RIPR and Criteria-Based Test Design

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Inspiration

"First law: The pesticide paradox. Every method you use to prevent or find bugs leaves a residue of subtler bugs against which those methods are ineffective." – Boris Beizer

Outcomes

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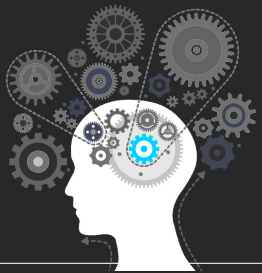
After today's lecture you will be able to:

- Describe the differences between Software faults, errors and failures
- Describe and use the RIPR Model
- Understand how our view of testing has changed
- Understand the basic concepts of Model-Driven Testing
- Understand the basic concepts of Criteria Based Testing
- Understand the basic concepts of Coverage



Software Faults, Errors & Failures

- **Software Fault**: A static defect in the software
- **Software Failure**: External, incorrect behavior with respect to the requirements or other description of the expected behavior
- **Software Error**: An incorrect internal state that is the manifestation of some fault

Faults in software are equivalent to design mistakes in hardware.

Software does not degrade.

Fault & Failure Model (RIPR)

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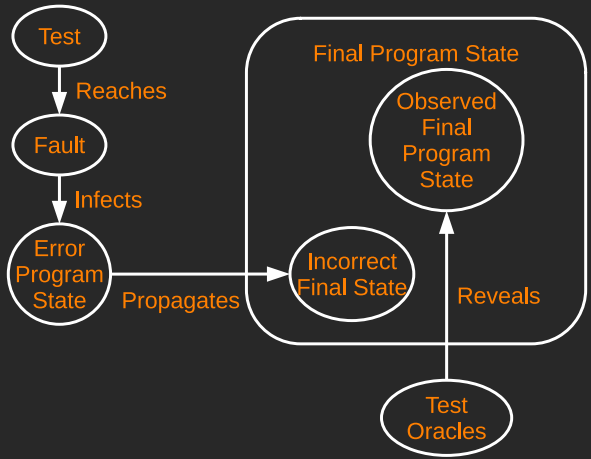
Four conditions necessary for a failure to be observed

1. **Reachability**: The location or locations in the program that contain the fault must be reached.
2. **Infection**: The state of the program must be incorrect
3. **Propagation**: The infected state must cause some output or final state of the program to be incorrect.
4. **Reveal**: The tester must observe part of the incorrect portion of the program state.

RIPR Model

- **R** eachability
- **I** nfection
- **P** ropagation
- **R** evealability



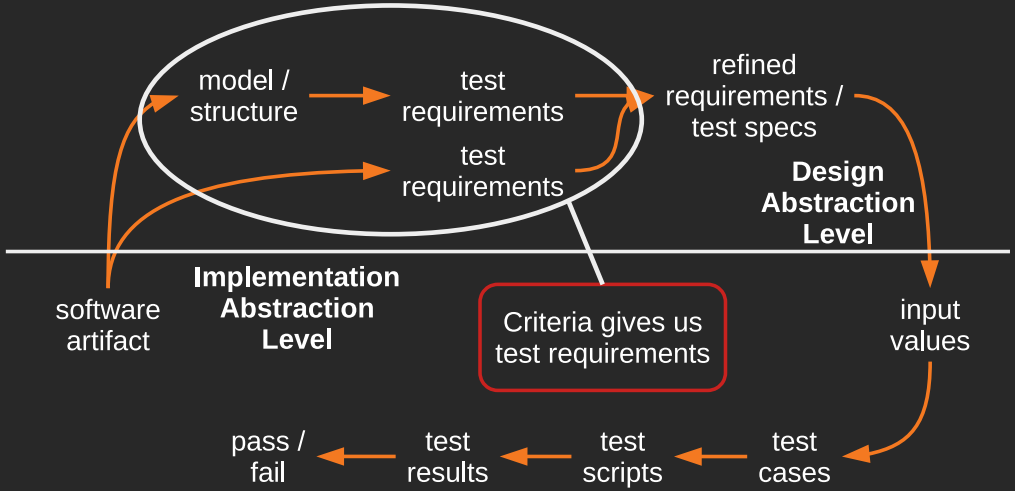
Criteria-Based Test Design

CS 3321

Changing Notions of Testing

- Old view focused on testing at each software development **phase** as being very different from other phases
  - 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



New: Test Coverage Criteria

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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 …

Source of Structures

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- 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

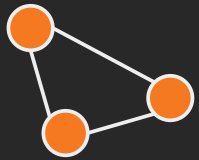
Criteria Based on Structures

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



Criteria Based on Structures

3. Logical Expressions

```
(not X or not Y) and A and B
```

4. Syntactic Structures (grammars)

```
if (x > y)
  z = x - y;
else
  z = 2 * x;
```

Example: Jelly Bean Coverage

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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 criterion *C*, a test set *T* satisfies *C* coverage iff 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

- Test Sets:
  - `T1 = { 3 Lemons, 1 Pistachio, 2 Cantaloupes, 1 Pear, 1 Tangerine, 4 Apricots}`
  - `T2 = { 1 Lemon, 2 Pistachios, 1 Pear, 3 Tangerines}`

- Does test set `T1` satisfy the **flavor criterion**?
- 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 5 test requirements

Two Ways to Use Test Criteria

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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

Comparing Criteria

- **Criteria Subsumption**: A test criterion $C1$ subsumes $C2$ iff every set of test cases that satisfies criterion $C1$ also satisfies $C2$
- 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 one of every color
  - If a test set has covered every branch in a program (satisfied the branch criterion), then the test set is guaranteed to also have covered every statement

Advantages

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- 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 Criterion

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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

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- Traditional software testing is **expensive** and **labor-intensive**
- Formal coverage criteria are used to decide **which test inputs** to use
- More likely that the tester 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 to Improve Testing?

- 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

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1. **Lack of test education**
   - Microsoft and Google say half their engineers are testers, programmers test half the time
   - Number of UG CS programs in US that require testing? **0**
   - Number of MS CS programs in US that require testing? **0**
   - Number of UG testing classes in the US? **~50**

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**

Needs from Researchers

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1. **Isolate**: **Invent** processes and techniques that isolate the theory from most test practitioners
2. **Disguise**: **Discover** engineering techniques, standards and frameworks that disguise theory
3. **Embed**: Theoretical ideas in **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**

Needs from Educators

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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

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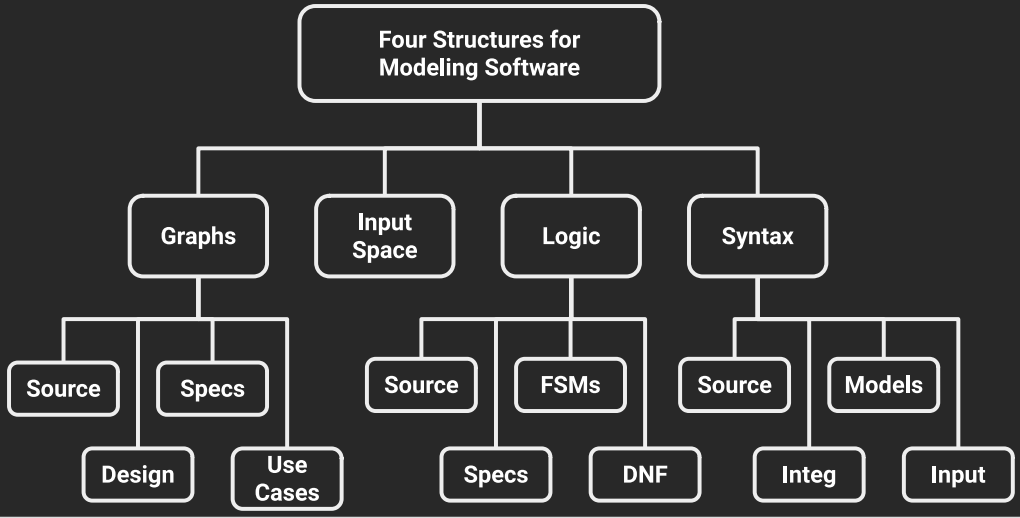
1. **Reorganize** test and QA teams to make effective use of individual abilities
   - One math-head can support many testers
2. **Retrain** test and QA teams
   - Use a process like MDTD
   - Learn more testing concepts
3. **Encourage** researchers to embed and isolate
   - We are very responsive to research grants
4. **Get involved** in curricular design efforts through industrial advisory boards

Criteria Summary

- Many companies till use "**monkey testing**"
  - A human sits at the keyboard, **wiggles** the mouse and **bangs** the keyboard
  - No **automation**
  - Minimial 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


Four Structures for Modeling Software
Graphs
Input Space
Logic
Syntax
Source
Specs
Design
Use Cases
Source
FSMs
Specs
DNF
Source
Models
Integ
Input

Summary

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- **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
- Model-Driven Test Design
  - Four types of **test activities** - test design, automation, execution and evaluation
- Test Automation
  - Testability, observability and controllability, test automation frameworks
- Test Driven Development
- Criteria-based test design
  - **Four structures** - test **requirements** and **criteria**

For Next Time

- Review the Reading
- Review this Lecture
- Come to Class

Are there any questions?