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Lecture 4: Testing Fundamentals

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DIT635 - January 29, 2021

Verification

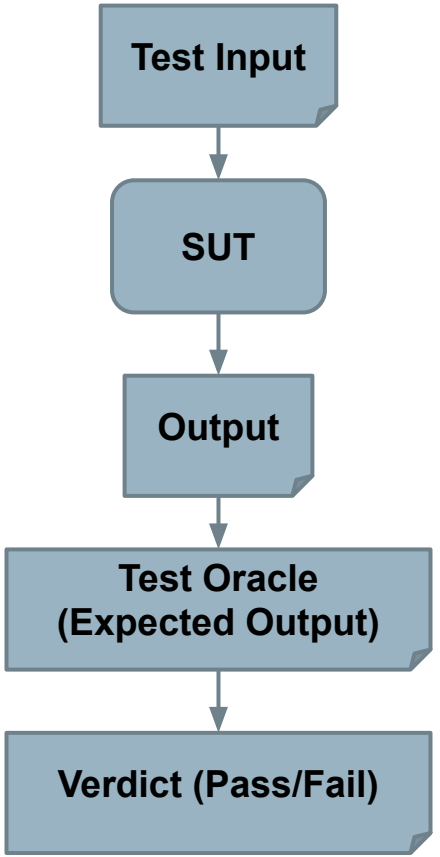
- Ensuring that an implementation conforms to its specification.
  - AKA: Under these conditions, does the software work?
- Proper V&V produces dependable software.
  - **Testing is the primary verification activity.**

We Will Cover

- What is testing?
- Definitions:
  - Let's get the language right.
  - What are the components of a test case?
- Testing stages:
  - Unit, System (Integration and Exploratory), and Acceptance Testing
- Test planning considerations

Software Testing

- An investigation into system quality.
- Based on sequences of **stimuli** and **observations**.
  - **Stimuli** that the system must react to.
  - **Observations** of system reactions.
  - **Verdicts** on correctness.



Bugs? What are Those?

- **Bug is an overloaded term.**
  - Does it refer to the bad behavior observed?
  - Is it the source code mistake that led to that behavior?
  - Is it both or either?

Faults and Failures

- **Failure**
  - An execution that yields an incorrect result.
- **Fault**
  - The problem that caused a failure.
  - Mistake in the code, omission from the code, misuse.
- **When we *observe a failure*, we try to *find the fault*.**

```
entrytrigger
12 if(ArrivalTime != current.ArrivalTime) {
13     current.ArrivalTime = ArrivalTime;
14     current.WIPs = [];
15     current.Cantidades = [];
16 }
17
18 current.labels.assert("WIP", []);
19 current.labels.assert("Cantidades", []);
20 int indice = current.WIPs.indexOf(WIP);
21
22 if(indice == -1) {
23     current.WIP.push(WIP);
24     current.Cantidades.push(1);
25     indice = current.Cantidades.length;
26 }
27 else
28     current.Cantidades[indice] += 1;
29
30 string Cantidad = string.fromNum(current.Cantidades[indice]);
31 string query;
32
33 if(Cantidad == "1") {
34     query = concat("insert into `flexsim`.`JamonesOutput` (`ArrivalTime`,`WIP`,`Cantidad`,`PT`,`WIP`)values ('", Arriv
35 }
36 else {
37     query = concat("update `flexsim`.`JamonesOutput` set Cantidad = '", Cantidad, "' where WIP = '", WIP, "' and Arriv
38 }
39
40 dbopen("flexsim", "select * from JamonesOutput", 0);
41 dbsqlquery(query);
42 dbclose();
```

Software Testing

- **The main purpose of testing is to find faults:**

  “Testing is the process of trying to discover every conceivable fault or weakness in a work product” - Glenford Myers

- Tests must reflect normal system usage and extreme boundary events.

Testing Scenarios

- **Verification:**
  - Demonstrate that software meets the specification.
  - Tests tend to reflect “normal” usage.
  - Any lack of conformance is a fault.
- **Resilience:**
  - Show that software can handle rare/extreme situations.
  - Tests tend to reflect extreme usage.
    - Large volume of data, null data, malformed data, attacks.

Axiom of Testing

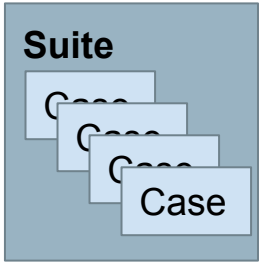
"Program testing can be used to show the presence of bugs, but **never their absence**."

- Dijkstra

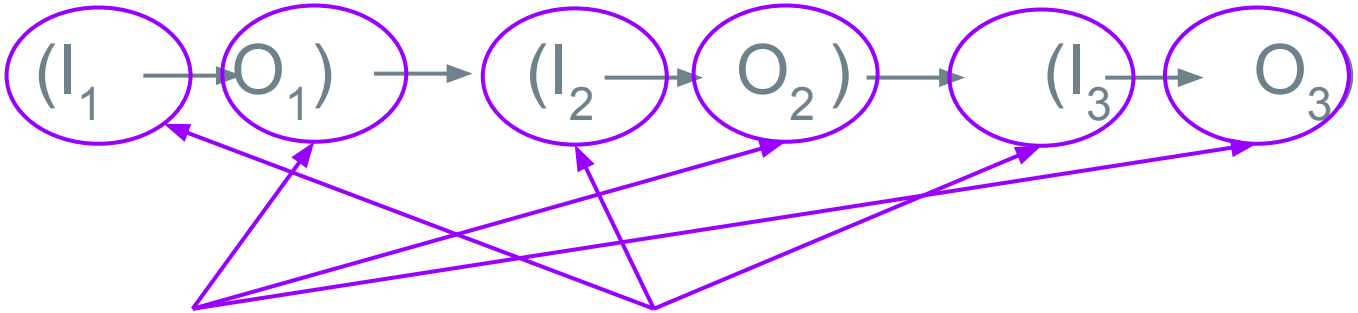
What Goes in a Test Case?

Test Suite and Test Case

- A **test suite** is a collection of **test cases**.
  - Executed together.
  - Each test case should be independent.
- May have multiple suites in one project.
  - Different types of tests, different resource/time needs.
- A test case consists of:
  - Initialization, Test Steps, Inputs, Oracles, Tear Down



Anatomy of a Test Case



if O_n = Expected(O_n)
then… Pass
else… Fail

Test Inputs

How we "stimulate" the system.

Test Oracle

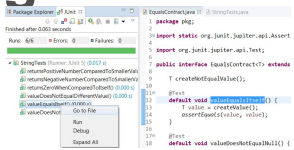
How we check the correctness of the resulting observation.

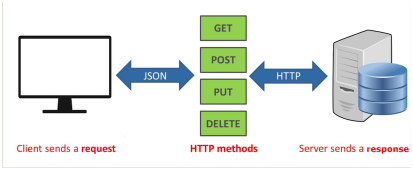
Anatomy of a Test Case

- Initialization
  - Any steps that must be taken before test execution.
- Test Steps
  - Interactions with the system, and comparisons between oracle and actual values.
- Tear Down
  - Any steps that must be taken after test execution.

Test Input

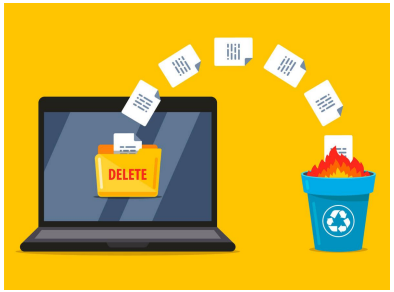
- Any deliberate interactions with a software feature.
  - **Generally, call a function through an interface.**
  - Method Call
  - API Call
  - CLI Interaction
  - GUI Interaction





Test Input

- Environment manipulation
  - Set up a database with particular records
  - Set up simulated network environment
  - Create/delete files
  - Control available CPU/memory/disc space
- Timing
  - Before/at/after deadline
  - Varying frequency/volume of input



Test Creation and Execution

- Can be **human-driven**
  - Exploratory testing, alpha/beta testing
- or **automated**
  - Tests written as code
    - Testing frameworks (JUnit)
    - Frameworks for manipulating interfaces (Selenium)
  - Capture/replay tools can re-execute UI-based tests (SWTBot for Java)
  - Automated input generation (AFL, EvoSuite)

Sources of Input

- **Black Box (Functional) Test Design**
- Use knowledge about how the system should act to design test cases.
  - Requirements, comments, user manuals, intuition.
- Tests can be designed before code is written.
  - (test-driven development)

Sources of Input

- **White Box (Structural) Test Design**
- Input chosen to exercise part of the code.
- Usually based on **adequacy criteria**:
  - Checklists based on program elements.
  - **Branch Coverage** - Make all conditional statements evaluate to all outcomes (if-statements, switches, loops)
- Fill in the gaps in black-box test design.

Test Oracle - Definition

- A predicate that determines whether a program is correct or not.
  - Based on observations of the program.
  - Output, timing, speed, energy use, ...
- Will respond with a **pass** or a **fail** verdict.
- Can be specific to one test or more general.

Test Oracle Components

- **Oracle Information**
  - Embedded information used to judge the correctness of the implementation, given the inputs.
- **Oracle Procedure**
  - Code that uses that information and relevant observations to arrive at a verdict.
  - Often as simple as...

```
if (actual value != expected value) { fail (...); }
assertEquals(actual value, expected value);
```

Oracles are Code

- Oracles must be developed.
  - Like the project, an oracle is built from the requirements.
    - … and is subject to interpretation by the developer
    - … and may contain faults
- A faulty oracle can be trouble.
  - May result in false positives - “pass” when there was a fault in the system.
  - May result in false negatives - “fail” when there was not a fault in the system.

Expected-Value Oracles

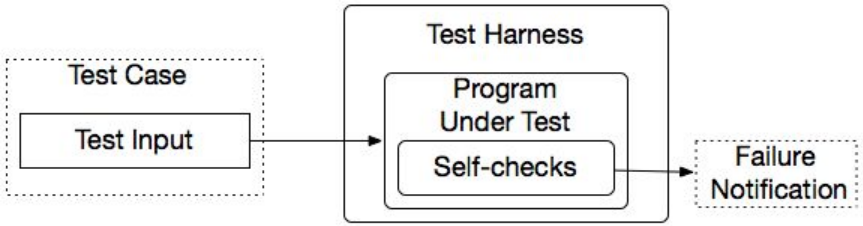
- Simplest oracle - what exactly should happen?

```
int expected = 7;
int actual = max(3, 7);
assertEquals(expected, actual);
```

- Oracle written for a single test case, not reusable.

Property-based Oracles

Rather than comparing actual values, use properties about results to judge sequences.




```
@Test
public void propertiesOfSort (String[] input) {
  // Tests
      String[] sorted = quickSort(input);
      assert(sorted.size >= 1, "This array can't be empty.")
      for (int item = 1; item < sorted.length; item++)
        assert(sorted[item] > sorted[item - 1], "Items
                  should be sorted in ascending order");
}
```

Uses assertions, contracts, and other logical properties.

Properties

- Usually written at “function” level.
  - For a method or high-level API/UI function.
  - Properties based on behavior of that function.
- Work for any input to that function.
- Trade-off: limited by number of properties.
  - Faults missed even if specified properties are obeyed.
  - More properties = more expensive to write.

Implicit Oracles

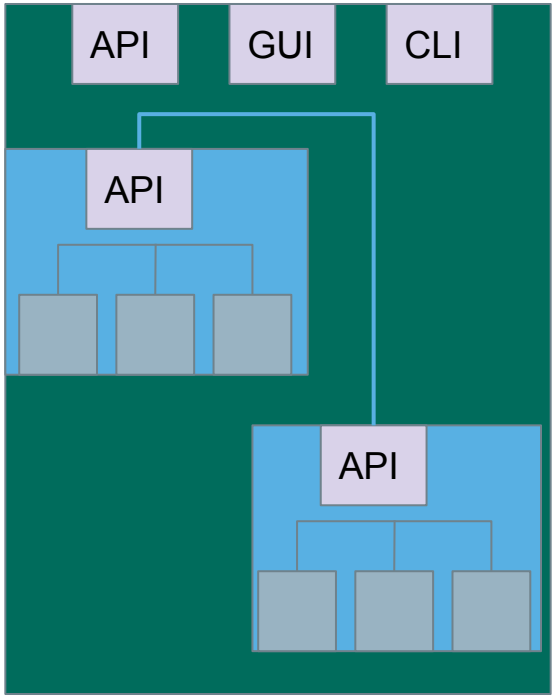
- Check properties expected of any program.
  - Crashes and exceptions.
  - Buffer overruns.
  - Deadlock.
  - Memory leaks.
  - Excessive energy usage or downloads.
- Faults that do not require expected output to detect.

Let’s take a break.

Testing Stages

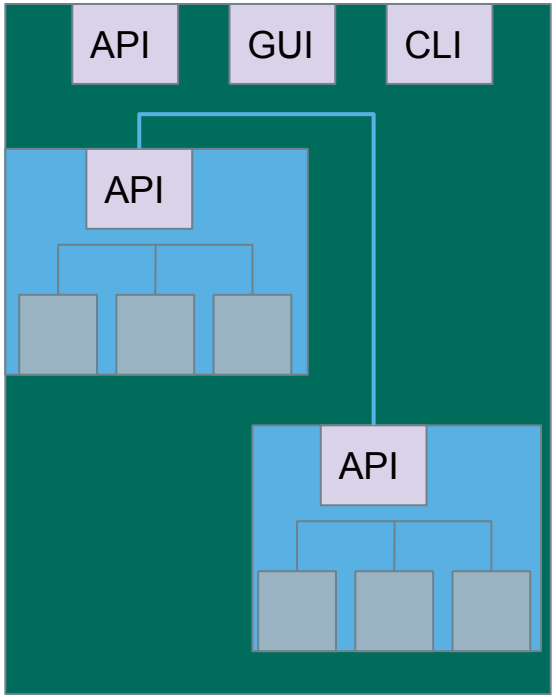
Testing Stages

- We interact with **systems** through **interfaces**.
  - APIs, GUIs, CLIs
- Systems built from **subsystems**.
  - With their own interfaces.
- Subsystems built from **units**.
  - Communication via method calls.
  - Set of methods is an interface.



Testing Stages

- **Unit Testing**
  - Do the methods of a class work?
- **System-level Testing**
  - **System (Integration) Testing**
    - (Subsystem-level) Do the collected units work?
    - (System-level) Does high-level interaction through APIs/UIs work?
  - **Exploratory Testing**
    - Does interaction through GUIs work?



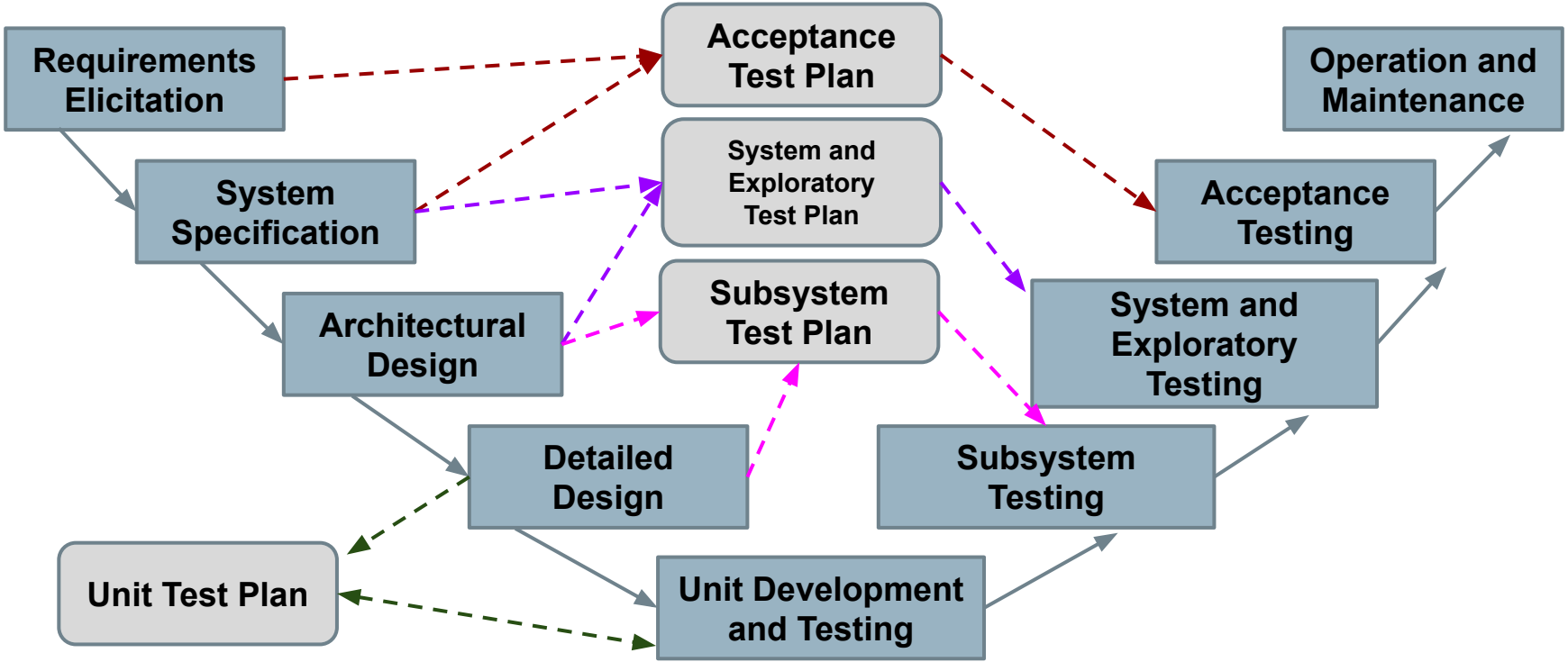
Testing Stages

- **Acceptance Testing/ AB Testing**
  - Give product to a set of users to check whether it meets their needs.
    - Alpha/beta Testing - controlled pools of users, generally on their own machine.
    - Acceptance Testing - controlled pool of customers, in a controlled environment, formal acceptance criteria
  - Can expose many faults.
  - Can be planned during requirements elicitation.

Automation vs Human-Driven

- Unit/System Testing heavily use automation.
  - Tests written as code.
  - Executed repeatedly, often on check-in.
- Exploratory/Acceptance Testing often human-driven
  - Humans interact with app.
  - Based on scenarios, without pre-planned input.
  - Some tool support, but not often repeated exactly.

The V-Model of Development

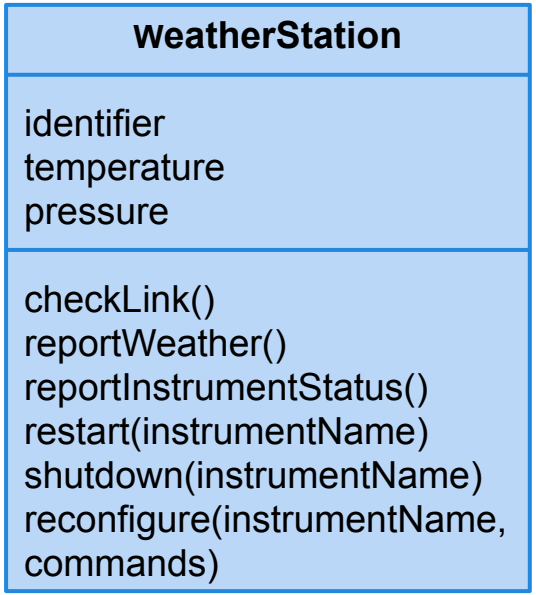


Unit Testing

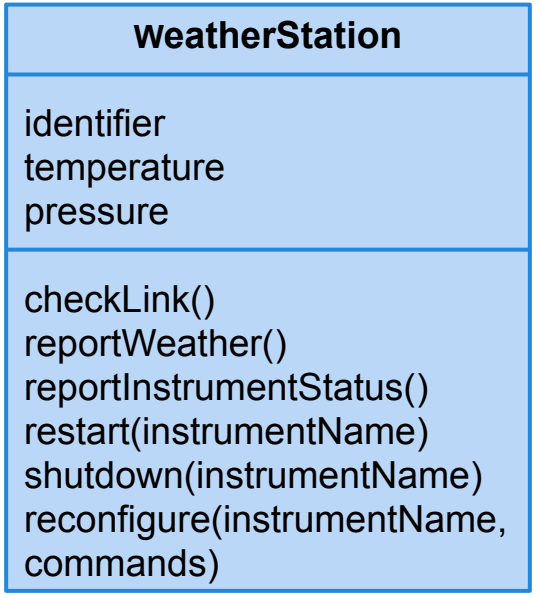
- Testing the smallest “unit” that can be tested.
  - Often, a class and its methods.
- Tested in **isolation** from all other units.
  - **Mock** the results from other classes.
- Test input = method calls.
- Test oracle = assertions on output/class variables.

Unit Testing

- For a unit, tests should:
  - Test all “jobs” associated with the unit.
    - Individual methods belonging to a class.
    - Sequences of methods that can interact.
  - Set and check class variables.
    - Examine how variables change after method calls.
    - Put the variables into all possible states (types of values).



Unit Testing - WeatherStation



Unit tests should cover:

- Set and check class variables.
  - Can any methods change identifier, temperature, pressure?
- Each “job” performed by the class.
  - Single methods or method sequences.
  - Vary the order methods are called.
  - Each outcome of each “job” (error handling, return conditions).

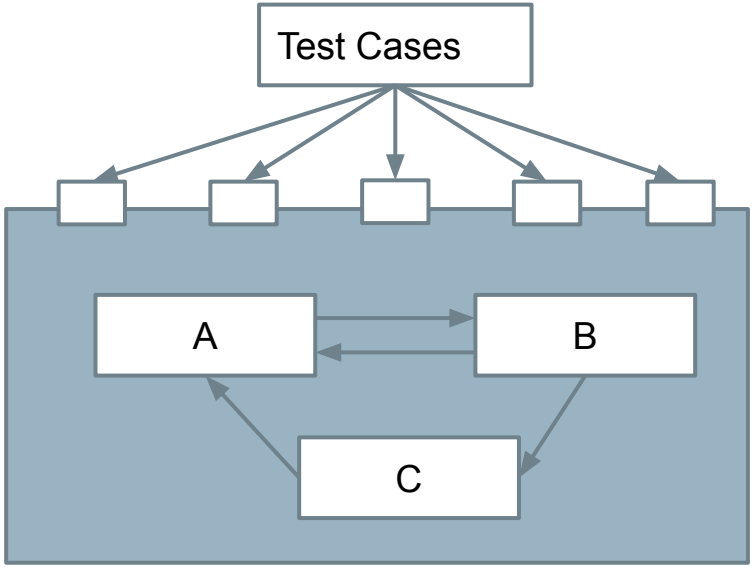
System (Integration) Testing

- After testing units, test their **integration**.
  - Integrate units in one subsystem.
  - Then integrate the subsystems.
- Test input through a defined interface.
  - Focus on showing that functionality accessed through interfaces is correct.
  - Subsystems: “Top-Level” Class, API
  - System: API, GUI, CLI, …

System Testing

Subsystem made up classes of A, B, and C. We have performed unit testing...

- Classes work together to perform subsystem functions.
- Tests applied to the interface of the subsystem they form.
- Errors in combined behavior not caught by unit testing.



Interface Errors

- Interface Misuse
  - Malformed data, order, number of parameters.
- Interface Misunderstanding
  - Incorrect assumptions made about called component.
  - A binary search called with an unordered array.
- Timing Errors
  - Producer of data and consumer of data access data in the wrong order.

GUI Testing

- Tests designed to reflect **end-to-end** user journeys.
  - From opening to closing.
  - Often based on **scenarios**.
- GUI Testing
  - Deliberate tests, specific input.
  - May be automated or human-executed.
- Exploratory Testing
  - Open-ended, human-driven exploration.

Exploratory Testing

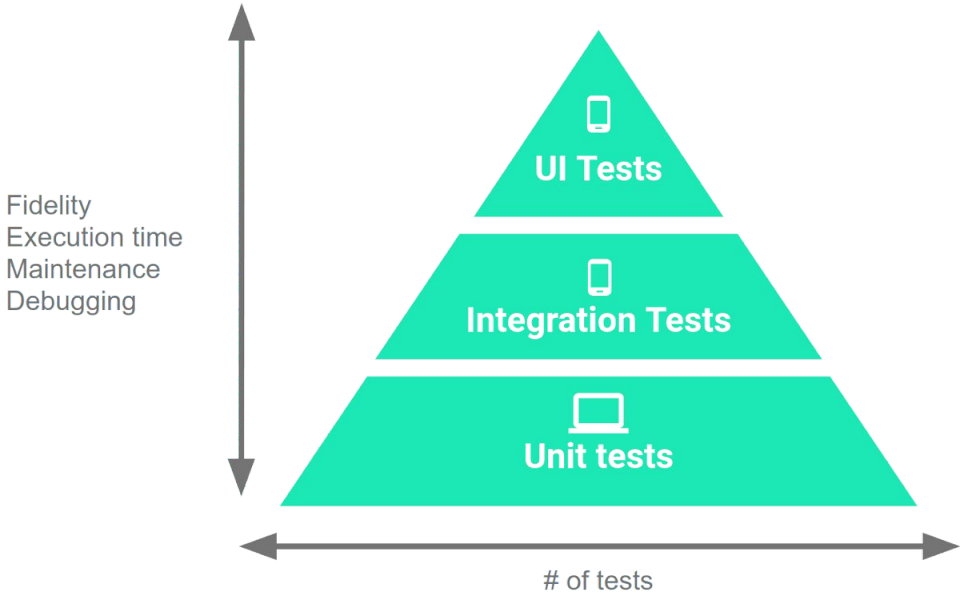
- Tests are not created in advance.
- Testers check the system on-the-fly.
  - Guided by scenarios.
  - Often based on ideas noted before beginning.
- Testing as a thinking idea.
  - About discovery, investigation, and role-playing.
  - Tests end-to-end journeys through app.
  - Test design and execution done concurrently.

Exploratory Testing

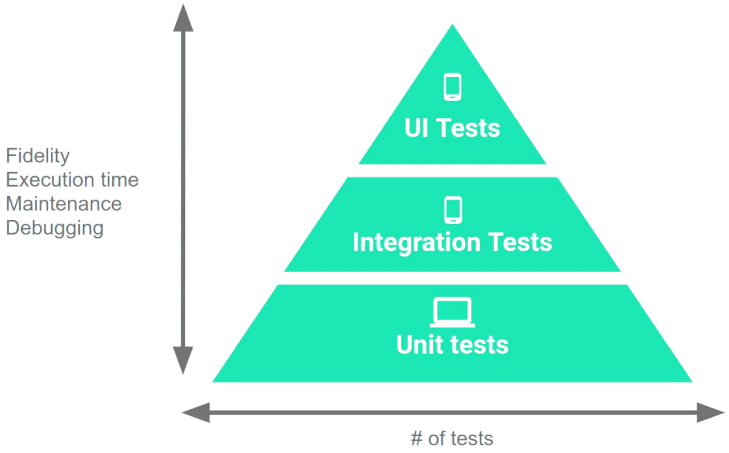
- Tester write down ideas to give direction, then create critical, practical, and useful tests.
  - Requires minimal planning. Tester chooses next action based on result of current action.
- Can find subtle faults missed by formal testing.
  - Allows tester to better learn system functionality, and identify new ways of using features.

Testing Percentages

- Unit tests verify behavior of a single class.
  - 70% of your tests.
- System tests verify class interactions.
  - 20% of your tests.
- GUI tests verify end-to-end journeys.
  - 10% of your tests.



Testing



- 70/20/10 recommended.
- Unit tests execute quickly, relatively simple.
- System tests more complex, require more setup, slower to execute.
- UI tests very slow, may require humans.
- Well-tested units reduce likelihood of integration issues, making high levels of testing easier.

Acceptance Testing

Once the system is internally tested, it should be placed in the hands of users for feedback.

- Users must ultimately approve the system.
- Many faults do not emerge until the system is used in the wild.
  - Alternative operating environments.
  - More eyes on the system.
  - Wide variety of usage types.

Acceptance Testing Types

- Alpha Testing
  - A small group of users work closely with development team to test the software.
- Beta Testing
  - A release of the software is made available to a larger group of interested users.
- Formal Acceptance Testing
  - Customers decide whether or not the system is ready to be released.

Acceptance Testing Stages

- Define acceptance criteria
  - Work with customers to define how validation will be conducted, and the conditions that will determine acceptance.
- Plan acceptance testing
  - Decide resources, time, and budget for acceptance testing. Establish a schedule. Define order that features should be tested. Define risks to testing process.

Acceptance Testing Stages

- Derive acceptance tests.
  - Design tests to check whether or not the system is acceptable. Test both functional and non-functional characteristics of the system.
- Run acceptance tests
  - Users complete the set of tests. Should take place in the same environment that they will use the software. Some training may be required.

Acceptance Testing Stages

- Negotiate test results
  - It is unlikely that all of the tests will pass the first time. Developer and customer negotiate to decide if the system is good enough or if it needs more work.
- Reject or accept the system
  - Developers and customer must meet to decide whether the system is ready to be released.

Let’s take a break.

Test Plans

Test Plans

- Plan for how we will test the system.
  - **What** is being tested (units, subsystems, features).
  - **When** it will be tested (required stage of completion).
  - **How** it will be tested (what scenarios do we run?).
  - **Where** we are testing it (types of environments).
  - **Why** we are testing it (what purpose do tests serve?).
  - **Who** will be responsible for writing test cases (assign responsibility to team members).

Why Make a Test Plan?

- Guides development team.
  - Rulebook for planning test cases.
- Helps people outside the team understand the testing process.
- Documents rationale for scope of testing, how we judge results, why we chose a strategy.
  - Can be reused when making decisions in future projects.

Analyze the Product

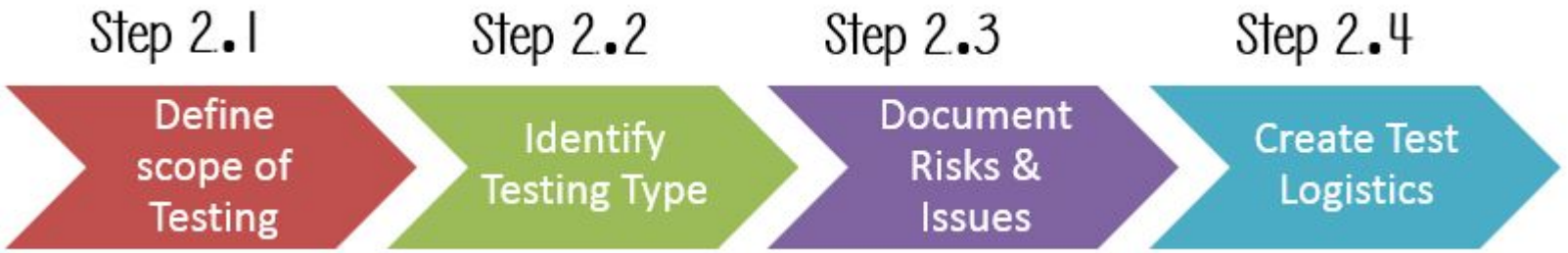
- Must understand the product before you can test it.
  - What are the needs of the users?
  - Who will use the product?
  - What will it be used for?
  - What are the dependencies of the product?
- Review requirements and documentation.
- Interview stakeholders and developers.
- Perform a product walkthrough (if code is running).

Analyze the Product

- Banking Website
  - What features do we want to see?
  - Account creation, deletion, manipulation.
  - Fund transfers
  - Fund withdrawal
  - Check deposit
  - …?

Develop the Test Strategy

- Document defining:
  - Test Objectives (and how to achieve them)
  - Testing Effort and Cost



Testing Scope

- **What are you planning to test?**
  - Software, hardware, middleware, ...
- … AND… What are you **NOT** going to test?
  - Gives project members a clear understanding about what you are responsible for.
- Must take into account:
  - Requirements, budget, skills of your testing team

Slides derived from https://www.guru99.com/what-everybody-ought-to-know-about-test-planing.html

Testing Scope

- Banking website
  - Requirements specified only for functionality and the external interface.
    - **These are in-scope.**
  - No requirements for database or client hardware.
  - No quality requirements (performance, availability).
    - **These are out-of-scope.**

Identify Testing Types

For the banking site:

- System Testing
  - Focus on verifying access points and interfaces.
  - Functionality likely spread over multiple classes, many features interact
- Exploratory Testing

Could limit:

- Unit Testing (focus on integration/interfaces over individual classes)

Can skip:

- Acceptance Testing

- Which should we apply?
  - Consider the project domain.
- Which can we skip or limit to save money?

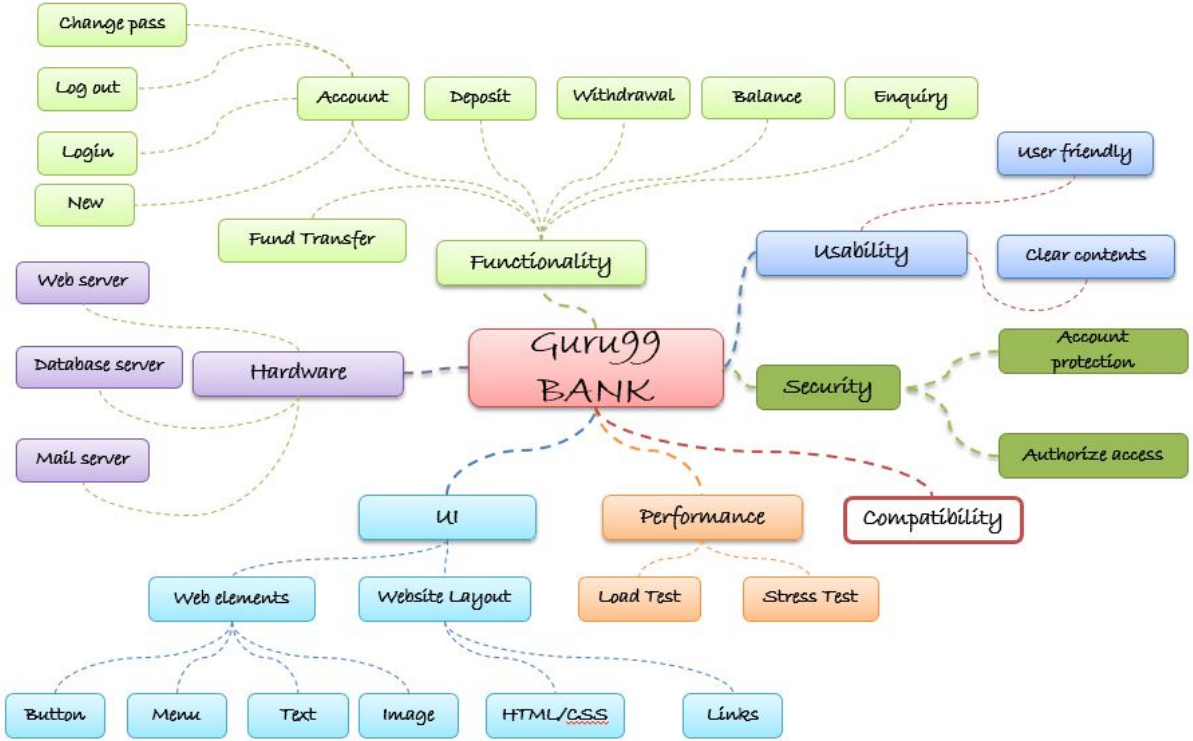
Create Test Logistics

- Who will write and execute test cases?
  - What types of testers do you need?
    - Skills needed for the targeted domain
  - What is the budget for testing?
    - How many people can you hire to test?
- When will each testing activity occur?
  - When to design and when to execute tests.
  - Pair with appropriate stage of development.
    - Unit development -> unit testing -> system testing -> ...

Define Test Objectives

- What are the goals of the testing process?
  - What features, system elements need to be tested?
  - What quality attributes do we need to demonstrate?
  - For each feature or quality, what scenarios do we want to walk through?
- Does not include a list of specific tests
  - But, at a high level, should detail scenarios we plan to examine by writing one or more test cases.

Define Test Objectives



Slides derived from https://www.guru99.com/what-everybody-ought-to-know-about-test-planing.html

Define Test Criteria

- When have we completed our testing objectives?
  - For qualities, set appropriate thresholds.
    - Availability, ROCOF, throughput, etc.
  - For functionality, commonly defined using:
    - **Run Rate: Number of Tests Executed / Number Specified**
    - **Pass Rate: Number of Passing Tests / Number Executed**
    - Often aim for 100% run rate and a high pass rate (> 95%)

Slides derived from https://www.guru99.com/what-everybody-ought-to-know-about-test-planing.html

Resource Planning

- Summarize resources that you have.
  - Allows estimation and adjustment of testing scope, objectives, and exit criteria.
- Human Resources: Managers, testers, developers who assist in testing, system administration.
- System Resources: Servers, testing tools, network resources, physical hardware.

Plan Test Environment

- Where will you execute test cases?
  - Software and hardware execution environment
  - Often defined as part of continuous integration.
- Need to account for:
  - Requirements on both server and client-side.
  - Different networking conditions (bandwidth, load).
  - Different client or server-side hardware.
  - Different numbers of concurrent users.

Schedule Estimation

- Break testing plans into individual tasks, each with an effort estimation (in person-hours)
  - Create test specification, 170 person-hours
  - Write unit tests, 80 person-hours
  - Write API tests, 50 person-hours
  - Perform test execution, 1 person-hour (per suite execution)
  - Write test report, 10 person-hours
  - …

We Have Learned

- What is testing?
- Testing terminology and definitions.
  - Input, oracles
  - Faults, failures
- Testing stages include unit testing, system testing, exploratory/GUI testing, and acceptance testing.
- Test planning needs to consider resources, time, scope, environment.

Next Time

- **Exercise session today: quality scenarios**
- Next lecture: System Testing
  - Optional reading: Pezze and Young, Ch 10-11
- Assignment 1

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