Software Quality Handbook

Lane Galvin

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Delhi - 110002
Email: info@wtbooks.com

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Chapter 1

Software Quality

In the context of software engineering, **software quality** measures how well software is designed (*quality of design*), and how well the software conforms to that design (*quality of conformance*), although there are several different definitions, including conformance to customer expectectations. It is often described as the 'fitness for purpose' of a piece of software.

Whereas *quality of conformance* is concerned with implementation, *quality of design* measures how valid the design and requirements are in creating a worthwhile product.

Definition

One of the challenges of software quality is that "everyone feels they understand it".

In addition to more software specific definitions given below, there are several applicable definitions of quality which are used in business.Quality_(business)#Definitions

Software quality may be defined as conformance to explicitly stated functional and performance requirements, explicitly documented development standards and implicit characteristics that are expected of all professionally developed software.

The three key points in this definition:

1. Software requirements are the foundations from which quality is measured.

   Lack of conformance to requirement is lack of quality.

2. Specified standards define a set of development criteria that guide the management in software engineering.

   If criteria are not followed lack of quality will usually result.

3. A set of implicit requirements often goes unmentioned, for example ease of use, maintainability etc.

> If software conforms to its explicit requirements but fails to meet implicit requirements, software quality is suspected.

A definition in Steve McConnell's *Code Complete* divides software into two pieces: **internal** and **external quality characteristics**. External quality characteristics are those parts of a product that face its users, where internal quality characteristics are those that do not.

Another definition by Dr. Tom DeMarco says "a product's quality is a function of how much it changes the world for the better." This can be interpreted as meaning that user satisfaction is more important than anything in determining software quality.

Another definition, coined by Gerald Weinberg in *Quality Software Management: Systems Thinking*, is "Quality is value to some person." This definition stresses that quality is inherently subjective - different people will experience the quality of the same software very differently. One strength of this definition is the questions it invites software teams to consider, such as "Who are the people we want to value our software?" and "What will be valuable to *them*?"

History

Software product quality

- Product quality
  - conformance to requirements or program specification; related to Reliability
- Scalability
- Correctness
- Completeness
- Absence of bugs
- Fault-tolerance
  - Extensibility
  - Maintainability
- Documentation

The Consortium for IT Software Quality (CISQ) was launched in 2009 to standardize the measurement of software product quality. The Consortium's goal is to bring together industry executives from Global 2000 IT organizations, system integrators, outsourcers, and package vendors to jointly address the challenge of standardizing the measurement of IT software quality and to promote a market-based ecosystem to support its deployment.

It is essential to supplement traditional testing – functional, non-functional, and run-time – with measures of application structural quality. Structural quality is the quality of the application's architecture and the degree to which its implementation accords with software engineering best practices. Industry data demonstrate that poor application structural quality results in cost and schedule overruns and creates waste in the form of rework (up to 45% of development time in some organizations). Moreover, poor structural quality is strongly correlated with high-impact business disruptions due to corrupted data, application outages, security breaches, and performance problems. As in any other field of engineering, an application with good structural software quality costs less to maintain and is easier to understand and change in response to pressing business needs.

Source code quality

A computer has no concept of "well-written" source code. However, from a human point of view source code can be written in a way that has an effect on the effort needed to comprehend its behavior. Many source code programming style guides, which often stress readability and usually language-specific conventions are aimed at reducing the cost of source code maintenance. Some of the issues that affect code quality include:

- Readability
- Ease of maintenance, testing, debugging, fixing, modification and portability
- Low complexity
- Low resource consumption: memory, CPU
- Number of compilation or lint warnings
- Robust input validation and error handling, established by software fault injection

Methods to improve the quality:

- Refactoring
- Code Inspection or software review
- Documenting the code

Software reliability

Software **reliability** is an important facet of software quality. It is defined as "the probability of failure-free operation of a computer program in a specified environment for a specified time".

One of reliability's distinguishing characteristics is that it is objective, measurable, and can be estimated, whereas much of software quality is subjective criteria. This distinction is especially important in the discipline of Software Quality Assurance. These measured criteria are typically called software metrics.

History

With software embedded into many devices today, software failure has caused more than inconvenience. Software errors have even caused human fatalities. The causes have ranged from poorly designed user interfaces to direct programming errors. An example of a programming error that lead to multiple deaths is discussed in Dr. Leveson's paper (PDF). This has resulted in requirements for development of some types software. In the

United States, both the Food and Drug Administration (FDA) and Federal Aviation Administration (FAA) have requirements for software development.

Goal of reliability

The need for a means to objectively determine software reliability comes from the desire to apply the techniques of contemporary engineering fields to the development of software. That desire is a result of the common observation, by both lay-persons and specialists, that computer software does not work the way it ought to. In other words, software is seen to exhibit undesirable behaviour, up to and including outright failure, with consequences for the data which is processed, the machinery on which the software runs, and by extension the people and materials which those machines might negatively affect. The more critical the application of the software to economic and production processes, or to life-sustaining systems, the more important is the need to assess the software's reliability.

Regardless of the criticality of any single software application, it is also more and more frequently observed that software has penetrated deeply into most every aspect of modern life through the technology we use. It is only expected that this infiltration will continue, along with an accompanying dependency on the software by the systems which maintain our society. As software becomes more and more crucial to the operation of the systems on which we depend, the argument goes, it only follows that the software should offer a concomitant level of dependability. In other words, the software should behave in the way it is intended, or even better, in the way it should.

Challenge of reliability

The circular logic of the preceding sentence is not accidental—it is meant to illustrate a fundamental problem in the issue of measuring software reliability, which is the difficulty of determining, in advance, exactly how the software is intended to operate. The problem seems to stem from a common conceptual error in the consideration of software, which is that software in some sense takes on a role which would otherwise be filled by a human being. This is a problem on two levels. Firstly, most modern software performs work which a human could never perform, especially at the high level of reliability that is often expected from software in comparison to humans. Secondly, software is fundamentally incapable of most of the mental capabilities of humans which separate them from mere mechanisms: qualities such as adaptability, general-purpose knowledge, a sense of conceptual and functional context, and common sense.

Nevertheless, most software programs could safely be considered to have a particular, even singular purpose. If the possibility can be allowed that said purpose can be well or even completely defined, it should present a means for at least considering objectively whether the software is, in fact, reliable, by comparing the expected outcome to the actual outcome of running the software in a given environment, with given data. Unfortunately, it is still not known whether it is possible to exhaustively determine either the expected outcome or the actual outcome of the entire set of possible environment and input data to a given program, without which it is probably impossible to determine the program's reliability with any certainty.

However, various attempts are in the works to attempt to rein in the vastness of the space of software's environmental and input variables, both for actual programs and theoretical descriptions of programs. Such attempts to improve software reliability can be applied at different stages of a program's development, in the case of real software. These stages principally include: requirements, design, programming, testing, and runtime evaluation. The study of theoretical software reliability is predominantly concerned with the concept of correctness, a mathematical field of computer science which is an outgrowth of language and automata theory.

Reliability in program development

Requirements

A program cannot be expected to work as desired if the developers of the program do not, in fact, know the program's desired behaviour in advance, or if they cannot at least determine its desired behaviour in parallel with development, in sufficient detail. What level of detail is considered sufficient is hotly debated. The idea of perfect detail is attractive, but may be impractical, if not actually impossible. This is because the desired behaviour tends to change as the possible range of the behaviour is determined through actual attempts, or more accurately, failed attempts, to achieve it.

Whether a program's desired behaviour can be successfully specified in advance is a moot point if the behaviour cannot be specified at all, and this is the focus of attempts to formalize the process of creating requirements for new software projects. In situ with the formalization effort is an attempt to help inform non-specialists, particularly non-programmers, who commission software projects without sufficient knowledge of what computer software is in fact capable. Communicating this knowledge is made more difficult by the fact that, as hinted above, even programmers cannot always know in advance what is actually possible for software in advance of trying.

Design

While requirements are meant to specify what a program should do, design is meant, at least at a high level, to specify how the program should do it. The usefulness of design is also questioned by some, but those who look to formalize the process of ensuring reliability often offer good software design processes as the most significant means to accomplish it. Software design usually involves the use of more abstract and general means of specifying the parts of the software and what they do. As such, it can be seen as a way to break a large program down into many smaller programs, such that those smaller pieces together do the work of the whole program.

The purposes of high-level design are as follows. It separates what are considered to be problems of architecture, or overall program concept and structure, from problems of actual coding, which solve problems of actual data processing. It applies additional constraints to the development process by narrowing the scope of the smaller software components, and thereby—it is hoped—removing variables which could increase the likelihood of programming errors. It provides a program template, including the specification of interfaces, which can be shared by different teams of developers working on disparate parts, such that they can know in advance how each of their contributions will interface with those of the other teams. Finally, and perhaps most controversially, it specifies the program independently of the implementation language or languages, thereby removing language-specific biases and limitations which would otherwise creep into the design, perhaps unwittingly on the part of programmer-designers.

Programming

The history of computer programming language development can often be best understood in the light of attempts to master the complexity of computer programs, which otherwise becomes more difficult to understand in proportion (perhaps exponentially) to the size of the programs. (Another way of looking at the evolution of programming languages is simply as a way of getting the computer to do more and more of the work, but this may be a different way of saying the same thing). Lack of understanding of a program's overall structure and functionality is a sure way to fail to detect errors in the program, and thus the use of better languages should, conversely, reduce the number of errors by enabling a better understanding.

Improvements in languages tend to provide incrementally what software design has attempted to do in one fell swoop: consider the software at ever greater levels of abstraction. Such inventions as statement, sub-routine, file, class, template, library, component and more have allowed the arrangement of a program's parts to be specified using abstractions such as layers, hierarchies and modules, which provide structure at different granularities, so that from any point of view the program's code can be imagined to be orderly and comprehensible.

In addition, improvements in languages have enabled more exact control over the shape and use of data elements, culminating in the abstract data type. These data types can be specified to a very fine degree, including how and when they are accessed, and even the state of the data before and after it is accessed.

Software Build and Deployment

Many programming languages such as C and Java require the program "source code" to be translated in to a form that can be executed by a computer. This translation is done by a program called a compiler. Additional operations may be involved to associate, bind, link or package files together in order to create a usable runtime configuration of the software application. The totality of the compiling and assembly process is generically called "building" the software.

The software build is critical to software quality because if any of the generated files are incorrect the software build is likely to fail. And, if the incorrect version of a program is inadvertently used, then testing can lead to false results.

Software builds are typically done in work area unrelated to the runtime area, such as the application server. For this reason, a deployment step is needed to physically transfer the software build products to the runtime area. The deployment procedure may also involve technical parameters, which, if set incorrectly, can also prevent software testing from beginning. For example, a Java application server may have options for parent-first or parent-last class loading. Using the incorrect parameter can cause the application to fail to execute on the application server.

The technical activities supporting software quality including build, deployment, change control and reporting are collectively known as Software configuration management. A number of software tools have arisen to help meet the challenges of configuration management including file control tools and build control tools.

Testing

Software testing, when done correctly, can increase overall software *quality of conformance* by testing that the product conforms to its requirements. Testing includes, but is not limited to:

1. Unit Testing
2. Functional Testing
3. Regression Testing
4. Performance Testing
5. Failover Testing
6. Usability Testing

A number of agile methodologies use testing early in the development cycle to ensure quality in their products. For example, the test-driven development practice, where tests are written before the code they will test, is used in Extreme Programming to ensure quality.

Runtime

runtime reliability determinations are similar to tests, but go beyond simple confirmation of behaviour to the evaluation of qualities such as performance and interoperability with other code or particular hardware configurations.

Software quality factors

A software quality factor is a non-functional requirement for a software program which is not called up by the customer's contract, but nevertheless is a desirable requirement which enhances the quality of the software program. Note that none of these factors are binary; that is, they are not “either you have it or you don’t” traits. Rather, they are characteristics that one seeks to maximize in one’s software to optimize its quality. So rather than asking whether a software product “has” factor *x*, ask instead the *degree* to which it does (or does not).

Some software quality factors are listed here:

Understandability
: Clarity of purpose. This goes further than just a statement of purpose; all of the design and user documentation must be clearly written so that it is easily understandable. This is obviously subjective in that the user context must be taken into account: for instance, if the software product is to be used by software engineers it is not required to be understandable to the layman.

Completeness
: Presence of all constituent parts, with each part fully developed. This means that if the code calls a subroutine from an external library, the software package must provide reference to that library and all required parameters must be passed. All required input data must also be available.

Conciseness
: Minimization of excessive or redundant information or processing. This is important where memory capacity is limited, and it is generally considered good practice to keep lines of code to a minimum. It can be improved by replacing repeated functionality by one subroutine or function which achieves that functionality. It also applies to documents.

Portability
: Ability to be run well and easily on multiple computer configurations. Portability can mean both between different hardware—such as running on a PC as well as a smartphone—and between different operating systems—such as running on both Mac OS X and GNU/Linux.

Consistency
: Uniformity in notation, symbology, appearance, and terminology within itself.

Maintainability
: Propensity to facilitate updates to satisfy new requirements. Thus the software product that is maintainable should be well-documented, should not be complex, and should have spare capacity for memory, storage and processor utilization and other resources.

Testability
: Disposition to support acceptance criteria and evaluation of performance. Such a characteristic must be built-in during the design phase if the product is to be easily testable; a complex design leads to poor testability.

Usability
: Convenience and practicality of use. This is affected by such things as the human-computer interface. The component of the software that has most impact on this is the user interface (UI), which for best usability is usually graphical (i.e. a GUI).

Reliability

Ability to be expected to perform its intended functions satisfactorily. This implies a time factor in that a reliable product is expected to perform correctly over a period of time. It also encompasses environmental considerations in that the product is required to perform correctly in whatever conditions it finds itself (sometimes termed robustness).

Efficiency

Fulfillment of purpose without waste of resources, such as memory, space and processor utilization, network bandwidth, time, etc.

Security

Ability to protect data against unauthorized access and to withstand malicious or inadvertent interference with its operations. Besides the presence of appropriate security mechanisms such as authentication, access control and encryption, security also implies resilience in the face of malicious, intelligent and adaptive attackers.

Measurement of software quality factors

There are varied perspectives within the field on measurement. There are a great many measures that are valued by some professionals—or in some contexts, that are decried as harmful by others. Some believe that quantitative measures of software quality are essential. Others believe that contexts where quantitative measures are useful are quite rare, and so prefer qualitative measures. Several leaders in the field of software testing have written about the difficulty of measuring what we truly want to measure well.

One example of a popular metric is the number of faults encountered in the software. Software that contains few faults is considered by some to have higher quality than software that contains many faults. Questions that can help determine the usefulness of this metric in a particular context include:

1. What constitutes "many faults?" Does this differ depending upon the purpose of the software (e.g., blogging software vs. navigational software)? Does this take into account the size and complexity of the software?
2. Does this account for the importance of the bugs (and the importance to the stakeholders of the people those bugs bug)? Does one try to weight this metric by the severity of the fault, or the incidence of users it affects? If so, how? And if not, how does one know that 100 faults discovered is better than 1000?
3. If the count of faults being discovered is shrinking, how do I know what that means? For example, does that mean that the product is now higher quality than it was before? Or that this is a smaller/less ambitious change than before? Or that fewer tester-hours have gone into the project than before? Or that this project was tested by less skilled testers than before? Or that the team has discovered that fewer faults reported is in their interest?

This last question points to an especially difficult one to manage. All software quality metrics are in some sense measures of human behavior, since humans create software. If a team discovers that they will benefit from a drop in the number of reported bugs, there is a strong tendency for the team to start reporting fewer defects. That may mean that email begins to circumvent the bug tracking system, or that four or five bugs get lumped into one bug report, or that testers learn not to report minor annoyances. The difficulty is measuring what we mean to measure, without creating incentives for software programmers and testers to consciously or unconsciously “game” the measurements.

Software quality factors cannot be measured because of their vague definitions. It is necessary to find measurements, or metrics, which can be used to quantify them as non-functional requirements. For example, reliability is a software quality factor, but cannot be evaluated in its own right. However, there are related attributes to reliability, which can indeed be measured. Some such attributes are mean time to failure, rate of failure occurrence, and availability of the system. Similarly, an attribute of portability is the number of target-dependent statements in a program.

A scheme that could be used for evaluating software quality factors is given below. For every characteristic, there are a set of questions which are relevant to that characteristic. Some type of scoring formula could be developed based on the answers to these questions, from which a measurement of the characteristic can be obtained.

Understandability

Are variable names descriptive of the physical or functional property represented? Do uniquely recognisable functions contain adequate comments so that their purpose is clear? Are deviations from forward logical flow adequately commented? Are all elements of an array functionally related?...

Completeness

Are all necessary components available? Does any process fail for lack of resources or programming? Are all potential pathways through the code accounted for, including proper error handling?

Conciseness

Is all code reachable? Is any code redundant? How many statements within loops could be placed outside the loop, thus reducing computation time? Are branch decisions too complex?

Portability

Does the program depend upon system or library routines unique to a particular installation? Have machine-dependent statements been flagged and commented? Has dependency on internal bit representation of alphanumeric or special characters been avoided? How much effort would be required to transfer the program from one hardware/software system or environment to another?

Consistency

Is one variable name used to represent different logical or physical entities in the program? Does the program contain only one representation for any given physical or mathematical constant? Are functionally similar arithmetic expressions similarly constructed? Is a consistent scheme used for indentation, nomenclature, the color palette, fonts and other visual elements?

Maintainability

Has some memory capacity been reserved for future expansion? Is the design cohesive—i.e., does each module have distinct, recognizable functionality? Does the software allow for a change in data structures (object-oriented designs are more likely to allow for this)? If the code is procedure-based (rather than object-oriented), is a change likely to require restructuring the main program, or just a module?

Testability

Are complex structures employed in the code? Does the detailed design contain clear pseudo-code? Is the pseudo-code at a higher level of abstraction than the code? If tasking is used in concurrent designs, are schemes available for providing adequate test cases?

Usability

Is a GUI used? Is there adequate on-line help? Is a user manual provided? Are meaningful error messages provided?

Reliability

Are loop indexes range-tested? Is input data checked for range errors? Is divide-by-zero avoided? Is exception handling provided? It is the probability that the software performs its intended functions correctly in a specified period of time under stated operation conditions, but there could also be a problem with the requirement document...

Efficiency

Have functions been optimized for speed? Have repeatedly used blocks of code been formed into subroutines? Has the program been checked for memory leaks or overflow errors?

Security

Does the software protect itself and its data against unauthorized access and use? Does it allow its operator to enforce security policies? Are security mechanisms appropriate, adequate and correctly implemented? Can the software withstand attacks that can be anticipated in its intended environment?

User's perspective

In addition to the technical qualities of software, the end user's experience also determines the quality of software. This aspect of software quality is called usability. It is hard to quantify the usability of a given software product. Some important questions to be asked are:

- Is the user interface intuitive (self-explanatory/self-documenting)?
- Is it easy to perform simple operations?
- Is it feasible to perform complex operations?
- Does the software give sensible error messages?
- Do widgets behave as expected?
- Is the software well documented?
- Is the user interface responsive or too slow?

Also, the availability of (free or paid) support may factor into the usability of the software.

Chapter 2

Anti-Pattern

In software engineering, an **anti-pattern** (or **antipattern**) is a pattern that may be commonly used but is ineffective and/or counterproductive in practice.

The term was coined in 1995 by Andrew Koenig, inspired by Gang of Four's book *Design Patterns*, which developed the concept of design patterns in the software field. The term was widely popularized three years later by the book *AntiPatterns*, which extended the use of the term beyond the field of software design and into general social interaction. According to the authors of the latter, there must be at least two key elements present to formally distinguish an actual anti-pattern from a simple bad habit, bad practice, or bad idea:

- Some repeated pattern of action, process or structure that initially appears to be beneficial, but ultimately produces more bad consequences than beneficial results, and
- A refactored solution exists that is clearly documented, proven in actual practice and repeatable.

Often pejoratively named with clever oxymoronic neologisms, many anti-pattern ideas amount to little more than mistakes, rants, unsolvable problems, or bad practices to be avoided if possible. Sometimes called *pitfalls* or *dark patterns*, this informal use of the term has come to refer to classes of commonly reinvented bad solutions to problems. Thus, many candidate anti-patterns under debate would not be formally considered anti-patterns.

By formally describing repeated mistakes, one can recognize the forces that lead to their repetition and learn how others have refactored themselves out of these broken patterns.

Known anti-patterns

Organizational anti-patterns

- Analysis paralysis: Devoting disproportionate effort to the analysis phase of a project
- Cash cow: A profitable legacy product that often leads to complacency about new products
- Design by committee: The result of having many contributors to a design, but no unifying vision
- Escalation of commitment: Failing to revoke a decision when it proves wrong
- Management by perkele: Authoritarian style of management with no tolerance of dissent
- Matrix Management: Unfocused organizational structure that results in divided loyalties and lack of direction
- Moral hazard: Insulating a decision-maker from the consequences of his or her decision
- Mushroom management: Keeping employees uninformed and misinformed (kept in the dark and fed manure), let to stew, and finally canned.
- Stovepipe or Silos: A structure that supports mostly up-down flow of data but inhibits cross organizational communication
- Vendor lock-in: Making a system excessively dependent on an externally supplied component

Project management anti-patterns

- Death march: Everyone knows that the project is going to be a disaster – except the CEO -- so the truth is hidden to prevent immediate cancellation of the project - (although the CEO often knows and does it anyway to maximise profit). However, the truth remains hidden and the project is artificially kept alive until the Day Zero finally comes ("Big Bang"). Alternative definition: Employees are pressured to work late nights and weekends on a project with an unreasonable deadline.
- Groupthink: During groupthink, members of the group avoid promoting viewpoints outside the comfort zone of consensus thinking
- Smoke and mirrors: Demonstrating how unimplemented functions will appear
- Software bloat: Allowing successive versions of a system to demand ever more resources
- Waterfall model: An older method of software development that inadequately deals with unanticipated change

Analysis anti-patterns

- Bystander apathy: When a requirement or design decision is wrong, but the people who notice this do nothing because it affects a larger number of people

Software design anti-patterns

- Abstraction inversion: Not exposing implemented functionality required by users, so that they re-implement it using higher level functions
- Ambiguous viewpoint: Presenting a model (usually Object-oriented analysis and design (OOAD)) without specifying its viewpoint
- Big ball of mud: A system with no recognizable structure
- Database-as-IPC: Using a database as the message queue for routine interprocess communication where a much more lightweight mechanism would be suitable
- Gold plating: Continuing to work on a task or project well past the point at which extra effort is adding value
- Inner-platform effect: A system so customizable as to become a poor replica of the software development platform
- Input kludge: Failing to specify and implement the handling of possibly invalid input
- Interface bloat: Making an interface so powerful that it is extremely difficult to implement
- Magic pushbutton: Coding implementation logic directly within interface code, without using abstraction
- Race hazard: Failing to see the consequence of different orders of events
- Stovepipe system: A barely maintainable assemblage of ill-related components

Object-oriented design anti-patterns

- Anemic Domain Model: The use of domain model without any business logic. The domain model's objects cannot guarantee their correctness at any moment, because their validation and mutation logic is placed somewhere outside (most likely in multiple places).
- BaseBean: Inheriting functionality from a utility class rather than delegating to it
- Call super: Requiring subclasses to call a superclass's overridden method
- Circle-ellipse problem: Subtyping variable-types on the basis of value-subtypes
- Circular dependency: Introducing unnecessary direct or indirect mutual dependencies between objects or software modules
- Constant interface: Using interfaces to define constants
- God object: Concentrating too many functions in a single part of the design (class)
- Object cesspool: Reusing objects whose state does not conform to the (possibly implicit) contract for re-use
- Object orgy: Failing to properly encapsulate objects permitting unrestricted access to their internals
- Poltergeists: Objects whose sole purpose is to pass information to another object
- Sequential coupling: A class that requires its methods to be called in a particular order
- Yo-yo problem: A structure (e.g., of inheritance) that is hard to understand due to excessive fragmentation

Programming anti-patterns

- Accidental complexity: Introducing unnecessary complexity into a solution
- Action at a distance: Unexpected interaction between widely separated parts of a system
- Blind faith: Lack of checking of (a) the correctness of a bug fix or (b) the result of a subroutine
- Boat anchor: Retaining a part of a system that no longer has any use
- Busy spin: Consuming CPU while waiting for something to happen, usually by repeated checking instead of messaging
- Caching failure: Forgetting to reset an error flag when an error has been corrected
- Cargo cult programming: Using patterns and methods without understanding why
- Coding by exception: Adding new code to handle each special case as it is recognized
- Error hiding: Catching an error message before it can be shown to the user and either showing nothing or showing a meaningless message
- Hard code: Embedding assumptions about the environment of a system in its implementation
- Lava flow: Retaining undesirable (redundant or low-quality) code because removing it is too expensive or has unpredictable consequences
- Loop-switch sequence: Encoding a set of sequential steps using a switch within a loop statement
- Magic numbers: Including unexplained numbers in algorithms
- Magic strings: Including literal strings in code, for comparisons, as event types etc.
- Soft code: Storing business logic in configuration files rather than source code
- Spaghetti code: Programs whose structure is barely comprehensible, especially because of misuse of code structures

Methodological anti-patterns

- Copy and paste programming: Copying (and modifying) existing code rather than creating generic solutions
- Golden hammer: Assuming that a favorite solution is universally applicable (See: Silver Bullet)
- Improbability factor: Assuming that it is improbable that a known error will occur
- Not Invented Here (NIH) syndrome: The tendency towards *reinventing the wheel* (Failing to adopt an existing, adequate solution)
- Premature optimization: Coding early-on for perceived efficiency, sacrificing good design, maintainability, and sometimes even real-world efficiency
- Programming by permutation (or "programming by accident"): Trying to approach a solution by successively modifying the code to see if it works
- Reinventing the wheel: Failing to adopt an existing, adequate solution
- Reinventing the square wheel: Failing to adopt an existing solution and instead adopting a custom solution which performs much worse than the existing one

- Silver bullet: Assuming that a favorite technical solution can solve a larger process or problem
- Tester Driven Development: Software projects in which new requirements are specified in bug reports

Configuration management anti-patterns

- Dependency hell: Problems with versions of required products
- DLL hell: Inadequate management of dynamic-link libraries (DLLs), specifically on Microsoft Windows
- Extension conflict: Problems with different extensions to pre-Mac OS X versions of the Mac OS attempting to patch the same parts of the operating system
- JAR hell: Overutilization of the multiple JAR files, usually causing versioning and location problems because of misunderstanding of the Java class loading model

Chapter 3

Software Bug

A **software bug** is the common term used to describe an error, flaw, mistake, failure, or fault in a computer program or system that produces an incorrect or unexpected result, or causes it to behave in unintended ways. Most bugs arise from mistakes and errors made by people in either a program's source code or its design, and a few are caused by compilers producing incorrect code. A program that contains a large number of bugs, and/or bugs that seriously interfere with its functionality, is said to be *buggy*. Reports detailing bugs in a program are commonly known as bug reports, fault reports, problem reports, trouble reports, change requests, and so forth.

Effects

Bugs trigger Type I and type II errors that can in turn have a wide variety of ripple effects, with varying levels of inconvenience to the user of the program. Some bugs have only a subtle effect on the program's functionality, and may thus lie undetected for a long time. More serious bugs may cause the program to crash or freeze leading to a denial of service. Others qualify as security bugs and might for example enable a malicious user to bypass access controls in order to obtain unauthorized privileges.

The results of bugs may be extremely serious. Bugs in the code controlling the Therac-25 radiation therapy machine were directly responsible for some patient deaths in the 1980s. In 1996, the European Space Agency's US$1 billion prototype Ariane 5 rocket was destroyed less than a minute after launch, due to a bug in the on-board guidance computer program. In June 1994, a Royal Air Force Chinook crashed into the Mull of Kintyre, killing 29. This was initially dismissed as pilot error, but an investigation by *Computer Weekly* uncovered sufficient evidence to convince a House of Lords inquiry that it may have been caused by a software bug in the aircraft's engine control computer.

In 2002, a study commissioned by the US Department of Commerce' National Institute of Standards and Technology concluded that *software bugs, or errors, are so prevalent and so detrimental that they cost the US economy an estimated $59 billion annually, or about 0.6 percent of the gross domestic product*.

Etymology

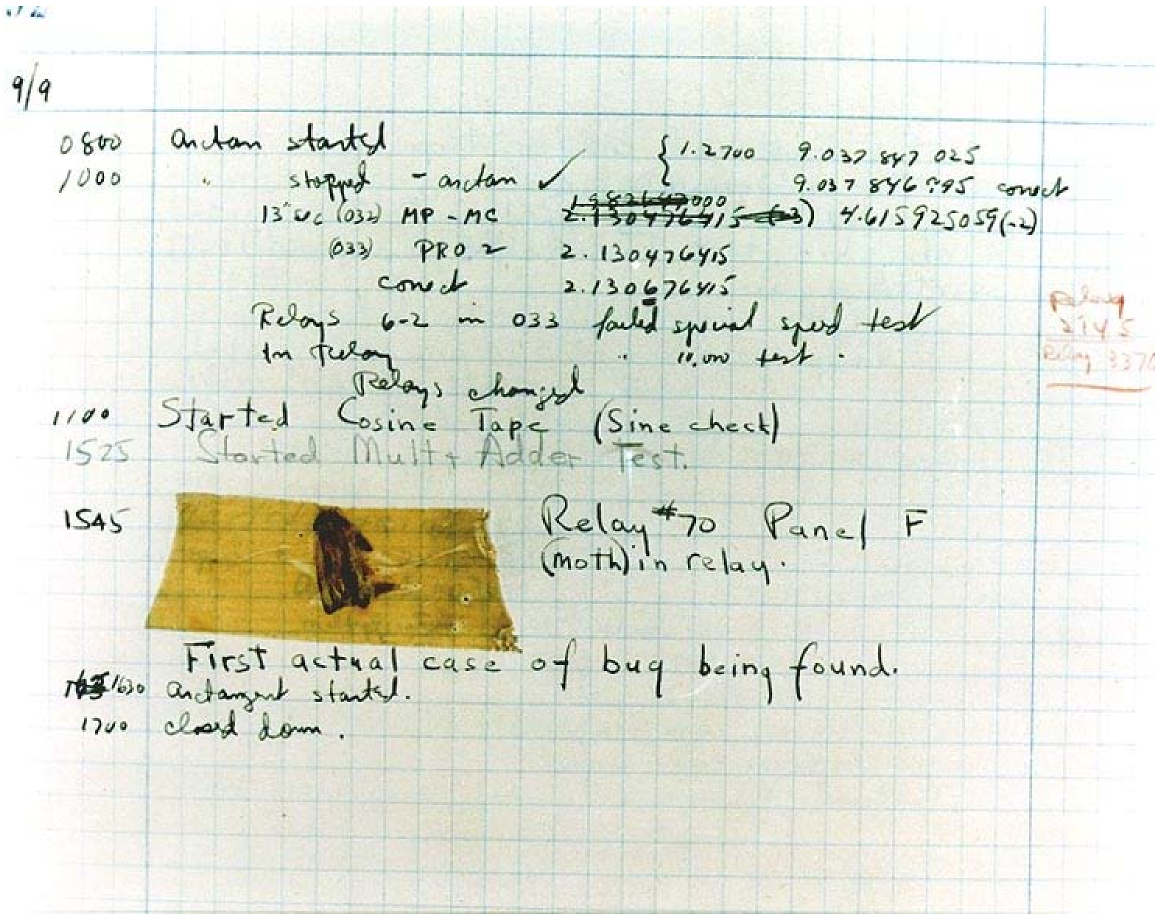
The concept that software might contain errors dates back to 1843 in Ada Byron's notes on the analytical engine in which she speaks of the difficulty of preparing program 'cards' for Charles Babbage's Analytical engine:

> “ ...an analyzing process must equally have been performed in order to furnish the Analytical Engine with the necessary operative data; and that herein may also lie a possible source of error. Granted that the actual mechanism is unerring in its processes, the cards may give it wrong orders. ”

Use of the term "bug" to describe inexplicable defects has been a part of engineering jargon for many decades and predates computers and computer software; it may have originally been used in hardware engineering to describe mechanical malfunctions. For instance, Thomas Edison wrote the following words in a letter to an associate in 1878:

> “ It has been just so in all of my inventions. The first step is an intuition, and comes with a burst, then difficulties arise—this thing gives out and *[it is]* then that 'Bugs' — as such little faults and difficulties are called—show themselves and months of intense watching, study and labor are requisite before commercial success or failure is certainly reached. ”

Problems with radar electronics during World War II were referred to as *bug*s (or glitches) and there is additional evidence that the usage dates back much earlier. Baffle Ball, the first mechanical pinball game, was advertised as being "free of bugs" in 1931.



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1630 antangent started.
1700 closed down.

Relay 2145
Relay 3370

Photo of what is possibly the first real bug found in a computer.

The invention of the term "bug" is often erroneously attributed to Grace Hopper, who publicized the cause of a malfunction in an early electromechanical computer. A typical version of the story is given by this quote:

> “ In 1946, when Hopper was released from active duty, she joined the Harvard Faculty at the Computation Laboratory where she continued her work on the Mark II and Mark III. Operators traced an error in the Mark II to a moth trapped in a relay, coining the term *bug*. This bug was carefully removed and taped to the log book. Stemming from the first bug, today we call errors or glitch's [*sic*] in a program a *bug*. ”

Hopper was not actually the one who found the insect, as she readily acknowledged. The date in the log book was 9 September 1947, although sometimes erroneously reported as 1945. The operators who did find it, including William "Bill" Burke, later of the Naval Weapons Laboratory, Dahlgren, Virginia, were familiar with the engineering term and, amused, kept the insect with the notation "First actual case of bug being found." Hopper loved to recount the story. This log book is on display in the Smithsonian National Museum of American History, complete with moth attached.

While it is certain that the Harvard Mark II operators did not coin the term "bug", it has been suggested that they did coin the related term, "debug". Even this is unlikely, since the Oxford English Dictionary entry for "debug" contains a use of "debugging" in the context of air-plane engines in 1945.

Prevention

Bugs are a consequence of the nature of human factors in the programming task. They arise from oversights or mutual misunderstandings made by a software team during specification, design, coding, data entry and documentation. For example: In creating a relatively simple program to sort a list of words into alphabetical order, one's design might fail to consider what should happen when a word contains a hyphen. Perhaps, when converting the abstract design into the chosen programming language, one might inadvertently create an off-by-one error and fail to sort the last word in the list. Finally, when typing the resulting program into the computer, one might accidentally type a '<' where a '>' was intended, perhaps resulting in the words being sorted into reverse alphabetical order. More complex bugs can arise from unintended interactions between different parts of a computer program. This frequently occurs because computer programs can be complex—millions of lines long in some cases—often having been programmed by many people over a great length of time, so that programmers are unable to mentally track every possible way in which parts can interact. Another category of bug called a *race condition* comes about either when a process is running in more than one thread or two or more processes run simultaneously, and the exact order of execution of the critical sequences of code have not been properly synchronized.

The software industry has put much effort into finding methods for preventing programmers from inadvertently introducing bugs while writing software. These include:

Programming style
: While typos in the program code are often caught by the compiler, a bug usually appears when the programmer makes a logic error. Various innovations in programming style and defensive programming are designed to make these bugs less likely, or easier to spot. In some programming languages, so-called typos, especially of symbols or logical/mathematical operators, actually represent logic errors, since the mistyped constructs are accepted by the compiler with a meaning other than that which the programmer intended.

Programming techniques
: Bugs often create inconsistencies in the internal data of a running program. Programs can be written to check the consistency of their own internal data while running. If an inconsistency is encountered, the program can immediately halt, so that the bug can be located and fixed. Alternatively, the program can simply inform the user, attempt to correct the inconsistency, and continue running.

Development methodologies
: There are several schemes for managing programmer activity, so that fewer bugs are produced. Many of these fall under the discipline of software engineering (which addresses software design issues as well). For example, formal program

specifications are used to state the exact behavior of programs, so that design bugs can be eliminated. Unfortunately, formal specifications are impractical or impossible for anything but the shortest programs, because of problems of combinatorial explosion and indeterminacy.

Programming language support

Programming languages often include features which help programmers prevent bugs, such as static type systems, restricted name spaces and modular programming, among others. For example, when a programmer writes (pseudocode) `LET REAL_VALUE PI = "THREE AND A BIT"`, although this may be syntactically correct, the code fails a type check. Depending on the language and implementation, this may be caught by the compiler or at runtime. In addition, many recently-invented languages have deliberately excluded features which can easily lead to bugs, at the expense of making code slower than it need be: the general principle being that, because of Moore's law, computers get faster and software engineers get slower; it is *almost always* better to write simpler, slower code than "clever", inscrutable code, especially considering that maintenance cost is considerable. For example, the Java programming language does not support pointer arithmetic; implementations of some languages such as Pascal and scripting languages often have runtime bounds checking of arrays, at least in a debugging build.

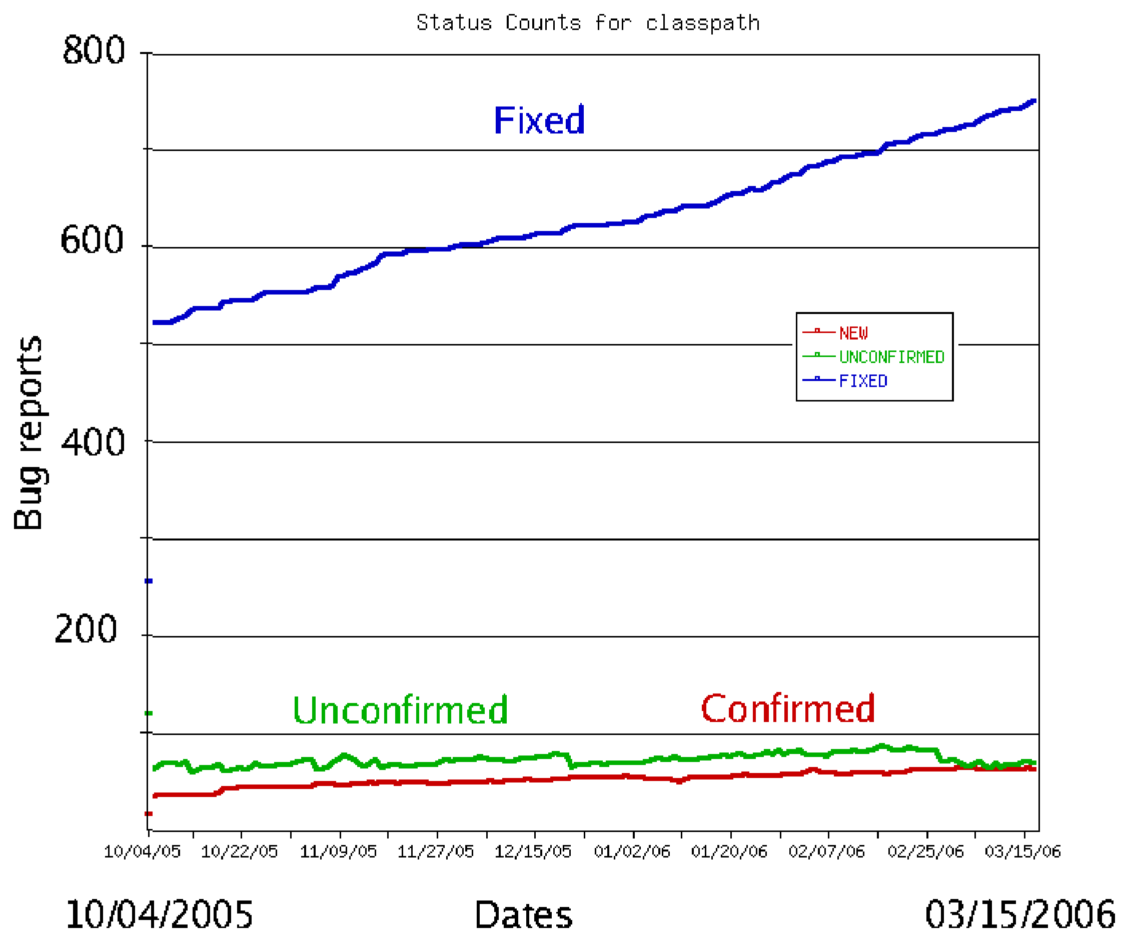
Code analysis

Tools for code analysis help developers by inspecting the program text beyond the compiler's capabilities to spot potential problems. Although in general the problem of finding all programming errors given a specification is not solvable, these tools exploit the fact that human programmers tend to make the same kinds of mistakes when writing software.

Instrumentation

Tools to monitor the performance of the software as it is running, either specifically to find problems such as bottlenecks or to give assurance as to correct working, may be embedded in the code explicitly (perhaps as simple as a statement saying `PRINT "I AM HERE"`), or provided as tools. It is often a surprise to find where most of the time is taken by a piece of code, and this removal of assumptions might cause the code to be rewritten.

Debugging



The typical bug history (GNU Classpath project data). A new bug submitted by the user is *unconfirmed.* Once it has been reproduced by a developer, it is a *confirmed* bug. The confirmed bugs are later *fixed*. Bugs belonging to other categories (unreproducible, will not be fixed, etc.) are usually in the minority

Finding and fixing bugs, or "debugging", has always been a major part of computer programming. Maurice Wilkes, an early computing pioneer, described his realization in the late 1940s that much of the rest of his life would be spent finding mistakes in his own programs. As computer programs grow more complex, bugs become more common and difficult to fix. Often programmers spend more time and effort finding and fixing bugs than writing new code. Software testers are professionals whose primary task is to find bugs, or write code to support testing. On some projects, more resources can be spent on testing than in developing the program.

Usually, the most difficult part of debugging is finding the bug in the source code. Once it is found, correcting it is usually relatively easy. Programs known as debuggers exist to help programmers locate bugs by executing code line by line, watching variable values, and other features to observe program behavior. Without a debugger, code can be added so that messages or values can be written to a console (for example with *printf* in the C programming language) or to a window or log file to trace program execution or show values.

However, even with the aid of a debugger, locating bugs is something of an art. It is not uncommon for a bug in one section of a program to cause failures in a completely different section, thus making it especially difficult to track (for example, an error in a graphics rendering routine causing a file I/O routine to fail), in an apparently unrelated part of the system.

Sometimes, a bug is not an isolated flaw, but represents an error of thinking or planning on the part of the programmer. Such *logic errors* require a section of the program to be overhauled or rewritten. As a part of Code review, stepping through the code modelling the execution process in one's head or on paper can often find these errors without ever needing to reproduce the bug as such, if it can be shown there is some faulty logic in its implementation.

But more typically, the first step in locating a bug is to reproduce it reliably. Once the bug is reproduced, the programmer can use a debugger or some other tool to monitor the execution of the program in the faulty region, and find the point at which the program went astray.

It is not always easy to reproduce bugs. Some are triggered by inputs to the program which may be difficult for the programmer to re-create. One cause of the Therac-25 radiation machine deaths was a bug (specifically, a race condition) that occurred only when the machine operator very rapidly entered a treatment plan; it took days of practice to become able to do this, so the bug did not manifest in testing or when the manufacturer attempted to duplicate it. Other bugs may disappear when the program is run with a debugger; these are heisenbugs (humorously named after the Heisenberg uncertainty principle.)

Debugging is still a tedious task requiring considerable effort. Since the 1990s, particularly following the Ariane 5 Flight 501 disaster, there has been a renewed interest in the development of effective automated aids to debugging. For instance, methods of static code analysis by abstract interpretation have already made significant achievements, while still remaining much of a work in progress.

As with any creative act, sometimes a flash of inspiration will show a solution, but this is rare and, by definition, cannot be relied on.

There are also classes of bugs that have nothing to do with the code itself. If, for example, one relies on faulty documentation or hardware, the code may be written perfectly properly to what the documentation says, but the bug truly lies in the documentation or hardware, not the code. However, it is common to change the code instead of the other parts of the system, as the cost and time to change it is generally less. Embedded systems frequently have workarounds for hardware bugs, since to make a new version of a ROM is much cheaper than remanufacturing the hardware, especially if they are commodity items.

Bug management

It is common practice for software to be released with known bugs that are considered non-critical, that is, that do not affect most users' main experience with the product. While software products may, by definition, contain any number of unknown bugs, measurements during testing can provide an estimate of the number of likely bugs remaining; this becomes more reliable the longer a product is tested and developed ("if we had 200 bugs last week, we should have 100 this week"). Most big software projects maintain two lists of "known bugs"— those known to the software team, and those to be told to users. This is not dissimulation, but users are not concerned with the internal workings of the product. The second list informs users about bugs that are not fixed in the current release, or not fixed at all, and a workaround may be offered.

There are various reasons for not fixing bugs:

- The developers often don't have time or it is not economical to fix all non-severe bugs.
- The bug could be fixed in a new version or patch that is not yet released.
- The changes to the code required to fix the bug could be large, expensive, or delay finishing the project.
- Even seemingly simple fixes bring the chance of introducing new unknown bugs into the system. At the end of a test/fix cycle some managers may only allow the most critical bugs to be fixed.
- Users may be relying on the undocumented, buggy behavior, especially if scripts or macros rely on a behavior; it may introduce a breaking change.
- It's "not a bug". A misunderstanding has arisen between expected and provided behavior

Given the above, it is often considered impossible to write completely bug-free software of any real complexity. So bugs are categorized by severity, and low-severity non-critical bugs are tolerated, as they do not affect the proper operation of the system for most users. NASA's SATC managed to reduce the number of errors to fewer than 0.1 per 1000 lines of code (SLOC) but this was not felt to be feasible for any real world projects.

The severity of a bug is not the same as its importance for fixing, and the two should be measured and managed separately. On a Microsoft Windows system a blue screen of death is rather severe, but if it only occurs in extreme circumstances, especially if they are well diagnosed and avoidable, it may be less important to fix than an icon not representing its function well, which though purely aesthetic may confuse thousands of users every single day. This balance, of course, depends on many factors; expert users have different expectations from novices, a niche market is different from a general consumer market, and so on. To better achieve this balance, some software developers use a formalized *bug triage* process (borrowing the medical term), in which each new bug is assigned a priority based on its severity, frequency, risk, and other predetermined factors.

A school of thought popularized by Eric S. Raymond as Linus's Law says that popular open-source software has more chance of having few or no bugs than other software, because "given enough eyeballs, all bugs are shallow". This assertion has been disputed, however: computer security specialist Elias Levy wrote that "it is easy to hide vulnerabilities in complex, little understood and undocumented source code," because, "even if people are reviewing the code, that doesn't mean they're qualified to do so."

Like any other part of engineering management, bug management must be conducted carefully and intelligently because "what gets measured gets done" and managing purely by bug counts can have unintended consequences. If, for example, developers are rewarded by the number of bugs they fix, they will naturally fix the easiest bugs first—leaving the hardest, and probably most risky or critical, to the last possible moment ("I only have one bug on my list but it says "Make sun rise in West"). If the management ethos is to reward the number of bugs fixed, then some developers may quickly write sloppy code knowing they can fix the bugs later and be rewarded for it, whereas careful, perhaps "slower" developers do not get rewarded for the bugs that were never there.

Security vulnerabilities

Malicious software may attempt to exploit known vulnerabilities in a system — which may or may not be bugs. Viruses are not bugs in themselves — they are typically programs that are doing precisely what they were designed to do. However, viruses are occasionally referred to as such in the popular press.

Common types of computer bugs

- Conceptual error (code is syntactically correct, but the programmer or designer intended it to do something else)

Arithmetic bugs

- Division by zero
- Arithmetic overflow or underflow
- Loss of arithmetic precision due to rounding or numerically unstable algorithms

Logic bugs

- Infinite loops and infinite recursion
- Off by one error, counting one too many or too few when looping

Syntax bugs

- Use of the wrong operator, such as performing assignment instead of equality test. In simple cases often warned by the compiler; in many languages, deliberately guarded against by language syntax

Resource bugs

- Null pointer dereference
- Using an uninitialized variable
- Using an otherwise valid instruction on the wrong data type
- Access violations
- Resource leaks, where a finite system resource such as memory or file handles are exhausted by repeated allocation without release.
- Buffer overflow, in which a program tries to store data past the end of allocated storage. This may or may not lead to an access violation or storage violation. These bugs can form a security vulnerability.
- Excessive recursion which though logically valid causes stack overflow

Multi-threading programming bugs

- Deadlock
- Race condition
- Concurrency errors in critical sections, mutual exclusions and other features of concurrent processing. Time-of-check-to-time-of-use (TOCTOU) is a form of unprotected critical section.

Interfacing bugs

- Incorrect API usage
- Incorrect protocol implementation
- Incorrect hardware handling

Teamworking bugs

- Unpropagated updates; e.g. programmer changes "myAdd" but forgets to change "mySubtract", which uses the same algorithm. These errors are mitigated by the Don't Repeat Yourself philosophy.
- Comments out of date or incorrect: many programmers assume the comments accurately describe the code
- Differences between documentation and the actual product

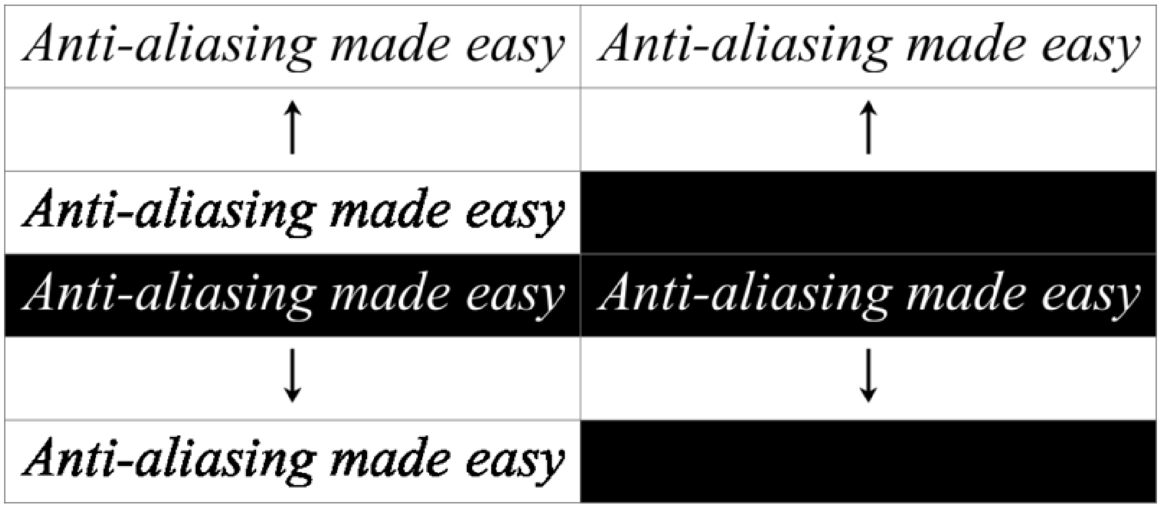
Chapter 4

Fault-Tolerant System and Feature Interaction Problem

Fault-tolerant system

Fault-tolerance or **graceful degradation** is the property that enables a system (often computer-based) to continue operating properly in the event of the failure of (or one or more faults within) some of its components. If its operating quality decreases at all, the decrease is proportional to the severity of the failure, as compared to a naïvely-designed system in which even a small failure can cause total breakdown. Fault-tolerance is particularly sought-after in high-availability or life-critical systems.

Fault-tolerance is not just a property of individual machines; it may also characterise the rules by which they interact. For example, the Transmission Control Protocol (TCP) is designed to allow reliable two-way communication in a packet-switched network, even in the presence of communications links which are imperfect or overloaded. It does this by requiring the endpoints of the communication to *expect* packet loss, duplication, reordering and corruption, so that these conditions do not damage data integrity, and only reduce throughput by a proportional amount.



An example of graceful degradation by design in an image with transparency. The top two images are each the result of viewing the composite image in a viewer that recognises transparency. The bottom two images are the result in a viewer with no support for transparency. Because the transparency mask (centre bottom) is discarded, only the overlay (centre top) remains; the image on the left has been designed to degrade gracefully, hence is still meaningful without its transparency information.

Data formats may also be designed to degrade gracefully. HTML for example, is designed to be forward compatible, allowing new HTML entities to be ignored by Web browsers which do not understand them without causing the document to be unusable.

Recovery from errors in fault-tolerant systems can be characterised as either **roll-forward** or **roll-back**. When the system detects that it has made an error, roll-forward recovery takes the system state at that time and corrects it, to be able to move forward. Roll-back recovery reverts the system state back to some earlier, correct version, for example using checkpointing, and moves forward from there. Roll-back recovery requires that the operations between the checkpoint and the detected erroneous state can be made idempotent. Some systems make use of both roll-forward and roll-back recovery for different errors or different parts of one error.

Within the scope of an *individual* system, fault-tolerance can be achieved by anticipating exceptional conditions and building the system to cope with them, and, in general, aiming for self-stabilization so that the system converges towards an error-free state. However, if the consequences of a system failure are catastrophic, or the cost of making it sufficiently reliable is very high, a better solution may be to use some form of duplication. In any case, if the consequence of a system failure is catastrophic, the system must be able to use reversion to fall back to a safe mode. This is similar to roll-back recovery but can be a human action if humans are present in the loop.

Fault tolerance requirements

The basic characteristics of fault tolerance require:

1. No single point of failure
2. Fault isolation to the failing component
3. Fault containment to prevent propagation of the failure
4. Availability of reversion modes

In addition, fault tolerant systems are characterized in terms of both planned service outages and unplanned service outages. These are usually measured at the application level and not just at a hardware level. The figure of merit is called availability and is expressed as a percentage. For example, a five nines system would statistically provide 99.999% availability.

Fault-tolerant systems are typically based on the concept of redundancy.

Fault-tolerance by replication

Spare components addresses the first fundamental characteristic of fault-tolerance in three ways:

- Replication: Providing multiple identical instances of the same system or subsystem, directing tasks or requests to all of them in parallel, and choosing the correct result on the basis of a quorum;
- Redundancy: Providing multiple identical instances of the same system and switching to one of the remaining instances in case of a failure (failover);
- Diversity: Providing multiple *different* implementations of the same specification, and using them like replicated systems to cope with errors in a specific implementation.

All implementations of RAID, redundant array of independent disks, except RAID 0 are examples of a fault-tolerant storage device that uses data redundancy.

A lockstep fault-tolerant machine uses replicated elements operating in parallel. At any time, all the replications of each element should be in the same state. The same inputs are provided to each replication, and the same outputs are expected. The outputs of the replications are compared using a voting circuit. A machine with two replications of each element is termed Dual Modular Redundant (DMR). The voting circuit can then only detect a mismatch and recovery relies on other methods. A machine with three replications of each element is termed Triple Modular Redundancy (TMR). The voting circuit can determine which replication is in error when a two-to-one vote is observed. In this case, the voting circuit can output the correct result, and discard the erroneous version. After this, the internal state of the erroneous replication is assumed to be different from that of the other two, and the voting circuit can switch to a DMR mode. This model can be applied to any larger number of replications.

Lockstep fault tolerant machines are most easily made fully synchronous, with each gate of each replication making the same state transition on the same edge of the clock, and the clocks to the replications being exactly in phase. However, it is possible to build lockstep systems without this requirement.

Bringing the replications into synchrony requires making their internal stored states the same. They can be started from a fixed initial state, such as the reset state. Alternatively, the internal state of one replica can be copied to another replica.

One variant of DMR is **pair-and-spare**. Two replicated elements operate in lockstep as a pair, with a voting circuit that detects any mismatch between their operations and outputs a signal indicating that there is an error. Another pair operates exactly the same way. A final circuit selects the output of the pair that does not proclaim that it is in error. Pair-and-spare requires four replicas rather than the three of TMR, but has been used commercially.

No single point of repair

If a system experiences a failure, it must continue to operate without interruption during the repair process.

Fault isolation to the failing component

When a failure occurs, the system must be able to isolate the failure to the offending component. This requires the addition of dedicated failure detection mechanisms that exist only for the purpose of fault isolation.

Recovery from a fault condition requires classifying the fault or failing component. The National Institute of Standards and Technology (NIST) categorizes faults based on Locality, Cause, Duration and Effect.

Fault containment

Some failure mechanisms can cause a system to fail by propagating the failure to the rest of the system. An example of this kind of failure is the "Rogue transmitter" which can swamp legitimate communication in a system and cause overall system failure. Mechanisms that isolate a rogue transmitter or failing component to protect the system are required.

Feature interaction problem

Feature interaction is a software engineering concept. It occurs when the integration of two **features** would modify the **behavior** of one or both features.

The term *feature* is used to denote a unit of functionality of a software application. Similar to many concepts in computer science, the term can be used at different levels of abstraction. For example, the plain old telephone service (POTS) is a telephony application feature at one level, but itself is composed of originating features and terminating features. The originating features may in turn include the provide dial tone feature, digit collection feature and so on.

This definition of *feature interaction* allows one to focus on certain behavior of the interacting features such as how their response time may be changed given the integration. Many researchers in the field consider problems that arise due to change in the execution *behavior* of the interacting features. Under that context, the *behavior* of a feature is defined by its execution flow and output for a given input. In other words, the interaction changes the execution flow and output of the interacting features for a given input.

Example

In the context of telephony, a telephone line (the system) typically offers a set of features that include call forwarding and call waiting. Call waiting allows one call to be suspended while a second call is answered, while call forwarding enables a customer to specify a secondary phone number to which additional calls will be forwarded in the event that the customer is already using the phone.

To illustrate the example, we consider a telephone line provided to a customer, and we assume that both call forwarding and call waiting are enabled on the line. When a first call arrives on the line, the phone rings and is answered. Since neither feature is activated by the first call, there is no noticeable problem. When a second call arrives before the first has terminated, the telephone system has a decision to make: whether the call should be forwarded to the secondary number (call forwarding) or the person who answered the first call should be notified that another call has arrived (call waiting). Since this decision has no obvious correct answer, the optimal answer depends on the needs of the customer. This *feature interaction* is a specific example of a general and common problem that has become prevalent due to increasing system complexity.

In this situation, it is possible that the system's decision will be made in a non-deterministic fashion due to race conditions and other design factors. The consequences of feature interactions can range from minor irritations to life-threatening software failures, and therefore there is ongoing research that aims to find ways of *detecting* as well as *resolving* feature interactions.

Chapter 5

Independent Software Verification and Validation and Software Assurance

Independent software verification and validation

ISVV stands for **Independent Software Verification and Validation**. ISVV is targeted at safety-critical software systems and aims to increase the quality of software products, thereby reducing risks and costs through the operational life of the software. ISVV provides assurance that software performs to the specified level of confidence and within its designed parameters and defined requirements.

ISVV activities are performed by independent engineering teams, not involved in the software development process, to assess the processes and the resulting products. The ISVV team independency is performed at three different levels: financial, managerial and technical.

ISVV goes far beyond “traditional” verification and validation techniques, applied by development teams. While the latter aim to ensure that the software performs well against the nominal requirements, ISVV is focused on non-functional requirements such as robustness and reliability, and on conditions that can lead the software to fail. ISVV results and findings are fed back to the development teams for correction and improvement.

ISVV History

ISVV derives from the application of IV&V (Independent Verification and Validation) to the software. Early ISVV application (as known today) dates back to the early 1970s when the U.S. Army sponsored the first significant program related to IV&V for the Safeguard Anti-Ballistic Missile System.

By the end of the 1970s IV&V was rapidly becoming popular. The constant increase in complexity, size and importance of the software lead to an increasing demand on IV&V applied to software (ISVV).

Meanwhile IV&V (and ISVV for software systems) gets consolidated and is now widely used by organisations such as the DoD, FAA, NASA and ESA. IV&V is mentioned in [DO-178B], [ISO/IEC 12207] and formalised in [IEEE 1012].

Initially in 2004-2005, a European consortium led by the European Space Agency, and composed by DNV(N), Critical Software SA(P), Terma(DK) and CODA Scisys(UK) created the first version of a guide devoted to ISVV, called "ESA Guide for Independent Verification and Validation" with support from other organizations, eg SoftWcare SL (E) (), etc.

In 2008 the European Space Agency released a second version, being SoftWcare SL was the supporting editor having received inputs from many different European Space ISVV stakeholders. This guide covers the methodologies applicable to all the software engineering phases in what concerns ISVV.

ISVV Methodology

ISVV is usually composed by five principal phases, these phases can be executed sequentially or as results of a tailoring process.

ISVV Planning

- Planning of ISVV Activities
- System Criticality Analysis: Identification of Critical Components through a set of RAMS activities (Value for Money)
- Selection of the appropriate Methods and Tools

Requirements Verification

- Verification for: Completeness, Correctness, Testability

Design Verification

- Design adequacy and conformance to Software Requirements and Interfaces
- Internal and External Consistency
- Verification of Feasibility and Maintenance

Code Verification

- Verification for: Completeness, Correctness, Consistency
- Code Metrics Analysis

- Coding Standards Compliance Verification

Validation

- Identification of unstable components/functionalities
- Validation focused on Error-Handling: complementary (not concurrent!) validation regarding the one performed by the Development team (More for the Money, More for the Time)
- Compliance with Software and System Requirements
- Black box testing and White box testing techniques
- Experience based techniques

Software assurance

Software Assurance (SwA) is defined as "the level of confidence that software is free from vulnerabilities, either intentionally designed into the software or accidentally inserted at anytime during its lifecycle, and that the software functions in the intended manner."

Alternate definitions

Department of Homeland Security (DHS)

According to the DHS, software assurance addresses:

- Trustworthiness - No exploitable vulnerabilities exist, either maliciously or unintentionally inserted;
- Predictable Execution - Justifiable confidence that software, when executed, functions as intended;
- Conformance - Planned and systematic set of multi-disciplinary activities that ensure software processes and products conform to requirements, standards/ procedures.

Contributing SwA disciplines, articulated in Bodies of Knowledge and Core Competencies: Software Engineering, Systems Engineering, Information Systems Security Engineering, Information Assurance, Test and Evaluation, Safety, Security, Project Management, and Software Acquisition.

Software Assurance is a strategic initiative of the U.S. Department of Homeland Security (DHS) to promote integrity, security, and reliability in software. The SwA Program is based upon the National Strategy to Secure Cyberspace - Action/Recommendation 2-14:

“DHS will facilitate a national public-private effort to promulgate best practices and methodologies that promote integrity, security, and reliability in software code development, including processes and procedures that diminish the possibilities of erroneous code, malicious code, or trap doors that could be introduced during development.”

United States Department of Defense (DoD)

According to the DoD, software assurance relates to "the level of confidence that software functions as intended and is free of vulnerabilities, either intentionally or unintentionally designed or inserted as part of the software."

Software Assurance Metrics and Tool Evaluation (SAMATE) project

According to the NIST SAMATE project, software assurance is "the planned and systematic set of activities that ensures that software processes and products conform to requirements, standards, and procedures to help achieve:

- Trustworthiness - No exploitable vulnerabilities exist, either of malicious or unintentional origin, and
- Predictable Execution - Justifiable confidence that software, when executed, functions as intended."

National Aeronautics and Space Administration (NASA)

According to NASA, Software Assurance is a "planned and systematic set of activities that ensures that software processes and products conform to requirements, standards, and procedures. It includes the disciplines of Quality Assurance, Quality Engineering, Verification and Validation, Nonconformance Reporting and Corrective Action, Safety Assurance, and Security Assurance and their application during a software life cycle." The NASA Software Assurance Standard also states: "The application of these disciplines during a software development life cycle is called Software Assurance."

Object Management Group (OMG)

According to the OMG, Software Assurance is “justifiable trustworthiness in meeting established business and security objectives.”

OMG's SwA Special Interest Group (SIG), works with Platform and Domain Task Forces and other software industry entities and groups external to the OMG, to coordinate the establishment of a common framework for analysis and exchange of information related to software trustworthiness by facilitating the development of a specification for a Software Assurance Framework that will:

- Establish a common framework of software properties that can be used to represent any/all classes of software so software suppliers and acquirers can represent their claims and arguments(respectively), along with the corresponding evidence, employing automated tools (to address scale)

- Verify that products have sufficiently satisfied these characteristics in advance of product acquisition, so that system engineers/integrators can use these products to build (compose) larger assured systems with them
- Enable industry to improve visibility into the current status of software assurance during development of its software
- Enable industry to develop automated tools that support the common framework.

Software Assurance Forum for Excellence in Code (SAFECode)

According to SAFECode, Software Assurance is "confidence that software, hardware and services are free from intentional and unintentional vulnerabilities and that the software functions as intended."

Webopedia

According to Webopedia, Software Quality Assurance, abbreviated as SQA, and also called "software assurance", is a level of confidence that software is free from vulnerabilities, either intentionally designed into the software or inserted at anytime during its lifecycle, and that the software functions in the intended manner."

As indicated in the Webopedia definition, the term "software assurance" has been used as a shorthand for Software Quality Assurance (SQA) when not necessarily considering security or trustworthiness. SQA is defined in the *Handbook of Software Quality Assurance* as: "the set of systematic activities providing evidence of the ability of the software process to produce a software product that is fit to use."

Chapter 6

Software Rot

Software rot, also known as **code rot** or **software erosion** or **software decay** or software entropy, is a type of bit rot. It describes the perceived slow deterioration of software over time that will eventually lead to it becoming faulty, unusable, or otherwise in need of maintenance. This is not a physical phenomenon: the software does not actually decay, but rather suffers from a lack of being updated with respect to the changing environment in which it resides.

Some software can deteriorate in performance over time as it runs and accumulates errors; this is not generally considered software rot, though it may have some of the same consequences. Usually, such a degraded state of software can be remedied by completely reinitializing its state (as by a complete reinstallation of all relevant software components, possibly including operating system software); this may also remedy some kinds of software rot, whereas other software rot is irreversible, as the operating environment of the software, or components of the software itself, have irrevocably changed.

Causes

There are several factors responsible for software rot. These include changes to the environment in which the software operates, degradation of compatibility between parts of the software itself, and the appearance of bugs in unused or rarely used code.

Environment change

When changes occur in the program's environment, particularly changes which the designer of the program did not anticipate, the software may no longer operate as originally intended. For example, many early computer game designers made assumptions about processing speed of the CPU which the games were designed for. A consequence of this was that when the CPU's clock speed was used as a timer in the game, the gameplay speed would increase with that of the CPU, making the software less usable over time.

Onceability

There are changes in the environment not related to the program's designer, but its users. A user could set up the system working once and have it working flawlessly for a time. But when the system stops working correctly, or the users want to access the configuration controls, they are unable to repeat that initial step because of the different context and the unavailable information (password lost, missing instructions, or simply a hard-to-manage user interface that was first configured by trial and error). Information Architect Jonas Söderström has named this concept *Onceability* , and defines it as "the quality in a technical system that prevents a user from restoring the system, once it has failed".

Unused code

Portions of code which are not normally executed, such as document filters or interfaces designed to be used by other programs, may contain bugs that go unnoticed. With changes in user requirements and other external factors, this code may be executed later, thereby exposing the bugs and making the software appear less functional.

Rarely updated code

Normal maintenance of software and systems may also cause software rot. In particular, when a program contains multiple parts which function at arm's length from one another, failing to consider how changes to one part affect the others may introduce bugs.

In some cases, this may take the form of libraries that the software uses being changed in a way which adversely affects the software. If the old version of a library that was previously used with the software cannot be used any longer due to conflicts with other software or security flaws that were found in the old version, there may no longer be a viable version of a needed library for the program to use.

Classification

Software rot is usually classified as being either **dormant rot** or **active rot**.

Dormant rot

Software that is not currently being used gradually becomes unusable as the remainder of the application changes. Changes in user requirements and the software environment also contribute to the deterioration.

Active rot

Software that is being continuously modified may lose its integrity over time if proper mitigating processes are not consistently applied. However, much software requires continuous changes to meet new requirements and correct bugs, and re-engineering software each time a change is made is rarely practical. This creates what is essentially an evolution process for the program, causing it to depart from the original engineered design. As a consequence of this and a changing environment, assumptions made by the original designers may be invalidated, introducing bugs.

Developers are often encouraged to fully understand a problem before programming a solution to it, and to keep accurate and complete software documentation. In practice, however, adding new features may be prioritized over updating documentation. Without documentation, however, it is possible for specific knowledge pertaining to parts of the program to be lost. To some extent, this can be mitigated by following best current practices with regards to internal documentation and variable names.

Active software rot slows once an application is near the end of its commercial life and further development ceases. Users often learn to work around any remaining software bugs, and the behaviour of the software becomes consistent as nothing is changing.

Example

Many seminal programs from the early days of AI research have suffered from irreparable software rot. For example, the original SHRDLU program (an early natural language understanding program) cannot be run on any modern day computer or computer simulator, as it was developed during the days when LISP and PLANNER were still in development stage, and thus uses non-standard macros and software libraries which do not exist anymore.

Suppose an administrator creates a forum using phpBB or other online forum software. He then heavily modifies and "hacks" it, adding new features and options. This process requires extensive modifications to existing code and deviation from the original functionality of that software.

From here, there are several ways software rot can affect the system:

- The administrator can accidentally make changes which conflict with each other or the original software, causing the forum to behave unexpectedly or break down altogether. This leaves him in a very bad position: as he has deviated so greatly from the original code, technical support and assistance in reviving the forum will be difficult to obtain.
- A security hole may be discovered in the original forum source code, requiring a security patch. However, because the administrator has modified the code so extensively, the patch may not be directly applicable to his code, requiring the administrator to effectively rewrite the update.
- The administrator who made the modifications could vacate his position, leaving the new administrator with a convoluted and heavily-modified forum that lacks full documentation. Without fully understanding the modifications, it is difficult for the new administrator to make changes without introducing conflicts and bugs. (Furthermore, documentation of the original system might no longer be available;

it might have been abandoned, become proprietary closed software, or, with the passage of enough time, been lost.)

Refactoring

Refactoring is a means of addressing the problem of software rot. It is described as the process of rewriting existing code to improve its structure without affecting its external behaviour. This includes removing dead code and rewriting sections that have been modified extensively and no longer work efficiently. Care must be taken not to change the software's external behaviour, as this could introduce incompatibilities and thereby itself contribute to software rot.

Chapter 7

Reverse Semantic Traceability

Reverse Semantic Traceability (**RST**) is a quality control method for verification improvement that helps to insure high quality of artifacts by backward translation at each stage of the software development process.

Brief introduction

Each stage of development process can be treated as a series of “translations” from one language to another. At the very beginning a project team deals with customer’s requirements and expectations expressed in natural language. These customer requirements sometimes might be incomplete, vague or even contradictory to each other. The first step is specification and formalization of customer expectations, transition (“translation”) of them into a formal requirement document for the future system. Then requirements are translated into system architecture and step by step the project team generates megabytes of code written in a very formal programming language. There is always a threat of inserting mistakes, misinterpreting or losing something during the translation. Even a small defect in requirement or design specifications can cause huge amounts of defects at the late stages of the project. Sometimes such misunderstandings can lead to project failure or complete customer dissatisfaction.

The highest usage scenarios of Reverse Semantic Traceability method can be:

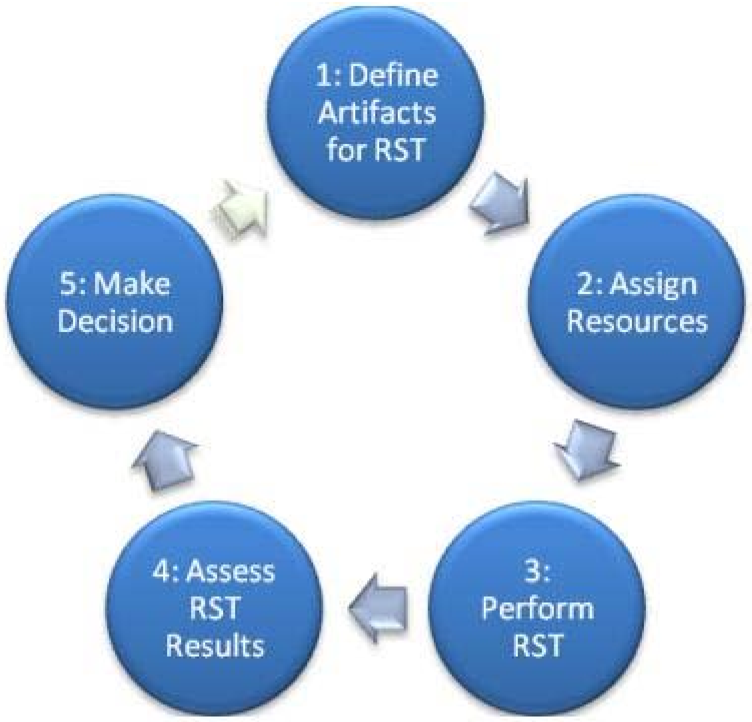
- Validating UML models: quality engineers restore a textual description of a domain, original and restored descriptions are compared.
- Validating model changes for a new requirement: given an original and changed versions of a model, quality engineers restore the textual description of the requirement, original and restored descriptions are compared.
- Validating a bug fix: given an original and modified Source code, quality engineers restore a textual description of the bug that was fixed, original and restored descriptions are compared.
- Integrating new software engineer into a team: a new team member gets an assignment to do Reverse Semantic Traceability for the key artifacts from the current projects.

RST roles

Main roles involved in RST session are:

- authors of project artifacts (both input and output),
- reverse engineers,
- expert group,
- project manager.

RST process



Define all project artifacts and their relationship

Reverse Semantic Traceability as a validation method can be applied to any project artifact, to any part of project artifact or even to a small piece of document or code. However, it is obvious that performing RST for all artifacts can create overhead and should be well justified (for example, for medical software where possible information loss is very critical).

It is a responsibility of company and Project manager to decide what amount of project artifacts will be "reverse engineered". This amount depends on project specific details: trade-off matrix, project and company quality assurance policies. Also it depends on importance of particular artifact for project success and level of quality control applied to this artifact.

Amount of RST sessions for project is defined at the project planning stage.

First of all project manager should create a list of all artifacts project team will have during the project. They could be presented as a tree with dependencies and relationships. Artifacts can be present in one occurrence (like Vision document) or in several occurrences (like risks or bugs). This list can be changed later during the project but the idea behind the decisions about RST activities will be the same.

Prioritize

The second step is to analyze deliverable importance for project and level of quality control for each project artifact.

Importance of document is the degree of artifact impact to project success and quality of final product. It's measured by the scale:

- Crucial (1): the quality of deliverable is very important for overall quality of project and even for project success. Examples: Functional requirements, System architecture, critical bug fixes (show stoppers), risks with high probability and critical impact.
- High (2): the deliverable has an impact to quality of final product. Examples: Test cases, User interface requirements, major severity bug fixes, risks with high expose.
- Medium (3): the artifact has a medium or indirect impact to quality of final product. Examples: Project plan, medium severity bug fixes, risks with medium expose.
- Low (4): the artifact has insignificant impact to the final product quality. Example: employees' tasks, cosmetic bugs, risks with low probability.

Level of quality control is a measure that defines amount of verification and validation activities applied to artifact, and probability of miscommunication during artifact creation.

- Low (1): No review is supposed for the artifact, miscommunication and information loss are high probable, information channel is distributed, language barrier exists etc
- Medium (2): No review is supposed for the artifact, information channel is not distributed (e.g. creator of artifact and information provider are members of one team)
- Sufficient (3): Pair development or peer review is done, information channel is not distributed.
- Excellent (4): Pair development, peer review and/or testing are done, automation or unit testing is done, or there are some tools for artifact development and validation.

Define responsible people

Success of RST session strongly depends on correct assignment of responsible people.

Perform Reverse Semantic Traceability of artifact

Reverse Semantic Traceability starts when decision that RST should be performed is made and resources for it are available.

Project manager defines what documents will be an input for RST session. For example, it can be not only an artifact to restore but some background project information. It is recommended to give to reverse engineers number of words in original text so that they have an idea about amount of text they should get as a result: it can be one sentence or several pages of text. Though, the restored text may not contain the same number of words as original text nevertheless the values should be comparable.

After that reverse engineers take the artifact and restore the original text from it. RST itself takes about 1 hour for one page text (750 words).

Value the level of quality and make a decision

To complete RST session, restored and original texts of artifact should be compared and quality of artifact should be assessed. Decision about artifacts rework and its amount is made based on this assessment.

For assessment a group of experts is formed. Experts should be aware of project domain and be an experienced enough to assess quality level of compared artifacts. For example, business analysts will be experts for comparison of vision statement and restored vision statement from scenario.

RST assessment criteria:

1. Restored and original texts have quite big differences in meaning and crucial information loss
2. Restored and original texts have some differences in meaning, important information loss
3. Restored and original texts have some differences in meaning, some insignificant information loss
4. Restored and original texts are very close, some insignificant information loss
5. Restored and original texts are very close, none information is lost

Each of experts gives his assessment, and then the average value is calculated. Depending on this value Project Manager makes a decision should both artifacts be corrected or one of them or rework is not required.

If the average RST quality level is in range from 1 to 2 the quality of artifact is poor and it is recommended not only rework of validated artifact to eliminate defects but corrections of original artifact to clear misunderstandings. In this case one more RST session after rework of artifacts is required. For artifacts that have more than 2 but less than 3 corrections of validated artifact to fix defects and eliminate information loss is required, however review of original artifact to find out if there any vague piece of information that cause misunderstandings is recommended. No additional RST sessions is needed. If the average mark is more than 3 but less than 4 then corrections of validated artifact to remove defects and insignificant information loss is supposed. If the mark is greater than 4 it means that artifact is of good quality and no special corrections or rework is required.

Obviously the final decision about rework of artifacts is made by project manager and should be based on analysis of reasons of differences in texts.

Chapter 8

Sneak Circuit Analysis and Verification and Validation (Software)

Sneak circuit analysis

Sneak Circuit Analysis is a vital part of the safety assurance of safety-critical electronic and electro-mechanical systems.

Sneak conditions are defined as latent hardware, software, or integrated conditions that may cause unwanted actions or may inhibit a desired function, and are not caused by component failure.

Sneak Circuit Analysis (SCA) is used in safety-critical systems to identify sneak (or hidden) paths in electronic circuits and electro-mechanical systems that may cause unwanted action or inhibit desired functions. The analysis is aimed at uncovering design flaws that allow for sneak conditions to develop. The sneak circuit analysis technique differs from other system analysis techniques in that it is based on identification of designed-in inadvertent modes of operation and is not based on failed equipment or software.

SCA is most applicable to circuits that can cause irreversible events. These include:

a. Systems that control or perform active tasks or functions
b. Systems that control electrical power and its distribution.
c. Embedded code which controls and times system functions.

Sneak conditions are classified into four basic types:

1. Sneak paths - unintended electrical (current) paths within a circuit and its external interfaces.

2. Sneak timing–unexpected interruption or enabling of a signal due to switch circuit timing problems which may cause or prevent the activation or inhibition of a function at an unexpected time.
3. Sneak indications–undesired activation or deactivation of an indicator which may cause an ambiguous or false display of system operating conditions.
4. Sneak labels–incorrect or ambiguous labeling of a switch which may cause operator error through inappropriate control activation.

Historical background

SCA is a detailed examination of switching circuitry that controls irreversible functions such as squibs and latches. The former Military Standard for Reliability Program (MIL-STD-785B) defines SCA (Task 205) as a task " … to identify latent paths which cause occurrence of unwanted functions or inhibit desired functions, assuming all components are functioning properly."

The Mercury-Redstone launch failure 1961 and a number of other mishaps caused by sneak circuits in missiles and torpedoes caused the military services and NASA to require formal procedures for prevention of these incidents. The first computer aided implementation of SCA was for the NASA Apollo program in 1967 by the Boeing Company . Among early publications in the field are a 1970 Boeing report "Sneak Circuit Analysis Handbook" by J. P. Rankin and C. F. White (NTIS N71-12487), and a 1977 AGARD report by J. L. Wilson and R. C. Clardy "Sneak Circuit Analysis Application to Control System Design" (AD A041042). By 1980 the requirements for SCA had become sufficiently common to lead to the Navy publication of a "Contract and Management Guide for Sneak Circuit Analysis" (NAVSEA-TE001-AA-GYD-010/SCA) . Subsequent efforts led to several Air Force reports in 1990: "Sneak Circuit Analysis for the Common Man", Rome Air Development Center Technical Report, RADC-TR-89-223, October, 1989 and "Intergration of Sneak Analysis with Design", Air Development Center Technical Report, RADC-TR-90-109, (June, 1990.) .

Current standards and guidelines include NASA's Sneak Circuit Analysis Guideline for Electromechanical Systems (PD-AP-1314) and AIAA's Performance-Based Sneak Circuit Analysis (SCA) Requirements (BSR/ANSI/AIAA S-102.2.5-2xxx) .

Sneak circuit example

Most sneak circuits reported from production systems are too complex to describe in an introductory discussion. However, the essential characteristics of a sneak circuit can be explained with a hypothetical example of an aircraft cargo door release latch as shown in Figure 1-1.

Figure 1-1 Sneak Circuit in Cargo Door Latching Function

To prevent unintended opening of the cargo door in flight, the normal cargo door control (CARGO OPEN) is powered in series with the GEAR DOWN switch. This permits routine opening on the ground. But there can be emergencies that require jettisoning cargo, and to be prepared for these there is an EMERGENCY CARGO OPEN switch that may be guarded with a safety wire to prevent its unintended operation. Now assume that an in-flight emergency exists that requires opening the cargo door. The flight personnel flips the normal CARGO OPEN switch and nothing happens (since the GEAR DOWN switch is open). It is realized that it is necessary to close the EMERGENCY CARGO OPEN switch, and when that action is taken the cargo door latch is indeed released, permitting the door to be opened. But at the same time the landing gear is lowered, not a desired action and one that probably will aggravate the emergency. The condition that permits this undesired lowering of the landing gear to occur when both cargo door switches are closed is a sneak circuit.

Two observations about this sneak circuit apply generally:

1. Switches or other control elements are operated in an unusual or even prohibited manner

2. The unintended function (in this example the lowering of the landing gear) is associated with current flow through a circuit element that is opposite to the intended current flow.

The latter of these conditions permits elimination of the sneak circuit by inserting a diode as shown in Figure 1-2.

Figure 1-2. Corrected Cargo Door Latching Circuit

Conventional SCA Techniques

The original SCA techniques depended on recognition of circuit patterns or “clues” for the detection of potential sneak circuits. The most common of these circuit patterns are shown in Figure 1-3.

Figure 1-3 Circuit Patterns for Sneak Circuit Analysis

The box symbols represent arbitrary circuit elements; in many cases the individual legs of the patterns include switches. It will be recognized that the leg containing the normal CARGO OPEN switch in Figure 1-1 constitutes the middle horizontal leg of an H-pattern. The inverted Y is also called a ground dome; note that the two bottom legs terminate in different ground levels, such as chassis ground and signal ground. The Y-pattern is also called a power dome. The two upper legs terminate at different power sources, such as V1 and V2.

To facilitate the recognition of these patterns or clues, the schematic diagrams were redrawn as “network trees”, with power sources at the top and grounds at the bottom. In sneak circuit analysis both positive and negative sources will be shown at the top of the figure. Because searching for the patterns is very labor intensive, computer programs were developed to recognize the common clues in the network trees. Main frame computers had to be utilized to perform the topological searches even on small designs. Despite the aid of computers, SCA remained a very expensive and lengthy activity, and it was usually conducted only after the circuit design was frozen to avoid having to repeat it after changes. This had a distinct disadvantage when a sneak circuit was detected: it became very expensive to fix it because usually the circuit card or cabling was already in production.

An effort of the Rome Air Development Center (now part of the USAF Research Laboratories) directed at finding techniques that would permit sneak circuit analysis to be conducted as part of the design activity led to the “bi-path” methodology, developed by SoHaR. The “bi-path” algorithm was implemented into an automated software tool that allowed large designs to be analyzed very quickly early in the design phase of a safety-critical circuit.

Editing

Editing is used to eliminate paths that cannot contribute to operation of sensitive elements (elements that can lead to critical actions). Circuits that control squibs or latches usually contain computational, instrumentation, and switching elements. An example of the integration of these functions for a hypothetical and simplified missile detonation system is shown in Figure 1-4. The computational elements at the top of the figure establish the conditions for operation of the pre-arm, arm, and detonate switches. The heavy lines constitute the switching elements. The instrumentation functions are shown in the lower part of the figure. Sneak circuit analysis encompasses only the switching functions; the computational and instrumentation elements are eliminated from the traced paths.

This editing is justified because the connection between the computational elements and the switches (shown as dashed lines in the figure) is non-conducting. In most cases the output of the computational element goes to the gate of a MOSFET while the switching function uses the source-drain path. The computational elements are typically quite complex and their failure probability is much higher than that of the switching path. Thus safeguards are provided to tolerate the worst failure modes of these devices and sneak circuit analysis of the computational elements is not required.

Figure 1-4. Hypothetical Missile Detonation System

The elimination of the instrumentation functions is justified by the isolation resistors at the connection with the switching function. The resistance values are typically of the order of 10k ohms. Since the switching voltage is in the 20V–30V range, the current flow through the isolation resistors cannot exceed a few milliamperes, while squibs fire only above 1 ampere. In addition to this editing of major blocks, individual elements connected to the switching circuit may have to be eliminated or modified by editing as shown in the examples of Figure 1-5. The feedback resistor Rf constitutes an intentional bi-path (not a sneak circuit). Its high resistance prevents significant current flow. In part

b. of the figure a mechanical connection keeps switches S1 and S2 from being closed at the same time, preventing a power-to-power tie.

Figure 1-5. Editing for Intentional and Irrelevant Paths

1.Sneak Circuit Analysis for the Common Man**.**

2. Integration of Sneak Analysis with Design**.**

3. Sneak Circuit Analysis**.**

4. Sneak Circuit Analysis Automated Tool, SCAT**.**

Verification and Validation (software)

In software project management, software testing, and software engineering, **Verification and Validation** (**V&V**) is the process of checking that a software system meets specifications and that it fulfils its intended purpose. It is normally part of the software testing process of a project.

Definitions

Also known as software quality control.

Validation checks that the product design satisfies or fits the intended usage (high-level checking) — i.e., you built the right product. This is done through dynamic testing and other forms of review.

According to the Capability Maturity Model (CMMI-SW v1.1),

- Verification: The process of evaluating software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase. [IEEE-STD-610].
- Validation: The process of evaluating software during or at the end of the development process to determine whether it satisfies specified requirements. [IEEE-STD-610]

In other words, validation ensures that the product actually meets the user's needs, and that the specifications were correct in the first place, while verification is ensuring that the product has been built according to the requirements and design specifications. Validation ensures that ‘you built the right thing’. Verification ensures that ‘you built it right’. Validation confirms that the product, as provided, will fulfill its intended use.

From testing perspective:

- Fault - wrong or missing function in the code.
- Failure - the manifestation of a fault during execution.
- Malfunction - according to its specification the system does not meet its specified functionality.

Within the modeling and simulation community, the definitions of validation, verification and accreditation are similar:

- Validation is the process of determining the degree to which a model, simulation, or federation of models and simulations, and their associated data are accurate representations of the real world from the perspective of the intended use(s).
- Accreditation is the formal certification that a model or simulation is acceptable to be used for a specific purpose.
- Verification is the process of determining that a computer model, simulation, or federation of models and simulations implementations and their associated data accurately represents the developer's conceptual description and specifications.

Related concepts

Both verification and validation are related to the concepts of quality and of software quality assurance. By themselves, verification and validation do not guarantee software quality; planning, traceability, configuration management and other aspects of software engineering are required.

Classification of methods

In mission-critical systems where flawless performance is absolutely necessary, formal methods can be used to ensure the correct operation of a system. However, often for non-mission-critical systems, formal methods prove to be very costly and an alternative method of V&V must be sought out. In this case, syntactic methods are often used.

Test cases

A test case is a tool used in the process.

Test cases are prepared for verification: to determine if the process that was followed to develop the final product is right.

Test case are executed for validation: if the product is built according to the requirements of the user. Other methods, such as reviews, are used when used early in the Software Development Life Cycle provide for validation.

Independent Verification and Validation

Verification and validation often is carried out by a separate group from the development team; in this case, the process is called "**Independent Verification and Validation**", or **IV&V**.

Regulatory environment

Verification and validation must meet the compliance requiements of law regulated industries, which is often guided by government agencies or industrial administrative authorities. e.g. The FDA requires software versions and patches to be validated.

Chapter 9

Software Security Assurance

Software Security Assurance is a process that helps design and implement software that protects the data and resources contained in and controlled by that software. Software is itself a resource and thus must be afforded appropriate security.

What is Software Security Assurance?

Software Security Assurance (SSA) is the process of ensuring that software is designed to operate at a level of security that is consistent with the potential harm that could result from the loss, inaccuracy, alteration, unavailability, or misuse of the data and resources that it uses, controls, and protects.

The Software Security Assurance process begins by identifying and categorizing the information that is to be contained in, or used by, the software. The information should be categorized according to its sensitivity. For example, in the lowest category, the impact of a security violation is minimal (i.e. the impact on the software owner's mission, functions, or reputation is negligible). For a top category, however, the impact may pose a threat to human life; may have an irreparable impact on software owner's missions, functions, image, or reputation; or may result in the loss of significant assets or resources.

Once the information is categorized, security requirements can be developed. The security requirements should address access control, including network access and physical access; data management and data access; environmental controls (power, air conditioning, etc.) and off-line storage; human resource security; and audit trails and usage records.

What causes software security problems?

All security vulnerabilities in software are the result of security bugs, or defects, within the software. In most cases, these defects are created by two primary causes: (1) non-conformance, or a failure to satisfy requirements; and (2) an error or omission in the software requirements.

Non-conformance, or a failure to satisfy requirements

A non-conformance may be simple–the most common is a coding error or defect–or more complex (i.e., a subtle timing error or input validation error). The important point about non-conformances is that verification and validation techniques are designed to detect them and security assurance techniques are designed to prevent them. Improvements in these methods, through a software security assurance program, can improve the security of software.

Errors or omissions in software requirements

The most serious security problems with software-based systems are those that develop when the software requirements are incorrect, inappropriate, or incomplete for the system situation. Unfortunately, errors or omissions in requirements are more difficult to identify. For example, the software may perform exactly as required under normal use, but the requirements may not correctly deal with some system state. When the system enters this problem state, unexpected and undesirable behavior may result. This type of problem cannot be handled within the software discipline; it results from a failure of the system and software engineering processes which developed and allocated the system requirements to the software.

Software Security Assurance Activities

There are two basic types of Software Security Assurance activities.

1. Some focus on ensuring that information processed by an information system is assigned a proper sensitivity category, and that the appropriate protection requirements have been developed and met in the system.
2. Others focus on ensuring the control and protection of the software, as well as that of the software support tools and data.

At a minimum, a Software Security Assurance program should ensure that:

1. A security evaluation has been performed for the software.
2. Security requirements have been established for the software.
3. Security requirements have been established for the software development and/or operations and maintenance (O&M) processes.
4. Each software review, or audit, includes an evaluation of the security requirements.
5. A configuration management and corrective action process is in place to provide security for the existing software and to ensure that any proposed changes do not inadvertently create security violations or vulnerabilities.
6. Physical security for the software is adequate.

Building in security

Improving the software development process and building better software are ways to improve software security, by producing software with fewer defects and vulnerabilities. A first-order approach is to identify the critical software components that control security-related functions and pay special attention to them throughout the development and testing process. This approach helps to focus scarce security resources on the most critical areas.

Tools and techniques

There are many commercial off-the-shelf (COTS) software packages that are available to support software security assurance activities. However, before they are used, these tools must be carefully evaluated and their effectiveness must be assured.

Common weaknesses enumeration

One way to improve software security is to gain a better understanding of the most common weaknesses that can affect software security. With that in mind, there is a current community-based program called the Common Weaknesses Enumeration project, which is sponsored by The Mitre Corporation to identify and describe such weaknesses. The list, which is currently in a very preliminary form, contains descriptions of common software weaknesses, faults, and flaws.

Security architecture/design analysis

Security Architecture/Design Analysis verifies that the software design correctly implements security requirements. Generally speaking, there are four basic techniques that are used for security architecture/design analysis.

Logic analysis

Logic analysis evaluates the equations, algorithms, and control logic of the software design.

Data analysis

Data analysis evaluates the description and intended usage of each data item used in design of the software component. The use of interrupts and their effect on data should receive special attention to ensure interrupt handling routines do not alter critical data used by other routines.

Interface analysis

Interface analysis verifies the proper design of a software component's interfaces with other components of the system, including hardware, software, and end-users.

Constraint analysis

Constraint analysis evaluates the design of a software component against restrictions imposed by requirements and real-world limitations. The design must be responsive to all known or anticipated restrictions on the software component. These restrictions may include timing, sizing, and throughput constraints, input and output data limitations, equation and algorithm limitations, and other design limitations.

Secure code reviews, inspections, and walkthroughs

Code analysis verifies that the software source code is written correctly, implements the desired design, and does not violate any security requirements. Generally speaking, the techniques used in the performance of code analysis mirror those used in design analysis.

Secure Code Reviews are conducted during and at the end of the development phase to determine whether established security requirements, security design concepts, and security-related specifications have been satisfied. These reviews typically consist of the presentation of material to a review group. Secure Code Reviews are most effective when conducted by personnel who have not been directly involved in the development of the software being reviewed.

Informal reviews

Informal secure code reviews can be conducted on an as-needed basis. To conduct an informal review, the developer simply selects one or more reviewer(s) and provides and/or presents the material to be reviewed. The material may be as informal as pseudo-code or hand-written documentation.

Formal reviews

Formal secure code reviews are conducted at the end of the development phase for each software component. The client of the software appoints the formal review group, who may make or affect a "go/no-go" decision to proceed to the next step of the software development life cycle.

Inspections and walkthroughs

A secure code inspection or walkthrough is a detailed examination of a product on a step-by-step or line-by-line (of source code) basis. The purpose of conducting secure code inspections or walkthroughs is to find errors. Typically, the group that does an inspection or walkthrough is composed of peers from development, security engineering and quality assurance.

Security testing

Software security testing, which includes penetration testing, confirms the results of design and code analysis, investigates software behavior, and verifies that the software complies with security requirements. Special security testing, conducted in accordance with a security test plan and procedures, establishes the compliance of the software with the security requirements. Security testing focuses on locating software weaknesses and identifying extreme or unexpected situations that could cause the software to fail in ways that would cause a violation of security requirements. Security testing efforts are often limited to the software requirements that are classified as "critical" security items.

Chapter 10

Algorithmic Efficiency

In computer science, **efficiency** is used to describe properties of an algorithm relating to how much of various types of resources it consumes. Algorithmic efficiency can be thought of as analogous to engineering productivity for a repeating or continuous process, where the goal is to reduce resource consumption, including time to completion, to some acceptable, optimal level.

Software metrics

The two most frequently encountered and measurable metrics of an algorithm are:-

- speed or running time - the time it takes for an algorithm to complete, and
- 'space' - the memory or 'non-volatile storage' used by the algorithm **during its operation**.

but also might apply to

- transmission size - such as required bandwidth during normal operation or
- size of external memory- such as temporary disk space used to accomplish its task

and perhaps even

- the size of required 'longterm' disk space required **after its operation** to record its output or maintain its required function during its required useful lifetime (examples: a data table , archive or a computer log) and also
- the performance per watt and the total energy, consumed by the chosen hardware implementation (with its System requirements, necessary auxiliary support systems including interfaces, cabling, switching, cooling and security), during its required useful lifetime.

(An extreme example of these metrics might be to consider their values in relation to a repeated simple algorithm for calculating and storing (**π**+n) to 50 decimal places running for say, 24 hours, either on a "pocket calculator" sized processor such as an ipod or an early mainframe operating in its own purpose-built heated or air conditioned unit.)

The process of making code more efficient is known as optimization and in the case of automatic optimization (i.e. compiler optimization - performed by compilers on request or by default), usually focus on space at the cost of speed, or vice versa. There are also quite simple programming techniques and 'avoidance strategies' that can actually improve both at the same time, usually irrespective of hardware, software or language. Even the re-ordering of nested conditional statements - to put the least frequently occurring condition first (example: test patients for blood type ='AB-', before testing age > 18, since this type of blood occurs in only about 1 in 100 of the population - thereby eliminating the second test at runtime in 99% of instances), can reduce actual instruction path length, something an optimizing compiler would almost certainly not be aware of - but which a programmer can research relatively easily even without specialist medical knowledge.

History

The first machines that were capable of computation were severely limited by purely mechanical considerations. As later electronic machines were developed they were, in turn, limited by the speed of their electronic counterparts. As software replaced hard-wired circuits, the efficiency of algorithms also became important. It has long been recognized that the precise 'arrangement of processes' is critical in reducing elapse time.

- "In almost every computation a great variety of arrangements for the succession of the processes is possible, and various considerations must influence the selections amongst them for the purposes of a calculating engine. One essential object is to choose that arrangement which shall tend to reduce to a minimum the time necessary for completing the calculation"

Ada Lovelace 1815-1852, generally considered as 'the first programmer' who worked on Charles Babbage's early mechanical general-purpose computer

- "In established engineering disciplines a 12% improvement, easily obtained, is never considered marginal and I believe the same viewpoint should prevail in software engineering"

Extract from "Structured Programming with go to Statements" by Donald Knuth, renowned computer scientist and Professor Emeritus of the Art of Computer Programming at Stanford University.

- "The key to performance is elegance, not battalions of special cases"

attributed to Jon Bentley and (Malcolm) Douglas McIlroy

Speed

The **absolute** speed of an algorithm for a given input can simply be measured as the duration of execution (or clock time) and the results can be averaged over several executions to eliminate possible random effects. Most modern processors operate in a multi-processing & multi-programming environment so consideration must be made for parallel processes occurring on the same physical machine, eliminating these as far as possible. For superscalar processors, the speed of a given algorithm can sometimes be improved through instruction-level parallelism within a single processor (but, for optimal results, the algorithm may require some adaptation to this environment to gain significant advantage ('speedup'), becoming, in effect, an entirely different algorithm). A **relative** measure of an algorithms performance can sometimes be gained from the total instruction path length which can be determined by a run time Instruction Set Simulator (where available).

An **estimate** of the speed of an algorithm can be determined in various ways. The most common method uses time complexity to determine the Big-O of an algorithm.

Memory

Often, it is possible to make an algorithm faster at the expense of memory. This might be the case whenever the result of an 'expensive' calculation is cached rather than recalculating it afresh each time. The additional memory requirement would, in this case, be considered additional overhead although, in many situations, the stored result occupies very little extra space and can often be held in pre-compiled static storage, reducing not just processing time but also allocation & deallocation of working memory. This is a very common method of improving speed, so much so that some programming languages often add special features to support it, such as C++'s 'mutable' keyword.

The memory requirement of an algorithm is actually two separate but related things:-

- The memory taken up by the compiled executable code (the object code or binary file) itself (on disk or equivalent, depending on the hardware and language). This can often be reduced by preferring run-time decision making mechanisms (such as virtual functions and run-time type information) over certain compile-time decision making mechanisms (such as macro substitution and templates). This, however, comes at the cost of speed.

- Amount of temporary "dynamic memory" allocated during processing. For example, dynamically pre-caching results, as mentioned earlier, improves speed at the cost of this attribute. Even the depth of sub-routine calls can impact heavily on this cost and increase path length too, especially if there are 'heavy' dynamic memory requirements for the particular functions invoked. The use of copied function parameters (rather than simply using pointers to earlier, already defined, and sometimes static values) actually **doubles** the memory requirement for this particular memory metric (as well as carrying its own processing overhead for the copying itself. This can be particularly relevant for quite 'lengthy' parameters such as html script, JavaScript source programs or extensive freeform text such as letters or emails.

Rematerialization

It has been argued that Rematerialization (re-calculating) may occasionally be more efficient than holding results in cache. This is the somewhat non-intuitive belief that it can be faster to re-calculate from the input - even if the answer is already known - when it can be shown, in some special cases, to decrease "register pressure". Some optimizing compilers have the ability to decide when this is considered worthwhile based on a number of criteria such as complexity and no side effects, and works by keeping track of the expression used to compute each variable, using the concept of available expressions.

This is most likely to be true when a calculation is very fast (such as addition or bitwise operations), while the amount of data which must be cached would be very large, resulting in inefficient storage. Small amounts of data can be stored very efficiently in registers or fast cache, while in most contemporary computers large amounts of data must be stored in slower memory or even slower hard drive storage, and thus the efficiency of storing data which can be computed quickly drops significantly.

Precomputation

Precomputing a complete range of results prior to compiling, or at the beginning of an algorithm's execution, can often increase algorithmic efficiency substantially. This becomes advantageous when one or more inputs is constrained to a small enough range that the results can be stored in a reasonably sized block of memory. Because memory access is essentially constant in time complexity (except for caching delays), any algorithm with a component which has worse than constant efficiency over a small input range can be improved by precomputing values. In some cases efficient approximation algorithms can be obtained by computing a discrete subset of values and interpolating for intermediate input values, since interpolation is also a linear operation.

Transmission size

Data compression algorithms can be useful because they help reduce the consumption of expensive resources, such as hard disk space or transmission bandwidth. This however also comes at a cost - which is additional processing time to compress and subsequently decompress. Depending upon the speed of the data transfer, compression may reduce overall response times which, ultimately, equates to speed - even though processing within the computer itself takes longer. For audio, MP3 is a compression method used extensively in portable sound systems. The efficiency of a data compression algorithm relates to the compression factor and speed of achieving both compression and decompression. For the purpose of archiving an extensive database, it might be considered worthwhile to achieve a very high compression ratio, since decompression is less likely to occur on the majority of the data.

Data presentation

Output data can be presented to the end user in many ways - such as via punched tape or card, digital displays, local display monitors, remote computer monitors or printed. Each of these has its own inherent initial cost and, in some cases, an ongoing cost (e.g. refreshing an image from memory) . As an example, the web site "Google" recently showed, as its logo, an image of the Vancouver olympics that is around 8K of gif image. The normally displayed Google image is a PNG image of 28K (or 48K), yet the raw text string for "Google" occupies only 6 octets or 48 bits (4,778 or 8192 *times* less). This graphically illustrates that how data is presented can significantly effect the overall efficiency of transmission (and also the complete algorithm - since both GIF and PNG images require yet more processing).

It is estimated by "Internet World Stats" that there were 1,733,993,741 internet users in 2009 and, to transmit this new image to each one of them, would require around 136,000 *billion* (10^9)octets of data to be transmitted - at least once - into their personal web cache. In "Computational Energy Cost of TCP", co-authors Bokyung Wang and Suresh Singh examine the energy costs for TCP and calculated, for their chosen example, a cost of 0.022 Joules per packet (of approx 1489 octets). On this basis, a total of around 2,000,000,000 joules (2 GJ) of energy might be expended by TCP elements alone to display the new logo for all users for the first time. To maintain or re-display this image requires still more processing and consequential energy cost (in contrast to printed output for instance).

Encoding and decoding methods (compared and contrasted)

When data is encoded for any 'external' use, it is possible to do so in an almost unlimited variety of different formats that are sometimes conflicting. This content encoding (of the raw data) may be designed for:

- optimal readability – by humans
- optimal decoding speed – by other computer programs
- optimal compression – for archiving or data transmission
- optimal compatibility – with "legacy" or other existing formats or programming languages
- optimal security – using encryption

It is unlikely that all of these goals could be met with a single 'generic' encoding scheme and so a compromise will often be the desired goal and will often be compromised by the need for standardization and/or legacy and compatibility issues.

Encoding efficiently

For data encoding whose destination is to be input for further computer processing, readability is not an issue – since the receiving processors algorithm can decode the data to any other desirable form including human readable. From the perspective of algorithmic efficiency, **minimizing subsequent decoding** (with zero or minimal parsing) should take highest priority. The general rule of thumb is that any encoding system that 'understands' the underlying data structure - sufficiently to encode it in the first place - should be equally capable of easily encoding it in such a way that makes decoding it highly efficient. For variable length data with possibly omitted data values, for instance, this almost certainly means the utilization of declarative notation (i.e. including the length of the data item as a prefix to the data so that a de-limiter is not required and parsing completely eliminated). For keyword data items, tokenizing the key to an index (integer) after its first occurrence not only reduces subsequent data size but, furthermore, reduces future decoding overhead for the same items that are repeated.

Historically, optimal encoding was not only worthwhile from an efficiency standpoint but was also common practise to conserve valuable memory, external storage and processor resources. Once validated a country name for example could be held as a shorter sequential country code which could then also act as an index for subsequent 'decoding', using this code as an entry number within a table or record number within a file. If the table or file contained fixed length entries, the code could easily be converted to an absolute memory address or disk address for fast retrieval. The ISBN system for identifying books is a good example of a practical encoding method which also contains a built-in hierarchy.

According to recent articles in New Scientist and Scientific American; "TODAY'S telecommunications networks could use one ten-thousandth of the power they presently consume if smarter data-coding techniques were used", according to Bell Labs, based in Murray Hill, New Jersey It recognizes that this is only a theoretical limit but nevertheless sets itself a more realistic, practical goal of a 1,000 fold reduction within 5 years with future, as yet unidentified, technological changes.

Examples of several common encoding methods

- Comma separated values (CSV - a list of data values separated by commas)
- Tab separated values (TSV) - a list of data values separated by 'tab' characters
- HyperText Markup Language (HTML) - the predominant markup language for web pages
- Extensible Markup Language (XML) - a generic framework for storing any amount of text or any data whose structure can be represented as a tree with at least one element - the root element.
- JavaScript Object Notation (JSON) - human-readable format for representing simple data structures

The last of these, (JSON) is apparently widely used for internet data transmission, primarily it seems because the data can be uploaded by a single JavaScript 'eval' statement - without the need to produce what otherwise would likely have been a more efficient purpose built encoder/decoder. There are in fact quite large amounts of repeated (and therefore redundant data) in this particular format, and also in HTML and XML source, that could quite easily be eliminated. XML is recognized as a verbose form of encoding. Binary XML has been put forward as one method of reducing transfer and processing times for XML and, while there are several competing formats, none has been widely adopted by a standards organization or accepted as a de facto standard. It has also been criticized by Jimmy Zhang for essentially trying to solve the wrong problem

There are a number of freely available products on the market that partially compress HTML files and perform some or all of the following:

- merge lines
- remove unnecessary whitespace characters
- remove unnecessary quotation marks. For example, BORDER="0" will be replaced with BORDER=0)
- replace some tags with shorter ones (e.g. replace STRIKE tags with S, STRONG with B and EM with I)
- remove HTML comments (comments within scripts and styles are not removed)
- remove <!DOCTYPE..> tags
- remove named meta tags

The effect of this limited form of compression is to make the HTML code smaller and faster to load, but more difficult to read manually (so the original HTML code is usually retained for updating), but since it is predominantly meant to be processed only by a browser, this causes no problems. Despite these small improvements, HTML, which is the predominant language for the web still remains a predominantly *source* distributed, interpreted markup language, with high redundancy.

Kolmogorov complexity

The study of encoding techniques has been examined in depth in an area of computer science characterized by a method known as Kolmogorov complexity where a value known as ('**K**') is accepted as 'not a computable function'. The Kolmogorov complexity of any computable object is the length of the shortest program that computes it and then halts. The invariance theorem shows that it is not really important which computer is used. Essentially this implies that there is no automated method that can produce an optimum result and is therefore characterized by a requirement for human ingenuity or Innovation.

Effect of programming paradigms

The effect that different programming paradigms have on algorithmic efficiency is fiercely contested, with both supporters and antagonists for each new paradigm. Strong supporters of structured programming, such as Dijkstra for instance, who favour entirely goto-less programs are met with conflicting evidence that appears to nullify its supposed benefits. The truth is, even if the structured code itself contains no gotos, the optimizing compiler that creates the binary code almost certainly generates them (and not necessarily in the most efficient way). Similarly, OOP protagonists who claim their paradigm is superior are met with opposition from strong sceptics such as Alexander Stepanov who suggested that OOP provides a mathematically limited viewpoint and called it, "almost as much of a hoax as Artificial Intelligence" In the long term, benchmarks, using real-life examples, provide the only real hope of resolving such conflicts - at least in terms of run-time efficiency.

Optimization techniques

The word optimize is normally used in relation to an existing algorithm/computer program (i.e. to improve upon completed code). Here, it is used both in the context of existing programs and also in the design and implementation of new algorithms, thereby avoiding the most common performance pitfalls. It is clearly wasteful to produce a working program - at first using an algorithm that ignores all efficiency issues - only to then have to redesign or rewrite sections of it if found to offer poor performance. Optimization can be broadly categorized into two domains:-

- Environment specific - that are essentially worthwhile only on certain platforms or particular computer languages
- General techniques - that apply irrespective of platform

Environment specific

Optimization of algorithms frequently depends on the properties of the machine the algorithm will be executed on as well as the language the algorithm is written in and chosen data types. For example, a programmer might optimize code for time efficiency in an application for home computers (with sizable amounts of memory), but for code destined to be embedded in small, "memory-tight" devices, the programmer may have to accept that it will run more slowly, simply because of the restricted memory available for any potential software optimization.

General techniques

- Linear search such as unsorted table look-ups in particular can be very expensive in terms of execution time but can be reduced significantly through use of efficient techniques such as indexed arrays and binary searches. Using a simple linear search on first occurrence and using a cached result thereafter is an obvious compromise.
- Use of indexed program branching, utilizing branch tables or "threaded code" to control program flow, (rather than using multiple conditional IF statements or unoptimized CASE/SWITCH) can drastically reduce instruction path length, simultaneously reduce program size and even also make a program easier to read and more easily maintainable (in effect it becomes a 'decision table' rather than repetitive spaghetti code).
- Loop unrolling performed manually, or more usually by an optimizing compiler, can provide significant savings in some instances. By processing 'blocks' of several array elements at a time, individually addressed, (for example, within a `While` loop), much pointer arithmetic and end of loop testing can be eliminated,

resulting in decreased instruction path lengths. Other Loop optimizations are also possible.

Tunnel vision

There are many techniques for improving algorithms, but focusing on a single favorite technique can lead to a "tunnel vision" mentality. For example, in this X86 assembly example, the author offers loop unrolling as a reasonable technique that provides some 40% improvements to his chosen example. However, the same example would benefit significantly from both inlining and use of a trivial hash function. If they were implemented, either as alternative or complementary techniques, an even greater percentage gain might be expected. A combination of optimizations may provide ever increasing speed, but selection of the most easily implemented and most effective technique, from a large repertoire of such techniques, is desirable as a starting point.

Dependency trees and spreadsheets

Spreadsheets are a 'special case' of algorithms that self-optimize by virtue of their dependency trees that are inherent in the design of spreadsheets to reduce re-calculations when a cell changes. The results of earlier calculations are effectively cached within the workbook and only updated if another cells changed value effects it directly.

Table lookup

Table lookups can make many algorithms more efficient, particularly when used to bypass computations with a high time complexity. However, if a wide input range is required, they can consume significant storage resources. In cases with a sparse valid input set, hash functions can be used to provide more efficient lookup access than a full table.

Hash function algorithms

A **hash function** is any well-defined procedure or mathematical function which converts a large, possibly variable-sized amount of data into a small datum, usually a single integer that may serve as an index to an array. The values returned by a hash function are called **hash values**, **hash codes**, **hash sums**, or simply **hashes**.

Hash functions are frequently used to speed up table lookups. The choice of a hashing function (to avoid a linear or brute force search) depends critically on the nature of the input data, and their probability distribution in the intended application.

Trivial hash function

Sometimes if the datum is small enough, a "trivial hash function" can be used to effectively provide constant time searches at almost zero cost. This is particularly relevant for single byte lookups (e.g. ASCII or EBCDIC characters)

Searching strings

Searching for particular text strings (for instance "tags" or keywords) in long sequences of characters potentially generates lengthy instruction paths. This includes searching for delimiters in comma separated files or similar processing which can be very simply and effectively eliminated (using declarative notation for instance).

Several methods of reducing the cost for general searching have been examined and the "Boyer–Moore string search algorithm" (or Boyer–Moore–Horspool algorithm, a similar but modified version) is one solution that has been proven to give superior results to repetitive comparisons of the entire search string along the sequence.

Hot spot analyzers

Special system software products known as "performance analyzers" are often available from suppliers to help diagnose "hot spots" - during actual execution of computer programs - using real or test data - they perform a Performance analysis under generally repeatable conditions. They can pinpoint sections of the program that might benefit from specifically targeted programmer optimization without necessarily spending time optimizing the rest of the code. Using program re-runs, a measure of relative improvement can then be determined to decide if the optimization was successful and by what amount. Instruction Set Simulators can be used as an alternative to measure the instruction path length at the machine code level between selected execution paths, or on the entire execution.

Regardless of the type of tool used, the quantitative values obtained can be used in combination with anticipated reductions (for the targeted code) to estimate a relative or absolute overall saving. For example if 50% of the total execution time (or path length) is absorbed in a subroutine whose speed can be doubled by programmer optimization, an overall saving of around 25% might be expected (Amdahl law).

Efforts have been made at the University of California, Irvine to produce dynamic executable code using a combination of hot spot analysis and run-time program trace tree. A JIT like dynamic compiler was built by Andreas Gal and others, "in which relevant (i.e., frequently executed) control flows are ...discovered lazily during execution"

Benchmarking & competitive algorithms

For new versions of software or to provide comparisons with competitive systems, benchmarks are sometimes used which assist with gauging an algorithms relative performance. If a new sort algorithm is produced for example it can be compared with its predecessors to ensure that at least it is efficient as before with known data - taking into consideration any functional improvements. Benchmarks can be used by customers when comparing various products from alternative suppliers to estimate which product will best suit their specific requirements in terms of functionality and performance. For example in the mainframe world certain proprietary sort products from independent software companies such as Syncsort compete with products from the major suppliers such as IBM for speed. Some benchmarks provide opportunities for producing an analysis comparing the relative speed of various compiled and interpreted languages for example and *The Computer Language Benchmarks Game* compares the performance of implementations of typical programming problems in several programming languages. (Even creating "do it yourself" benchmarks to get at least some appreciation of the relative performance of different programming languages, using a variety of user specified criteria, is quite simple to produce as this "Nine language Performance roundup" by Christopher W. Cowell-Shah demonstrates by example)

Compiled versus interpreted languages

A compiled algorithm will, in general, execute faster than the equivalent interpreted algorithm simply because some processing is required even at run time to 'understand' (i.e. interpret) the instructions to effect an execution. A compiled program will normally output an object or machine code equivalent of the algorithm that has already been processed by the compiler into a form more readily executed by microcode or the hardware directly. The popular Perl language is an example of an interpreted language and benchmarks indicate that it executes approximately 24 times more slowly than compiled C.

Optimizing compilers

Many compilers have features that attempt to optimize the code they generate, utilizing some of the techniques outlined here and others specific to the compilation itself. Loop optimization is often the focus of optimizing compilers because significant time is spent in program loops and parallel processing opportunities can often be facilitated by automatic code re-structuring such as loop unrolling. Optimizing compilers are by no means perfect. There is no way that a compiler can guarantee that, for all program source code, the fastest (or smallest) possible equivalent compiled program is output; such a compiler is fundamentally impossible because it would solve the halting problem. Additionally, even optimizing compilers generally have no access to runtime metrics to enable them to improve optimization through 'learning'.

Just-in-time compilers

'On-the-fly' processors known today as just-in-time or 'JIT' compilers combine features of interpreted languages with compiled languages and may also incorporate elements of optimization to a greater or lesser extent. Essentially the JIT compiler can compile small sections of source code statements (or bytecode) as they are newly encountered and (usually) retain the result for the next time the same source is processed. In addition, pre-compiled segments of code can be in-lined or called as dynamic functions that themselves perform equally fast as the equivalent 'custom' compiled function. Because the JIT processor also has access to run-time information (that a normal compiler can't have) it is also possible for it to optimize further executions depending upon the input and also perform other run-time introspective optimization as execution proceeds. A JIT processor may, or may not, incorporate self modifying code or its equivalent by creating 'fast path' routes through an algorithm. It may also use such techniques as dynamic Fractional cascading or any other similar runtime device based on collected actual runtime metrics. It is therefore entirely possible that a JIT compiler might (counter intuitively) execute even faster than an optimally 'optimized' compiled program.

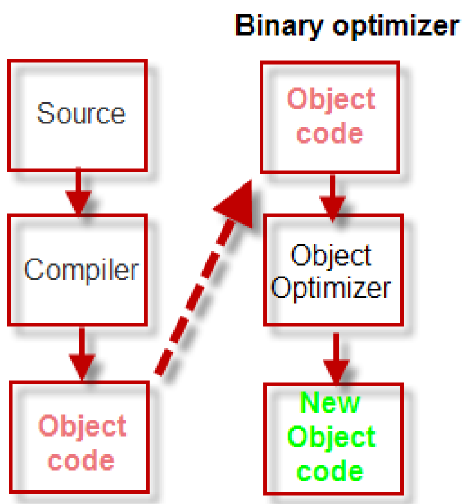
Self-modifying code

As mentioned above, just-in-time compilers often make extensive use of self-modifying code to generate the actual machine instructions required to be executed. The technique can also be used to reduce instruction path lengths in application programs where otherwise repetitive conditional tests might otherwise be required within the main program flow. This can be particularly useful where a sub routine may have embedded debugging code that is either active (testing mode) or inactive (production mode) depending upon some input parameter. A simple solution using a form of dynamic dispatching is where the sub routine entry point is dynamically 'swapped' at initialization, depending upon the input parameter. Entry point A) includes the debugging code prologue and entry point B) excludes the prologue; thus eliminating all overhead except the initial 'test and swap' (even when test/debugging is selected, when the overhead is simply the test/debugging code itself).

Genetic algorithm

In the world of performance related algorithms it is worth mentioning the role of genetic algorithms which compete using similar methods to the natural world in eliminating inferior algorithms in favour of more efficient versions.

Object code optimizers



A binary optimizer takes the existing output from a compiler and produces a better execution file with the same functionality.

Some proprietary program optimizers such as the "COBOL Optimizer" developed by Capex Corporation in the mid 1970's for COBOL, actually took the unusual step of optimizing the Object code (or binary file) **after** normal compilation. This type of optimizer, recently sometimes referred to as a "post pass" optimizer or peephole optimizer, depended, in this case, upon knowledge of 'weaknesses' in the standard IBM COBOL compiler and actually replaced (or patched) sections of the object code with more efficient code.

A number of other suppliers have recently adopted the same approach.

Alignment of data

Most processors execute faster if certain data values are aligned on word, doubleword or page boundaries. If possible design/specify structures to satisfy appropriate alignments. This avoids exceptions.

Locality of reference

To reduce Cache miss exceptions by providing good spatial locality of reference, specify 'high frequency'/volative working storage data within defined structure(s) so that they are also allocated from contiguous sections of memory (rather than possibly scattered over many pages). Group closely related data values also 'physically' close together within these structures. Consider the possibility of creating an 'artificial' structure to group some otherwise unrelated, but nevertheless frequently referenced, items together.

Choice of instruction or data type

Particularly in an Assembly language (although also applicable to HLL statements), the choice of a particular 'instruction' or data type, can have a large impact on execution efficiency. In general, instructions that process variables such as signed or unsigned 16-bit or 32-bit integers are faster than those that process floating point or packed decimal. Modern processors are even capable of executing multiple 'fixed point' instructions in parallel with the simultaneous execution of a floating point instruction. If the largest integer to be encountered can be accommodated by the 'faster' data type, defining the variables as that type will result in faster execution - since even a non-optimizing compiler will, in-effect, be 'forced' to choose appropriate instructions that will execute faster than would have been the case with data types associated with 'slower' instructions. Assembler programmers (and optimizing compiler writers) can then also benefit from the ability to perform certain common types of arithmetic for instance - division by 2, 4, 8 etc. by performing the very much faster binary shift right operations (in this case by 1, 2 or 3 bits).

If the choice of input data type is not under the control of the programmer, although prior conversion (outside of a loop for instance) to a faster data type carries some overhead, it can often be worthwhile if the variable is then to be used as a loop counter, especially if the count could be quite a high value or there are many input values to process. As mentioned above, choice of individual assembler instructions (or even sometimes just their order of execution) on particular machines can effect the efficiency of an algorithm.

Data granularity

The greater the granularity of data definitions (such as splitting a geographic address into separate street/city/postal code fields) can have performance overhead implications during processing. Higher granularity in this example implies more procedure calls in Object-oriented programming and parallel computing environments since the additional objects are accessed via multiple method calls rather than perhaps one.

Subroutine granularity

For structured programming and procedural programming in general, great emphasis is placed on designing programs as a hierarchy of (or at least a set of) subroutines. For object oriented programming, the method call (a subroutine call) is the standard method of testing and setting all values in objects and so increasing data granularity consequently causes increased use of subroutines. The greater the granularity of subroutine usage, the larger the proportion of processing time devoted to the mechanism of the subroutine linkages themselves.The presence of a (called) subroutine in a program contributes nothing extra to the functionality of the program. The extent to which subroutines (and their consequent memory requirements) influences the overall performance of the complete algorithm depends to a large extent on the actual implementation.

In assembly language programs, the invocation of a subroutine need not involve much overhead, typically adding just a couple of machine instructions to the normal instruction path length, each one altering the control flow either *to* the subroutine or returning *from* it (saving the state on a stack being optional, depending on the complexity of the subroutine and its requirement to reuse general purpose registers). In many cases, small subroutines that perform frequently used data transformations using 'general purpose' work areas can be accomplished without the need to save or restore any registers, including the return register.

By contrast, HLL programs typically always invoke a 'standard' procedure call (the *calling convention*), which involves saving the program state by default and usually allocating additional memory on the stack to save all registers and other relevant state data (the prologue and epilogue code). Recursion in a HLL program can consequently consume significant overhead in both memory and execution time managing the stack to the required depth.

Guy Steele pointed out in a 1977 paper that a *well-designed* programming language implementation *can* have very low overheads for procedural abstraction (but laments, in most implementations, that they seldom achieve this in practice - being "rather thoughtless or careless in this regard"). Steele concludes that "we should have a healthy respect for procedure calls" (because they are powerful) but he also cautioned "use them sparingly"

Choice of language / mixed languages

Some computer languages can execute algorithms more efficiently than others. As stated already, interpreted languages often perform less efficiently than compiled languages. In addition, where possible, 'high-use' , and time-dependent sections of code may be written in a language such as assembler that can usually execute faster and make better use of resources on a particular platform than the equivalent HLL code on the same platform. This section of code can either be statically called or dynamically invoked (external function) or embedded within the higher level code (e.g. Assembler instructions embedded in a 'C' language program). The effect of higher levels of abstraction when using a HLL has been described as the *Abstraction penalty* Programmers who are familiar with assembler language (in addition to their chosen HLL) and are also familiar with the code that will be generated by the HLL, under known conditions, can sometimes use HLL language primitives of that language to generate code almost identical to assembler language. This is most likely to be possible only in languages that support pointers such as PL/1 or C. This is facilitated if the chosen HLL compiler provides an optional assembler listing as part of its printout so that various alternatives can be explored without also needing specialist knowledge of the compiler internals.

Software validation versus hardware validation

An optimization technique that was frequently taken advantage of on 'legacy' platforms was that of allowing the hardware (or microcode) to perform validation on numeric data fields such as those coded in (or converted to) packed decimal (or packed BCD). The choice was to either spend processing time checking each field for a valid numeric content in the particular internal representation chosen or simply assume the data was correct and let the hardware detect the error upon execution. The choice was highly significant because to check for validity on multiple fields (for sometimes many millions of input records), it could occupy valuable computer resources. Since input data fields were in any case frequently built from the output of earlier computer processing, the actual probability of a field containing invalid data was exceedingly low and usually the result of some 'corruption'. The solution was to incorporate an 'event handler' for the hardware detected condition ('data exception)' that would intercept the occasional errant data field and either 'report, correct and continue' or, more usually, abort the run with a core dump to try to determine the reason for the bad data.

Similar event handlers are frequently utilized in today's web based applications to handle other exceptional conditions but repeatedly parsing data input, to ensure its validity before execution, has nevertheless become much more commonplace - partly because processors have become faster (and the perceived need for efficiency in this area less significant) but, predominantly - because data structures have become less 'formalized' (e.g. .csv and .tsv files) or uniquely identifiable (e.g. packed decimal). The potential savings using this type of technique may have therefore fallen into general dis-use as a consequence and therefore repeated data validations and repeated data conversions have become an accepted overhead. Ironically, one consequence of this move to less formalized data structures is that a corruption of say, a numeric binary integer value, will not be detected at all by the hardware upon execution (for instance: is an ASCII hexadecimal value '20202020' a valid signed or unsigned binary value - or simply a string of blanks that has corrupted it?)

Algorithms for vector & superscalar processors

Algorithms for vector processors are usually different than those for scalar processors since they can process multiple instructions and/or multiple data elements in parallel. The process of converting an algorithm from a scalar to a vector process is known as vectorization and methods for automatically performing this transformation as efficiently as possible are constantly sought. There are intrinsic limitations for implementing instruction level parallelism in Superscalar processors but, in essence, the overhead in deciding for certain if particular instruction sequences can be processed in parallel can sometimes exceed the efficiency gain in so doing. The achievable reduction is governed primarily by the (somewhat obvious) law known as Amdahl's law, that essentially states that the improvement from parallel processing is determined by its slowest sequential component. Algorithms designed for this class of processor therefore require more care if they are not to unwittingly disrupt the potential gains.

Avoiding costs

- Defining variables as integers for indexed arrays instead of floating point will result in faster execution (see above).
- Defining structures whose structure length is a multiple of a power of 2 (2,4,8,16 etc.), will allow the compiler to calculate array indexes by shifting a binary index by 1, 2 or more bits to the left, instead of using a multiply instruction will result in faster execution. Adding an otherwise redundant short filler variable to 'pad out' the length of a structure element to say 8 bytes when otherwise it would have been 6 or 7 bytes may reduce overall processing time by a worthwhile amount for very large arrays.
- Storage defined in terms of bits, when bytes would suffice, may inadvertently involve extremely long path lengths involving bitwise operations instead of more efficient single instruction 'multiple byte' copy instructions. (This does not apply to 'genuine' intentional bitwise operations - used for example instead of multiplication or division by powers of 2 or for TRUE/FALSE flags.)
- Unnecessary use of allocated dynamic storage when static storage would suffice, can increase the processing overhead substantially - both increasing memory requirements and the associated allocation/deallocation path length overheads for each function call.
- Excessive use of function calls for very simple functions, rather than in-line statements, can also add substantially to instruction path lengths and stack/unstack overheads. For particularly time critical systems that are not also code size sensitive, automatic or manual inline expansion can reduce path length by eliminating all the instructions that call the function and return from it. (A conceptually similar method, loop unrolling, eliminates the instructions required to set up and terminate a loop by, instead; repeating the instructions inside the

loop multiple times. This of course eliminates the branch back instruction but may also increase the size of the binary file or, in the case of JIT built code, dynamic memory. Also, care must be taken with this method, that re-calculating addresses for each statement within an unwound indexed loop is not more expensive than incrementing pointers within the former loop would have been. If absolute indexes are used in the generated (or manually created) unwound code, rather than variables, the code created may actually be able to avoid generated pointer arithmetic instructions altogether, using offsets instead).

Memory management
Whenever memory is *automatically* allocated (for example in HLL programs, when calling a procedure or when issuing a system call), it is normally released (or 'freed'/ 'deallocated'/ 'deleted') automatically when it is no longer required - thus allowing it to be re-used for another purpose *immediately*. Some memory management can easily be accomplished by the compiler, as in this example. However, when memory is *explicitly* allocated (for example in OOP when "new" is specified for an object), releasing the memory is often left to an asynchronous 'garbage collector' which does not necessarily release the memory at the earliest opportunity (as well as consuming some additional CPU resources deciding if it can be). The current trend nevertheless appears to be towards taking full advantage of this fully automated method, despite the tradeoff in efficiency - because it is claimed that it makes programming easier. Some functional languages are known as 'lazy functional languages' because of the significant use of garbage collection and can consume much more memory as a result.

- Array processing may simplify programming but use of separate statements to sum different elements of the same array(s) may produce code that is not easily optimized and that requires multiple passes of the arrays that might otherwise have been processed in a single pass. It may also duplicate data if array slicing is used, leading to increased memory usage and copying overhead.
- In OOP, if an object is known to be immutable, it can be copied simply by making a copy of a reference to it instead of copying the entire object. Because a reference (typically only the size of a pointer) is usually much smaller than the object itself, this results in memory savings and a boost in execution speed.

Readability, trade offs and trends

One must be careful, in the pursuit of good coding style, not to over-emphasize efficiency. Frequently, a clean, readable and 'usable' design is much more important than a fast, efficient design that is hard to understand. There are exceptions to this 'rule' (such as embedded systems, where space is tight, and processing power minimal) but these are rarer than one might expect.

However, increasingly, for many 'time critical' applications such as air line reservation systems, point-of-sale applications, ATMs (cash-point machines), Airline Guidance systems, Collision avoidance systems and numerous modern web based applications -

operating in a real-time environment where speed of response is fundamental - there is little alternative.

Determining if optimization is worthwhile

The essential criteria for using optimized code are of course dependent upon the expected use of the algorithm. If it is a new algorithm and is going to be in use for many years and speed is relevant, it is worth spending some time designing the code to be as efficient as possible from the outset. If an existing algorithm is proving to be too slow or memory is becoming an issue, clearly something must be done to improve it.

For the average application, or for one-off applications, avoiding inefficient coding techniques and encouraging the compiler to optimize where possible may be sufficient.

One simple way (at least for mathematicians) to determine whether an optimization is worthwhile is as follows: Let the original time and space requirements (generally in Big-O notation) of the algorithm be O_1 and O_2. Let the new code require N_1 and N_2 time and space respectively. If $N_1N_2 < O_1O_2$, the optimization should be carried out. However, as mentioned above, this may not always be true.

Implications for algorithmic efficiency

A recent report, published in December 2007, from Global Action Plan, a UK-based environmental organisation found that computer servers are "at least as great a threat to the climate as SUVs or the global aviation industry" drawing attention to the carbon footprint of the IT industry in the UK. According to an Environmental Research Letters report published in September 2008, "Total power used by information technology equipment in data centers represented about 0.5% of world electricity consumption in 2005. When cooling and auxiliary infrastructure are included, that figure is about 1%. The total data center power demand in 2005 is equivalent (in capacity terms) to about seventeen 1000 MW power plants for the world."

Some media reports claim that performing two Google searches from a desktop computer can generate about the same amount of carbon dioxide as boiling a kettle for a cup of tea, according to new research; however, the factual accuracy of this comparison is disputed, and the author of the study in question asserts that the two-searches-tea-kettle statistic is a misreading of his work.

Greentouch, a recently established consortium of leading Information and Communications Technology (ICT) industry, academic and non-governmental research experts, has set itself the mission of reducing reduce energy consumption per user by a factor of 1000 from current levels. "A thousand-fold reduction is roughly equivalent to being able to power the world’s communications networks, including the Internet, for three years using the same amount of energy that it currently takes to run them for a single day". The first meeting in February 2010 will establish the organization’s five-year plan, first year deliverables and member roles and responsibilities. Intellectual property issues will be addressed and defined in the forum’s initial planning meetings. The conditions for research and the results of that research will be high priority for discussion in the initial phase of the research forum’s development.

Computers having become increasingly more powerful over the past few decades, emphasis was on a 'brute force' mentality. This may have to be reconsidered in the light of these reports and more effort placed in future on reducing carbon footprints through optimization. It is a timely reminder that algorithmic efficiency is just another aspect of the more general thermodynamic efficiency. The genuine economic benefits of an optimized algorithm are, in any case, that more processing can be done for the same cost or that useful results can be shown in a more timely manner and ultimately, acted upon sooner.

Criticism of the current state of programming

- David May FRS a British computer scientist and currently Professor of Computer Science at University of Bristol and founder and CTO of XMOS Semiconductor, believes one of the problems is that there is a reliance on Moore's law to solve inefficiencies. He has advanced an 'alternative' to Moore's law (May's law) stated as follows:

  Software efficiency halves every 18 months, compensating Moore's Law

  He goes on to state

  In ubiquitous systems, halving the instructions executed can double the battery life and big data sets bring big opportunities for better software and algorithms: Reducing the number of operations from N x N to N x log(N) has a dramatic effect when N is large... for N = 30 billion, this change is as good as 50 years of technology improvements

- Software author Adam N. Rosenburg in his blog "*The failure of the Digital computer*", has described the current state of programming as nearing the "Software event horizon", (alluding to the fictitious "*shoe event horizon*" described by Douglas Adams in his *Hitchhiker's Guide to the Galaxy* book). He estimates there has been a 70 dB factor loss of productivity or "99.99999 percent, of its ability to deliver the goods", since the 1980s - "When Arthur C. Clarke compared the reality of computing in 2001 to the computer HAL in his book 2001: A Space Odyssey, he pointed out how wonderfully small and powerful computers were but how disappointing computer programming had become".
- Conrad Weisert gives examples, some of which were published in ACM SIGPLAN (Special Interest Group on Programming Languages) Notices, December, 1995 in: "Atrocious Programming Thrives"

Chapter 11

Application Security and Software Portability

Application security

Application security encompasses measures taken throughout the application's life-cycle to prevent exceptions in the security policy of an application or the underlying system (vulnerabilities) through flaws in the design, development, deployment, upgrade, or maintenance of the application.

Applications only control the use of resources granted to them, and not *which* resources are granted to them. They, in turn, determine the use of these resources by users of the application through application security.

Open Web Application Security Project (OWASP) and Web Application Security Consortium (WASC) updates on the latest threats which impair web based applications. This aids developers, security testers and architects to focus on better design and mitigation strategy. OWASP Top 10 has become an industrial norm is assessing Web Applications.

Methodology

According to the patterns & practices *Improving Web Application Security* book, a principle-based approach for application security includes:

- Knowing your threats.
- Securing the network, host and application.
- Incorporating security into your software development process

Note that this approach is technology / platform independent. It is focused on principles, patterns, and practices.

Threats, Attacks, Vulnerabilities, and Countermeasures

According to the patterns & practices *Improving Web Application Security* book, the following terms are relevant to application security:

- **Asset**. A resource of value such as the data in a database or on the file system, or a system resource.
- **Threat**. A negative effect.
- **Vulnerability**. A weakness that makes a threat possible.
- **Attack** (or exploit). An action taken to harm an asset.
- **Countermeasure**. A safeguard that addresses a threat and mitigates risk.

Application Threats / Attacks

According to the patterns & practices *Improving Web Application Security* book, the following are classes of common application security threats / attacks:

Category	**Threats / Attacks**
Input Validation	Buffer overflow; cross-site scripting; SQL injection; canonicalization
Authentication	Network eavesdropping ; Brute force attack; dictionary attacks; cookie replay; credential theft
Authorization	Elevation of privilege; disclosure of confidential data; data tampering; luring attacks
Configuration management	Unauthorized access to administration interfaces; unauthorized access to configuration stores; retrieval of clear text configuration data; lack of individual accountability; over-privileged process and service accounts
Sensitive information	Access sensitive data in storage; network eavesdropping; data tampering
Session management	Session hijacking; session replay; man in the middle
Cryptography	Poor key generation or key management; weak or custom encryption
Parameter manipulation	Query string manipulation; form field manipulation; cookie manipulation; HTTP header manipulation
Exception management	Information disclosure; denial of service
Auditing and logging	User denies performing an operation; attacker exploits an application without trace; attacker covers his or her tracks

Mobile Application Security

The proportion of mobile devices providing open platform functionality is expected to continue to increase as time moves on. The openness of these platforms offers significant opportunities to all parts of the mobile eco-system by delivering the ability for flexible program and service delivery options that may be installed, removed or refreshed multiple times in line with the user's needs and requirements. However, with openness comes responsibility and unrestricted access to mobile resources and APIs by applications of unknown or untrusted origin could result in damage to the user, the device, the network or all of these, if not managed by suitable security architectures and network precautions. Mobile Application Security is provided in some form on most open OS mobile devices (Symbian OS, Microsoft, BREW, etc.). Industry groups have also created recommendations including the GSM Association and Open Mobile Terminal Platform (OMTP)

Security testing for applications

Security testing techniques scour for vulnerabilities or security holes in applications. These vulnerabilities leave applications open to exploitation. Ideally, security testing is implemented throughout the entire software development life cycle (SDLC) so that vulnerabilities may be addressed in a timely and thorough manner. Unfortunately, testing is often conducted as an afterthought at the end of the development cycle.

Vulnerability scanners, and more specifically web application scanners, otherwise known as penetration testing tools (i.e. ethical hacking tools) have been historically used by security organizations within corporations and security consultants to automate the security testing of http request/responses; however, this is not a substitute for the need for actual source code review. Physical code reviews of an application's source code can be accomplished manually or in an automated fashion. Given the common size of individual programs (often 500K Lines of Code or more), the human brain can not execute a comprehensive data flow analysis needed in order to completely check all circuitous paths of an application program to find vulnerability points. The human brain is suited more for filtering, interrupting and reporting the outputs of automated source code analysis tools available commercially versus trying to trace every possible path through a compiled code base to find the root cause level vulnerabilities.

The two types of automated tools associated with application vulnerability detection (application vulnerability scanners) are Penetration Testing Tools (often categorized as Black Box Testing Tools) and static code analysis tools (often categorized as White Box Testing Tools). Tools in the Black Box Testing arena include IBM Rational AppScan, HP Application Security Center suite of applications (through the acquisition of SPI Dynamics), Nikto (open source). Tools in the static code analysis arena include Veracode, Pre-Emptive Solutions, and Parasoft.

Banking and large E-Commerce corporations have been the very early adopter customer profile for these types of tools. It is commonly held within these firms that both Black

Box testing and White Box testing tools are needed in the pursuit of application security. Typically sited, Black Box testing (meaning Penetration Testing tools) are ethical hacking tools used to attack the application surface to expose vulnerabilities suspended within the source code hierarchy. Penetration testing tools are executed on the already deployed application. White Box testing (meaning Source Code Analysis tools) are used by either the application security groups or application development groups. Typically introduced into a company through the application security organization, the White Box tools complement the Black Box testing tools in that they give specific visibility into the specific root vulnerabilities within the source code in advance of the source code being deployed. Vulnerabilities identified with White Box testing and Black Box testing are typically in accordance with the OWASP taxonomy for software coding errors. White Box testing vendors have recently introduced dynamic versions of their source code analysis methods; which operates on deployed applications. Given that the White Box testing tools have dynamic versions similar to the Black Box testing tools, both tools can be correlated in the same software error detection paradigm ensuring full application protection to the client company.

The advances in professional Malware targeted at the Internet customers of online organizations has seen a change in Web application design requirements since 2007. It is generally assumed that a sizable percentage of Internet users will be compromised through malware and that any data coming from their infected host may be tainted. Therefore application security has begun to manifest more advanced anti-fraud and heuristic detection systems in the back-office, rather than within the client-side or Web server code.

Software portability

Portability is one of the key concepts of high-level programming. Portability is the software codebase feature to be able to reuse the existing code instead of creating new code when moving software from an environment to another. The prerequirement for portability is the generalized abstraction between the application logic and system interfaces. When one is targeting several platforms with the same application, portability is the key issue for development cost reduction.

Strategies for portability

Software portability may be achieved on three different levels:

- Installed program files may be transferred to another computer.
- The program may be reinstalled (from the distribution files) on another computer.
- The source files may be compiled for another computer.

These alternatives were ranked for decreasing user-friendliness, and hence decreasing system quality ambition.

Which of these user-friendliness levels is obtainable, depends on the degree of similarity between the systems ported between.

Similar systems

When the same operating system version is installed on two compatible computers, it is often possible to transfer one or more program files between them, but the software will generally have to be prepared in a special manner: It must be decided which program libraries can be assumed to exist on the target computer, and which must be included with the application package. A portable application intended to run from a USB stick demonstrates this ultimate portability. It is designed to leave no traces on the computer it is installed on. This property is not required for the present situation, when the program is supposed to remain on this computer. But if the program is self-contained in e.g. its own directory, it will be easier to port it on to a third system.

Different operating systems, using similar processors

When the systems in question are using similar processors (in practice: x86-compatible processors), they will execute the low-level program instructions in the same manner, but the system calls are likely to differ between different operating systems. New operating systems of UNIX heritage — including Linux, BSD, Solaris and MacOS X – are able to achieve such software portability by using the POSIX standard for calling OS functions. Such POSIX-based programs can be used in Windows by means of interface software such as Cygwin.

Different processors

Many people write programs that require the Intel-compatible 32 bit x86 instruction set, even though there is another instruction set architecture used by more 32 bit CPUs. It is mainly for the smallest (pocket-sized) computers that alternative processors, such as ARM architecture, are used, but these are generally thought to require less sophisticated programs. Web applications are required to be processor independent, so using web programming techniques is a popular method for achieving portability, and this programming strategy is convenient, even when quite similar systems are targeted. The program can then be written in JavaScript, which can run in a common web browser, which may now be assumed to have a Java package containing the Java virtual machine and its Java Class Library. Such web applications must, for security reasons, have limited powers on the host computer, especially when it comes to reading and writing files. Non-web programs, installed upon a computer in the normal manner, can have full powers, and yet achieve system portability by linking to the Java package. By using Java bytecode instructions instead of conventional processor dependent machine code, maximum software portability is achieved. This doesn't mean the programs have to be written in Java, as compilers for several other languages can generate Java bytecode: Jruby does it from Ruby programs, Jython from Python programs, and there are several others.

Recompilation

Porting a program by compiling and linking it again is a valid portability strategy if the porting is to be done by programmers, and the need for porting by users is disregarded. It is then wise to write the program in a programming language for which there are compatible compilers on the interesting platforms.

It is possible for users to port software in this way if the source code is available to them, but this will normally be a demanding procedure, except for technically advanced users. An automated compile/link, using a Make tool, is in principle a simple procedure, but when something goes wrong, the error messages from a compiler or linker are likely to be too demanding for the end users. Some Linux distros distribute software to their users in source form, but it may then be assumed the users are running at least the same Linux distro.

Chapter 12

Software Testing

Software testing is an investigation conducted to provide stakeholders with information about the quality of the product or service under test. Software testing also provides an objective, independent view of the software to allow the business to appreciate and understand the risks of software implementation. Test techniques include, but are not limited to, the process of executing a program or application with the intent of finding software bugs (errors or other defects).

Software testing can also be stated as the process of validating and verifying that a software program/application/product:

1. meets the business and technical requirements that guided its design and development;
2. works as expected; and
3. can be implemented with the same characteristics.

Software testing, depending on the testing method employed, can be implemented at any time in the development process. However, most of the test effort occurs after the requirements have been defined and the coding process has been completed. As such, the methodology of the test is governed by the software development methodology adopted.

Different software development models will focus the test effort at different points in the development process. Newer development models, such as Agile, often employ test driven development and place an increased portion of the testing in the hands of the developer, before it reaches a formal team of testers. In a more traditional model, most of the test execution occurs after the requirements have been defined and the coding process has been completed.

Overview

Testing can never completely identify all the defects within software. Instead, it furnishes a *criticism* or *comparison* that compares the state and behavior of the product against oracles—principles or mechanisms by which someone might recognize a problem. These oracles may include (but are not limited to) specifications, contracts, comparable products, past versions of the same product, inferences about intended or expected purpose, user or customer expectations, relevant standards, applicable laws, or other criteria.

Every software product has a target audience. For example, the audience for video game software is completely different from banking software. Therefore, when an organization develops or otherwise invests in a software product, it can assess whether the software product will be acceptable to its end users, its target audience, its purchasers, and other stakeholders. **Software testing** is the process of attempting to make this assessment.

A study conducted by NIST in 2002 reports that software bugs cost the U.S. economy $59.5 billion annually. More than a third of this cost could be avoided if better software testing was performed.

History

The separation of debugging from testing was initially introduced by Glenford J. Myers in 1979. Although his attention was on breakage testing ("a successful test is one that finds a bug") it illustrated the desire of the software engineering community to separate fundamental development activities, such as debugging, from that of verification. Dave Gelperin and William C. Hetzel classified in 1988 the phases and goals in software testing in the following stages:

- Until 1956 - Debugging oriented
- 1957–1978 - Demonstration oriented
- 1979–1982 - Destruction oriented
- 1983–1987 - Evaluation oriented
- 1988–2000 - Prevention oriented

Software testing topics

Scope

A primary purpose of testing is to detect software failures so that defects may be discovered and corrected. This is a non-trivial pursuit. Testing cannot establish that a product functions properly under all conditions but can only establish that it does not function properly under specific conditions. The scope of software testing often includes examination of code as well as execution of that code in various environments and conditions as well as examining the aspects of code: does it do what it is supposed to do and do what it needs to do. In the current culture of software development, a testing organization may be separate from the development team. There are various roles for testing team members. Information derived from software testing may be used to correct the process by which software is developed.

Functional vs non-functional testing

Functional testing refers to activities that verify a specific action or function of the code. These are usually found in the code requirements documentation, although some development methodologies work from use cases or user stories. Functional tests tend to answer the question of "can the user do this" or "does this particular feature work".

Non-functional testing refers to aspects of the software that may not be related to a specific function or user action, such as scalability or other performance, behavior under certain constraints, or security. Non-functional requirements tend to be those that reflect the quality of the product, particularly in the context of the suitability perspective of its users.

Defects and failures

Not all software defects are caused by coding errors. One common source of expensive defects is caused by requirement gaps, e.g., unrecognized requirements, that result in errors of omission by the program designer. A common source of requirements gaps is non-functional requirements such as testability, scalability, maintainability, usability, performance, and security.

Software faults occur through the following processes. A programmer makes an error (mistake), which results in a defect (fault, bug) in the software source code. If this defect is executed, in certain situations the system will produce wrong results, causing a failure. Not all defects will necessarily result in failures. For example, defects in dead code will never result in failures. A defect can turn into a failure when the environment is changed. Examples of these changes in environment include the software being run on a new hardware platform, alterations in source data or interacting with different software. A single defect may result in a wide range of failure symptoms.

Finding faults early

It is commonly believed that the earlier a defect is found the cheaper it is to fix it. The following table shows the cost of fixing the defect depending on the stage it was found. For example, if a problem in the requirements is found only post-release, then it would cost 10–100 times more to fix than if it had already been found by the requirements review.

Cost to fix a defect		Time detected				
		Requirements	Architecture	Construction	System test	Post-release
Time introduced	Requirements	1×	3×	5–10×	10×	10–100×
	Architecture	-	1×	10×	15×	25–100×
	Construction	-	-	1×	10×	10–25×

Compatibility

A common cause of software failure (real or perceived) is a lack of compatibility with other application software, operating systems (or operating system versions, old or new), or target environments that differ greatly from the original (such as a terminal or GUI application intended to be run on the desktop now being required to become a web application, which must render in a web browser). For example, in the case of a lack of backward compatibility, this can occur because the programmers develop and test software only on the latest version of the target environment, which not all users may be running. This results in the unintended consequence that the latest work may not function on earlier versions of the target environment, or on older hardware that earlier versions of the target environment was capable of using. Sometimes such issues can be fixed by proactively abstracting operating system functionality into a separate program module or library.

Input combinations and preconditions

A very fundamental problem with software testing is that testing under *all* combinations of inputs and preconditions (initial state) is not feasible, even with a simple product. This means that the number of defects in a software product can be very large and defects that occur infrequently are difficult to find in testing. More significantly, non-functional dimensions of quality (how it is supposed to *be* versus what it is supposed to *do*)—usability, scalability, performance, compatibility, reliability—can be highly subjective; something that constitutes sufficient value to one person may be intolerable to another.

Static vs. dynamic testing

There are many approaches to software testing. Reviews, walkthroughs, or inspections are considered as static testing, whereas actually executing programmed code with a given set of test cases is referred to as dynamic testing. Static testing can be (and unfortunately in practice often is) omitted. Dynamic testing takes place when the program itself is used for the first time (which is generally considered the beginning of the testing stage). Dynamic testing may begin before the program is 100% complete in order to test particular sections of code (modules or discrete functions). Typical techniques for this are either using stubs/drivers or execution from a debugger environment. For example, spreadsheet programs are, by their very nature, tested to a large extent interactively ("on the fly"), with results displayed immediately after each calculation or text manipulation.

Software verification and validation

Software testing is used in association with verification and validation:

- Verification: Have we built the software right? (i.e., does it match the specification).
- Validation: Have we built the right software? (i.e., is this what the customer wants).

The terms verification and validation are commonly used interchangeably in the industry; it is also common to see these two terms incorrectly defined. According to the IEEE Standard Glossary of Software Engineering Terminology:

Verification is the process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase.
Validation is the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements.

The software testing team

Software testing can be done by software testers. Until the 1980s the term "software tester" was used generally, but later it was also seen as a separate profession. Regarding the periods and the different goals in software testing, different roles have been established: *manager*, *test lead*, *test designer*, *tester*, *automation developer*, and *test administrator*.

Software quality assurance (SQA)

Though controversial, software testing is a part of the software quality assurance (SQA) process. In SQA, software process specialists and auditors are concerned for the software development process rather than just the artefacts such as documentation, code and systems. They examine and change the software engineering process itself to reduce the amount of faults that end up in the delivered software: the so-called *defect rate.*

What constitutes an "acceptable defect rate" depends on the nature of the software; A flight simulator video game would have much higher defect tolerance than software for an actual airplane.

Although there are close links with SQA, testing departments often exist independently, and there may be no SQA function in some companies.

Software testing is a task intended to detect defects in software by contrasting a computer program's expected results with its actual results for a given set of inputs. By contrast, QA (quality assurance) is the implementation of policies and procedures intended to prevent defects from occurring in the first place.

Testing methods

The box approach

Software testing methods are traditionally divided into white- and black-box testing. These two approaches are used to describe the point of view that a test engineer takes when designing test cases.

White box testing

White box testing is when the tester has access to the internal data structures and algorithms including the code that implement these.

Types of white box testing

The following types of white box testing exist:

- API testing (application programming interface) - testing of the application using public and private APIs
- Code coverage - creating tests to satisfy some criteria of code coverage (e.g., the test designer can create tests to cause all statements in the program to be executed at least once)
- Fault injection methods - improving the coverage of a test by introducing faults to test code paths
- Mutation testing methods
- Static testing - White box testing includes all static testing

Test coverage

White box testing methods can also be used to evaluate the completeness of a test suite that was created with black box testing methods. This allows the software team to examine parts of a system that are rarely tested and ensures that the most important function points have been tested.
Two common forms of code coverage are:

- *Function coverage*, which reports on functions executed
- *Statement coverage*, which reports on the number of lines executed to complete the test

They both return a code coverage metric, measured as a percentage.

Black box testing

Black box testing treats the software as a "black box"—without any knowledge of internal implementation. Black box testing methods include: equivalence partitioning, boundary value analysis, all-pairs testing, fuzz testing, model-based testing, exploratory testing and specification-based testing.

Specification-based testing: Specification-based testing aims to test the functionality of software according to the applicable requirements. Thus, the tester inputs data into, and only sees the output from, the test object. This level of testing usually requires thorough test cases to be provided to the tester, who then can simply verify that for a given input, the output value (or behavior), either "is" or "is not" the same as the expected value specified in the test case.
Specification-based testing is necessary, but it is insufficient to guard against certain risks.
Advantages and disadvantages: The black box tester has no "bonds" with the code, and a tester's perception is very simple: a code *must* have bugs. Using the principle, "Ask and you shall receive," black box testers find bugs where programmers do not. On the other hand, black box testing has been said to be "like a walk in a dark labyrinth without a flashlight," because the tester doesn't know how the software being tested was actually constructed. As a result, there are situations when (1) a tester writes many test cases to check something that could have been tested by only one test case, and/or (2) some parts of the back-end are not tested at all.

Therefore, black box testing has the advantage of "an unaffiliated opinion", on the one hand, and the disadvantage of "blind exploring", on the other.

Grey box testing

Grey box testing (American spelling: **gray box testing**) involves having knowledge of internal data structures and algorithms for purposes of designing the test cases, but testing at the user, or black-box level. Manipulating input data and formatting output do not qualify as grey box, because the input and output are clearly outside of the "black-box" that we are calling the system under test. This distinction is particularly important when conducting integration testing between two modules of code written by two different developers, where only the interfaces are exposed for test. However, modifying a data repository does qualify as grey box, as the user would not normally be able to change the data outside of the system under test. Grey box testing may also include reverse engineering to determine, for instance, boundary values or error messages.

Testing levels

Tests are frequently grouped by where they are added in the software development process, or by the level of specificity of the test. The main levels during the development process as defined by the SWEBOK guide are unit-, integration-, and system testing that are distinguished by the test target without impliying a specific process model. Other test levels are classified by the testing objective.

Test target

Unit testing

Unit testing refers to tests that verify the functionality of a specific section of code, usually at the function level. In an object-oriented environment, this is usually at the class level, and the minimal unit tests include the constructors and destructors.

These type of tests are usually written by developers as they work on code (white-box style), to ensure that the specific function is working as expected. One function might have multiple tests, to catch corner cases or other branches in the code. Unit testing alone cannot verify the functionality of a piece of software, but rather is used to assure that the building blocks the software uses work independently of each other.

Unit testing is also called *component testing*.

Integration testing

Integration testing is any type of software testing that seeks to verify the interfaces between components against a software design. Software components may be integrated in an iterative way or all together ("big bang"). Normally the former is considered a better practice since it allows interface issues to be localised more quickly and fixed.

Integration testing works to expose defects in the interfaces and interaction between integrated components (modules). Progressively larger groups of tested software components corresponding to elements of the architectural design are integrated and tested until the software works as a system.

System testing

System testing tests a completely integrated system to verify that it meets its requirements.

System integration testing

System integration testing verifies that a system is integrated to any external or third-party systems defined in the system requirements.

Objectives of testing

Regression testing

Regression testing focuses on finding defects after a major code change has occurred. Specifically, it seeks to uncover software regressions, or old bugs that have come back. Such regressions occur whenever software functionality that was previously working correctly stops working as intended. Typically, regressions occur as an unintended consequence of program changes, when the newly developed part of the software collides with the previously existing code. Common methods of regression testing include re-running previously run tests and checking whether previously fixed faults have re-emerged. The depth of testing depends on the phase in the release process and the risk of the added features. They can either be complete, for changes added late in the release or deemed to be risky, to very shallow, consisting of positive tests on each feature, if the changes are early in the release or deemed to be of low risk.

Acceptance testing

Acceptance testing can mean one of two things:

1. A smoke test is used as an acceptance test prior to introducing a new build to the main testing process, i.e. before integration or regression.
2. Acceptance testing is performed by the customer, often in their lab environment on their own hardware, is known as user acceptance testing (UAT). Acceptance testing may be performed as part of the hand-off process between any two phases of development.

Alpha testing

Alpha testing is simulated or actual operational testing by potential users/customers or an independent test team at the developers' site. Alpha testing is often employed for off-the-shelf software as a form of internal acceptance testing, before the software goes to beta testing.

Beta testing

Beta testing comes after alpha testing and can be considered a form of external user acceptance testing. Versions of the software, known as beta versions, are released to a limited audience outside of the programming team. The software is released to groups of people so that further testing can ensure the product has few faults or bugs. Sometimes, beta versions are made available to the open public to increase the feedback field to a maximal number of future users.

Non-functional testing

Special methods exist to test non-functional aspects of software. In contrast to functional testing, which establishes the correct operation of the software (correct in that it matches the expected behavior defined in the design requirements), non-functional testing verifies that the software functions properly even when it receives invalid or unexpected inputs. Software fault injection, in the form of fuzzing, is an example of non-functional testing. Non-functional testing, especially for software, is designed to establish whether the device under test can tolerate invalid or unexpected inputs, thereby establishing the robustness of input validation routines as well as error-handling routines. Various commercial non-functional testing tools are linked from the software fault injection page; there are also numerous open-source and free software tools available that perform non-functional testing.

Software performance testing and load testing

Performance testing is executed to determine how fast a system or sub-system performs under a particular workload. It can also serve to validate and verify other quality attributes of the system, such as scalability, reliability and resource usage. Load testing is primarily concerned with testing that can continue to operate under a specific load, whether that be large quantities of data or a large number of users. This is generally referred to as software scalability. The related load testing activity of when performed as a non-functional activity is often referred to as *endurance testing*.

Volume testing is a way to test functionality. *Stress testing* is a way to test reliability. *Load testing* is a way to test performance. There is little agreement on what the specific goals of load testing are. The terms load testing, performance testing, reliability testing, and volume testing, are often used interchangeably.

Stability testing

Stability testing checks to see if the software can continuously function well in or above an acceptable period. This activity of non-functional software testing is often referred to as load (or endurance) testing.

Usability testing

Usability testing is needed to check if the user interface is easy to use and understand.It approach towards the use of the application.

Security testing

Security testing is essential for software that processes confidential data to prevent system intrusion by hackers.

Internationalization and localization

The general ability of software to be internationalized and localized can be automatically tested without actual translation, by using pseudolocalization. It will verify that the application still works, even after it has been translated into a new language or adapted for a new culture (such as different currencies or time zones).

Actual translation to human languages must be tested, too. Possible localization failures include:

- Software is often localized by translating a list of strings out of context, and the translator may choose the wrong translation for an ambiguous source string.
- Technical terminology may become inconsistent if the project is translated by several people without proper coordination or if the translator is imprudent.
- Literal word-for-word translations may sound inappropriate, artificial or too technical in the target language.
- Untranslated messages in the original language may be left hard coded in the source code.
- Some messages may be created automatically in run time and the resulting string may be ungrammatical, functionally incorrect, misleading or confusing.
- Software may use a keyboard shortcut which has no function on the source language's keyboard layout, but is used for typing characters in the layout of the target language.
- Software may lack support for the character encoding of the target language.
- Fonts and font sizes which are appropriate in the source language, may be inappropriate in the target language; for example, CJK characters may become unreadable if the font is too small.
- A string in the target language may be longer than the software can handle. This may make the string partly invisible to the user or cause the software to crash or malfunction.
- Software may lack proper support for reading or writing bi-directional text.
- Software may display images with text that wasn't localized.
- Localized operating systems may have differently-named system configuration files and environment variables and different formats for date and currency.

To avoid these and other localization problems, a tester who knows the target language must run the program with all the possible use cases for translation to see if the messages are readable, translated correctly in context and don't cause failures.

Destructive testing

Destructive testing attempts to cause the software or a sub-system to fail, in order to test its robustness.

The testing process

Traditional CMMI or waterfall development model

A common practice of software testing is that testing is performed by an independent group of testers after the functionality is developed, before it is shipped to the customer. This practice often results in the testing phase being used as a project buffer to compensate for project delays, thereby compromising the time devoted to testing.

Another practice is to start software testing at the same moment the project starts and it is a continuous process until the project finishes.

Agile or Extreme development model

In counterpoint, some emerging software disciplines such as extreme programming and the agile software development movement, adhere to a "test-driven software development" model. In this process, unit tests are written first, by the software engineers (often with pair programming in the extreme programming methodology). Of course these tests fail initially; as they are expected to. Then as code is written it passes incrementally larger portions of the test suites. The test suites are continuously updated as new failure conditions and corner cases are discovered, and they are integrated with any regression tests that are developed. Unit tests are maintained along with the rest of the software source code and generally integrated into the build process (with inherently interactive tests being relegated to a partially manual build acceptance process). The ultimate goal of this test process is to achieve continuous deployment where software updates can be published to the public frequently.

A sample testing cycle

Although variations exist between organizations, there is a typical cycle for testing. The sample below is common among organizations employing the Waterfall development model.

- **Requirements analysis**: Testing should begin in the requirements phase of the software development life cycle. During the design phase, testers work with developers in determining what aspects of a design are testable and with what parameters those tests work.
- **Test planning**: Test strategy, test plan, testbed creation. Since many activities will be carried out during testing, a plan is needed.
- **Test development**: Test procedures, test scenarios, test cases, test datasets, test scripts to use in testing software.
- **Test execution**: Testers execute the software based on the plans and test documents then report any errors found to the development team.
- **Test reporting**: Once testing is completed, testers generate metrics and make final reports on their test effort and whether or not the software tested is ready for release.

- **Test result analysis**: Or Defect Analysis, is done by the development team usually along with the client, in order to decide what defects should be treated, fixed, rejected (i.e. found software working properly) or deferred to be dealt with later.
- **Defect Retesting**: Once a defect has been dealt with by the development team, it is retested by the testing team. AKA Resolution testing.
- **Regression testing**: It is common to have a small test program built of a subset of tests, for each integration of new, modified, or fixed software, in order to ensure that the latest delivery has not ruined anything, and that the software product as a whole is still working correctly.
- **Test Closure**: Once the test meets the exit criteria, the activities such as capturing the key outputs, lessons learned, results, logs, documents related to the project are archived and used as a reference for future projects.

Automated testing

Many programming groups are relying more and more on automated testing, especially groups that use test-driven development. There are many frameworks to write tests in, and continuous integration software will run tests automatically every time code is checked into a version control system.

While automation cannot reproduce everything that a human can do (and all the ways they think of doing it), it can be very useful for regression testing. However, it does require a well-developed test suite of testing scripts in order to be truly useful.

Testing tools

Program testing and fault detection can be aided significantly by testing tools and debuggers. Testing/debug tools include features such as:

- Program monitors, permitting full or partial monitoring of program code including:
    - Instruction set simulator, permitting complete instruction level monitoring and trace facilities
    - Program animation, permitting step-by-step execution and conditional breakpoint at source level or in machine code
    - Code coverage reports
- Formatted dump or symbolic debugging, tools allowing inspection of program variables on error or at chosen points
- Automated functional GUI testing tools are used to repeat system-level tests through the GUI
- Benchmarks, allowing run-time performance comparisons to be made
- Performance analysis (or profiling tools) that can help to highlight hot spots and resource usage

Some of these features may be incorporated into an Integrated Development Environment (IDE).

- A regression testing technique is to have a standard set of tests, which cover existing functionality that result in persistent tabular data, and to compare pre-change data to post-change data, where there should not be differences, using a tool like diffkit. Differences detected indicate unexpected functionality changes or "regression".

Measurement in software testing

Usually, quality is constrained to such topics as correctness, completeness, security, but can also include more technical requirements as described under the ISO standard ISO/IEC 9126, such as capability, reliability, efficiency, portability, maintainability, compatibility, and usability.

There are a number of frequently-used software measures, often called *metrics*, which are used to assist in determining the state of the software or the adequacy of the testing.

Testing artifacts

Software testing process can produce several artifacts.

Test plan

A test specification is called a test plan. The developers are well aware what test plans will be executed and this information is made available to management and the developers. The idea is to make them more cautious when developing their code or making additional changes. Some companies have a higher-level document called a test strategy.

Traceability matrix

A traceability matrix is a table that correlates requirements or design documents to test documents. It is used to change tests when the source documents are changed, or to verify that the test results are correct.

Test case

A test case normally consists of a unique identifier, requirement references from a design specification, preconditions, events, a series of steps (also known as actions) to follow, input, output, expected result, and actual result. Clinically defined a test case is an input and an expected result. This can be as pragmatic as 'for condition x your derived result is y', whereas other test cases described in more detail the input scenario and what results might be expected. It can occasionally be a series of steps (but often steps are contained in a separate test procedure that can be exercised against multiple test cases, as a matter of economy) but with one expected result or expected outcome. The optional fields are a test case ID, test step, or order of execution number, related requirement(s), depth, test category, author, and check boxes for whether the test is automatable and has been automated. Larger test cases may also contain prerequisite states or steps, and descriptions. A test case should also contain a place for the actual result. These steps can be stored in a word processor document, spreadsheet, database, or other common repository. In a database system, you may also be able to see past test results, who generated the results, and what system configuration was used to generate those results. These past results would usually be stored in a separate table.

Test script

The test script is the combination of a test case, test procedure, and test data. Initially the term was derived from the product of work created by automated regression test tools. Today, test scripts can be manual, automated, or a combination of both.

Test suite

The most common term for a collection of test cases is a test suite. The test suite often also contains more detailed instructions or goals for each collection of test cases. It definitely contains a section where the tester identifies the system configuration used during testing. A group of test cases may also contain prerequisite states or steps, and descriptions of the following tests.

Test data

In most cases, multiple sets of values or data are used to test the same functionality of a particular feature. All the test values and changeable environmental components are collected in separate files and stored as test data. It is also useful to provide this data to the client and with the product or a project.

Test harness

The software, tools, samples of data input and output, and configurations are all referred to collectively as a test harness.

Certifications

Several certification programs exist to support the professional aspirations of software testers and quality assurance specialists. No certification currently offered actually requires the applicant to demonstrate the ability to test software. No certification is based on a widely accepted body of knowledge. This has led some to declare that the testing field is not ready for certification. Certification itself cannot measure an individual's productivity, their skill, or practical knowledge, and cannot guarantee their competence, or professionalism as a tester.

Software testing certification types

- *Exam-based*: Formalized exams, which need to be passed; can also be learned by self-study [e.g., for ISTQB or QAI]
- *Education-based*: Instructor-led sessions, where each course has to be passed [e.g., International Institute for Software Testing (IIST)].

Testing certifications

- Certified Associate in Software Testing (CAST) offered by the Quality Assurance Institute (QAI)
- CATe offered by the *International Institute for Software Testing*
- Certified Manager in Software Testing (CMST) offered by the Quality Assurance Institute (QAI)
- Certified Software Tester (CSTE) offered by the Quality Assurance Institute (QAI)
- Certified Software Test Professional (CSTP) offered by the *International Institute for Software Testing*
- CSTP (TM) (Australian Version) offered by *K. J. Ross & Associates*
- ISEB offered by the Information Systems Examinations Board
- ISTQB Certified Tester, Foundation Level (CTFL) offered by the International Software Testing Qualification Board
- ISTQB Certified Tester, Advanced Level (CTAL) offered by the International Software Testing Qualification Board
- TMPF TMap Next Foundation offered by the *Examination Institute for Information Science*
- TMPA TMap Next Advanced offered by the *Examination Institute for Information Science*

Quality assurance certifications

- CMSQ offered by the *Quality Assurance Institute* (QAI).
- CSQA offered by the *Quality Assurance Institute* (QAI)
- CSQE offered by the American Society for Quality (ASQ)
- CQIA offered by the American Society for Quality (ASQ)

Controversy

Some of the major software testing controversies include:

What constitutes responsible software testing?

Members of the "context-driven" school of testing believe that there are no "best practices" of testing, but rather that testing is a set of skills that allow the tester to select or invent testing practices to suit each unique situation.

Agile vs. traditional

Should testers learn to work under conditions of uncertainty and constant change or should they aim at process "maturity"? The agile testing movement has received growing popularity since 2006 mainly in commercial circles, whereas government and military software providers use this methodology but also the traditional test-last models (e.g. in the Waterfall model).

Exploratory test vs. scripted

Should tests be designed at the same time as they are executed or should they be designed beforehand?

Manual testing vs. automated

Some writers believe that test automation is so expensive relative to its value that it should be used sparingly. More in particular, test-driven development states that developers should write unit-tests of the XUnit type before coding the functionality. The tests then can be considered as a way to capture and implement the requirements.

Software design vs. software implementation

Should testing be carried out only at the end or throughout the whole process?

Who watches the watchmen?

The idea is that any form of observation is also an interaction—the act of testing can also affect that which is being tested.