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# QUANTUM COMPUTING

FOR BEGINNERS



Paul Pham, Autumn 2012

Illustrated by Stephen Rice

# First Lecture: Computation is Physical

- \* What is quantum computing?
- \* Why take this class?
- \* Syllabus and Course Objectives
- \* Class format
- \* In-class problems
- \* Logistics, and for next time

# Computation is Physical

- \* Why should computer scientists care about physics?
- \* Computation is inherently physical
  - \* dissipates energy
  - \* takes up space
  - \* has mass
- \* Eventually these limits will be reached

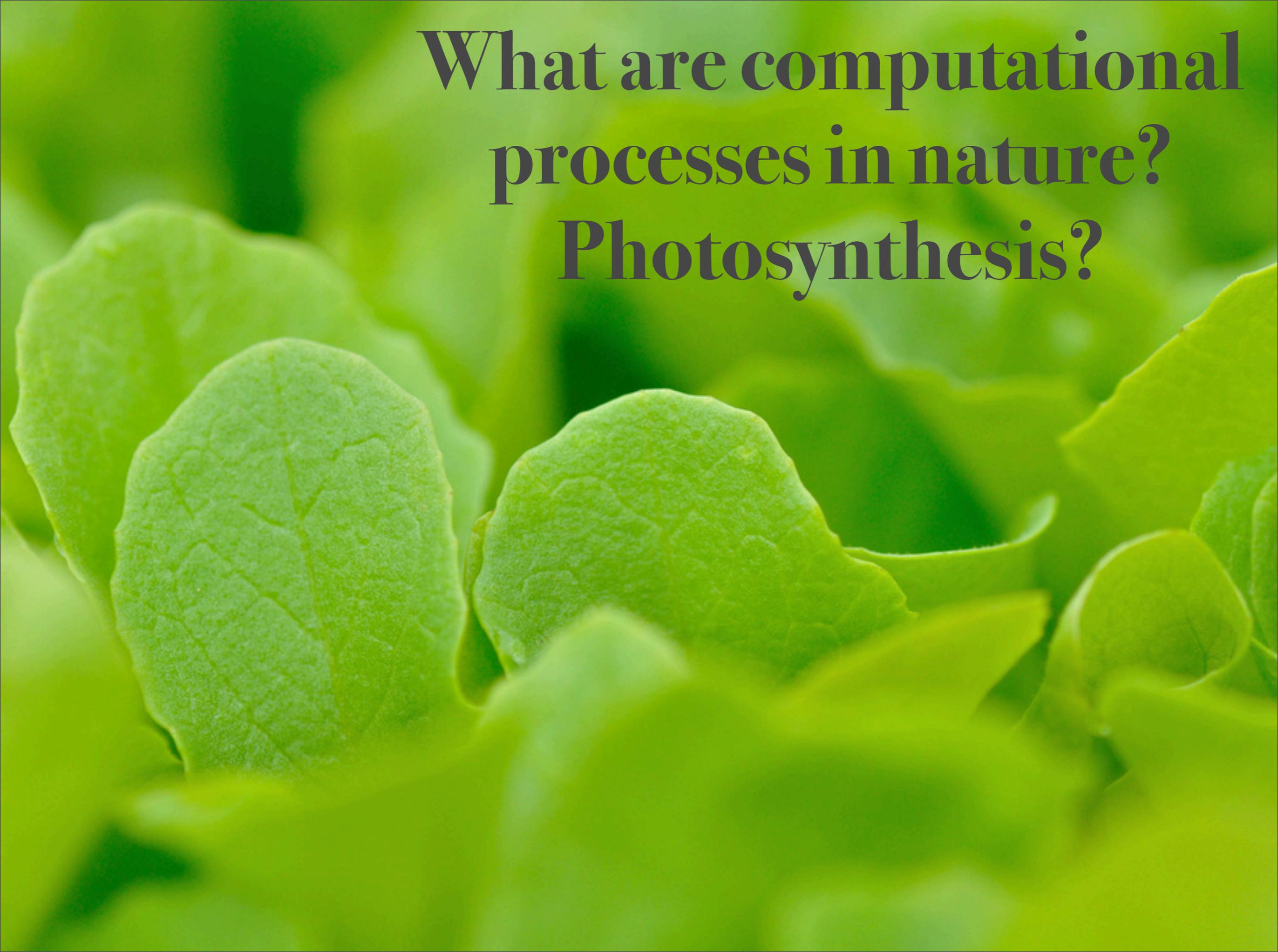
# What are computational resources in nature?



# Can nature compute an uncomputable function?

- \* and if it could, how would we know it?
- \* why do we trust our digital computers?



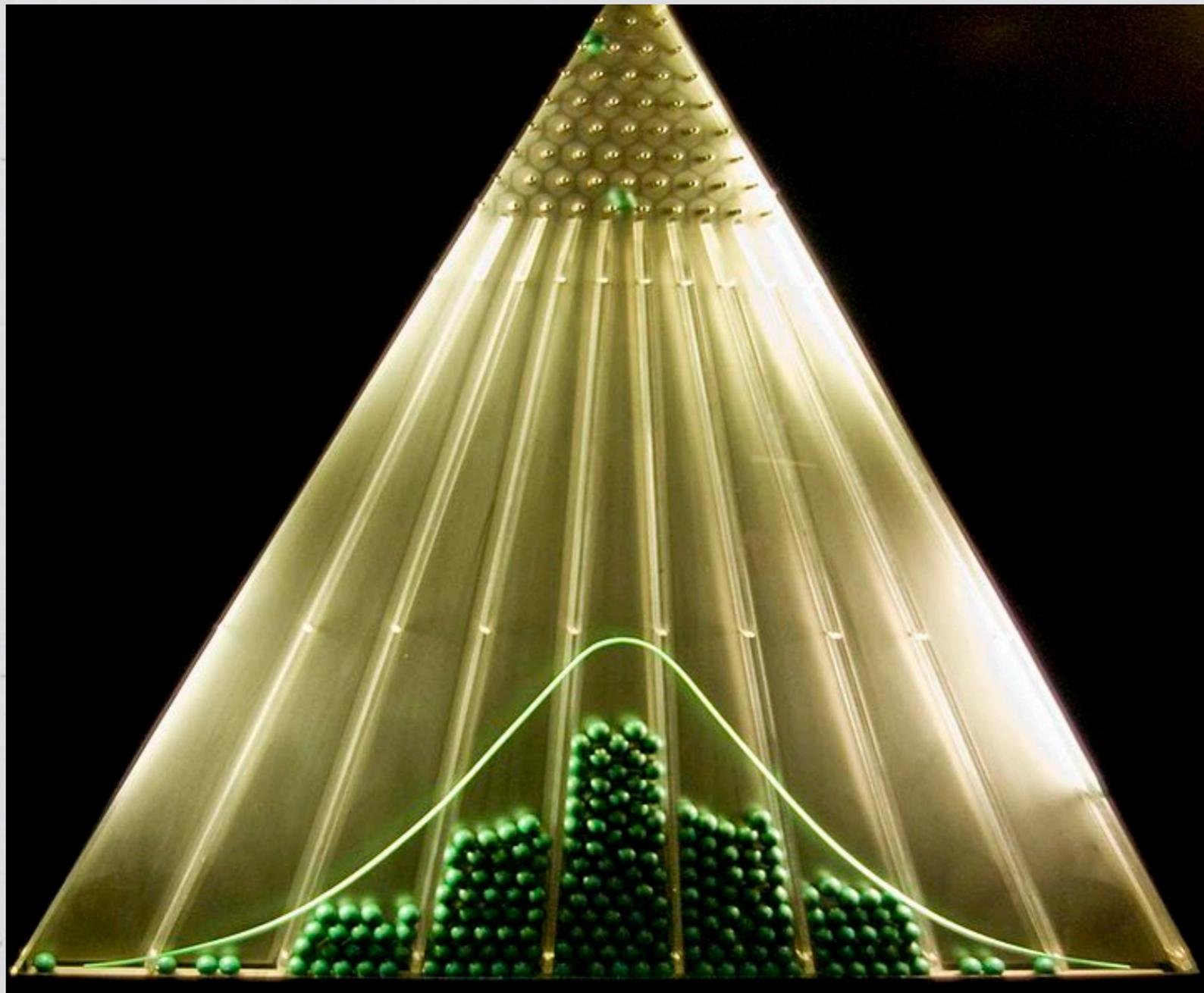


**What are computational  
processes in nature?  
Photosynthesis?**

A photograph of four white swans flying in a V-formation over a body of water. The sky is filled with soft, grey clouds. The swans are in various stages of flight, with their wings spread wide. The water in the foreground is calm, and a distant shoreline with some buildings and a sailboat is visible on the horizon.

*Avian compass and  
magnetoreception?*

# What is a probabilistic computer?



# What is an analog computer?



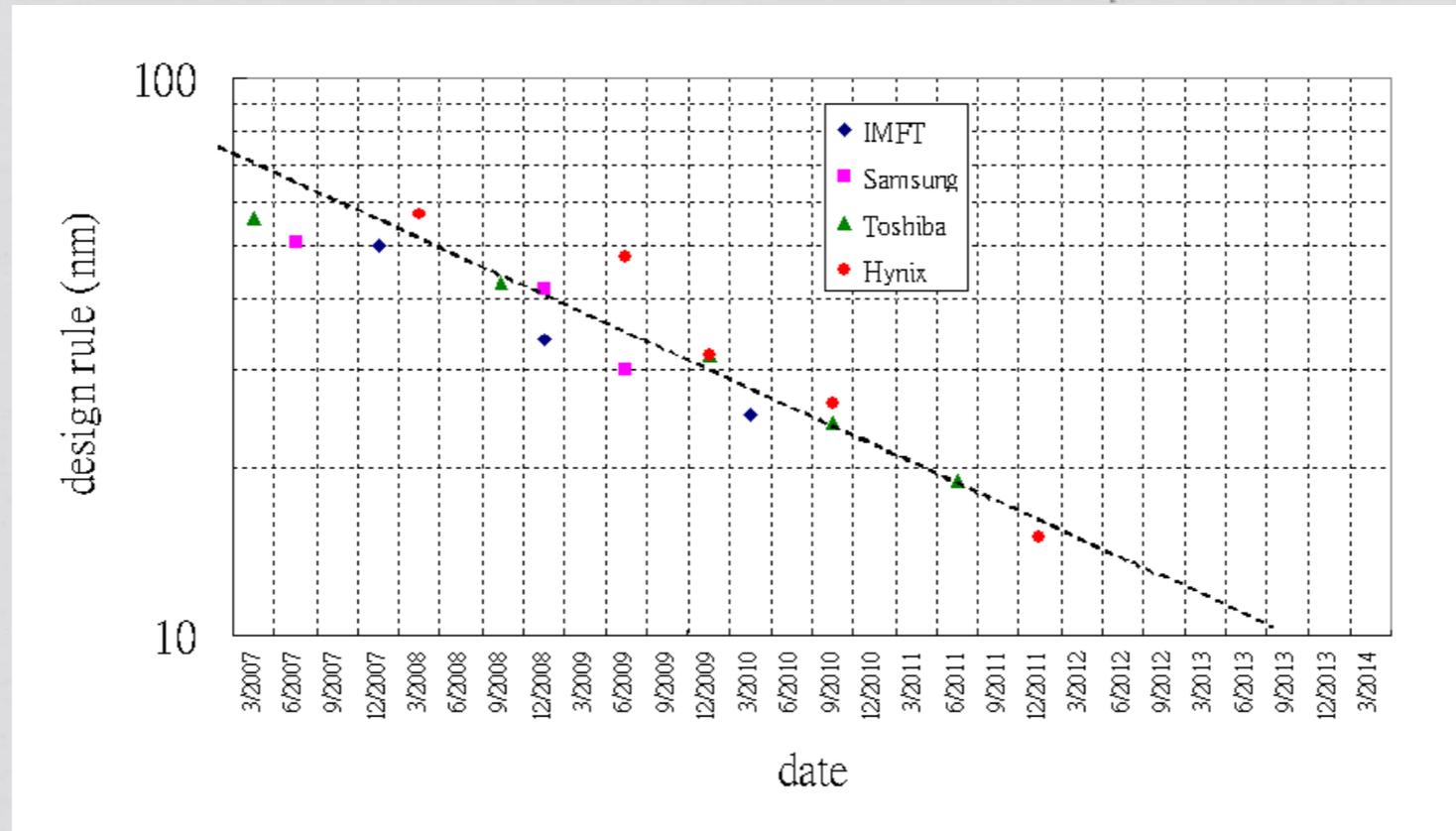
# What is an analog computer?

- \* Slime molds can compute the solution to a maze or a distribution network
- \* Soap film can compute Steiner (minimum spanning) trees



# What happens when Moore's law runs out?

- \* Number of transistors on a chip doubles every 18 months
- \* Alternatively, transistor feature size halves every 18 months



# Why else study quantum computing?

- \* Quantum mechanics could be wrong
- \* Insights into classical computing from a more general model
- \* Factoring integers can break the RSA cryptosystem
  - \* and other quantum algorithms!
- \* The romance of computers which are gigantic and unreliable

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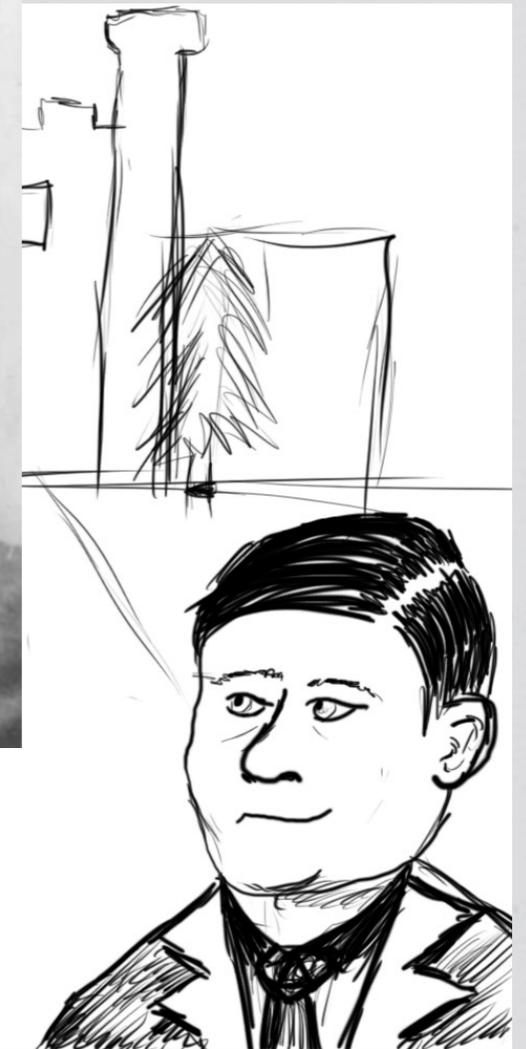
# The Story Begins: September 1930

- \* People are challenging the morality of the decadent 1920s while seeking new ideas and a break from the past.
- \* The Weimar Republic has rebuilt Germany after WWI but is faltering.
- \* Trending in the art world:  
#surrealism, #cinematography, #futurism.
- \* Quantum physics is an infant.  
Computers don't exist.



# Alan Turing

- \* Kings College,  
Cambridge, England
- \* “Father of CS”
- \* Discovered a universal  
model of computation in  
1936.
- \* Worked on breaking the  
German Enigma code in  
WWII



# Richard Feynman

- \* MIT, Cambridge, MA
- \* “Great explainer”
- \* Worked on the Manhattan Project in WWII
- \* Proposed quantum simulation in 1982

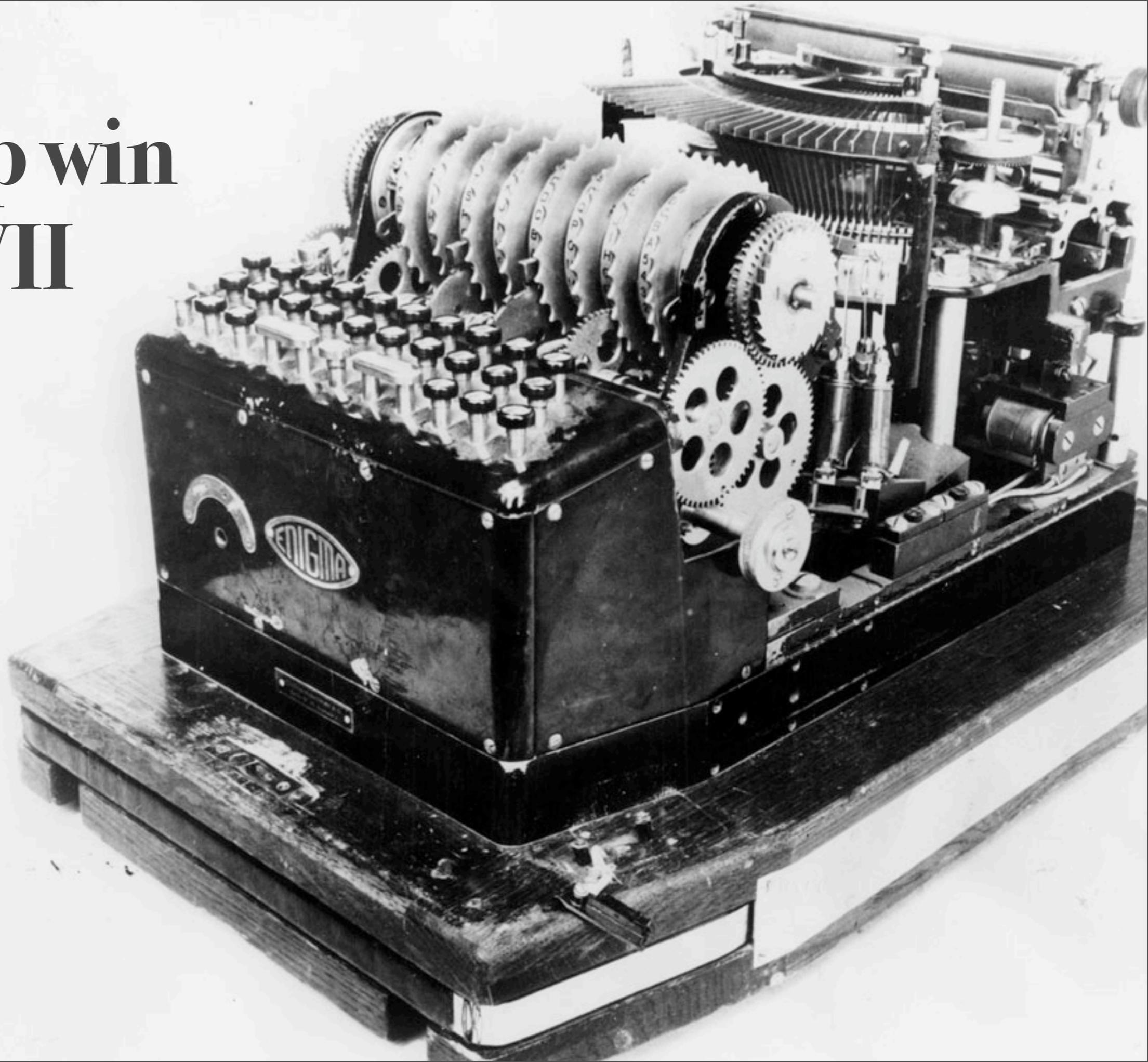


# Elina Gamow

- \* Göttingen, Germany
- \* Niece of Russian physicist George Gamow
- \* Visiting Max Planck to work as a keypunch operator.
- \* She hears about quantum physics for the first time and is curious.



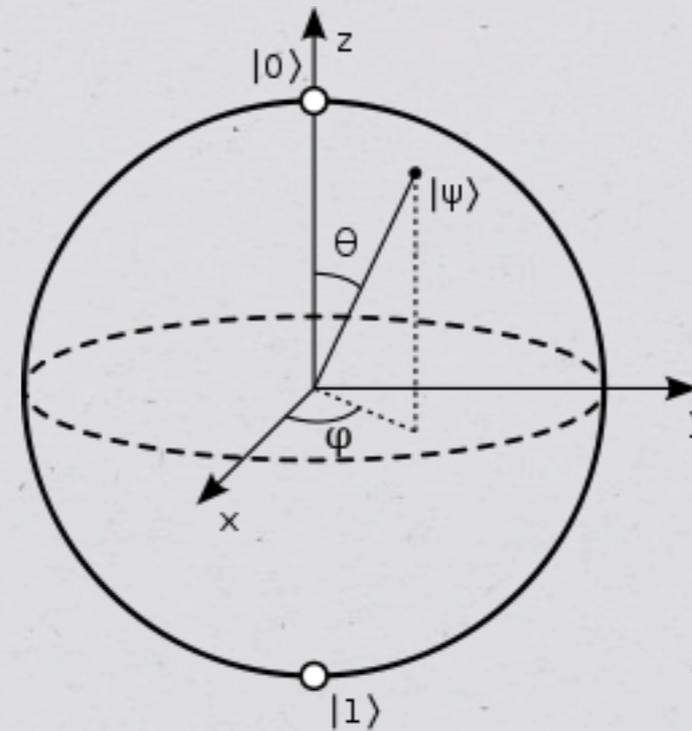
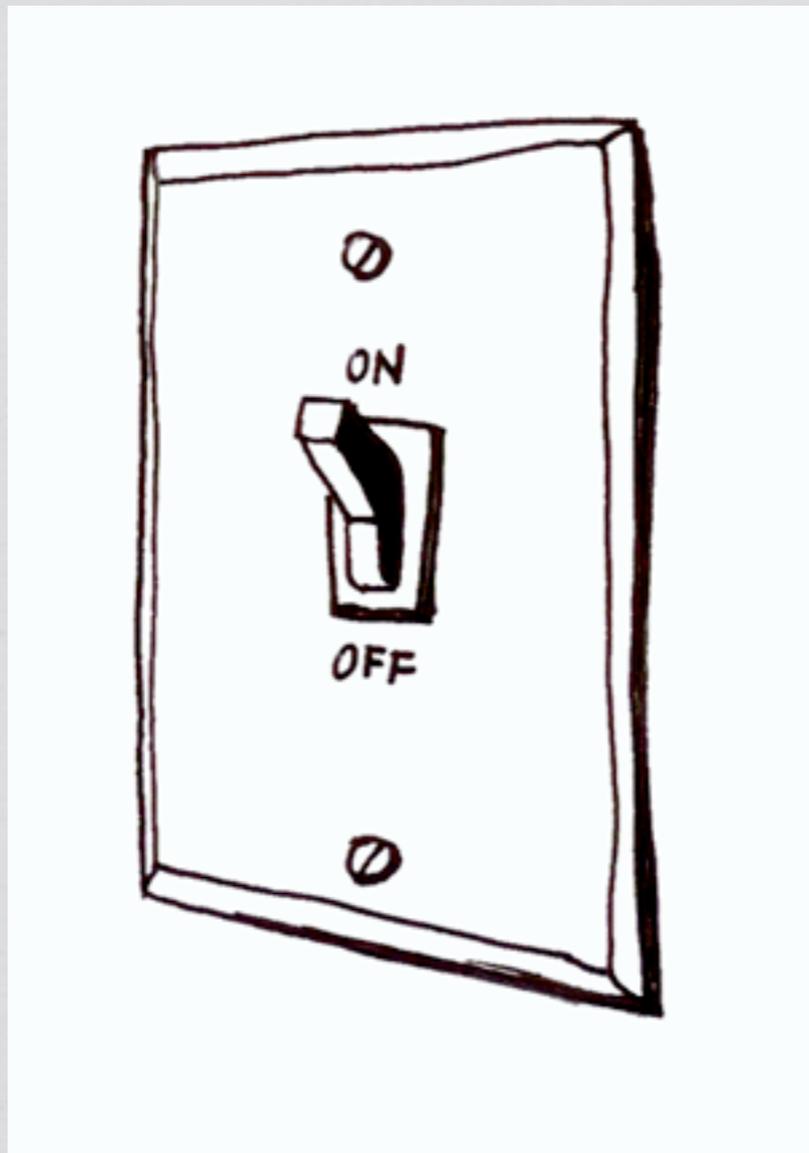
Help win  
WWII



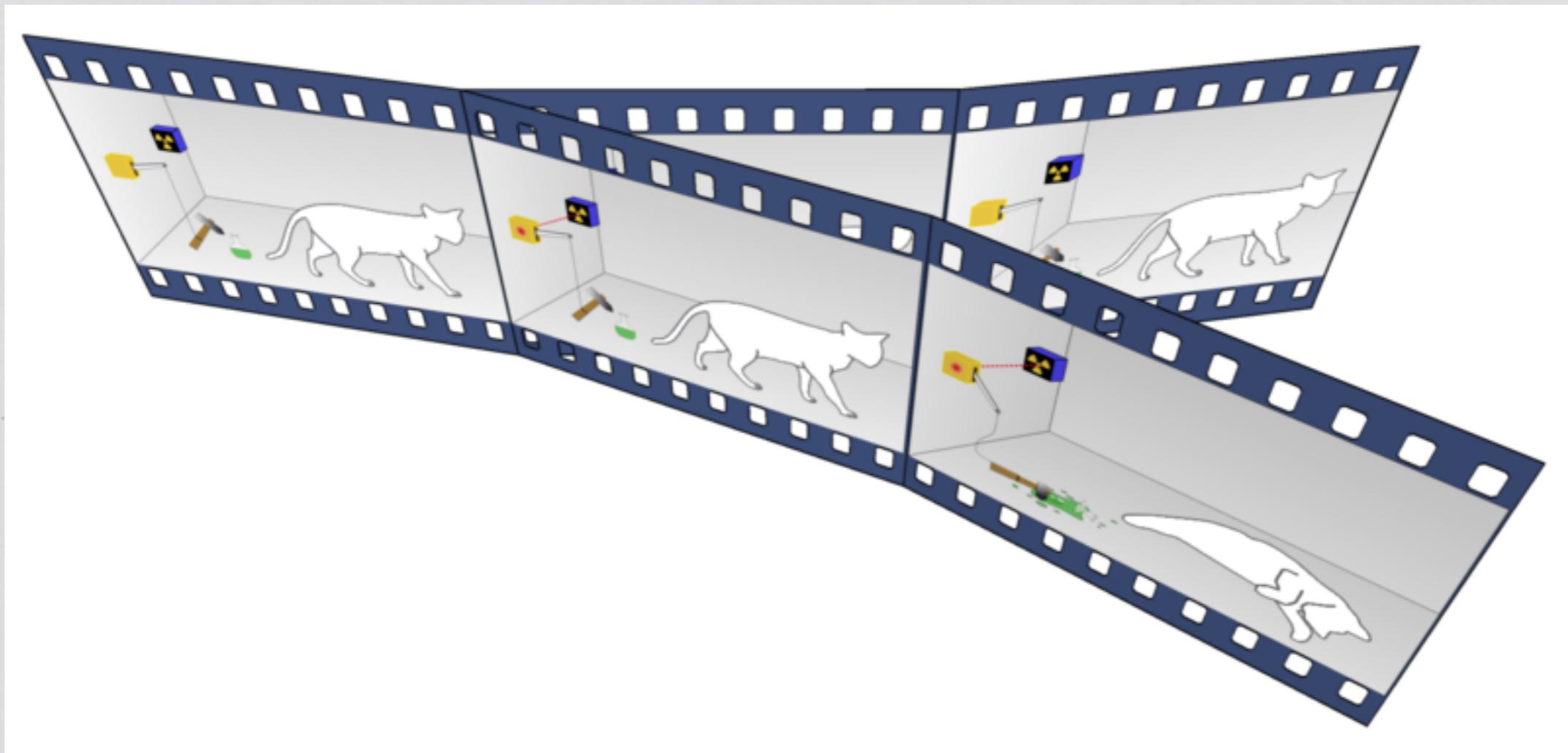
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# Syllabus: quantum bits



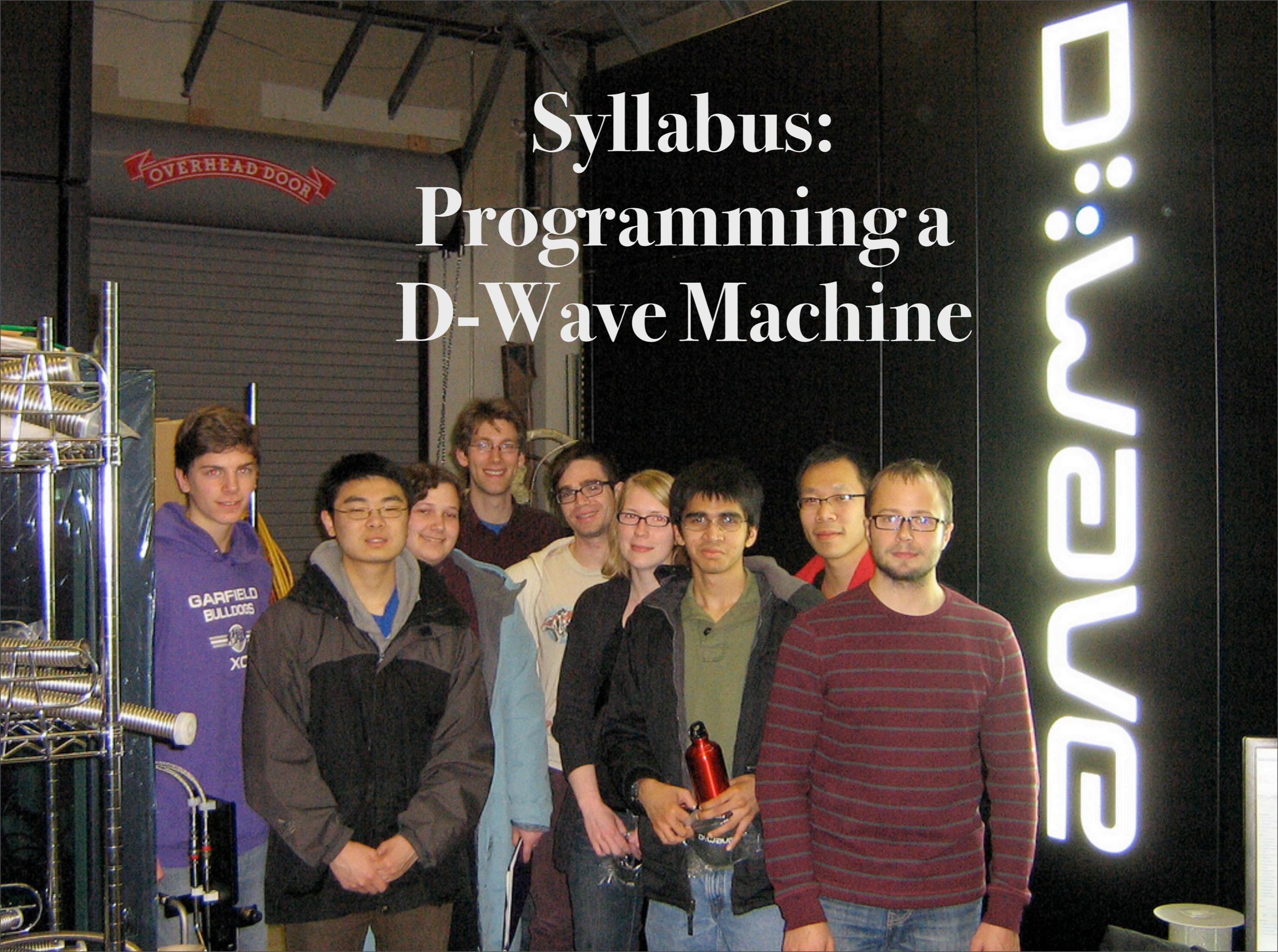
# Syllabus: interpretations of quantum mechanics



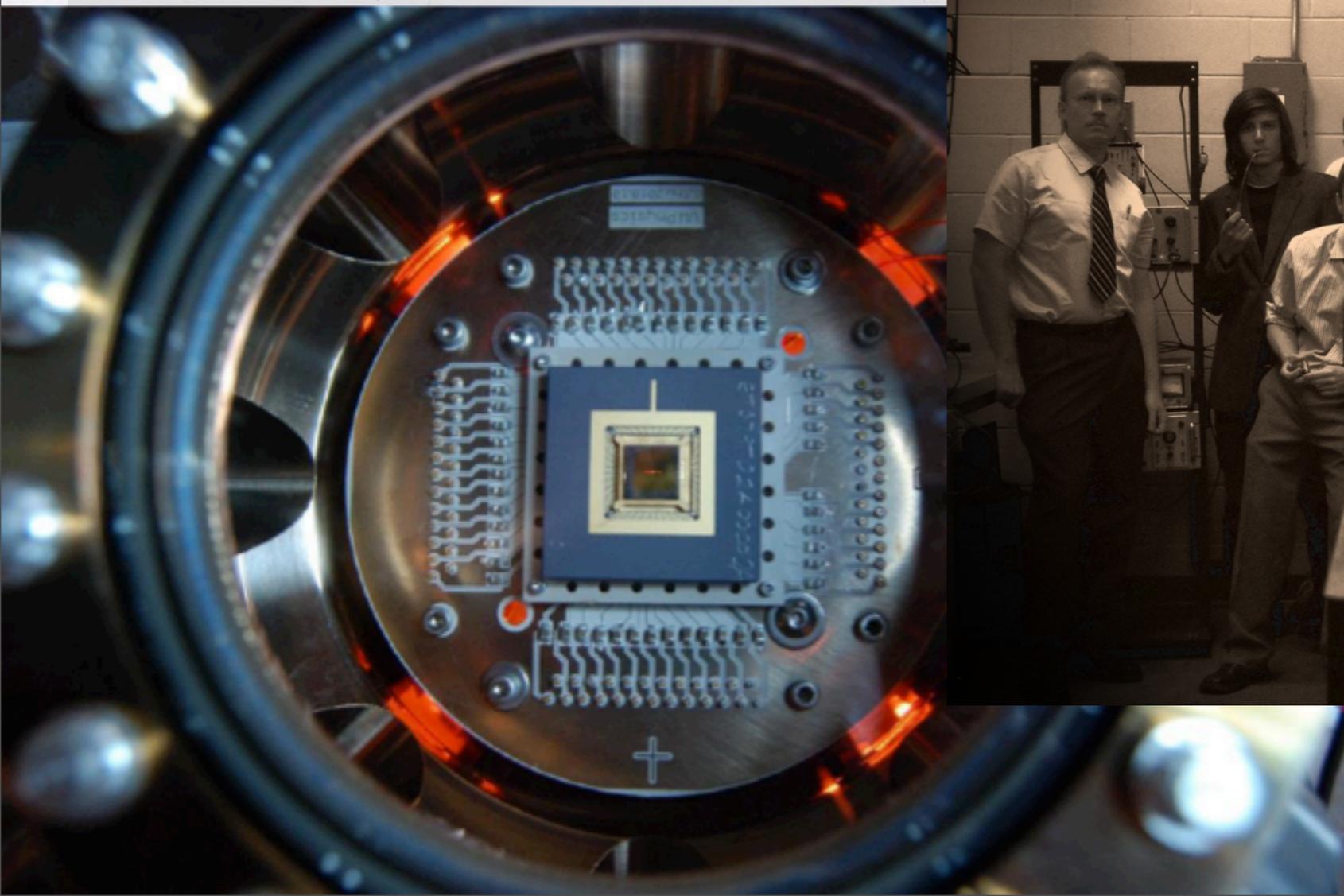
# Syllabus continued...

- \* Dirac notation, Heisenberg uncertainty principle, Pauli matrices
- \* Energy and Hamiltonians of quantum systems
- \* Quantum circuit model
- \* Quantum Fourier transform
- \* Shor's factoring algorithm
- \* Error-correction and fault-tolerance

# Syllabus: Programming a D-Wave Machine



# Syllabus: current experiments



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# Class Format

- \* This class is partially flipped. Class meetings will be:
  - \* Half lecture
  - \* Half working problems in-class
- \* You will work in randomly-chosen groups of 4
  - \* Pairs of groups will teach each other one of the problems
  - \* Volunteers will present their answer to the class

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# In-class Problems

- \* What are three other examples of analog computers or functions computed by nature? What variables do they model and how do they model it?
- \* What are two examples of a probabilistic device? What is its input? What is its output distribution?
- \* What is one example of a model, system, device, or personal experience that breaks down due to physical effects, possibly operating outside of its intended environment or scale?

# CHAPTER 1

# UNLOCKED

- \* The seed of the idea to use quantum physics for computation has now been planted in the minds of Alan Turing and Richard Feynman.
- \* I will e-mail you the Chapter 1 notes and homework problems as a PDF file on Thursday.
- \* Make sure you have signed up for the course mailing list!
- \* Check the course website: <http://qcb2012.wordpress.com/>