編程語言的設計原理
Design Principles of Programming Languages

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胡振江、赵海燕、熊英飞

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Self-Introduction
Zhenjiang Hu

Professor and Chair
Department of Computer Science and Technology
Peking University

Professor (by special appointment)
Programming Research Laboratory
National Institute of Informatics (NII)

I just joined Peking University as a professor and the chair of Department of Computer Science and Technology in 2019. In the transition period, I am also a professor by special appointment in Information Systems Architecture Research Division of NII, and a visiting professor in Department of Informatics of SOKENDAI. I received BS and MS degrees from Department of Computer Science and Engineering of Shanghai Jiaotong University in 1988 and 1991 respectively, and PhD degree from Department of Information Engineering of University of Tokyo in 1996. I became a lecturer (assistant professor) in 1997 and an associate professor in 2000 in University of Tokyo. I joined National Institute of Informatics as a full professor in 2008. I was a full professor in Department of Communication and Information Engineering of University of Tokyo for the period of 2018-2019.

I am Fellow of JFES (Japan Federation of Engineering Society, 2016), ACM Distinguished Scientist (2016), Member of Academy of Europe (2019) and Fellow of IEEE (2020).

http://sei.pku.edu.cn/~hu/
About Me

• 1988: BS, Computer Science, Shanghai Jiaotong Univ.
• 1991: MS, Computer Science, Shanghai Jiaotong Univ.
• 1996: PhD, Information Engineering, Univ. of Tokyo
• 1996: Assistant Professor, Univ. of Tokyo
• 1997: Lecturer, Univ. of Tokyo
• 2000: Associate Professor, Univ. of Tokyo
• 2008: Full Professor, National Institute of Informatics
• 2018: Full Professor, NII/University of Tokyo
• 2019: Full Professor, Peking University

Fellow of JFES, Member of Academy of Europe
Fellow of IEEE, ACM Distinguished Scientist
Research Interest

• **Functional Programming**
  – Calculating Efficient Functional Programs
  – ACM ICFP 2011 General Co-Chair
  – ACM ICFP Steering Committee Co-Chair (2012-2013)
  – AMC Haskell Symposium Steering Committee Member (2014-)

• **Algorithmic Languages and Calculi**
  – Parallel programming and Automatic Parallelization
  – IFIP WG 2.1 Member (IFIP TC 2, Japan Representative)

• **Bidirectional Transformation Languages in SE**
  – Bidirectional languages for software evolution
  – Steering Committee Member of BX, ICMT
About Prof. Zhao

• 2003  : PhD, Univ. of Tokyo
• 2003 - : Associate Professor, Peking Univ.

• Research Interest
  – Software engineering
  – Requirements Engineering, Requirements reuse in particular
  – Model transformations
  – Programming Languages

• Contact:
  – Office:   Rm. 1809, Science Blg #1
  – Email : zhhy@sei.pku.edu.cn
  – Phone : 62757670
About Prof. Xiong

- 2009: PhD, Univ. of Tokyo
- 2009-2011: Postdoc, Univ. of Waterloo
- 2012: Assistant Professor, Peking Univ.
- 2018: Associate Professor, Peking Univ.

Research Interest
- Program Analysis
- Program Repair
- Program Synthesis

Contact:
- 理科一号楼1431房间
- Mail：xiongyf@pku.edu.cn
- Tel：62757008
Course Overview
Designing Programming Languages is an Art

• Art vs. Knowledge
  – Art cannot be taught, while knowledge can
  – What in general people have invented
  – How to reason their properties formally

• Why formal reasoning important
  – Poorly designed languages widely used
    • Java array flaw
    • PHP, Javascript, etc.
  – Well designed language needs strictly reasoning
    • A small set of general, consistent principles
    • Devils in details

The three worst programming languages:
https://medium.com/smalltalk-talk/the-three-worst-programming-languages-b1ec25a232c1#.jdsfib20v
What is this course about?

• Study fundamental (formal) approaches to describing 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
What you can get out of this course?

• A more sophisticated perspective on programs, programming languages, and the activity of programming
  – How to view programs and whole languages as formal, mathematical objects
  – How to make and prove rigorous claims about them
  – Detailed study of a range of basic language features

• Powerful tools/techniques for language design, description, and analysis
This course is not about …

• An introduction to programming
• A course on compiler
• A course on functional programming
• A course on language paradigms/styles

All the above are certainly helpful for your deep understanding of this course.
What background is required?

• Basic knowledge on
  – Discrete mathematics: sets, functions, relations, orders
  – Algorithms: list, tree, graph, stack, queue, heap
  – Elementary logics: propositional logic, first-order logic

• Familiar with a programming language and basic knowledge of compiler construction
Textbook

- **Types and Programming Languages**
- 作者: Benjamin Pierce
- 出版社: The MIT Press
- 出版年: 2002-02-01
- 页数: 648
- 定价: USD 72.00
- 装帧: Hardcover
- ISBN: 9780262162098
Grading

- Activity in class / Mid-Term Test: 20%
- Homework: 40%
- Final (Report/Presentation): 40%

Design a programming language with a type system that addresses real-world issues and provides basic implementations.

- Design a programming language without deadlocks.
- Design a type system with embedded complexity, ensuring that the complexity of the written programs does not exceed the indicated complexity.
- Design a type system ensuring that sensitive information is never leaked.
- Design a type system ensuring that parallel programs do not have race problems.
- Design a type system ensuring that all floating-point calculations meet a certain precision requirement.
- Design a differential programming language ensuring that the written expressions are differentiable.
- Design a probability programming language, write probability models and derive them.
- Solve specific problems in your research area.
近年部分选题举例

• 扬子毅：高阶逻辑编程语言
  – 将高阶逻辑引入Prolog

• 李博：绘图编程语言
  – 用于生命科学领域，根据一些递归规则绘制复杂图形的语言

• 张宇博 吴瑾昭 许涵：类型安全的Latex
  – Latex的宏不是类型安全的，设计了一个新版宏，可以编译成普通Latex

• 张煜皓，陈牧歌，赵子健：描述PS修图的编程语言
  – 修图的时候常常需要根据一些简单条件进行大量重复，设计编程语言来自动化这个过程

• 谢睿峰 董子宁：可验证的函数式程序设计语言
  – 在Lambda Calculus上加入前后条件，同时在编译时调用SMT Solver来证明性质成立
How to study this course?

- **Before class**: scanning through the chapters to learn and gain feeling about what will be studied

- **In class**: trying your best to understand the contents and speaking out when you have questions

- **After class**: doing exercises seriously

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>★</td>
<td>Quick check</td>
<td>30 seconds to 5 minutes</td>
</tr>
<tr>
<td>★★</td>
<td>Easy</td>
<td>≤ 1 hour</td>
</tr>
<tr>
<td>★★★</td>
<td>Moderate</td>
<td>≤ 3 hours</td>
</tr>
<tr>
<td>★★★★</td>
<td>Challenging</td>
<td>&gt; 3 hours</td>
</tr>
</tbody>
</table>
Personnel

• Instructors
  – Zhenjiang Hu, Professor, NII/PKU
    zhenjianghu@pku.edu.cn
  – Haiyan Zhao, Associate Professor, PKU
    zhhy@sei.pku.edu.cn
  – Yingfei Xiong, Assistant Professor, PKU
    xiongyf@pku.edu.cn

• Teaching Assistant:
  – 张云帆, zyf0726@pku.edu.cn
Information

• Course website:

http://sei.pku.edu.cn/~xiongyf04/DPPL/main.htm

  – Syllabus
  – News/Announcements
  – Lecture Notes (slides)
  – Other useful resources
北京大学最好的计算机类课程有哪些？

北京大学

吴争铭，但是鸽子为什么这么大呢？
王迪，陈牧歌等18人赞同

推荐语言的设计原理

利益相关：熊英飞是我的本科导师

这门课程的教材是TAPL，Types and Programming Languages。书很经典，讲的也比较深，我看了一些其他的用这本书的学校稍微讲讲recursive typing后面的一些拓展都不讲。
三位老师本身就是PL方面的学者，讲课讲的也不错，而且前期还会让同学们现场写代码，不管是有无志于进行PL研究，还是想加深对于编程语言的认识的同学都有帮助。
缺点是后面内容有点赶，而且我认为这门课最好还是有个formal的exam比较好。

另外熊老师的软件分析技术，软件分析技术，我看过不少课程，但不是很好，我自己没上过。
熊英飞
Chapter 1: Introduction

What is a type system?
What type systems are good for?
Type Systems and Programming Languages
What is a type system (type theory)?

- A type system is a tractable syntactic method for proving the absence of certain (bad) program behaviors by classifying phrases according to the kinds of values they compute.

  - Tools for program reasoning
  - Fully automatic (and efficient)
  - Classification of terms
  - Static approximation
  - Proving the absence rather than presence
What is a type system (type theory)?

• A **type system** is a tractable syntactic method for proving the absence of certain (bad) program behaviors by **classifying** phrases according to the kinds of values they compute.

  – Tools for program reasoning
  – Fully automatic (and efficient)
  – Classification of terms
  – Static approximation
  – Proving the absence rather than presence

**Tractable**: be finished in short time, often polynomial  
**Syntactic**: be part of the programming language
What is a type system (type theory)?

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  - Tools for program reasoning
  - Fully automatic (and efficient)
  - Classification of terms
  - Static approximation
  - Proving the absence rather than presence

True, false    Boolean
1, 2, 3, …    Int
‘a’, ‘b’, ‘c’, …    Char
What is a type system (type theory)?

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  - Classification of terms
  - Static approximation
  - Proving the absence rather than presence

Given a property that correct programs should satisfy, does this program satisfy it?

- Based on Rice’s theorem, we cannot precisely answer the question on any non-trivial property

- Approximation method 1 (type checking): only determine the program definitely satisfies a property

- Approximation method 2 (testing): only determine the program definitely violates a property

Can you give a correct program that cannot type-check?

- Static approximation
- Proving the absence rather than presence
What are type systems good for?

• Detecting Errors
  – Many programming errors can be detected early, fixed intermediately and easily.

• Abstraction
  – Type systems form the backbone of the module languages: an interface itself can be viewed as “the type of a module.”

• Documentation
  – The type declarations in procedure headers and module interfaces constitute a form of (checkable) documentation.

• Language Safety
  – A safe language is one that protects its own abstractions.

• Efficiency
  – Removal of dynamic checking; smart code-generation
Type Systems and Languages Design

• Language design should go hand-in-hand with type system design.

  – Languages without type systems tend to offer features that make typechecking difficult or infeasible.

  – Concrete syntax of typed languages tends to be more complicated than that of untyped languages, since type annotations must be taken into account.

In typed languages the type system itself is often taken as the foundation of the design and the organizing principle in light of which every other aspect of the design is considered.
Homework

• Read Chapters 1 and 2.

• Install OCaml and read “Basics”