Software Quality Engineering

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Testing, Quality Assurance, and Quantiable Improvement
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Chapter 10. Coverage and Usage Testing Based on FSMs and Markov Chains

- Finite-State Machines (FSMs)
- FSM-Based Testing
- Markov Chains as Enhanced FSMs
- Unified Markov Models for Testing

Alternative Testing Models

- Motivation: Why FSMs?
  - Complicated operations involve many steps/stages in the end-to-end chain
  - Not modeled in checklists/partitions
  - Ability to use existing models and structural information
  - Ability to use localized knowledge
  - Local information easy to gather
- FSM: Basic ideas
  - State: operations/functions
  - Transition: link in a chain
  - Input/output associated with transition
  - Complete operation: chain

FSMs as Graphs

- FSMs often represented by graphs.
- State/node and properties
  - Represents status/processing/component
  - Identification and labeling
  - Other properties: node weights
- Links and link properties
  - Represent state transitions
  - Labeling: Often by the nodes they link
  - Other properties: link weights
    - associated input and output
  - Directed (e.g., A-B link <> B-A link)

Types of FSMs

- Types of FSMs:
  - Classification by input/output
  - Classification by state
  - Other classifications possible
- FSM types by input/output representation
  - Mealy model: both input and output associated with transitions
  - Moore model: output represented as separate states
  - Mealy model used in this book

Types of FSMs

- Classification by state representation
  - Type I. state = status, with most of the processing and I/O at transition
  - Type II. transition = I/O free link, with most of the processing and I/O at state
  - We use both, and mixed type too
- Type I & II as Mealy models

- Type I: classical Mealy model
- Type II: modified Mealy model, I/O not explicitly represented in FSMs
- Mixed type: used for convenience if not leading to confusion

Types of FSMs

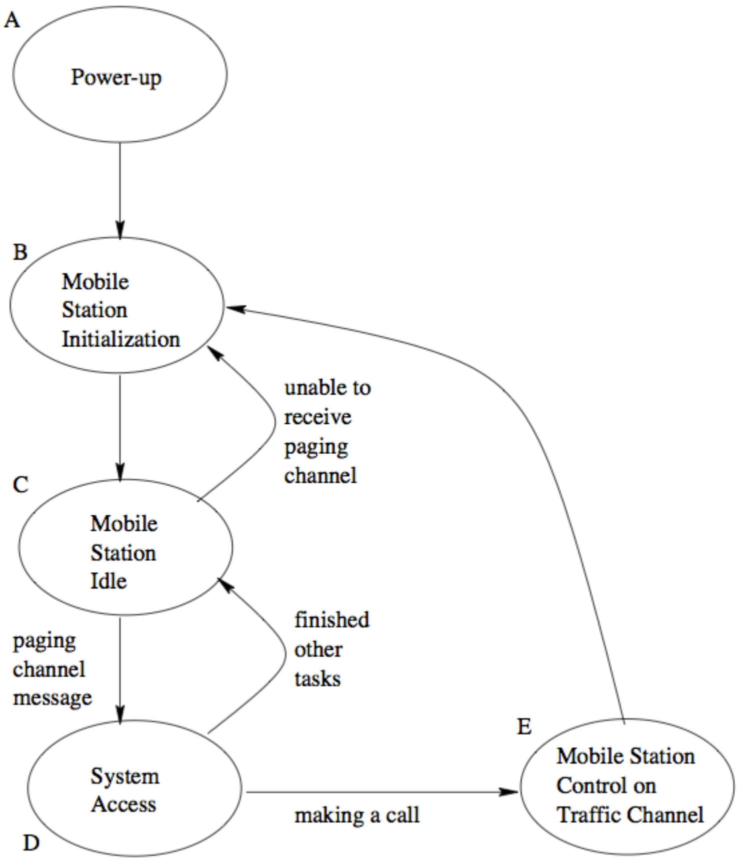
- Type I example: classical Mealy model
    - also web testing example in Section 10.3
- States:
    - "initial" state: when program starts
    - "final" state: where program terminates
    - other states (and transitions below)
- State transitions accompanied by some processing and associated I/O
    - performing user-oriented functions
    - execution some statements
    - I/O associated with above (or empty)

Types of FSMs

- Type II example: control flow graph (CFG) or flow chart in Chapter 11
- Mixed type for convenience
    - Hard to restrict to one type

      => use mixed type
    - Ensure no confusion
    - Key: significant difference among states so that state transitions are meaningful

Types of FSMs



- Mixed type example: Fig 10.1 (p.151)
    - states with processing: A, B, D, E
    - state w/o processing: C (status)
    - transitions: implicit or no output
        - explicit input: C-D, C-B, D-C, D-E
        - implicit/no input: A-B, B-C, E-B

FSM Representation

- FSM as a table/matrix
- Cell (x, y): I/O associated with transition from state x to state y

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- "na": transition not allowed
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- Table 10.1 (p.152) for FSM in Fig 10.1

	A	B	C	D	E
A	na	-/-	na	na	na
B	na	na	-/-	na	na
C	na	NoC/-	na	msg/-	na
D	na	na	done/-	na	call/-
E	na	-/-	na	na	na

FSM/Graph Representation

- Types of graphs
    - Directed graph: FSM etc
    - Undirected graph: neighbor-relation, etc
    - Connectivity vs. disconnected graphs
- Graph representation:
    - Graphical: good for human processing

      (mostly in the book)
    - Tables/matrices: machine processing
    - Lists: compact sets of items like {C, B, "unable to receive paging channel", -}
    - Conversion: easy, but need to know how

Basic FSM Testing

- Typical problems:
    - Missing, extra, or incorrect states
    - Missing, extra, or incorrect transitions
    - Input problems: treat as related state or transition problems
    - Output problems: as oracle problems.
- Basic approach:
    - Missing/extra states/transitions dealt with at FSM construction stage
    - Basic coverage: Node and link coverage via state traversal based on graph theory and algorithms
    - Assuming correct functioning of individual state ensured by lower level testing

Basic FSM Testing

- Checking for missing/extra states/links during model construction
- Model construction steps
    - Identify info. sources and collect data
    - Construct initial FSM
    - Model refinement and validation
- Identify information sources and collect data
    - external functional behavior (black-box)
        - specification, usage scenarios, etc.

- internal program execution (white-box)
  - design, code, execution trace, etc.
- also existing test cases, documents, etc.
- key: linking individual pieces together

Basic FSM Testing

- Construct initial FSM.
  - state identification and enumeration

    (states^^ => nested/hierarchical FSMs)
  - transition/link identification
  - identify I/O relations (as test oracles)
  - key sub-step: link identification
- Link identification and problem detection:
  - identify all possible input for each state
  - input values may be partitioned (Chapter 9)
  - each partitioned subset/subdomain associated with a state transition
  - undefined transition for some input => missing state or extra link identified.
  - extra state or missing link identified by the collective states and transitions (or by connectivity algorithm later)

Basic FSM Testing

- Model refinement and validation.
  - Refinement with additional states/links.
  - State explosion concerns
    - at most \dozens" of states in FSMs
  - Proper granularity needed

    => use of nested/hierarchical FSMs
- Applicability
  - Suitable for menu driven software
  - Systems with clearly identified states/stages
  - Interactive mode (many I/O pairs)
  - Control systems, OOS, etc.
- Key limitation: state explosion!

  => nested FSMs, or Markov chains (later)

Basic FSM Testing

- Node/link coverage via state traversal
  - Based on graph theory/algorithms
  - States directly covered
  - Link coverage: starting from state in combination with input domain testing ideas (Chapter 8 & 9).
- Implementation issues:
  - Sensitization: easy, with specific input
  - State cover: series of links with input
  - Capability to \save" state information
    - help with link coverage from the state
    - state traversal w/o much repeating
  - Oracle: output with link

    (and destination state too!)

Case Study: FSMs for Web Testing

- Web applications vs. menu-driven systems
  - Many similarity but significant differences
  - Computation vs. information/document
  - Separate vs. merged navigations
  - Entry/exit/control difference
  - Differences in population size/diversity
  - Layers in web applications
- Web layers: Fig. 10.2 (p.158)

Client – Web Browsers
Web Server
Middleware
Database – Backend

Case Study: FSMs for Web Testing

- Web problems: What to test
    - Reliability: failure-free content delivery
    - Failure sources identified accordingly
        - host or network failures
        - browser failures
        - source or content failures
        - user problems
    - Focus on source/content failures
- Web source/content components
    - HTML and other documents
    - Programs (Java/JavaScript/ActiveX/etc.)
    - Data forms and backend databases
    - Multi-media components

FSMs for Web Testing

- Testing of individual components

  ~ traditional testing (mostly coverage)
- Testing of overall operation
    - FSMs for navigation/usage
    - States = pages
    - Transitions = embedded links

      (direct URLs not by content providers)
    - I/O: clicks & info. loading/displaying
- Difficulty: size!

  => extending FSMs for selective testing

Markov Usage Model: Overview

- Markov-chain OP models
    - State transitions and probability
    - Markov property
    - Attractive in interactive systems, GUI, and many state-transition types
    - Structural and conceptual integrity
- Comparison with Musa OP
    - Similar to FSM vs list/partitions
    - Musa OP as collapsed Markov chains
    - Coverage: harder to achieve

Markov Usage Model

- Applications
    - Similar to flat OP (Musa), but captures more detailed information
    - Models functional structure and usage
    - Test case generation more complex
    - Result: both analytical and observational
- Background and Linkage
    - Augmented FSMs
    - Cleanroom background: testing technique and tools
    - (Whittaker and Thomason, 1994)
        - TSE 20(10):812-824 (10/94)

- UMM and web testing at SMU

Markov OP

Client – Web Browsers
Web Server
Middleware
Database – Backend

- Example Markov chains: Fig 10.3 (p.162)
- FSMs with probabilistic state transition pij, probability from state i to state j

  0 <= pij <= 1, and SUM(pij) = 1

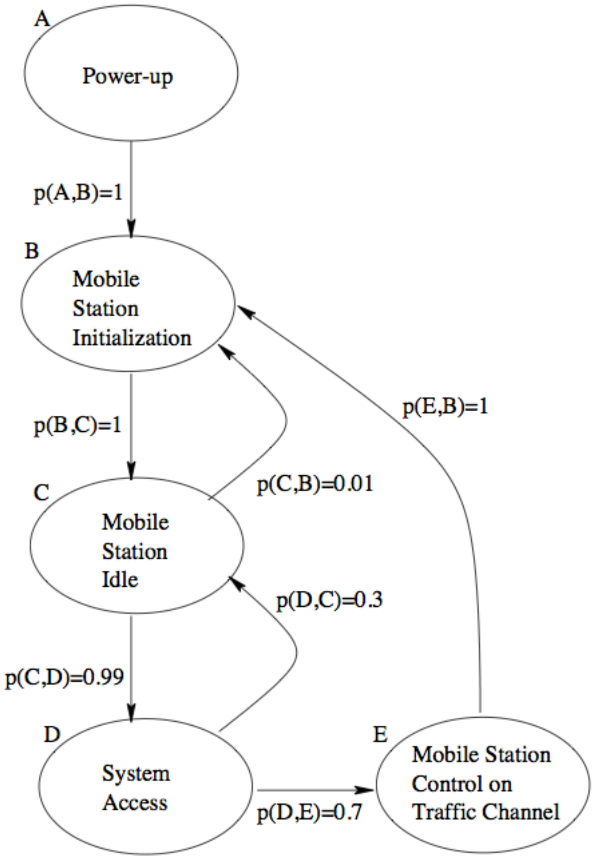
Markov OP and UMMs

- Memoryless or Markovian property

$$P\{X_{n+1} = j | X_n = i, X_{n-1} = s_{n-1}, \ldots, X_0 = s_0\}$$
$$= P\{X_{n+1} = j | X_n = i\}$$
$$= p_{ij}.$$

- Markov chain: pij history independent
  - most well-studied stochastic process
  - rich analytical/theoretical results
  - many applications
- UMM: Unified Markov Models
  - Hierarchical modeling idea.
  - Markov chains at different-levels.
  - More flexibility for statistical testing.

UMM Example



- Example UMM
  - Fig 10.3 (p.162): top-level Markov OP
  - expand state E into Fig 10.4 (p.163) above

Markov/UMM Construction: Steps

- Structure of Markov chain
  - State machines

    e.g., IS-95 call processing) Fig 10.3

  - Flow diagram/function description.
  - At proper granularity
  - Same as FSM construction earlier
- Transition probabilities:
  - Various way to obtain
    - measurement/survey/expert-opinion
    - Musa procedures (Chapter 8) usable?
  - May use structural/domain knowledge
- UMM hierarchy determination/adjustment along the way

Markov/UMM Construction

- Other sources of information
  - Sources for FSMs, with emphasis on external/black-box information
  - Existing flow charts/testing model
  - Performance models (especially for real time systems)
  - Analytical (e.g. queuing) models
  - Market/requirement analyses
  - Similar/earlier products

    - Industry standards/external surveys
- Use of the above information sources
    - for FSMs and transition probabilities
    - existing hierarchies) UMM hierarchies?

Markov/UMM Analysis

- Analysis of the chain/model
    - Static/stationary properties
    - Transient properties
    - Analysis difficulties if size increases or non-stationary process
    - Alternative: simulation & measurement
- Testing result analysis
    - Testing using Markov OP
    - Collect failure data
    - Fit to reliability models

    => direct reliability assessment

Markov/UMM: Testcase Generation

- Basic approaches
    - Markov chain => test cases
    - Static: off-line, traditional
        - need more analysis support
    - Dynamic: on-line, dynamic decisions
        - need more run-time support
- Whittaker/Thomason
    - Basic testing chain from Markov chain
    - Incorporating failure data
    - Results and result analysis
        - testing vs. usage comparison
        - mean-steps-between-failures

Markov/UMM: Testcase Generation

- Avritzer/Weyuker (TSE 21, 9/95)
    - Both coverage &usage
    - Off-line test case generation
    - Path probability and coverage
        - overall testing, similar to Musa OP
    - Node probability and coverage
        - critical component testing
    - Call-pair probability and coverage
        - transition/interface testing
- Hierarchical testing with UMMs
    - High level coverage
    - Low level selective/statistical testing
    - Dynamic expansion

UMM in Web Testing

- Web testing factors
    - Existing: coverage-based testing
    - Web size, complexity, user focus
    - Dynamic nature
    - Focus on source failures
    - Statistical web testing
        - modeling, testing, result analysis
- Measurement and analysis support
    - Model construction: access-log
    - Analysis: error-/access-logs
    - Some existing analyzers

Statistical Web Testing

- High level testing: UMMs
  - Overall structure and linkage
  - Usage and criticality information
  - Guide/drive low level testing
  - Performance and reliability analyses
- Low level testing
  - HTML checkers
  - Other existing tools
  - Future: formal specification checker

UMMs: Web Usage Modeling

```
129.119.4.17 - - [16/Aug/1999:00:00:11 -0500]
"GET /img/XredSeal.gif HTTP/1.1" 301 328
"http://www.seas.smu.edu/" "Mozilla/4.0 (compat-
ible; MSIE 4.01; Windows NT)"

....

129.119.4.17 - - [16/Aug/1999:00:00:11
-0500] "GET /img/ecom.gif HTTP/1.1" 304 -
"http://www.seas.smu.edu/" "Mozilla/4.0 (compat-
ible; MSIE 4.01; Windows NT)".
```

- Example access log: Fig 10.5 (p.168)
- Web usage modeling based on information extracted from web access logs

UMMs: Web Usage Modeling

- Access log analysis
  - Access frequency from different users
  - Timing analysis of accesses
  - Network traffic and performance
- For usage-based web testing?
  - usage patterns and frequencies
  - usage model: UMMs
  - using existing tool, e.g., FastStats, for summary statistics etc
  - new utility programs for other purposes
  - missing information: need extra effort and ways to collect additional data

UMMs: Web Usage Modeling

Entry Page	Occurrences
/index.html	18646
/ce/index.html	2778
/co/cams/index.html	2568
/ce/smu/index.html	2327
/netech/index.html	2139
/disted/phd/index.html	1036
/co/cams/clemscam.html	963
/disted/index.html	878
/cse/index.html	813

- Entry pages: Table 10.2 (p.170)
- Skewed distribution => single top model
- Exit pages: implicit

UMMs: Web Usage Modeling

Entry Page	Occurren
/index.html	186
/ce/index.html	27
/co/cams/index.html	25
/ce/smu/index.html	23
/netech/index.html	21
/disted/phd/index.html	10
/co/cams/clemscam.html	9
/disted/index.html	8
/cse/index.html	8

- Top level model: Fig 10.6 (p.170)
    - Node and link information

      #s not probabilities due to omission
    - Selection of top-hit pages
    - Grouping of low-hit pages
    - Lower level models connected to this

UMMs vs. Musa

- Flat (Musa) vs. Markovian OPs
    - Granularity and sequencing differences
    - Use in test case generation
        - Musa: direct test cases
        - Markov: tool to generate test cases
    - Use in reliability analysis
        - overall (both) vs. localized (Markov)
- Common issues
    - Musa's 5 steps applicable to both
    - Focus on customer and reliability
    - Information collection
- Integrating Markov and Musa OPs

  (and traditional testing): Chapter 12

Choice: Musa vs Markov/UMM

- External (primary) factors to consider

    - Product size
    - Product/usage structure
    - Link/sequence of operations
    - Granularity of info. available
- Internal (secondary) factors to consider
    - Ability to handle complexity
    - Desired level of detail
    - Tool support
- Key: What does the user see?

  (unit of operation or in a lump?)

Conversion: Musa <> Markov

- Is conversion meaningful?
- Musa to Markovian
    - enough info?
    - additional information gathering
    - additional analysis/construction
- Markovian to Musa
    - prob(path) from prob(links)
    - loops => prob. threshold
    - mostly related to test case generation

Summary and Comparison

- FSMs and Markov-OPs/UMMs
    - More complex operations/interactions
    - More complex models too!
    - Need algorithm and tool support for analysis and testing
    - Difficulties with FSMs: state explosion

      => UBST with Markov-OPs/UMMs
- FSM testing focus on traversal of individual states and links => extend FSMs to test problems involving more states/links
    - specialized FSM to test execution paths
    - test related data dependencies?
    - CFT and DFT techniques (Chapeter 11)