

Foundations of Software

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Slides in part adapted from:

University of Pennsylvania CIS 500: Software Foundations - Fall 2006
by Benjamin Pierce

Course Overview

Staff

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What is “software foundations”?

Software foundations (or “theory of programming languages”) is the mathematical study of the [meaning](#) of programs.

The goal is finding ways to describe program behaviors that are both [precise](#) and [abstract](#).

- ▶ [precise](#) so that we can use mathematical tools to formalize and check interesting properties
- ▶ [abstract](#) so that properties of interest can be discussed clearly, without getting bogged down in low-level details

Why study software foundations?

- ▶ To prove specific properties of particular programs (i.e., program verification)
 - ▷ Important in some domains (safety-critical systems, hardware design, security protocols, inner loops of key algorithms, ...), but still quite difficult and expensive
- ▶ To develop intuitions for *informal* reasoning about programs
- ▶ To prove general facts about all the programs in a given programming language (e.g., safety or isolation properties)
- ▶ To understand language features (and their interactions) deeply and develop principles for better language design
(PL is the "materials science" of computer science...)

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What you can expect to get out of the course

- ▶ A more sophisticated perspective on programs, programming languages, and the activity of programming
 - ▷ See programs and whole languages as formal, mathematical objects
 - ▷ Make and prove rigorous claims about them
 - ▷ Detailed knowledge of a variety of core language features
- ▶ Deep intuitions about key language properties such as type safety
- ▶ Powerful tools for language design, description, and analysis

Most software designers are language designers!

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Greenspun's Tenth Rule Of Programming

Any sufficiently complicated C or Fortran program contains an ad-hoc, informally-specified, bug-ridden, slow implementation of half of Common Lisp.

– Philip Greenspun

What this course is not

- ▶ An introduction to programming
- ▶ A course on functional programming (though we'll be doing some functional programming along the way)
- ▶ A course on compilers (you should already have basic concepts such as lexical analysis, parsing, abstract syntax, and scope under your belt)
- ▶ A comparative survey of many different programming languages and styles

Approaches to Program Meaning

Quesdiscussion: How can we precisely model and study the semantics of computer programs?

Approaches to Program Meaning

Question: What systems have you heard of or studied that study the semantics of programs?

Approaches to Program Meaning

- ▶ **Denotational semantics** and **domain theory** view programs as simple mathematical objects, abstracting away their flow of control and concentrating on their input-output behavior.
- ▶ **Program logics** such as **Hoare logic** and **dependent type theories** focus on logical rules for reasoning about programs.
- ▶ **Operational semantics** describes program behaviors by means of abstract machines. This approach is somewhat lower-level than the others, but is extremely flexible.
- ▶ **Process calculi** focus on the communication and synchronization behaviors of complex concurrent systems.
- ▶ **Type systems** describe approximations of program behaviors, concentrating on the shapes of the values passed between different parts of the program.

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Overview

This course will concentrate on operational techniques and type systems.

- ▶ **Part I: Modeling programming languages**
 - ▷ Abstract syntax
 - ▷ Operational semantics
 - ▷ Inductive proof techniques
 - ▷ The lambda-calculus
 - ▷ Syntactic sugar; fully abstract translations
- ▶ **Part II: Type systems**
 - ▷ Simple types
 - ▷ Type safety
 - ▷ References
 - ▷ Subtyping

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Overview

- ▶ Part III: Object-oriented features (case study)
 - ▷ A simple imperative object model
 - ▷ An analysis of core Java
 - ▷ An analysis of core Scala.js IR

Organization of the Course

Information

Textbook: Types and Programming Languages,
Benjamin C. Pierce, MIT Press, 2002

Webpage: <https://fos-2023.github.io>
Q&A Ed Discussions via Moodle

The electronic version of the book is available for free in the EPFL digital library.

Elements of the Course

- ▶ The Foundations of Software course consists of
 - ▷ book reading
 - ▷ lectures (Tue 14:15-16:00, INF 1)
 - ▷ exercises and project work (Wed 11:15-13:00, INJ 218)
- ▶ The lectures will build on [required reading](#) from the textbook.
- ▶ The course website lists what sections of the book must be read before each lecture.

Homework and Projects

You will be asked to

- ▶ solve and hand in some written exercise sheets,
- ▶ do a number of programming assignments, including
 - ▷ interpreters and reduction engines,
 - ▷ type checkers, and
 - ▷ small illustration programsfor a variety of small languages.
- ▶ The implementation language for these assignments is [Scala](#).

Scala

- ▶ Scala is a functional and object-oriented language that is closely interoperable with Java.
- ▶ It is very well suited as an implementation language for type-checkers, in particular because it supports:
 - ▷ pattern matching,
 - ▷ higher-order functions.

Learning Scala

If you don't know Scala yet, there's help:

- ▶ The Scala web site:
www.scala-lang.org
- ▶ On this site, the documents:
 - ▷ *A Brief Scala Tutorial - an introduction to Scala for Java programmers.* (short and basic).
 - ▷ *An Introduction to Scala* (longer and more comprehensive).
 - ▷ *An Overview of the Scala Programming Language* (high-level).
 - ▷ *Scala By Example* (long, comprehensive, tutorial style).
- ▶ The assistants.

Grading and Exams

Final course grades will be computed as follows:

- ▶ Homework: 20%
- ▶ Projects: 20%
- ▶ Final exam: 60%

Collaboration

- ▶ Collaboration on homework and projects is [strongly encouraged](#).
- ▶ Studying with other people is the best way to internalize the material
- ▶ Groups of 2 or 3 students.

"You never really misunderstand something
until you try to teach it...
" – Anon.

Plagiarism

- ▶ A single group will of course share code.
- ▶ But plagiarizing [code](#) by [other groups](#) as part of a project is unethical and will not be tolerated, whatever the source.