ECSE 429 Study guide

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Part I
Introduction

2 Idealized Tests

There is no single testing method to cover all situations. This would be an ideal test, that is, one that:

- Detects any and all defects
- Pass all good devices

The challenges when trying to design idealized tests are that there is a very large number of defects to be tested, of different types, and not all defects are testable (due to the way the system interfaces are designed, dependence on external factors etc).

There are external dependencies to almost any program, whether that be the hardware, the OS the program is running in, applications yours depends on, interacts with, or libraries your program utilizes. An ideal test would have to cover cases of failure in ALL of these dependencies, which with modern systems is infeasible.

3 What Does Testing Do?

With increased reliance on software systems, we must be able to have confidence in mission-critical pieces of software that govern our lives. Improper or lack of testing can lead to massive losses.

Traditionally and in hardware, testing has the following roles:

- Determine if the device has faults
- Diagnose which faults occurred
- Determine and correct errors in design or testing

- Failure mode analysis: What could have caused the defects in the devices

More specifically for software, testing has 3 responsibilities:

1. Does the software satisfy the requirements
2. Does the software perform adequately
3. Does the software have defects?

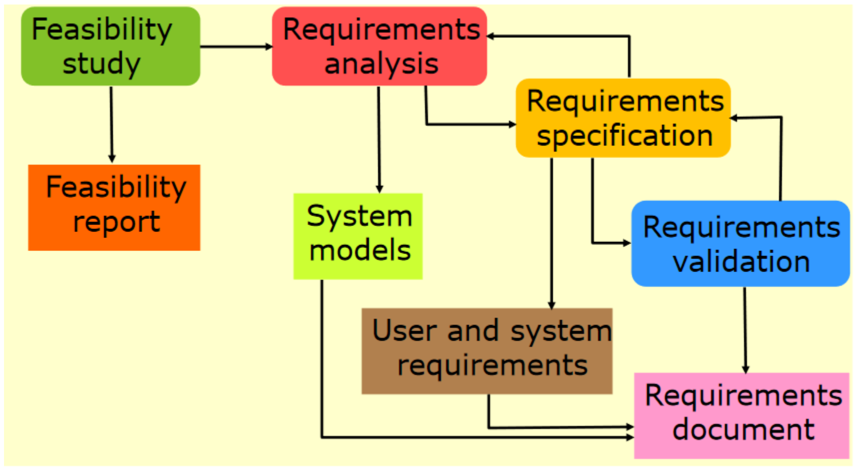
4 Software Development Processes

A software development process is a structured plan or set of activities to develop a software system. It has the task of specifying requirements, designing, validating and evolving the system further.

4.1 Specification Phase

The specification phase of software development is where we must establish what the system must be able to do, the constraints under which the system is to be built and operated. To determine this, there are several phases involved:

- Determine if the requirements are feasible
- Analyze requirements
- Formally specify requirements
- Validate requirement specification matches true requirements



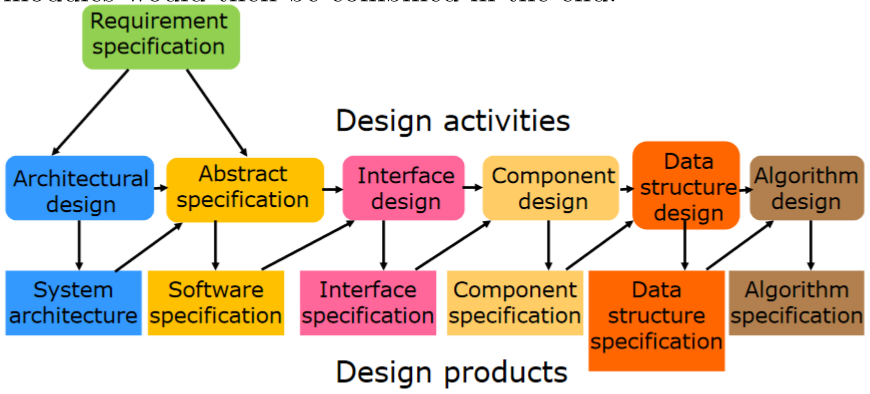
4.2 Design Phase

The design phase is where the system is built "in-theory" to a level of detail which proves it can match the requirements determined in the specification phase.

Phases:

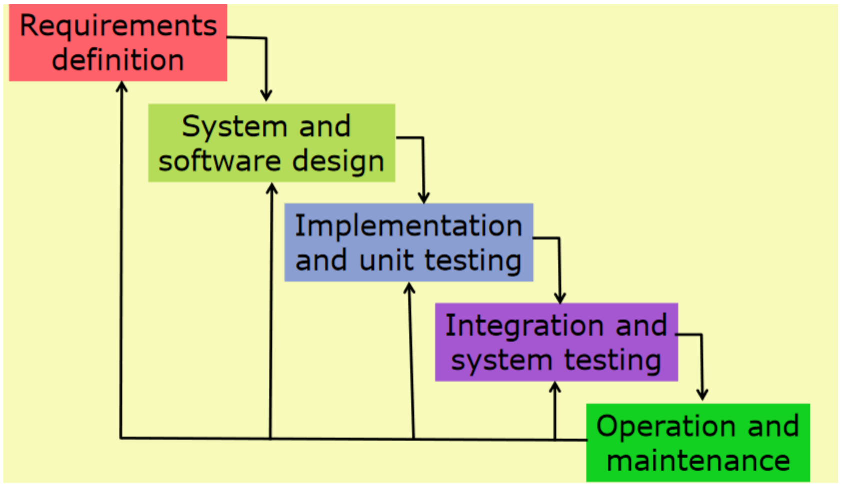
- Data design : How the data will be structured
- Architectural Design : How the structure of the application will be laid out
- Interface Design : How the components will communicate
- Procedural Design : Specify how the exection flow will work
- Algorithm Design : Low-level design of individual algorithms used

To accomplish this there are two common approaches: *refinement* in which the entire system is described in increasing levels of detail, and *Modularity* where the software is divided into conceptual (and functional) modules which can be developed independently. These modules would then be combined in the end.



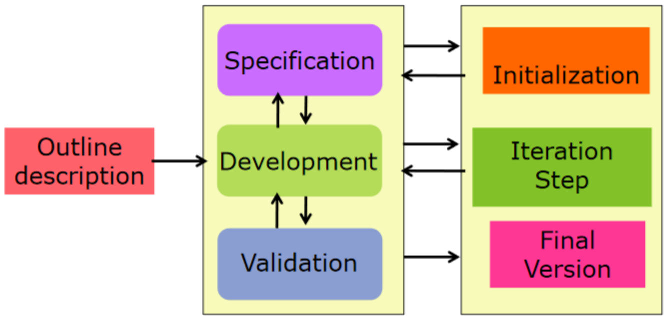
4.3 Generic Software Process Models

There are several generified models for designing software. The classic is the *Waterfall Model*. In this method, the phases are distinct and disjoint. First specify requirements, then implement, test etc. There is never any "backtracking" to previous phases.


Requirements definition
System and software design
Implementation and unit testing
Integration and system testing
Operation and maintenance

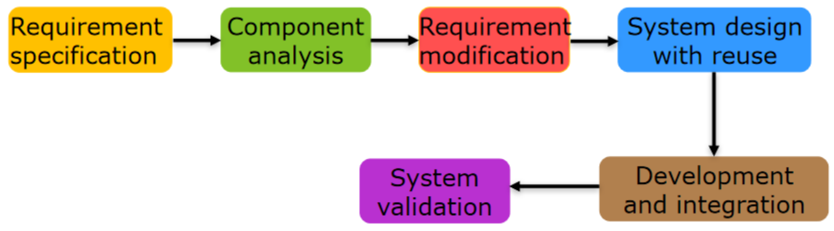
The advantage to this model is that if a design cannot be implemented for any reason, this will be detected and corrected far before time and money has gone into the implementation. This was especially useful for hardware, where manufacturing is also involved. The disadvantage is that its very difficult to say a phase is "completed" and never return, as this requires full-knowledge of the requirements, limitations and changes to the requirements are limited or non-existent.

In the *evolutionary* model interleaves the phases and iteratively improves the software by adding more and more requirements.



The advantage to this is that problems can be addressed early, requirements are more flexible, and feedback from the stakeholders can be leveraged to make course-corrections. However, the disadvantage is that it can involve a lot of re-writing of "poorly-designed" components, and often it is difficult to make the early stages "generic" enough to be flexible for later changes. This strategy is best used for small to medium sized interactive systems, or for parts of a larger system.

In *component* based model the software is built by plugging several existing components together.



. Here the advantage is that often it can be assumed that the components built can be trusted, and so their inner-workings do not need to be tested. Instead, only interactions between components is to be tested. Using "off-the-shelf" solutions also saves development time, and (depending on the cost of the module) costs.

5 Quality

Software quality is the degree to which a system meets specific requirements, customer needs and expectations.

The environment in which the software is developed brings many challenges for quality assurance. The features requested, budgeting, timeline, customer relation, team dynamics, etc.

Software Quality Factors:

- Usability: How is the user experience?
- Maintainability: Find and fix bugs
- Flexibility: ability to add new features
- Testability
- Portability: adaptation to execution environments
- Reusability of components
- Interoperability with other components/systems
- Robustness, performance, understandability etc.

5.1 Quality Assurance and Control

Quality Assurance aims to plan and minimize cost of guarenteeing quality, while *quality control* is a set of activities to implement quality assurance principles.

The cost of independent contractors for QA is often high. However, forming QA teams within a company is often done to minimize cost and maximize effectiveness, since the team will form a deeper knowledge of your software. These teams aim to know what the software is doing, what it should be doing, and how to measure the difference. This is accomplished through being involved with development teams, business teams, and using methods to measure software performance:

- Formal methods: mathematically verification
- Testing: explicit input/ouput to the software and check results
- Inspections: Human interaction to check requirements, design, code etc
- Metrics: data generated about the program to analyze quality

Part II
Testing and Verification Terminology

6 Validation vs Verification vs Testing

Validation is the process of evaluating software to ensure compliance with intended usage. ”Did we build the *right* thing?”

Verification is the process of determining if products of a given phase of the software development cycle fulfills the requirements of the previous phase. ”Did we build the thing *correctly*?”

Validation is more than just testing. It must demonstrate reliability, ensure compliance, generate knowledge about the application, and establish future requirements.

There are several techniques of validation:

- Formal Methods: Math based, often not possible
- Fault Injection: Intentional, methodical injection of faults to see how the system react and verify it matches the expected behavior.
- Dependency Analysis: Identification of hazards and proposing methods of how to get around them.

7 Testing vs Debugging

Testing is finding the existence of bugs, failures and defects. This job is handled by a QA team.

Debugging is finding the cause, analyzing and correcting the bugs. Done mostly by development team.

8 Cost of Testing

At least half of development budget is spent on testing. In reality, testing is a post-design activity, which increases cost since errors are not caught early during the design phase.

Not 2

9 Faults, Failures and Errors

Often it is not possible to establish that software is correct under all conditions due to application complexity. Therefore we must rely on showing that software fails under more specific condition. The problem then lies in which conditions we simulate with the system to target the majority of all possible cases.

9.1 Errors

An **error** is defined as an incorrect internal state that is the manifestation of some fault.

This fault must change the operation to be performed by a statement without changing the execution flow, OR, one that changed the execution flow.

However the software may still execute correctly even if it is Erroneous. (Redundant code, dead code etc.)

9.2 Faults

Faults are only design faults when talking about software. Whether it was mistyped or misunderstood, it is a fault. The same is not true for hardware where faults can be caused by outside influences.

A fault is *active* if it causes an error, otherwise it is *dormant*. *Fault activation* is when dormant fault becomes active through some change to the execution inputs or context.

9.2.1 Fault Causes

Faults can often be traced to a single root cause, whether that be software or hardware. This cause is not always logical errors in code or defects in hardware. The causes can come from:

- Failures in Communication
- Improper Resource management
- Inadequate Verification

- Bad Risk management
- Faulty Assumptions

9.3 Failures

An error which causes incorrect behavior with respect to the requirements specification. Software fails due to two things:

- Differ from specification
- Specification does not describe intended behavior.

Failure of some software component causes a **permanent fault** in software that uses that component. Failure of the whole software leads to a **permanent external fault**.

9.4 Defects

A defect is anything that produces wrong results causing failure. A single defect can cause a wide range of failures, but not all defects result in failure. Kind of like a fault.

So all in all, faults activate errors which propagate to failures. Failures are caused ultimately by faults.

There are 9 major causes of defects:

1. Faulty requirements definition
2. Client-developer communication failure
3. Deliberate deviation (in development or usage of system)
4. Design logic errors
5. Coding errors
6. Non-compliance with documentation of code
7. Improper testing
8. Documentation errors
9. Procedure errors (misusing a UI etc)

10 The 7 Testing Principles

10.1 Bug Presence over Absence

The purpose of testing is not to show the absence of buggs, but rather to show the presence of bugs.

If no bugs are found this does not mean that the software is correct.

Of course this doesn't mean the software is bad no matter what, its just that we did not stretch the software to its limit during testing.

10.2 Exhaustive Testing is Impossible

There is often very large number of possible inputs, outputs, states, execution paths for a piece of software, which makes it practically impossible to exhaustively test. Further, specifications may be ambiguous or subjective, leading to multiple "correct" implementations.

Clearly, if the function execution time is long, then it is infeasible to do many inputs.

Example:

```
for (int i=0; i < n; i++){
   if (some cond){
      do one thing
   }else{
      do another thing
   }
}
```

For each loop, there is 2 possible paths. So for n=1 there are 3 paths, n=2 5 paths, and so on. So there are $2^n + 1$ possible paths which quickly grows impossible to exhaustively test.

10.3 Defect cost is exponential

The later defects are caught and fixed, the more they cost. It turns out this is generally exponential.

10.4 Defects Cluster Together

Generally defects are not distributed evenly across the application. This means that the tester can focus on specific key areas.

10.5 Software Becomes Resistant to Testing

After several test iterations the software will be revised to make the tests pass. Thus the tests must always also be revised and improved to try and find more bugs.

10.6 Testing is Content Dependent

Different systems are tested differently. This means that something mission-critical like a piece of military software must be more rigorously tested than something like a cat picture web scraper.

10.7 Absence of errors is a Fallacy

Finding and fixing defects will not make your application "good" if its unusable or doesn't fullfil the users requirements/expectations, it's still bad software.

11 Four Types of Testing Activities

- Test Design: Select appropriate test method based on characteristics of the software
- Test Automation: Tools for making testing feasible and repeatable
- Test Execution: Run the test cases
- Test Evaluation: Check test coverage criteria to estimate the quality of the test and reliability of the results.

12 IQ, QQ, PQ

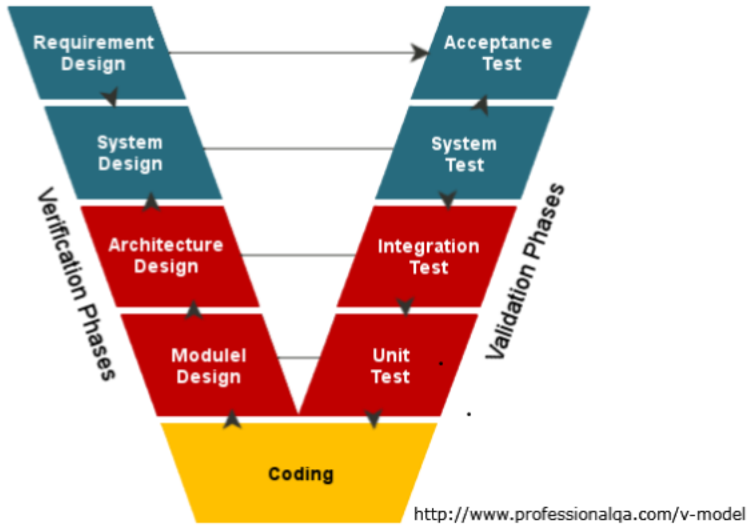
TODO

- IQ: Installation Qualification
- OQ: Operational Qualification
- PQ: Performance Qualification

13 V Model

The V-model is is a verification and validation model that extends to the waterfall design model.

It matches each design phase with a verification/validation counterpart.



V Model is best implemented when there are no ambiguous or undefined requirements, the project is short, and the product definition is static.

The advantages of this model is that testing starts early, testers can be prepared with test cases by the time development is done. Testing is done at each stage so more opportunity to refine the product.

The disadvantages to this model is that it lacks flexibility when it comes to late modifications. There is also no ”early prototype” of the product.

14 Levels of Testing

14.1 Unit Testing

Unit testing attempts to test a single component of the system in isolation. This may cover functional and non-functional aspects. Often these are very detailed and low-level. Tests the design, code, data model and component specs.

Often approached with Test Driven Development (TDD) or white-box coding testing scenarios.

14.2 Integration Testing

Component Integration testing tests the interactions and interfaces between integrated components. Typically also automated.

System Integration testing tests interactions between packages, subsystems, microservices and external services. Often this is done after or in parallel with sytstem testing.

This tends to catch incorrect message structure, timing issues, interface mismatches, communication failures, and incorrect assumptions about the boundaries and units of the system.

14.3 System Testing

Typically this is carried out by humans. The goal is to verify the completeness and usability of the system. This is done through end-to-end testing, exploratory testing and behavior-driven-development. It tends to catch incorrect calculation, failures in end-to-end functional tasks, unexpected behaviors, discrepancies with user manuals, failures to operate in production environment etc.

14.4 Acceptance Testing

Acceptance testing determines the applications fitness for use by end users. It is run in a real or simulated environment.

Generally formally documented procedure.

Operational acceptance testing is done by SysAdmins to ensure backup/restore, install / uninstall, disaster recovery, user management , performance and vulnerability checks are all up to standard.

Additionally, tests for contractual and regulatory restrictions may be tested (generally by some sort of audit group).

Alpha and beta testing may also be used to further increase confidence before final release.

15 Software Aging

Often software faults are the source or cause of software aging. Software aging is when a software gets worse and worse over time due to accumulation of bugs.

This may be caused by failure to keep up with changing demands, or can be caused by bad patches to the code introducing new faults.

16 Hardware Faults and Fault Modeling

An **Error** in hardware is improper behavior, ie wrong circuit output.

Defects in hardware is an unintended implementation problem. This includes material inconsistencies, environmental issues, designer mistakes, specification imprecisions etc.

A **fault** is an abstracted representation of defects. For example suppose we have the AND gate: $c = a \wedge c$, if a is shorted to the ground (defect), then $c = 0, a = 1, b = 1$ (error). The fault is represented as **s-a-0**.

16.1 Fault Models

Fault modeling is the translation of physical defects into a mathematical construct that can be used by software simulation.

This is used to test rather than than real defects since real defects are too numerous and often not analyzable.

A fault model identifies targets for testing and enables analysis.

Logical fault modeling aims to model only faults which affect logical function or time-based performance. This shifts the scope of fault analysis from physical faults to software simulations.

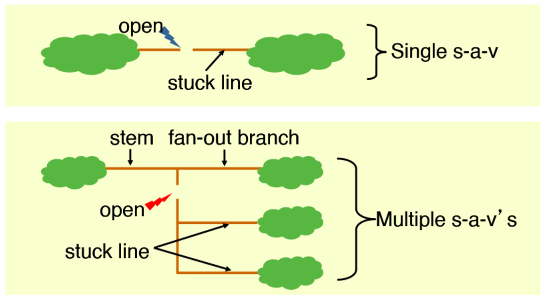
Solid or **permanent** faults do not change over time, while **non-permanent** faults occur and random moments for unspecified periods of time. Detecting non-permanent faults is difficult. They may be **transient** (hard to detect and not-well defined ie: cosmic rays, dust, temperature) or **intermittent** (disappearing / reappearing).

A **non-logical** fault is one that doesn't change the logical function of the unit but affects other circuit parameters such as delays, voltage or current levels.

16.2 Stuck-Open and Short-Faults

Stuck-at faults assume that the components are correct (no-faults) but that the interconnections have faults. **Shorts** are formed by unintended connections, and **opens** are results of broken connections.

These correspond to logical faults known as **stuck-at value** faults (s-a-v) where $v \in \{0, 1\}$.



A single stuck-at-fault (s-a-v) is characterized by :

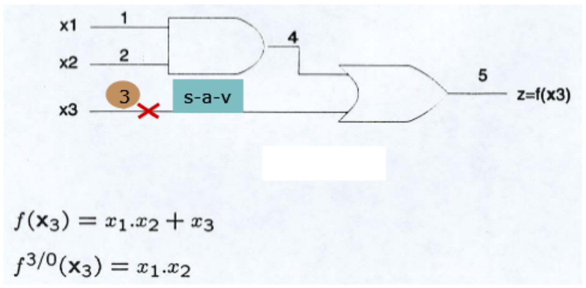
- One faulty line

- Line is set to 0 or 1 (permanently)
- Fault can be input or output of a gate.

Testing for s-a faults is a matter of supplying several input vectors collecting the output responses and comparing to the expected values.

16.3 Notation and Terminology

$f(x_n) = f(x_1, ..., x_n)$ represents a fault-free circuit, while $f^{\frac{p}{d}}(x_n)$ is the same circuit with fault p/d where p is sa wire, and d is an s-a-v fault (0 for s-a-0 and 1 for s-a-1).



A test, T_i detecting a fault p/d is an input x_n^j to the network producing a different response when the fault is present vs not present. If the response was the same regardless, then x_n^j is not a test.

So we can say that $f(x_n^j)$ XOR $f^{p/d}(x_n^j) = 1$ since they are always inverse of each other.

A **test set** is the set of all tests applied to a circuit during testing. The test set is **exhaustive** if it guarantee detection of all possible faults in the circuit. Note that exhaustive testing is nearly impossible: example: 32-bit adder would have 2^32 different inputs possible to test. For this reason generally randomly generated test sets are used. Otherwise, **deterministic test patterns** can be generated by analyzing the circuit, and carefully crafting a test set to cover all possible cases. However even this does not guarantee detection of call possible faults.

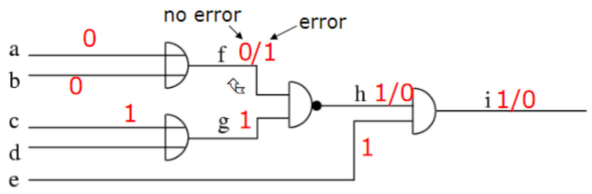
16.4 Test Tables and the XOR Method

A **fault table** displays the outputs of networks subject to test vectors. These are created by first generating the truth table for f and $f^{p/d}$ for each p, d. Next, to generate test cases for $f^{p/d}$, take input cases for which the f column and $f^{p/d}$ values are different.

An alternative method to generate test cases is the boolean difference, in which we express f and $f^{p/d}$ algebraically, and apply rules of Boolean algebra to find a test pattern.

16.5 Path-Sensitizing Method

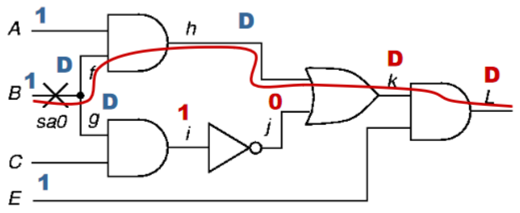
Another way of determining test vectors for a fault is the path-sensitizing method, in which the error is forward propagated to the output to determine the effects of the fault, and then backward propagation is used to determine the test vectors.



Here, to detect a s-a-1 fault at f, we first want to propagate the error to the output. Since this is an s-a-1 fault, if we set $a = b = 0$, then if $f = 1$ we will know for sure there is a fault. In order to see this, we must propagate to the output. g must be 1 so that h can be 1/0 depending on f, and we set e to 1 so that i will show whether the fault exists or not. To determine the test vector, we must back-propagate to determine which inital values lead to the output. We already know $a = b = 0$ and $e = 1$, and since $g = 1$ we can have $c = d = 1$.

Note that this is not unique. We could have set $c = 1$, $d = 0$ or visa versa.

There are cases when this method doesn't work. For example:



If we chose the sensitizing path forward with f, h, k, L, we cannot determine if the fault exists. Suppose it does not exist, then $B = C = E = 1$ and the output $L = 1$. But if the fault does exist then $h = 0$, $j = 1$ and the output is still 1. We say this is blocked at j since backpropagation cannot find a value for i for which the outcome will be different depending on the fault.

16.6 Controllability and Observability

Controllability is the ability to activate certain parts of a circuit ie: how easy is it to establish a specific signal at each internal node by setting inputs, and **observability** is to be able to see the outputs to determine correctness, ie: how easily can we determine internal values by controlling inputs and observing outputs.

Inputs closer to the beginning of a circuit are easier to control than those which are outputs of other circuit elements.

5- Valued logic :

1. $0 \Rightarrow 0$ in both true and faulty circuits

2. 1 ⇒ 1 in both true and faulty circuits
3. D ⇒ 1 in a true circuit, 0 in faulty
4. $\bar{D}$ ⇒ 0 in a true circuit, 1 in a faulty
5. X ⇒ unknown for either true or faulty circuit

The goal is to find some inputs that cause D or $\bar{D}$ at some output.

16.7 Fault Equivalence

Not all faults need to be tested if they are equivalent. Two faults are considered equivalent if all tests that detect one also detects the other.

Formal definition:

$$f_1(V) \equiv f_2(V) \Leftrightarrow f_1(V) XOR f_2(V) = 0$$

for all 2^n vectors V.

Equivalent faults also have identical test sets.

16.7.1 Gate equivalence

For a k input AND gate, there are k possible s-a-0 faults for the inputs and one for the output so $k+1$ s-a-0 faults overall. Each s-a-0 changes the output to a constant 0 and so are all equivalent. Therefore there is really only 1 unique s-a-0 fault for the AND gate.

Similarly for an OR gate, s-a-1 faults are all equivalent.

In NOT gate, s-a-0 input is equivalent to s-a-1 output, and s-a-1 input is equivalent to s-a-0 output.

Similar logic applies for NAND and NOR gates.

16.7.2 Fault Collapsing

Fault collapsing is a method of determining all unique faults (non-equivalent) in a circuit.

First, all faults are partitioned in to equivalence classes, and a single fault from each is kept in a fault list.

CollapseRatio = |collapsed faults|/|all faults |

16.8 Classes of Stuck-At-Faults

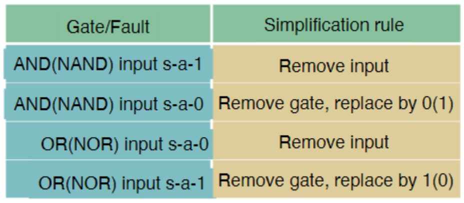
- Potentially detectable faults: The test produces an unknown state, and whether or not the fault can be detected from this state is probabilistic. For example, a flip-flop that cannot be initialized due to a s-a-0 fault. These are really just an artifact from test simulation, not something that can occur in reality.
- Initialization Fault: The fault prevents initialization of the faulty circuit, and can be treated as a potentially detectable fault.
- Redundant Fault: No test exists for the fault because its effects are not visible.
- Untestable Fault: Test generator cannot find a test for it (test vector does not exist).

16.9 Redundant and Untestable Faults

Sometimes, circuits can have redundancies not detected by tests. for example, 3 NOT gates in a line with 2 s-a-v faults between the gates. This is testable, and will always produce distinct outputs for different inputs, but there is clearly 2 redundant NOT gates. This is an example of an *irredundant* circuit since all s-a-v faults can be removed by simplification.

If the circuit contains an undetectable s-a-v fault it is redundant since it can always be simplified by removing a gate or gate input.

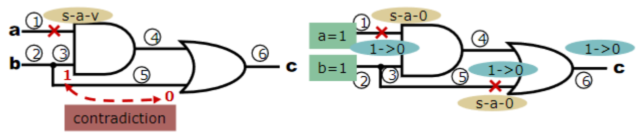
For example, if the input to an OR gate is s-a-0, then this is the same as just removing the gate and connecting the other wire directly to the next section in the circuit. There are actually several easy simplification rules:



Gate/Fault	Simplification rule
AND(NAND) input s-a-1	Remove input
AND(NAND) input s-a-0	Remove gate, replace by 0(1)
OR(NOR) input s-a-0	Remove input
OR(NOR) input s-a-1	Remove gate, replace by 1(0)

Note that if a line i can be replaced with a constant $v = \{0, 1\}$ then fault i/v is untestable. (and redundant).

It is common that an untestable fault become testable (activated) with the presence of some other testable s-a-v fault. However if an untestable fault is activated, this may invalidate other tests!

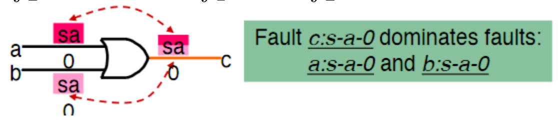


Notice here that the fault on line 1 is untestable, but if there is a s-a-0 on line 5, then the s-a-0 on line 1 becomes testable!

16.10 Fault Dominance

Let T_g be the set of all test vectors detecting a fault g. A fault f dominates $g \Leftrightarrow$ any test t that detects g also detects f. That is, $T_g \subseteq T_f$ Also note that if f_1 dominates f_2 and f_2 dominates f_1 then they are equivalent.

If f_2 dominates f_1 then f_2 can be removed from the fault list.



17 Fault Simulation and Detection

Fault simulations start with fault-free ones to establish correct behavior. Next, there are 4 key steps involved:

1. Fault Specification: The definition of the collapsed fault set
2. Fault Insertion: Select faults to be simulated in parallel, and their recognition by the simulation
3. Fault Effect Generation/Propagation: Create the input vector which will excite the fault.
4. Fault Detection and Discarding: remove the fault from the fault list once observation is complete

As for detecting faults, (Fault Detection), there are 3 major parts:

1. Fault List Generation: First we must find the collapsed list of faults (according to equivalence and dominance rules)
2. Test Patter Generation: Find the vectors detecting the faults
3. Fault simulation, run the fault simulator over the test vectors.

Testability $= \frac{detectable}{total}$ faults

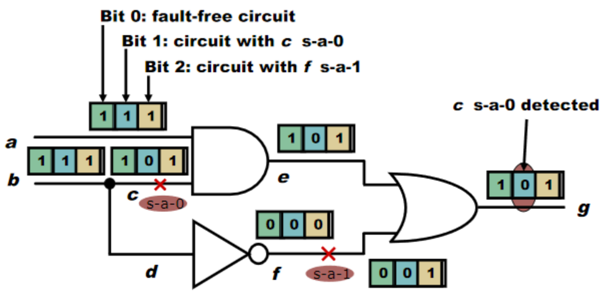
17.1 Serial and Parallel Fault Simulation

A simple algorithm for serially simulating faults is the following:

First simulate the fault free circuit to determine correct outputs. Next, for each fault in the fault list, inject one fault and simulate the circuit. If the response differs from the expected, report the fault and suspend further testing.

However for most circuits, this will take much too long. The solution is to simulate multiple faults together at once.

In parallel fault simulation, we do the same thing but for $w-1$ vectors at a time, where w is the word length. This is possible since Boolean operators are bit-wise independent. Meaning we can compute 10110001 AND 10110001 = 11111111 in one operation.


Bit 0: fault-free circuit
Bit 1: circuit with c s-a-0
Bit 2: circuit with f s-a-1
c s-a-0 detected
a
b
c
d
e
f
g
s-a-0
s-a-1
1 1 1
1 0 1
0 0 0
0 0 1

17.2 Multiple s-a-v Faults and Delay Test

Multiple s-a-v faults affect more than one circuit line with some combination of values.

The total number of single and multiple stuck-at-faults in a circuit with k single-fault sites is $3^k - 1$.

Tests for single s-a-v are not sufficient for detecting multiple s-a-v faults. However statistically, single s-a-v tests cover most multiple s-a-v faults.

Delay Testing aims to answer if a device works when running at speed. If a circuit passes a delay test then it produces correct outputs when supplied inputs and a specified timing. This is needed because there can be delay in an individual gate, or for time taken for a signal to traverse wires between gates.

17.3 Test Coverage

- Statement coverage: the percent of statements run
- Path coverage: the number of paths run
- Expression coverage: number of expressions within statements run

However 100% coverage does not mean the design is correct!

18 Software Testing Terminology Revisited

- Testing: finding inputs that cause software to fail
- Debugging: finding the faults that caused a given failure
- Software fault-tolerance: Ability to detect and recover from a fault. Often redundancy is used to guarentee that required services are provided in spite of faults.
- Test Case Values: the values that satisfy a test requirement
- Expected Results: the result that should be produced when executing the test
- Observability: Same as hardware, but note that software that interacts with hardware, databases and remote files tend to have low observability. Programs giving no outputs are hard to test for this reason, they are not observable.
- Controllability: Easy to control software with inputs, data abstraction tends to hinder controllability and observability

19 Mutation Testing

The idea behind mutation testing is to take a program and test data generated for it, and to create similar (but different) programs known as mutants which each differ from the original in a small way, each with a fault. The original test data is passed though each of the mutants. If the test data detects all differences, then the mutants are said to be dead, and the test set is adequate.

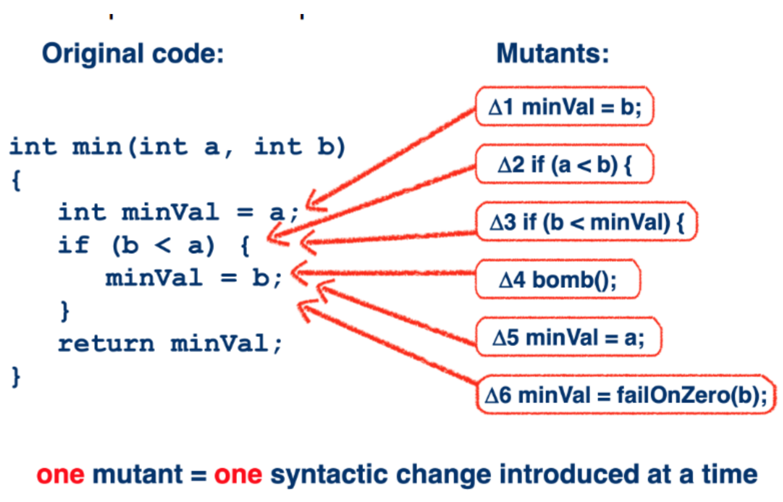
Failure to kill the mutant means that either it is equivalent to the original program or that the test set is inadequate.

There are a few types of mutants:

- Stillborn mutant: Syntactically incorrect, and so killed by the compiler
- Trivial mutant: Killed by most test cases
- Equivalent mutant: Always produces same output as original.

Ideally, we want to select mutation operators that are representative of all types of faults that might occur in practice. However there is still a very large number of them.

Mutation Coverage is the ratio of dead-mutants to all non-equivalent mutants. Each mutant can be seen as a test requirement, and the number of mutants depends on our definition of possible mutant operators for the syntax/structure of the software.



```
int min(int a, int b)
{
   int minVal = a;
   if (b < a) {
      minVal = b;
   }
   return minVal;
}
```

In general, errors are not that simple. We tend to assume that programmers are competent individuals and that errors are the result of a combination of simple errors. We also assume that by testing for simple errors, the tests are sensitive enough that we would also detect more complex errors.

19.1 Equivalence Partitioning

This is a form of black box testing that divides the inputs into classes of data from which tests can be derived. For example, if a program is computing $\sqrt{(X-1)*(X-2)}$ we might divide into $X < -2$, $-2 < X < 1$ and $x \geq 1$. And test cases would be chosen from each equivalence class.

Generally we assume that behavior under these classes is similar, and that programming errors tend to occur near extreme values (boundaries between classes). Thus we generally test values at their minimum, just above minimum, at a normal (nominal) value, just below the max and at the max. The same applies for output values, try to choose inputs that will generate values at the bounds of possible outputs.

Using this method, a function with n variables will need at least $4n+1$ test cases. However this only works for variables that represent bounded physical quantities, as the actual meaning of the variables is not taken into account. We can also extend this to test for robustness by testing invalid domain values as well (total $6n+$ now).

We can also extend this to scenarios where more than one variable has an extreme value by taking the cartesian product of the bounds. Here there would be 5^n cases for n variables.

19.2 Summary

Mutation testing is most useful for white-box unit testing, and is also useful for assessing different test strategies. The mutation score can be used to predict fault detection effectiveness. However, this is very expensive to compute, and high coverage is not a guarentee of a fault-free software.

20 Test Cases and Types of Tests

A **test case** describes how to test different levels of the software. These might be the entire system (end-to-end test), a particular module or specific function.

Each test case must specify:

- System state prior to test execution
- The function to be tested
- The parameters to be tested
- The expected outcome of the test

Each requirement of the software needs at least one test case.

20.1 Test Case Design

Our goal is to generate test cases which discover all errors with minimal effort and time.

Test cases can follow a formal structure:

- Information
  - Identifier
  - Test case creator
  - Test case version
  - Name of the test case
  - Description
  - Dependencies
- Activities
  - Initialization
  - Post-actions
  - Step-by-step actions during test
  - Input data
- Results (information about expected results and actual results)

20.1.1 Test Driven Development (TDD)

TDD is a practice in which test cases are written before the software. This enforces testability of the software, meaning the ideas of observability and controllability are kept in mind during development. There are less cases of needing to adjust testing to the program behavior since the program is created in accordance to the tests.

20.2 Dynamic Testing

Dynamic Testing is the practice of testing by executing the program with real inputs.

Within dynamic testing, there's blackbox (functional), whitebox (structural) and random testing.

20.2.1 Functional Testing

Functional testing requires identifying and testing all of the required functionality of the system. This type of testing assumes no knowledge of the implementation of the system. Test cases for black-box functional testing are derived from the external descriptions of that the software *should* do.

The advantage is that the test engineer does not need to understand the underlying code, and so might find bugs in places the programmers did not expect due to the "naive" perspective.

The disadvantage is that by having no knowledge of the underlying system its kind of poking around the system to look for bugs. There's no guided approach. Other than trying lots of test cases and seeing what happens.

20.2.2 Structural Testing

This type of testing aims at finding bugs during the coding process. It requires full knowledge of the system.

Generally this is applied in unit, integration and system levels of testing. Since these are tightly coupled to the implementation, whitebox tests will need to change as the code changes.

The advantage to this is that its possible to generate test cases that cover all independent paths at least once. And cover all different logical decisions by exploring their different outcomes.

Within structural (whitebox) testing there are different types:

- Fault injection
- Mutation testing
- Static testing

Often this can be used to evaluate the completeness black-box tests.

20.3 Code Coverage

In white-box testing, there are different metrics of coverage that can be applied to attempt to measure the ”completeness” of the test set.

- Statements covered
- Branches covered
- Paths covered
- Conditions covered

The idea behind these is that without exercising the piece of code, (statement, branch, etc) we have no way of knowing if an error exists there.

20.4 Static Testing

Static testing is more focused on finding specific kinds of defects that do not depend on the dynamic nature of the program. Basically this is when the testing is done by looking at the ”code” rather than running it.

This can find things like:

- Requirement defects
- Design defects: inefficent code, coupling
- Code defects: dead code, duplicate code, uninitialized variables
- Interface specifications
- Security vulnerabilities: sql injection, buffer overflow etc.
- Missing tests
- Maintainability / style defects

20.5 Testing Techniques

20.5.1 Stress Testing

The goal of this is to determine whether the software can handle the expected (or above expected) load. Often applied to distributed systems who are often limited by network congestion.

20.5.2 Execution Testing

This verifies the efficiency of execution of the system. Performance, resource usage, response time, transaction turnaround time etc.

20.5.3 Recovery Testing

This checks how the system recovers from failures. There are some external factors that the system may not have control over, but the system should be able to at least recover from these situations. Recovery testing often simulates disaster situations to validate the system functions correctly under these conditions.

20.5.4 Operations Testing

Verifying that the system can be executed under normal operational conditions.

20.5.5 Compliance Testing

A set of checks that ensure the system was developed in accordance with standards and procedures required by law or contract.

20.5.6 Security Testing

Often tied to compliance testing, this ensures the software is protected from malicious attacks. This includes ensuring resources and access levels are correctly defined and that security procedures have been followed.

20.6 Random Testing

In this type of testing, random selection of test cases to detect faults.

20.7 Static Testing

Static testing, or static code analysis is the process of inspecting source code without execution. This can be quite effective at finding common, simple bugs or design flaws.

Generally it is used as a ”consistency technique” to ensure the program remains high-quality. Things such as:

- Syntax

- Parameters between procedures match
- Type checking
- Requirements and specifications translataed correctly

The benefits of static testing is that it can capture defects very early (often *during* coding) which saves much of the cost of finding the errors later.

Note that its not just for code! Static verification and validation can be applied at any stage in the developement process, from requirement specification to design to the actual code.

21 Integration Testing Methods

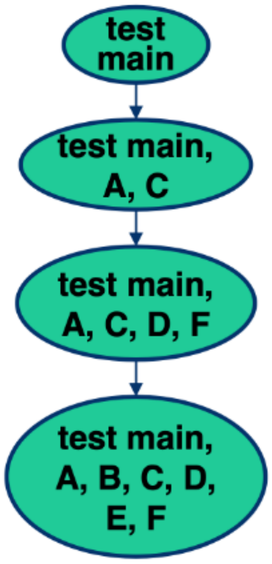
21.1 Big Bang Integration Testing

This is a non-incremental strategy in which all components of the system are integrated in one fell swoop. It assumes that each component is tested in isolation beforehand.

The advantage is its convienience for small, easy to maintain systems. However it does not allow testing to be done in parallel with development, and it can be difficult to localize faults.

21.2 Top-Down Testing

Top-down testing breaks down the system from, well, the top-down. From higher-level modules down into the individual classes, methods and statements.



Advantages:

- Fault location is easier
- Few to no driver classes needed
- Early prototype possible
- Testing parallel to implemetation
- Rearrangements of testing order is possible
- Major design flaws are found first (top of heirarchy)

Disadvantages:

- Need lots of stubs
- Bottom of hierarchy could be inadequately tested

21.3 Bottom-Up Testing

The bottom up approach starts with the basic blocks of the program (statements, methods, classes) and puts them together into larger and larger components.

Advantages:

- Fault location still easier than big-bang
- No need for stubs since small compenents thoroughly tested

- Reusable components tested throroughly
- Testing parallel to implementation
- Different testing order possible

Disadvantages:

- Drivers needed
- High-level components that are more related to the requirements are tested last (major design flaws caught last)
- No prototyping through skeletal system

21.4 Sandwich Method

This combines the top-down and bottom up approaches. The top layers (aka logical layers) are tested more for design and logic. Whereas the bottom layers (operational layers) are tested to ensure they carry out the logic correctly.

21.5 Critical Modules

In this strategy, we start with modules that are the "riskiest" or those for which a failure would have the largest impact.

This requires an initial risk-assessment.

21.6 Scaffolding

Scaffolding is not a testing method but is a category of code that is produced to support development and testing. This is not part of the "product" directly.

21.6.1 Drivers

Drivers are pieces of code that call the testing modules. They handle parameter passing, handling return values, failures/sucesses, and manage stubs.

In bottom-up testing, we must have a driver for each module, and get replaced to group larger and larger subsystems as the system grows.

21.6.2 Stubs

Stubs are the key to controllable code. They are peices of code that replace the actual implementation to a temporary, minimal implementation of the component to be able to modify behavior.

Some code might not be written yet, so using a stub would be necessary. Otherwise, if some piece of code is slow, a stub may be more efficient if only testing certain portions.

Stubs for input modules pass test data into the system, whereas stubs for output modules return expected results.

They must have the same interfaces as the real modules so that they act exactly the same.

21.6.3 Test Harness

The test harness is an automated test framework. It is configured to test program units by running them under varying conditions. Automatically generated tests are often too generic and insufficient to fully test the software, so the harness is used to facsilitate writing new automated tests.

It is made up of two main parts, the **test execution engine** and the **test script repository**.

Part III
Coverage