

Goals of testing

- **Reveal faults**
 - Correctness
 - Reliability
 - Usability
 - Robustness
 - Performance

Top-down/Bottom-up

- **Bottom-up**
 - **Lowest level modules tested first**
 - Don't depend on any other modules
 - Driver
 - Auxiliary code that calls the module
- **Top-down**
 - **Executive module tested first**
 - Stub
 - Auxiliary code that simulates the results of a routine

Facts About Testing

- Question "does program P obey specification S" is undecidable!
- Every testing technique embodies some compromise between accuracy and computational cost
- **Facts**
 - Inaccuracy is not a limitation of the technique
 - It is theoretically impossible to devise a completely accurate technique
 - Every practical technique must sacrifice accuracy in some way

Cost/benefit

- Testing takes more than 50% of the total cost of software development
 - **More for critical software**
- Software quality will become the dominant success criterion

Types of Verification

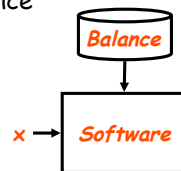
- Execution-based Verification
- Non-execution based Verification
- Discussion

Execution-based Verification

- Generating and *executing* test cases on the software
- Types of testing
 - Testing to specifications
 - Black-box testing
 - Testing to code
 - Glass-box (white-box) testing
 - Remember: difference is in generating test cases only! Verification of correctness is usually done via specifications in both cases

Black-box Testing

- Discussion: MAC/ATM machine example
 - Specs
 - Cannot withdraw more than \$300
 - Cannot withdraw more than your account balance



White-box Testing

- Example

```
x: 1..1000;
1 INPUT-FROM-USER(x);
  If (x <= 300) {
2     INPUT-FROM-FILE(BALANCE);
    If (x <= BALANCE)
3       GiveMoney x;
4     else Print "You don't have $x in your account!!"
  }
  else
5     Print "You cannot withdraw more than $300";
6 Eject Card;
```

Discussion

- Which is superior?
- Neither can be done exhaustively
 - Too many test cases
- Each technique has its strengths - use both
 - Generally, first use black-box
 - Then white-box for missed code
- Accept that all faults cannot be detected
 - When to stop?

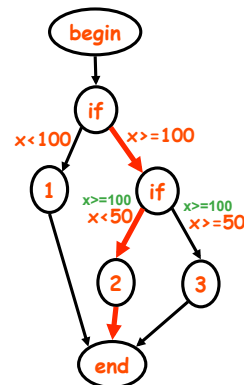
Determining Adequacy

- Statement coverage
 - Statements
- Branch coverage
 - Both IF and ELSE
- Path coverage
- All-def-use-path coverage
- Philosophy: what does it all mean?
 - Does coverage guarantee absence of faults?
- Can we always get 100% coverage?

Surprise Quiz

- Determine test cases so that each **print statement** is executed at least once

```
input(x);  
if (x < 100)  
    print "Line 1";  
else {  
    if (x < 50) print "Line 2";  
    else print "Line 3";  
}
```



Sampling the State Space

- If ($i == j$)
 - Do something wrong
- Else
 - Do the right thing
- Endif
- Uniform sampling of the input space
- Test adequacy criteria
 - Designed to insure behaviors chosen are appropriately distributed to increase the likelihood of revealing errors

Non-execution Based

- Key idea
 - Review by a team of experts: syntax checker?
- Code readings
- Walkthroughs
 - Manual simulation by team leader
- Inspections
 - Developer narrates the reading
- Formal verification of correctness
 - Very expensive
 - Justified in critical applications
- Semi-formal: some assertions

Non-execution Based

- JPL
 - On the average, 2 hour inspection
 - 4 major and 14 minor faults
 - Saved \$25,000 per inspection
- Rate of faults
 - Decreases exponentially by phase
- Cleanroom approach
 - Incremental development, formal specs and design, readings, inspections

Simulation

- Integration with system hardware is central to the design
- Model the external hardware
- Model the interface
- Examples
- Discussion

Boundary-value Analysis

- Partition the program domain into input classes
- Choose test data that lies both inside each input class and at the boundary of each class
- Select input that causes output at each class boundary and within each class
- Also known as stress testing

Testing Approaches

- Top-down
- Bottom-up
- Big bang

- Unit testing
- Integration testing
- Stubs
- System testing

Glossary

- Fault
 - An incorrect step, process, or data definition in a computer program
- Error (ISO)
 - A discrepancy between a computed, observed, or measured value or condition and the true, specified, or theoretically correct value or condition
- Failure (IEEE)
 - The inability of a system or component to perform its required functions within specified performance requirements

Glossary

- Exception (IEEE)
 - An event that causes suspension of normal program operation. Types include addressing exception, data exception, operation exception, overflow exception, protection exception, underflow exception
- Anomaly (IEEE)
 - Anything observed in the documentation or operation of software that deviates from expectations based on previously verified software products or reference documents

Structural Testing

- Coverage-based testing
 - Test cases to satisfy statement coverage
 - Or branch coverage, etc
- Complexity-based testing
 - Cyclomatic complexity
 - Graph representation
 - Find the basis set
 - # Of braches + 1

Mutation Testing

- Errors are introduced in the program to produce "mutants"
- Run test suite on all mutants and the original program

Test Case Generation

- Test input to the software
- Some researchers/authors also define the test case to contain the **expected output** for the test input

Category-partition Method

- **Key idea**
 - **Method for creating functional test suites**
 - **Role of test engineer**
 - Analyze the system specification
 - Write a series of formal test specifications
 - **Automatic generator**
 - Produces test descriptions

AI Planning Method

- **Key idea**
 - **Input to command-driven software is a sequence of commands**
 - **The sequence is like a plan**
- **Scenario to test**
 - **Initial state**
 - **Goal state**

Example

- VCR command-line software
- Commands
 - Rewind
 - If at the end of tape
 - Play
 - If fully rewound
 - Eject
 - If at the end of tape
 - Load
 - If VCR has no tape

Preconditions & Effects

- Rewind
 - Precondition: if at end of tape
 - Effects: at beginning of tape
- Play
 - Precondition: if at beginning of tape
 - Effects: at end of tape
- Eject
 - Precondition: if at end of tape
 - Effects: VCR has no tape
- Load
 - Precondition: if VCR has no tape
 - Effects: VCR has tape

Preconditions & Effects

- Rewind
 - Precondition: end_of_tape
 - Effects: ¬end_of_tape
- Play
 - Precondition: ¬end_of_tape
 - Effects: end_of_tape
- Eject
 - Precondition: end_of_tape
 - Effects: ¬has_tape
- Load
 - Precondition: ¬has_tape
 - Effects: has_tape

Initial and Goal States

- Initial state
 - end_of_tape
- Goal state
 - ¬end_of_tape
- Plan?
 - Rewind

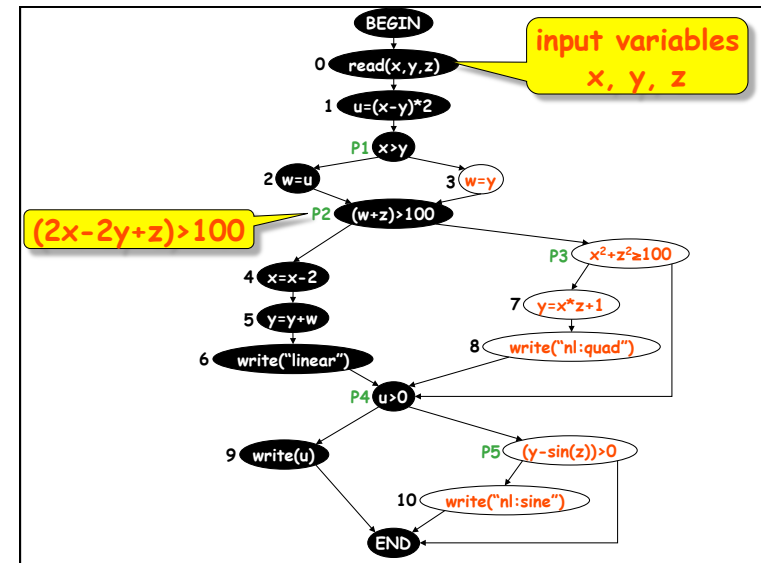
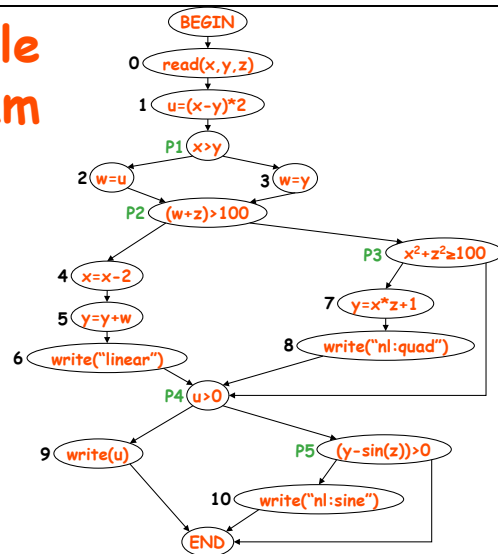
Initial and Goal States

- Initial state
 - $\neg \text{end_of_tape}$ & has_tape
- Goal state
 - $\neg \text{has_tape}$
- Plan?
 - Play
 - Eject

Iterative Relaxation

- Key idea
 - Path-oriented testing
 - Problem: generation of test data that causes a program to follow a given path
- Technique
 - Choose arbitrary input
 - Iteratively refine it until all the branch predicates on the given path evaluate to the desired outcome

Example Program



Test Coverage & Adequacy

- How much testing is enough?
- When to stop testing
- Test data selection criteria
- Test data adequacy criteria
 - Stopping rule
 - Degree of adequacy
- Test coverage criteria
- Objective measurement of test quality

Preliminaries

- Test data selection
 - What test cases
- Test data adequacy criteria
 - When to stop testing
- Examples
 - Statement coverage
 - Branch coverage
 - Def-use coverage
 - Path coverage

Goodenough & Gerhart ['75]

- What is a software test adequacy criterion
 - Predicate that defines "what properties of a program must be exercised to constitute a thorough test", i.e., One whose successful execution implies no errors in a tested program

Uses of Test Adequacy

- Objectives of testing
- In terms that can be measured
 - For example branch coverage
- Two levels of testing
 - First as a stopping rule
 - Then as a guideline for additional test cases

Categories of Criteria

- Specification based
 - All-combination criterion
 - Choices
 - Each-choice-used criterion
- Program based
 - Statement
 - Branch
- Note that in both the above types, the correctness of the output must be checked against the specifications

Others

- Random testing
- Statistical testing

Classification according to underlying testing approach

- Structural testing
 - Coverage of a particular set of elements in the structure of the program
- Fault-based testing
 - Some measurement of the fault detecting ability of test sets
- Error-based testing
 - Check on some error-prone points

Structural Testing

- Program-based structural testing
 - Control-flow based adequacy criteria
 - Statement coverage
 - Branch coverage
 - Path coverage
 - Length-i path coverage
 - Multiple condition coverage
 - All possible combinations of truth values of predicates
 - Data-flow based adequacy criteria

Structural Testing

- Data-flow based adequacy criteria
 - All definitions criterion
 - Each definition to some reachable use
 - All uses criterion
 - Definition to each reachable use
 - All def-use criterion
 - Each definition to each reachable use

Fault-based Adequacy

- Error seeding
 - Introducing artificial faults to estimate the actual number of faults
- Program mutation testing
 - Distinguishing between original and mutants
 - Competent programmer assumption
 - Mutants are close to the program
 - Coupling effect assumption
 - Simple and complex errors are coupled

Test Oracles

- Discussion
 - Automation of oracle necessary
 - Expected behavior given
 - Necessary parts of an oracle

Test Oracle

- A test oracle determines whether a system behaves correctly for test execution
- Webster dictionary - oracle
 - A person giving wise or authoritative decisions or opinions
 - An authoritative or wise expression or answer

Purpose of Test Oracle

- Sequential systems
 - Check functionality
- Reactive (event-driven) systems
 - Check functionality
 - Timing
 - Safety

Reactive Systems

- Complete specification requires use of multiple computational paradigms
- Oracles must judge all behavioral aspects in comparison with all system specifications and requirements
- Hence oracles may be developed directly from formal specifications

Parts of an Oracle

- Oracle information
 - Specifies what constitutes correct behavior
 - Examples: input/output pairs, embedded assertions
- Oracle procedure
 - Verifies the test execution results with respect to the oracle information
 - Examples: equality
- Test monitor
 - Captures the execution information from the run-time environment
 - Examples
 - Simple systems: directly from output
 - Reactive systems: events, timing information, stimuli, and responses

Regression Testing

- Developed first version of software
- Adequately tested the first version
- Modified the software; Version 2 now needs to be tested
- How to test version 2?
- Approaches
 - Retest entire software from scratch
 - Only test the changed parts, ignoring unchanged parts since they have already been tested
 - Could modifications have adversely affected unchanged parts of the software?

Regression Testing

- "Software maintenance task performed on a modified program to instill confidence that changes are correct and have not adversely affected unchanged portions of the program."

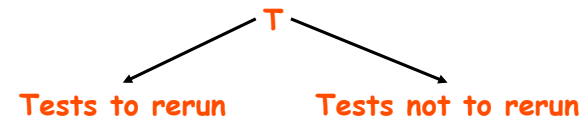
Regression Testing Vs. Development Testing

- During regression testing, an established test set may be available for reuse
- Approaches
 - Retest all
 - Selective retest (selective regression testing) ← main focus of research

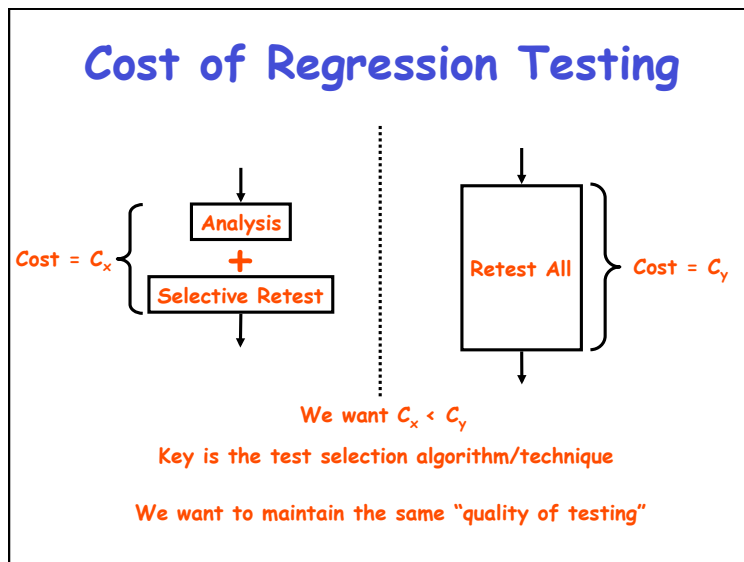
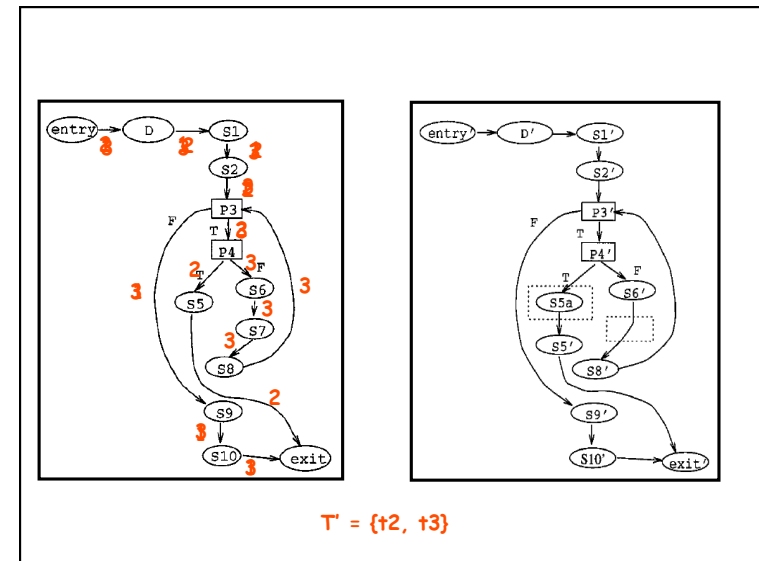
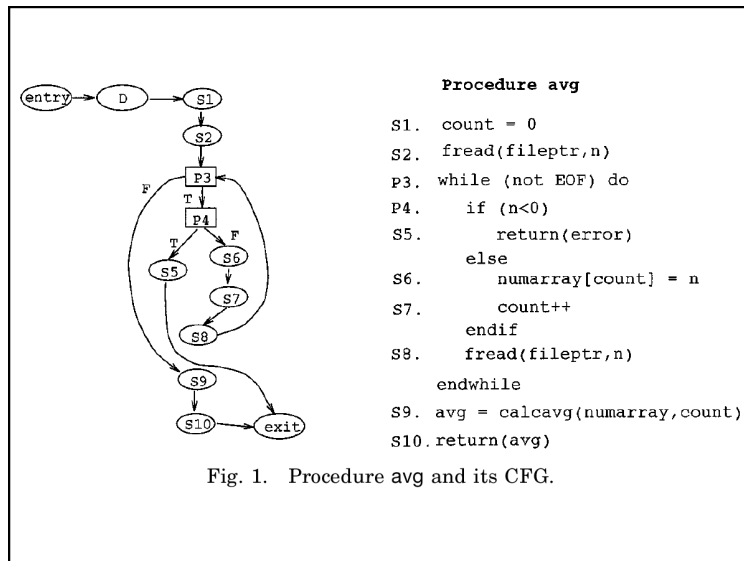
Formal Definition

- Given a program P ,
- Its modified version P' , and
- A test set T
 - Used previously to test P
- Find a way, making use of T to gain sufficient confidence in the correctness of P'

Selective Retesting



- Tests to rerun
 - Select those tests that will produce different output when run on P'
 - Modification-revealing test cases
 - It is impossible to always find the set of modification-revealing test cases - (we cannot predict when P' will halt for a test)
 - Select modification-traversing test cases
 - If it executes a new or modified statement in P' or misses a statement in P that it executed in P



- ### Factors to Consider
- Testing costs
 - Fault-detection ability
 - Test suite size vs. Fault-detection ability
 - Specific situations where one technique is superior to another

Data-flow Testing

