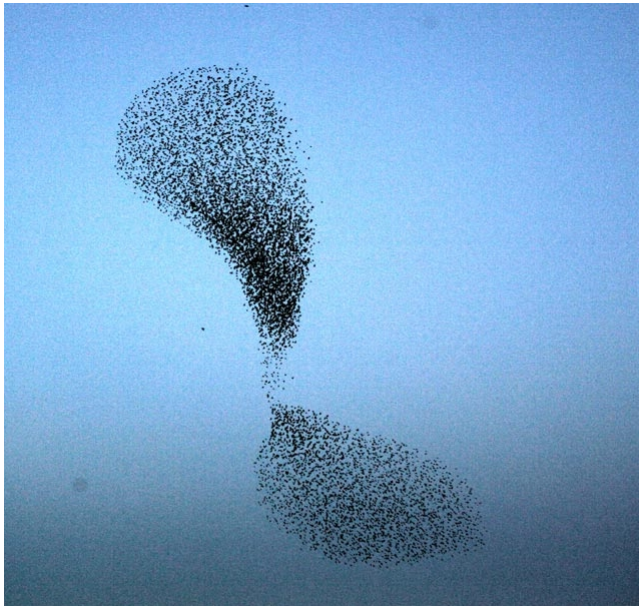
Physics 131: Week 2
Complexity and Emergence



Hi!

Please introduce yourself by name.

Eight Minutes of End-of-Class Thoughts

Eight minutes before end of each class, will stop the class so you can write your thoughts about two things:

1. What was the *single* most important insight or fact you learned today and why?
   6 minutes, at least 50 words.

2. What was the *single* question that most puzzled you or that you most wanted to understand better?
   2 minutes, at least 10 words.

Grade based on showing that you were present in class *and* thinking, not on how well you write but do try to be clear and specific.

Final Paper

End-of-week paper due Sunday afternoon by 6 pm, on some topic related to this week's classes.

- At least 3 pages of text long, no bigger than 12-point font. Citations, figures not included in 3-page count.

Please email me or meet with me to explain what you plan to write about before you start writing the paper, so that I can make sure the topic is a good choice (not too hard, not too long).

Hand in paper by sliding it under my Physics office door, Rm 097 in Physics.

Any Questions Before We Begin?

Piazza accounts, installing Mathematica, reading email regularly...

Create Names for your Groups

Group 1:
Lihao Yang, Yucen Chen, Kun Lin Tsai, and Peicheng Tang

Group 2:
Max Wicklander, Chris Jin, Peter Tearse, Scott Reese

Group 3:
Ana Aguilera, Mariana Alvarez, Haocheng Du, and Jinnong Zhao

Group 4:
Tonio Naka, Naman Thackar, Siyuan Ma

Group 5:
Yue Wang, Xiaoyi Tang, Alexandra Zrenner, Emre Isbir and Lingyun Chai

Discussion:How to define “complex”?

To help you consider possible definitions, break up into your groups and work together to order the following objects from least to most “complex”.

A cubic meter of vacuum	A proton
A hydrogen atom	A water molecule H_2O
A 1-cm cube of ice	The same cube as melted water
The same cube as steam at 1 atm	A pendulum moving back and forth
A cloud in the sky	The Earth
The Sun	A galaxy (the Milky Way)
A prokaryotic cell (germ E. Coli)	A mouse
A human	An alive 1-month-old baby brain
An alive adult brain	A dead brain preserved in a jar
A car	A laptop computer
The Internet (network of computers)	The early universe (quark-gluon plasma)
The current universe	

Any other “complex” systems worth discussing?

Discussion:
Why is the complexity of things important to understand?

Discussion:
Why is the complexity of things important to understand?

Some possible examples:

- Economics
- Medicine
- Engineering
- Meteorology and climate
- Politics and sociology
- Basic curiosity

Key Insights for This Week

1) Macroscopic sustained nonequilibrium systems produce an extraordinary diversity of behavior temporally and spatially, important for society, deeply interesting scientifically.

2) Nature seems to know just afew ways to produce more complicated structure from simpler structure; physicists, engineers, mathematicians, and computer scientists have made much progress in identifying possible transitions and kinds of structure.

3) Quite simple mechanisms can produce “complex” behavior.

4) But not all complex behavior is due to simple rules, what then?

The Big Bang: Raw Material for Complex Structure

A “Big” Question:
Why Does Our Universe Have Structure?
(The Fine Tuning Problem)

Best current theory is QCD (quantum chromodynamics)

This theory has many parameters whose values we don't know how to predict, known only by experiment: e, m_e, m_p, G, K, h, dimensionality of space.

We do know from calculations that tiny changes in values of these constants would lead to universes for which complexity not possible: only hydrogen atoms, only black holes, only photons (light particles).

Example: ratio of gravitational to electrical forces for hydrogen atom

$$F_{\text{elec}} = \frac{K q_e q_p}{d^2}$$

$$F_{\text{grav}} = \frac{G m_e m_p}{d^2}$$

$$\frac{F_{\text{elec}}}{F_{\text{grav}}} = \frac{K e^2}{G m_e m_p} \approx 10^{39}$$

Would you invent a universe with such a such a crazy big number?

Change by factor of 10^2 bigger/smaller leads to boring universes.

Guess by Paul Dirac Why F_{elec}/F_{grav} So Big: Think About Other Big Physical Ratios

Three Suggested Answers for Fine Tuning

- An incredibly smart entity (deity) chose these parameters so as to lead to interesting structure, including living organisms like ourselves.
- The multiverse: there are many coexisting universes, each with their own different (random?) choices of laws of nature and of physical parameters, most leading to no structure, and our universe won the lottery.
- Multiple space dimensions (Lisa Randall): gravity “leaks” into extra spatial dimensions, making it especially weak. (But why gravity only interaction that “leaks”?)

Hierarchies of Structure

- Many objects when interacting with each other can develop new features that are not features of the objects. (Quarks and gluons in a proton, electrons about a nucleus, biological molecules like an enzyme, atoms in a crystal.)
- These new features often do not depend on “lower-level” details. For example, fact that water acts like a fluid does not depend on understanding fine details of water molecules, so don't need to know atomic properties of water molecules.
- One of the great current questions in all of science is when one level of structure decouples from lower levels, how and why do hierarchies form?

  Even if we had unified theory like string theory right now, would NOT help us understand many observed phenomena.

  For example, we have a unified theory for all of material science, the Schrodinger equation, but can't deduce existence and properties of clouds, existence and properties of germs, can't predict the weather can't understand brains, etc

$$i\hbar\partial_t \left|\Psi\right\rangle = H\left|\Psi\right\rangle$$

Two Grand Unsolved Hierarchy Problems

- **Origin of life on Earth**. What is the probability of life spontaneously forming? (Early appearance of life on Earth, implications of nucleosynthesis, huge number of galaxies each with huge number of stars, immense age of the universe, but...)
- **How does consciousness “emerge” from activity of neurons in human brains?** If brains or computers got even bigger, would new and different kinds of intelligence and consciousness occur?