15-251
Great Theoretical Ideas in Computer Science

Lecture 1:
Introduction to the course

Instructors:

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Anil Ada

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What is computer science?

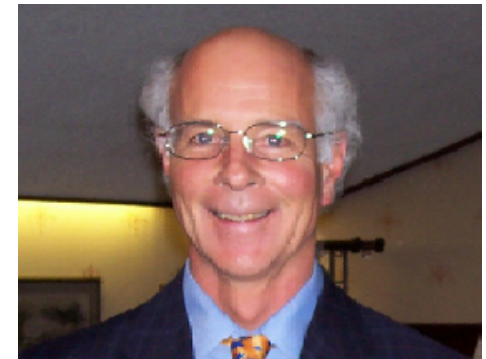
What is *theoretical* computer science?

Motivational Quote of the Course

"Computer Science is no more about computers than astronomy is about telescopes."

~~*Edsger Dijkstra*~~

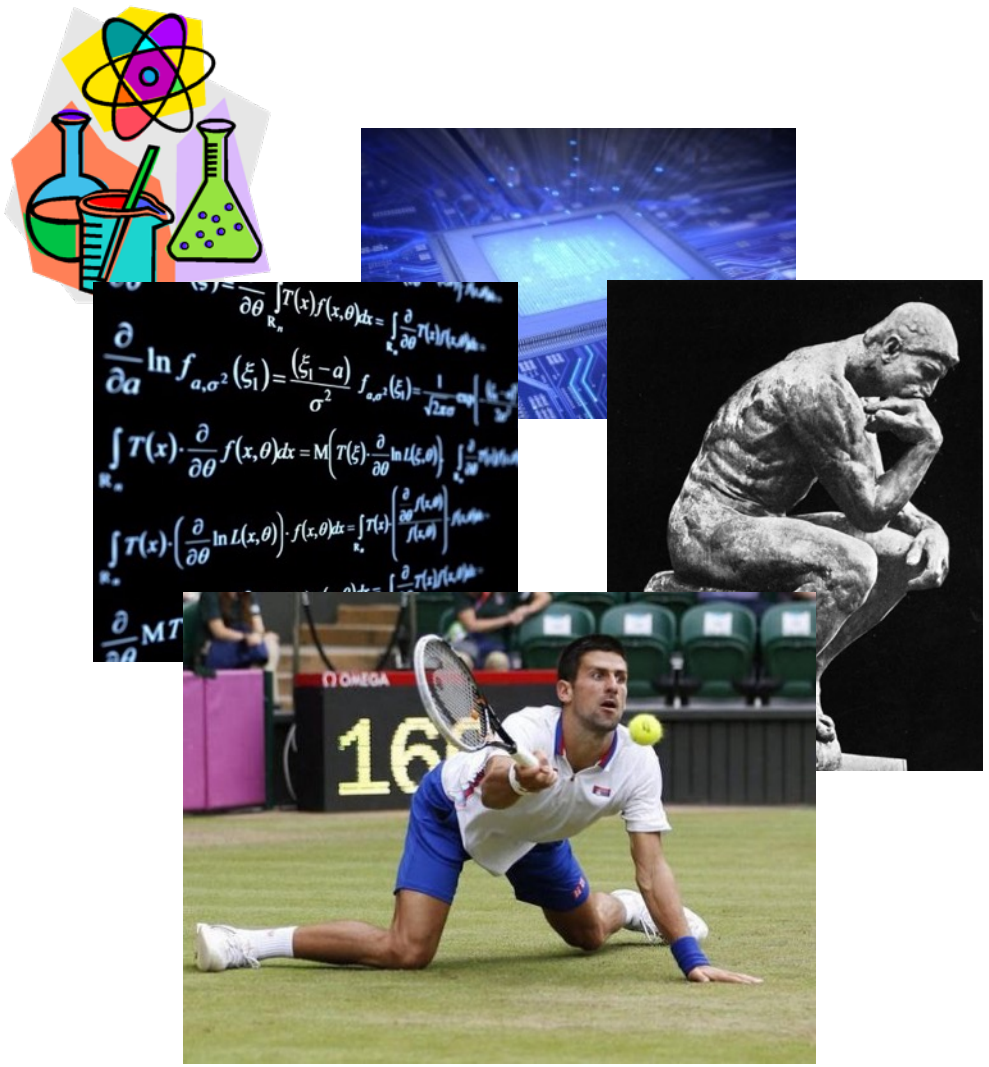
- Michael Fellows



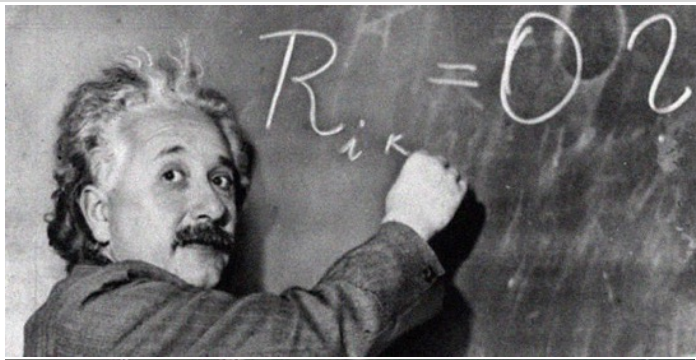
What is computer science?

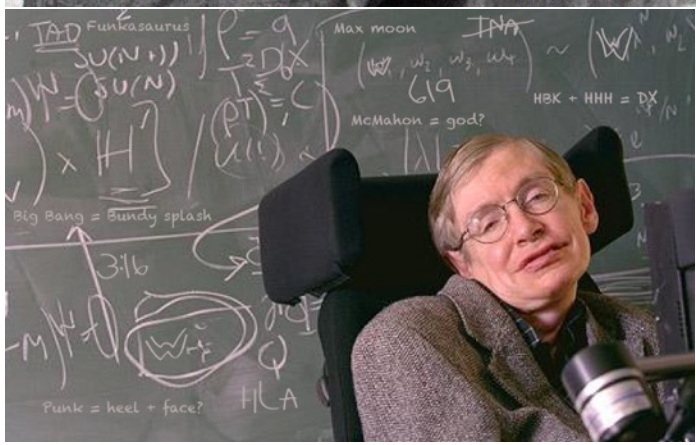
Is it branch of:

- science?
- engineering?
- math?
- philosophy?
- sports?



Physics





Theoretical physics

- come up with mathematical models

  Nature's language is mathematics

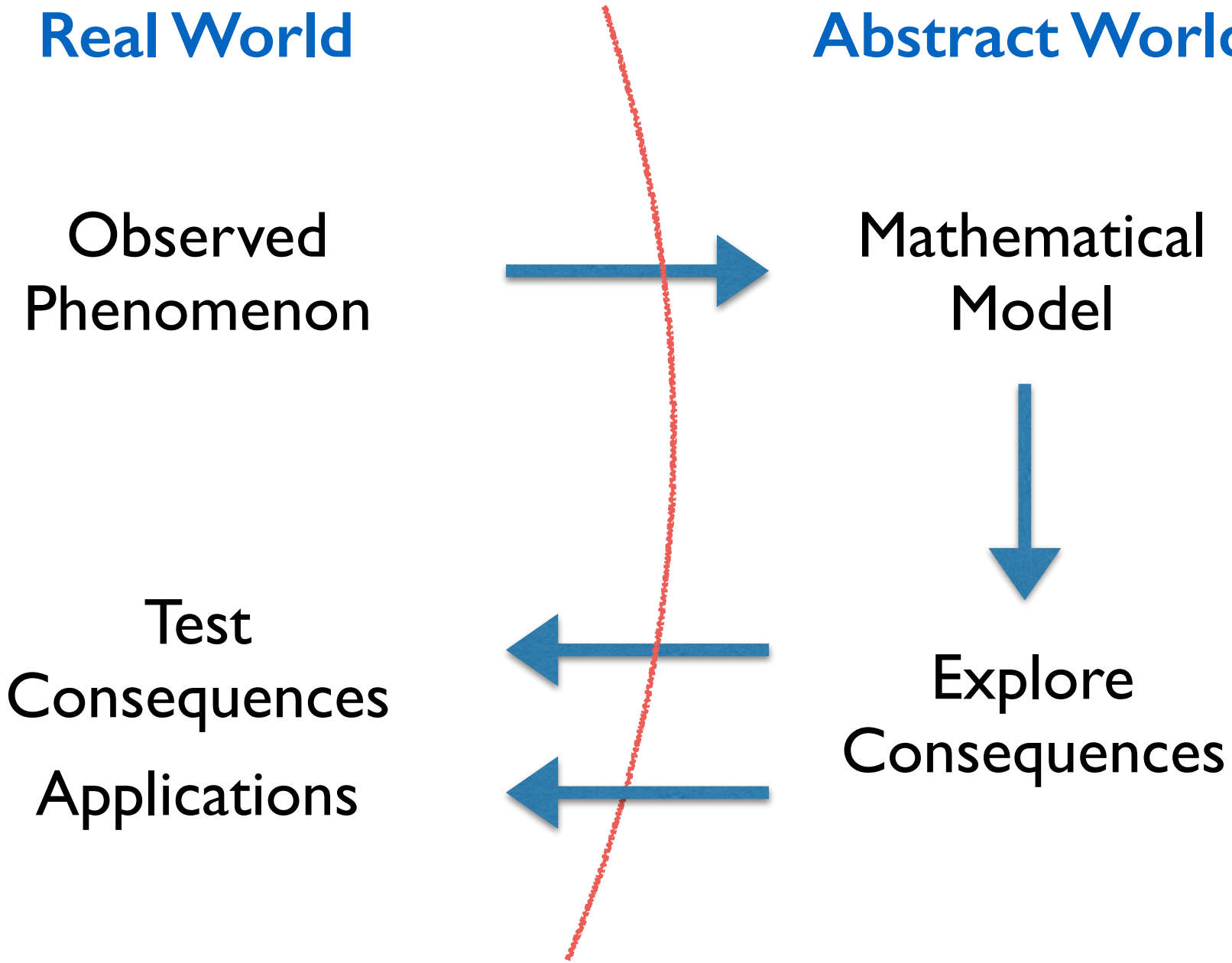
- derive the logical consequences

Experimental physics

- make observations about the universe
- test mathematical models with experiments

Applications/Engineering

The role of theoretical physics



(Theoretical) Physics

- science?
- engineering?
- math?
- philosophy?
- sports?

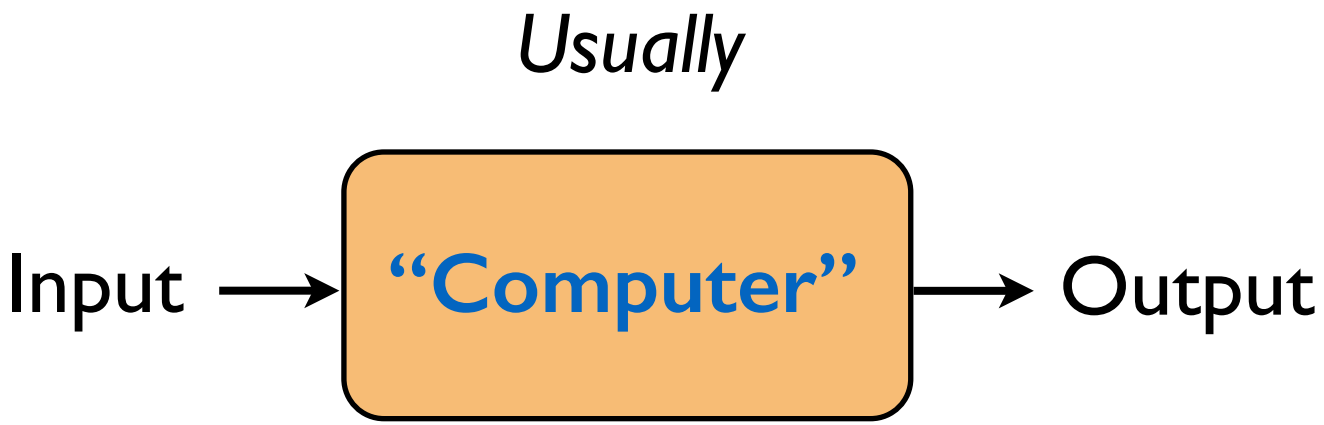
Computer Science

The science that studies computation.

Computation: manipulation of information/data.

Algorithm: description of how the data is manipulated.

Computational problem: the input-output pairs.



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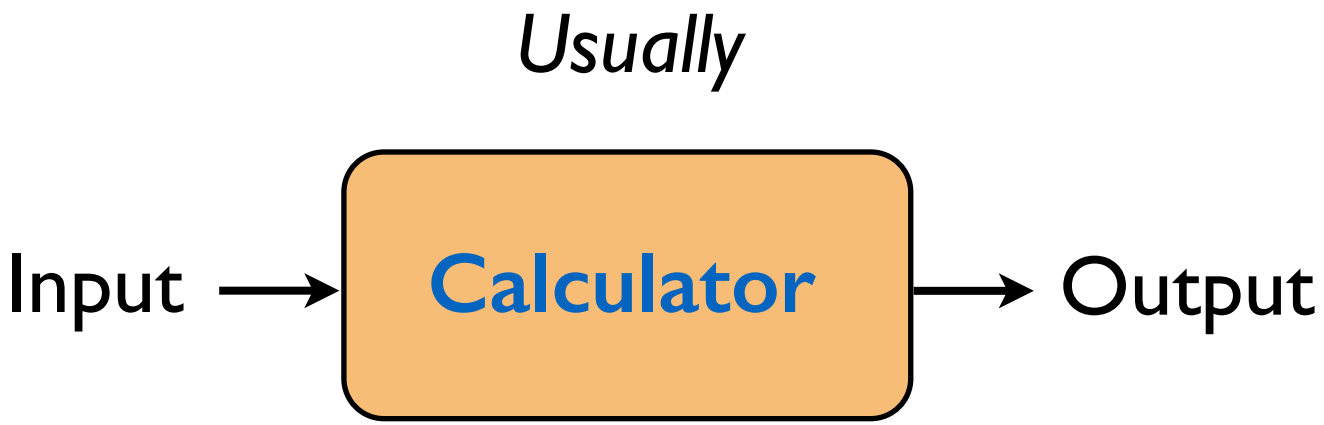

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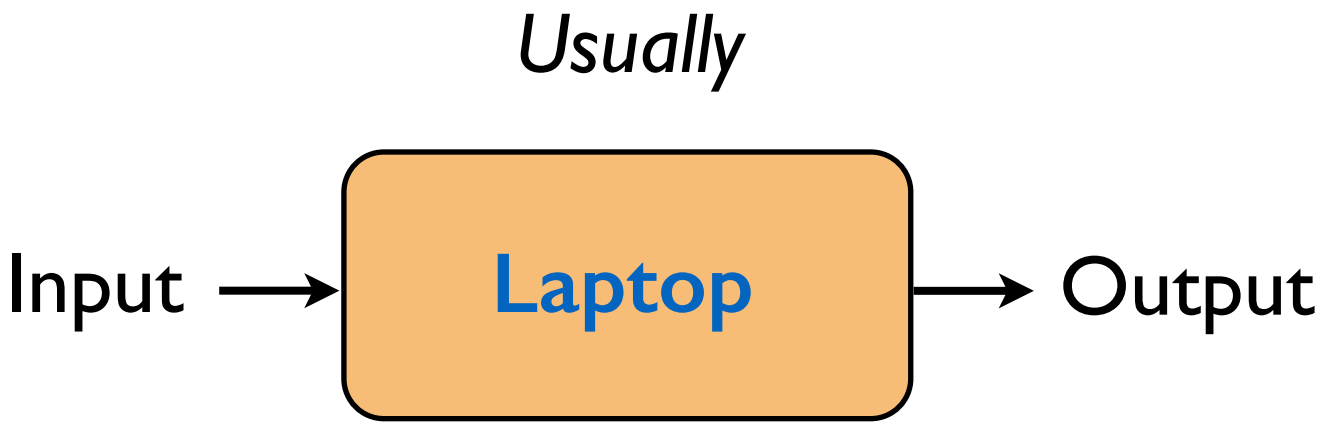

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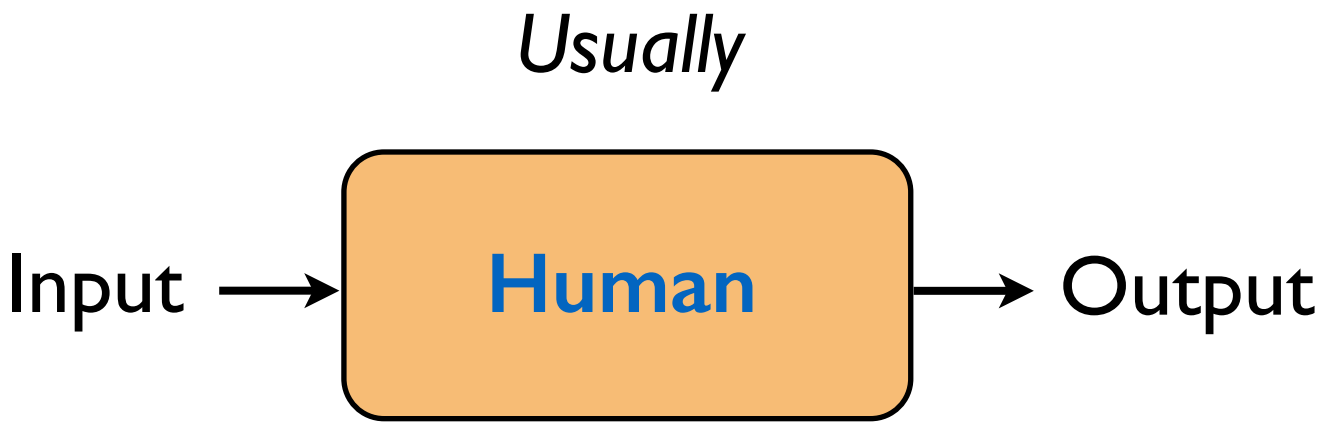

“Computers” in early 20th century

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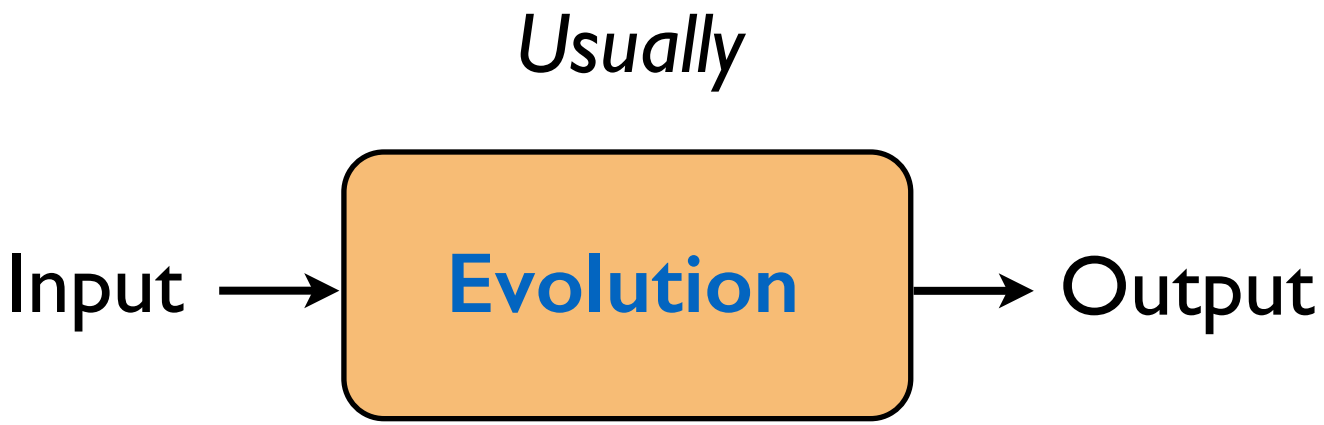


The computational lens

Computational physics

Computational biology

Computational chemistry

Computational neuroscience

Computational economics

Computational finance

Computational linguistics

Computational statistics

…

Wikipedia definition

" Computer Science deals with the theoretical foundations of information and computation, together with practical techniques for the implementation and application of the foundations. "

- *Wikipedia*

The role of theoretical computer science

Build a mathematical model for computation.

Explore the logical consequences.
Gain insight about computation.

http://youtu.be/pTeZP-XfuKI

https://goo.gl/gGkpMv

http://youtu.be/J4TkHuTmHsg

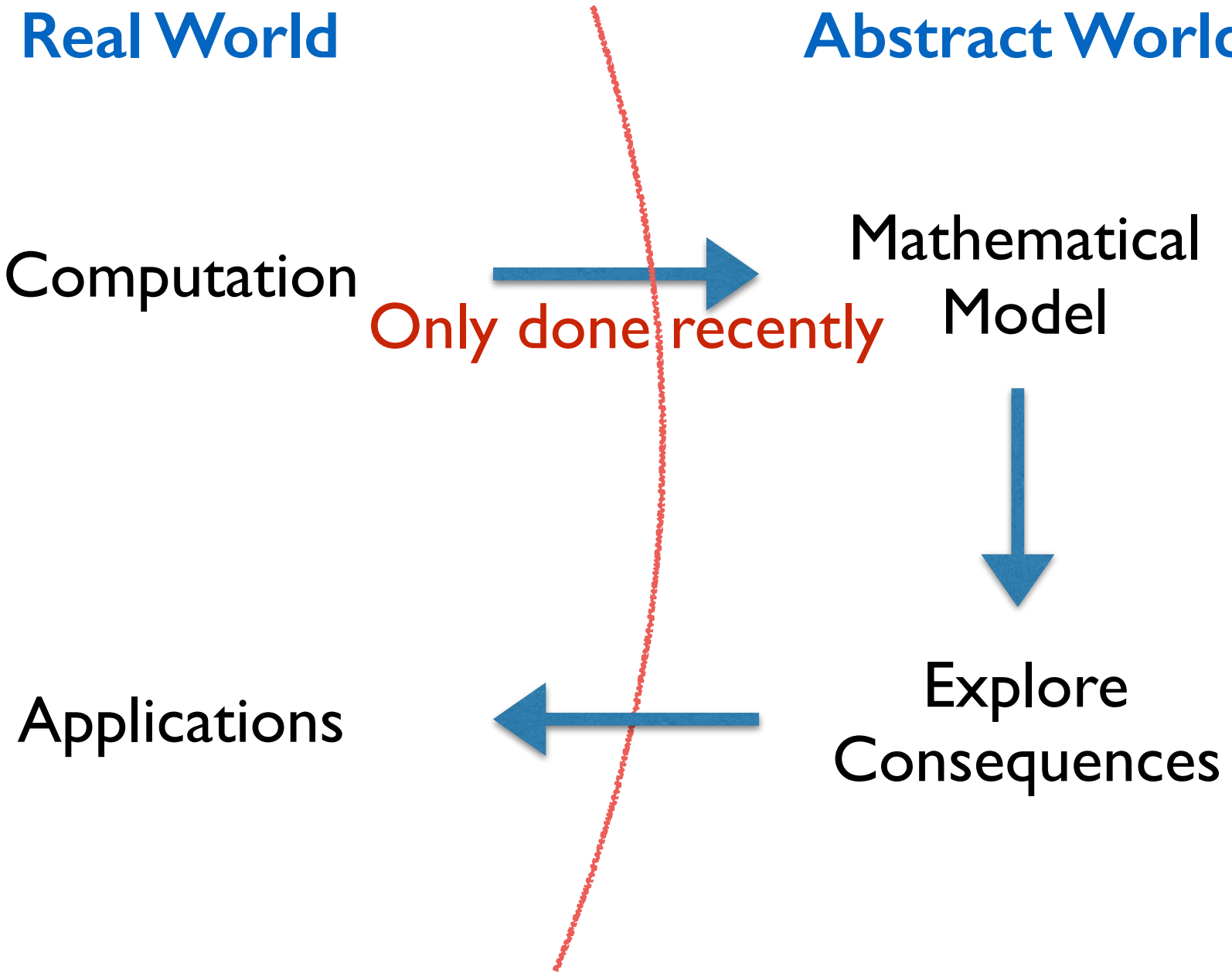
Look for interesting applications.

CMU undergrad

CMU Prof.

OK, we don't have everybody

The role of theoretical computer science



Simple examples of computation

We have been using algorithms for thousands of years.

```
   5127
 x 4265
------
  25635
 307620
1025400
20508000
--------
21866655
```

Simple examples of computation

We have been using algorithms for thousands of years.

Euclid's algorithm (~ 300BC):

```
def gcd(a, b):
    while (a != b):
        if (a > b):
            a = a - b
        else:
            b = b - a
    return a
```

Formalizing computation

We have been using algorithms for thousands of years.

Algorithm/Computation was only formalized in the 20th century!

Someone had to ask the right **question**.

David Hilbert, 1900

The Problems of Mathematics

"Who among us would not be happy to lift the veil behind which is hidden the future; to gaze at the coming developments of our science and at the secrets of its development in the centuries to come? What will be the ends toward which the spirit of future generations of mathematicians will tend? What methods, what new facts will the new century reveal in the vast and rich field of mathematical thought?"

2 of Hilbert's Problems

Hilbert's 10th problem (1900)

Is there a finitary procedure to determine if a given multivariate polynomial with integral coefficients has an integral solution?

e.g. $5x^2yz^3 + 2xy + y - 99xyz^4 = 0$

Entscheidungsproblem (1928)

Is there a finitary procedure to determine the validity of a given logical expression?

e.g. $\neg\exists x, y, z, n \in \mathbb{N} : (n \geq 3) \wedge (x^n + y^n = z^n)$

(Mechanization of mathematics)

2 of Hilbert's Problems

Fortunately, the answer turned out to be NO.

2 of Hilbert's Problems

Gödel (1934):

Discusses some ideas for mathematical definitions of computation. But not confident what is a good definition.

Church (1936):

Invents lambda calculus.
Claims it should be the definition of an "algorithm".

Gödel, Post (1936):

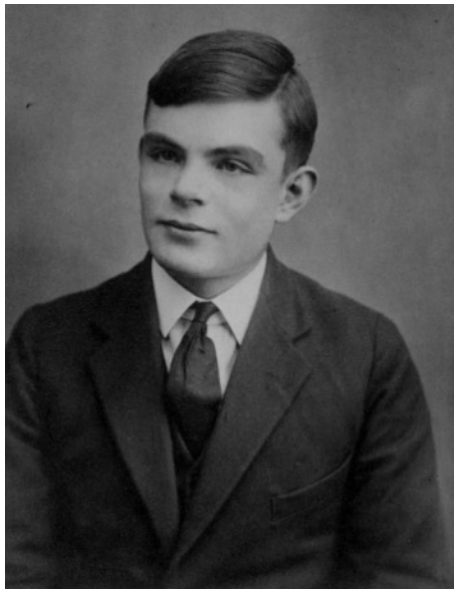
Arguments that Church's claim is not justified.

Meanwhile… in New Jersey… a certain British grad student, unaware of all these debates…

2 of Hilbert's Problems

Alan Turing (1936, age 22):

Describes a new model for computation, now known as the Turing Machine.™



Gödel, Kleene, and even Church:

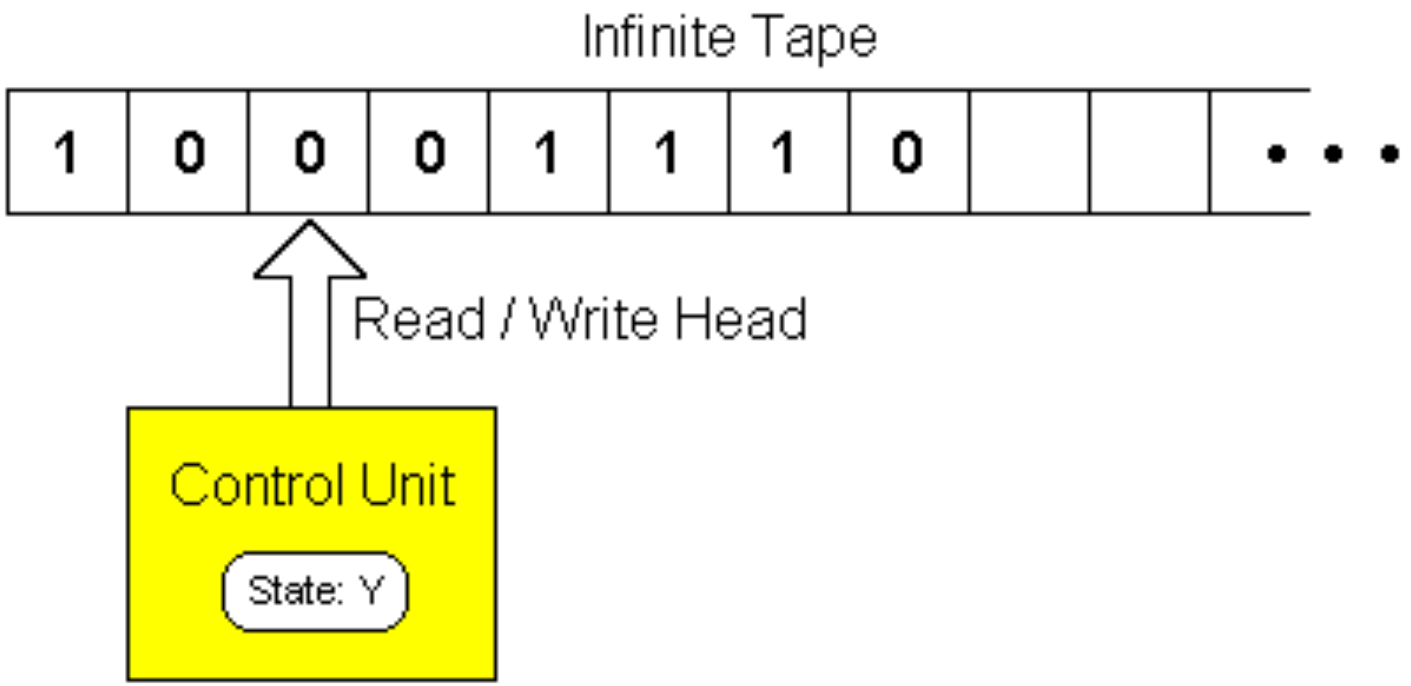
"Umm. Yeah. He nailed it. Game over. "Algorithm" defined."

Turing (1937):

TMs ≡ lambda calculus

Formalization of computation: Turing Machine

Turing Machine:



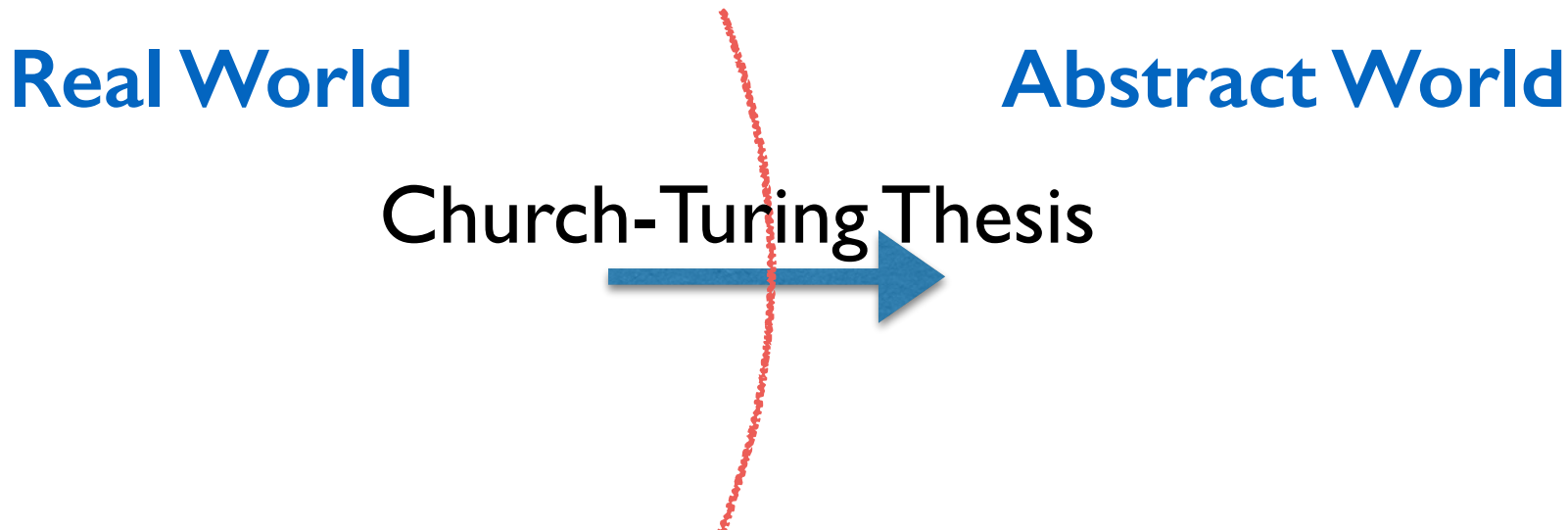
Church-Turing Thesis

Church-Turing Thesis:

The intuitive notion of "computable" is captured by functions computable by a Turing Machine.

(Physical) Church-Turing Thesis

Any computational problem that can be solved by a physical device, can be solved by a Turing Machine.



Back to Hilbert's Problems

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(Mechanization of mathematics)

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Is there an **algorithm** (a TM) to determine if a given multivariate polynomial with integral coefficients has an integral solution?

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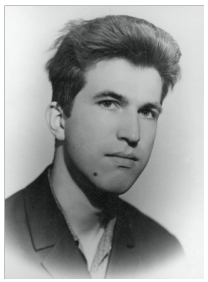
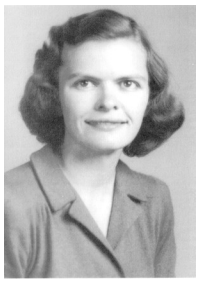
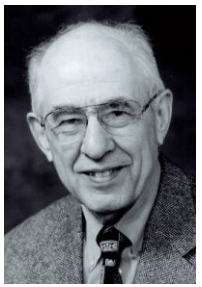
(Mechanization of mathematics)

Back to Hilbert's Problems

Hilbert's 10th problem (1900)

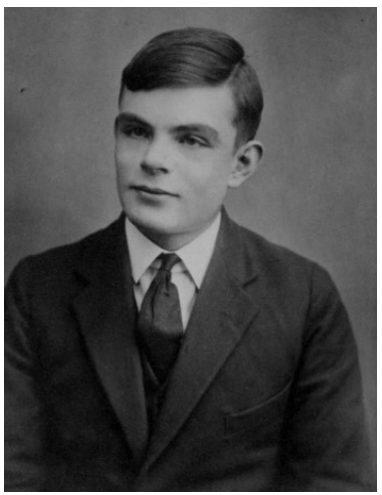
Matiyasevich-Robinson-Davis-Putnam (1970):



There is no algorithm to solve this problem.

Entscheidungsproblem (1928)

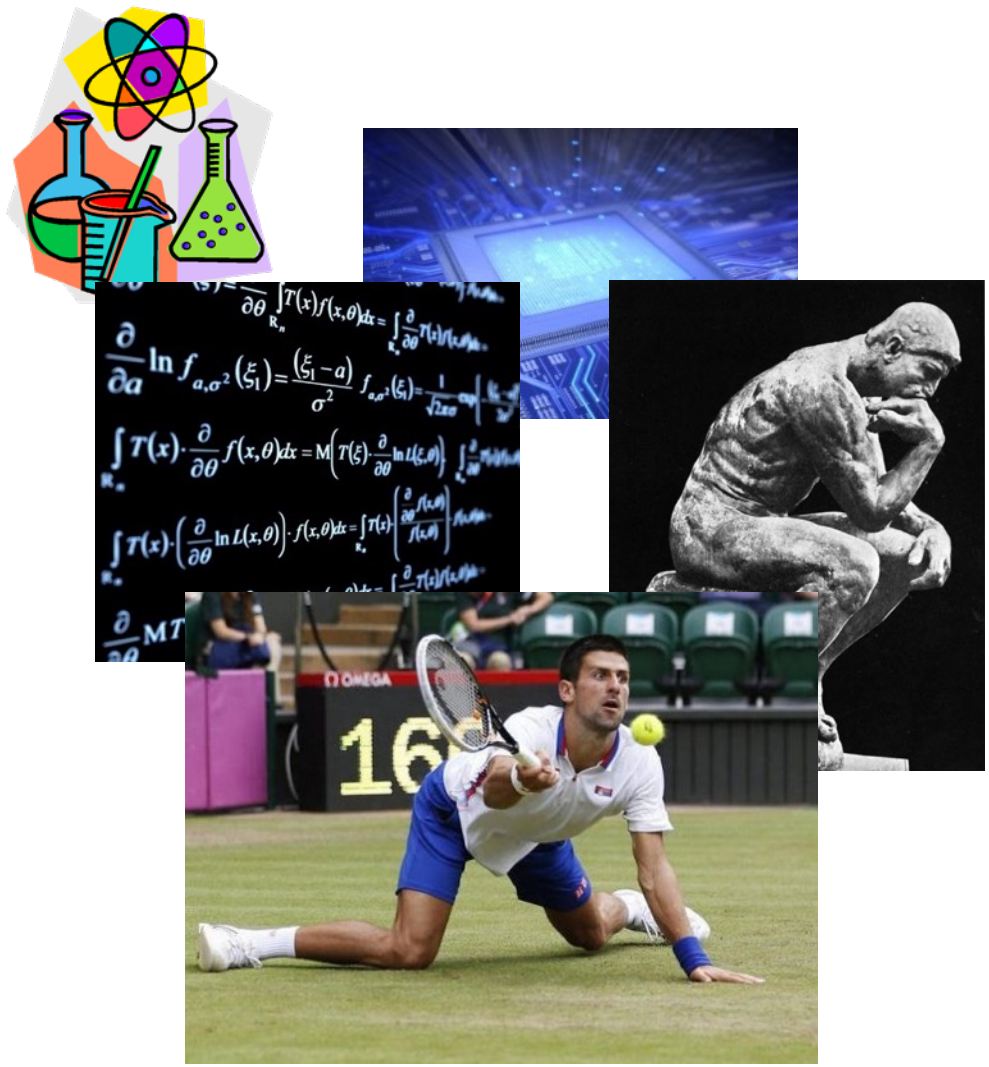


Turing (1936):

There is no algorithm to solve this problem.

Computer science

- science?
- engineering?
- math?
- philosophy?
- sports?



2 Main Questions in TCS

Computability of a problem:

Is there an algorithm to solve it?

Complexity of a problem:

Is there an efficient algorithm to solve it?

- time
- space (memory)
- randomness
- quantum resources

Computational Complexity

Complexity of a problem:

Is there an efficient algorithm to solve it?

- time
- space (memory)
- randomness
- quantum resources

2 camps:

- trying to come up with efficient algorithms (algorithm designers)
- trying to show no efficient algorithm exists (complexity theorists)

Computational Complexity

2 camps:

- trying to come up with efficient algorithms (algorithm designers)
- trying to show no efficient algorithm exists (complexity theorists)

multiplying two integers
factoring integers
sorting a list
protein structure prediction
simulation of quantum systems
computing Nash Equilibria of games

Some other interesting questions

If a problem has a space-efficient solution
does it also have a time-efficient solution?

Can every randomized algorithm be derandomized efficiently?

Can we use quantum properties of matter to build faster computers?

P vs NP

Learning Objectives

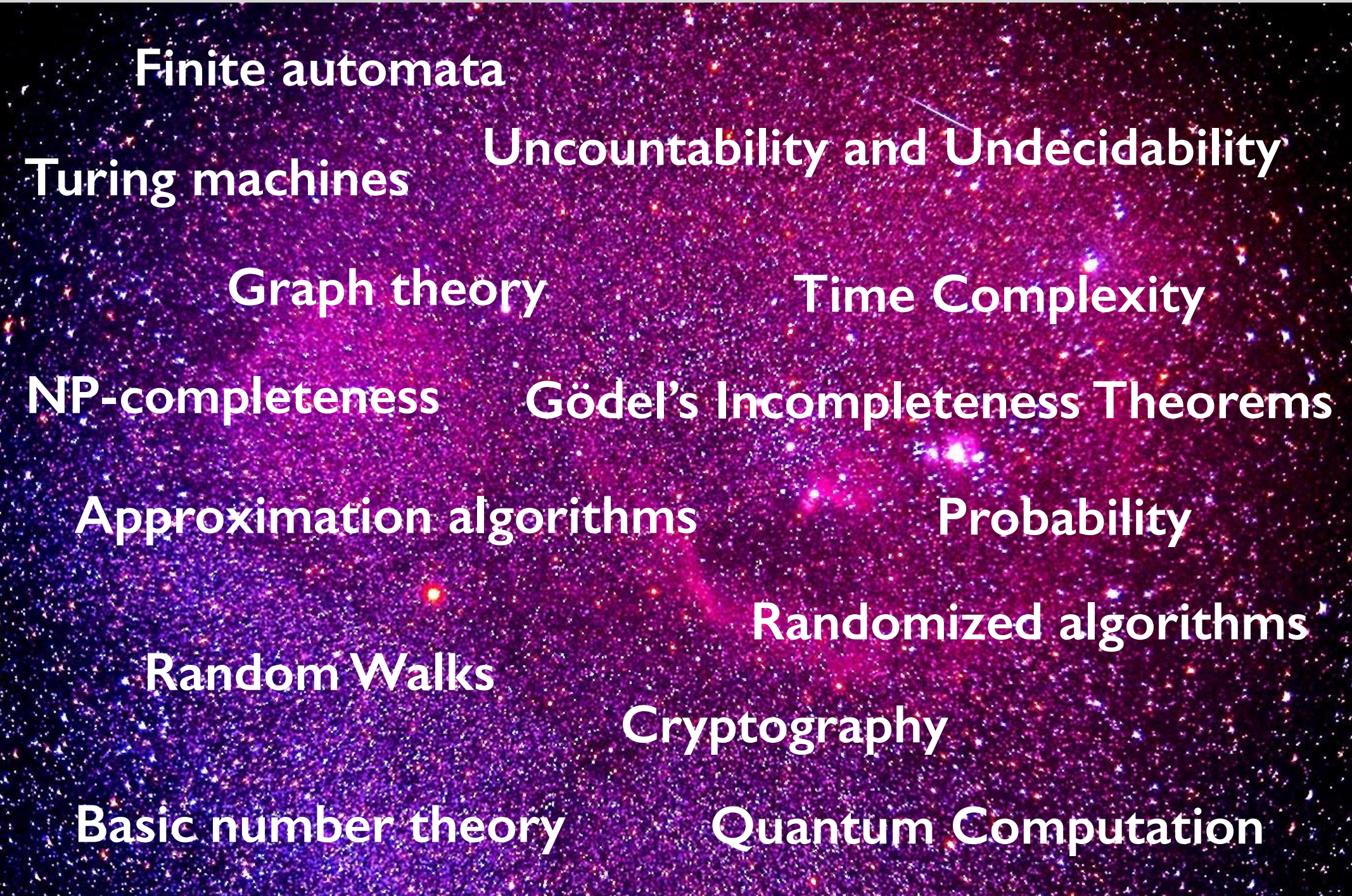
Topics Overview

Part 1: Formalizing the notions of problems, algorithms, and computability.

Part 2: Efficient computation:
basic algorithms and complexity

Part 3: Some highlights of theoretical CS and the mathematics behind them.

This is a "big picture" course



Goals

- Learn about the **foundational ideas and concepts** in the **theory of computation**.

- Learn the **mathematical constructs** and **techniques** needed to understand and develop key computational concepts.

- Improve **rigorous**, **logical**, and **abstract** thinking skills.

- Develop **problem-solving skills**.

- Refine **proof-writing skills**.

- Express complex ideas and arguments **clearly**, both in written and oral form.

- **Cooperate** with others in order to solve challenging and rigorous problems related to the study of computer science.

A review of the course syllabus

Webpage

Course webpage: www.cs.cmu.edu/~15251

Grading Scheme

Grading:

12 homework assignments

30%

2 midterm exams

20% + 20% = 40%

Mar 1, Apr 19
6:30pm - 9:30pm

1 final exam

25%

Participation (attending classes and recitations)

5%

Grading Scheme

Alternate Grading:

12 homework assignments

30%, lowest 4 homeworks half-weighted

2 midterm exams

Higher midterm: 30%

1 final exam

35%

Participation (attending classes and recitations)

5%

Important Note:

With this scheme, max letter grade you can receive is a C.

A poll

What is your favorite TV show?

- Game of Thrones
- Breaking Bad
- Seinfeld
- Friends
- The Wire
- Sherlock
- The Sopranos
- Arrested Development
- Sesame Street
- None of the above
- I don't watch TV!

Homework System

4 types of questions:

SOLO, GROUP, OPEN COLLABORATION, PROGRAMMING

SOLO - work by yourself

GROUP - work in groups of 3 or 4

OPEN - work with anyone you would like from class

PROG - same rules as SOLO. submit to Autolab.

Homework System

General rules:

Don't share written material with anyone.

Erase public whiteboard when done.

Can search books to learn more about a subject.

Can't Google specific keywords from the homework.

Always cite your sources!

Think about a problem before you collaborate.

Homework System

Homework writing sessions:

Wednesdays 6:30pm to 7:50pm at DH 2210

Write the solutions to a random subset of the problems.

You must practice writing the solutions beforehand!!!

You will lose points for poor presentation.

You get 20% of the credit for the question if you write:

- nothing
- "I don't know", or
- "WTF!"

Homework System

Homework Grading:

Step 1:

TAs grade and give back the hw on Friday.

You will know who graded which question.

Step 2:

If

- you think there has been a mistake in grading
- you don't understand why you lost points

email the TA who graded the question.
(attach a picture of your write-up)

Homework System

Learn from your mistakes —> more points:

To get back 25% of the lost credit on a problem:

Submit electronically (via email) a completely correct solution by 10pm Sunday.

Piazza

Everyone must sign up.

Course announcements will be made on Piazza.
You have to check it every day.

Great resource, make use of it.

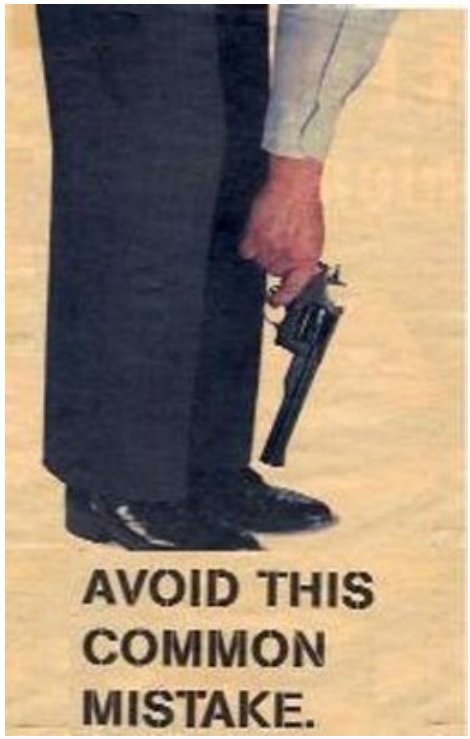
Please be polite.

Don’t give away any hints.

Office hours

See course webpage.

You have to use the OHs!



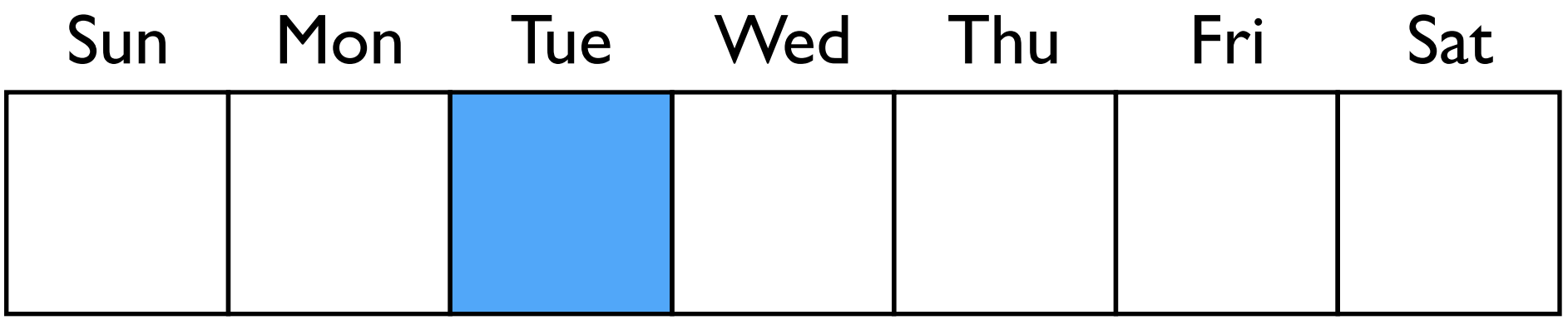
We have separate conceptual OHs.

Small Group Review Sessions

Sign up for an hour long time slot.

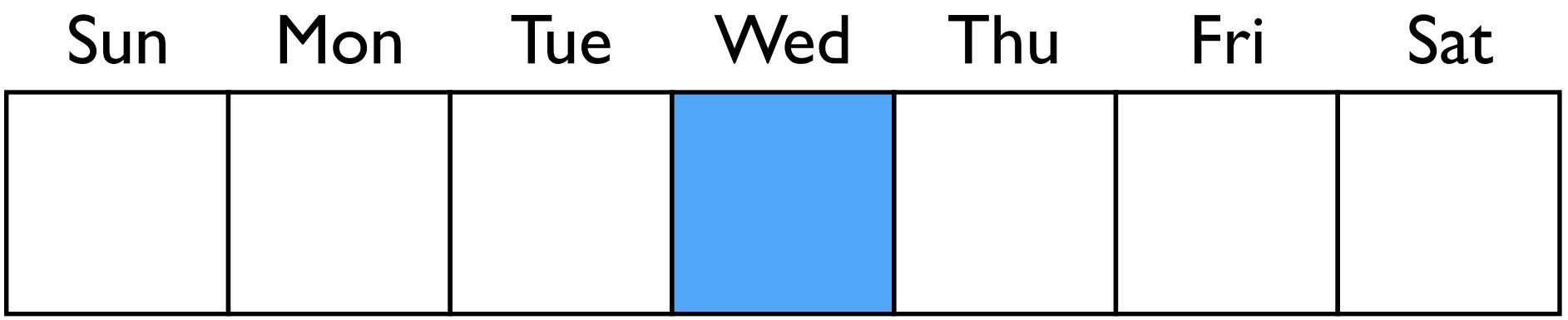
Review material with a TA and 2, 3 other students.

A typical week



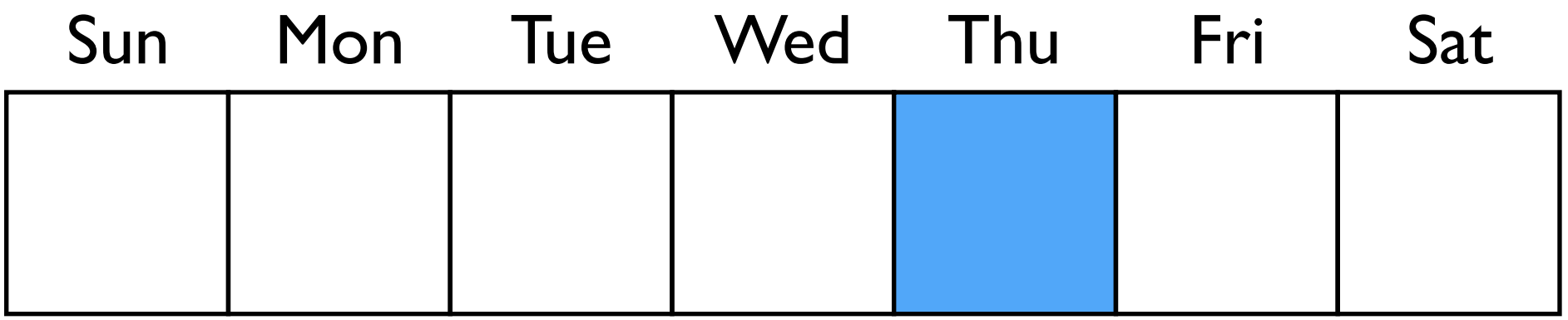
Lecture 1

A typical week



Lecture 1.5 (6:30 - 7:50pm) (for this week only)

A typical week



Lecture 2

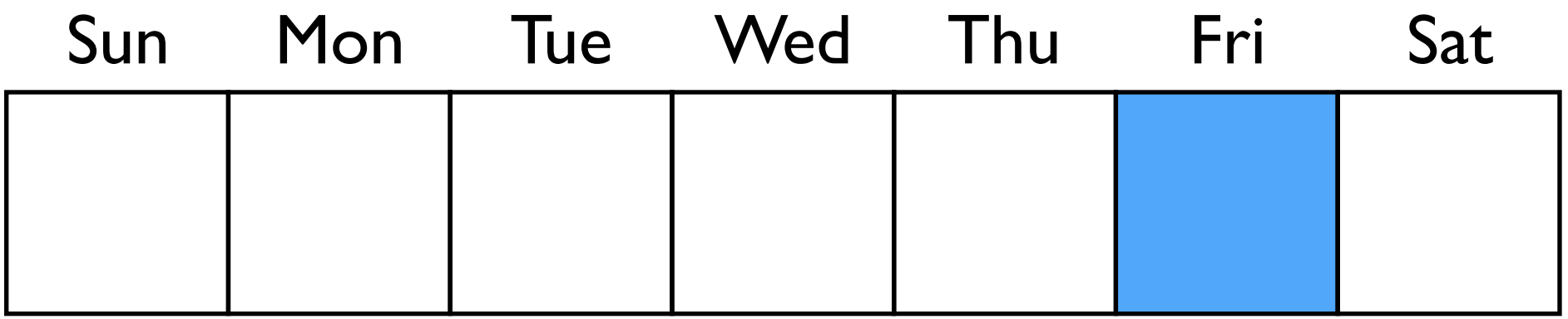
Office hour (Anil) (this week OHs start on Thu)

Review that week's material.

Homework comes out.

Maybe start thinking about SOLO problems.

A typical week



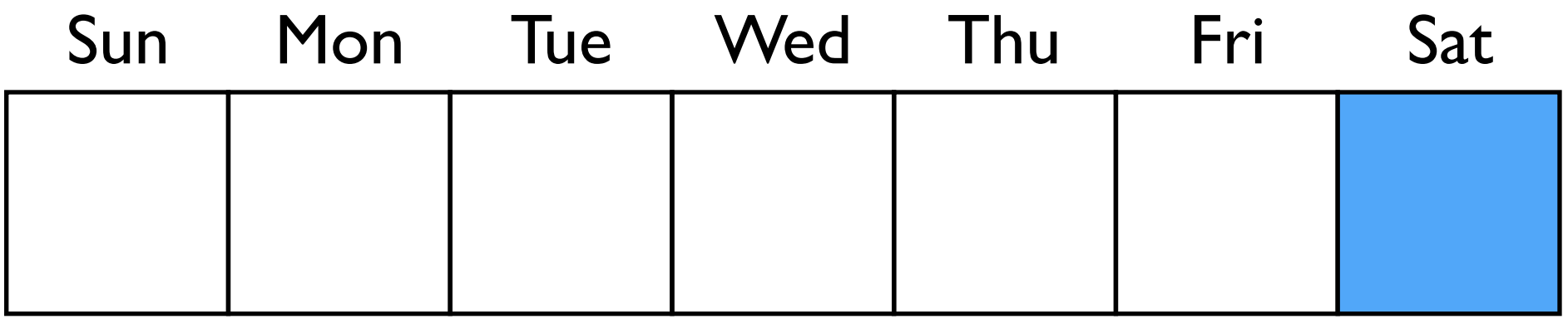
Recitation

Make progress on SOLO problems.

Start thinking about the GROUP problems.

Make appointments to meet with your group.

A typical week



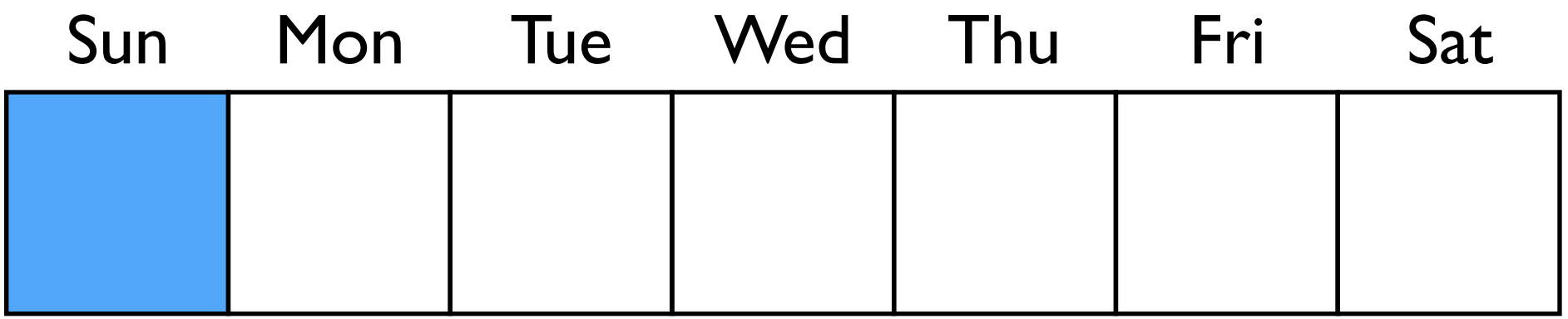
Meet with your group.

Make some progress on the questions.

Maybe solve some of them.

Go to office hours.

A typical week

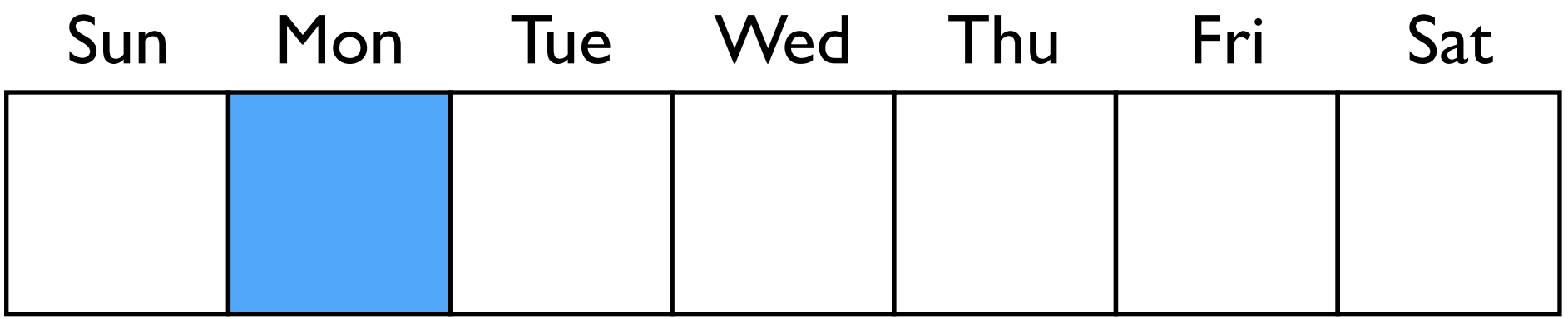


Meet with your group.

Go to office hours, get some help.

Solve some more problems.

A typical week



Finish up GROUP problems.

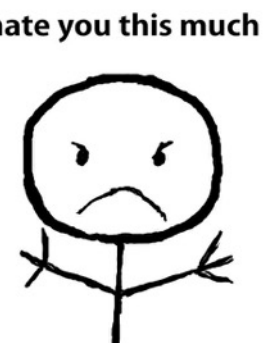
Go to office hours.

A typical week

Sun	Mon	Tue	Wed	Thu	Fri	Sat

Realize that you still need to do the OPEN problem(s)!

Express hate towards the professors.



Lecture

Rush to OH to get help.

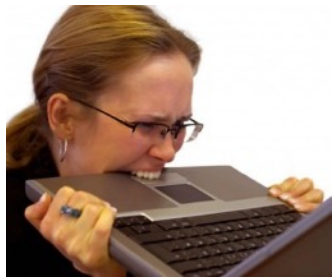
Don’t sleep until you solve the hardest problem.

A typical week

Sun	Mon	Tue	Wed	Thu	Fri	Sat

Practice writing up the solutions to the problems.

Realize you have a mistake in one of the questions.



Express hate towards the professors.

Learning moment:
write solution down once you think you figured it out.

Keys to success in this course

Come to lecture tomorrow!!

Video