

Contents

List of Figures xi

Preface xv

I Type Problems in Object-Oriented Languages 1

1 Introduction 3

- 1.1 Type systems in programming languages 4
- 1.2 Type checking and strongly typed languages 6
- 1.3 Focus on statically typed class-based languages 12
- 1.4 Foundations: A look ahead 13

2 Fundamental Concepts of Object-Oriented Languages 17

- 2.1 Objects, classes, and object types 17
- 2.2 Subclasses and inheritance 22
- 2.3 Subtypes 24
- 2.4 Covariant and contravariant changes in types 26
- 2.5 Overloading versus overriding methods 27
- 2.6 Summary 32

3 Type Problems in Object-Oriented Languages 33

- 3.1 Type checking object-oriented languages is difficult 33
- 3.2 Simple type systems are lacking in flexibility 35
- 3.3 Summary of typing problems 48

4 Adding Expressiveness to Object-Oriented Languages 49

4.1	GJ	49	
4.2	Even more flexible typing with Eiffel	60	
4.3	Summary	69	
5	<i>Understanding Subtypes</i>	71	
5.1	Subtyping for non-object types	72	
5.2	Object types	83	
5.3	Subtyping for class types	84	
5.4	Summary	86	
6	<i>Type Restrictions on Subclasses</i>	89	
6.1	Allowable changes to method types	89	
6.2	Instance variable types invariant in subclasses	91	
6.3	Changing visibility	92	
6.4	Summary	93	
7	<i>Varieties of Object-Oriented Programming Languages</i>	95	
7.1	Multi-methods vs. object-based vs. class-based languages	95	
7.2	Well-known object-oriented languages	103	
7.3	Summary	111	
	<i>Historical Notes and References for Section I</i>	113	
II Foundations:			
The Lambda Calculus 117			
8	<i>Formal Language Descriptions and the Lambda Calculus</i>	119	
8.1	The simply-typed lambda calculus	120	
8.2	Adding pairs, sums, records, and references	132	
8.3	Summary	140	
9	<i>The Polymorphic Lambda Calculus</i>	141	
9.1	Parameterized types and polymorphism	141	
9.2	Recursive expressions and types	147	
9.3	Information hiding and existential types	151	
9.4	Adding subtypes to the polymorphic lambda calculus	156	
9.5	Summary	165	
	<i>Historical Notes and References for Section II</i>	167	

III Formal Descriptions of Object-Oriented Languages	171
10 <i>SOOL, a Simple Object-Oriented Language</i>	173
10.1 Informal description and example	173
10.2 Syntax and type-checking rules	176
10.3 Summary	200
11 <i>A Simple Translational Semantics of Objects and Classes</i>	201
11.1 Representing objects at runtime	201
11.2 Modeling <i>SOOL</i> types in $\Lambda_{<}^P$	203
11.3 Modeling <i>SOOL</i> expressions in $\Lambda_{<}^P$	207
11.4 Modeling classes — first try	212
11.5 Problems with modeling subclasses	218
11.6 Summary	223
12 <i>Improved Semantics for Classes</i>	225
12.1 (Re-)Defining classes	225
12.2 A correct subclass encoding	232
12.3 Summary and a look ahead	233
13 <i>SOOL's Type System Is Safe (and Sound)</i>	239
13.1 The translation of <i>SOOL</i> to $\Lambda_{<}^P$ is sound	239
13.2 The translation is well defined	255
13.3 <i>SOOL</i> is type safe	258
13.4 Errors	260
13.5 Summary	262
14 <i>Completing SOOL: super, nil, Information Hiding, and Multiple Inheritance</i>	263
14.1 Using methods from superclasses	263
14.2 Translating <code>nil</code>	266
14.3 A complication with <code>self</code>	271
14.4 Finer control over information hiding	272
14.5 Multiple inheritance	275
14.6 Summary	279
<i>Historical Notes and References for Section III</i>	283

IV Extending Simple Object-Oriented Languages	289
15 Adding Bounded Polymorphism to <i>SOOL</i>	291
15.1 Introducing <i>PSOOL</i>	291
15.2 Translational semantics of <i>PSOOL</i>	296
15.3 Summary	297
16 Adding <i>MyType</i> to Object-Oriented Programming Languages	299
16.1 Typing <code>self</code> with <i>MyType</i>	300
16.2 <i>MOOL</i> : Adding <i>MyType</i> to <i>SOOL</i>	309
16.3 Translational semantics of <i>MOOL</i>	319
16.4 Soundness of translation for <i>MOOL</i>	322
16.5 Summary	330
17 Match-Bounded Polymorphism	331
17.1 Benefits of match-bounded polymorphism	331
17.2 Introducing <i>PMOOL</i>	333
17.3 Examples and comparison with F-bounded polymorphism	334
17.4 Translational semantics of <i>PMOOL</i>	335
17.5 Soundness of the translation of <i>PMOOL</i>	342
17.6 Summary	347
18 Simplifying: Dropping Subtyping for Matching	349
18.1 Can we drop subtyping?	349
18.2 Introducing hash types	352
18.3 Type-checking rules	356
18.4 An informal semantics of hash types	360
18.5 Summary	361
Historical Notes and References for Section IV	363
Bibliography	367
Index	379