CHALMERS
UNIVERSITY OF TECHNOLOGY

UNIVERSITY OF GOTHENBURG

Lecture 4: Testing Fundamentals

Gregory Gay
DIT636/DAT560 - January 29, 2025

Verification

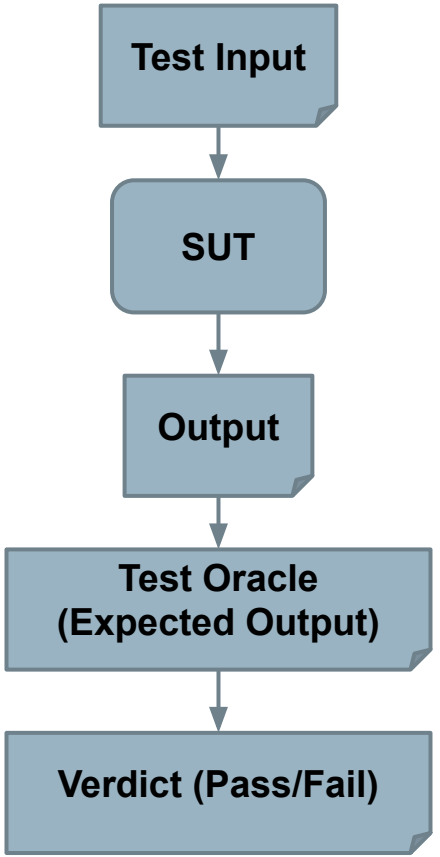
- Ensuring that an implementation conforms to its specification.
  - AKA: Under these conditions, does the software work?
- Proper V&V produces dependable software.
  - **Testing is the primary verification activity.**

We Will Cover

- What is testing?
  - Definitions and components of a test case
  - Testing stages
  - Planning considerations

Software Testing

- *Experimental investigation* of 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?
  - Both?

Faults and Failures

- **Failure**
  - An execution that yields an incorrect result.
- **Fault**
  - Problem that caused failure.
  - Mistake, omission, 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 remove faults:**

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

- Tests must reflect normal *and* abnormal usage.

Testing Scenarios

- **Verification**:
  - Demonstrate that software meets the specification.
  - Tests tend to reflect “normal” usage.
- **Resilience**:
  - Show that software can handle abnormal situations.
  - Tests tend to reflect extreme usage or hazards.
    - Large volume of data, null data, malformed data, attacks.

Axiom of Testing

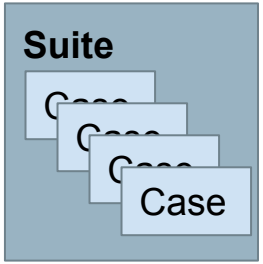
"Testing can be used to show the presence of bugs, but ***never their absence***."

- Dijkstra

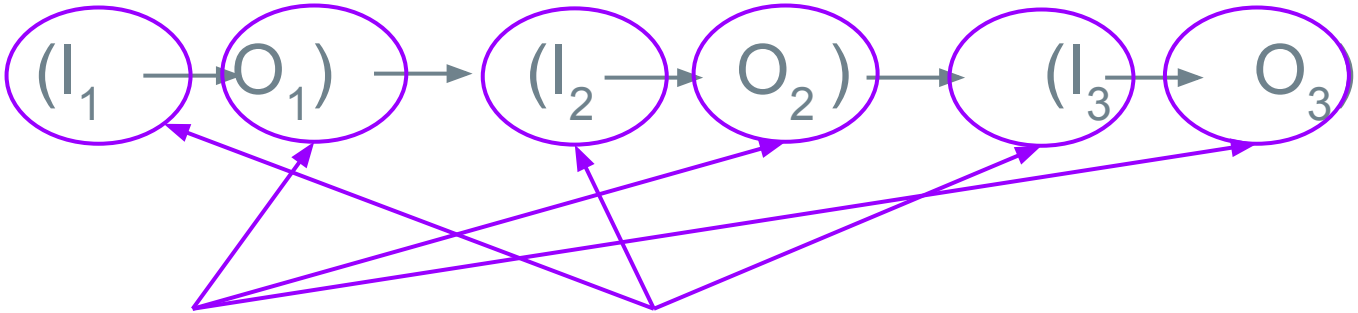
What Goes in a Test Case?

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.



Anatomy of a Test Case



if O_n = Expected(O_n)

then… Pass

else… Fail

Test Inputs

How we "stimulate" the system.

Test Oracle

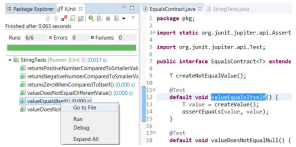
How we check the correctness of the resulting observation.

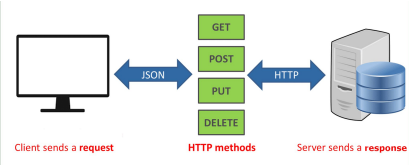
Anatomy of a Test Case

- 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

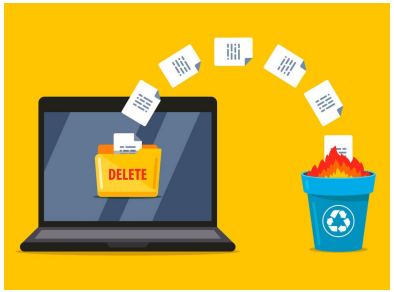
- Interactions with a software feature.
  - **Invoke a function through an interface.**
    - Method Call
    - API Call
    - CLI Interaction
    - GUI Interaction





Test Input

- Environment manipulation
  - Database with particular records
  - Simulated network environment
  - Create/delete files
  - Available CPU/memory/disc space
- Timing
  - Before/at/after deadline
  - Varying frequency/volume of input



Test Execution

- **Human-driven**
  - Exploratory testing, alpha/beta testing
- **Automated**
  - Tests written as code
    - Testing frameworks (JUnit)
    - Frameworks for manipulating interfaces (Selenium)
  - Capture/replay tools
    - Re-execute UI-based tests (SWTBot for Java)

Sources of Input

- **Black Box (Functional) Test Design**
  - Use documentation of system behavior to design tests.
  - 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 code in specific way.
  - Usually based on **adequacy criteria**:
    - Checklists based on program elements.
    - **Branch Coverage** - All conditional statements evaluate to all outcomes.
  - Fill in the gaps in black-box test design.

Test Oracle

- Comparison of observations to expectations.
  - Expected output, timing, speed, energy use, ...
- Calculate 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 information and observations to calculate a verdict.
    - `if (actual value != expected value) { fail (...); }`
    - `assertEquals(actual value, expected value);`

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

- Assert properties about results to judge correctness.
- Can be reused, but loss of precision.
  - Know less about any one I/O pair.

```
@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");
}
```

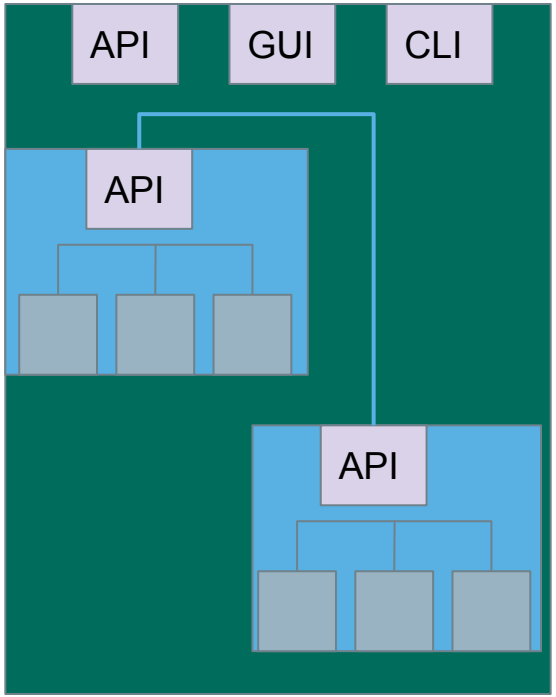
Implicit Oracles

- See if general failures occur:
  - Crashes and exceptions.
  - Buffer overruns.
  - Deadlock.
  - Memory leaks.
  - Excessive energy usage or downloads.
  - Poor performance.
- Failures that do not require expected output.

Testing Stages

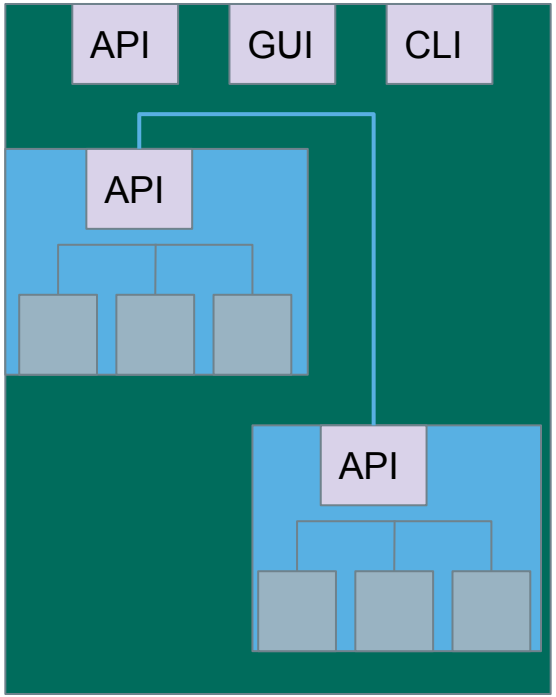
Testing Stages

- 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.



Testing Stages

- **Unit Testing**
  - Methods of a single class
- **System-level Testing**
  - **System (Integration) Testing**
    - (Subsystem-level) Collected units
    - (System-level) High-level interfaces
  - **Exploratory Testing**
    - Ad-hoc GUI testing method



Testing Stages

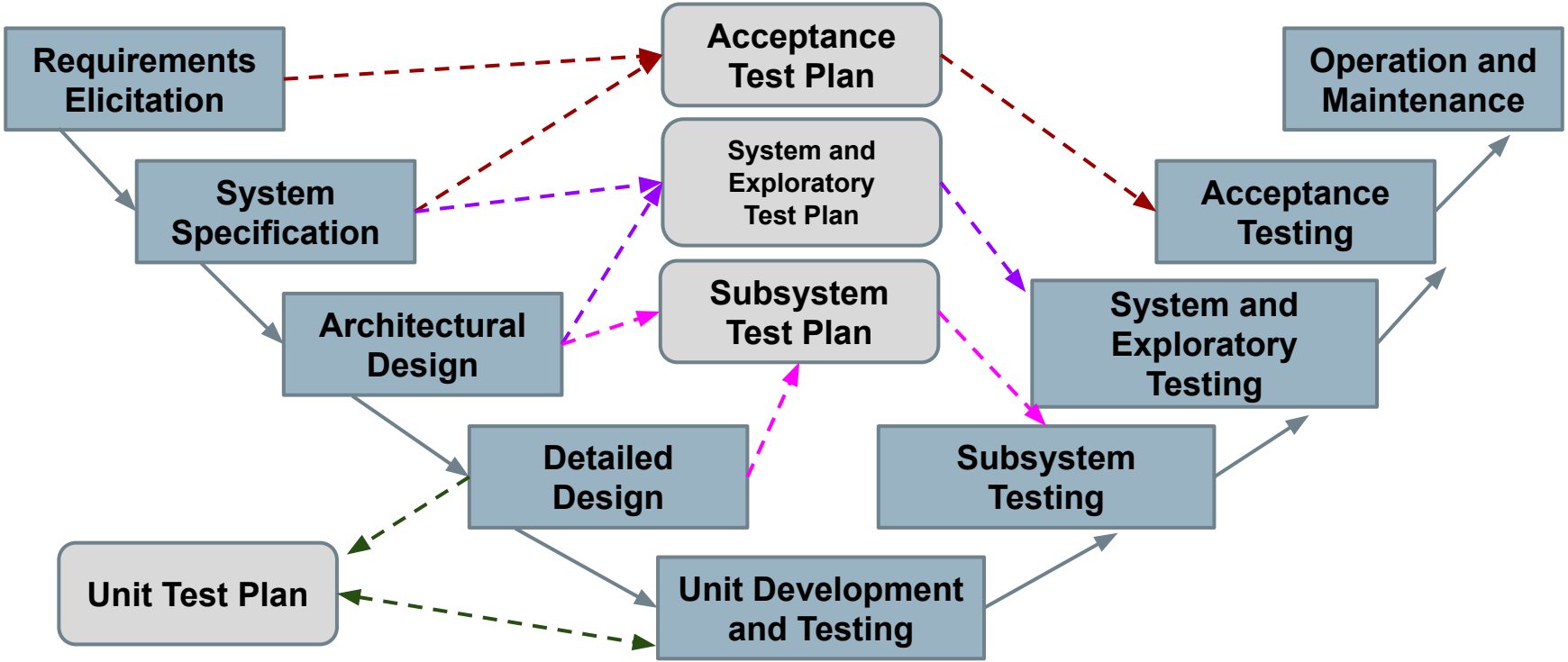
- **Acceptance Testing/ AB Testing**
  - Give product to a set of users to check whether it meets their needs.
    - **Alpha/Beta Testing** - End-users, generally on their own machine.
    - **Acceptance Testing** - Formal customers, in a controlled environment, formal acceptance criteria

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
  - Based on scenarios, without pre-planned input.
  - Some tool support, but not often repeated exactly.

Let’s take a break.

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.

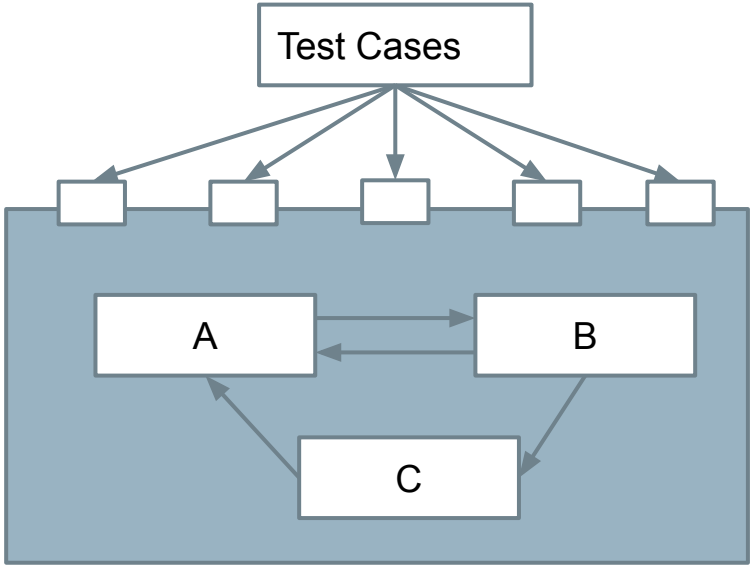
System (Integration) Testing

- After testing units, test their **integration**.
  - Integrate units in one subsystem.
  - Integrate subsystems.
- Test input through a defined interface.
  - 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.



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

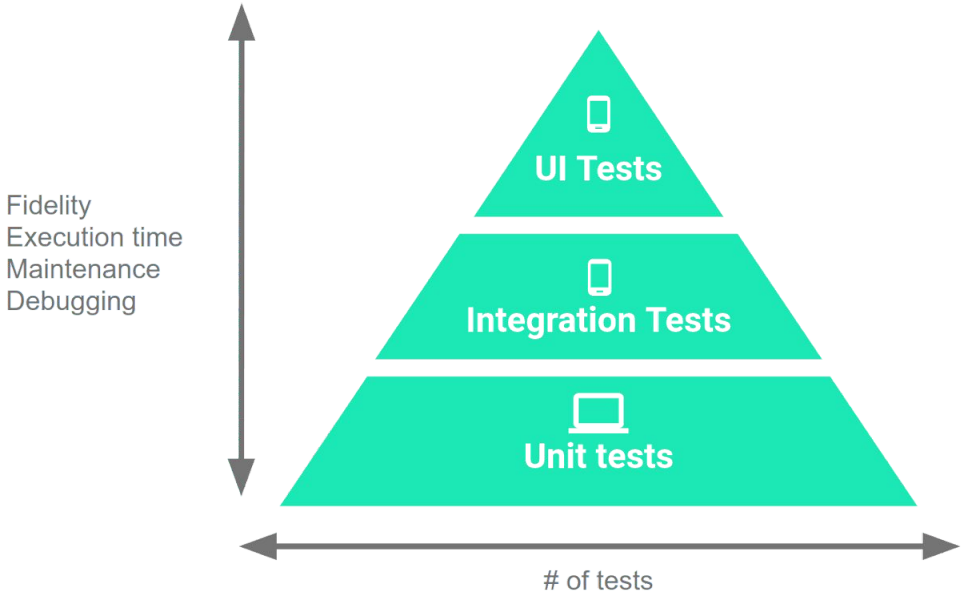
- Tests not created in advance.
- Testers check the system on-the-fly.
- Testing as a thinking idea.
  - About discovery, investigation, and role-playing.
  - Tests end-to-end journeys through app.
  - Test design and execution done concurrently.

Exploratory Testing

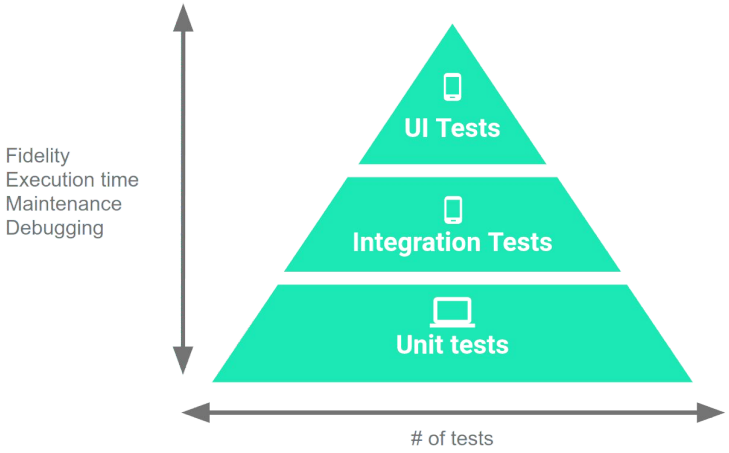
- Tester write down ideas to give direction, then create tests while using system.
  - Requires minimal planning.
  - Choose next action based on current state.
- Can find subtle faults missed by formal testing.
  - Allows tester to better learn system functionality, and identify new ways of using features.

Testing Percentages

- Unit tests verify behavior of a single class.
  - 70% of your tests.
- System tests verify class interactions.
  - 20% of your tests.
- GUI/exploratory 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 only emerge 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.

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

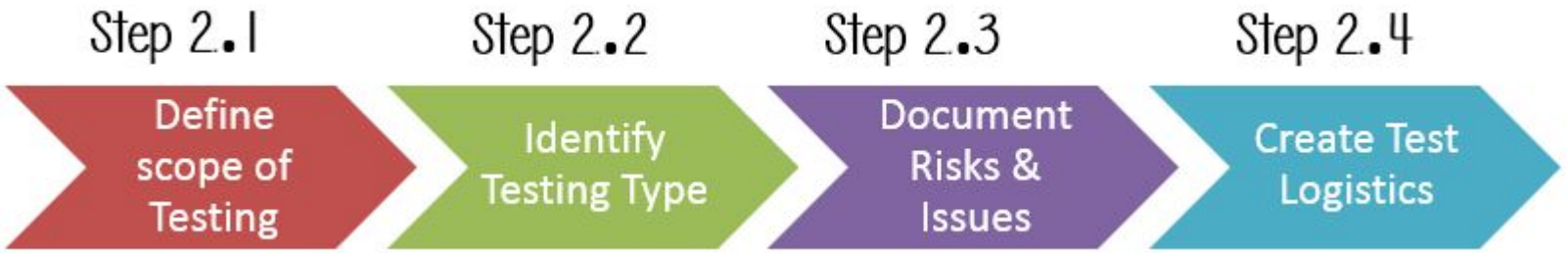
- Must understand the product before you can test it.
  - What are the needs of the users?
  - Who will use the product?
  - What will it be used for?
  - What are the dependencies of the product?
- Review requirements and documentation.
- Interview stakeholders and developers.
- Perform a product walkthrough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

- Example: Banking website
  - Requirements specified for functionality and external interface.
    - **These are in-scope.**
  - No requirements specified for database or client hardware.
    - **These may be 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

May choose to limit:

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

May choose to 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 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 Created / 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 this afternoon:**
  - **Quality scenarios**
- Next week: Test Design and Unit Testing

UNIVERSITY OF
GOTHENBURG

CHALMERS
UNIVERSITY OF TECHNOLOGY