Software Testing

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What is Software Testing?

- Software Testing is the design and implementation of a special kind of software system: one that exercises another software system with the intent of finding bugs.

- Testing software typically involves:
  - Executing software with **inputs** representative of actual operation conditions (or **operational profiles**)
  - Comparing produced/expected **outputs**
  - Comparing resulting/expected **states**
  - **Measuring** execution characteristics (e.g., memory used, time consumed, etc.)

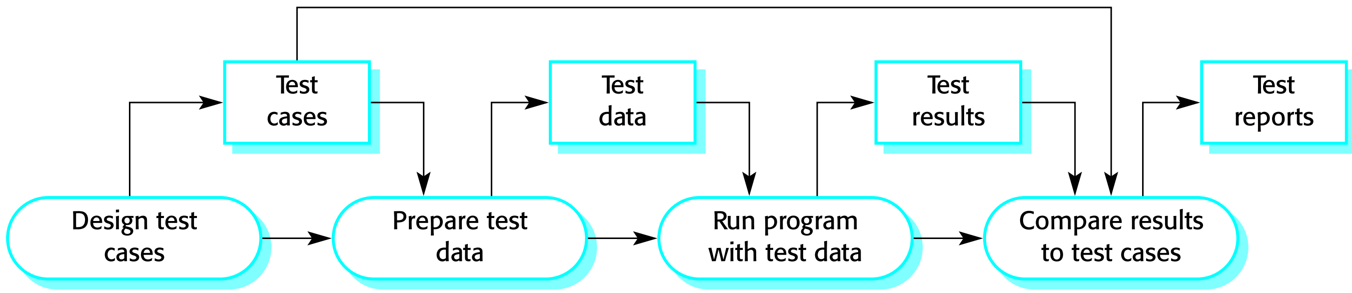
Terminology

- **Fault**: an imperfection that may lead to a failure
  - E.g., missing/incorrect code that may result in a failure
  - **Bug**: another name for a fault in code
- **Error**: where the system state is incorrect but may not have been observed
- **Failure**: some failure to deliver the expected service that is observable to the user

A few more definitions

- **Test Case**: set of inputs, execution conditions, and expected results developed for a particular objective
- **Test Suite**: collection of test cases, typically related by a testing goal or an implementation dependency
- **Test Driver**: class or utility program that applies test cases
- **Test harness**: system of test drivers and other tools that support test execution
- **Test Strategy**: algorithm or heuristic to create test cases from a representation, implementation, or a test model
- **Oracle**: means to check the output from a program is correct for the given input
- **Stub**: partial temporary implementation of a component (usually required for a component to operate)

A Software Testing Process



Testing process goals

- Validation testing
  - To demonstrate to the developer and the system customer that the software meets its requirements;
  - A successful test shows that the system operates as intended.
- Defect testing
  - To discover faults or defects in the software where its behavior is incorrect or not in conformance with its specification;
  - A successful test is a test that makes the system perform incorrectly and so exposes a defect in the system.

Effectiveness vs. Efficiency

- **Test Effectiveness**
  - Relative ability of testing strategy to find bugs in the software
- **Test Efficiency**
  - Relative cost of finding a bug in the software under test

What is a successful test?

- **Pass**
  - Status of a completed test case whose actual results are the same as the expected results
- **No Pass**
  - Status of a completed software test case whose actual results differ from the expected ones
  - "**Successful**" test (i.e., we want this to happen)

What software testing is not…

- Model verification (e.g., by simulation)
- Tool-based static code analysis
- Human documentation/code scrutiny (inspection)
- Debugging:
  - Testing is NOT debugging, and debugging is NOT testing

Software Testing Features

- The scope of testing
  - The different levels of the system that testing addresses
- Test techniques
  - Some of the approaches to building and applying tests
- Test management
  - How we manage the testing process to maximize the effectiveness and efficiency of the process for a given product

Testing scope

- <u>**"Testing in the small"**</u> (**unit testing**)
  - Exercising the smallest executable units of the system
- <u>**"Testing the build"**</u> (**integration testing**)
  - Finding problems in the interaction between components
- <u>**"Testing in the large"**</u> (**system testing**)
  - Putting the entire system to test

Testing Categorization

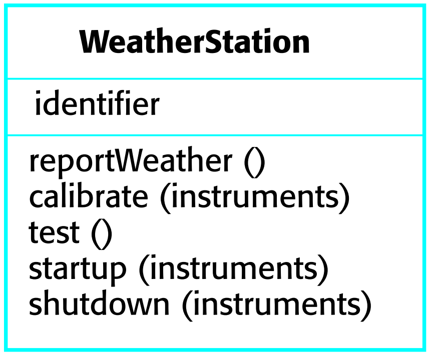
- **Fault-directed** testing
  - Unit testing
  - Integration testing
- **Conformance-directed** testing
  - System testing
  - Acceptance testing

Testing "in the small"

- **Unit Testing**
  - Exercising the smallest individually executable code units
  - It is a defect testing process.
  - Component or unit testing is the process of testing individual components in isolation.
- **Objectives**
  - Finding faults
  - Assure correct functional behaviour of units
- Usually performed by **programmers**

- Components may be:
  - Individual functions or methods within an object;
  - Object classes with several attributes and methods;
  - Composite components with defined interfaces used to access their functionality.
- **Object Class Testing**
  - Complete **test coverage** of a class involves: Testing all **operations** associated with an object; Setting and interrogating all object **attributes**; Exercising the object in all possible **states**.
  - Inheritance makes it more difficult to design object class tests as the information to be tested is not localised.

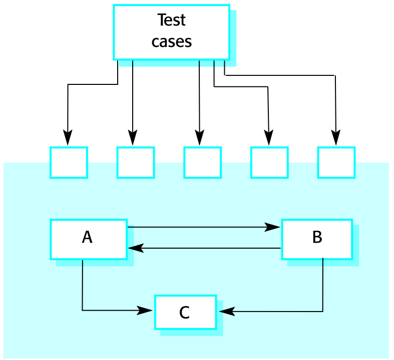
An Example of Object Class Testing



- Need to define test cases for reportWeather, calibrate, test, startup and shutdown.
- Using a state model, identify sequences of **state transitions** to be tested and the event sequences to cause these transitions
- For example:
  - Waiting -> Calibrating -> Testing -> Transmitting -> Waiting

Interface Testing

- Objectives are to detect faults due to interface errors or invalid assumptions about interfaces.
- Particularly important for object-oriented development as objects are defined by their interfaces.
- **Interface Types**: **Parameter interfaces** (Data passed from one procedure to another), **Shared memory interfaces** (Block of memory is shared between procedures or functions), **Procedural interfaces** (Sub-system encapsulates a set of procedures to be called by other sub-systems), **Message passing interfaces** (Sub-systems request services from other sub-systems)



Interface Errors

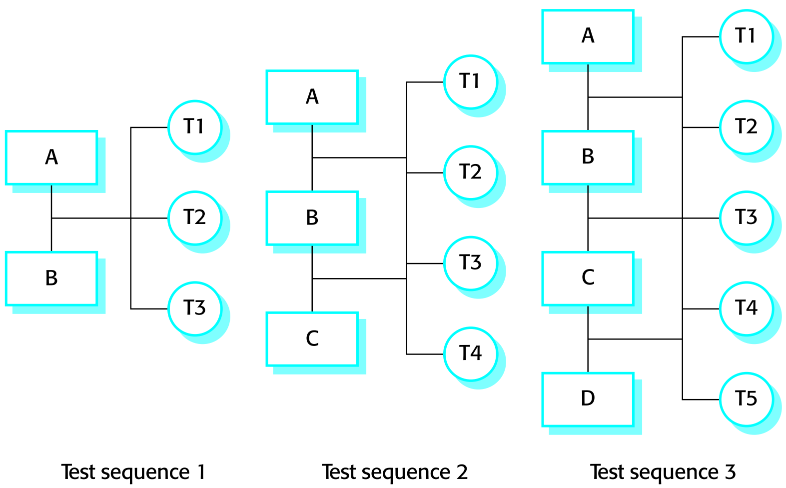
- **Interface misuse**. A calling component calls another component and makes an error in its use of its interface e.g. parameters in the wrong order.
- **Interface misunderstanding**. A calling component embeds assumptions about the behaviour of the called component which are incorrect.
- **Timing errors**. The called and the calling component operate at different speeds and out-of-date information is accessed.

Testing the "build"

- **Integration Testing**
  - Exercising two or more units or components
- **Objectives**
  - Detect interface errors
  - Assure the functionality of the combined units
- Performed by **programmers** or **testing group**
- **Issues**
  - Strategy for combining units?
  - Compatibility with third-party components (e.g., Commercial Of The Shelf – COTS)?
  - Correctness of third-party components?

Integration Testing

- Involves building a system from its components and testing it for problems that arise from **component interactions**.
- Top-down integration
  - Develop the skeleton of the system and populate it with components.
- Bottom-up integration
  - Integrate infrastructure components then add functional components.
- To simplify error localisation, systems should be **incrementally integrated**.



Testing "in the large": System

- **System Testing**
  - Exercising the functionality, performance, reliability, and security of the entire system
- **Objectives**
  - Find errors in the overall system behaviour
  - Establish confidence in system functionality
  - Validate non-functional system requirements
- Usually performed by a separate **testing group**

Testing “in the large”: Accept

- **Acceptance Testing**
  - Operating the system in the user environment with standard user input scenario
- **Objectives**
  - Evaluate whether the system meets the customer criteria
  - Determine whether the customer will accept the system
- Usually performed by the **end user**

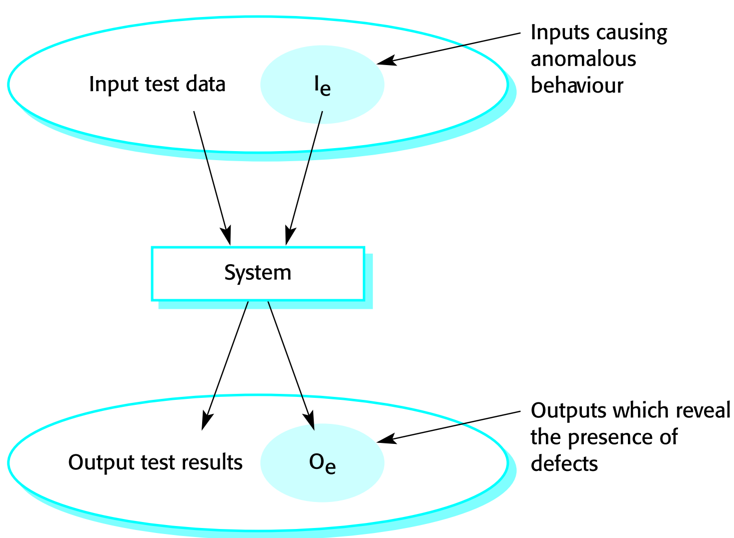
Testing "in the large": Operation

- **Regression Testing**
  - Testing modified versions of a previously validated system
- **Objectives**
  - Assuring that changes to the system have not introduced new errors
- Performed by the system itself or by a regression test group
- Capture/Replay (CR) Tools

Test Generation Methods

- **Black-box testing**
  - No knowledge of the software structure
  - Also called specification-based or functional testing
- **White-box testing**
  - Knowledge of the software structure and implementation
  - White-box methods can be used for test generation and test adequacy analysis
  - Usually used as adequacy criteria (after generation by a black-box method)
  - Methods based on internal code structure: **Statement**, **Branch**, **Path** or **Data-flow coverage**
- **Fault-based testing**
  - Objective is to find faults in the software, e.g., Unit testing
- **Model-based testing**
  - Use of a data or behaviour model of the software, e.g., finite state machine
- **Random testing**

Black-box Testing



Structural Testing

- **Statement Testing**: requires that very statements in the program be executed
- **Branch Testing**: seeks to ensure that every branch has been executed.
  - Branch coverage can be checked by probes inserted at the points in the program that represent arcs from branch points in the flowgraph.
  - This instrumentation suffices for statement coverage as well.
- **Expression Testing**: requires that every expression assume a variety of valued during a test in such a way that no expression can be replaced by a simpler expression and still pass the test.
  - Expression testing does require significant runtime support for the instrumentation.
- **Path Testing**: data is selected to ensure that all paths of the program have been executed.
  - In practice, path coverage is impossible to achieve

Issues with Structural Testing

- Is code **coverage** effective at detecting faults?
- How much coverage is enough?
- Is one coverage criterion better than another?
- Is coverage testing more effective that random test case selection?

Experimental Studies

- **Experiment**: Black-box generation followed by white-box coverage-based testing
- **Results**:
  - High coverage alone does not guarantee fault detection
  - Fault detection increases significantly as coverage goes above 95%
  - No significant difference between branch and Data-flow (expression) coverage
  - Both Branch and Data-flow coverage are significantly more effective that random test cases

[Hutchins et al.]

Test Management

- **Concerns**
  - Attitude to testing
  - Effective documentation and control of the whole test process
  - Documentation of tests and control of the test codebase
  - Independence of test activities
  - Costing and estimation of test activities
  - Termination: deciding when to stop
  - Managing effective reuse
- **Activities**
  - Test Planning
  - Test case generation – can involve massive amounts of data for some systems
  - Test environment development
  - Execution of tests
  - Evaluating test results
  - Problem reporting
  - Defect tracking

From Use Cases to Test Cases

From Use Cases to Test cases

- One of the greatest benefits of use cases is that they provide a set of assets that can be used to drive the testing process
- Use cases can directly drive, or seed, the development of test cases
- The scenarios of a use case create templates for individual test cases
- Adding data values completes the test cases
- Testing non-functional requirement completes the testing process

A (Black-box) Tester's Viewpoint

- What is the system supposed to do?
- What are the things that can go wrong?
- How can I create and record a set of testing scenarios?
- How will I know when to stop testing?
- Is there anything else the system is supposed to do?

From Use Cases to Test cases

- A comprehensive set of use cases that documents an ordered sequence of events describing how the system interacts with the user and how it delivers its results to that user
- A use case model that documents all the use cases for the system, as well as how they interact and what actors drive them
- Within each use case, both a basic flow of events and a series of alternative flows that defines what the system does in various "what if" scenarios
- Descriptions of pre-conditions and post-conditions
- A supplementary specification that defines the non-function requirements of the system

Deriving Test Cases from Use Cases

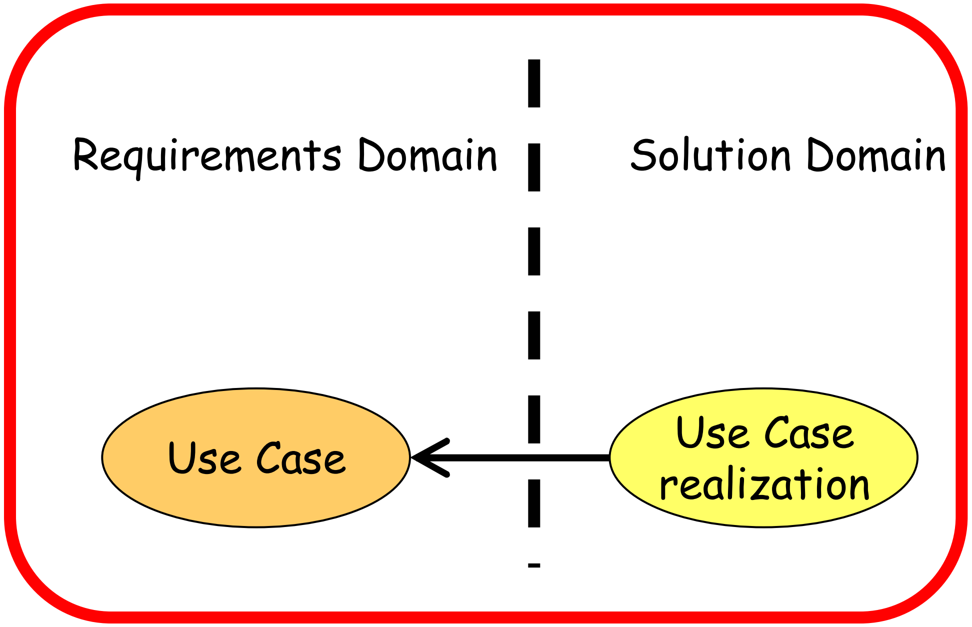
1. Identify the use-case scenarios
2. For each scenario, identify one or more test cases
3. For each test case, identify the conditions that will cause it to execute
4. Complete the test case by adding data values

Managing Test Coverage

- Select the most appropriate or critical use cases for the most thorough testing
  - Often these use cases are primary user interfaces, are architecturally significant, or present a hazard or hardship of some kind to the user should a defect remain undiscovered
- Chose each use case to test based on a balance between cost, risk, and necessity of verifying the use case
- Determine the relative importance of your use cases by using priorities specific to your context

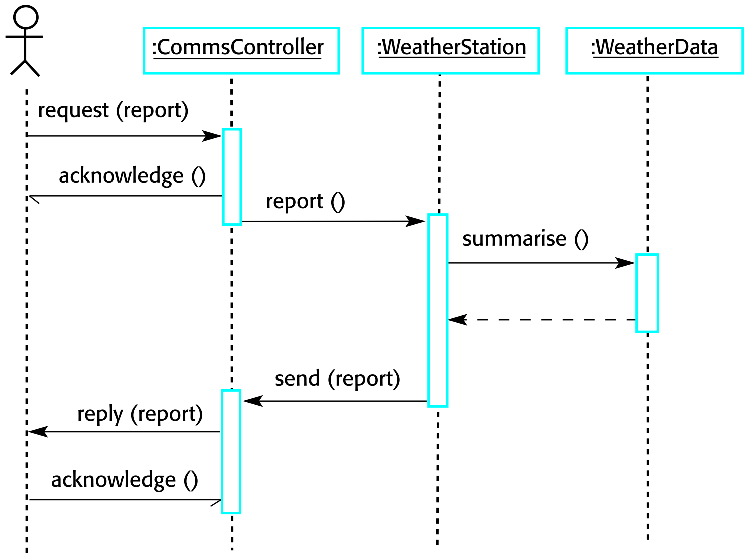
Black-box vs. White-box Testing with Use Cases

- For every use case, there is a use case realization that represents how the system is designed to accomplish the use case
- The use case itself lives in the requirements domain and simply specify necessary behaviour
- The use-case realization lives inside the solution space and describes how the behaviour is accomplished by the system



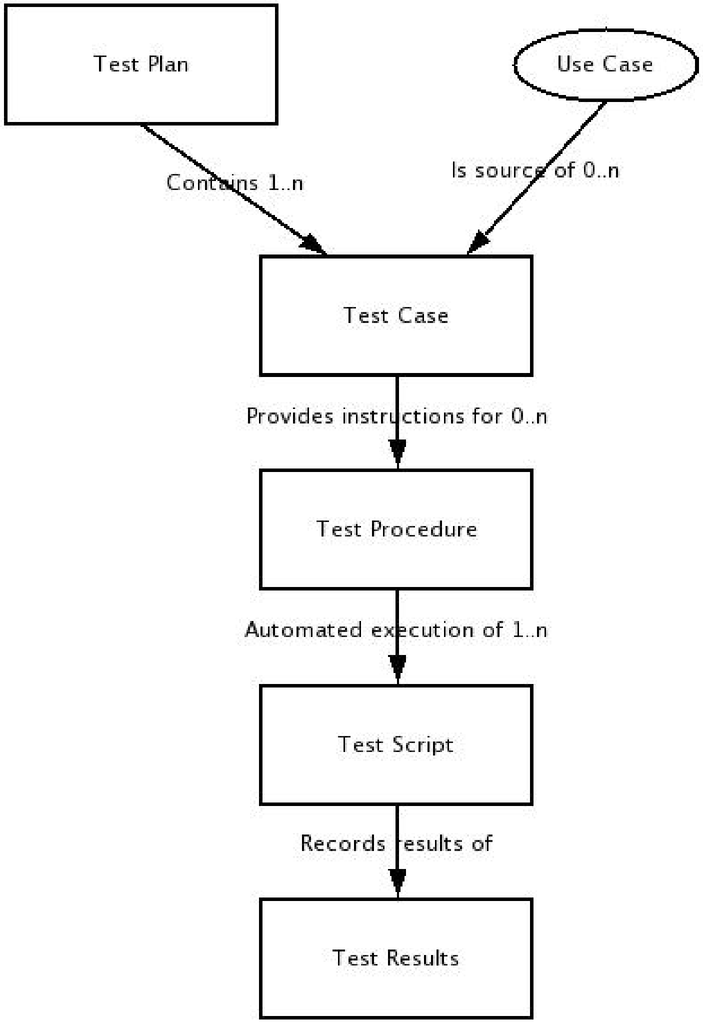
An Example of Use Case-based Testing

- Use cases can be a basis for deriving the tests for a system. They help identify operations to be tested and help design the required test cases.
- From an associated sequence diagram, the inputs and outputs to be created for the tests can be identified.



Is a Use Case a Test Case?

- NO
- Test cases
  - Test cases form the foundation on which to design and develop test procedures
  - The "depth" of the testing activity is proportional to the number of test cases
  - The scale of the test effort is proportional to the number of use cases
  - Test design and development, and the resources needed, are largely governed by the required test cases
- Use-case Scenarios
  - A scenario, or an instance of a use case, is a use-case execution wherein a specific user executes the use case in a specific way



A Matrix for Testing Specific Scenarios

Test Case ID	Scenario / Condition	Description	Data Value 1 / Condition 1	Data Value 2 / Condition 2	…	Expected Result	Actual Result
1	Scenario 1						
2	Scenario 2						
3	Scenario 2						

Reading/Activity

- Please read
  - the SWEBOK's chapter on Software Testing for an overview on Software Testing
  - James A. Whittaker. What is Software Testing? And Why is it so Hard?. In IEEE Software, January/February 2000, pp. 70-79.
  - Hutchins et al., Experiments on the Effectiveness of Dataflow- and Controlflow-Based Test Adequacy Criteria. ICST, May 1994.
  - Antonia Bertolino, Eda Marchetti, Henry Muccini: Introducing a Reasonably Complete and Coherent Approach for Model-based Testing. Electr. Notes Theor. Comput. Sci. 116: 85-97 (2005)

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- Robert V. Binder. Testing Object-Oriented Systems: Models, Patterns, and Tools (1999).
- William E. Perry. Effective Methods for Software Testing. Second Edition, John Wiley and Sons, 2000.

Summary

- Testing is a critical part of the development of any system
- Testing can be carried out at a number of levels and is planned as an integral part of the development process
- There is a wide range of approaches to test case generation and evolution of the adequacy of a test suite
- Test needs to be managed effectively if it is to be efficient