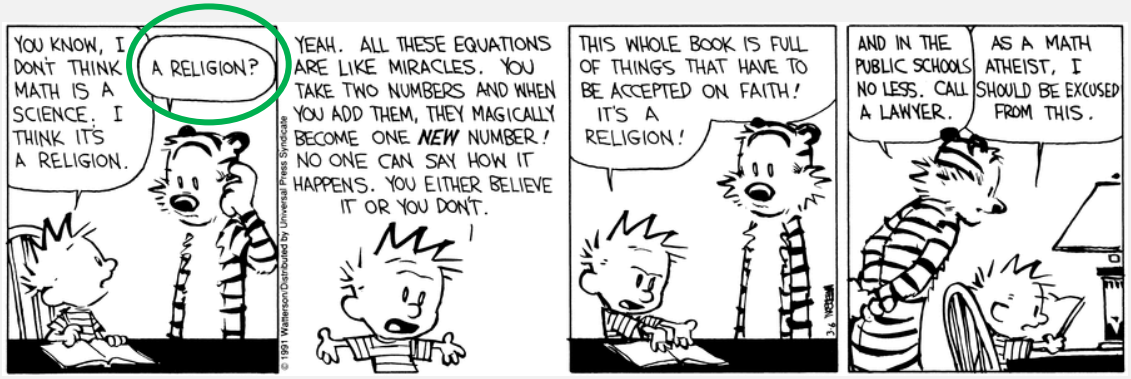
# Welcome to CS420!

# Intro to Theory of Computation

UMass Boston Computer Science

Instructor: Stephen Chang

Fall 2022



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What's this?

# CS 420 Lecture Logistics

- I expect lecture to be interactive
  - Participation is a part of your grade
  - It's the best way to learn!

- I may call on students randomly
  - It's ok to be wrong – will not affect your grade
  - It's the best way to learn!

- Please tell me your name before speaking
  - Sorry in advance if I get it wrong
  - It's the best way for me to learn!

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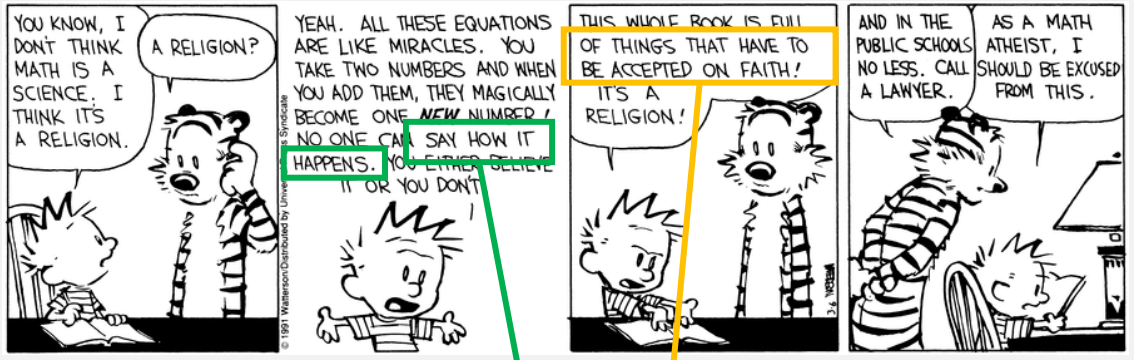
How would you define this?

# Computation Is …




- 1 + 1 = ??
- = 2

… some base definitions and assumptions ("**axioms**"),
e.g., "A **Number** is either 0, or the successor of another **Number**" …

- 11 + 11 = ??
- = 22

… and rules that use the definitions and axioms ("**algorithm**"),
e.g., grade school arithmetic

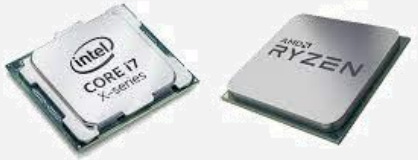
- 9999999999 + 9999999999 = ??
- = 19999999998

Computation rules can be executed by hand, or by a **machine** / **automaton**

- 1 +1 = ??
- = 10

(binary)

There are many possible definitions (**models**) **of computation**




(hint)

# Many Different Kinds of Computation





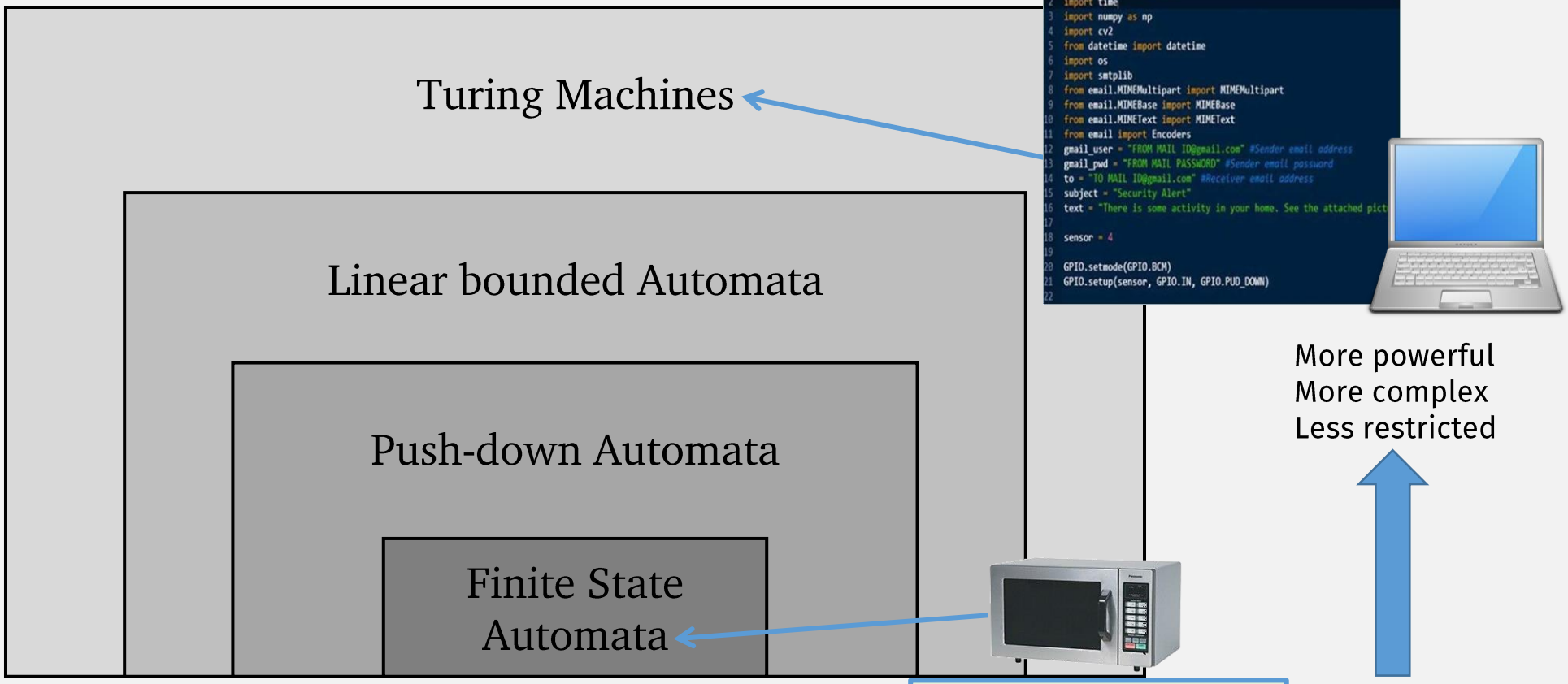

This class is about: *(definitions + rules)*

- **formally defining models of computation,**
- and **studying their <u>relation</u> to each other!**

# Models of Computation Hierarchy

… and get to here …

… and also look at what's out here??




```
import RPi.GPIO as GPIO
import time
import numpy as np
import cv2
from datetime import datetime
import os
import smtplib
from email.MIMEMultipart import MIMEMultipart
from email.MIMEBase import MIMEBase
from email.MIMEText import MIMEText
from email import Encoders
gmail_user = "FROM MAIL ID@gmail.com" #Sender email address
gmail_pwd = "FROM MAIL PASSWORD" #Sender email password
to = "TO MAIL ID@gmail.com" #Receiver email address
subject = "Security Alert"
text = "There is some activity in your home. See the attached pict

sensor = 4

GPIO.setmode(GPIO.BCM)
GPIO.setup(sensor, GPIO.IN, GPIO.PUD_DOWN)
```

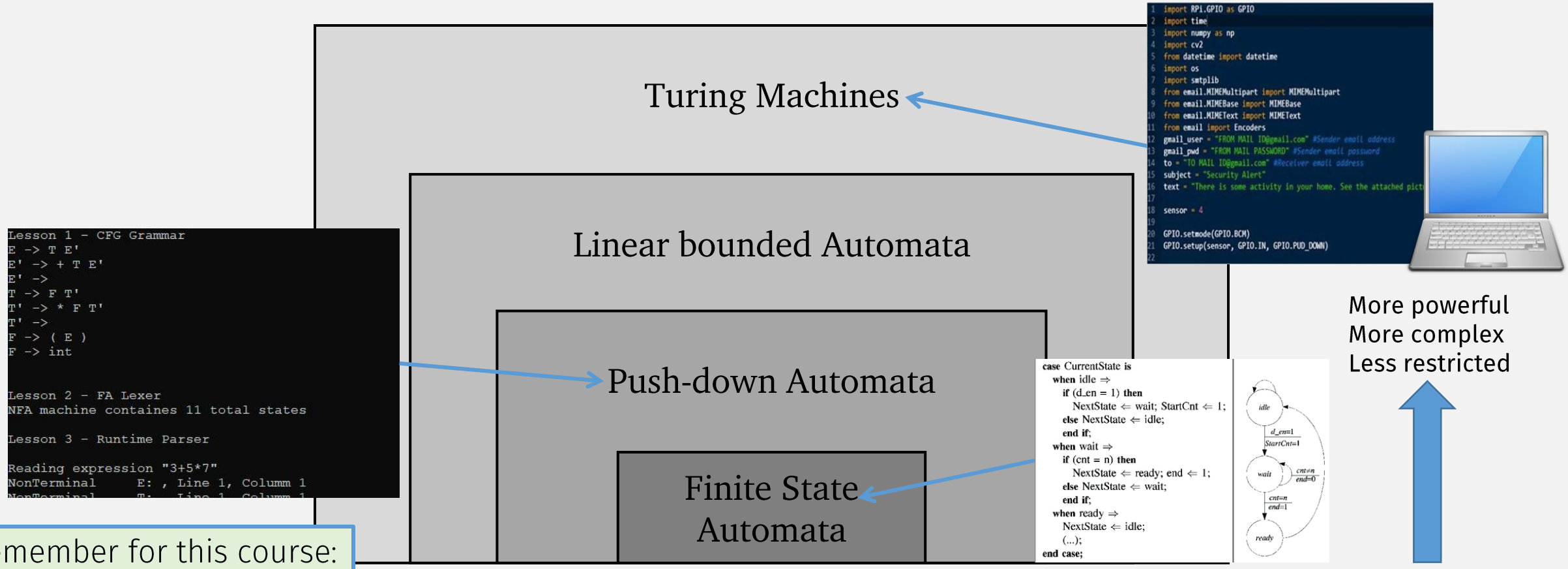


More powerful
More complex
Less restricted



We'll start here …

# Computation = Programs!




More powerful
More complex
Less restricted

Remember for this course:

- A **model of computation** is represented by a **class of machines** (each box)
- Think of: a **class** of machines = a **Programming Language!**
- Think of: a **single** machine instance = a **Program!**

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# Intro to Theory of Computation

## Models of & Programs

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# Welcome to CS420!

# Intro to Theory of Computation

Models of & Programs

This class is about **formally** defining models of computation!

Fall 2022

**"formally" = mathematically**
(This is a math course!)

# A (Mathematical) Theory is …

## Mathematical theory

From Wikipedia, the free encyclopedia

A **mathematical theory** is a mathematical model of a branch of mathematics that is based on a set of axioms. It can also simultaneously be a body of knowledge (e.g., based on known axioms and definitions, and so in this sense can refer to an area of mathematical research within the established framework.[1][2]

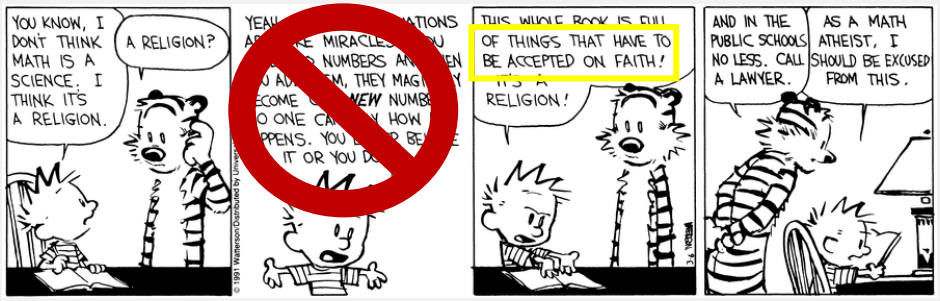
Explanatory depth is one of the most significant theoretical virtues in mathematics. For example, set theory has the ability to systematize and explain number theory and geometry/analysis. Despite the widely logical necessity (and self-evidence) of arithmetic truths such as 1<3, 2+2=4, 6-1=5, and so on, a theory that just postulates an infinite blizzard of such truths would be inadequate. Rather an adequate theory is one in which such truths are derived from explanatorily prior axioms, such as the Peano Axioms or set theoretic axioms, which lie at the foundation of ZFC axiomatic set theory.

The singular accomplishment of axiomatic set theory is its ability to give a foundation for the derivation of the entirety of classical mathematics from a handful of axioms. The reason set theory is so prized is because of its explanatory depth. So a mathematical theory which just postulates an infinity of arithmetic truths without explanatory depth would not be a serious competitor to Peano arithmetic or Zermelo-Fraenkel set theory.[3][4]

… a mathematical model, i.e., **axioms** and **definitions**, of some domain, e.g. computation …

… that **explains** (**predicts**) some real-world phenomena …

i.e., a theory must be useful in practice!

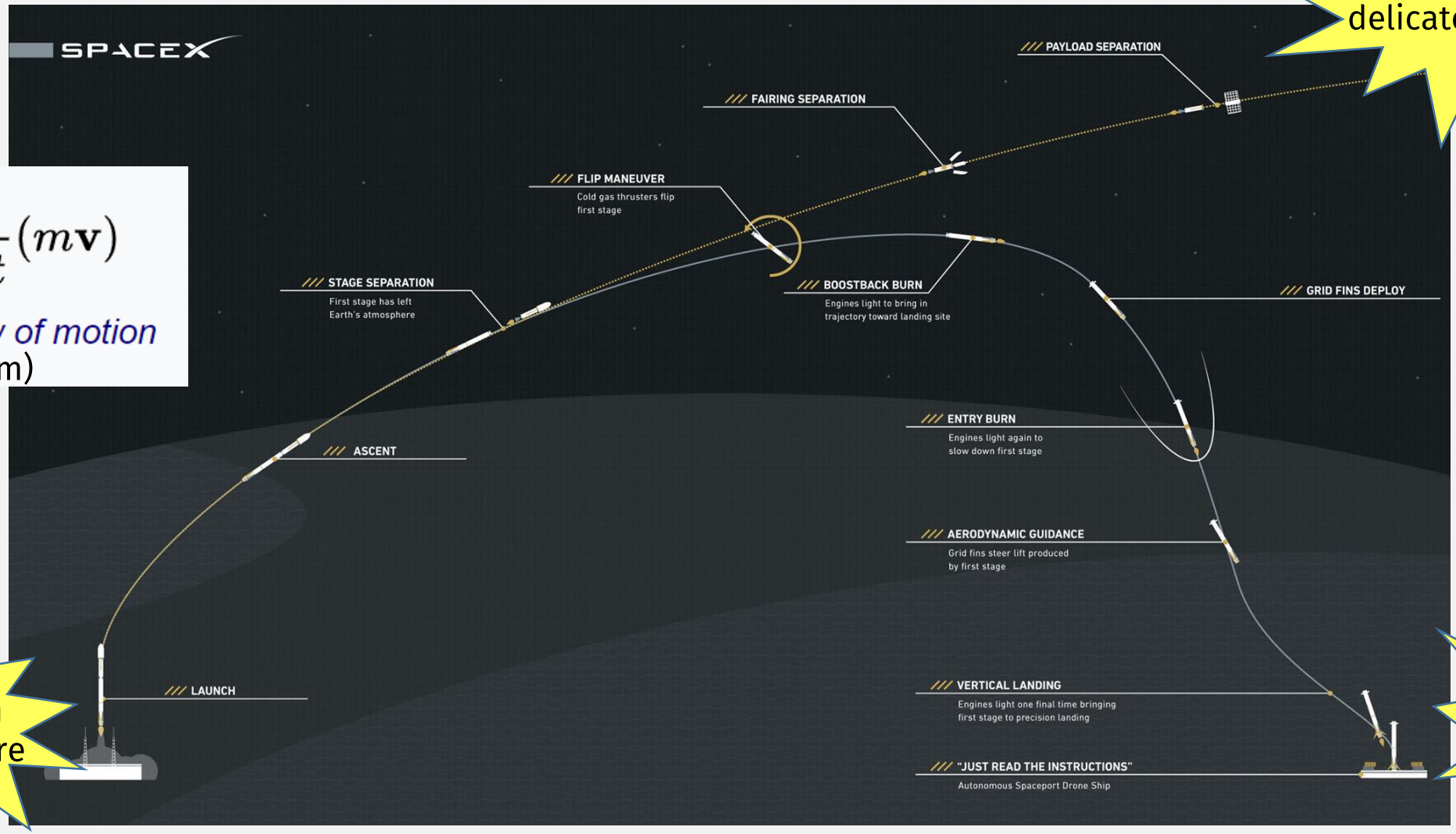


# *Example*: Theory of Classical Mechanics

Drop off $1b of delicate stuff here

$$\mathbf{F} = \frac{d}{dt}(m\mathbf{v})$$

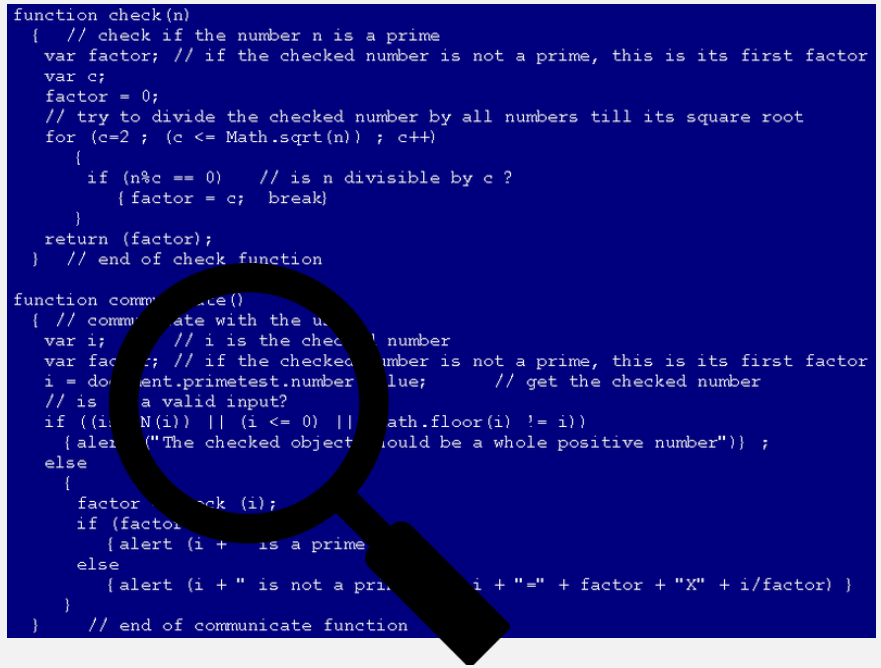
*Second law of motion*
(axiom)




Do 1000 ton explosion here

Predicts landing exactly here

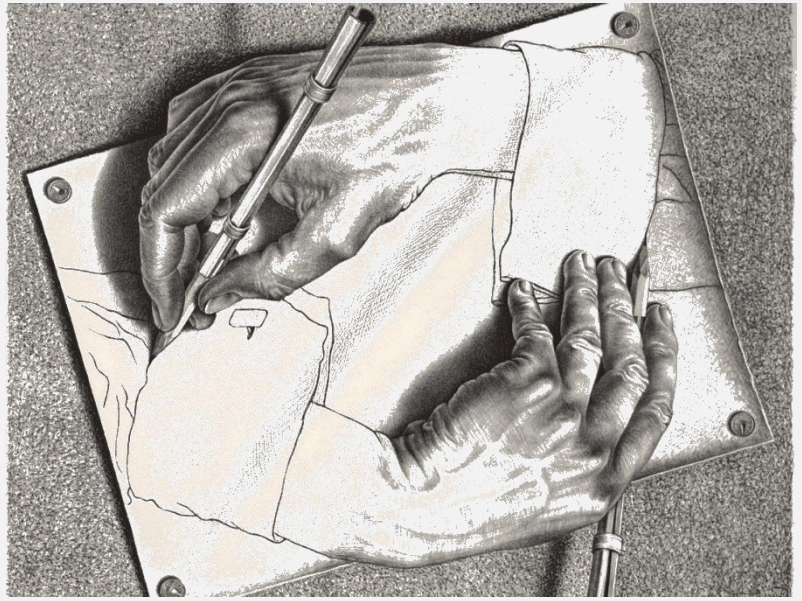
# Why make predictions about computation?





Predict result without running a program?

# Can we make predictions about computation?



It's tricky: **Trying to predict computation requires computation!**

# Can we make predictions about computation?

- The **Halting Lemma** says:


- And **Rice's Theorem** says:
  - "all non-trivial, semantic properties of programs are undecidable"
- Actually:
  - it depends on the computation model!

# Predicting What Some Programs Will Do …

microsoft.com/en-us/research/project/slam/

SLAM is a project for checking that software satisfies critical behavioral properties of the interfaces it uses and to aid software engineers in designing interfaces and software that ensure reliable and correct functioning. Static Driver Verifier is a tool in the Windows Driver Development Kit that uses the SLAM verification engine.

*"Things like even software verification, this has been the Holy Grail of computer science for many decades but now in some very key areas, for example, driver verification we're building tools that can do actual proof about the software and how it works in order to guarantee the reliability."* **Bill Gates, April 18, 2002. Keynote address at WinHec 2002**

Holy grail of CS!


Static Driver Verifier Research Platform README

## Overview of Static Driver Verifier Research Platform

Static Driver Verifier (SDV) is a compile-time static verification tool, included in the Windows Driver Kit (WDK). The SDV Research Platform (SDVRP) is an extension to SDV that allows you to adapt SDV to:

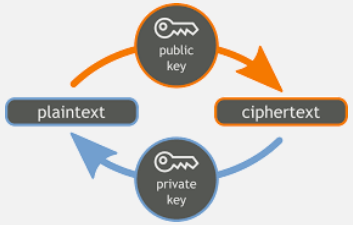
- Support additional frameworks (or APIs) and write custom SLIC rules for this framework.
- Experiment with the model checking step.

# Knowing What Computers Can't Do is Still Useful!

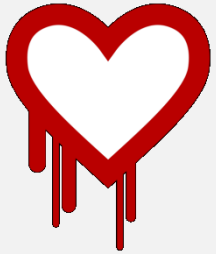
In Cryptography:

- Perfect secrecy is impossible in practice
- But with slightly imperfect secrecy (i.e., a computationally bounded adversary) we get:


amazon


- But there are still problems, even with strong mathematical foundations:
  - with users, implementors **who don't understand theory of computation**



LOG4J

# Which Computation Model to Choose?


Turing Machines

Linear bounded Automata

Push-down Automata

Finite State Automata

e.g., logging?

Which programs need more powerful computation … ?

More powerful
More complex
Less restricted

… and which need weaker compuation?

# The Computing Power of Logs?

## Log4Shell

From Wikipedia, the free encyclopedia

**Log4Shell** (**CVE-2021-44228**) was a zero-day vulnerability in Log4j, a popular Java logging framework, involving arbitrary code execution.[2][3] The vulnerability has existed unnoticed since 2013 and was privately disclosed to the Apache Software Foundation, of which Log4j is a project, by Chen Zhaojun of Alibaba Cloud's security team on 24 November 2021, and was publicly disclosed on 9 December 2021.[1][4][5][6] Apache gave Log4Shell a CVSS severity rating of 10, the highest available score.[7] The exploit is simple to execute and is estimated to affect hundreds of millions of devices.[6][8]

**Log4Shell**

| | |
|---|---|
| **CVE identifier(s)** | CVE-2021-44228 |
| **Date discovered** | 24 November 2021; 57 days ago |
| **Date patched** | 6 December 2021; 45 days ago |
| **Discoverer** | Chen Zhaojun of the Alibaba Cloud Security Team[1] |
| **Affected software** | Applications logging user in using Log4j 2 |

The vulnerability takes advantage of Log4j's allowing requests to arbitrary LDAP and JNDI servers,[2][9][10] allowing attackers to execute arbitrary Java code on a server or other computer, or leak sensitive information.[5] A list of its affected software projects has been published by the Apache Security Team.[11] Affected commercial services include Amazon Web Services,[12] Cloudflare, iCloud,[13] *Minecraft: Java Edition*,[14] Steam, Tencent QQ and many others.[9][15][16] According to Wiz and EY, the vulnerability affected 93% of enterprise cloud environments.[17]

# The Computing Power of Fonts?

ars TECHNICA BIZ & IT TECH SCIENCE POLICY CARS GAMING & C

*IN THE WILD —*

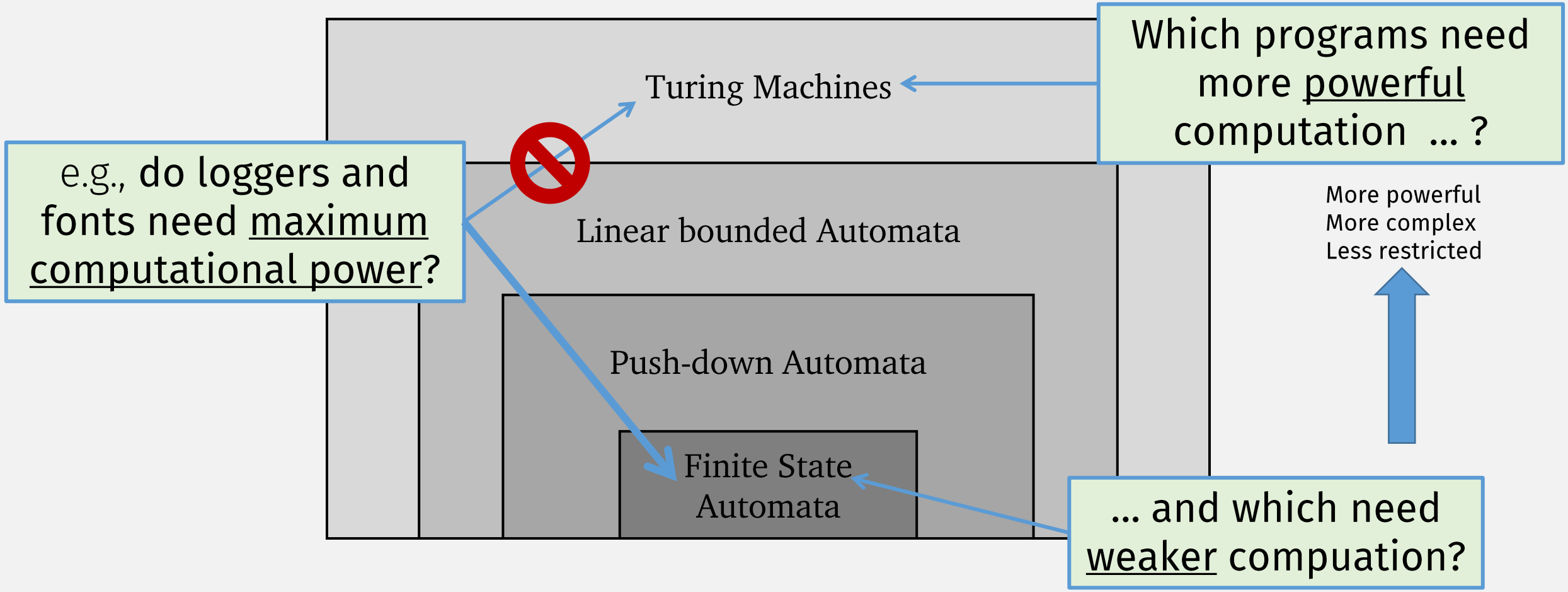
## Windows code-execution zeroday is under active exploit, Microsoft warns

**There's no patch available now. Here's what to do until Microsoft issues one.**

DAN GOODIN - 3/23/2020, 3:40 PM

The font-parsing remote code-execution vulnerability is being used in "limited targeted attacks," against Windows 7 systems, the software maker said in an advisory published on Monday morning. The security flaw exists in the Adobe Type Manager Library, a Windows DLL file that a wide variety of apps use to manage and render fonts available from Adobe Systems. The vulnerability consists of two code-execution flaws that can be triggered by the improper handling of maliciously crafted master fonts in the Adobe Type 1 Postscript format. Attackers can exploit them by convincing a target to open a booby-trapped document or viewing it in the Windows preview pane.

# Which Computation Model to Choose?



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… a mathematical model, i.e., **axioms** and **definitions**, of some domain, e.g. computers …

… that **explains** (**predicts**) some real-world phenomena …

… and can **derive** additional results (**lemmas** & **theorems**) …

# How Mathematics Works

Mathematician
(or student)

Actually, it's not always so easy to create the next level ...
**Preciseness is important**

**Proofs** = Figuring out how to (precisely) stack the pieces together

**More Theorems**

**More Axioms**

**More Definitions**

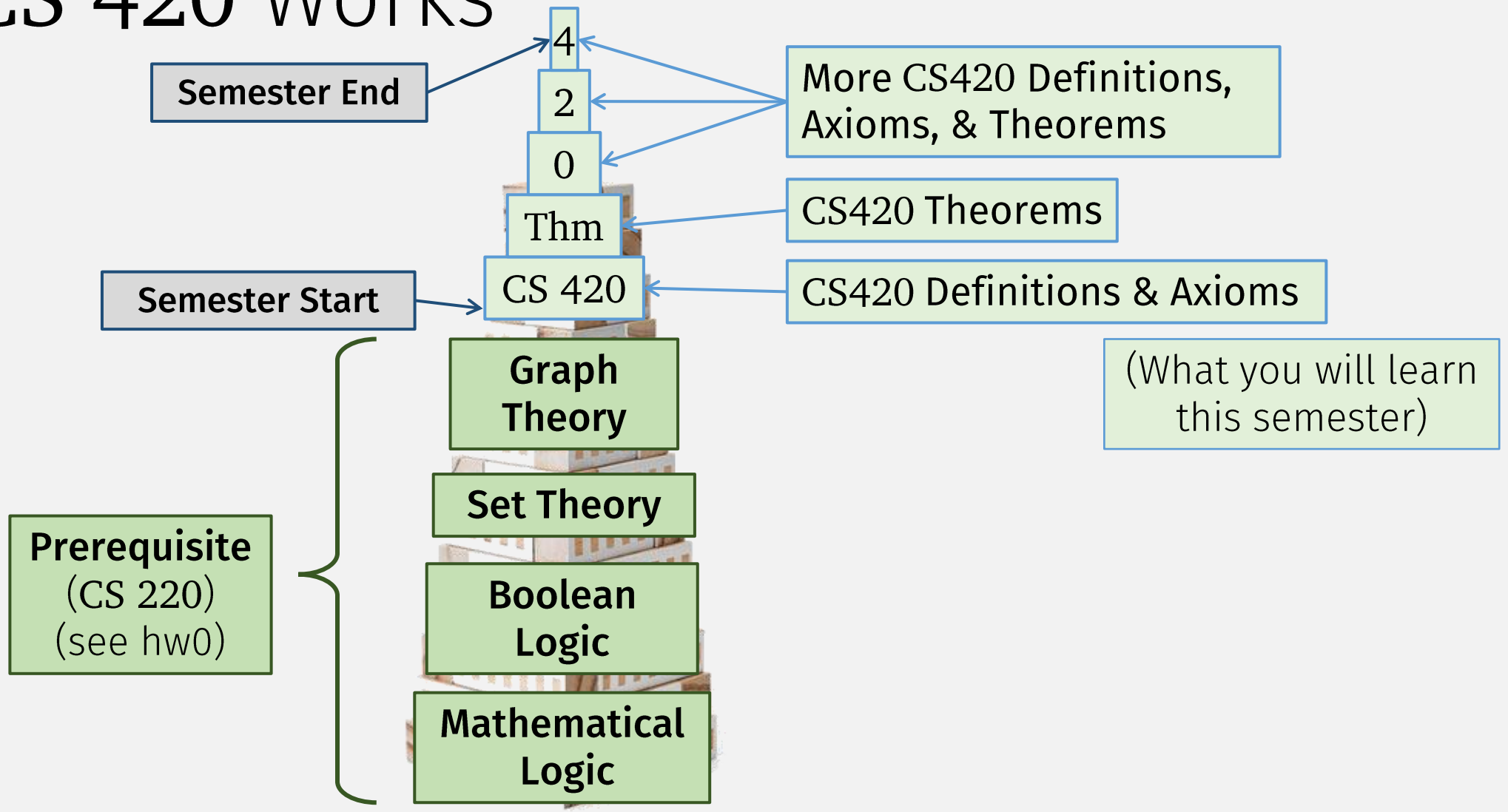
**Theorem**

**Theorem**

**Axioms**

**Definitions**

# How CS 420 Works



# A Word of Advice

Important:
**Do not fall behind**
in this course

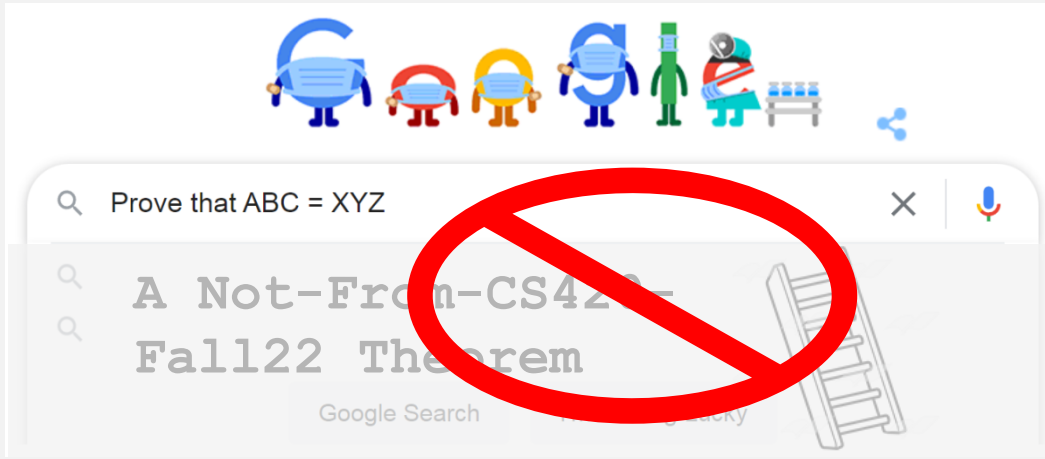
To **prove** a (new) **theorem** …

… need to know all **axioms**, **definitions**, and (previous) **theorems** below it

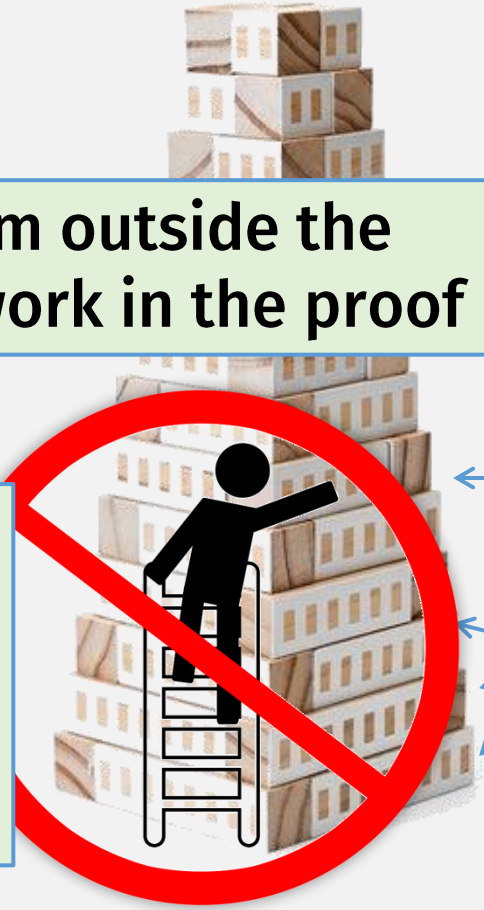
# Another Word of Advice

HW 1, Problem 1

Prove that $ABC = XYZ$




**"Blocks" from outside the course won't work in the proof**



… can be used to **prove** (new) **theorems** in this course

Only **axioms, definitions,** and **theorems** from this course …

Remember:
**Preciseness is important**
(Proofs must connect facts from this course exactly)

# How to Do Well in this Course

- Learn the “blocks”
  - I.e., axioms, definitions, and theorems
- To solve a problem (prove a new theorem) …
  … think about how to (precisely) combine and use existing “blocks”
- Don’t Fall Behind!
  - Start HW Early (HW 0 due Sunday 11:59pm EST)
- Participate and Engage
  - Lecture
  - Office Hours
  - Message Boards (piazza)

# Textbooks

- Sipser. *Intro to Theory of Computation*, 3rd ed.

- Hopcroft, Motwani, Ullman. *Intro to Automata Theory, Languages, and Computation*, 3rd ed.

- Recommended but not required,
    - slides and lecture should be self-contained,
- Readings to accompany lectures will be posted

All course info available on web site:
`https://www.cs.umb.edu/~stchang/cs420/f22`

# Grading

- **HW**: 80%
  - Weekly: Out Monday, In Sunday
  - Approx. 12 assignments
  - Lowest grade dropped
- **Quizzes**: 5%
  - End of every lecture
  - To help everyone keep up
- **Participation**: 15%
  - Lecture, office hours, piazza
- No exams

- **A** range: 90-100
- **B** range: 80-90
- **C** range: 70-80
- **D** range: 60-70
- **F**: < 60

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# Late HW

- Is bad … try not to do it please
  - Grades get delayed
  - Can’t discuss solutions
  - You fall behind!

- Late Policy: **3 late days** to use during the semester

# HW Collaboration Policy

**Allowed**

- Discussing HW with classmates
- Using other resources, e.g., youtube, other books, etc.
- Writing up answers on your own, from scratch, in your own words

**Not Allowed**

- Submitting someone else's answer
- It's still someone else's answer if:
  - variables are changed,
  - words are omitted,
  - or sentences rearranged …
- Using sites like Chegg, CourseHero, Bartleby, Study, etc.
- Don't use "blocks" from outside this course

# Honesty Policy

- 1st offense: zero on problem
- 2nd offense: zero on hw, reported to school
- 3rd offense+: F for course

Regret policy

- If you self-report an honesty violation, you'll only receive a zero on the problem and the issue will be immediately resolved (don't abuse this please).

# All Up to Date Course Info

Survey, Schedule, Office Hours, HWs, …

See course website:

https://www.cs.umb.edu/~stchang/cs420/f22/

# Check-In Quiz 9/6

(see gradescope)