Verification and Validation

CSE 403, Winter 2006
Software Engineering

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Verification and Validation

Verification: “Did we build the system right?”
  » Design and Implementation verification
  » Does the system do specific tasks correctly?
  » Developer / Tester has the knowledge

Validation: “Did we build the right system?”
  » Requirements validation
  » Does the system do the required set of tasks?
  » Customer / Integrator has the knowledge

Readings and References

• References
  » If You Didn’t Test It, It Doesn’t Work, Bob Colwell,
    • IEEE Computer, May 2002 (Vol. 35, No. 5) pp. 11-13

• Acknowledgment
  » much of the content of this lecture is derived from a similar
    lecture by G. Kimura in an earlier instance of CSE 403

Some Approaches to Verification

• Process
  » Improving the likelihood that code is correct

• Testing
  » A dynamic approach

• Proof of correctness
  » Use formal analysis to show an equivalence between a specification and a program
Process

- Process includes a broad set of ideas and approaches
  - Software inspections, walkthroughs, reviews
  - Capability maturity model, ISO 9000
  - etc
- Software correctness depends on thousands and thousands of details being correct
  - Good processes help you avoid making mistakes
  - Processes are not magic

Testing vs. Proving

- Dynamic Testing
  - Builds confidence (not certainty)
    - Can only show the presence of bugs, not their absence
  - Used widely in practice
  - Costly
- Static Proving
  - Proofs are human processes - mistakes are possible!
  - Applicability is limited in practice
  - Extremely costly

Engineering: intelligent compromise

- Dynamic techniques are unattractive because they are unsound
  - you can believe something is true when it’s not
- Static techniques are unattractive because they are often very costly
  - and can overlook fundamental problems
- The truth is that they should be considered to be complementary, not competitive

Testing

- Testing is by far the dominant approach to demonstrating that code does what it supposed to (whatever that means!)
- Testing is a lot like the weather
  - everybody complains about it
  - but nobody seems to do much about it
- However, unlike the weather, you can actually do something about it!
### Terminology

- **An error**
  - mistake the programmer made in design or implementation
- leads to a **defect**
  - inappropriate code
- that leads to a **fault**
  - when a program's internal state is inconsistent with what is expected
- that causes a **failure**.
  - when the program doesn't satisfy its specification

### Root cause analysis

- Track a failure back to an error
  - Failures are precious information because an error has finally become visible
- Identifying errors is important because it can
  - help identify and remove other related defects
    - other defects might not cause visible failures yet
  - help a programmer (and perhaps a team) avoid making the same or a similar error again
    - If an error is made once, it is very likely made twice

### Discreteness

- Testing software is different from testing widgets
  - In general, physical widgets can be analyzed in terms of continuous mathematics
  - Software is based on discrete mathematics
- Why does this matter?
- In continuous math, a small change in an input corresponds to a small change in the output
  - This allows safety factors to be built in
- In discrete math, a small change in an input can correspond to a huge change in the output

### Kinds of testing

- **Unit**
- **White-box**
- **Black-box**
- **Gray-box**
- **Bottom-up**
- **Top-down**
- **Boundary condition**
- **Syntax-driven**
- **Big bang**
- **Integration**
- **Acceptance**
- **Stress**
- **Regression**
- **Alpha**
- **Beta**
- **etc**
Picking Test Cases

- A goal of picking a test case is that it be characteristic of a class of other tests
- That is, one case builds confidence in how other cases will perform

Cover the behavior space

- The overall objective is to cover as much of the behavior space as possible
  » It’s an infinite space ...
- In general, it’s useful to distinguish the notions of common vs. unusual cases for testing

Black box testing

- Treat the unit under test as a black box
  » You can hypothesize about the way it is built, but you can’t see inside it
- Depend on a specification, formal or informal, for determining whether it behaves properly
- How to pick cases that cover the space of behaviors for the unit?
  » equivalence partitioning, boundary values, etc
  » independent testers

Equivalence partitioning

- Based on input conditions
  » If input conditions are specified as a range, you have one valid class (in the range) and two invalid classes (outside the range on each side)
  » If specified as a set, then you can be valid (in the set) or invalid (outside the set)
  » Etc, etc, etc, etc
Boundary values

- Problems tend to arise on the boundaries of input domains than in the middle
- So, extending equivalence partitioning, make sure to pick added test cases that exercise inputs near the boundaries of valid and invalid ranges

Off-the-wall testing

- Real life and real people are not interested in what you thought the specification said
  - Life takes strange turns
  - Users are not focused on treating your program with kid gloves
- When your program is released in the wild, it will get knocked around
  - welcome the comments of the tester who pushes your program to its limits, don’t shout them down

White box testing

- In this approach, the tester has access to the actual software
  - They needn’t guess at the structure of the code, since they can see it
  - The focus tends to shift from how the system behaves to what parts of the code are exercised
    • this can be very useful, and very misleading
- The tester’s challenge: Can you find a defect that leads to a fault that causes a failure?

White box coverage

- In black box, the tests are usually intended to cover the space of behavior
- In white box, the tests are usually intended to cover the space of parts of the program
Statement coverage

- One approach is to cover all statements
  » Develop a test suite that exercises all of a program’s statements
- What’s a statement?

\[
\text{max} = (x > y) \ ? x : y;
\]

\[
\text{if} \ x > y \ \text{then}
\]
\[
\text{max} := x
\]
\[
\text{else}
\]
\[
\text{max} := y
\]
\[
\text{endif}
\]

Weakness

- Coverage may miss some obvious issues
  » In this example a single test (any negative number for \(x\)) covers all statements
  » But it’s not satisfying with respect to input condition coverage, for example

\[
\text{if} \ x < 0 \ \text{then}
\]
\[
\ x := \ -x;
\]
\[
\text{endif};
\]
\[
\ z := x;
\]

More Coverage

- Edge coverage
  » Use control flow graph (CFG) representation of a program
  » Ensure that the suite covers all edges in the CFG
- Condition coverage
  » Complex conditions can confound edge coverage
    - is this a single conditional statement in the CFG?
    - How are short-circuit conditionals handled?
- Path coverage
  » Edge coverage is in some sense very static
  » Edges can be covered without covering paths (sequences of edges)
  » Paths are better models of the actual execution

Path Coverage and Loops

- In general, we can’t bound the number of times a loop executes
- So there are unbounded number of paths in general
  » We resort to heuristics like those from black box testing to exercise these loops
Some more practical aspects

- Who tests the tests, especially a large complicated test?
  » If your test program generates random data, who confirms the results?
  » Another example is testing trig functions.
- Testing the error cases can be a wider set of inputs. You have two problems
  » Making sure you have proper test coverage and
  » Making sure the results are correct.
- Fault injection is another way of testing systems.
  » For example, injecting I/O failures in a disk controller can test the error cases for the disk driver and file system.
  » Another example is injecting memory allocation errors, to see how programs behave when they run out of memory.

Final note on testing

- It’s unsound and based on heuristics
  
- It’s extremely useful and important

- Good testing requires a special mindset
  » “I’m going to find a way to make that system fail!”
  » “My test case is a success - it found a system problem.”
- Good coding requires a special mindset
  » “Nobody’s going to break my code!”
  » “Good thing we found the failure now, not in real life.”