Some Observations

- It is impossible to completely test any nontrivial module or any system
  - Theoretical limitations: Halting problem
  - Practical limitations: Prohibitive in time and cost
- Testing can only show the presence of bugs, not their absence (Dijkstra)

Testing takes creativity

- Testing often viewed as dirty work.
- To develop an effective test, one must have:
  - Detailed understanding of the system
  - Knowledge of the testing techniques
  - Skill to apply these techniques in an effective and efficient manner
- Testing is done best by independent testers
  - We often develop a certain mental attitude that the program should in a certain way when in fact it does not.
- Programmer often stick to the data set that makes the program work
  - "Don't mess up my code!"
- A program often does not work when tried by somebody else.
  - Don't let this be the end-user.
Testing Activities

- Subsystem Code
  - Unit Test
  - System Design Document
  - Requirements Analysis Document

Integration Test

Functional Test

Testing Activities cont.

- Performance Test
  - Acceptance Test
  - Installation Test

Tests by developer

Tests by client

Tests (?) by user
Quality Assurance encompasses Testing

- Fault Avoidance
  - Verification
  - Configuration Management
  - Reviews
  - Walkthrough
  - Inspection
- Fault Tolerance
  - Atomic Transactions
  - Modular Redundancy
- Fault Detection
  - Testing
  - Component Testing
  - Integration Testing
  - System Testing
  - Correctness Debugging
  - Performance Debugging
- Usability Testing
  - Scenario Testing
  - Prototype Testing
  - Product Testing

Component Testing

- Unit Testing:
  - Individual subsystem
  - Carried out by developers
  - **Goal:** Confirm that subsystems is correctly coded and carries out the intended functionality

- Integration Testing:
  - Groups of subsystems (collection of classes) and eventually the entire system
  - Carried out by developers
  - **Goal:** Test the interface among the subsystem
System Testing

- System Testing:
  - The entire system
  - Carried out by developers
  - **Goal**: Determine if the system meets the requirements (functional and global)

- Acceptance Testing:
  - Evaluates the system delivered by developers
  - Carried out by the client. May involve executing typical transactions on site on a trial basis
  - **Goal**: Demonstrate that the system meets customer requirements and is ready to use

- Implementation (Coding) and testing go hand in hand

Unit Testing

- Informal:
  - Incremental coding

- Static Analysis:
  - Hand execution: Reading the source code
  - Walk-Through (informal presentation to others)
  - Code Inspection (formal presentation to others)
  - Automated Tools checking for
    - syntactic and semantic errors
    - departure from coding standards

- Dynamic Analysis:
  - Black-box testing (Test the input/output behavior)
  - White-box testing (Test the internal logic of the subsystem or object)
  - Data-structure based testing (Data types determine test cases)
Black-box Testing

- Focus: I/O behavior. If for any given input, we can predict the output, then the module passes the test.
  - Almost always impossible to generate all possible inputs ("test cases")

Goal: Reduce number of test cases by equivalence partitioning:
- Divide input conditions into equivalence classes
- Choose test cases for each equivalence class.
  (Example: If an object is supposed to accept a negative number, testing one negative number is enough)

Black-box Testing (Contd)

- Selection of equivalence classes (No rules, only guidelines):
  - Input is valid across range of values. Select test cases from 3 equivalence classes:
    - Below the range
    - Within the range
    - Above the range
  - Input is valid if it is from a discrete set. Select test cases from 2 equivalence classes:
    - Valid discrete value
    - Invalid discrete value

- Another solution to select only a limited amount of test cases:
  - Get knowledge about the inner workings of the unit being tested
  => white-box testing
White-box Testing

• Focus: Thoroughness (Coverage). Every statement in the component is executed at least once.
• Four types of white-box testing
  ■ Statement Testing
  ■ Loop Testing
  ■ Path Testing
  ■ Branch Testing

White-box Testing (Continued)

• Statement Testing (Algebraic Testing): Test single statements (Choice of operators in polynomials, etc)
• Loop Testing:
  ■ Cause execution of the loop to be skipped completely. (Exception: Repeat loops)
  ■ Loop to be executed exactly once
  ■ Loop to be executed more than once
• Path testing:
  ■ Make sure all paths in the program are executed
• Branch Testing (Conditional Testing): Make sure that each possible outcome from a condition is tested at least once

```c
if (i = TRUE) printf("YES\n"); else printf("NO\n");
```
Test cases: 1) i = TRUE; 2) i = FALSE
White-box Testing Example

```c
FindMean(float Mean, FILE ScoreFile)
{
    float SumOfScores = 0.0; int NumberOfScores = 0; Mean = 0;
    Read(ScoreFile, Score); /*Read in and sum the scores*/
    while (! EOF(ScoreFile) ) {
        if ( Score > 0.0 ) {
            SumOfScores = SumOfScores + Score;
            NumberOfScores++;
        }
        Read(ScoreFile, Score);
    }
    /* Compute the mean and print the result */
    if (NumberOfScores > 0 ) {
        Mean = SumOfScores/NumberOfScores;
        printf("The mean score is \%f \n", Mean);
    } else
        printf("No scores found in file\n");
}
```

White-box Example: Determining the Paths

```c
FindMean (FILE ScoreFile)
{
    float SumOfScores = 0.0;
    int NumberOfScores = 0;
    float Mean=0.0; float Score;
    Read(ScoreFile, Score);
    while (! EOF(ScoreFile) ) {
        if (Score > 0.0 ) {
            SumOfScores = SumOfScores + Score;
            NumberOfScores++;
        }
        Read(ScoreFile, Score);
    }
    /* Compute the mean and print the result */
    if (NumberOfScores > 0 ) {
        Mean = SumOfScores / NumberOfScores;
        printf("The mean score is \%f\n", Mean);
    } else
        printf ("No scores found in file\n");
}
```
Constructing the Logic Flow Diagram

Finding the Test Cases
Test Cases

- Test case 1: ? (To execute loop exactly once)
- Test case 2: ? (To skip loop body)
- Test case 3: ?, ? (to execute loop more than once)

These 3 test cases cover all control flow paths

Comparison of White & Black-box Testing

- White-box Testing:
  - Potentially infinite number of paths have to be tested
  - White-box testing often tests what is done, instead of what should be done
  - Cannot detect missing use cases

- Black-box Testing:
  - Potential combinatorial explosion of test cases (valid & invalid data)
  - Often not clear whether the selected test cases uncover a particular error
  - **Does not discover extraneous use cases** ("features")

- Both types of testing are needed
- White-box testing and black box testing are the extreme ends of a testing continuum.
- Any choice of test case lies in between and depends on the following:
  - Number of possible logical paths
  - Nature of input data
  - Amount of computation
  - Complexity of algorithms and data structures
The 4 Testing Steps

1. Select what has to be measured
   - Completeness of requirements
   - Code tested for reliability
   - Design tested for cohesion

2. Decide how the testing is done
   - Code inspection
   - Proofs
   - Black-box, white box,
   - Select integration testing strategy
     (big bang, bottom up, top down, sandwich)

3. Develop test cases
   - A test case is a set of test data or situations that will be used to exercise the unit (code, module, system) being tested or about the attribute being measured

4. Create the test oracle
   - An oracle contains the predicted results for a set of test cases
   - The test oracle has to be written down before the actual testing takes place

Guidance for Test Case Selection

- Use requirements knowledge about functional requirements (black-box):
  - Use cases
  - Expected input data
  - Invalid input data

- Use design knowledge about system structure, algorithms, data structures (white-box):
  - Control structures
    - Test branches, loops, ...
  - Data structures
    - Test records fields, arrays, ...

- Use implementation knowledge about algorithms:
  - Force division by zero
  - Use sequence of test cases for interrupt handler
Unit-testing Heuristics

1. Create unit tests as soon as object design is completed:
   - Black-box test: Test the use cases & functional model
   - White-box test: Test the dynamic model
   - Data-structure test: Test the object model

2. Develop the test cases
   - Goal: Find the minimal number of test cases to cover as many paths as possible

3. Cross-check the test cases to eliminate duplicates
   - Don’t waste your time!

4. Desk check your source code
   - Reduces testing time

5. Create a test harness
   - Test drivers and test stubs are needed for integration testing

6. Describe the test oracle
   - Often the result of the first successfully executed test

7. Execute the test cases
   - Don’t forget regression testing
   - Re-execute test cases every time a change is made.

8. Compare the results of the test with the test oracle
   - Automate as much as possible

Component-Based Testing Strategy

- The entire system is viewed as a collection of subsystems (sets of classes) determined during the system and object design.
- The order in which the subsystems are selected for testing and integration determines the testing strategy
  - Big bang integration (Nonincremental)
  - Bottom up integration
  - Top down integration
  - Sandwich testing
  - Variations of the above
- For the selection use the system decomposition from the System Design
Using the Bridge Pattern to enable early Integration Testing

- Use the bridge pattern to provide multiple implementations under the same interface.
- Interface to a component that is incomplete, not yet known or unavailable during testing

Example: Three Layer Call Hierarchy
Integration Testing: Big-Bang Approach

- Unit Test UI
- Unit Test Billing
- Unit Test Learning
- Unit Test Event Service
- Unit Test Network
- Unit Test Database

Don’t try this!

System Test PAID

Bottom-up Testing Strategy

- The subsystems in the lowest layer of the call hierarchy are tested individually
- Then the next subsystems are tested that call the previously tested subsystems
- This is done repeatedly until all subsystems are included in the testing
- Special program needed to do the testing,
  **Test Driver:**
  - A routine that calls a particular subsystem and passes a test case to it
Bottom-up Integration

Pros and Cons of bottom up integration testing

- Bad for functionally decomposed systems:
  - Tests the most important subsystem last
- Useful for integrating the following systems
  - Object-oriented systems
  - real-time systems
  - systems with strict performance requirements
Top-down Testing Strategy

- Test the top layer or the controlling subsystem first
- Then combine all the subsystems that are called by the tested subsystems and test the resulting collection of subsystems
- Do this until all subsystems are incorporated into the test
- Special program is needed to do the testing, Test stub:
  - A program or a method that simulates the activity of a missing subsystem by answering to the calling sequence of the calling subsystem and returning back fake data.

Top-down Integration Testing

- Test A
- Test A, B, C, D
- Test A, B, C, D, E, F, G

Layer I

Layer I + II

All Layers
Pros and Cons of top-down integration testing

- Test cases can be defined in terms of the functionality of the system (functional requirements)
- Writing stubs can be difficult: Stubs must allow all possible conditions to be tested.
- Possibly a very large number of stubs may be required, especially if the lowest level of the system contains many methods.
- One solution to avoid too many stubs: *Modified top-down testing strategy*
  - Test each layer of the system decomposition individually before merging the layers
  - Disadvantage of modified top-down testing: Both, stubs and drivers are needed

Sandwich Testing Strategy

- Combines top-down strategy with bottom-up strategy
- *The system is viewed as having three layers*
  - A target layer in the middle
  - A layer above the target
  - A layer below the target
  - Testing converges at the target layer
- How do you select the target layer if there are more than 3 layers?
  - Heuristic: Try to minimize the number of stubs and drivers
Selecting Layers for Testing

- Top Layer:
  - Application Interface
- Middle Layer:
  - User Dialogue, Window Graphics, Simulation package
- Bottom Layer
  - Operating System

Sandwich Testing Strategy

Diagram showing the testing strategy with layers and corresponding tests.
Pros and Cons of Sandwich Testing

- Top and Bottom Layer Tests can be done in parallel
- Does not test the individual subsystems thoroughly before integration
- Solution: Modified sandwich testing strategy

Modified Sandwich Testing Strategy

- Test in parallel:
  - Middle layer with drivers and stubs
  - Top layer with stubs
  - Bottom layer with drivers
- Test in parallel:
  - Top layer accessing middle layer (top layer replaces drivers)
  - Bottom accessed by middle layer (bottom layer replaces stubs)
**Modified Sandwich Testing Strategy**

- **Layer I**
  - Test A
  - Test B
  - Test C
  - Test D
  - Test E
  - Test F
  - Test G

- **Layer II**
  - Triple Test I: Test B, E, F
  - Double Test I: Test D, G

- **Layer III**
  - Double Test II: Test A, B, C, D, E, F, G

**Scheduling Sandwich Tests:**

**Example of a Dependency Chart**

- **Unit Tests**
- **Double Tests**
- **Triple Tests**
- **System Tests**
### Steps in Component-Based Testing

| 1. Based on the integration strategy, select a component to be tested. Unit test all the classes in the component. | 4. Do structural testing: Define test cases that exercise the selected component |
| 2. Put selected component together; do any preliminary fix-up necessary to make the integration test operational (drivers, stubs) | 5. Execute performance tests |
| 3. Do functional testing: Define test cases that exercise all uses cases with the selected component | 6. Keep records of the test cases and testing activities. |
|  | 7. Repeat steps 1 to 7 until the full system is tested. |

The primary goal of integration testing is to identify errors in the (current) component configuration.

### Which Integration Strategy should you use?

<table>
<thead>
<tr>
<th>Factors to consider</th>
<th>...Top-level components are usually important and cannot be neglected up to the end of testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Amount of test harness (stubs &amp; drivers)</td>
<td>- Detection of design errors postponed until end of testing</td>
</tr>
<tr>
<td>- Location of critical parts in the system</td>
<td>- Top down approach</td>
</tr>
<tr>
<td>- Availability of hardware</td>
<td>- Test cases can be defined in terms of functions examined</td>
</tr>
<tr>
<td>- Availability of components</td>
<td>- Need to maintain correctness of test stubs</td>
</tr>
<tr>
<td>- Scheduling concerns</td>
<td>- Writing stubs can be difficult</td>
</tr>
</tbody>
</table>

- Bottom up approach
  - Good for object oriented design methodologies
  - Test driver interfaces must match component interfaces
  - ...
System Testing

- Functional Testing
- Structure Testing
- Performance Testing
- Acceptance Testing
- Installation Testing

Impact of requirements on system testing:
- The more explicit the requirements, the easier they are to test.
- Quality of use cases determines the ease of functional testing
- Quality of subsystem decomposition determines the ease of structure testing
- Quality of nonfunctional requirements and constraints determines the ease of performance tests:

Structure Testing

- *Essentially the same as white box testing.*
- **Goal: Cover all paths in the system design**
  - Exercise all input and output parameters of each component.
  - Exercise all components and all calls (each component is called at least once and every component is called by all possible callers.)
  - Use conditional and iteration testing as in unit testing.
Functional Testing

*Essentially the same as black box testing*

- **Goal: Test functionality of system**
  - Test cases are designed from the requirements analysis document (better: user manual) and centered around requirements and key functions (use cases)
  - The system is treated as black box.
  - Unit test cases can be reused, but in end user oriented new test cases have to be developed as well.

Performance Testing

- **Stress Testing**
  - Stress limits of system (maximum # of users, peak demands, extended operation)
- **Volume testing**
  - Test what happens if large amounts of data are handled
- **Configuration testing**
  - Test the various software and hardware configurations
- **Compatibility test**
  - Test backward compatibility with existing systems
- **Security testing**
  - Try to violate security requirements
- **Timing testing**
  - Evaluate response times and time to perform a function
- **Environmental test**
  - Test tolerances for heat, humidity, motion, portability
- **Quality testing**
  - Test reliability, maintain-ability & availability of the system
- **Recovery testing**
  - Tests system’s response to presence of errors or loss of data.
- **Human factors testing**
  - Tests user interface with user
Test Cases for Performance Testing

- Push the (integrated) system to its limits.
  - **Goal: Try to break the subsystem**
  - Test how the system behaves when overloaded.
    - Can bottlenecks be identified? (First candidates for redesign in the next iteration)
  - Try unusual orders of execution
    - Call a `receive()` before `send()`
  - Check the system’s response to large volumes of data
    - If the system is supposed to handle 1000 items, try it with 1001 items.
  - What is the amount of time spent in different use cases?
    - Are typical cases executed in a timely fashion?

Acceptance Testing

- **Goal: Demonstrate system is ready for operational use**
  - Choice of tests is made by client/sponsor
  - Many tests can be taken from integration testing
  - Acceptance test is performed by the client, not by the developer.
  - Majority of all bugs in software is typically found by the client after the system is in use, not by the developers or testers. Therefore two kinds of additional tests:

- **Alpha test:**
  - Sponsor uses the software at the developer’s site.
  - Software used in a controlled setting, with the developer always ready to fix bugs.

- **Beta test:**
  - Conducted at sponsor’s site (developer is not present)
  - Software gets a realistic workout in target environment
  - Potential customer might get discouraged
Testing has its own Life Cycle

Establish the test objectives
Design the test cases
Write the test cases
Test the test cases
Execute the tests
Evaluate the test results
Change the system
Do regression testing

Test Team
Summary

- Testing is still a black art, but many rules and heuristics are available
- Testing consists of component-testing (unit testing, integration testing) and system testing
- Design Patterns can be used for component-based testing
- Testing has its own lifecycle