Software Testing and Analysis: Process, Principles, and Techniques

THE WILEY BICENTENNIAL–KNOWLEDGE FOR GENERATIONS

Each generation has its unique needs and aspirations. When Charles Wiley first opened his small printing shop in lower Manhattan in 1807, it was a generation of boundless potential searching for an identity. And we were there, helping to define a new American literary tradition. Over half a century later, in the midst of the Second Industrial Revolution, it was a generation focused on building the future. Once again, we were there, supplying the critical scientific, technical, and engineering knowledge that helped frame the world. Throughout the 20th Century, and into the new millennium, nations began to reach out beyond their own borders and a new international community was born. Wiley was there, expanding its operations around the world to enable a global exchange of ideas, opinions, and know-how.

For 200 years, Wiley has been an integral part of each generation's journey, enabling the flow of information and understanding necessary to meet their needs and fulfill their aspirations. Today, bold new technologies are changing the way we live and learn. Wiley will be there, providing you the must-have knowledge you need to imagine new worlds, new possibilities, and new opportunities.

Generations come and go, but you can always count on Wiley to provide you the knowledge you need, when and where you need it!

William J. Pesce

WILLIAM J. PESCE
PRESIDENT AND CHIEF EXECUTIVE OFFICER

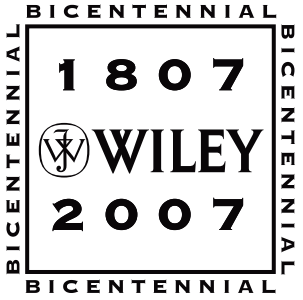
Peter Booth Wiley

PETER BOOTH WILEY
CHAIRMAN OF THE BOARD

Software Testing and Analysis: Process, Principles, and Techniques

Mauro Pezzè
Università di Milano Bicocca

Michal Young
University of Oregon



PUBLISHER	Daniel Sayre
SENIOR PRODUCTION EDITOR	Lisa Wojcik
EDITORIAL ASSISTANT	Lindsay Murdock
COVER DESIGNER	Madelyn Lesure
COVER PHOTO	Rick Fischer/Masterfile
WILEY 200TH ANNIVERSARY LOGO DESIGN	Richard J. Pacifico

This book was typeset by the authors using pdfLaTeXand printed and bound by Malloy Lithographing. The cover was printed by Phoenix Color Corp. This book is printed on acid free paper. ∞

Copyright © 2008 John Wiley & Sons, Inc. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc. 222 Rosewood Drive, Danvers, MA 01923, website www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030-5774, (201) 748-6011, fax (201) 748-6008, website http://www.wiley.com/go/permissions.

To order books or for customer service please, call 1-800-CALL WILEY (225-5945).

ISBN-13 978-0-471-45593-6

Printed in the United States of America

10 9 8 7 5 6 4 3 2 1

Contents

List of Figures **xi**

List of Tables **xv**

I Fundamentals of Test and Analysis **1**

1 Software Test and Analysis in a Nutshell **3**
1.1 Engineering Processes and Verification 3
1.2 Basic Questions 5
1.3 When Do Verification and Validation Start and End? 5
1.4 What Techniques Should Be Applied? 7
1.5 How Can We Assess the Readiness of a Product? 10
1.6 How Can We Ensure the Quality of Successive Releases? 11
1.7 How Can the Development Process Be Improved? 11

2 A Framework for Test and Analysis **15**
2.1 Validation and Verification 15
2.2 Degrees of Freedom 18
2.3 Varieties of Software 23

3 Basic Principles **29**
3.1 Sensitivity 29
3.2 Redundancy 32
3.3 Restriction 33
3.4 Partition 35
3.5 Visibility 36
3.6 Feedback 36

4 Test and Analysis Activities Within a Software Process **39**
4.1 The Quality Process 39
4.2 Planning and Monitoring 41
4.3 Quality Goals 42
4.4 Dependability Properties 43
4.5 Analysis 46

4.6 Testing . . . 48
4.7 Improving the Process . . . 49
4.8 Organizational Factors . . . 50

II Basic Techniques 53

5 Finite Models 55
5.1 Overview . . . 55
5.2 Finite Abstractions of Behavior . . . 58
5.3 Control Flow Graphs . . . 59
5.4 Call Graphs . . . 63
5.5 Finite State Machines . . . 65

6 Dependence and Data Flow Models 77
6.1 Definition-Use Pairs . . . 77
6.2 Data Flow Analysis . . . 82
6.3 Classic Analyses: Live and Avail . . . 85
6.4 From Execution to Conservative Flow Analysis . . . 91
6.5 Data Flow Analysis with Arrays and Pointers . . . 94
6.6 Interprocedural Analysis . . . 96

7 Symbolic Execution and Proof of Properties 101
7.1 Symbolic State and Interpretation . . . 102
7.2 Summary Information . . . 104
7.3 Loops and Assertions . . . 105
7.4 Compositional Reasoning . . . 108
7.5 Reasoning about Data Structures and Classes . . . 109

8 Finite State Verification 113
8.1 Overview . . . 113
8.2 State Space Exploration . . . 116
8.3 The State Space Explosion Problem . . . 126
8.4 The Model Correspondence Problem . . . 129
8.5 Granularity of Modeling . . . 131
8.6 Intensional Models . . . 134
8.7 Model Refinement . . . 138
8.8 Data Model Verification with Relational Algebra . . . 140

III Problems and Methods 149

9 Test Case Selection and Adequacy 151
9.1 Overview . . . 151
9.2 Test Specifications and Cases . . . 152
9.3 Adequacy Criteria . . . 154
9.4 Comparing Criteria . . . 157

10 Functional Testing **161**
10.1 Overview . . . 161
10.2 Random versus Partition Testing Strategies . . . 162
10.3 A Systematic Approach . . . 167
10.4 Choosing a Suitable Approach . . . 174

11 Combinatorial Testing **179**
11.1 Overview . . . 180
11.2 Category-Partition Testing . . . 180
11.3 Pairwise Combination Testing . . . 188
11.4 Catalog-Based Testing . . . 194

12 Structural Testing **211**
12.1 Overview . . . 212
12.2 Statement Testing . . . 215
12.3 Branch Testing . . . 217
12.4 Condition Testing . . . 219
12.5 Path Testing . . . 222
12.6 Procedure Call Testing . . . 229
12.7 Comparing Structural Testing Criteria . . . 230
12.8 The Infeasibility Problem . . . 230

13 Data Flow Testing **235**
13.1 Overview . . . 236
13.2 Definition-Use Associations . . . 236
13.3 Data Flow Testing Criteria . . . 239
13.4 Data Flow Coverage with Complex Structures . . . 241
13.5 The Infeasibility Problem . . . 243

14 Model-Based Testing **245**
14.1 Overview . . . 245
14.2 Deriving Test Cases from Finite State Machines . . . 246
14.3 Testing Decision Structures . . . 251
14.4 Deriving Test Cases from Control and Data Flow Graphs . . . 257
14.5 Deriving Test Cases from Grammars . . . 257

15 Testing Object-Oriented Software **271**
15.1 Overview . . . 271
15.2 Issues in Testing Object-Oriented Software . . . 272
15.3 An Orthogonal Approach to Test . . . 280
15.4 Intraclass Testing . . . 282
15.5 Testing with State Machine Models . . . 282
15.6 Interclass Testing . . . 286
15.7 Structural Testing of Classes . . . 293
15.8 Oracles for Classes . . . 298
15.9 Polymorphism and Dynamic Binding . . . 301

15.10 Inheritance . . . 303
15.11 Genericity . . . 306
15.12 Exceptions . . . 308

16 Fault-Based Testing 313
16.1 Overview . . . 313
16.2 Assumptions in Fault-Based Testing . . . 314
16.3 Mutation Analysis . . . 315
16.4 Fault-Based Adequacy Criteria . . . 319
16.5 Variations on Mutation Analysis . . . 321

17 Test Execution 327
17.1 Overview . . . 327
17.2 From Test Case Specifications to Test Cases . . . 328
17.3 Scaffolding . . . 329
17.4 Generic versus Specific Scaffolding . . . 330
17.5 Test Oracles . . . 332
17.6 Self-Checks as Oracles . . . 334
17.7 Capture and Replay . . . 337

18 Inspection 341
18.1 Overview . . . 341
18.2 The Inspection Team . . . 343
18.3 The Inspection Process . . . 344
18.4 Checklists . . . 345
18.5 Pair Programming . . . 351

19 Program Analysis 355
19.1 Overview . . . 355
19.2 Symbolic Execution in Program Analysis . . . 356
19.3 Symbolic Testing . . . 358
19.4 Summarizing Execution Paths . . . 359
19.5 Memory Analysis . . . 360
19.6 Lockset Analysis . . . 363
19.7 Extracting Behavior Models from Execution . . . 365

IV Process 373

20 Planning and Monitoring the Process 375
20.1 Overview . . . 375
20.2 Quality and Process . . . 376
20.3 Test and Analysis Strategies . . . 377
20.4 Test and Analysis Plans . . . 382
20.5 Risk Planning . . . 386
20.6 Monitoring the Process . . . 389

20.7 Improving the Process . . . 394
20.8 The Quality Team . . . 399

21 Integration and Component-based Software Testing 405
21.1 Overview . . . 405
21.2 Integration Testing Strategies . . . 408
21.3 Testing Components and Assemblies . . . 413

22 System, Acceptance, and Regression Testing 417
22.1 Overview . . . 417
22.2 System Testing . . . 418
22.3 Acceptance Testing . . . 421
22.4 Usability . . . 423
22.5 Regression Testing . . . 427
22.6 Regression Test Selection Techniques . . . 428
22.7 Test Case Prioritization and Selective Execution . . . 434

23 Automating Analysis and Test 439
23.1 Overview . . . 439
23.2 Automation and Planning . . . 441
23.3 Process Management . . . 441
23.4 Static Metrics . . . 443
23.5 Test Case Generation and Execution . . . 445
23.6 Static Analysis and Proof . . . 445
23.7 Cognitive Aids . . . 448
23.8 Version Control . . . 449
23.9 Debugging . . . 449
23.10 Choosing and Integrating Tools . . . 451

24 Documenting Analysis and Test 455
24.1 Overview . . . 455
24.2 Organizing Documents . . . 456
24.3 Test Strategy Document . . . 458
24.4 Analysis and Test Plan . . . 458
24.5 Test Design Specification Documents . . . 460
24.6 Test and Analysis Reports . . . 462

Bibliography 467

Index 479