

Contents

I Introduction	1
1 Context and Motivation	3
2 Targeted Services	9
3 Design Goals	13
4 Solution Concept	17
5 Structure of this Thesis	21
II Foundations	23
6 The Clojure Programming Language	27
6.1 Evaluation Cycle	28
6.2 Syntax	29
6.3 Basic Types	29
6.4 Collection Types	30
6.5 Special Forms	33
6.6 Abstractions	39
6.7 Destructuring	48
6.8 Higher-Order Functions	50
6.9 Metadata	53
6.10 Namespaces	55
6.11 Java Interop	57
6.12 Macros	60
6.13 Utility macros	64
6.14 Protocols	66
7 Modeling Frameworks	69
7.1 JGraLab	69
7.2 The Eclipse Modeling Framework	73
III The FunnyQT Approach	79
8 On Genericity	83
8.1 Viable Options for Genericity	83

8.2	Protocol-Based Genericity for Model Querying and Transformation	88
9	Terminology and Conventions	91
10	The FunnyQT Architecture	95
11	Related Work	99
IV	On Model Management and Querying	103
12	Generic Model Management and Querying	107
12.1	Creating and Deleting Elements and Relationships	107
12.2	Iterating Elements and Relationships	109
12.3	Attribute Value Access	111
12.4	Role Name Navigation	112
12.5	Type Checks	113
12.6	Containers and Contents	114
12.7	Neighboring Elements	115
12.8	Model Equality	115
12.9	Copying Models	116
12.10	Metamodel Access	116
12.11	Generating a Metamodel-Specific API	120
13	Managing and Querying TGraphs	123
13.1	Loading and Saving Graphs and Schemas	123
13.2	Creating Graphs, Vertices, and Edges	124
13.3	Accessing Graph Elements by ID	125
13.4	Accessing Vertices and Edges by their Order	125
13.5	Querying and Manipulating Element Order	126
13.6	Lazy Vertex and Edge Sequences	127
13.7	Attribute Value Access	128
13.8	Auxiliary Graph Functions	129
13.9	Auxiliary Vertex Functions	129
13.10	Auxiliary Edge Functions	130
13.11	Type Predicates	131
13.12	Schema Access	131
13.13	Generating a Schema-Specific API	132
13.14	Traversal Contexts	133
14	Managing and Querying EMF Models	137
14.1	Managing Resources	137
14.2	Creating and Deleting EObjects	138
14.3	Lazy Content Sequences	139
14.4	EObject Structural Feature Access	140
14.5	Access to Referenced Objects and Conceptual Edges	141
14.6	Type Predicates	143
14.7	Metamodel Access	143
14.8	Generating an Ecore-Model-Specific API	144

15 Generic Querying and Model Management Features	147
15.1 Regular Path Expressions	147
15.2 Polymorphic Functions	154
15.3 Model Visualization	158
15.4 XML Processing	159
15.5 Persistence of Model-Related Data	162
15.6 Miscellaneous	168
16 Related Work	173
V On Pattern Matching	179
17 Introduction	183
17.1 Pattern Matching in Functional Languages	184
17.2 Pattern Matching on Graphs	188
18 Defining Patterns	193
18.1 Pattern Syntax and Semantics	195
18.2 Framework-Specific Patterns	212
19 Related Work	217
VI On In-Place Transformations	219
20 Introduction	223
21 Defining In-Place Rules	227
22 Defining Control Flow and Modifying Behavior	231
22.1 Higher-Order Rule Combinators	231
22.2 Rule Application Modifiers	235
23 Exploring State Space	237
24 Related Work	249
VII On Out-Place Transformations	257
25 Introduction	261
26 Defining Rule-Based Transformations	265
26.1 Transformation Definitions	265
26.2 Example	276
27 Defining Extensional Transformations	281
27.1 Metamodel Constituents and Their Extensions	282
27.2 Indirect Specification of Extensions	284
27.3 Traceability	285

27.4	Extensional Transformation Constructs	287
27.5	Example	294
28	Related Work	301
VIII On Relational Model Querying		309
29	Introduction	313
29.1	Relational Programming with core.logic	314
30	Defining Relational Model Queries	323
30.1	Generic Relations	323
30.2	Metamodel-Specific Relations	328
30.3	Utilities	329
31	Example	331
32	Related Work	335
IX On Bidirectional Transformations		337
33	Introduction	341
34	Defining Bidirectional Transformations	345
34.1	Transformation Definitions	346
34.2	Transformation Relations	347
34.3	Traceability	347
34.4	Transformation Direction and Modes	349
34.5	Preconditions	353
34.6	Target Clauses	354
34.7	Postconditions	355
34.8	Transformation Relation Inheritance	356
34.9	Transformation Inheritance	357
34.10	Plain Relations	359
35	Characteristics	361
36	Example	363
37	Related Work	369
X On Co-Evolution Transformations		373
38	Introduction	377
39	Defining Co-Evolution Transformations	379
39.1	Conformance of Schemas and Graphs	381
39.2	Co-Evolution Operations	383

40 Example	393
41 Related Work	397
XI Finale	401
42 Evaluation	405
42.1 The TTC 2013 Flowgraphs Case	406
42.2 The TTC 2013 Class Diagram Restructuring Case	407
42.3 The TTC 2013 Petri-Nets to Statechart Case	407
42.4 The TTC 2014 Movie Database Case	408
42.5 The TTC 2014 FIXML to Java, C#, and C++ Case	409
42.6 The TTC 2015 Model Execution Case	410
42.7 The TTC 2015 Java Refactoring Case	411
42.8 The TTC 2015 Train Benchmark Case	412
42.9 TTC Summary	413
43 Conclusion	415
43.1 Summary and Contributions	415
43.2 Outlook	418
XII Appendix	421
A Extensibility	423
A.1 Extending Regular Path Expressions	423
A.2 Extending Polymorphic Functions	423
A.3 Extending the Pattern Matching Facilities	424
A.4 Extending the Rule-Based Out-Place Transformation DSL	426
A.5 Extending the Extensional Out-Place Transformation API	426
A.6 Extending the Relational Querying API	427
A.7 Extending the Bidirectional Transformation DSL	427
Bibliography	429
Index	445
Curriculum Vitae	455

Part I

Introduction