Contents

Preface v

1 An Introduction to Data Flow Analysis 1
  1.1 A Motivating Example ........................................... 1
    1.1.1 Optimizing for Heap Memory .................................. 1
    1.1.2 Computing Liveness ......................................... 4
    1.1.3 Computing Aliases .......................................... 9
    1.1.4 Performing Optimization .................................... 10
    1.1.5 General Observations ....................................... 10
  1.2 Program Analysis: The Larger Perspective ...................... 12
  1.3 Characteristics of Data Flow Analysis .......................... 16
  1.4 Summary and Concluding Remarks ............................... 18
  1.5 Bibliographic Notes ........................................... 19

I Intraprocedural Data Flow Analysis 21

2 Classical Bit Vector Data Flow Analysis 23
  2.1 Basic Concepts and Notations ................................... 23
  2.2 Discovering Local Data Flow Information ....................... 24
  2.3 Discovering Global Properties of Variables ................... 26
    2.3.1 Live Variables Analysis .................................... 26
    2.3.2 Dead Variables Analysis ................................... 29
    2.3.3 Reaching Definitions Analysis ................................ 29
    2.3.4 Reaching Definitions for Copy Propagation ................. 32
  2.4 Discovering Global Properties of Expressions .................. 33
    2.4.1 Available Expressions Analysis ............................... 33
    2.4.2 Partially Available Expressions Analysis .................... 36
    2.4.3 Anticipable Expressions Analysis ............................. 37
    2.4.4 Classical Partial Redundancy Elimination ................... 39
    2.4.5 Lazy Code Motion ........................................... 49
  2.5 Combined May-Must Analyses ..................................... 53
  2.6 Summary and Concluding Remarks ................................ 56
  2.7 Bibliographic Notes ............................................ 57
3 Theoretical Abstractions in Data Flow Analysis

3.1 Graph Properties Relevant to Data Flow Analysis
3.2 Data Flow Framework
  3.2.1 Modeling Data Flow Values Using Lattices
  3.2.2 Modeling Flow Functions
  3.2.3 Data Flow Frameworks
3.3 Data Flow Assignments
  3.3.1 Meet Over Paths Assignment
  3.3.2 Fixed Point Assignment
  3.3.3 Existence of Fixed Point Assignment
3.4 Computing Data Flow Assignments
  3.4.1 Computing MFP Assignment
  3.4.2 Comparing MFP and MOP Assignments
  3.4.3 Undecidability of MOP Assignment Computation
3.5 Complexity of Data Flow Analysis for Rapid Frameworks
  3.5.1 Properties of Data Flow Frameworks
  3.5.2 Complexity for General CFGs
  3.5.3 Complexity in Special Cases
3.6 Summary and Concluding Remarks
3.7 Bibliographic Notes

4 General Data Flow Frameworks

4.1 Non-Separable Flow Functions
4.2 Discovering Properties of Variables
  4.2.1 Faint Variables Analysis
  4.2.2 Possibly Uninitialized Variables Analysis
  4.2.3 Constant Propagation
  4.2.4 Variants of Constant Propagation
4.3 Discovering Properties of Pointers
  4.3.1 Points-To Analysis of Stack and Static Data
  4.3.2 Alias Analysis of Stack and Static Data
  4.3.3 Formulating Data Flow Equations for Alias Analysis
4.4 Liveness Analysis of Heap Data
  4.4.1 Access Expressions and Access Paths
  4.4.2 Liveness of Access Paths
  4.4.3 Representing Sets of Access Paths by Access Graphs
  4.4.4 Data Flow Analysis for Explicit Liveness
  4.4.5 The Motivating Example Revisited
4.5 Modeling Entity Dependence
  4.5.1 Primitive Entity Functions
  4.5.2 Composite Entity Functions
4.6 Summary and Concluding Remarks
4.7 Bibliographic Notes
10.2.2 Examining the Gimple Version of CFG 342
10.2.3 Examining the Result of Data Flow Analysis 346
10.3 Implementing the Generic Data Flow Analyzer gdfa 352
  10.3.1 Specification Primitives 352
  10.3.2 Interface with GCC 354
  10.3.3 The Preparatory Pass 358
  10.3.4 Local Data Flow Analysis 358
  10.3.5 Global Data Flow Analysis 360
10.4 Extending the Generic Data Flow Analyzer gdfa 363

A An Introduction to GCC 365
  A.1 About GCC 365
  A.2 Building GCC 366
  A.3 Further Readings in GCC 368

References 371

Index 378