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
- physics
- chemistry
- “computing”

Engineering
- structural engineering, …
- chemical engineering, …
- 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
Why study programming languages?
Languages are at the heart of computer science
Good languages really matter

How to study programming languages

Course logistics
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:

$$\text{MMCDXXXI} \div \text{XVII} = ?$$

…even basic arithmetic is hard!

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

\[
\begin{array}{c}
143 \\
17 \overline{2431} \\
\hline
1700 \\
\hline
731 \\
\hline
680 \\
\hline
51 \\
\hline
\end{array}
\]
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

\[ F = ma \]
\[ E = mc^2 \]

Why study programming languages?
Outline

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Course logistics
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

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Course logistics
Learning strategy

In class

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

Outside of class

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

“Learning pyramid”