguments about causes and consequences
- Bringing together theory, observations, and evidence to draw conclusions
- Recognizing scientific findings that challenge or invalidate a scientific theory or model

Skill 3: Reasoning about the Design and Execution of Research

- Identifying the role of theory, past findings, and observations in scientific questioning
- **Identifying testable research questions and hypotheses**
- **Distinguishing between samples and populations and results that support generalizations about populations**
- Identifying independent and dependent variables
- Reasoning about the features of research studies that suggest associations between variables or causal relationships between them (e.g., temporality, random assignment)
- Identifying conclusions that are supported by research results
- Determining the implications of results for real-world situations

Skill 4: Data-based and Statistical Reasoning

- Using, analyzing, and interpreting data in figures, graphs, and tables
- Evaluating whether representations make sense for particular scientific observations and data
- Using measures of central tendency (mean, median, and mode) and measures of dispersion (range, inter-quartile range, and standard deviation) to describe data
- Reasoning about random and systematic error
- Reasoning about statistical significance and uncertainty (i.e., interpreting statistical significance levels, interpreting a confidence interval)
- Using data to explain relationships between variables or make predictions
- Using data to answer research questions and draw conclusions

General Mathematical Concepts and Techniques

- Recognize and interpret linear, semilog, and log-log scales and calculate slopes from data found in figures, graphs, and tables
- Demonstrate a general understanding of significant digits and the use of reasonable numerical estimates in performing measurements and calculations
- Use metric units, including conversion of units within the metric system, conversions between metric and English units (conversion factors will be provided when needed); dimensional analysis (using units to balance equations)
- Demonstrate a general understanding (Algebra II-level) of exponentials and logarithms (natural and base ten), solving simultaneous equations
- Demonstrate a general understanding of the following trigonometric concepts: definitions of basic (sine, cosine, tangent) and inverse (sin-1, cos-1, tan-1) functions; sin and cos values of 0°, 90°, and 180°; relationships between the lengths of sides or right triangles containing angles of 30°, 45°, and 60°
- Demonstrate a general understanding of vector addition and subtraction.

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- **Use metric units, including conversion of units within the metric system, conversions between metric and English units (conversion factors will be provided when needed); dimensional analysis (using units to balance equations)**
- **Demonstrate a general understanding (Algebra II-level) of exponentials and logarithms (natural and base ten), solving simultaneous equations**
- **Demonstrate a general understanding of the following trigonometric concepts: definitions of basic (sine, cosine, tangent) and inverse (sin-1, cos-1, tan-1) functions; sin and cos values of 0°, 90°, and 180°; relationships between the lengths of sides or right triangles containing angles of 30°, 45°, and 60°**
- **Demonstrate a general understanding of vector addition and subtraction.**

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- ***If all else fails, convince your visiting committee to beat up on your colleagues.***

5.2: A few results

Incredibly, 80 responses including students who took the course up to 7 years ago. See details at
http://www.physics.upenn.edu/biophys/PMLS/pdf/141130survey_Report.pdf

2. My level of computer-math experience prior to taking this course was

#	Answer	Bar
1	1 = No prior experience	
2	2	
3	3	
4	4 = Extensive prior experience	
	Total	

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3. My level of computer-math facility after finishing this course was

#	Answer	Bar
1	1 = Inadequate for needs I encountered later	
2	Click to write Choice 2	
3	Click to write Choice 3	
4	4 = Adequate for needs I encountered later	

4. Completing this course benefited my work in later courses

#	Answer	Bar
1	1 = Not really	
2	Click to write Choice 2	
3	Click to write Choice 3	
4	4 = Significantly	

6. Completing this course led me to take more advanced science course(s) that I might not otherwise have considered

#	Answer	Bar
1	1 = Not really	
2	Click to write Choice 2	
3	Click to write Choice 3	
4	4 = Really	

8. Completing this course conferred skills that made me more attractive to research labs and/or graduate programs

#	Answer	Bar
1	1 = I don't think so	
2	Click to write Choice 2	
3	Click to write Choice 3	
4	4 = I think so	

80 anonymous respondents, survey response rate about 80%.

Thanks

University of Pennsylvania

NSF BIO

W H Freeman and Co.

NSF NSEC

For these slides see:

www.physics.upenn.edu/~pcn

(or just google me)