Introduction to Software Testing
Criteria-based Test Design

Software Testing & Maintenance
SWE 437
http://go.gmu.edu/swe437

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Changing notions of testing

Old view sees testing at each software development phase as being very different from others
Unit, module, integration, system…

New view is in terms of structures and criteria
Input space, graphs, logical expressions, syntax

Test design is largely the same at each phase
Creating the model is different
Choosing values and automating the tests is different
Model-driven test design

- Model-driven test design
- Software artifact
- Implementation abstraction level
- Criteria gives us test requirements
- Test cases
- Test results
- Test scripts
- Pass / Fail
- Design abstraction level
- Refined requirements / Test specs
- Input values
Test coverage criteria

A tester’s job is simple:
Define a model of the software, then find ways to cover it

Test requirements: A specific element of a software artifact that a test case must satisfy or cover

Coverage criterion: A rule or collection of rules that impose test requirements on a test set

Testing researchers have defined dozens of criteria, but they are all really just a few criteria on four types of structures…
Criteria based on structures

Structures: Four ways to model software

1. Input domain characterization (sets)
   - A: \{0, 1, >1\}
   - B: \{600, 700, 800\}
   - C: \{swe, cs, isa, infs\}

2. Graphs

3. Logical expressions
   - (not X or not Y) and A and B

4. Syntactic structures
   - if (x > y)
     - z = x - y;
   - else
     - z = 2 * x;
Sources for structure

These structures can be extracted from lots of software artifacts
- **Graphs** can be extracted from UML use cases, finite state machines, source code, ...
- **Logical expressions** can be extracted from decisions in program source, guards on transitions, conditionals in use cases, ...

This is **not the same as “model-based testing”** which derives tests from a model that describes some aspects of the system under test
- The model usually describes part of the behavior
- The source is explicitly not considered a model
**Example: jelly bean coverage**

**Flavors:**
1. Lemon
2. Pistachio
3. Cantaloupe
4. Pear
5. Tangerine
6. Apricot

**Colors:**
1. Yellow (Lemon, Apricot)
2. Green (Pistachio)
3. Orange (Cantaloupe, Tangerine)
4. White (Pear)

Possible coverage criteria:
1. Taste one jelly bean of each flavor
   - Deciding if yellow jelly bean is Lemon or Apricot is a controllability problem
2. Taste one jelly bean of each color
Coverage

Given a set of test requirements $TR$ for coverage criteria $C$, a test set $T$ satisfies $C$ coverage if and only if for every test requirement $tr$ in $TR$, there is at least one test $t$ in $T$ such that $t$ satisfies $tr$.

Infeasible test requirements: test requirements that cannot be satisfied

- No test case values exist that meet the test requirements
- Example: dead code
- Detection of infeasible test requirements is formally undecidable for most test criteria

Thus, 100% coverage is impossible in practice
More jelly beans

T1 = { three Lemons, one Pistachio, two Cantaloupes, one Pear, one Tangerine, four Apricots }

Does test set T1 satisfy the flavor criterion?

T2 = { One Lemon, two Pistachios, one Pear, three Tangerines }

Does test set T2 satisfy the flavor criterion?
Does test set T2 satisfy the color criterion?
Coverage level

The ratio of the number of test requirements satisfied by $T$ to the size of $TR$

T2 on the previous slide satisfies 4 of 6 test requirements.
Using test criteria

1. **Directly generate** test values **to satisfy** the criterion
   - Often assumed by the research community
   - Most obvious way to use criteria
   - Very hard without automated tools

2. Generate test values **externally** and **measure** against the criterion
   - Usually favored by industry
   - Sometimes misleading
   - If tests do not reach 100% coverage, what does that mean?

*Test criteria are sometimes called metrics.*
Generators and recognizers

**Generator**: A procedure that automatically generates values to satisfy a criterion

**Recognizer**: A procedure that decides whether a given set of test values satisfies a criterion

Both problems are provably **undecidable** for most criteria

It is possible to recognize whether test cases satisfy a criterion far more often than it is possible to generate tests that satisfy the criterion

**Coverage analysis tools** are quite plentiful
Criteria subsumption (5.2)

Criteria Subsumption: a test criterion $C_1$ subsumes $C_2$ if and only if every set of test cases that satisfies criterion $C_1$ also satisfies $C_2$

Must be true for every set of test cases

Examples:
- The flavor criterion on jelly beans subsumes the color criterion…if we taste every flavor, we taste every color
- If a test set has covered every branch in program (satisfied branch criterion), the test set is guaranteed to also have covered every statement
Criteria-based test design pros (5.3)

Criteria maximize the “bang for the buck”
- Fewer tests that are more effective at finding faults

Comprehensive test set with minimal overlap

Traceability from software artifacts to tests
- The “why” for each test is answered
- Built-in support for regression testing

A “stopping rule” for testing – advance knowledge of how many tests are needed

Natural to automate
Good coverage criteria

1. It should be fairly easy to compute test requirements automatically
2. It should be efficient to generate test values
3. The resulting tests should reveal as many faults as possible

Subsumption is only a rough approximation of fault revealing capability

Researchers still need to give us more data on how to compare coverage criteria
Test coverage criteria

Traditional software testing is **expensive** and **labor-intensive**

Formal coverage criteria are used to decide **which test inputs** to use

More likely that the test will **find problems**

Greater assurance that the software is of **high quality** and **reliability**

A goal or **stopping rule** for testing

Criteria makes testing more **efficient** and **effective**

How do we start applying these ideas in practice?
How do we improve?

Testers need more and better **software tools**

Testers need to adopt **practices and techniques** that lead to more **efficient** and **effective** testing

- More **education**
- Different **management** organizational strategies

Testing & QA teams need more **technical expertise**

- **Developer** expertise has been increasing dramatically

Testing & QA teams need to **specialize** more

- This same trend happened for **development** in the 1990s
Four roadblocks to adoption

1. **Lack of test education**
   Microsoft and Google say half their engineers are testers, programmers test half the time
   Number of UG CS programs that require testing?
   Number of MS CS programs that require testing?
   Number of UG testing classes in the US?

2. **Necessity to change process**
   Adoption of many test techniques and tools require changes in development process
   This is expensive for most software companies
Four roadblocks to adoption

3. **Usability of tools**
   Many testing tools require the user to know the underlying theory to use them
   Do we need to know how an internal combustion engine works to drive?
   Do we need to understand parsing and code generation to use a compiler?

4. **Weak and ineffective tools**
   Most test tools don’t do much – but most users do not realize they could be better
   Few tools solve the key technical problem -- **generating test values automatically**
We need researchers to...

1. **Isolate**: Invent processes and techniques that isolate the theory from most test practitioners
2. **Disguise**: Discover engineering techniques, standards, and frameworks that disguise the theory
3. **Embed**: Operationalize theoretical ideas into tools
4. **Experiment**: Demonstrate economic value of criteria-based testing and ATDG (ROI)
   - Which criteria should be used and when?
   - When does the extra effort pay off?
5. **Integrate** high-end testing with development

We need researchers to...
We need educators to ...

1. **Disguise** theory from engineers in classes

2. **Omit** theory when it is not needed

3. **Restructure** curricula to teach more than test design and theory
   - Test **automation**
   - Test **evaluation**
   - **Human-based** testing
   - **Test-driven** development
Changes in practice

1. **Reorganize** test and QA teams to make effective use of individual abilities
   - One math-head can support many testers

2. **Retrain** test and QA teams
   - Use a process like MDTD
   - Learn more testing concepts

3. **Encourage** researchers to embed and isolate

4. **Get involved** in curricular design efforts through industrial advisory boards
Many companies still use “monkey testing”
   -A human sits at the keyboard, wiggles the mouse and bangs the keyboard
   -No automation
   -Minimal training required

Some companies automate human-designed tests

But companies that use both automation and criteria-based testing

   Save money
   Find more faults
   Build better software
Structures for criteria-based testing

Four Structures for Modeling Software

Input Space
- Source
- Specs
  - Design
  - Use cases

Graphs
- Source
- FSMs
- Specs
- DNF

Logic

Syntax
- Source
- Models
  - Integ
  - Input
Summary of what’s new in Part 1

1. **Why** do we test – to **reduce the risk** of using software
   - faults, failures, the RIPR model
   - Test **process maturity** levels – level 4 is a **mental discipline** that improves the **quality** of the software

2. Model-driven test design
   - Four types of test **activities** – test design, automation, execution, and evaluation

3. Test automation
   - Testability, observability and controllability, test automation frameworks (e.g., JUnit)

4. Test-driven development

5. Criteria-based test design
   - **Four structures** – test **requirements** and **criteria**

   *Earlier and better testing empowers test managers.*