System, Acceptance, and Regression Testing

Learning objectives

- Distinguish system and acceptance testing
  - How and why they differ from each other and from unit and integration testing
- Understand basic approaches for quantitative assessment (reliability, performance, ...)
- Understand interplay of validation and verification for usability and accessibility
  - How to continuously monitor usability from early design to delivery
- Understand basic regression testing approaches
  - Preventing accidental changes

	System	Acceptance	Regression
Test for ...	Correctness, completion	Usefulness, satisfaction	Accidental changes
Test by ...	Development test group	Test group with users	Development test group
	Verification	*Validation*	Verification

System Testing

- Key characteristics:
  - Comprehensive (the whole system, the whole spec)
  - Based on specification of observable behavior
    - Verification against a requirements specification, not validation, and not opinions
  - Independent of design and implementation

Independence: Avoid repeating software design errors in system test design

Independent V&V

- *One strategy for maximizing independence:* System (and acceptance) test performed by a different organization
  - Organizationally isolated from developers (no pressure to say "ok")
  - Sometimes outsourced to another company or agency
    - Especially for critical systems
    - Outsourcing for independent judgment, not to save money
    - May be *additional* system test, not replacing internal V&V
  - Not all outsourced testing is IV&V
    - Not *independent* if controlled by development organization

Independence without changing staff

- If the development organization controls system testing ...
  - Perfect independence may be unattainable, but we can reduce undue influence
- Develop system test cases early
  - As part of requirements specification, before major design decisions have been made
    - Agile "test first" and conventional "V model" are both examples of designing system test cases before designing the implementation
    - An opportunity for "design for test": Structure system for critical system testing early in project

Incremental System Testing

- System tests are often used to measure progress
  - System test suite covers all features and scenarios of use
  - As project progresses, the system passes more and more system tests
- Assumes a "threaded" incremental build plan: Features exposed at top level as they are developed

Global Properties

- Some system properties are inherently global
  - Performance, latency, reliability, ...
  - Early and incremental testing is still necessary, but provide only estimates
- A major focus of system testing
  - The only opportunity to verify global properties against actual system specifications
  - Especially to find unanticipated effects, e.g., an unexpected performance bottleneck

Context-Dependent Properties

- Beyond system-global: Some properties depend on the system context and use
  - Example: Performance properties depend on environment and configuration
  - Example: Privacy depends both on system and how it is used
    - Medical records system must protect against unauthorized use, and authorization must be provided only as needed
  - Example: Security depends on threat profiles
    - And threats change!
- Testing is just one part of the approach

Establishing an Operational Envelope

- When a property (e.g., performance or real-time response) is parameterized by use ...
  - requests per second, size of database, ...
- Extensive stress testing is required
  - varying parameters within the envelope, near the bounds, and beyond
- Goal: A well-understood model of how the property varies with the parameter
  - How sensitive is the property to the parameter?
  - Where is the "edge of the envelope"?
  - What can we expect when the envelope is exceeded?

Stress Testing

- Often requires extensive simulation of the execution environment
  - With systematic variation: What happens when we push the parameters? What if the number of users or requests is 10 times more, or 1000 times more?
- Often requires more resources (human and machine) than typical test cases
  - Separate from regular feature tests
  - Run less often, with more manual control
  - Diagnose deviations from expectation
    - Which may include difficult debugging of latent faults!

Estimating Dependability

- Measuring quality, not searching for faults
  - Fundamentally different goal than systematic testing
- Quantitative dependability goals are statistical
  - Reliability
  - Availability
  - Mean time to failure
  - ...
- Requires valid statistical samples from *operational profile*
  - Fundamentally different from systematic testing

Statistical Sampling

- We need a valid *operational profile* (model)
  - Sometimes from an older version of the system
  - Sometimes from operational environment (e.g., for an embedded controller)
  - *Sensitivity testing* reveals which parameters are most important, and which can be rough guesses
- And a clear, precise definition of what is being measured
  - Failure rate? Per session, per hour, per operation?
- And many, many random samples
  - Especially for high reliability measures

Is Statistical Testing Worthwhile?

- Necessary for ...
  - Critical systems (safety critical, infrastructure, ...)
- But difficult or impossible when ...
  - Operational profile is unavailable or just a guess
    - Often for new functionality involving human interaction
      - But we may factor critical functions from overall use to obtain a good model of only the critical properties
  - Reliability requirement is very high
    - Required sample size (number of test cases) might require years of test execution
    - Ultra-reliability can seldom be demonstrated by testing

Process-based Measures

- Less rigorous than statistical testing
  - Based on similarity with prior projects
- System testing process
  - Expected history of bugs found and resolved
- Alpha, beta testing
  - Alpha testing: Real users, controlled environment
  - Beta testing: Real users, real (uncontrolled) environment
  - May statistically sample users rather than uses
  - Expected history of bug reports

Usability

- A usable product
  - is quickly learned
  - allows users to work efficiently
  - is pleasant to use
- Objective criteria
  - Time and number of operations to perform a task
  - Frequency of user error
    - blame user errors on the product!
- Plus overall, subjective satisfaction

Verifying Usability

- Usability rests ultimately on testing with real users — validation, not verification
  - Preferably in the usability lab, by usability experts
- But we can *factor* usability testing for process visibility — validation *and verification* throughout the project
  - Validation establishes criteria to be verified by testing, analysis, and inspection

Factoring Usability Testing

Validation (usability lab)

- Usability testing establishes usability check-lists
  - Guidelines applicable across a product line or domain
- Early usability testing evaluates "cardboard prototype" or mock-up
  - Produces interface design

Verification (developers, testers)

- Inspection applies usability check-lists to specification and design
- Behavior objectively verified (e.g., tested) against interface design

Varieties of Usability Test

- Exploratory testing
  - Investigate mental model of users
  - Performed early to guide interface design
- Comparison testing
  - Evaluate options (specific interface design choices)
  - Observe (and measure) interactions with alternative interaction patterns
- Usability validation testing
  - Assess overall usability (quantitative and qualitative)
  - Includes measurement: error rate, time to complete

Typical Usability Test Protocol

- Select *representative sample* of user groups
  - Typically 3-5 users from each of 1-4 groups
  - Questionnaires verify group membership
- Ask users to perform a representative sequence of tasks
- Observe without interference (no helping!)
  - The hardest thing for developers is to *not help*. Professional usability testers use one-way mirrors.
- Measure (clicks, eye movement, time, ...) and follow up with questionnaire

Accessibility Testing

- Check usability by people with disabilities
  - Blind and low vision, deaf, color-blind, ...
- Use accessibility guidelines
  - Direct usability testing with all relevant groups is usually impractical; checking compliance to guidelines is practical and often reveals problems
- Example: W3C Web Content Accessibility Guidelines
  - Parts can be checked automatically
  - but manual check is still required
    - e.g., is the "alt" tag of the image meaningful?

Regression

- Yesterday it worked, today it doesn't
  - I was fixing X, and accidentally broke Y
  - That bug was fixed, but now it's back
- Tests must be re-run after any change
  - Adding new features
  - Changing, adapting software to new conditions
  - Fixing other bugs
- Regression testing can be a major cost of software maintenance
  - Sometimes much more than making the change

Basic Problems of Regression Test

- Maintaining test suite
  - If I change feature X, how many test cases must be revised because they use feature X?
  - Which test cases should be removed or replaced? Which test cases should be added?
- Cost of re-testing
  - Often proportional to product size, not change size
  - Big problem if testing requires manual effort
    - Possible problem even for automated testing, when the test suite and test execution time grows beyond a few hours

Test Case Maintenance

- Some maintenance is inevitable
  - If feature X has changed, test cases for feature X will require updating
- Some maintenance should be avoided
  - Example: Trivial changes to user interface or file format should not invalidate large numbers of test cases
- Test suites should be modular!
  - Avoid unnecessary dependence
  - *Generating* concrete test cases from test case specifications can help

Obsolete and Redundant

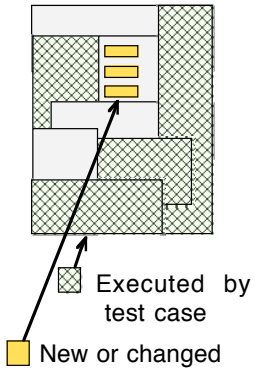
- Obsolete: A test case that is not longer valid
  - Tests features that have been modified, substituted, or removed
  - Should be removed from the test suite
- Redundant: A test case that does not differ significantly from others
  - Unlikely to find a fault missed by similar test cases
  - Has some cost in re-execution
  - Has some (maybe more) cost in human effort to maintain
  - May or may not be removed, depending on costs

Selecting and Prioritizing Regression Test Cases

- Should we re-run the whole regression test suite? If so, in what order?
  - Maybe you don't care. If you can re-rerun everything automatically over lunch break, do it.
  - Sometimes you do care ...
- Selection matters when
  - Test cases are expensive to execute
    - Because they require special equipment, or long run-times, or cannot be fully automated
- Prioritization matters when
  - A very large test suite cannot be executed every day

Code-based Regression Test Selection

- Observation: A test case code it doesn't execute
  - In a large system, many p untouched by many test
- So: Only execute test ca changed or new code



Control-flow and Data-flow Regression Test Selection

- Same basic idea as code-based selection
  - Re-run test cases only if they include changed elements
  - Elements may be modified control flow nodes and edges, or definition-use (DU) pairs in data flow
- To automate selection:
  - Tools record elements touched by each test case
    - Stored in database of regression test cases
  - Tools note changes in program
  - Check test-case database for overlap

Specification-based Regression Test Selection

- Like code-based and structural regression test case selection
  - Pick test cases that test new and changed functionality
- Difference: No guarantee of independence
  - A test case that isn't "for" changed or added feature X might find a bug in feature X anyway
- Typical approach: Specification-based prioritization
  - Execute all test cases, but start with those that related to changed and added features

Prioritized Rotating Selection

- Basic idea:
  - Execute all test cases, eventually
  - Execute some sooner than others
- Possible priority schemes:
  - Round robin: Priority to least-recently-run test cases
  - Track record: Priority to test cases that have detected faults before
    - They probably execute code with a high fault density
  - Structural: Priority for executing elements that have not been recently executed
    - Can be coarse-grained: Features, methods, files, ...

Summary

- System testing is verification
  - System consistent with specification?
  - Especially for global properties (performance, reliability)
- Acceptance testing is validation
  - Includes user testing and checks for usability
- Usability and accessibility require both
  - Usability testing establishes objective criteria to verify throughout development
- Regression testing repeated after each change
  - After initial delivery, as software evolves