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

Winter 2018

35 Analysis (Ch. 6)

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35 Analysis (Ch. 6)

- 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

- Today's slide are partially based on slides by Dr. Wassyng
- A4: Due April 9 at 11:59 pm
- Final tutorials on Friday, Apr 6
- Course evaluations
  - https://evals.mcmaster.ca
  - Start: Tues, Mar 27, 10:00 am
  - Close: Tues, Apr 10, 11:59 pm
  - Your participation is highly valued
  - Grade bonus for class participation
- Provide course feedback in last lecture

Unix Command of the Day: grep

- Search for the lines in a collection of data that match a specified pattern
- From `se2aa4_cs2me3/Lectures`
  - `grep -r Parnas . > parnas.txt`
  - `grep -c L04 parnas.txt`
  - `grep -c 'L0.'  parnas.txt`

Strategies Without An Oracle

- Using an independent program to approximate the oracle (pseudo oracle)
- Method of manufactured solutions
- Properties of the expected values can be easier than stating the expected output
  - Examples?

Strategies Without An Oracle

- Using an independent program to approximate the oracle (pseudo oracle)
- Method of manufactured solutions
- Properties of the expected values can be easier than stating the expected output
  - List is sorted
  - Number of entries in file matches number of inputs
  - Conservation of energy or mass
  - Expected trends in output are observed (metamorphic testing)
  - etc.

Metamorphic Testing

- Used for testing when there is no test oracle
- Test program has properties known as Metamorphic Relations (MR)
- MRs specify how a change in inputs should change the output
- For instance (KanewalaEtAl2014)
  - Finding the maximum of a list should be the same no matter the permutation of the list
  - The average of a set of numbers will increase if each number added is larger than all previous numbers added
  - Etc.
- Metamorphic testing gets its name because new test cases are evolved from the old ones (ChenEtAl1998)

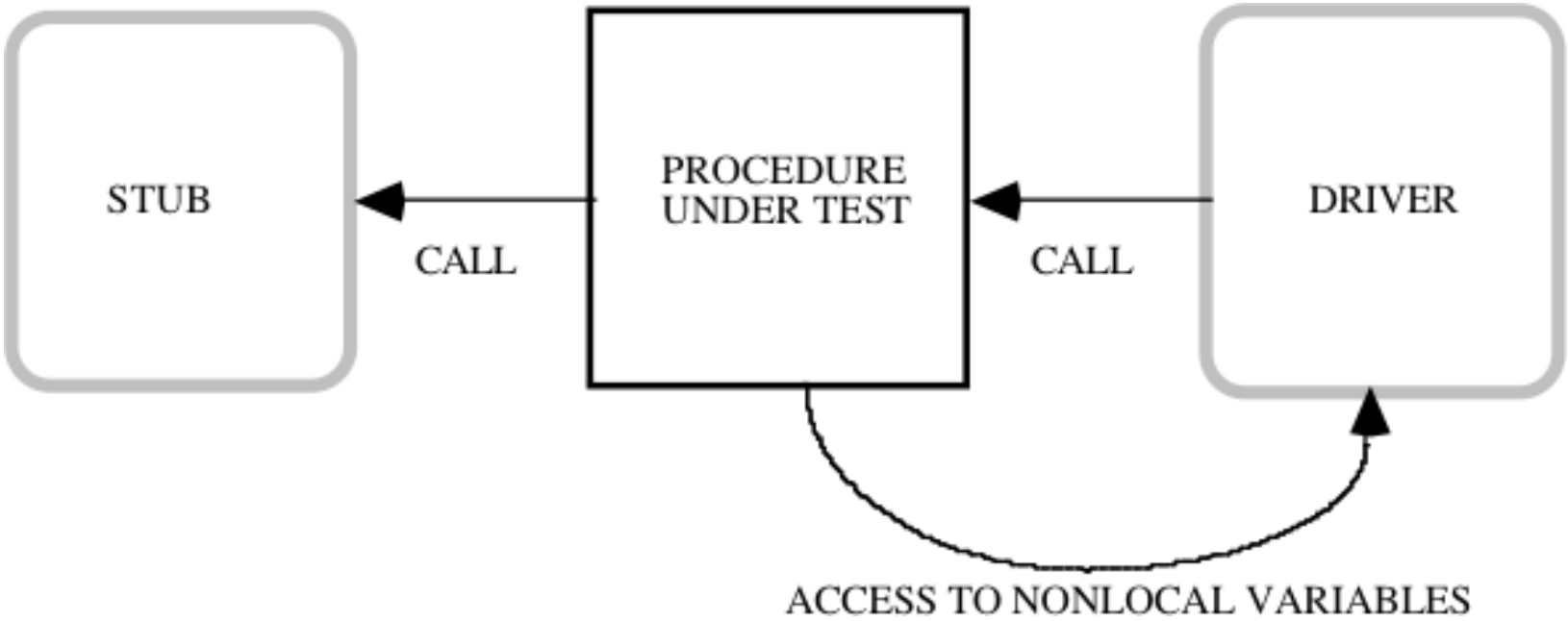
Module Testing

Is it possible to begin testing before all of the modules have been implemented when there is a use relation between modules?

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



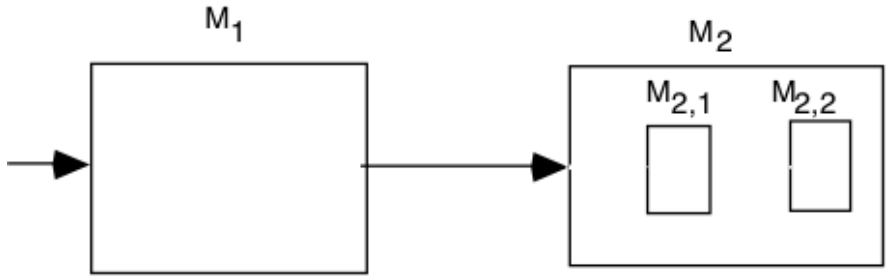
Integration Testing

- 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

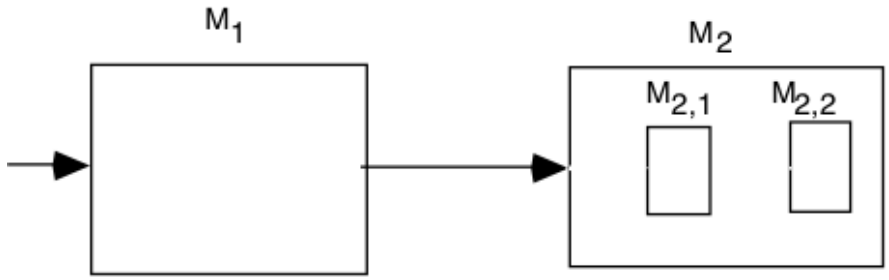
- If integration and test proceed bottom-up only need drivers
- Otherwise if we proceed top-down only stubs are needed

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

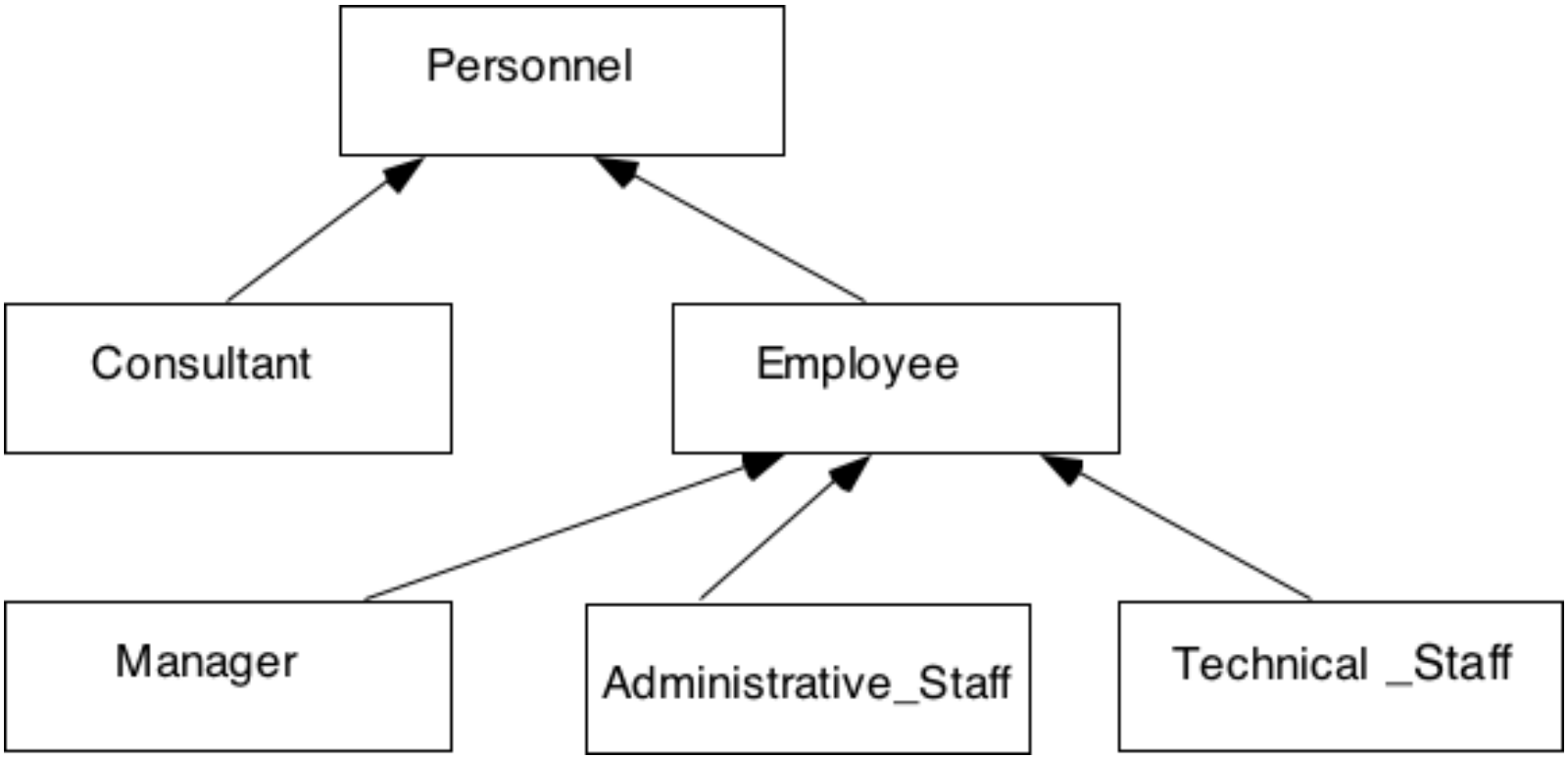


- M_1 USES M_2 and M_2 IS_COMPOSED_OF $\{M_{2,1}, M_{2,2}\}$
- Case 1
  - Test M_1 providing a stub for M_2 and a driver for M_1
  - Then provide an implementation for $M_{2,1}$ and a stub for $M_{2,2}$
- Case 2
  - Implement $M_{2,2}$ and test it by using a driver
  - Implement $M_{2,1}$ and test the 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

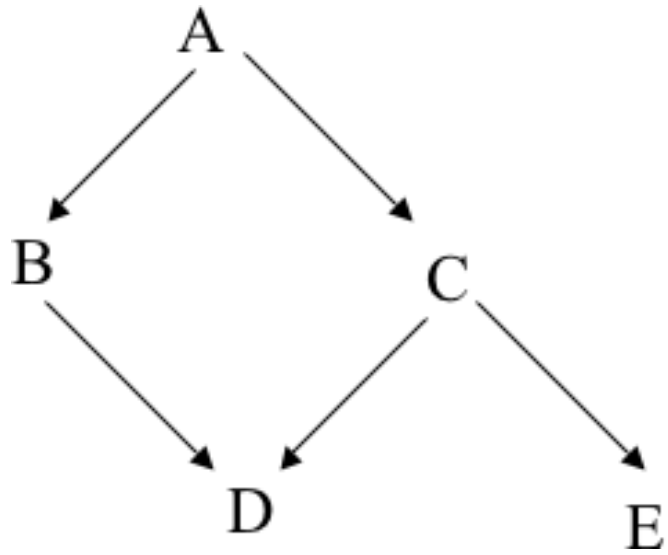
Inheritance



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.py and PointMassT.py

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