Introduction to Combinatorial Testing

D. Richard Kuhn
Raghu N. Kacker
Yu Lei
## Contents

Preface, xiii  
Authors, xvii  
Note of Appreciation, xix  
Nomenclature, xxi  

### CHAPTER 1 • Combinatorial Methods in Testing  
1.1 SOFTWARE FAILURES AND THE INTERACTION RULE  
1.2 TWO FORMS OF COMBINATORIAL TESTING  
  1.2.1 Configuration Testing  
  1.2.2 Input Testing  
1.3 COVERING ARRAYS  
  1.3.1 Covering Array Definition  
  1.3.2 Size of Covering Arrays  
1.4 THE TEST ORACLE PROBLEM  
1.5 QUICK START: HOW TO USE THE BASICS OF COMBINATORIAL METHODS RIGHT AWAY  
1.6 CHAPTER SUMMARY  
REVIEW  

### CHAPTER 2 • Combinatorial Testing Applied  
2.1 DOCUMENT OBJECT MODEL  
  CARMELO MONTANÉZ-RIVERA, D. RICHARD KUHN, MARY BRADY, RICK RIVELLO, JENISE REYES RODRIGUEZ, AND MICHAEL POWERS  
  2.1.1 Constructing Tests for DOM Events  

---

**Note:** The contents listed above are from the provided document and have been formatted into a readable table. The page numbers and sections are listed as expected from the document's structure.
### 2.1.2 Combinatorial Testing Approach 25
### 2.1.3 Test Results 25
### 2.1.4 Cost and Practical Considerations 29

#### RICH WEB APPLICATIONS 30

**CHAD M. MAUGHAN**

- **2.2.1 Systematic Variable Detection in Semantic URLs** 31
- **2.2.2 JavaScript Fault Classification and Identification** 31
- **2.2.3 Empirical Study** 33

#### CHAPTER SUMMARY 35

### 3.1 RUNTIME ENVIRONMENT CONFIGURATIONS 37
### 3.2 HIGHLY CONFIGURABLE SYSTEMS AND SOFTWARE PRODUCT LINES 39
### 3.3 INVALID COMBINATIONS AND CONSTRAINTS 44
  - **3.3.1 Constraints among Parameter Values** 44
  - **3.3.2 Constraints among Parameters** 46
### 3.4 COST AND PRACTICAL CONSIDERATIONS 48
### 3.5 CHAPTER SUMMARY 49

#### REVIEW 50

### 4.1 PARTITIONING THE INPUT SPACE 51
### 4.2 INPUT VARIABLES VERSUS TEST PARAMETERS 55
### 4.3 FAULT TYPE AND DETECTABILITY 57
### 4.4 BUILDING TESTS TO MATCH AN OPERATIONAL PROFILE 61
### 4.5 SCALING CONSIDERATIONS 64
### 4.6 COST AND PRACTICAL CONSIDERATIONS 66
### 4.7 CHAPTER SUMMARY 67

#### REVIEW 68
CHAPTER 5  ■  Test Parameter Analysis  

EDUARDO MIRANDA

5.1 WHAT SHOULD BE INCLUDED AS A TEST PARAMETER 72
5.2 COMBINATION ANOMALIES 74
5.3 CLASSIFICATION TREE METHOD 76
5.4 MODELING METHODOLOGY 81
  5.4.1 Flexible Manufacturing System Example 81
  5.4.2 Audio Amplifier 89
  5.4.3 Password Diagnoser 94
5.5 SELECTING THE SYSTEM UNDER TEST 103
5.6 COMBINATORIAL TESTING AND BOUNDARY VALUE ANALYSIS 106
5.7 CHAPTER SUMMARY 111
REVIEW 111

CHAPTER 6  ■  Managing System State  

GEORGE SHERWOOD

6.1 TEST FACTOR PARTITIONS WITH STATE 114
  6.1.1 Partitions for Expected Results 115
  6.1.2 Partitions with Constraints 116
  6.1.3 Direct Product Block Notation 116
6.2 TEST FACTOR SIMPLIFICATIONS 119
  6.2.1 All the Same Factor Value 119
  6.2.2 All Different Factor Values 119
  6.2.3 Functionally Dependent Factor Values 119
  6.2.4 Hybrid Factor Values 121
6.3 SEQUENCE UNIT REPLAY MODEL 122
6.4 SINGLE REGION STATE MODELS 126
6.5 MULTIPLE REGION STATE MODELS 133
6.6 CHAPTER SUMMARY 137
REVIEW 140
CHAPTER 7 • Measuring Combinatorial Coverage 143

7.1 SOFTWARE TEST COVERAGE 144

7.2 COMBINATORIAL COVERAGE 145

7.2.1 Simple t-Way Combination Coverage 146
7.2.2 Simple (t + k)-Way 147
7.2.3 Tuple Density 148
7.2.4 Variable-Value Configuration Coverage 149

7.3 USING COMBINATORIAL COVERAGE 152

7.4 COST AND PRACTICAL CONSIDERATIONS 156

7.5 ANALYSIS OF (t + 1)-WAY COVERAGE 160

7.6 CHAPTER SUMMARY 161

REVIEW 161

CHAPTER 8 • Test Suite Prioritization by Combinatorial Coverage 163

RENEE BRYCE AND SREEDEVI SAMPATH

8.1 COMBINATORIAL COVERAGE FOR TEST SUITE PRIORITIZATION 163

8.2 ALGORITHM 166

8.3 PRIORITIZATION CRITERIA 167

8.4 REVIEW OF EMPIRICAL STUDIES 169

8.4.1 Subject Applications 169
8.4.2 Prioritization Criteria 169
8.4.2.1 Test Cases 170
8.4.2.2 Faults 170
8.4.2.3 Evaluation Metric 171
8.4.2.4 Results 171

8.5 TOOL: COMBINATORIAL-BASED PRIORITIZATION FOR USER-SESSION-BASED TESTING 173

8.5.1 Apache Logging Module 173
8.5.2 Creating a User Session–Based Test Suite from Usage Logs Using CPUT 173
8.5.3 Prioritizing and Reducing Test Cases 173
8.6 OTHER APPROACHES TO TEST SUITE PRIORITIZATION USING COMBINATORIAL INTERACTIONS 174
8.7 COST AND PRACTICAL CONSIDERATIONS 175
8.8 CHAPTER SUMMARY 176
REVIEW 176

CHAPTER 9 Combinatorial Testing and Random Test Generation 179

9.1 COVERAGE OF RANDOM TESTS 180
9.2 ADAPTIVE RANDOM TESTING 184
9.3 TRADEOFFS: COVERING ARRAYS AND RANDOM GENERATION 186
9.4 COST AND PRACTICAL CONSIDERATIONS 189
9.5 CHAPTER SUMMARY 190
REVIEW 191

CHAPTER 10 Sequence-Covering Arrays 193

10.1 SEQUENCE-COVERING ARRAY DEFINITION 193
10.2 SIZE AND CONSTRUCTION OF SEQUENCE-COVERING ARRAYS 195
   10.2.1 Generalized t-Way Sequence Covering 197
   10.2.2 Algorithm Analysis 197
10.3 USING SEQUENCE-COVERING ARRAYS 198
10.4 COST AND PRACTICAL CONSIDERATIONS 199
10.5 CHAPTER SUMMARY 199
REVIEW 202

CHAPTER 11 Assertion-Based Testing 203

11.1 BASIC ASSERTIONS FOR TESTING 204
11.2 STRONGER ASSERTION-BASED TESTING 208
11.3 COST AND PRACTICAL CONSIDERATIONS 209
11.4 CHAPTER SUMMARY 210
REVIEW 210
### Chapter 12 • Model-Based Testing

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1 Overview</td>
<td>214</td>
</tr>
<tr>
<td>12.2 Access Control System Example</td>
<td>215</td>
</tr>
<tr>
<td>12.3 SMV Model</td>
<td>216</td>
</tr>
<tr>
<td>12.4 Integrating Combinatorial Tests into the Model</td>
<td>218</td>
</tr>
<tr>
<td>12.5 Generating Tests from Counterexamples</td>
<td>222</td>
</tr>
<tr>
<td>12.6 Cost and Practical Considerations</td>
<td>224</td>
</tr>
<tr>
<td>12.7 Chapter Summary</td>
<td>225</td>
</tr>
<tr>
<td>REVIEW</td>
<td>225</td>
</tr>
</tbody>
</table>

### Chapter 13 • Fault Localization

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1 Fault Localization Process</td>
<td>228</td>
</tr>
<tr>
<td>13.1.1 Analyzing Combinations</td>
<td>229</td>
</tr>
<tr>
<td>13.1.2 New Test Generation</td>
<td>230</td>
</tr>
<tr>
<td>13.1.2.1 Alternate Value</td>
<td>230</td>
</tr>
<tr>
<td>13.1.2.2 Base Choice</td>
<td>230</td>
</tr>
<tr>
<td>13.2 Locating Faults: Example</td>
<td>231</td>
</tr>
<tr>
<td>13.2.1 Generating New Tests</td>
<td>234</td>
</tr>
<tr>
<td>13.3 Cost and Practical Considerations</td>
<td>235</td>
</tr>
<tr>
<td>13.4 Chapter Summary</td>
<td>236</td>
</tr>
<tr>
<td>REVIEW</td>
<td>236</td>
</tr>
</tbody>
</table>

### Chapter 14 • Evolution from Design of Experiments

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.1 Background</td>
<td>237</td>
</tr>
<tr>
<td>14.2 Pairwise (Two-Way) Testing of Software Systems</td>
<td>239</td>
</tr>
<tr>
<td>14.3 Combinatorial t-Way Testing of Software Systems</td>
<td>245</td>
</tr>
<tr>
<td>14.4 Chapter Summary</td>
<td>246</td>
</tr>
</tbody>
</table>
CHAPTER 15 • Algorithms for Covering Array Construction  247

LINBIN YU AND YU LEI

15.1 OVERVIEW  247
15.1.1 Computational Approaches  247
15.1.2 Algebraic Approaches  248

15.2 ALGORITHM AETG  249

15.3 ALGORITHM IPOG  252

15.4 COST AND PRACTICAL CONSIDERATIONS  255
15.4.1 Constraint Handling  255
15.4.2 Mixed-Strength Covering Arrays  256
15.4.3 Extension of an Existing Test Set  257

15.5 CHAPTER SUMMARY  258

REVIEW  258

APPENDIX A: MATHEMATICS REVIEW, 261
A.1 COMBINATORICS  261
  A.1.1 Permutations and Combinations  261
  A.1.2 Orthogonal Arrays  262
  A.1.3 Covering Arrays  263
  A.1.4 Number of Tests Required  264
A.2 REGULAR EXPRESSIONS  265
  A.2.1 Expression Operators  265
  A.2.2 Combining Operators  266

APPENDIX B: EMPirical DATA ON SOFTWARE FAILURES, 267

APPENDIX C: RESOURCES FOR COMBINATORIAL TESTING, 273

APPENDIX D: TEST TOOLS, 277
D.1 ACTS USER GUIDE  278
D.1.1 Core Features
  
  D.1.1.1 t-Way Test Set Generation 278
  D.1.1.2 Mixed Strength 278
  D.1.1.3 Constraint Support 279
  D.1.1.4 Coverage Verification 279

D.1.2 Command Line Interface 279

D.1.3 The GUI 282
  
  D.1.3.1 Create New System 284
  D.1.3.2 Build Test Set 288
  D.1.3.3 Modify System 289
  D.1.3.4 Save/Save as/Open System 291
  D.1.3.5 Import/Export Test Set 291
  D.1.3.6 Verify t-Way Coverage 292

REFERENCES, 293

INDEX, 309