Software Testing

Introduction

Structure of the Module

- Introduction to Testing
- The Principles of Software Testing
- Static Verification
- Black Box Software Testing – Methods and Examples
- White Box Software Testing – Methods and Examples

Structure of the Module

- Integration testing
- System testing
- Testing in the Software Process

Textbook

- Software Testing – Principles and Practice by S. Brown, J. Timoney, T. Lysaght and D. Ye, China Machine Press

What is Software?

- It is not just about computer programs
- It is also associated with documentation and configuration data that is needed to make these programs operate correctly

Define a Software System

- A software system usually consists of a number of:
  - instructions within separate programs that when executed give some desired function
  - data structures that enable the programs to adequately manipulate information
  - configuration files which are used to set up these programs
  - system documentation which describes the structure of the system
  - user documentation which explains how to use the system and web sites for users to download recent product information

Challenges of Software Systems

- Major challenges in building a software system:
  - Effort intensive (organize carefully)
  - High cost (if there is failure then the investment is lost)
  - Long development time
  - Changing needs/requirements for users
  - High risk of failure
    - user acceptance – may reject it
    - Performance
    - maintainability…

Quality and Software

- There are risks associated with Software Development
- Modern programs are complex and have thousands of lines of code
- The customer's requirements can be vague, lacking in exactness
- Deadlines and budgets put pressure on the development team

Quality and Software

- The combination of these factors can lead to a lack of emphasis being placed on the final quality of the software product
- Poor quality can result in software failure resulting in high maintenance costs and long delays before the final deployment
- The impact on the business can be loss of reputation, legal claims, decrease in market share

Quality and Software

- The International Standard ISO 91261 Software Engineering – Product Quality is structured around six main attributes
- These can be measured using a mix of objective and subjective metrics

ISO 91261 Attributes

Functionality	Suitability, accurateness, interoperability, compliance, security
Reliability	Maturity, fault tolerance, recoverability
Usability	Understandability, learnability, operability
Efficiency	Time behavior, resource behavior
Maintainability	Analysability, changeability, stability, testability
Portability	Adaptability, installability, conformance, replaceability

Detailed Description

Attributes	Subcharacteristics	Definition
Functionality	Suitability	Attributes of software that bear on the presence and appropriateness of a set of functions for specified tasks
	Accurateness	Attributes of software that bear on the provision of right or agreed upon results or effects
	Interoperability	Attributes of software that bear on its ability to interact with specified systems
	Compliance	Attributes of software that make the software adhere to application-related standards or conventions or regulations in laws and similar prescriptions
	Security	Attributes of software that bear on its ability to prevent unauthorized access, whether accidental or deliberate, to programs or data
Reliability	Maturity	Attributes of software that bear on the frequency of failure by faults in the software
	Fault tolerance	Attributes of software that bear on its ability to maintain a specified level of performance in case of software faults or of infringement of its specified interface
	Recoverability	Attributes of software that bear on the capability to re-establish its level of performance and recover the data directly affected in case of a failure and on the time and effort needed for it

Early Days of Software – Hardware Engineering

- In the early days of computing, computer-based systems were developed using hardware-oriented management
- Project managers focused on hardware
- Project managers applied the controls, methods, and tools that we recognize as hardware engineering

Early Days of Software -The programmer

- Programming was viewed as an art form
- The programmer often learned his craft by trial and error
- The software world was undisciplined

The Crisis in Software Engineering

- In the 1970's there were a number of problems with software:
  - Projects were running over-budget
  - Projects were running over-time
  - The Software products were of low quality
  - The Software products often did not meet their requirements
  - Projects were chaotic
  - Software maintenance was very difficult

Software Engineering

- The actual term 'software engineering' was first proposed as far back as 1968 at a conference held to discuss what was then called the 'software crisis'.
- It was becoming clear by then that individual approaches to program development did not scale up to large and complex software systems. These were unreliable, cost more than expected, and were delivered late.

Software Engineering

- To overcome these problems throughout 1970s and 1980s, a variety of new software engineering techniques and methods were developed
- These include structured programming, information hiding and object-oriented development.
- Tools and standard notations that were developed at that time are now extensively used

Problems with Software

- These can be broken down into three elements of Errors, Faults and Failures

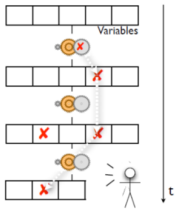
Errors, Faults and Failures

1. Errors: these are mistakes made by software developers. They exist in the mind, and can result in one or more faults in the software.
2. Faults: these consist of incorrect material in the source code, and can be the product of one or more errors. Faults can lead to failures during program execution.
3. Failures: these are symptoms of a fault, and consist of incorrect, or out-of specification behaviour by the software. Faults may remain hidden until a certain set of conditions are met which reveal them as a failure in the software execution.

From Fault to Failure

1. The programmer creates a *fault* in the code.
2. When executed, the *fault* creates an *infection*.
3. The infection *propagates*.
4. The infection causes a *failure*.

This infection chain must be traced back – and broken.



Not every *fault* creates an infection – not every infection results in a failure

Software Faults - Categories

- Algorithmic faults
  - Algorithmic faults are the ones that occurs when a unit of the software does not produce an output corresponding to the given input under the designated algorithm
- Syntax Faults
  - These occur when code is not in conformance to the programming language specification, (i.e. source code compiled a few years back with older versions of compilers may have syntax that does not conform to present syntax checking by compilers (because of standards conformity).

Software Faults - Categories

- Documentation faults
  - Incomplete or incorrect documentation will lead to Documentation faults
- Stress or overload faults
  - Stress or Overload faults happens when data structures are filled past their specific capacity where as the system characteristics are designed to handle no more than a maximum load planned under the requirements
- Capacity and boundary faults
  - Capacity or Boundary faults occur when the system produces an unacceptable performance because the system activity may reach its specified limit due to overload
- Computation and precision faults
  - Computation and Precision faults occur when the calculated result using the chosen formula does not confirm to the expected accuracy or precision

Software Faults - Categories

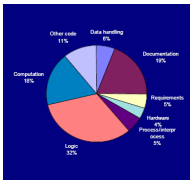
- Throughput or performance faults
  - This is when the developed system does not perform at the speed specified under the stipulated requirements
- Recovery faults
  - This happens when the system does not recover to the expected performance even after a fault is detected and corrected
- Timing or coordination faults
  - These are typical of real time systems when the programming and coding are not commensurate to meet the co-ordination of several concurrent processes or when the processes have to be executed in a carefully defined sequence

Software Faults - Categories

- Standards and Procedure Faults
  - Standards and Procedure faults occur when a team member does not follow the standards deployed by the organization which will lead to the problem of other members having to understand the logic employed or to find the data description needed for solving a problem.

Software Faults

- A study by Hewlett Packard on the frequency of occurrence of various fault types, found that 50% of the faults were either Algorithmic or Computation and Precision



Software Failures

1. Failure causes a system crash and the recovery time is extensive; or failure causes a loss of function and data and there is no workaround
2. Failure causes a loss of function or data but there is manual workaround to temporarily accomplish the tasks
3. Failure causes a partial loss of function or data where user can accomplish most of the tasks with a small amount of workaround
4. Failure causes cosmetic and minor inconveniences where all the user tasks can still be accomplished

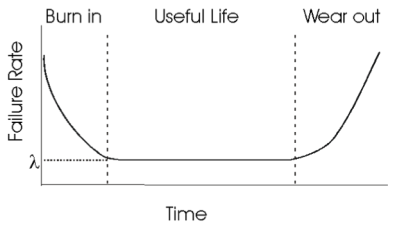
Comparing Software with Hardware

- To gain an understanding of SW and how to approach testing it, it is important to examine the characteristics of software that make it different from other things that human beings built.
- When hardware is built, the human creative process (analysis, design, construction, testing) is ultimately translated into a physical form.
- Software is a logical rather than a physical system element.
- Therefore, software has characteristics that differ considerably from those of hardware

Difference between Software and Hardware

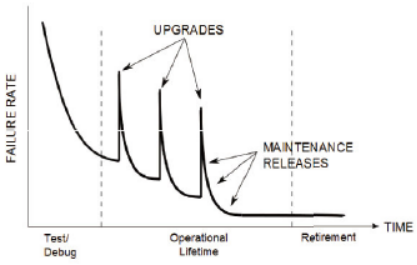
- Software is developed or engineered, it is not manufactured in the classical sense.
- Software does not wear out
- See failure curves for hardware and software
- Most software is custom-built, rather than being assembled from existing components

Failure Curve for Hardware



Burn-in: Procedure used in spotting weak parts or circuits of an electronic device (such as a computer) by running it at full power in a hot and humid environment for extended periods (up to 30 days for critical systems). This practice is based on the experience that semiconductor devices often show their defects in the first few days or weeks of operation.

Curve for Failure Rate over Product lifecycle



Curve for Failure Rate over Product lifecycle

- Unlike hardware software does not physically wear out.
- It is subject to ongoing changes after release and is subject to changes in the external environment (such as an OS upgrade).
- These changes can introduce new faults or expose latent faults.

Curve for Failure Rate over Product lifecycle

- Initially, the first version has a high failure rate. With debugging and testing, as these are found and corrected the failure rate decreases until it reaches an acceptable level.
- Upgrades introduce new faults that are then fixed via maintenance releases
- Once the software is no longer supported the failure rate levels off until the product becomes obsolete.

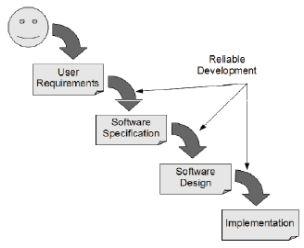
Difficulties with Software vs Hardware

1. It is difficult for a customer to specify requirements completely.
2. It is difficult for the supplier to understand fully the customer needs.
3. In defining and understanding requirements, especially changing requirements, large quantities of information need to be communicated and assimilated continuously.
4. Software is easy to change.
5. Software is primarily intangible; much of the process of creating software is also intangible, involving experience, thought and imagination.
6. It is difficult to test software exhaustively

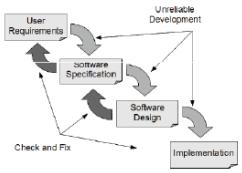
Forward Engineering

- This is an approach to designing correct systems. It starts with the user and ends with the correct implementation. The end product matches the specification.

Forward Engineering

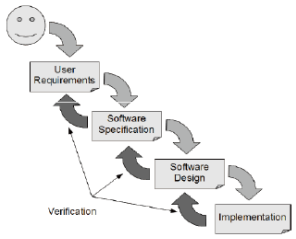


Check and Fix



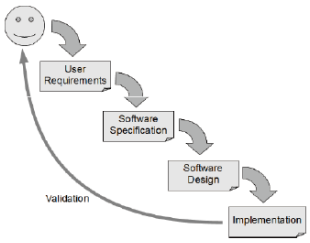
In practice, all development steps must be subject to a check to ensure it has been carried out properly and any mistakes encountered are fixed.

Including verification in the development process



Check that each step meets its specifications

Validation in the development process



Check that the software meets the users needs

Specifications

- Specifications play a key role. Detailed specifications provide the correct behaviour of the software.
- They must describe normal and error behaviour.

Testing in the development process

- Software has three key characteristics
  - User requirements that state the user's needs
  - A functional specification stating what the software must do
  - A number of modules that are integrated to form the final system
- These must be verified using the following four test activities

Unit Testing

- An individual unit of software is tested to ensure that it works correctly. This may be a single component or a compound component.
- A component might be a method, a class, or subsystem. It could be a single GUI component (e.g. button) or a collection of them (e.g. a window).
- This makes use of the programming interface of the unit.

Integration Testing

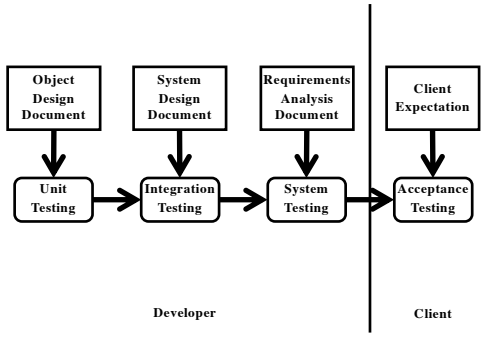
- Two or more units are tested to ensure that they interoperate correctly.
- This may use the programming interface or the System interface.
- Can be Top-Down, Bottom-up, or take an 'end-to-end user functionality' approach

System Testing

- The entire software system is tested to make sure that it works correctly and that it meets/solves the user's needs/problem.
- This uses the system interface which may be a GUI, Network interface, web interface etc…

Acceptance Testing

- The entire software system is tested to make sure that it meets the user's needs.
- Again, this uses the system interface.



Regression testing

- Regression testing is a form of software testing that confirms or denies a software's functionality after the software undergoes changes.
- make new regression tests as you find and correct bugs
- Ensure that you don't reintroduced errors that were previously fixed

Regression Testing practice

- Maintain a Strict regular Testing Schedule
- Use Test Management Software
- Categorize Your Tests so they are easily understood
- Prioritize Tests based on need, e.g. customer's requirements

Theory of Testing

- The goal is to identify the ideal test – that is, the minimum test data required to ensure that the software works for all inputs.

Exhaustive Testing

- This is generally not feasible as it would take too long or require too much memory space.
- A good test should have a high probability of finding faults, not duplicate another test, be independent in what it measures so no faults conceal one another, and test as much of the code as possible.

Exhaustive Testing Example

- Consider a method `bound()` as defined below:

```
// return a value of x bounded by the
  upper and lower values
// return lower if x<=lower
// return upper if x>=upper
// return x if lower<x<upper
long bound(int lower, int x, int upper);
```

Exhaustive Testing Example

- If *int* is defined as a 32-bit, signed integer, then each input parameter has 2^{32} possible input values.
- Exhaustive testing would require using every possible combination of input values, leading to 2^{96} tests.
- If, on average, each test took 1 nano-second to execute – possible on a modern, multi-core processor – then the test would take 2^{96} (or about 10^{29}) nano-seconds to complete. This is approximately 10^{12} years!
- The sun is only $4.6 * 10^9$ years old. So clearly this is not feasible, even for a simple function.

Time Spent on Testing

- 50%~Brooks/Myers, 1970s
- 80%~Arthur Andersons' Director of testing in North America, 1990s

Time Allocation to create Software

	Requirements Analysis	Preliminary Design	Detailed Design	Coding and Unit Testing	Integration and Test	System Test
1960s – 1970s	10%			80%	10%	
1980s	20%		60%		20%	
1990s	40%	30%		30%		

Source: Andersson, M., and J. Bergstrand. 1995. "Formalizing Use Cases with Message Sequence Charts." Unpublished Master's thesis. Lund Institute of Technology, Lund, Sweden.

Time Allocation to create Software

- Since the 1970s, software developers began to increase their efforts on requirements analysis and preliminary design, spending 20 percent of their effort in these phases.
- More recently, software developers started to invest more time and resources in integrating the different pieces of software and testing the software pieces as units rather than as a complete entity
- Effort spent on determining the developmental requirements has also increased in importance, with 40% of software developers effort now happening in the requirements analysis phase

Time Spent on Testing

	Planning	Code & Unit Test	Integration & Test
Commercial DP	25%	40%	35%
Internet Systems	55%	15%	30%
Real-time Systems	35%	25%	40%
Defense Systems	40%	20%	40%

DP: Desktop Publishing

Bennatan, E.M, "On Time Within Budget", 2000

Time Spent on Testing

Activity	Small Project (2.5K LOC)	Large Project (500K LOC)
Analysis	10%	30%
Design	20%	20%
Code	25%	10%
Unit Test	20%	5%
Integration	15%	20%
System test	10%	15%

McConnell, Steve, "Rapid Development", 1996

Testing Types

- Black-box testing – generate input values that exercise the specification and compare the actual output with the expected output
- White-box testing – generate input values that exercise the implementation and compare the actual output with the expected output
- Fault insertion – insert faults into the code or data to measure the effectiveness of testing or ensure that the fault is detected and handled correctly

Finishing Testing

- A budgetary point of view: when the time or budget allocated has expired
- An activity point of view: when the software has passed all of the planned tests
- A risk management point of view: when the predicted failure rate meets some quality criteria

Criteria

- Usage-based criteria give priority to the most frequent sequences of program events.
- Risk of Release predicts the cost of future failures based on their chance of occurring.