Software Quality Engineering

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Testing, Quality Assurance, and Quantiable Improvement
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Chapter 8. Coverage and Usage Testing

Based on Checklists and Partitions

- Checklist-Based Testing
- Partitions and Partition Testing
- Usage-Based Testing with Musa's OPs
- OP Development: Procedures/Examples

Checklists for Testing

- Ad hoc testing:
    - "run-and-observe"
    - How to start the run?
    - Areas/focuses of "observations"?
    - Implicit checklists may be involved.
- Explicit checklists:
    - Function/features (external)
    - Implementation (internal)
    - Standards, etc.
    - Mixed or combined checklists

Function Checklists

- Function/feature (external) checklists:
    - Black-box in nature
    - List of major functions expected
- Example: Table 8.1 (p.105)
    - abnormal termination
    - backup and restore
    - communication
    - co-existence
    - file I/O
    - gateway
    - index management
    - installation
    - logging and recovery
    - locking
    - migration
    - stress

Implementation Checklists

- Implementation (internal) checklists:
    - White-box in nature
    - At different levels of abstraction
        - e.g., lists of modules/components/etc.
        - statement coverage as covering a list
- Related: cross-cutting features/structures:
    - Multiple elements involved.
    - Examples: call-pairs, diff. parts that cooperate/collaborate/communicate/etc.
- Other checklists:
    - related to certain properties
        - e.g., coding standards,
    - hierarchical list, e.g., refined Table 8.1

Other Checklists

- Combined x-list based on n attributes for large products,
- Example: Table 8.2 (p.106)

Component	Standards Items			
	s_1	s_2	$\cdots$	s_n
c_1				
c_2				
$\vdots$				
c_m				

- Checklists in other forms:
  - tree/graph/etc. => enumerate into lists
  - certain elements of complex models
    - e.g., lists of states and links in FSMs

Checklists: Assessment

- Key advantage: simplicity.
- Possible drawbacks of checklists:
  - Coverage: need to fill "hole".
  - Duplication: need to improve efficiency.
  - Complex interactions not modeled.
  - Root cause: complexity
    - contributing to all 3 problems above.
- Possible solutions:
  - specialized checklists => partitions.
  - alternatives to checklists: FSMs.

Checklists to Partitions

- Examples: solving ax^2 + bx + c = 0,
  - solution: $$r = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$
    - input: a; b; c; output: r.
    - 32 bits floating point numbers used
    - input combinations:

      2^232 * 2^232 * 2^232 = 2^96
- 3 solution partitions (Table 8.3, p.108):

Test Case	Condition $d = b^2 - 4ac$	Input a	b	c
1	$d > 0$	1	2	-1
2	$d = 0$	1	2	1
3	$d < 0$	1	2	3

Partitions: Ideas and Definitions

- Partitions: a special type of checklists

- Mutually exclusive => no overlaps.
- Collectively exhaustive => coverage.
- Address two problems of checklists.

  (Third addressed by FSMs in Chapter 10.)

- Partition of set S into subsets

$G_1,\ G_2,\ \ldots,\ G_n\ (G_i \subset S)$:

▷ G_i's are mutually exclusive:

$$\forall i, j,\ i \neq j \Rightarrow G_i \cap G_j = \emptyset$$

▷ G_i's are collectively exhaustive:

$$\bigcup_{i=1}^{n} G_i = S.$$

- Each Gi forms an equivalent class (next).

Partitions: Formal Definitions

- Relation: An association of interest to some observers among objects.
  - R(A1; A2; : : : ; An)
  - Binary relations: R(A; B) or ARB.

    most commonly used relations.

- Relational properties
  - Transitivity: ARB ^ BRC => ARC

    e.g., ">" relation.

  - Symmetry: ARB ^ BRA

    e.g., "is-neighbor-to" relation.

  - Reflexivity: ARA

    e.g., "=" relation.

- Equivalence relation:

  All the above properties hold.

Partition-Based Testing (1)

- Different types of partition definitions:
  - membership based partition definitions
  - properties/relations used in definitions
  - combinations
- Basic idea of partition-based testing:
  - membership/equivalence-class analysis

    => defining meaningful partitions

  - sampling from partitioned subsets for different types of partitions

- Extending basic coverage to perform non-uniform testing (later).

Partition-Based Testing (2)

- Testing for membership in partitions:
  - partitions: components in a subsystems
  - testing via direct sampling,

    e.g., sampling 1 component/subsystem

- Testing for general partitions:
  - properties/relations used in definitions
  - direct predicates on logical variables

        - direct derivation of test cases
    - operations on numerical variables
        - sensitize (select) input values
- Testing for combinations of the above partition definitions

Partition-Based Testing (3)

- Testing predicates on logical variables:
    - logical variable P as input
        - 2 partitions/test-cases: P=T, P=F.
    - P ^ Q, with 2 partitions (outcomes):
        - P ^ Q = T , with P = T and Q = T .
        - P ^ Q = F , 1 test case from 3 pairs:

          {(P=T, Q=F); (P=F, Q=T); (P=F, Q=F)}
- Testing comparisons on numerical variables:
    - x > 0, many possible test cases
        - x = 101: a specific test case
    - combinations: satisfy all conditions, e.g.,
        - (x > 0) ^ (y < 100), select x, y values individually, say x = 101 and y = 21;
        - (x > 0) ^ (x (cid:20) 100), select x value to satisfy both conditions, say x = 17.

Partition-Based Testing (4)

- Testing multiple sets of partitions:
    - Divide-and-conquer.
    - Model as stages.
    - Combination (cross-product) of the stages.
        - e.g. binary partitions P followed by Q: four combinations: TT, TF, FT, FF.
- General: an m-way partition followed by an n-way partition: m * n combinations.
- Coordinated sensitization often needed, similar to for (x > 0) ^ (x <= 100) above.

Partition-Based Testing (5)

- Extensions to basic ideas:
    - Sampling from partitioned subsets.
    - Coverage of partitions: non-uniform?
    - Testing based on related problems:
        - usage-related problems?
        - boundary problems?
    - Testing based on level/hierarchy/etc.?
- Usage-related problems:
    - More use => failures more likely
    - Usage information in testing

      => (Musa's) operational profiles (OPs)
- Boundary problems:

  Input domain boundary testing (Ch.9).

Usage-Based Statistical Testing

- Usage based statistical testing (UBST) to ensure reliability.
- Reliability: Probability of failure-free operation for a specific time period or a given set of input under a specific environment
    - Reliability: customer view of quality
    - Probability: statistical modeling
    - Time/input/environment: OP
- OP: Operational Profile
    - Quantitative characterization of the way a (software) system will be used.
    - Generate/execute test cases for UBST
    - Realistic reliability assessment
    - Development decisions/priorities

UBST: General Issues

- General steps:
  - Information collection.
  - OP construction.
  - UBST under OP.
  - Analysis (reliability!) and followup.
- Linkage to development process
  - Construction: Requirement/specification, and spill over to later phases.
  - Usage: Testing techniques and SRE
- Procedures for OP construction necessary

UBST: Primary Benefit

- Primary benefit:
  - Overall reliability management.
  - Focus on high leverage parts

    => productivity and schedule gains:

    - same effort on most-used parts
    - reduced effort on lesser-used parts
    - reduction of 56% system testing cost
    - or 11.5% overall cost (Musa, 1993)
- Gains vs. savings situations
  - Savings situation: AT&T (above)
    - reliability goal within reach
    - not to over test lesser-used parts
  - Gains situation: more typical
    - re-focusing testing effort
    - constrained reliability maximization

UBST: Other Benefits

- Introducing new product
  - Highly-used features quickly
  - Lesser-used: subsequent releases
- Better communications/customer relations
  - Customer perspective & involvement

    => closer ties to customers

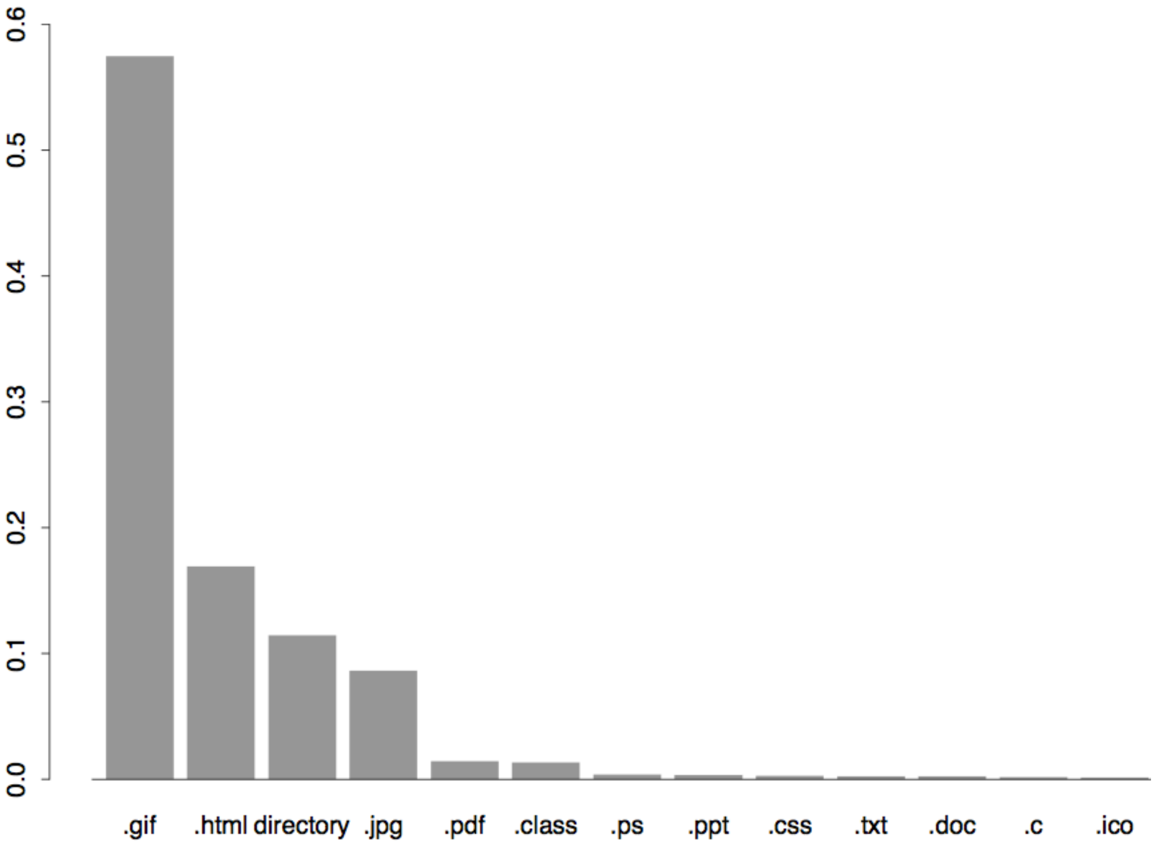
  - More precise requirement/specification
  - Better training focus
- High return on investment:
  - OP cost, "average" 1 staff-month
    - 10 developers, 100KLOC, 18 months
    - sub-linear increase for larger ones
  - Cost-benefit ratio: 10

OP: Concepts and an Example (1)

- Profile: Disjoint alternatives and their probabilities (sorted in decreasing order).
- Example: Table 8.4, p.112
  - file type usage OP for SMU/SEAS

File type	Hits	% of total
.gif	438536	57.47%
.html	128869	16.89%
directory	87067	11.41%
.jpg	65876	8.63%
.pdf	10784	1.41%
.class	10055	1.32%
.ps	2737	0.36%
.ppt	2510	0.33%
.css	2008	0.26%
.txt	1597	0.21%
.doc	1567	0.21%
.c	1254	0.16%
.ico	849	0.11%
Cumulative	753709	98.78%
Total	763021	100%

OP: Concepts and an Example (2)



- OP often as a graph, e.g., Fig 8.1 (p.113).

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- attractive alternative to table earlier.
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OP Characteristics and Usage

- Uneven distribution: basis for UBST to ensure product reliability (otherwise uniform sampling adequate)
- Usage of OPs in UBST:

    - Pure random sampling rare
        - requires dynamic (on-the-fly) decisions
        - might interfere with system functions
    - More often: pre-prepared test cases
        - "pseudo" randomness
    - Other variations:
        - normal cases and then perturbations
        - use of adjustable thresholds
    - #operations^^ => cutoff threshold.
- OP sometimes directly used in reliability evaluations and improvement.

Developing OP (1)

- OP: operations & their probabilities.
    - probability: partition that sum up to 1.
- Obtaining OP information:
    - identify distinct operations as disjoint alternatives.
    - assign associated probabilities
        - occurrences/weights => probabilities.
    - in two steps or via an iterative procedure
- OP information sources:
    - actual measurement.
    - customer surveys.
    - expert opinion.

Developing OP (2)

- Actual measurement for OP construction:
    - Most accurate but also most costly.
    - Limitations for new products.
    - Legal/IP issues.
- Overcoming difficulties for new products:
    - Measurement for similar products.
    - Necessary adjustment.
- Overcoming legal/IP difficulties:
    - Similar to new product strategy above?
    - Voluntary participation:
        - "out" participation: beta testing,
        - "in" participation: ECI in IBM
    - Use of existing logs/records/etc.

Developing OP (3)

- Customer surveys:
    - Less accurate/costly than measurement.
    - But without the related difficulties.
    - Key to statistical validity:
        - large enough participation
        - "right" individuals completing surveys
    - More important to cross-validate
        - see example study in Section 8.5.
- Expert opinion:
    - Least accurate and least costly.
    - Ready availability of internal experts.
    - Use as a rough starting point.

Developing OP (4)

- Who should develop OP?
    - System engineers

        - requirement => specification
    - High-level designers
        - specification => product design
    - Planning and marketing
        - requirement gathering
    - Test planners (testing)
        - users of OP
    - Customers (implicitly assumed)
        - as the main information source
- Key: those who can help us
    - identify distinct alternatives (operations)
    - assign associated probabilities

Developing OP (5)

- One OP or multiple OPs?
    - One OP for each homogeneous group of users or operations:
        - user group or market segmentation
        - groups of operations (op. modes)
    - Fundamental differences) split
    - Hybrid strategy often useful:
        - develop separate OPs
        - merged OP for overall picture
        - both types offer valuable info.
- Development procedure (2 variations)
    - Top-down/Musa-1: (Musa, 1993)
    - Musa-2: Musa 1998 book (Chapter 3)

OP Development: Musa-1

- One OP for each homogeneous group of users or operations.
- Top-down procedure focusing on external users and their product usage.
- Generic steps:
    1. Find the customer profile.
    2. Establish the user profile.
    3. Define the system modes.
    4. Determine the functional profile.
    5. Determine the operational profile.
- First two steps external view;

  last three steps internal view.

Musa-1.1: Finding the Customer Profile

- Differentiate customer from users
    - Customer: acquisition of software
    - User: using software
- Weight assignment:
    - By #customers
    - By importance/marketing concerns, etc.
- Example: Table 8.5 (p.118)

Customer Type	Weight
corporation	0.5
government	0.4
education	0.05
other	0.05

Musa-1.2: Establishing the User Profile (1)

- Breakdown of customer groups
    - Different usages of user groups
    - Merging similar users across customers
- Weighting factor assignment for user weights within customer types:
    - by users (equal usage intensity)
    - by usage frequency
    - other factors also possible
- Comprehensive user profile derivation:

  weighted sum of individual user profiles

Musa-1.2: Establishing the User Profile (2)

Customer Type	Weight
corporation	0.5
government	0.4
education	0.05
other	0.05

- Example: Table 8.6 (p.119)
    - row: user type
    - column: user profile in a customer type
    - customer profile used to calculate

  comprehensive user profile: 0:8 * 0:5 (com) + 0:9 * 0:4 (gov) + 0:9 * 0:05 (edu) + 0:7 * 0:05 (etc) = 0.84

Musa-1.3: Defining System Modes

- System mode
    - A set of functions/operations
    - For operational behavior analysis
    - Practicality: expert for system mode
- Example modes
    - Business use mode
    - Personal use mode
    - Attendant mode
    - System administration mode
    - Maintenance mode
    - Probabilities (weighting factors)

Musa-1.4: Determining Functional Profile

- Identifying functions
    - Function: high-level task/work of the projected system in the requirement.
    - Input domain partitions/combinations
    - Hardware/OS/system configuration
    - Base on environmental variables
- Creating/consolidating function list
    - From system requirement
    - From prototypes/previous release/user manual etc.
- Determining occurrence probabilities
    - Measurement and adjustment
    - Functions <=> operations

Musa-1.5: Determining OP

- Refining functional profile into OP
- Defining operations
    - Operation: implemented task/work that can be used as part of system test plan
    - Defining the input space
    - Partitioning input space into operations

    - Typically: 1 function) n operations
- Obtaining occurrence probabilities
    - In-field measurement
    - Estimation for new systems or added functionalities using symbolic models or prototypes
    - Help from functional probabilities

OP Development: Musa-2 (1)

- One OP for each operational mode

  (testing under specific modes in practice)
- General idea:
    - Op. group: coarse -> fine -> individual.
    - Focus: internal users (testers).
- Generic steps:
    1. Identify initiators of operations.
    2. Tabular or graphical representation.
    3. Operations lists:

       initiators -> consolidated.
    4. Determine the occurrence rate.
    5. Determine the occurrence probability.

OP Development: Musa-2 (2)

- Identify initiators of operations
    - Who are the users of the system?

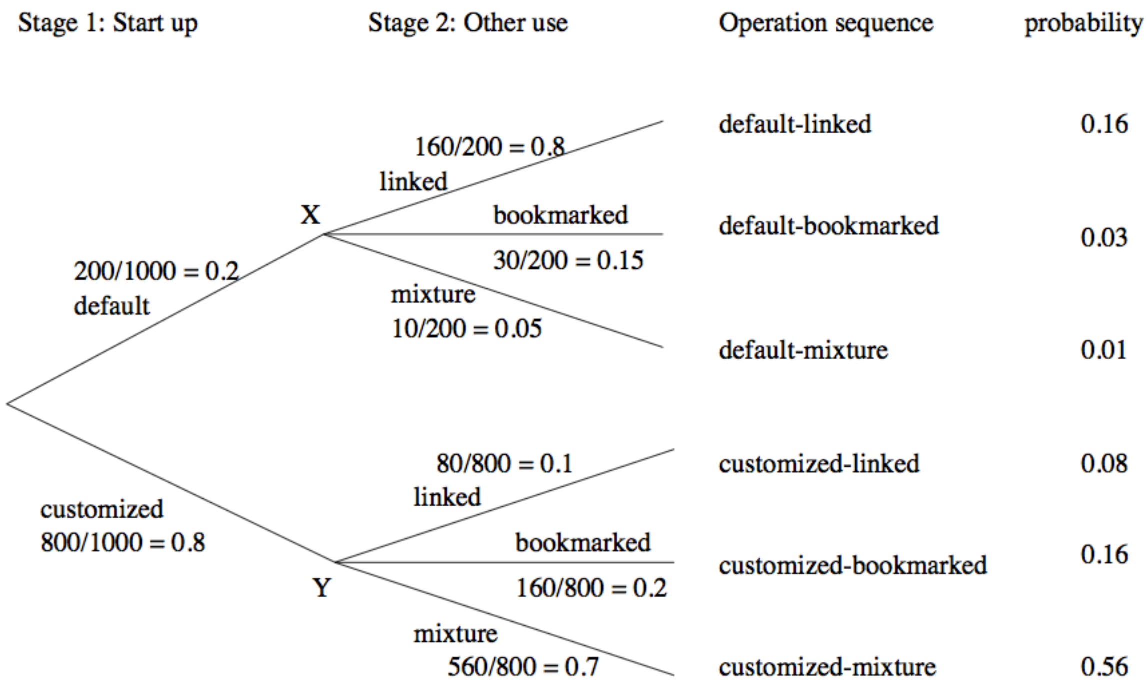
      human users, other hw/sw/network/etc.
    - Consolidate across organizations or customer types
- Tabular vs graphical representation
    - Tabular: operation-probability pairs.
    - Graphical: stages/steps of operation
        - operation = a path in graph/tree
        - probability for branching

          (joint prob = product of indiv. prob.)

OP Development: Musa-2 (3)

- Operations lists:
    - Initiators => indiv. op. lists
    - Consolidation) overall op. lists
    - Proper granularity adjustment:
        - possible split/merge
- Determine the occurrence rate
    - Measurement (and survey?)
    - Tabulation
- Determine the occurrence probability
    - Normalized occurrence rate
    - 0 <= pi <= 1 and Pi pi = 1

OP Development: Musa-2 Example



- Example: Fig 8.2, p.121
  - a tree-structured OP
  - graphical (not tabular) representation
  - far right: equivalent flat OP

Comparison: Musa-1 vs. Musa-2

- Generic steps:
  - Musa-1: customer -> user -> sys. modes -> functional -> operational
  - Musa-2: initiator -> representation -> list -> rate -> probability
- Comparison
  - Size/environment/population differences.
  - One OP for each distinguished group
    - Musa-1: user or operation group,
    - Musa-2: operational modes.
  - Musa-1: 5 profiles, refined along.
  - Musa-2: different elements for 1 profile.

OP Construction: A Case Study

- Background:
  - Former CSE 5314 student
  - Course project: OP development
  - Application of Musa-1
  - Chruscielski/Tian: ISSRE'97 paper (IEEE-ISSRE'97 best paper award)
- Problem and key decisions:
  - Product: LMTAS/CSS
  - Product characteristics) OP type
    - menu selection/classification type
    - flat instead of Markovian
  - Result OP, validation, and application

OP Case Study (1)

- Participants:
    - Software Product Manager
    - Test Engineers
    - Systems Engineers
    - Customers
    - Chruscielski: pulling it together
    - Tian: technical advising
    - Chruscielski/Tian: documentation
- Information gathering
    - Interview Software Product Manager to identify target customers
    - Customer survey/questionnaire to obtain customer usage information
    - Preparation, OP construction and followup

OP Case Study (2)

- Customer profile:
    - US Air Force and other AFs
    - Similar customers/usage) one OP
- User profile: Table 8.7 (p.123)

User Group	Marketing Concerns	Frequency of Use	Total Weighting Factor
Air Force Pilot	0.85	0.05	0.45
Flight Test Support	0.10	0.80	0.45
Avionics System Test	0.05	0.15	0.1

OP Case Study (3)

- User profile weighting:
    - User groups & marketing concerns.
    - Profile reflects both.
    - Idea applicable to other steps:
        - profile can be importance weighted
- System modes
    - No significant difference in op.
    - By-pass: proceed to functional profile
- Functional/operational profile:
    - CSS: functions ~= operations
    - Flat structure/choices => implicit profile

      (function-usage% vs. prob(op-sequence))
    - OPs: for both individual user groups and comprehensive

OP Case Study (4)

- Analysis and followup
    - Cross-validation: Peer review by Software Product Manager, System Engineers and Test Engineers
    - Classification of usage frequencies found to be useful (table below)
    - Followup actions
- Table 8.8 (p.134) classified usage.

User Group	Marketing Concerns	Frequency of Use	Total Weighting Factor
Air Force Pilot	0.85	0.05	0.45
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Avionics System Test	0.05	0.15	0.1

Alternative Usage Models

- Motivation: enhance flat OP
    - Complicated operations involve many steps/stages in the end-to-end chain
    - Ability to use existing models and structural information
    - Ability to use localized knowledge

  - Local information easy to gather
- Markov OP: Basic ideas
  - Markov chain for usage information
  - State: operations/functions
  - Transition: probabilistic
    - reflects usage sequence/frequency
    - history independent (Markovian)
    - but reflects local usage info.
  - Details in Chapter 10.