# Software Testing Strategies

- A strategic approach to testing
- Test strategies for conventional software
- Test strategies for object-oriented software
- Test strategies for web applications
- Validation testing
- System testing

# Software Quality

Software quality can be defined as:

*An effective software process applied in a manner that creates a useful product that provides measurable value for those who produce it and those who use it.*

- J Bessin, "The Business Value of Quality" (IBM DeveloperWorks)

## Cost of Quality

***Prevention costs:***

*Quality planning*
*Formal technical reviews*
*Test equipment*
*Training*

**Appraisal Costs:**

*Technical reviews*
*Data Collection*
*Testing & Debugging*

***Internal failure costs:***

*Rework*
*Repair*
*failure mode analysis*

***External failure costs:***

*complaint resolution*
*product return and replacement*
*help line support*
*warranty work*

## Achieving Software Quality

Critical success factors:

- **Software Engineering Methods**
- **Project Management Techniques**
- **Quality Control**
- **Quality Assurance**

## Achieving Software Quality

**Software Engineering Methods**

- Understand the problem to be solved
- Create design that conforms to the problem
- Design and Software exhibit quality dimensions

**Project Management Techniques**

- Use estimation for achievable delivery dates
- Understand schedule dependencies and avoid short cuts
- Conduct risk planning

# Achieving Software Quality

**Quality Control**

- Reviews
- Inspection
- Testing
- Measurements and Feedback

**Quality Assurance**

- Establish infrastructure for software engineering
- Audit effectiveness and completeness of quality control

## Software Testing Strategies

## Introduction

- A strategy for software testing integrates the design of software test cases into a well-planned series of steps that result in successful development of the software
- The strategy provides a road map that describes the steps to be taken, when, and how much effort, time, and resources will be required
- The strategy incorporates test planning, test case design, test execution, and test result collection and evaluation
- The strategy provides guidance for the practitioner and a set of milestones for the manager
- Because of time pressures, progress must be measurable and problems must surface as early as possible

## Strategic Approach To Testing

- To perform effective testing, a software team should conduct effective formal technical reviews
- Testing begins at the component level and work outward toward the integration of the entire computer-based system
- Different testing techniques are appropriate at different points in time
- Testing is conducted by the developer of the software and (for large projects) by an independent test group
- Testing and debugging are different activities, but debugging must be accommodated in any testing strategy

# Successful Strategies for Testing

- Specify product requirements in a quantifiable manner long before testing commences.
- State testing objectives explicitly.
- Understand the users of the software and develop a profile for each user category.
- Develop a testing plan that emphasizes “rapid cycle testing.”
- Build “robust” software that is designed to test itself
- Use effective technical reviews as a filter prior to testing
- Conduct technical reviews to assess the test strategy and test cases themselves.
- Develop a continuous improvement approach for the testing process.

-Tom Gilb

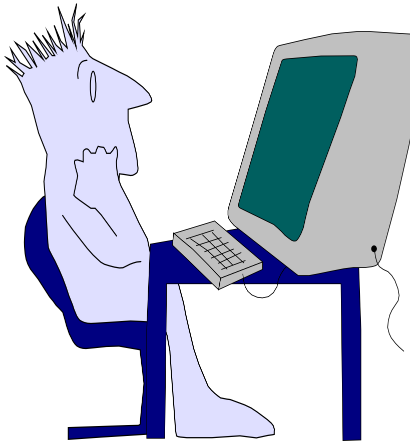
# When is Testing Complete?

- There is no definitive answer to this question
- Every time a user executes the software, the program is being tested
- Sadly, testing usually stops when a project is running out of time, money, or both
- One approach is to divide the test results into various severity levels
  - Then consider testing to be complete when certain levels of errors no longer occur or have been repaired or eliminated

# Verification and Validation

- Software testing is part of a broader group of activities called verification and validation that are involved in software quality assurance
- Verification (Are the algorithms coded correctly?)
  - The set of activities that ensure that software correctly implements a specific function or algorithm
  - Are we building the product right? [Boehm]
- Validation (Does it meet user requirements?)
  - The set of activities that ensure that the software that has been built is traceable to customer requirements
  - Are we building the right product? [Boehm]

# Who Tests the Software?



***developer***

***independent tester***

**Understands the system**

**but, will test "gently"**

**and, is driven by "delivery"**

**Must learn about the system,**

**but, will attempt to break it**

**and, is driven by quality**

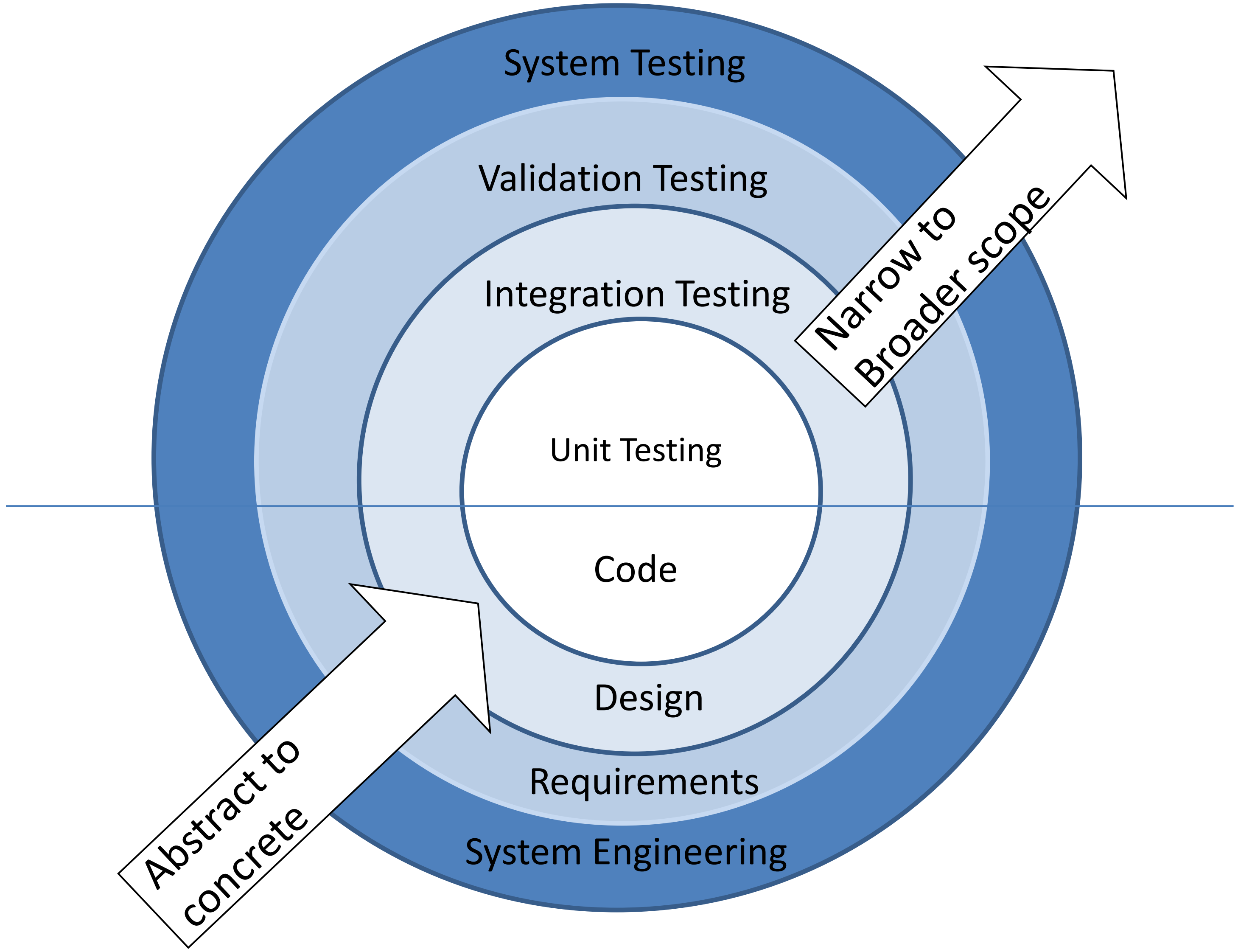
# Organizing for Software Testing

- Testing should aim at "breaking" the software
- Common misconceptions
  - The developer of software should do no testing at all
  - The software should be given to a secret team of testers who will test it unmercifully
  - The testers get involved with the project only when the testing steps are about to begin
- Reality: Independent test group
  - Removes the inherent problems associated with letting the builder test the software that has been built
  - Removes the conflict of interest that may otherwise be present
  - Works closely with the software developer during analysis and design to ensure that thorough testing occurs

# Levels of Testing for Conventional Software

- Unit testing
  - Concentrates on each component/function of the software as implemented in the source code
  - Exercises specific paths in a component's control structure to ensure complete coverage and maximum error detection
  - Components are then assembled and integrated
- Integration testing
  - Focuses on the design and construction of the software architecture
  - Focuses on inputs and outputs, and how well the components fit together and work together
- Validation testing
  - Requirements are validated against the constructed software
  - Provides final assurance that the software meets all functional, behavioral, and performance requirements
- System testing
  - The software and other system elements are tested as a whole
  - Verifies that all system elements (software, hardware, people, databases) mesh properly and that overall system function and performance is achieved

# Levels of Testing for Software (contd…)



## Testing Strategy applied to Object-Oriented Software

- Must broaden testing to include detections of errors in analysis and design models
- Unit testing loses some of its meaning and integration testing changes significantly
- Use the same philosophy but different approach as in conventional software testing
- Test "in the small" and then work out to testing "in the large"
  - Testing in the small involves class attributes and operations; the main focus is on communication and collaboration within the class
  - Testing in the large involves a series of regression tests to uncover errors due to communication and collaboration among classes
- Finally, the system as a whole is tested to detect errors in fulfilling requirements

## Test Strategies for Conventional Software

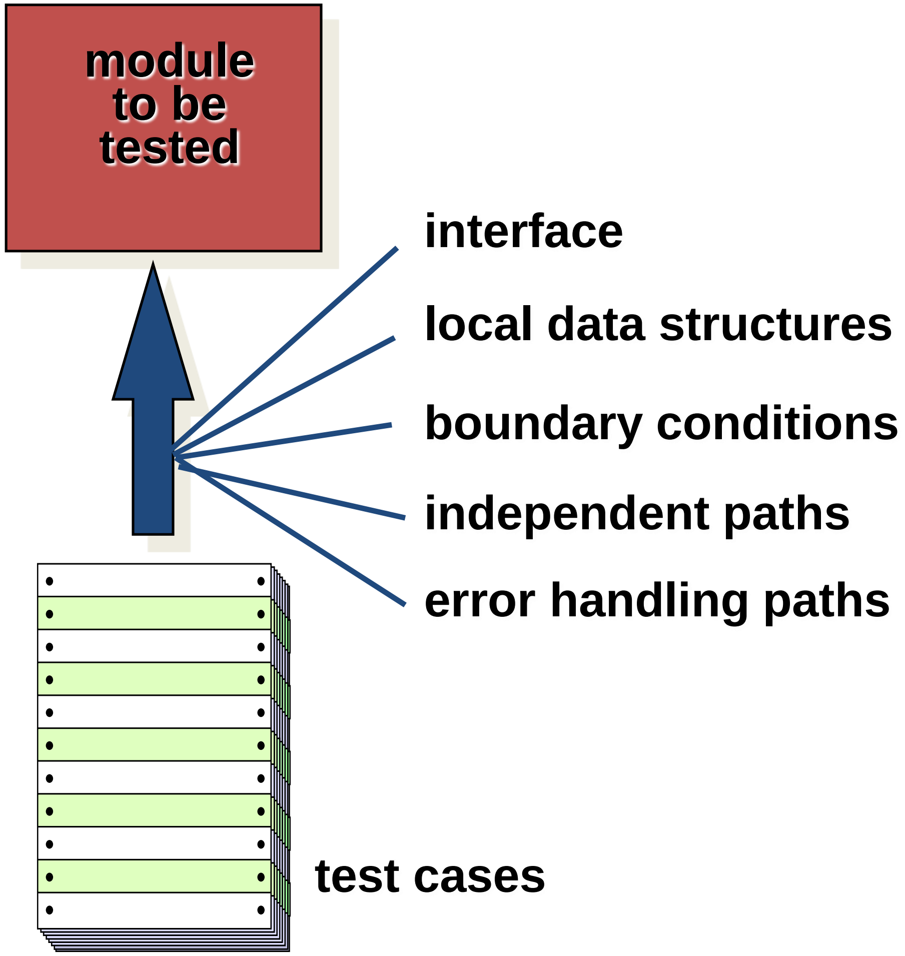
# Unit Testing

- Focuses testing on the function or software module
- Concentrates on the internal processing logic and data structures
- Is simplified when a module is designed with high cohesion
  - Reduces the number of test cases
  - Allows errors to be more easily predicted and uncovered
- Concentrates on critical modules and those with **high cyclomatic complexity** when testing resources are limited

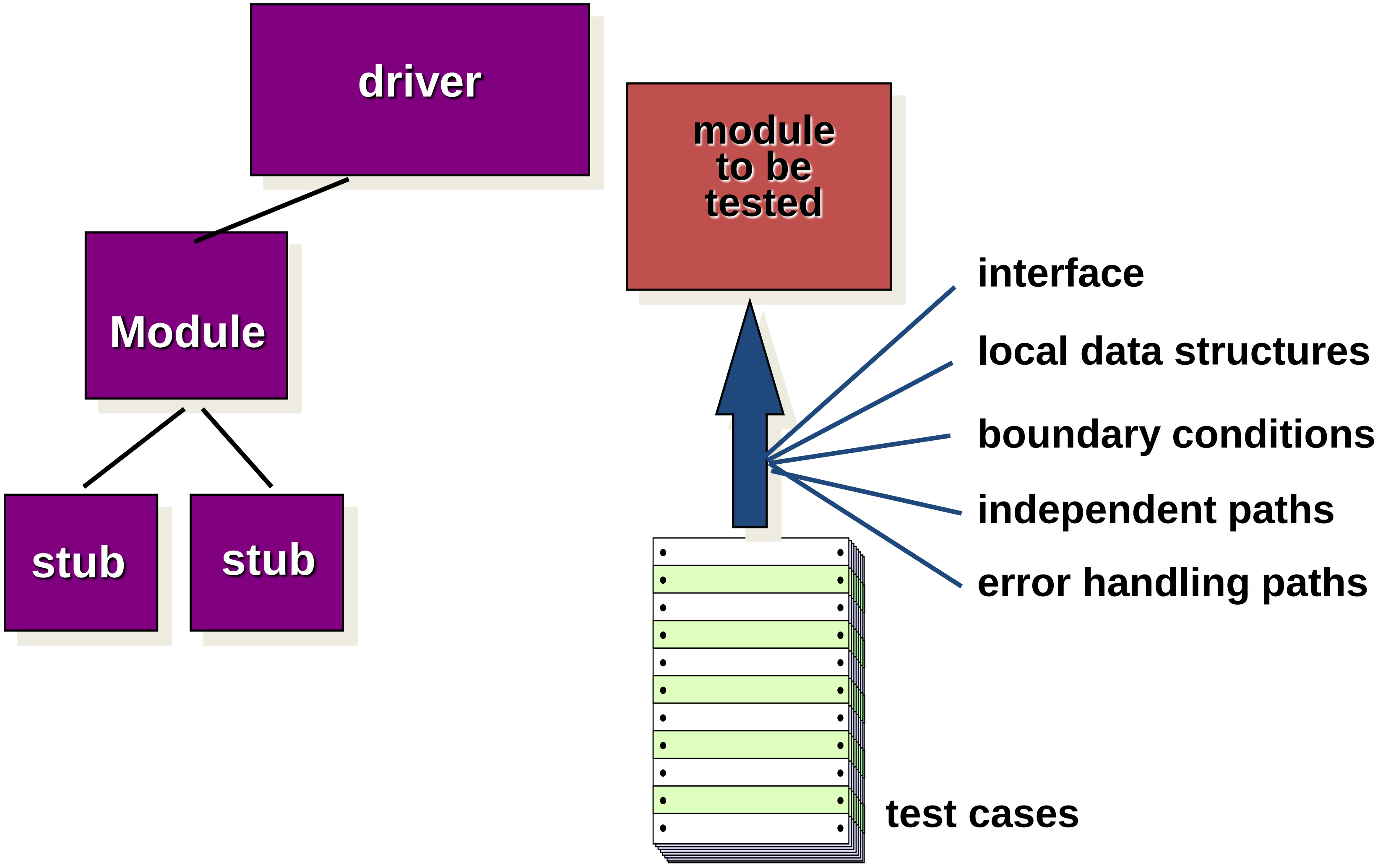
## Targets for Unit Test Cases

- Module interface
  - Ensure that information flows properly into and out of the module
- Local data structures
  - Ensure that data stored temporarily maintains its integrity during all steps in an algorithm execution
- Boundary conditions
  - Ensure that the module operates properly at boundary values established to limit or restrict processing
- Independent paths (basis paths)
  - Paths are exercised to ensure that all statements in a module have been executed at least once
- Error handling paths
  - Ensure that the algorithms respond correctly to specific error conditions

# Unit Testing



# Unit Testing Environment



## Common Computational Errors in Execution Paths

- Misunderstood or incorrect arithmetic precedence
- Mixed mode operations (e.g., int, float, char)
- Incorrect initialization of values
- Precision inaccuracy and round-off errors
- Incorrect symbolic representation of an expression (int vs. float)

# Other Errors to Uncover

- Comparison of different data types
- Incorrect logical operators or precedence
- Expectation of equality when precision error makes equality unlikely (using == with float types)
- Incorrect comparison of variables
- Improper or nonexistent loop termination
- Failure to exit when divergent iteration is encountered
- Improperly modified loop variables
- Boundary value violations

# Problems to uncover in Error Handling

- Error description is unintelligible or ambiguous
- Error noted does not correspond to error encountered
- Error condition causes operating system intervention prior to error handling
- Exception condition processing is incorrect
- Error description does not provide enough information to assist in the location of the cause of the error

# Drivers and Stubs for Unit Testing

- Driver
  - A simple main program that accepts test case data, passes such data to the component being tested, and prints the returned results
- Stubs
  - Serve to replace modules that are subordinate to (called by) the component to be tested
  - It uses the module's exact interface, may do minimal data manipulation, provides verification of entry, and returns control to the module undergoing testing
- Drivers and stubs both represent overhead
  - Both must be written but don't constitute part of the installed software product

# Integration Testing

- Defined as a systematic technique for constructing the software architecture
  - At the same time integration is occurring, conduct tests to uncover errors associated with interfaces
- Objective is to take unit tested modules and build a program structure based on the prescribed design
- Two Approaches
  - Non-incremental Integration Testing
  - Incremental Integration Testing

# Non-incremental Integration Testing

- Commonly called the “Big Bang” approach
- All components are combined in advance
- The entire program is tested as a whole
- Potential for Chaos in results
- Many seemingly-unrelated errors are encountered
- Correction is difficult because isolation of causes is complicated
- Once a set of errors are corrected, more errors occur, and testing appears to enter an endless loop

# Incremental Integration Testing

- Three kinds
  - Top-down integration
  - Bottom-up integration
  - Sandwich integration
- The program is constructed and tested in small increments
- Errors are easier to isolate and correct
- Interfaces are more likely to be tested completely
- A systematic test approach is applied

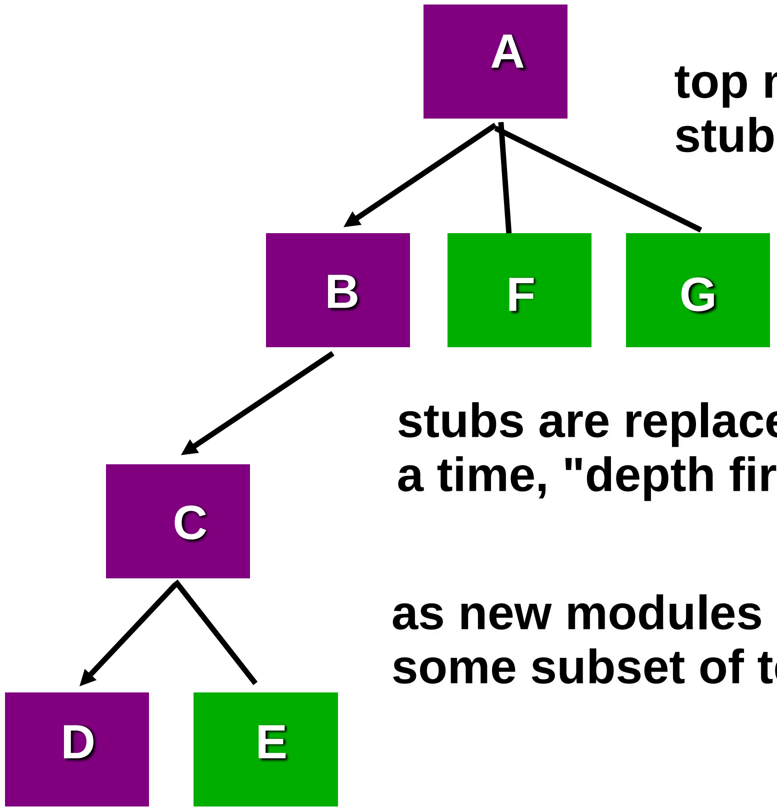
## Top-down Integration

- Modules are integrated by moving downward through the control hierarchy, beginning with the main module
- Subordinate modules are incorporated in either a depth-first or breadth-first fashion
  - DF: All modules on a major control path are integrated
  - BF: All modules directly subordinate at each level are integrated
- Advantages
  - This approach verifies major control or decision points early in the test process
- Disadvantages
  - Stubs need to be created to substitute for modules that have not been built or tested yet; this code is later discarded
  - Because stubs are used to replace lower level modules, no significant data flow can occur until much later in the integration/testing process

## Bottom-up Integration

- Integration and testing starts with the most atomic modules in the control hierarchy
- Advantages
  - This approach verifies low-level data processing early in the testing process
  - Need for stubs is eliminated
- Disadvantages
  - Driver modules need to be built to test the lower-level modules; this code is later discarded or expanded into a full-featured version
  - Drivers inherently do not contain the complete algorithms that will eventually use the services of the lower-level modules; consequently, testing may be incomplete or more testing may be needed later when the upper level modules are available

# Top Down Integration

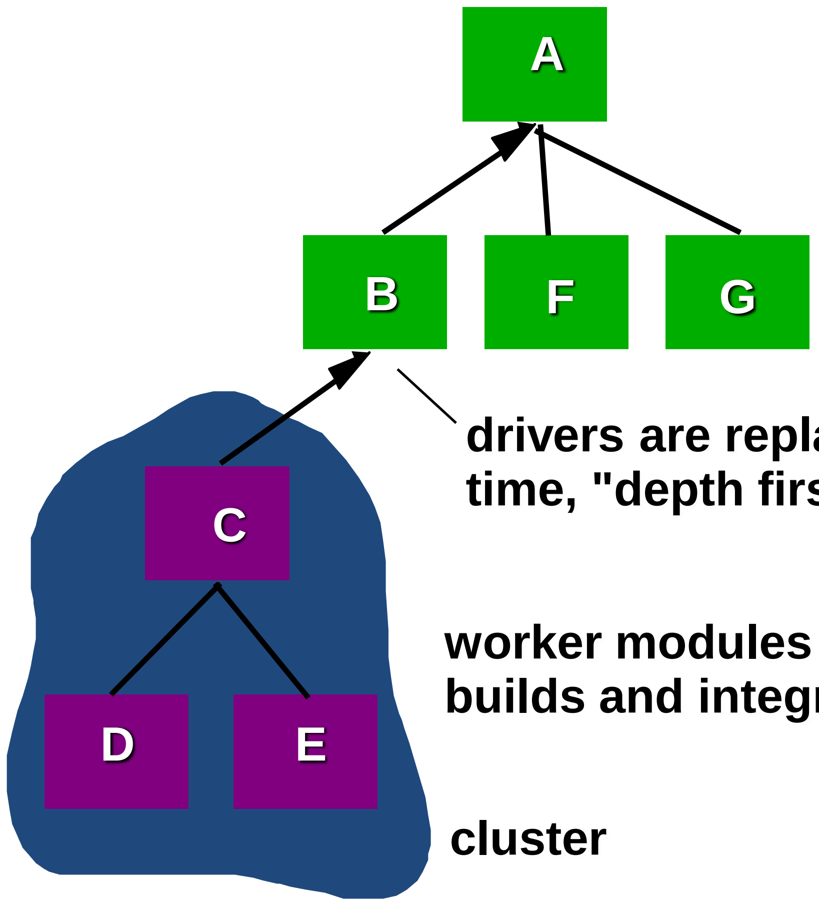


top module is tested with stubs

stubs are replaced one at a time, "depth first"

as new modules are integrated, some subset of tests is re-run

# Bottom-Up Integration



drivers are replaced one at a time, "depth first"

worker modules are grouped into builds and integrated

cluster

## Sandwich Integration

- Consists of a combination of both top-down and bottom-up integration
- Occurs both at the highest level modules and also at the lowest level modules
- Proceeds using functional groups of modules, with each group completed before the next
  - High and low-level modules are grouped based on the control and data processing they provide for a specific program feature
  - Integration within the group progresses in alternating steps between the high and low level modules of the group
  - When integration for a certain functional group is complete, integration and testing moves onto the next group
- Reaps the advantages of both types of integration while minimizing the need for drivers and stubs
- Requires a disciplined approach so that integration doesn’t tend towards the “big bang” scenario

# Regression Testing

- Each new addition or change to baselined software may cause problems with functions that previously worked flawlessly
- Regression testing re-executes a small subset of tests that have already been conducted
  - Ensures that changes have not propagated unintended side effects
  - Helps to ensure that changes do not introduce unintended behavior or additional errors
  - May be done manually or through the use of automated capture/playback tools
- Regression test suite contains three different classes of test cases
  - A representative sample of tests that will exercise all software functions
  - Additional tests that focus on software functions that are likely to be affected by the change
  - Tests that focus on the actual software components that have been changed

# Smoke Testing

- Taken from the world of hardware
  - Power is applied and a technician checks for sparks, smoke, or other dramatic signs of fundamental failure
- Designed as a pacing mechanism for time-critical projects
  - Allows the software team to assess its project on a frequent basis
- Includes the following activities
  - The software is compiled and linked into a build
  - A series of breadth tests is designed to expose errors that will keep the build from properly performing its function
    - The goal is to uncover “show stopper” errors that have the highest likelihood of throwing the software project behind schedule
  - The build is integrated with other builds and the entire product is smoke tested daily
    - Daily testing gives managers and practitioners a realistic assessment of the progress of the integration testing
  - After a smoke test is completed, detailed test scripts are executed

# Benefits of Smoke Testing

- Integration risk is minimized
  - Daily testing uncovers incompatibilities and show-stoppers early in the testing process, thereby reducing schedule impact
- The quality of the end-product is improved
  - Smoke testing is likely to uncover both functional errors and architectural and component-level design errors
- Error diagnosis and correction are simplified
  - Smoke testing will probably uncover errors in the newest components that were integrated
- Progress is easier to assess
  - As integration testing progresses, more software has been integrated and more has been demonstrated to work
  - Managers get a good indication that progress is being made

## Test Strategies for Object-Oriented Software

# Test Strategies for Object-Oriented Software

- With object-oriented software, you can no longer test a single operation in isolation (conventional thinking)
- Traditional top-down or bottom-up integration testing has little meaning
- Class testing for object-oriented software is the equivalent of unit testing for conventional software
  - Focuses on operations encapsulated by the class and the state behavior of the class
- Drivers can be used
  - To test operations at the lowest level and for testing whole groups of classes
  - To replace the user interface so that tests of system functionality can be conducted prior to implementation of the actual interface
- Stubs can be used
  - In situations in which collaboration between classes is required but one or more of the collaborating classes has not yet been fully implemented

## Test Strategies for Object-Oriented Software (continued)

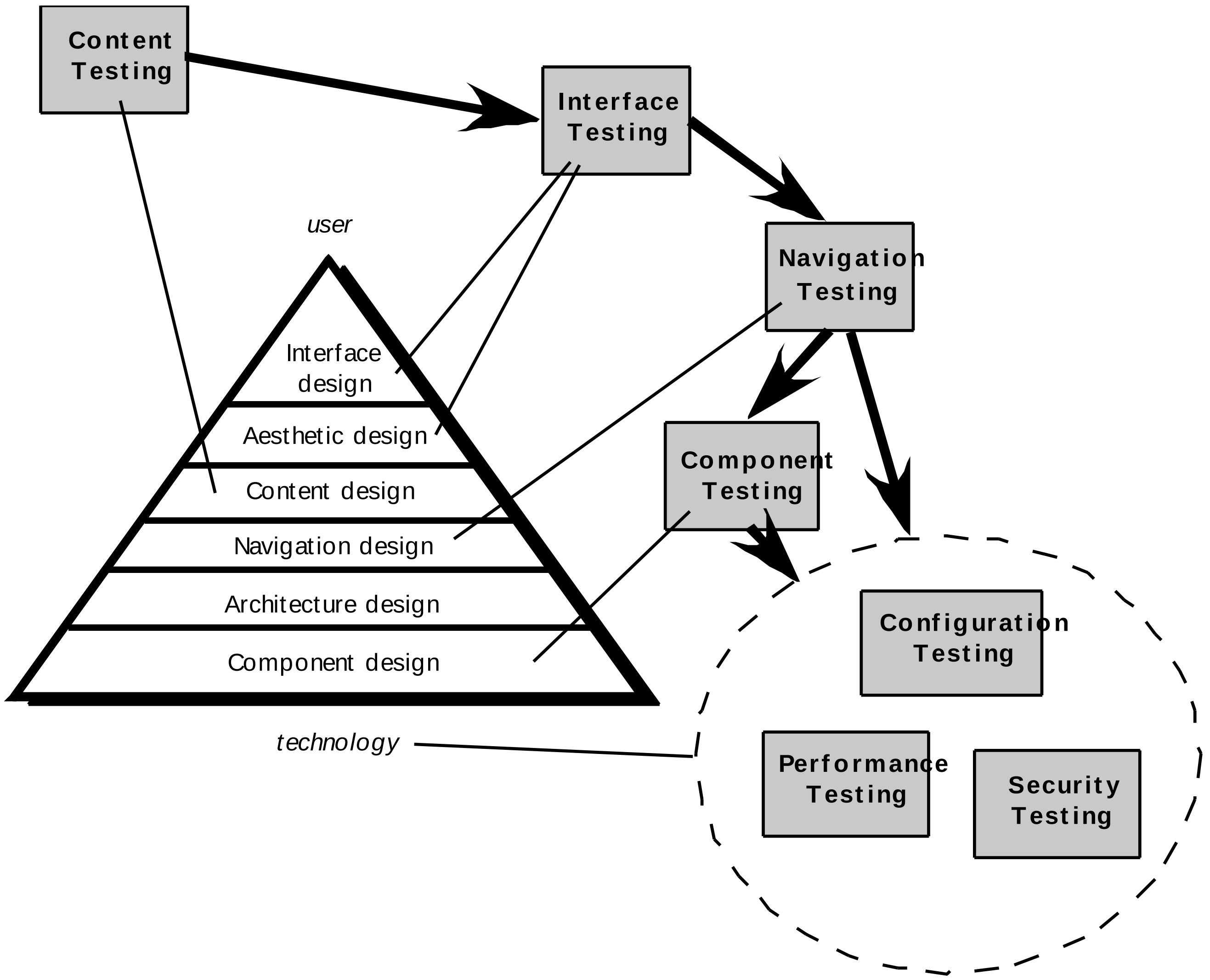
- Different object-oriented testing strategies (for integration)
  - thread-based testing—integrates the set of classes required to respond to one input or event
  - use-based testing—start with independent classes & proceed to integrate dependent classes
  - cluster testing—integrates the set of classes required to demonstrate one collaboration

## Test Strategies for Web Applications

# WebApp Testing

- The user interface is tested to uncover errors in presentation and/or navigation mechanics.
- Each functional component is unit tested.
- Navigation throughout the architecture is tested.
- The WebApp is implemented in a variety of different environmental configurations and is tested for compatibility with each configuration.
- Security tests are conducted in an attempt to exploit vulnerabilities in the WebApp or within its environment.
- Performance tests are conducted.
- The WebApp is tested by a controlled and monitored population of end-users. The results of their interaction with the system are evaluated for content and navigation errors, usability concerns, compatibility concerns, and WebApp reliability and performance.

# WebApp Testing Process



## Testing Interface Mechanisms

- *Links*—navigation mechanisms that link the user to some other content object or function.
- *Forms*—a structured document containing blank fields that are filled in by the user. The data contained in the fields are used as input to one or more WebApp functions.
- *Client-side scripting*—a list of programmed commands in a scripting language (e.g., Javascript) that handle information input via forms or other user interactions
- *Dynamic HTML*—leads to content objects that are manipulated on the client side using scripting or cascading style sheets (CSS).
- *Client-side pop-up windows*—small windows that pop-up without user interaction. These windows can be content-oriented and may require some form of user interaction.
- *CGI scripts*—a common gateway interface (CGI) script implements a standard method that allows a Web server to interact dynamically with users (e.g., a WebApp that contains forms may use a CGI script to process the data in the form once it is submitted by the user).
- *Streaming content*—Without explicit request from the client-side, server "pushes" content objects to the client.
- *Cookies*—a block of data sent by the server and stored by a browser as a consequence of a specific user interaction. The content of the data is WebApp-specific (e.g., user identification data or a list of items that have been selected for purchase by the user).
- *Application specific interface mechanisms*—include one or more "macro" interface mechanisms such as a shopping cart, credit card processing, or a shipping cost calculator.

# Configuration Testing - WebApp

- Client-side
  - *Hardware*—CPU, memory, storage and printing devices
  - *Operating systems*—Linux, Macintosh OS, Microsoft Windows, a mobile-based OS
  - *Browser software*—Internet Explorer, Mozilla/Netscape, Opera, Safari, and others
  - *User interface components*—Active X, Java applets and others
  - *Plug-ins*—QuickTime, RealPlayer, and many others
  - *Connectivity*—cable, DSL, regular modem, T1

- The number of configuration variables must be reduced to a manageable number

## Security Testing

- Designed to probe vulnerabilities of the client-side environment, the network communications that occur as data are passed from client to server and back again, and the server-side environment
- On the client-side, vulnerabilities can often be traced to pre-existing bugs in browsers, e-mail programs, or communication software.
- On the server-side, vulnerabilities include denial-of-service attacks and malicious scripts that can be passed along to the client-side or used to disable server operations

## Performance Testing

- Does the server response time degrade to a point where it is noticeable and unacceptable?
- At what point (in terms of users, transactions or data loading) does performance become unacceptable?
- What system components are responsible for performance degradation?
- What is the average response time for users under a variety of loading conditions?
- Does performance degradation have an impact on system security?
- Is WebApp reliability or accuracy affected as the load on the system grows?
- What happens when loads that are greater than maximum server capacity are applied?

# Load Testing

- The intent is to determine how the WebApp and its server-side environment will respond to various loading conditions
  - *N,* the number of concurrent users
  - *T,* the number of on-line transactions per unit of time
  - *D,* the data load processed by the server per transaction
- Overall throughput, *P,* is computed in the following manner:
    - $P = N \times T \times D$

# Stress Testing

- Does the system degrade ‘gently’ or does the server shut down as capacity is exceeded?
- Does server software generate “server not available” messages? More generally, are users aware that they cannot reach the server?
- Does the server queue requests for resources and empty the queue once capacity demands diminish?
- Are transactions lost as capacity is exceeded?
- Is data integrity affected as capacity is exceeded?
- What values of *N, T,* and *D* force the server environment to fail? How does failure manifest itself? Are automated notifications sent to technical support staff at the server site?
- If the system does fail, how long will it take to come back on-line?
- Are certain WebApp functions (e.g., compute intensive functionality, data streaming capabilities) discontinued as capacity reaches the 80 or 90 percent level?

# Validation Testing

## Background

- Validation testing follows integration testing
- *The distinction between conventional and object-oriented software disappears*
- Focuses on user-visible actions and user-recognizable output from the system
- Demonstrates conformity with requirements
- Designed to ensure that
  - All functional requirements are satisfied
  - All behavioral characteristics are achieved
  - All performance requirements are attained
  - Documentation is correct
  - Usability and other requirements are met (e.g., transportability, compatibility, error recovery, maintainability)
- After each validation test
  - The function or performance characteristic conforms to specification and is accepted
  - A deviation from specification is uncovered and a deficiency list is created
- A configuration review or audit ensures that all elements of the software configuration have been properly developed, cataloged, and have the necessary detail for entering the support phase of the software life cycle

# Alpha and Beta Testing

- Alpha testing
  - Conducted at the developer's site by end users
  - Software is used in a natural setting with developers watching intently
  - Testing is conducted in a controlled environment
- Beta testing
  - Conducted at end-user sites
  - Developer is generally not present
  - It serves as a live application of the software in an environment that cannot be controlled by the developer
  - The end-user records all problems that are encountered and reports these to the developers at regular intervals
- After beta testing is complete, software engineers make software modifications and prepare for release of the software product to the entire customer base

## System Testing

# Different Types of System Test

- Recovery testing
  - Tests for recovery from system faults
  - Forces the software to fail in a variety of ways and verifies that recovery is properly performed
  - Tests reinitialization, checkpointing mechanisms, data recovery, and restart for correctness
- Security testing
  - Verifies that protection mechanisms built into a system will, in fact, protect it from improper access
- Stress testing
  - Executes a system in a manner that demands resources in abnormal quantity, frequency, or volume

# Different Types of System Test (contd…)

- Performance testing
  - Tests the run-time performance of software within the context of an integrated system
  - Often coupled with stress testing and usually requires both hardware and software instrumentation
  - Can uncover situations that lead to degradation and possible system failure
- Deployment Testing
  - Exercises the software in each environment in which it is expected to operate (e.g. multiple browsers)
  - Examine installation procedures and specialized installation software
  - Validate the documentation used to introduce software to end-users

# Summary – Testing Strategies

- Software testing must be planned carefully to avoid wasting development time and resources.
- Testing begins “in the small” and progresses “to the large”.
- Initially individual components are tested and debugged.
- After the individual components have been tested and added to the system, integration testing takes place.
- Once the full software product is completed, system testing is performed.
- The Test Specification document should be reviewed like all other software engineering work products.