Next Week

- Recorded lecture reviewing 2nd half material (link on Schedule page)
- Look at directions for project submission under Week 10
  - Presentations
  - Project submission

Testing

- Objectives of software testing
- Types of testing
- Testing strategy
- Reflections

Testing Fundamentals

- Coding produces errors
  - Data show 30-85 errors are made per 1000 SLOC
- Testing: processes of executing the code to detect errors
- In practice, it is impossible to check for all possible errors by testing
- Even checking a useful subset is expensive
  - 40%-80% of development cost
  - Must be re-done when software changes
  - Potentially unbounded effort

Testing Fundamentals (2)

- Reality: must settle for testing a subset of possible inputs
  - Even extensively tested software contains 0.5-3 errors per 1000 SLOC
    - Pesticide Paradox: *every method used to prevent or find bugs leaves a residue of subtler bugs against which those methods are ineffectual [Beizer]*
  - Always a tradeoff of cost vs. errors found
- Fundamental cost/benefit questions
  - Which subsets of possible test cases will find the most errors?
  - Which will find the most important errors?
  - How much testing is enough?

Ideal Testing Goal

- Goal: choose a sufficiently small but adequate set of test cases (input domain)
  - Small enough to economically run the complete set and re-run when software changes
  - "Adequate" much harder to define, generally means some combination of:
    - Acceptably close to required functional behavior
    - Contains no catastrophic faults
    - Reliable to an acceptable level (mean time to failure)
    - Within tolerance levels for qualities like performance, security, etc.

Testing Objectives

- Disagreement over best criteria for choosing the test set leads to two general approaches
- Fault Detection: testing intended to find as many faults as possible
- Confidence Building: testing intended to increase confidence that the software works as intended

Why continuing disagreement?

- Both approaches have notable weaknesses
- Fault Detection (bug hunt)
  - Tests according to coverage criteria
  - Equal chance, cost for finding arbitrary error
  - *Implicitly assumes all bugs are equal*, clearly not true in many cases
- Confidence Building (usage emulation)
  - Tests according to expected use
  - Higher chance of finding bugs that users will routinely encounter, misses others
  - *Implicitly assumes that infrequent bugs are unimportant*, also untrue in many cases

Methods by Adequacy Criteria

- Test methods typically classified by the criteria used to choose the test set
- Classification based on the source of information to derive test cases:
  - black-box testing (functional, specification-based)
  - white-box testing (structural, program-based)
- Classification based on the criterion to measure the adequacy of a set of test cases:
  - coverage-based testing
  - fault-based testing
  - error-based testing

White-Box Testing

- Also “clear box”
- Testing strategies based on knowledge of the code within a program or module
- Generally applies one or more forms of *code coverage criteria*
  - Every non-commentary line of code is executed (statement coverage)
  - Every branch is taken (branch coverage)
  - Every block of code is executed (block coverage)
  - Every path is executed (path coverage)
  - Every defined variable is (correctly) used (define-use coverage)

Black-Box Testing

- Testing strategies based on program or module interface specification (but not of the code)
- For module tests:
  - Returned values conform to syntactic and semantic specifications for the interface
  - Inputs beyond parameter bounds, or that violate syntax or semantics, throw exceptions
  - Performance requirements are met (where defined)
- For integration and system tests
  - Sunny day, rainy day scenarios produce expected results
  - Based on requirements, use cases

Coverage Testing

- Looks at internal code structure (white-box)
- Test set adequacy defined by some form of coverage criteria
  - E.g., Proportion of statements executed
- Three common techniques:
  - control-flow coverage
  - data-flow coverage
  - coverage-based testing of requirements

Example: Control Flow Coverage

- Model program as flow graph
  - E.g., branches are nodes with multiple edges
  - An execution is one path through the graph
  - Generally very large number of possible paths
- Adequacy based on coverage of some aspect of the graph, in increasing order:
  - Node coverage: execute each statement
  - Branch coverage: execute each branch
  - Path coverage: execute every path
- % Coverage provides a test-set metric
- Many supporting tools

Control Flow Graph

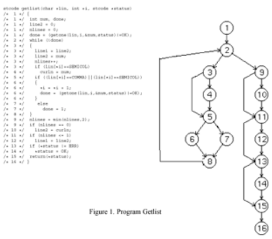
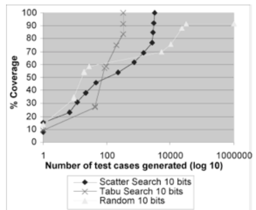


Figure 1. Program Getlist



- Supporting tools
  - Generate flow graphs
  - Generate test cases,
  - Track coverage metrics

Example: Fault-based Testing

- Does not look at code structure (black-box)
- Looks for a test set with a high ability to detect faults
- Two techniques:
  - Fault seeding
  - Mutation testing

Fault Seeding

- Adequacy of test set judged by ability to find seeded errors
  - Seeds errors randomly into the code
  - Look at percentage of seeded errors found
  - Better test sets find more of the seed errors
- Infer that those sets will also find more latent errors
  - Look for high percentage of seeded to latent errors

Example: Operational Scenarios

- Focus on *confidence building* (rather than error-detection), also black-box
- Based on knowledge about how users do or will use the system
  - Inputs based on statistical analysis of actual inputs
  - Inputs based on estimates, use cases, user observation, focus groups, etc.
  - Inputs based on limited deployment (E.g., Netflix, Amazon)
- Supports statistical inference about the likelihood of a failure in actual use (i.e., Cleanroom)
  - Usability requirements
  - Performance requirements
- Misses unlikely events
  - Low-frequency events tend not to be tested (edge cases, exceptions, unpredictable behavior)
  - Some low frequency events are critical

Experimental Results

- There is no uniformly best technique
- Different techniques tend to reveal different types of faults
- Multiple techniques reveal more faults (at a cost)
- Cost-effectiveness of run-time testing is low, particularly compared to inspections (vast majority of tests find no errors)
  - Design review: 8.44
  - Code review: 1.38
  - Testing: 0.17

Interpretation

- A combination of manual and automated techniques is most cost effective
  - People are better at detecting many kinds of errors than machines
  - Machines are better at repetitive checks and minute details (comparing values)
- Testing works best in a supporting role (checking assumptions)
  - Activity of producing test cases and results double-checks other artifacts
    - Is it well enough defined to write a good test case?
    - Are edge cases defined? Etc.
  - Gives feedback on assumptions and expectations: does the system do what we expect?

Quality is Cumulative

Requirements Analysis	• Are the requirements valid? • Complete? Consistent? Implementable? • Testable?
Architectural Design	• Does the design satisfy requirements? • Are all functional capabilities included? • Are qualities addressed (performance, maintainability, usability, etc.?
Detailed Design	• Do the modules work together to implement all the functionality? • Are likely changes encapsulated? • Is every module well defined
Coding	• Implement the required functionality? • Race conditions? Memory leaks? Buffer overflow?

Best Approach

- Start early, test often
  - For every work product, we ask: *How can I find defects as early as possible?*
  - Create test plans and test cases as a way of checking the qualities of requirements, design, etc.
- Use a combination of methods
  - Inspections and reviews of every artifact
  - Testing at every stage possible
    - Manual
    - Module
    - System

Software Testing in Practice

- Most companies' new hires are testers
  - Regarded as less prestigious, lower skilled activity
- Most testing work is manual; help from tools is still limited
- In many cases, testing is not performed using systematic testing methods or techniques
- Often delayed, cut short by schedule pressure
- Sometimes there are "conflicts of interest" between testers and developers
  - Testing should be "destructive" as possible
  - Difficult attitude for developer
- Result is poor return for time/money spent

QA Planning

- Effective testing must be part of the overall plan
  - Fully supported by management (time, budget, skills)
  - Fully integrated into the development plan from the beginning
- Include use and evaluation of results
  - Process for addressing defects found
  - Measures of code quality
  - Measures of test quality and completeness
- Test results must provide feedback for improvement
  - Better QA process
  - Better coding practices, etc.
- Look at example plan

Questions