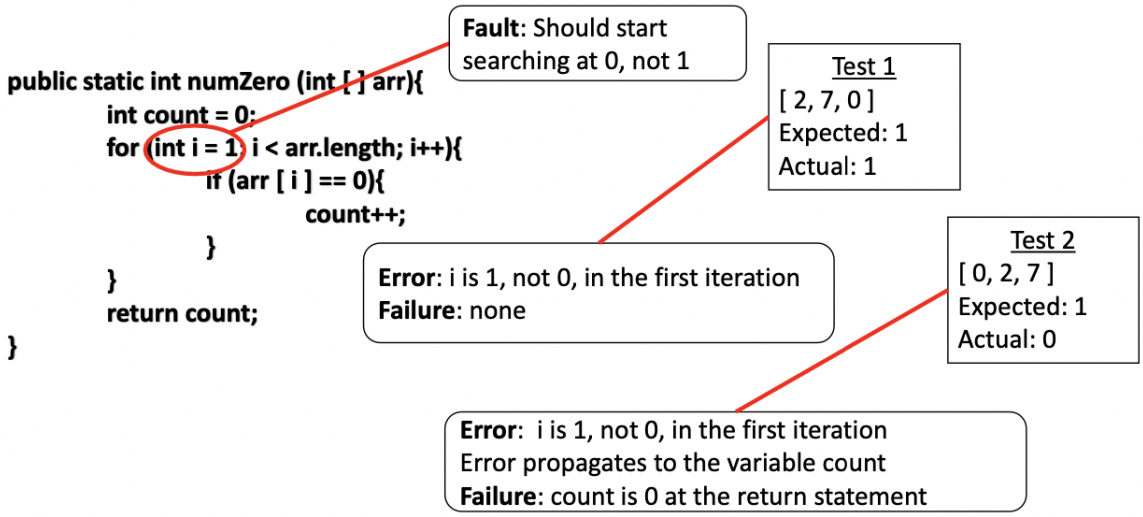
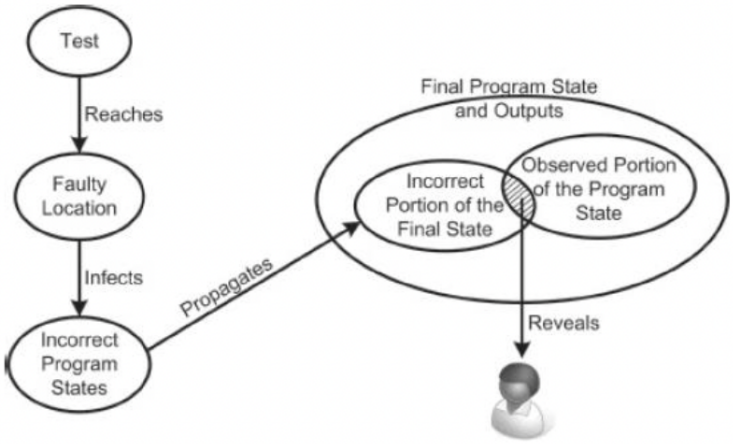
Lecture 5 - Software Testing

- What is Software Testing?
  - Running a program in order to find faults
    - Examining the code without execution is not testing
  - The main practical approach to validate/verify software
    - Formal methods that aim at proving the correctness of a program are not scalable
  - "Program testing can be used to show the presence of bugs, but never to show their absence!" – Edsger W. Dijkstra
- Testing Levels
  - Acceptance testing
    - Test whether the software is acceptable to the user
  - System testing
    - Test the overall functionality of the system
  - Integration testing
    - Test how modules interact with each other
  - Module testing
    - A module is a collection of related units the are assembled in a file, package, or class
    - Test modules in isolation including how the components interact with each other
    - Responsibility of the programmer
  - Unit testing
    - Test units (methods individually)
    - Responsibility of the programmer
- Black-Box and White-Box Testing
  - Black-Box Testing
    - Test are derived from external descriptions of the software
  - White-Box Testing
    - Test are derived from source code internals of the software
    - More expensive to apply
- Why is Software Testing Hard?
  - Exhaustive testing is infeasible
    - e.g. Exhaustively testing a method with two integer parameters would require $\sim 10^{19}$ tests
  - Random/statistical testing is not effective
- Why Do We Test Software?
  - Software is everywhere
    - Communication, transportation, healthcare, finance, education, etc.
  - Software failures could have severe consequences
    - A 2002 NIST report estimated that defective software costs the U.S. economy $59.5 billion per year and that improvements in testing could reduce this cost by about a third
    - In certain areas such as healthcare and transportation, software failures could cost lives

- Infamous Software Failures
  - Northeast blackout of 2003
    - Caused by a failure of the alarm system
    - Affected 40 million people in USA and 10 million people in Canada
    - Contributed to at least 11 deaths
    - Cost around $6 billion
  - Ariane 5 explosion (1996)
    - Unhandled floating point conversion exception
    - Estimated loss: $370 million
  - NASA's Mars lander (1999)
    - Crashed due to an integration fault
    - Estimated loss: $165 million
  - Boeing 737 Max
    - Crashed due to overly aggressive software flight overrides
  - Boeing A220
    - Engines failed after software update allowed excessive vibrations
  - Toyota brakes failure
    - Dozens dead
    - Thousands of crashes
  - Therac-25 radiation therapy machine
    - Three patients were killed[o]
- Fault/Error/Failure
  - ***Software Fault***: A static defect in the software
  - ***Software Error***: An incorrect internal state that is the manifestation of some fault
  - ***Software Failure***: External, incorrect behavior with respect to the requirements or another description of the expected behaviour
  - The term ***bug*** is often used informally to refer to all three of fault, error, and failure
    - The first computer bug was an actual bug!
  - Example

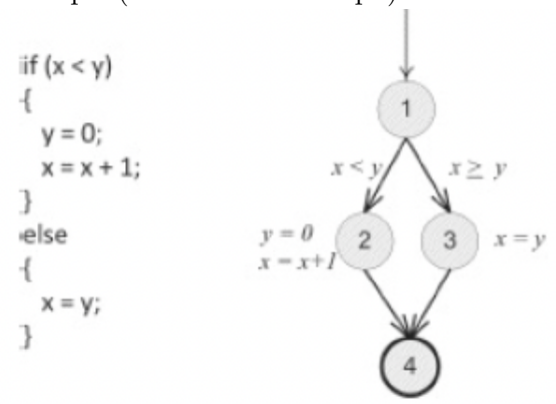


- The RIPR model
  - Four conditions are needed for a failure to be observed
    1. ***Reachability***: a test must reach the location in the program that contains the fault
    2. ***Infection***: After the faulty location is executed, the state of the program must be incorrect
    3. ***Propagation***: The infected state must propagate through the rest of the execution and cause some output or final state of the program to be incorrect
    4. ***Revealability***: The tester must observe part of the incorrect portion of the final program state



- Criteria-based Test Design
  - ***Coverage Criterion***: A rule or collection of rules that impose test requirements on a test set
    - e.g. For each statement in the code, there should be at least one test case that covers it
  - Coverage criteria give us structured, practical ways to search the input space. Satisfying a coverage criterion gives a tester some amount of confidence in two crucial goals:
    1. We have looked in many corners of the input space, and
    2. Our tests have a fairly low amount of overlap
  - Criteria subsumption
    - C_1 subsumes C_2 if and only if every test set that satisfies C_1 satisfies C_2
- Graph Coverage
  - The software is modeled as a graph where nodes and edges could represent:
    - Methods and calls
    - Statements and branches
    - Etc.
  - Coverage criteria are defined based on the graph. For example:
    - Cover every node
    - Cover every edge
    - Cover every path
    - Etc.

– Example (Control Flow Graph)



- Logic Coverage
  - Involves the boolean expressions of the code
  - Coverage criteria include:
    * Predicate coverage
    * Clause coverage
    * Combinational coverage
    * Etc.
  - Example

```
if(((a>b) || c) && (x<y))
...
else
...
```

  - Predicate coverage
    * The test set should make each predicate evaluate to true and false
    * e.g. $((a > b) \,||\, c) \,\&\&\, (x < y) = \{\text{True}, \text{False}\}$
  - Clause coverage
    * The test set should make each clause evaluate to true and false
    * e.g. $(a > b) = \{\text{True}, \text{False}\}, c = \{\text{True}, \text{False}\}, (x < y) = \{\text{True}, \text{False}\}$
- Active clause coverage
  - Clause coverage has a weakness
    * The values do not always make a difference
  - A clause c_i in predicate p, called the major clause, determines p *if and only if* the values of the remaining minor clauses c_j are such that changing c_i changes the value of p
  - Two requirements for each c_i: c_i evaluates to true and c_i evaluates to false
  - This is a form of MCDC, which is required by the FAA for safety critical software
- Inactive clause coverage
  - Ensures that "major" clauses do not affect the predicates
  - Four requirements for each c_i
    1. c_i evaluates to true with p true
    2. c_i evaluates to false with p true
    3. c_i evaluates to true with p false
    4. c_i evaluates to false with p false

  - Example
    * Testing the control software for a shutdown system in a reactor where the specification states that the status of a particular valve (**open** vs. **closed**) is relevant to the reset operation in **Normal** mode, but not in **Override** mode

- Test Oracles
  - A *test oracle* is an encoding of the expected results of a given test
    * e.g. JUnit assertion
  - Must strike a balance between checking too much (unnecessary cost) and checking too little (perhaps not revealing failures)
  - What should be checked?
    * The output state is everything that is produced by the software under test, including outputs to the screen, file, databases, messages, and signals
    * Each test should have a goal and testers should check the output(s) that are mainly related to that goal
      · At the unit testing level, checking the return values of the methods and returned parameter values are almost always enough
      · At the system level, it is usually sufficient to check the directly visible output such as to the screen
  - How to determine what the correct results are
    * Specification-Based direct verification of outputs
      · e.g. "a **sort** program should produce a permutation of its input in increasing order "
      · Specifications are hard to write
    * Redundant computations
      · Refer to another trustworthy implementation of the program
      · Usually used for regression testing
    * Consistency checks
      · Check whether certain properties hold (e.g. a value representing probability should neither be negative nor larger than one)