SE 2AA4, CS 2ME3 (Introduction to Software Development)

Winter 2018

35 Analysis (Ch. 6) DRAFT

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March 14, 2018

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- Administrative details
- Module testing
- Integration testing
- Testing OO programs
- Testing concurrent and real-time systems
- Mutation testing
- Analysis
  - Code walk throughs and inspections
  - Correctness proofs
  - Symbolic execution
  - Model checking
- Debugging

Administrative Details

TBD

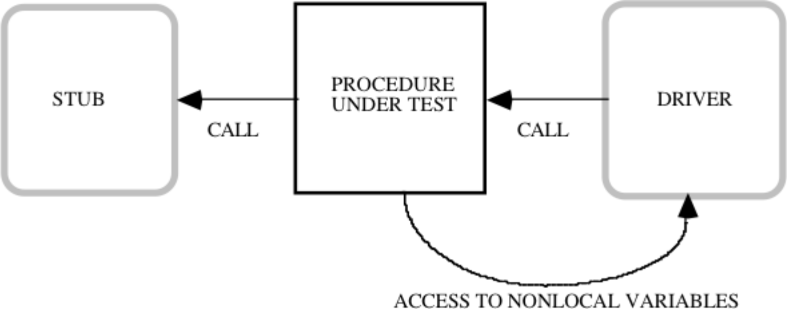
The Oracle Problem Continued

- Devising an oracle for concurrent and real time systems
  - The challenge is not coming up with the oracle
  - The challenge is having adequate test coverage (or analysis) of all of the cases (more on this later)
- Other examples where an oracle is challenging to devise
  - Artificial general intelligence
  - Machine learning
  - Simulation with random numbers

Module Testing

- Scaffolding needed to create the environment in which the module should be tested
- Stubs - a module used by the module under test
- Driver - module activating the module under test

Testing a Functional Module



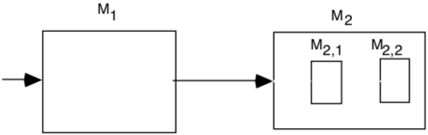
Integration Testing

- Big-bang approach
  - First test individual modules in isolation
  - Then test integrated system
- Incremental approach
  - Modules are progressively integrated and tested
  - Can proceed both top-down and bottom-up according to the USES relation

Integration Testing and USES relation

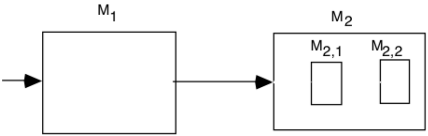
- If integration and test proceed bottom-up only need drivers
- Otherwise if we proceed top-down only stubs are needed

Example



- M_1 USES M_2 and M_2 IS_COMPOSED_OF $\{M_{2,1}, M_{2,2}\}$
- In what order would you test these modules?

Example

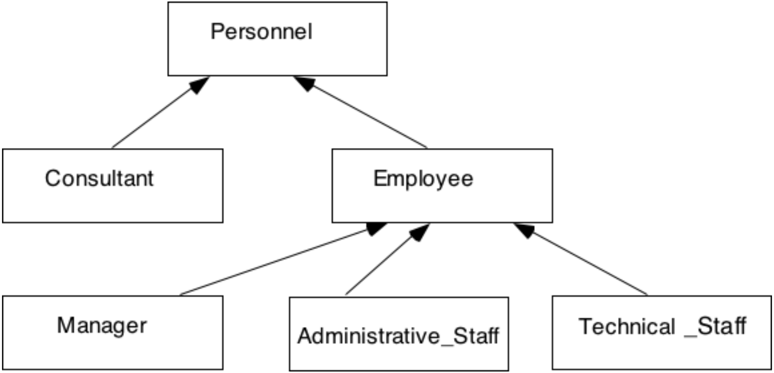


- M_1 USES M_2 and M_2 IS_COMPOSED_OF $\{M_{2,1}, M_{2,2}\}$
- Case 1
  - Test M_1 providing a stub for M_2 and a driver for M_1
  - Then provide an implementation for $M_{2,1}$ and a stub for $M_{2,2}$
- Case 2
  - Implement $M_{2,2}$ and test it by using a driver
  - Implement $M_{2,1}$ and test the combination of $M_{2,1}$ and $M_{2,2}$ (i.e. M_2) by using a driver
  - Finally implement M_1 and test it with M_2 using a driver for M_1

Testing OO and Generic Programs

- New issues
  - Inheritance
  - Genericity
  - Polymorphism
  - Dynamic binding
- Open problems still exist

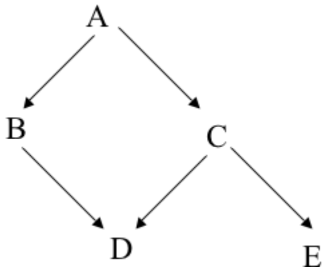
Inheritance



How to Test Classes of the Hierarchy

How would you approach testing for a class hierarchy?

How to Test Classes of the Hierarchy



- "Flattening" the whole hierarchy and considering every class as totally independent component
- This does not exploit incrementality
- Finding an ad-hoc way to take advantage of the hierarchy
- Think about testing PointT.java and PointMassT.java

A Sample Strategy

- A test that does not have to be repeated for any heir
- A test that must be performed for heir class X and all of its further heirs
- A test that must be redone by applying the same input data, but verifying that the output is not (or is) changed
- A test that must be modified by adding other input parameters and verifying that the the output changes accordingly

Testing Concurrent and Real-time Systems

What are the challenges for testing concurrent and real-time systems?

Testing Concurrent and Real-time Systems

- Nondeterminism inherent in concurrency affects repeatability
- For real-time systems, a test case consists not only of input data, but also of the times when such data are supplied
- Many potential time traces for the different inputs
- System changes depends on the control actions
- Considerable care and detail when testing real-time systems

Testing your Tests

- How did we estimate the number of errors in our code?
- Can any of the ideas from estimating the number of errors in our code be used to test our tests?

Testing your Tests: Mutation Testing

- Generate changes to the source code, called mutants, which become code faults
- Mutants include changing an operation, modifying constants, changing the order of execution, etc.
- The adequacy of a set of tests is established by running the tests on all generated mutants

Analysis Versus Testing

- Testing characterizes a single execution
- Analysis characterizes a class of executions; it is based on a model
- They have complementary advantages and disadvantages

Informal Analysis Techniques and Code Walkthroughs

- Recommended prescriptions
  - Small number of people (three to five)
  - Participants receive written documentation from the designer a few days before the meeting
  - Predefined duration of the meeting (a few hours)
  - Focus on the discovery of errors, not on fixing them
  - Participants: designer, moderator, and a secretary
  - Foster cooperation; no evaluation of people
  - Experience shows that most errors are discovered by the designer during the presentation, while trying to explain the design to other people
- Forces looking at the code from a different viewpoint
- Can be used for documentation too

Informal Analysis Techniques Code Inspection

- A reading technique aiming at error discovery
- Based on checklists
  - Use of uninitialized variables
  - Jumps into loops
  - Nonterminating loops
  - Array indexes out of bounds

Correctness Proofs

- Formal program analysis is a verification aid that may enhance program reliability
- Mathematically prove that the program's semantics implies its specification
- Can use pre and post conditions
- We can prove correctness of operations (like those on an abstract data type)
- Use the proof of operations to prove fragments that operate on the objects of an ADT
- Tabular expressions can be proven to match between specification of requirements and a specification of the design
- In many cases verification can be automated, at least partially

Assessment of Correctness Proofs

- Not often used in practice
- However
  - May be used for very critical portions
  - Assertions may be the basis for a systematic way of inserting runtime checks
  - Proofs may become more practical as more powerful support tools are developed
  - Knowledge of correctness theory helps programmers being rigorous

Symbolic Execution

- Can be viewed as a middle way between testing and analysis
- Executes the program on symbolic values
- One symbolic execution corresponds to many actual executions

Model Checking

- Correctness verification, in general, is an undecidable problem
- Model checking is a recent verification technique based on the fact that most interesting system properties become decidable (algorithmically verifiable) when the system is modelled as a finite state machine

Model Checking Continued

- Describe a given system - software or otherwise - as an FSM
- Express a given property of interest as a suitable formula
  - Does a computation exist that allows a process to enter a critical region?
  - Is there a guarantee that a process can access shared resources?
- Verify whether the system's behaviour does indeed satisfy the desired property
  - This step can be performed automatically
  - The model checker either provides a proof that the property holds or gives a counter example in the form of a test case that exposes the system's failure to behave according to the property

Why so Many Approaches to Testing and Analysis?

- Testing versus (correctness) analysis
- Formal versus informal techniques
- White-box versus black-box techniques
- Techniques in the small/large
- Fully automatic versus semi-automatic techniques (for undecidable problems)
- ...

View all of these as complementary

Debugging

What approaches do you use for debugging?

Debugging

- The activity of locating and correcting errors
- It can start once a failure has been detected
- The goal is closing the gap between a fault and a failure
  - Memory dumps, watch points
  - Intermediate assertions can help
  - Tools like gdb, valgrind, etc.
- Incremental integration tests helps
- Incrementally add complexity to test cases
- Like investigating an experiment - one controlled variable at a time

Verifying Performance

How might you measure/assess performance?

Verifying Performance

- Worst case analysis versus average behaviour
- For worst case focus on proving that the system response time is bounded by some function of the external requests
- Standard deviation
- Analytical versus experimental approaches
- Consider verifying the performance of a pacemaker
- Visualize performance via
  - Identify a measure of performance (time, storage, FLOPS, accuracy, etc.)
  - Identify an independent variable (problem size, number of processors, condition number, etc.)

Verifying Reliability

- There are approaches to measuring reliability on a probabilistic basis, as in other engineering fields
- Unfortunately there are some difficulties with this approach
- Independence of failures does not hold for software
- Reliability is concerned with measuring the probability of the occurrence of failure
- Meaningful parameters include
  - Average total number of failures observed at time t: $AF(t)$
  - Failure intensity: $FI(T) = AF'(t)$
  - Mean time to failure at time t: $MTTF(t) = 1/FI(t)$
- Time in the model can be execution or clock or calendar time

Verifying Subjective Qualities

- What do you think is meant by empirical software engineering?
- What problems might be studied by empirical software engineering?
- Does the usual engineering analogy hold for empirical software engineering?

Verifying Subjective Qualities

- Consider notions like simplicity, reusability, understandability
- Software science (due to Halstead) has been an attempt
- Tries to measure some software qualities, such as abstraction level, effort,
- by measuring some quantities on code, such as
  - η_1, number of distinct operators in the program
  - η_2, number of distinct operands in the program
  - N_1, number of occurrences of operators in the program
  - N_2, number of occurrences of operands in the program
- Extract information from repo, including number of commits, issues etc.
- Empirical software engineering
- Appropriate analogy switches from engineering to medicine

Source Code Metric

- What are the consequences of complex code?
- How might you measure code complexity?

McCabe's Source Code Metric

- Cyclomatic complexity of the control graph
  - $C = e - n + 2p$
  - e is number of edges, n is number of nodes, and p is number of connected components
- McCabe contends that well-structured modules have C in range 3..7, and $C = 10$ is a reasonable upper limit for the complexity of a single module
- Confirmed by empirical evidence