CS 581: Programming Languages I
Course Introduction

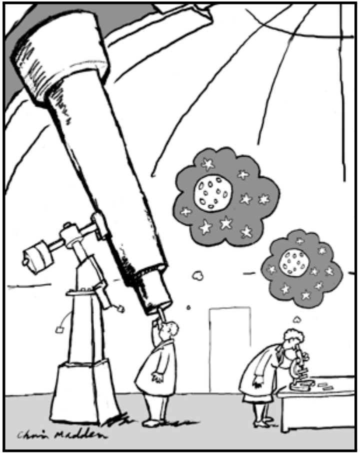
Fall 2020

Q: Why study programming languages?

A: Languages are at the ♡ of computer science!

A: Good programming languages really matter!

What is computer science?

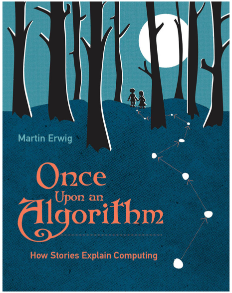


Computer science is no more about computers than astronomy is about telescopes.

—Edsger Dijkstra

Computer Science = the science of **computation**

What is computation?



Computation = systematic transformation of representation

- **Systematic**: according to a fixed plan
- **Transformation**: process that has a changing effect
- **Representation**: abstraction that encodes particular features

Languages play a central role:

- The “fixed plan” is an **algorithm**, which is described in a **language**
- The “representation” is **data**, which is also often described in a **language**

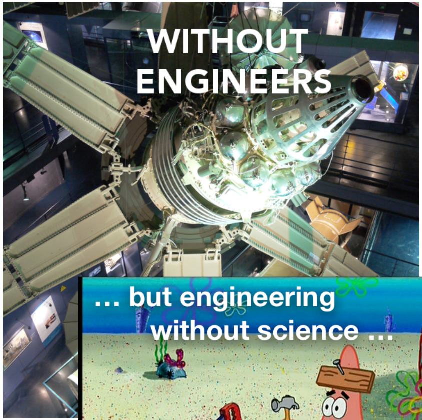
What about software engineering?

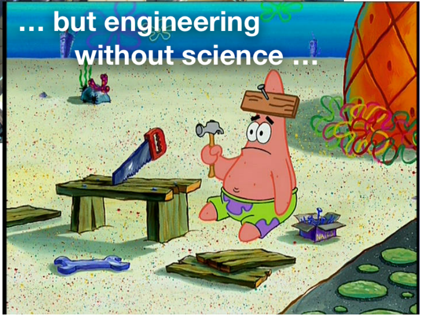
Science vs. Engineering

Science: tries to understand and explain
Engineering: applies science to build stuff

Science	**Engineering**
physics	structural engineering, …
chemistry	chemical engineering, …
"computing"	software engineering, …

Both are part of "computer science"





Central role of PL in CS

PL supports both aspects of CS:

- to understand and explain (science)
  we need **languages** to describe and reason about computations for ourselves

- to build cool stuff (engineering)
  we need **languages** to describe computations for a computer to execute

Outline

Why good languages matter: preventing bugs

Good languages can help **prevent bugs**

- Mars Climate Orbiter failure, 1998
  - caused by mismatched units between ground and spacecraft
  - lost $327.6 million + years of effort
- Heartbleed bug in SSL, 2012–2014
  - caused by missing bounds check
  - huge violations of privacy, including 4.5 million medical records
  - estimated $500 million in damage
- Steam's Linux client deletes root, 2015
  - caused by silent failure of a directory lookup operation
  - offending line commented by "Scary!"... :-/

Why good languages matter: managing complexity

Large-scale software systems are complex!

Good languages can help us **manage this complexity**

- “Structured programming”, 1950–1960s
  - problem: “spaghetti code” caused by GOTOs
  - solution: subroutines, conditionals, loops

- Rust programming language, Mozilla, 2010s
  - problem: managing memory in low-level, concurrent systems code
  - solution: ownership system

Why good languages matter: medium of thought

The languages we use …

- influence our **perceptions**
- guide and support our **reasoning**
- enable and shape our **communication**

- What problems do we see? How do we reason about and discuss them?
- How do we develop, express, and share solutions?

By relieving the brain of all unnecessary work, a good notation sets it free to concentrate on more advanced problems, and in effect increases the mental power of the race.

—Alfred North Whitehead via Kenneth Iverson's ACM Turing Award Lecture, "Notation as a Tool of Thought"

Example: Positional number system

In the 13th century, this is how numbers were represented in Europe:

$$\mathrm{MMCDXXXI} \div \mathrm{XVII} = \,?\quad :\!-\!($$

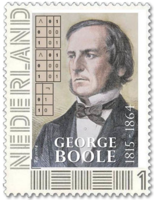
…even basic arithmetic is hard!

$$\begin{array}{r} 143 \\ 17\,\overline{)\,2431} \\ 1700 \\ \hline 731 \\ 680 \\ \hline 51 \\ 51 \\ \hline 0 \end{array}$$

Fibonacci popularized the Hindu-Arabic notation

- didn't just make arithmetic much more convenient …
- completely changed the way people thought about numbers, revolutionizing European mathematics

Example: Symbolic logic



For **over 2000 years** the European study of logic focused on syllogisms

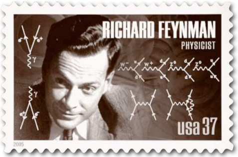
Every philosopher is mortal.
Aristotle is a philosopher.
Therefore, Aristotle is mortal.

Only 256 possible forms … field solved!

A couple of **notational** innovations in the 19th century cracked it wide open

- George Boole – Boolean algebra
- Gottlob Frege – *Beggriffsschrift* (symbolic predicate logic)

Example: Feynman diagrams

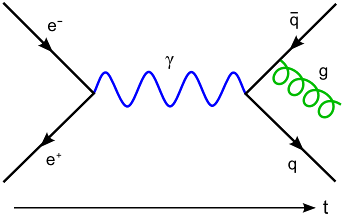


Interactions of subatomic particles lead to brain-melting equations

- reasoning about interactions requires complex math
- high overhead to communicating problems and solutions

Only a handful of people can do this stuff!

In 1948, Richard Feynman introduced a **visual language** for representing interactions

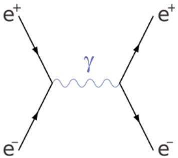


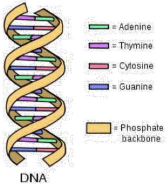
Raises level of abstraction

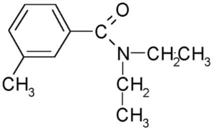
- eliminates *incidental complexity* (math)
- focus on *essential complexity* (interactions)
- supports communication, collaboration (undergrads can do it)

Domain-specific languages

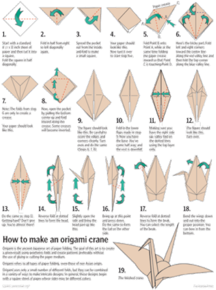
$$F = ma$$
$$E = mc^2$$

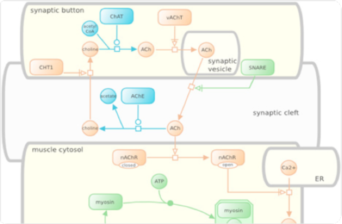


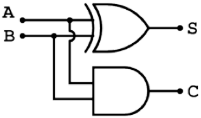


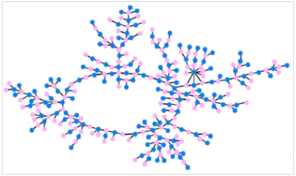


$$2H_2 + O_2 \rightarrow 2H_2O$$









Outline

One idea: just try out a bunch of languages

Not this course!

Our focus: programming language concepts and theory

Focus on how to **define** programming languages

For several toy languages, we will:

- define the **structure** of its programs
- define the **meaning** of its programs
- identify the **features** that are common to many languages

Role of metalanguages

Metalanguage: a language to define the structure and meaning of another language!

In this course:

- grammars
- mathematics
- inference rules
- Haskell
- English

Summary of our strategy

Focus mostly on programming language **concepts**

1. define **abstract syntax** of languages
2. define **semantics** of languages
3. compare different **language features**
4. in-depth study of **lambda calculus**

We use **metalanguages** for examining these concepts

1. formal definitions using **grammars**, **mathematics**, and **inference rules**
2. interpreters in **Haskell**

Outline

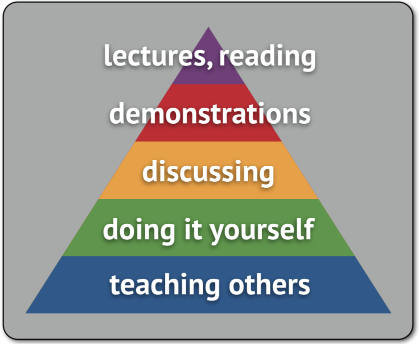
Why study programming languages?

- Languages are at the heart of computer science
- Good languages really matter

How to study programming languages

Course logistics

Learning strategy



"Learning pyramid"

In class

- lectures
- demonstrations / live coding
- in-class exercises

Outside of class

- outside reading
- study for quizzes, exams
- homework
- peer-feedback/discussion of homework