Welcome to CS622!

Theory of Formal Languages

Lecture 2

UMass Boston Computer Science

Instructor: Stephen Chang

Wednesday, January 24, 2024

Last Time

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Analogy:

Programming Language

⇔

Computation Model

(system of definitions and rules)

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"Theory" + "Formal" = math
(This is a math course!)

(But programming is math too!)

Analogy:

Programming Language

⇔

A precisely defined

Computation Model
(system of definitions and rules)

Last Time

Programming = Mathematical logic!

- “logic is the foundation of all computer programming”
  - https://www.technokids.com/blog/programming/its-easy-to-improve-logical-thinking-with-programming/

- “logic is the fundamental key to becoming a good developer”
  - https://www.geeksforgeeks.org/i-cant-use-logic-in-programming-what-should-i-do/

- “Analytical skill and logical reasoning are prerequisites of programming because coding is effectively logical problem solving at its core”
  - https://levelup.gitconnected.com/the-secret-weapon-of-great-software-engineers-22d57f427937

In CS 622 this semester, we will …

1. *Formally* define and study **models of computation**
   - models will be as *simple* as possible (to make them easier to study)

2. Compare & contrast models of computation
   - which "programs" are *included* / *excluded* by a model
   - *Equality* or *overlap* between models?

3. Prove things about the models

You already do “Proof” when Programming

```
def f(x):
    if (x > 0) | (x < 0) | (x == 0):
        return x + 1
    else:
        return 1 / 0
```

Can this function ever throw `ZeroDivisionError`?

How did you figure out the answer?

You did a proof!

(Let’s write it out formally)

How Mathematics (Proofs) Work

More **Theorems**

More **Axioms**

More **Definitions**

Theorem

Theorem

Axioms

Definitions

Mathematician
(or student)

Adding next level is hard …
Preciseness is **important**
(just like in programming)

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

The “Modus Ponens” Inference Rule

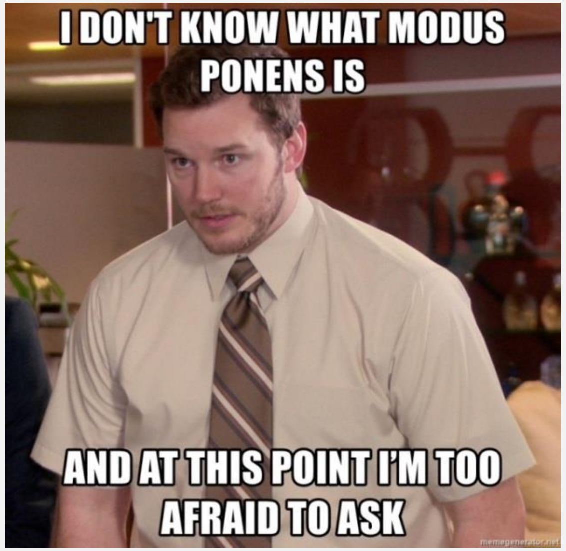
(Precisely Fitting Blocks Together)

Premises (if we can show these statements are true)

- If P then Q
- P is TRUE

Conclusion (then we can say that this is also true)

- Q must also be TRUE



Deductive Proof Example

```
def f(x):      "test expr"
    if (x > 0) | (x < 0) | (x == 0):
        return x + 1 "first branch"
    else:
        return 1 / 0 "second branch"
```

Prove: fn f never throws `ZeroDivisionError`

Statements / Justifications Table

Proof: Prior steps are already-proved, can be used to prove later steps!

Statements	Justifications
1. If running "test expr" is `True`, then "first branch" runs	1. Rules of Python
2. If running "test expr" is `False`, then "second branch" runs	2. Rules of Python
3. running "test expr" is (always) `True`	3. Definition of "numbers"
4. "first branch" (always) runs	4. By steps **1**, **3**, and modus ponens
7. fn f never throws `ZeroDivisionError`	

Modus Ponens

If we can prove these:

- If P then Q
- P

Then we've proved:

- Q

Deductive Proof Example

```
def f(x):
    if (x > 0) | (x < 0) | (x == 0):
        return x + 1“first branch”
    else:
        return 1 / 0“second branch”
```

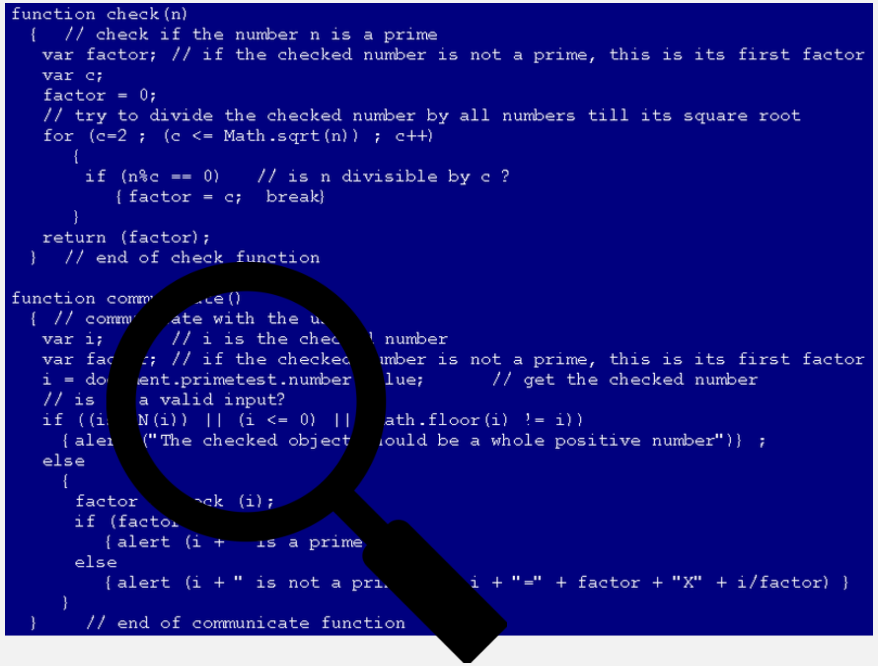
Prove: fn f never throws `ZeroDivisionError`

Statements / Justifications Table

Proof:

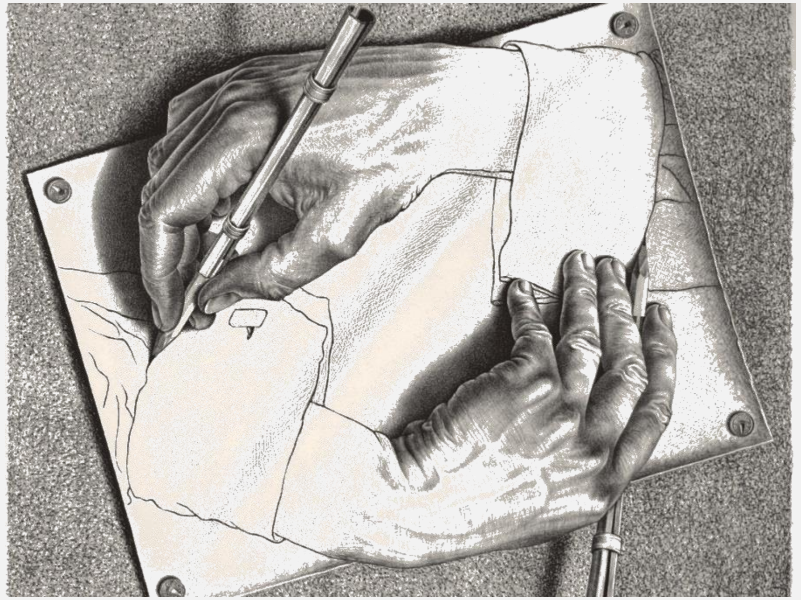
Statements	Justifications
1. If running “test expr” is `True`, then “first branch” runs	1. Rules of Python
2. If running “test expr” is `False`, then “second branch” runs	2. Rules of Python
3. running “test expr” is (always) `True`	3. Definition of “numbers”
4. “first branch” (always) runs	4. By steps **1, 3,** and modus ponens
5. “second branch” *never* runs	5. By steps **1, 2,** and ???
6. fn f never runs `1 / 0`	6. By step **5**
7. fn f never throws `ZeroDivisionError`	7. By step **6** and **???**

What else can we prove about programs?



Predict result without running a program?

<u>Can</u> we make predictions about computation?



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

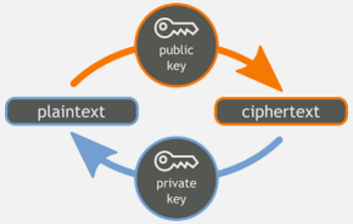
<u>Can</u> we make predictions about computation?

- The **Halting Lemma** says:
- And **Rice's Theorem** says:
  - "all non-trivial, <u>semantic</u> properties of programs are <u>undecidable</u>"

Knowing What Computers Can't Do is Still Useful!

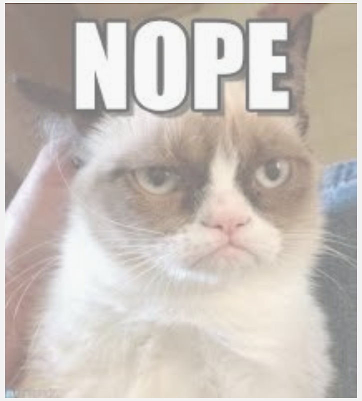
In Cryptography:

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



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 <u>Some</u> 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**

SLAM

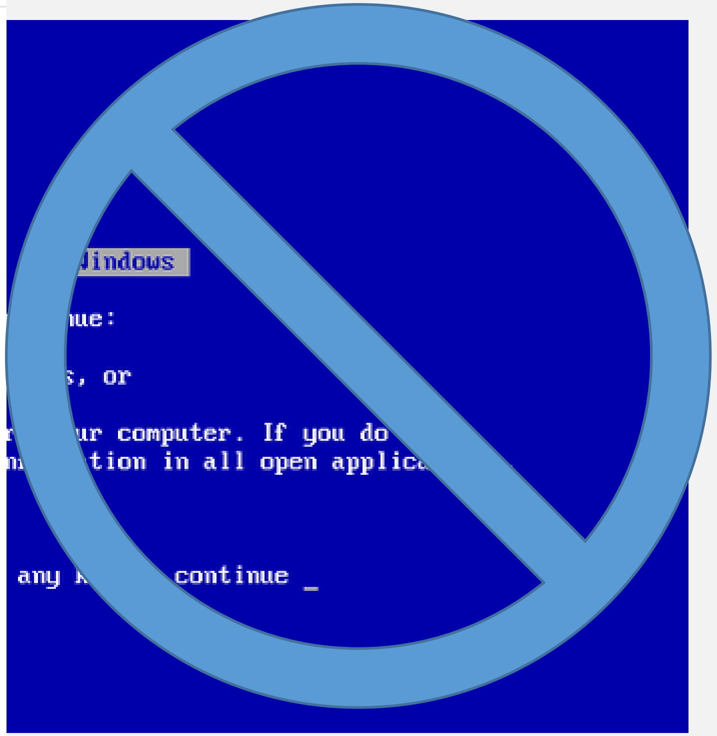
Predicting things about programs … is the Holy grail of CS!

Static Driver Verifier Research Platform README

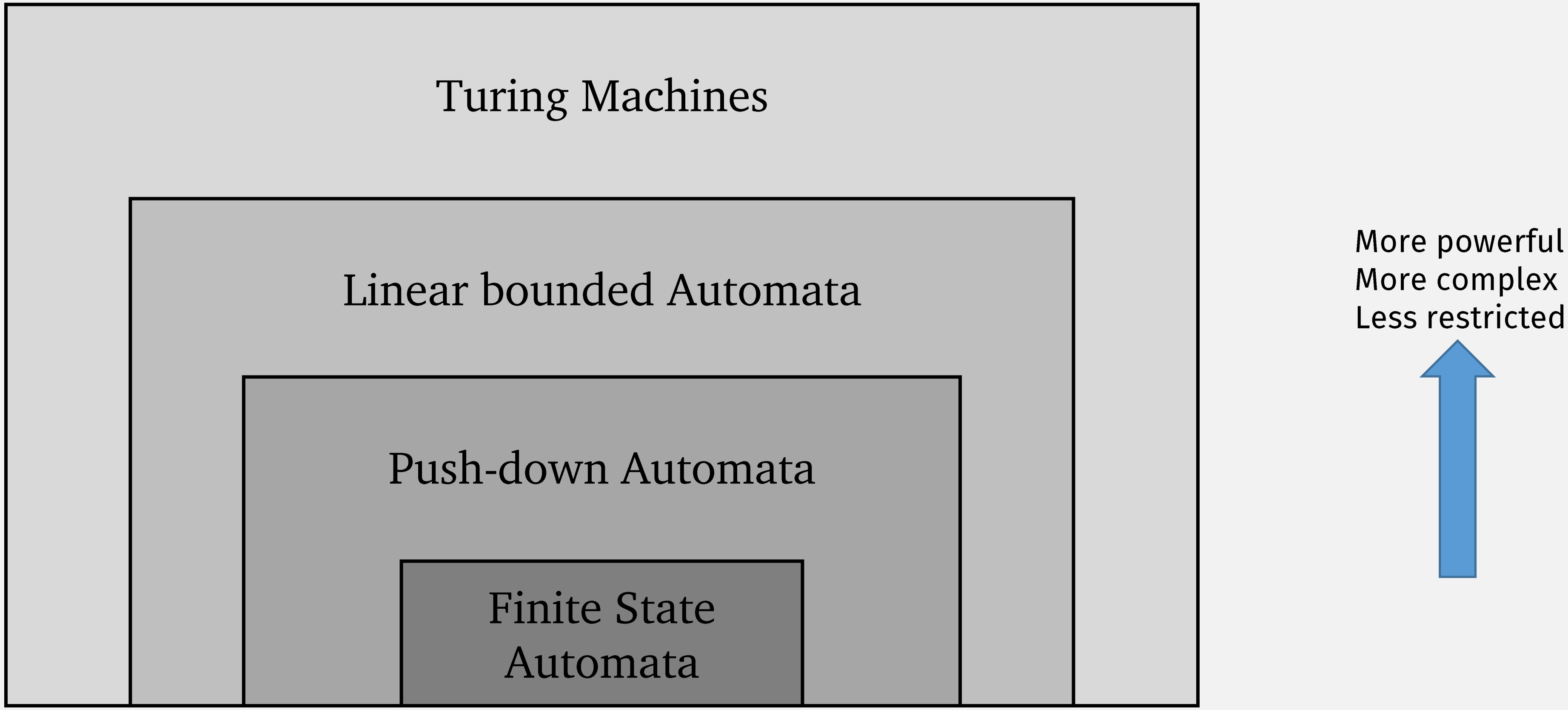
Overview of Static Driver Verifier Research Platform

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.

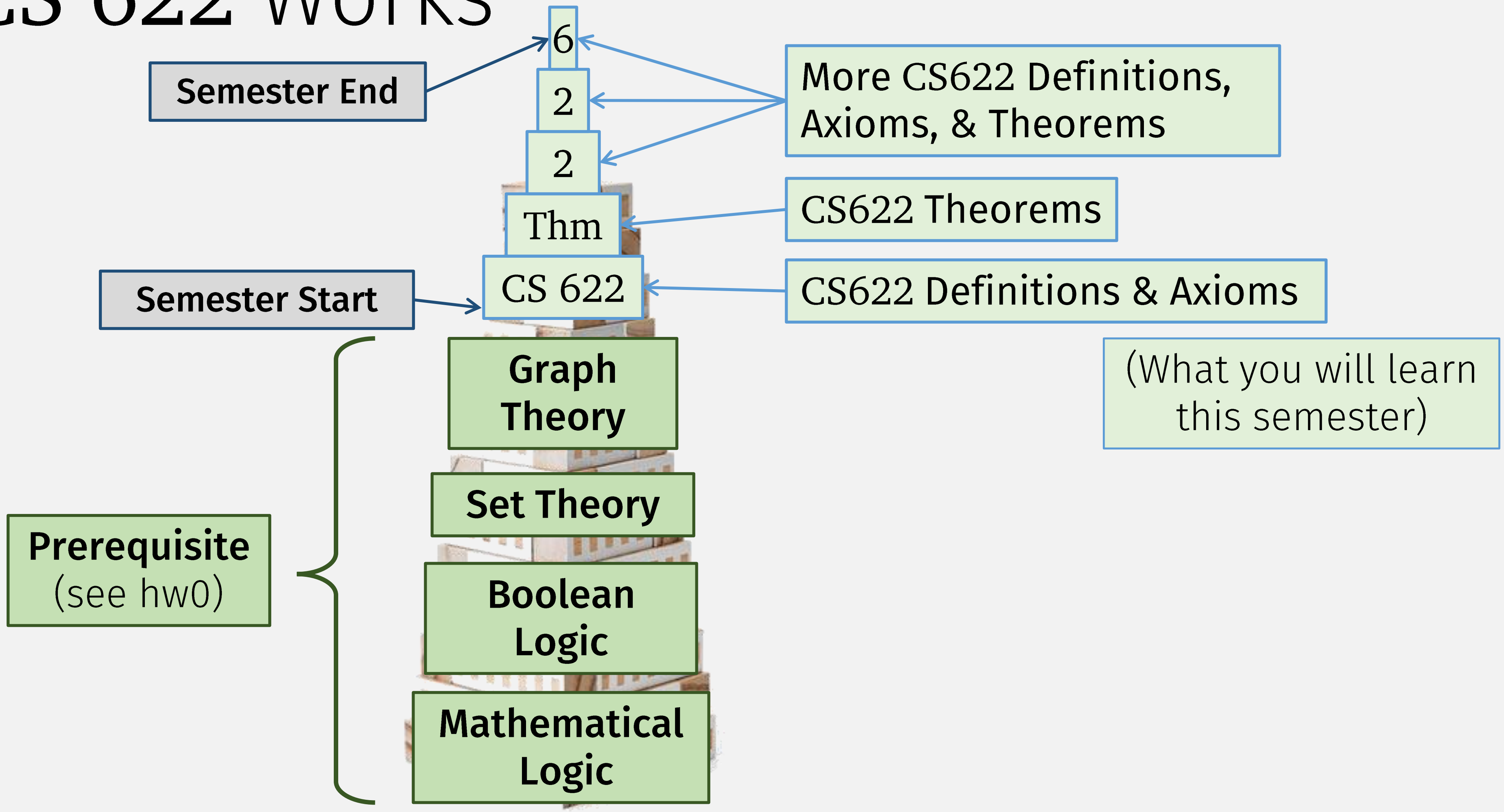


CS 420 Proofs About Computational Models



In this class, **we will prove things about our <u>simple</u> computational models**

How **CS 622** Works



A Word of Advice

To **prove** a (new) **theorem** ...

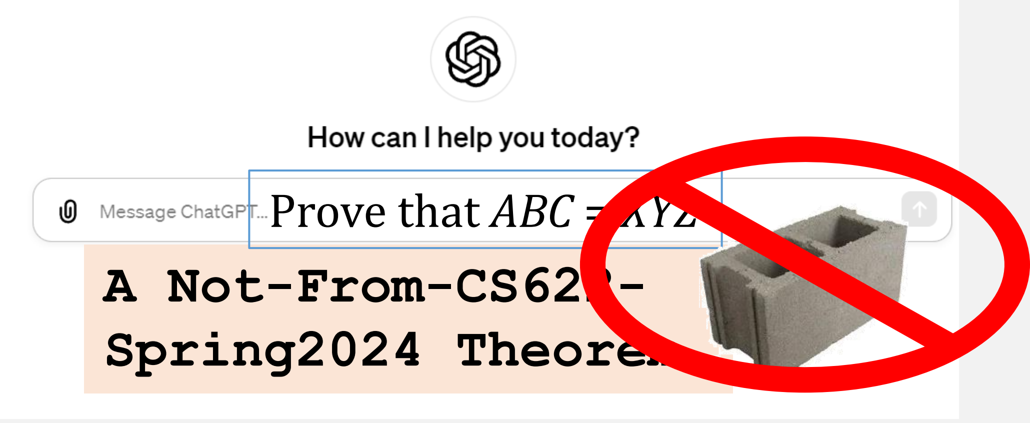
... need to know <u>all</u> **axioms, definitions,** and (previous) **theorems** below it

<u>Important</u>:
Do not fall behind
in this course

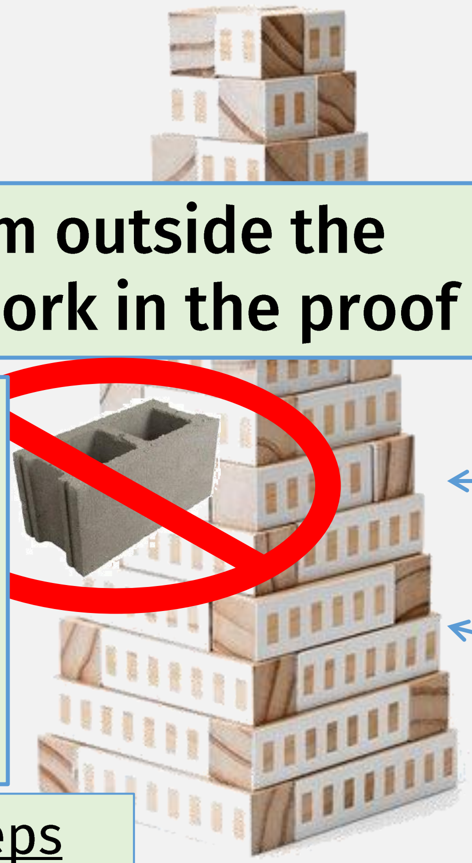
Another Word of Advice

HW 1, Problem 1

Prove that $ABC = XYZ$



“Blocks” from outside the course won’t work in the proof



Remember:
Preciseness in proofs (just like in programming) **is critical**
(Proofs must connect facts from this course exactly)

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

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

HW problems are *graded* on precise steps in the proof, not on the final theorem itself!

Textbooks

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

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

Strongly Recommended (but not required)

- Slides (posted) and lecture should be **self-contained**
- BUT, **Students who do well read the book**

All course info available on web site:
`https://www.cs.umb.edu/~stchang/cs622/s24`

How to Do Well in this Course

- Learn the " building blocks"
  - I.e., **axioms, definitions,** and **theorems**
- To solve a problem (prove a new theorem) …
  … think about how to (precisely) combine existing "blocks"
- HW problems graded on steps to the answer (not final theorem)
- Don't Fall Behind!
  - Start HW Early (HW 0 due Monday 1/22 12pm EST noon)
- Participate and Engage
  - Lecture
  - Office Hours
  - Message Boards (piazza)

Grading

- **HW**: 80%
  - Weekly: In / Out Monday
  - Approx. 12 assignments
  - Lowest grade dropped
- **Participation**: 20%
  - Lecture participation, in-class work, 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 (but must cite)
- Using other resources to learn, e.g., `youtube`, other textbooks, …
- Writing up answers <u>on your own</u>, from scratch, in your own words

Not Allowed

- Submitting someone else's answer
- Submitting someone else's answer with:
  - variables changed,
  - thesaurus words,
  - or sentences rearranged …
- Using sites like Chegg, CourseHero, Bartleby, Study, ChatGPT, etc.
- Using theorems or definitions <u>not from this course</u>

Honesty Policy

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

<u>Regret policy</u>

- If you <u>self-report</u> an honesty violation, you'll only receive a zero on the problem and we move on.

All Up to Date Course Info

Survey, Schedule, Office Hours, HWs, …

See course website:

https://www.cs.umb.edu/~stchang/cs622/s24/

hw0 (pre-req quiz)

(see gradescope)