Integration and Component-based Software Testing

Learning objectives

- Be able to identify integration testing issues
  - Distinguish integration faults from faults that should be eliminated in unit testing
  - Be able to prevent and detect integration faults
- Be able to apply strategies for ordering construction and testing
  - E.g. incremental assembly and testing to reduce effort and control risk
  - Continuous Integration to reduce effort and control risk
- Be able to identify challenges and utilize approaches to testing component-based systems

What is integration testing?

	Module test	Integration test	System test
Specification:	Module interface	Interface specs, module breakdown	Requirements specification
Visible structure:	Coding details	Modular structure (software architecture)	— none —
Scaffolding required:	Some	Often extensive	Some
Looking for faults in:	Modules	Interactions, compatibility	System functionality

Continuous Integration

- In a more agile development setting
- Architecture may emerge slowly and evolve
- Complexity of interfaces and interaction will grow as systems develop
- Continuous integration may reduce the need for scaffolding code
  - Because the context for a module is being developed at the same time, perhaps by a different team.
  - Scaffolding is replaced by the real code for the context.
  - This may still add issues around observing the interaction of modules
- However, refactoring may result in the need for scaffolding

Integration versus Unit Testing

- Unit (module) testing is a necessary foundation
  - Unit level has maximum controllability and visibility
  - Integration testing can never compensate for inadequate unit testing
- Integration testing may serve as a *process check*
  - If module faults are revealed in integration testing, they signal inadequate unit testing
  - If integration faults occur in interfaces between correctly implemented modules, the errors can be traced to module breakdown and interface specifications

Integration Faults

- Inconsistent interpretation of parameters or values
  - Example: Mixed units (meters/yards) in Martian Lander
- Violations of value domains, capacity, or size limits
  - Example: Buffer overflow
- Side effects on parameters or resources
  - Example: Conflict on (unspecified) temporary file
- Omitted or misunderstood functionality
  - Example: Inconsistent interpretation of web hits
- Nonfunctional properties
  - Example: Unanticipated performance issues
- Dynamic mismatches
  - Example: Incompatible polymorphic method calls

Example: A Memory Leak

Apache web server, version 2.0.48
Response to normal page request on secure (https) port

```
static void ssl io filter disable(ap filter t *f)
{   bio filter in ctx t *inctx = f->ctx;

    inctx->ssl = NULL;
    inctx->filter ctx->pssl = NULL;
}
```

No obvious error, but Apache leaked memory slowly (in normal use) or quickly (if exploited for a DOS attack)

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```

The missing code is for a **structure defined and created elsewhere**, accessed through an opaque pointer.

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Almost impossible to find with unit testing. (Inspection and some dynamic techniques could have found it.)

Maybe you've heard ...

- Yes, I implemented ⟨module A⟩, but I didn't test it thoroughly yet. It will be tested along with ⟨module B⟩ when that's ready.

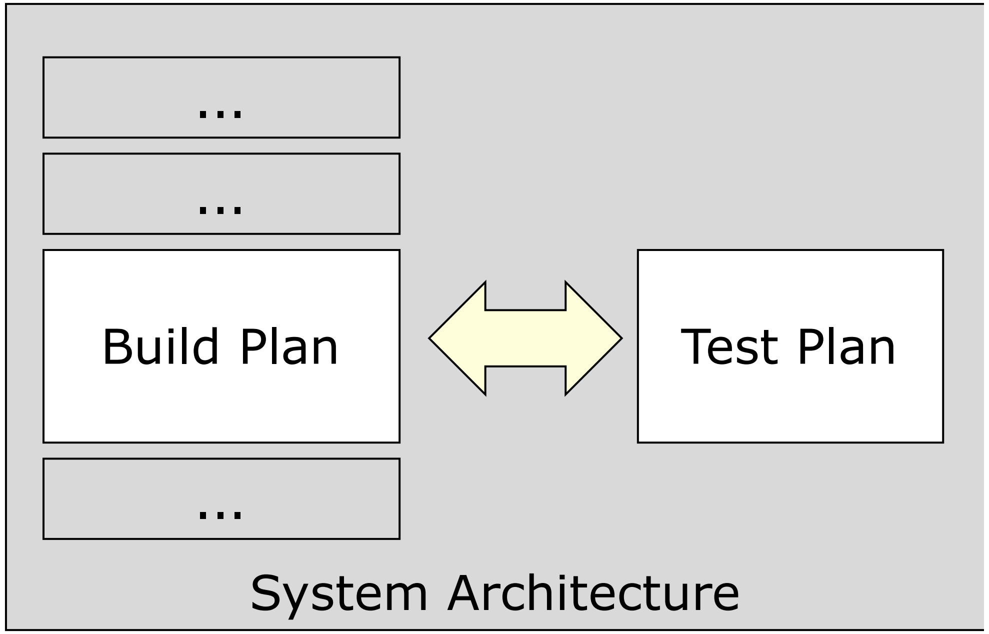
Translation...

- Yes, I implemented ⟨module A⟩, but I didn't test it thoroughly yet. It will be tested along with ⟨module B⟩ when that's ready.

- I didn't think at all about the strategy for testing. I didn't design ⟨module A⟩ for testability and I didn't think about the best order to build and test modules ⟨A⟩ and ⟨B⟩.

Integration Plan + Test Plan

- Integration test plan drives and is driven by the project "build plan"
  - A key feature of the system architecture and project plan



Big Bang Integration Test

An extreme and desperate approach:

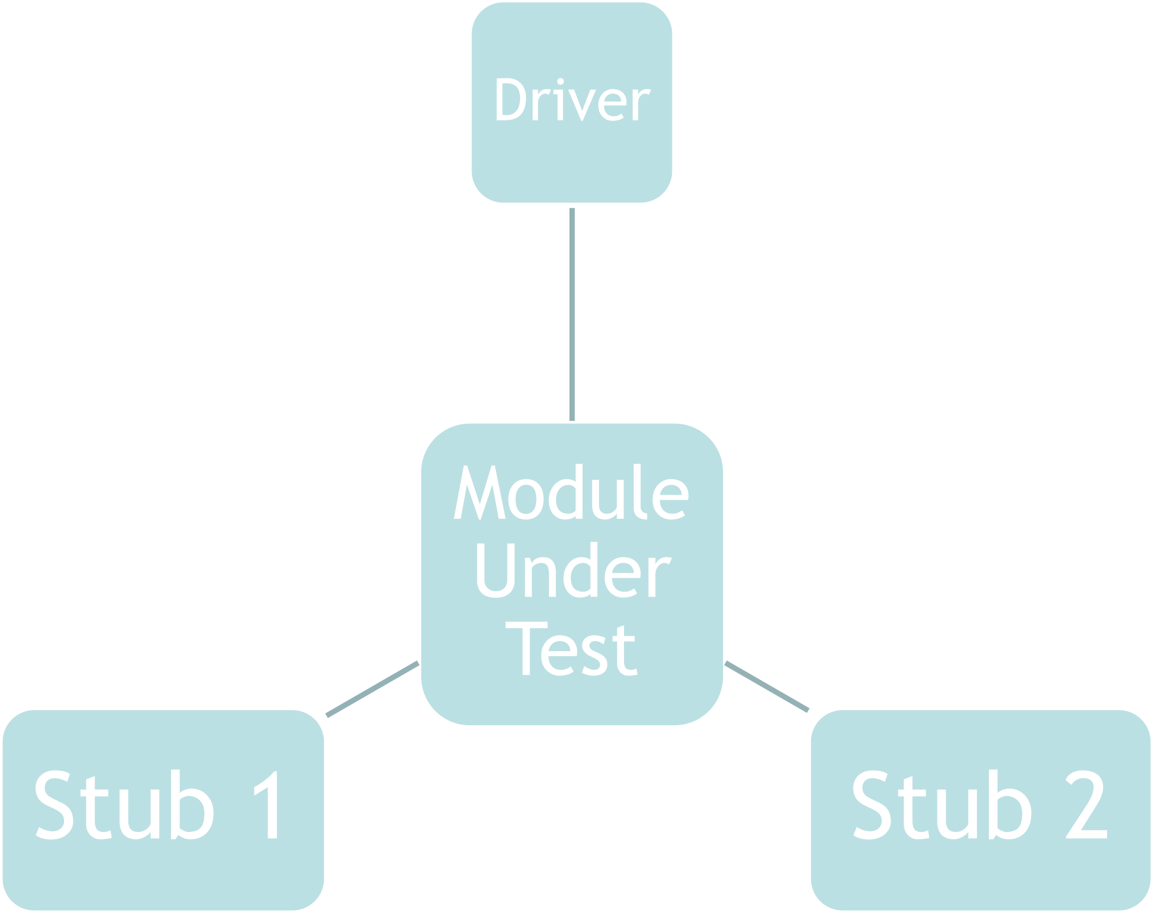
Test only after integrating all modules

+ Does not require scaffolding
    - The only excuse, and a bad one
- Minimum observability, diagnosability, efficacy, feedback
- High cost of repair
    - Recall: Cost of repairing a fault rises as a function of *time between error and repair*

Structural and Functional Strategies

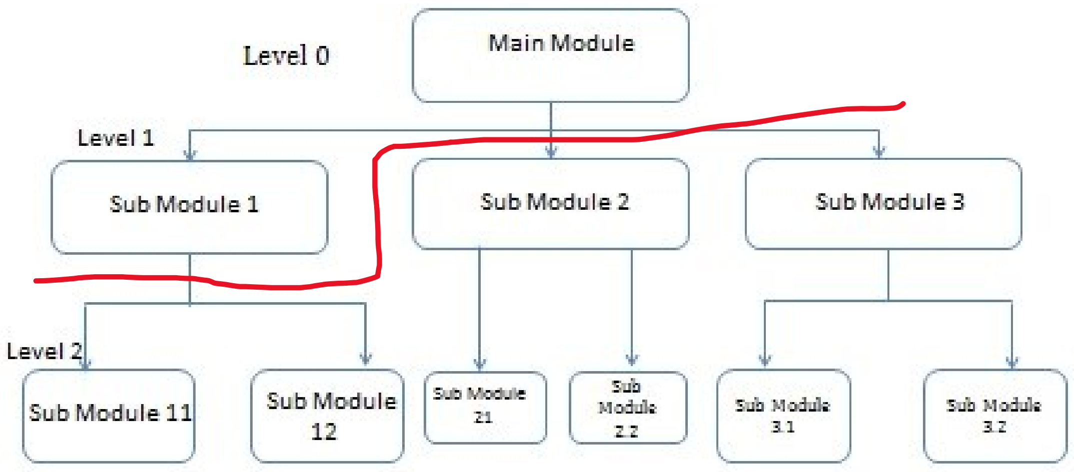
- Structural orientation:
  Modules constructed, integrated and tested based on a hierarchical project structure
  - Top-down, Bottom-up, Sandwich, Backbone
- Functional orientation:
  Modules integrated according to application characteristics or features
  - Threads, Critical module

Drivers and Stubs



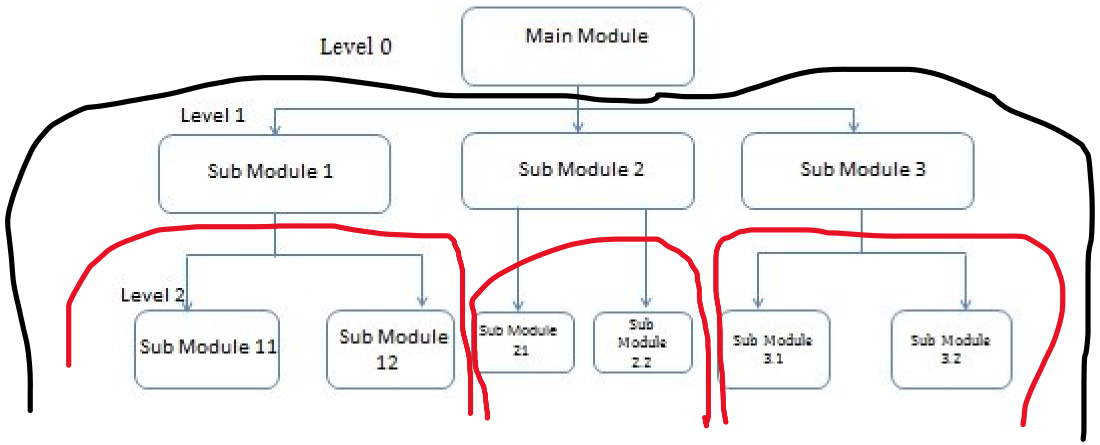
- In systems a module will be asked to do things and will ask other modules to do things for it.
- We might not have those when we are testing the modules so we need:
  - Drivers that make some of the demands that will be made on the module.
  - Stubs that behave somewhat like the modules the module under test will use.

Top down



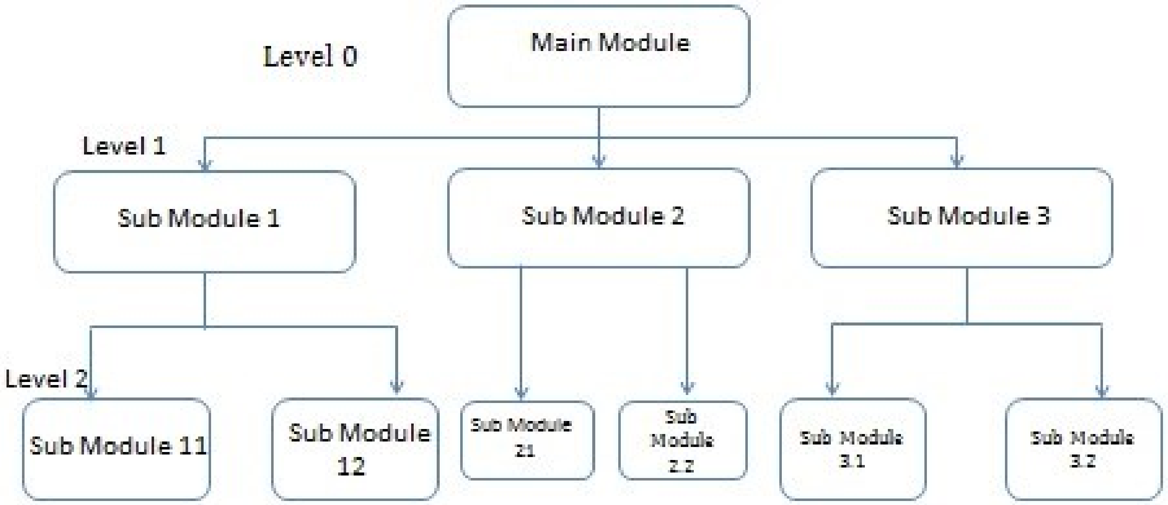
- Working from the top level (in terms of "use" or "include" relation) toward the bottom.
- No drivers required if program tested from top-level interface (e.g. GUI, CLI, web app, etc.)
- But we will need stubs for sub modules 11, 12, 2 and 3
- As we substitute modules for stubs the tests can be more thorough.
- Eventually we don't need stubs and the system is complete

Bottom Up



- Starting at the leaves of the “uses” hierarchy, we never need stubs
- But we do need drivers that behave like the non-leaf modules to drive things below them.
- As we develop modules, the module replaces a driver and the tests get more thorough.
- If we look at the red lines – we might have 3 subsystems we are working with.
- Eventually all the drivers get replaced and we have a working system.

Sandwich, etc



- Working from the extremes (top and bottom) toward center, we may use fewer drivers and stubs, OR
- A “thread” is a portion of several modules that together provide a user-visible program feature.
- Integrating one thread, then another, etc., we maximize visibility for the user
- This can reduce the number of stubs and drivers

Critical Modules

- Strategy: Start with riskiest modules
  - Risk assessment is necessary first step
  - May include technical risks (is X feasible?), process risks (is schedule for X realistic?), other risks
- May resemble thread or sandwich process in tactics for flexible build order
  - E.g., constructing parts of one module to test functionality in another
- Key point is risk-oriented process
  - Integration testing as a risk-reduction activity, designed to deliver any bad news as early as possible

Choosing a Strategy

- Functional strategies require more planning
  - Structural strategies (bottom up, top down, sandwich) are simpler
  - But thread and critical modules testing provide better process visibility, especially in complex systems
- Possible to combine
  - Top-down, bottom-up, or sandwich are reasonable for relatively small components and subsystems
  - Combinations of thread and critical modules integration testing are often preferred for larger subsystems

Working Definition of *Component*

- Reusable unit of deployment and composition
  - Deployed and integrated multiple times
  - Integrated by different teams (usually)
    - Component producer is distinct from component user
- Characterized by an *interface* or *contract*
    - Describes access points, parameters, and all functional and non-functional behavior and conditions for using the component
    - No other access (e.g., source code) is usually available
- Often larger grain than objects or packages
  - Example: A complete database system may be a component

Components — Related Concepts

- Framework
  - Skeleton or micro-architecture of an application
  - May be packaged and reused as a component, with “hooks” or “slots” in the interface contract
- Design patterns
  - Logical design fragments
  - Frameworks often implement patterns, but patterns are not frameworks. Frameworks are concrete, patterns are abstract
- Component-based system
  - A system composed primarily by assembling components, often “Commercial off-the-shelf” (COTS) components
  - Usually includes application-specific “glue code”

Component Interface Contracts

- Application programming interface (API) is distinct from implementation
  - Example: DOM interface for XML is distinct from many possible implementations, from different sources
- Interface includes *everything* that must be known to use the component
  - More than just method signatures, exceptions, etc
  - May include non-functional characteristics like performance, capacity, security
  - May include dependence on other components

Challenges in Testing Components

- The component builder’s challenge:
  - Impossible to know all the ways a component may be used
  - Difficult to recognize and specify all potentially important properties and dependencies

- The component user’s challenge:
  - No visibility “inside” the component
  - Often difficult to judge suitability for a particular use and context

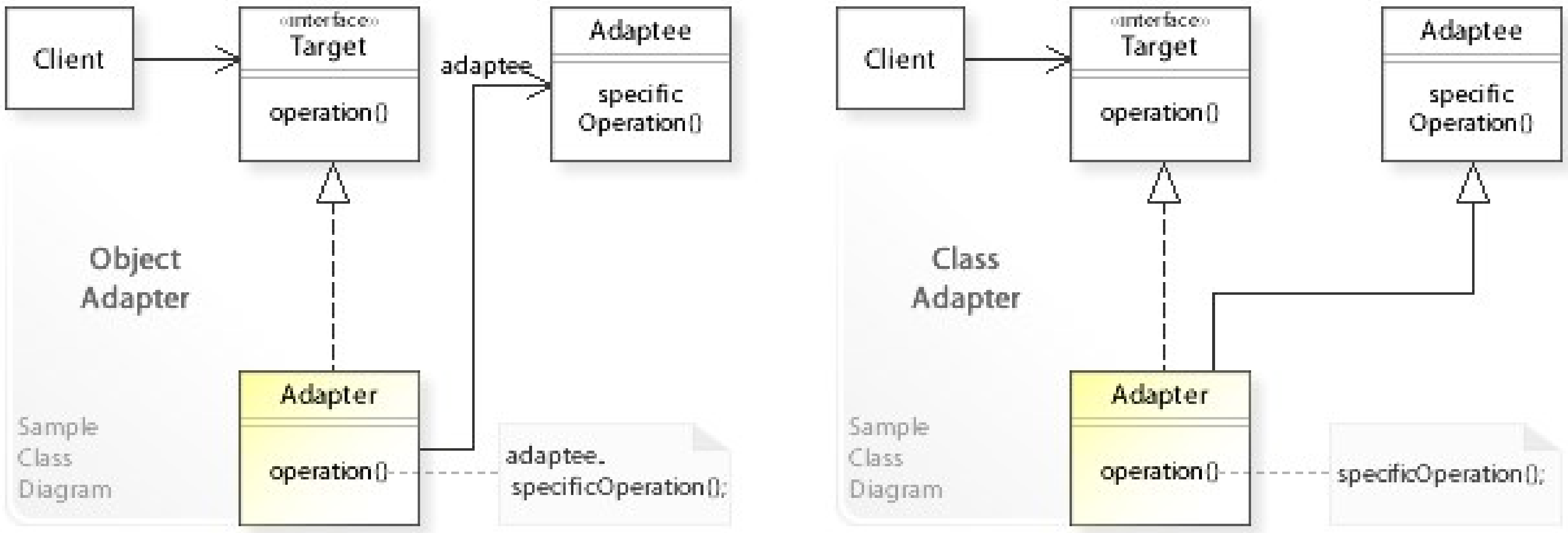
Testing a Component: Producer View

- First: Thorough unit and subsystem testing
  - Includes thorough functional testing based on application program interface (API)
  - Rule of thumb: Reusable component requires at least twice the effort in design, implementation, and testing as a subsystem constructed for a single use (often more)
- Second: Thorough acceptance testing
  - Based on scenarios of expected use
  - Includes stress and capacity testing
    - Find and document the limits of applicability

Testing a Component: User View

- Not primarily to find faults in the component
- Major question: Is the component suitable for *this* application?
  - Primary risk is not fitting the application context:
    - Unanticipated dependence or interactions with environment
    - Performance or capacity limits
    - Missing functionality, misunderstood API
  - Risk high when using component for first time
- Reducing risk: Trial integration early
  - Often worthwhile to build driver to test model scenarios, long before actual integration

Adapting and Testing a Component



- Applications often access components through an adaptor, which can also be used by a test driver (or at least a standard way to access a stub).

Summary

- Integration testing focuses on interactions
  - Must be built on foundation of thorough unit testing
  - Integration faults often traceable to incomplete or misunderstood interface specifications
    - Prefer prevention to detection, and make detection easier by imposing design constraints
- Strategies tied to project *build order*
  - Order construction, integration, and testing to reduce cost or risk
- Reusable components require special care
  - For component builder, and for component user