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Practical Foundations for Programming Languages

Types are the central organizing principle of the theory of programming languages. In this innovative book, Professor Robert Harper offers a fresh perspective on the fundamentals of these languages through the use of type theory. Whereas most textbooks on the subject emphasize taxonomy, Harper instead emphasizes genetics, examining the building blocks from which all programming languages are constructed.

Language features are manifestations of type structure. The syntax of a language is governed by the constructs that define its types, and its semantics is determined by the interactions among those constructs. The soundness of a language design – the absence of ill-defined programs – follows naturally.

Professor Harper's presentation is simultaneously rigorous and intuitive, relying on only elementary mathematics. The framework he outlines scales easily to a rich variety of language concepts and is directly applicable to their implementation. The result is a lucid introduction to programming theory that is both accessible and practical.

Robert Harper has been a member of the faculty of Computer Science at Carnegie Mellon University since 1988. His main research interest is in the application of type theory to the design and implementation of programming languages and to the development of systems for mechanization of mathematics. Professor Harper is a recipient of the Allen Newell Medal for Research Excellence and the Herbert A. Simon Award for Teaching Excellence at Carnegie Mellon, and he is a Fellow of the Association for Computing Machinery.

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Part IV Finite Data Types

Part V Infinite Data Types

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Part XIX Appendix

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Preface

Types are the central organizing principle of the theory of programming languages. Language features are manifestations of type structure. The syntax of a language is governed by the constructs that define its types, and its semantics is determined by the interactions among those constructs. The soundness of a language design – the absence of ill-defined programs – follows naturally.

The purpose of this book is to explain this remark. A variety of programming language features are analyzed in the unifying framework of type theory. A language feature is defined by its *statics*, the rules governing the use of the feature in a program, and its *dynamics*, the rules defining how programs using this feature are to be executed. The concept of *safety* emerges as the coherence of the statics and the dynamics of a language.

In this way we establish a foundation for the study of programming languages. But why these particular methods? The main justification is provided by the book itself. The methods we use are both *precise* and *intuitive*, providing a uniform framework for explaining programming language concepts. Importantly, these methods *scale* to a wide range of programming language concepts, supporting rigorous analysis of their properties. Although it would require another book in itself to justify this assertion, these methods are also *practical* in that they are *directly applicable* to implementation and *uniquely effective* as a basis for mechanized reasoning. No other framework offers as much.

Being a consolidation and distillation of decades of research, this book does not provide an exhaustive account of the history of the ideas that inform it. Suffice it to say that much of the development is not original, but rather is largely a reformulation of what has gone before. The notes at the end of each chapter signpost the major developments but are not intended as a complete guide to the literature. For further information and alternative perspectives, the reader is referred to such excellent sources as Constable (1986, 1998), Girard (1989), Martin-Löf (1984), Mitchell (1996), Pierce (2002, 2004), and Reynolds (1998).

The book is divided into parts that are, in the main, independent of one another. Parts I and II, however, provide the foundation for the rest of the book and must therefore be considered prior to all other parts. On first reading it may be best to skim Part I and begin in earnest with Part II, returning to Part I for clarification of the logical framework in which the rest of the book is cast.

Numerous people have read and commented on earlier editions of this book and have suggested corrections and improvements to it. I am particularly grateful to Andrew Appel, Iliano Cervesato, Lin Chase, Derek Dreyer, Zhong Shao, and Todd Wilson for their extensive efforts in reading and criticizing the book. I also thank the following people for their suggestions: Arbob Ahmad, Zena Ariola, Eric Bergstrome, Guy Blelloch, William Byrd,

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Luis Caires, Luca Cardelli, Manuel Chakravarty, Richard C. Cobbe, Karl Crary, Yi Dai, Daniel Dantas, Anupam Datta, Jake Donham, Favonia, Matthias Felleisen, Kathleen Fisher, Dan Friedman, Peter Gammie, Maia Ginsburg, Byron Hawkins, Kevin Hely, Justin Hsu, Cao Jing, Salil Joshi, Gabriele Keller, Scott Kilpatrick, Danielle Kramer, Akiva Leffert, Ruy Ley-Wild, Dan Licata, Karen Liu, Dave MacQueen, Chris Martens, Greg Morrisett, Tom Murphy, Aleksandar Nanevski, Georg Neis, David Neville, Doug Perkins, Frank Pfenning, Jean Pichon, Benjamin Pierce, Andrew M. Pitts, Gordon Plotkin, David Renshaw, John Reynolds, Carter Schonwald, Dale Schumacher, Dana Scott, Robert Simmons, Pawel Sobocinski, Daniel Spoonhower, Paulo Tanimoto, Peter Thiemann, Bernardo Toninho, Michael Tschantz, Kami Vaniea, Carsten Varming, David Walker, Dan Wang, Jack Wileden, Roger Wolff, Omer Zach, Luke Zarko, and Yu Zhang. I am grateful to the students of 15–312 and 15–814 at Carnegie Mellon, who have provided the impetus for the preparation of this book and who have endured the many revisions to it over the last ten years.

I thank the Max Planck Institute for Software Systems in Germany for its hospitality and support. I also thank Espresso a Mano in Pittsburgh, CB2 Cafe in Cambridge, and Thonet Cafe in Saarbrücken for providing a steady supply of coffee and a conducive atmosphere for writing.

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Robert Harper
Pittsburgh
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