Lecture 10: System-Level Testing

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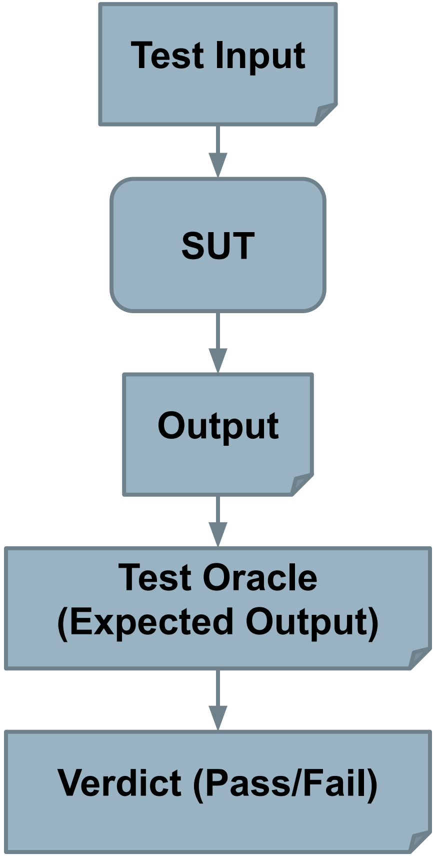
Today's Goals

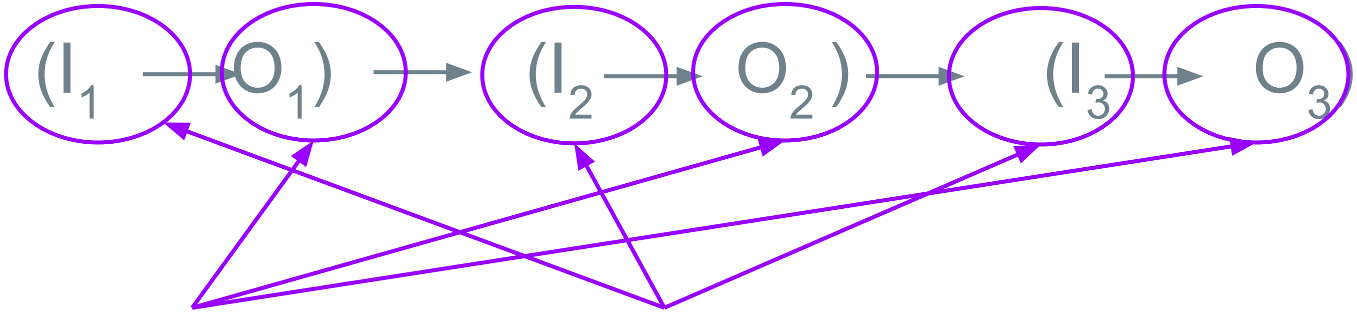
- Discuss testing at the system level.
  - System (Integration) Testing versus Unit Testing.
- Introduce process for creating System-Level Tests.
  - Identify Independently Testable Functionality
  - Identify Choices (AKA variation points)
  - Identify Representative Values for each Choice
  - Generate Test Case Specifications
  - Generate Concrete Test Cases

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.



Anatomy of a Test Case



Test Inputs

How we “stimulate” the system (method call, API request, GUI event).

Test Oracle

How we check the correctness of the resulting observation (assertions).

if O_n = Expected(O_n)

then… Pass

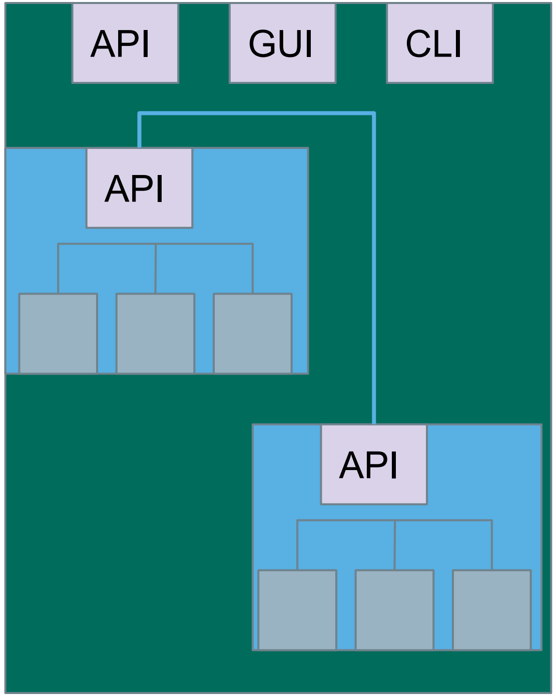
else… Fail

Anatomy of a Test Case

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

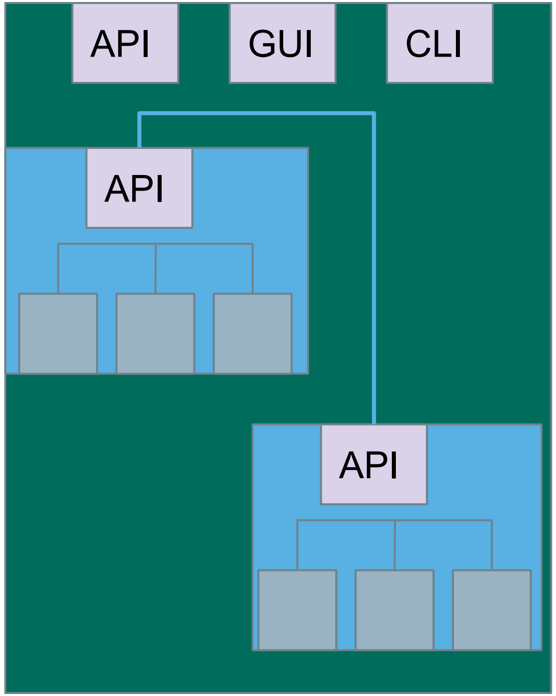
Testing Stages

- 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?



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).

Account
- name - personnummer - balance
Account (name, personnummer, Balance) withdraw (double amount) deposit (double amount) changeName(String name) getName() getPersonnummer() getBalance()

Unit Testing - Account

Account
- name - personnummer - balance
Account (name, personnummer, Balance) withdraw (double amount) deposit (double amount) changeName(String name) getName() getPersonnummer() getBalance()

Some tests we might want to write:

- Execute constructor, verify fields.
- Check the name, change the name, make sure changed name is in place.
- Check that personnummer is correct.
- Check the balance, withdraw money, verify that new balance is correct.
- Check the balance, deposit money, verify that new balance is correct.

Unit Testing - Account

Account

- name
- personnummer
- balance

Account (name, personnummer, Balance)

withdraw (double amount)
deposit (double amount)
changeName(String name)
getName()
getPersonnummer()
getBalance()

Some potential error cases:

- Withdraw more than is in balance.
- Withdraw a negative amount.
- Deposit a negative amount.
- Withdraw/Deposit a small amount (potential rounding error)
- Change name to a null reference.
- Can we set an “malformed” name?
  - (i.e., are there any rules on a valid name?)

Unit Testing - Account

Account
- name - personnummer - balance
Account (name, personnummer, Balance) withdraw (double amount) deposit (double amount) changeName(String name) getName() getPersonnummer() getBalance()

- Withdraw money, verify balance.

Each test is

Name based on type of scenario, and expectation on outcome.

```
@Test
public void testWithdraw_normal() {
    // Setup
    Account account = new Account("Test McTest", "19850101-1001", 48.5);
    // Test Steps
    double toWithdraw = 16.0; //Input
    account.withdraw(toWithdraw);
    double actual = account.getBalance();
    double expectedBalance = 32.5; // Oracle
    assertEquals(expected, actual); // Oracle
}
```

Initialization

Input

Test Steps

Oracle

Unit Testing - Account

Account
- name - personnummer - balance
Account (name, personnummer, Balance) withdraw (double amount) deposit (double amount) changeName(String name) getName() getPersonnummer() getBalance()

- Withdraw a negative amount.
  - (should throw an exception with appropriate error message)

```
@Test
public void testWithdraw_negative() {
    // Setup
    Account account = new Account("Test McTest", "19850101-1001", 48.5);
    // Test Steps
    double toWithdraw = -2.5; //Input
    Throwable exception = assertThrows(
        () -> { account.withdraw(toWithdraw); } );
    assertEquals("Cannot withdraw a negative amount: -2.50",
                    exception.getMessage()); // Oracle
}
```

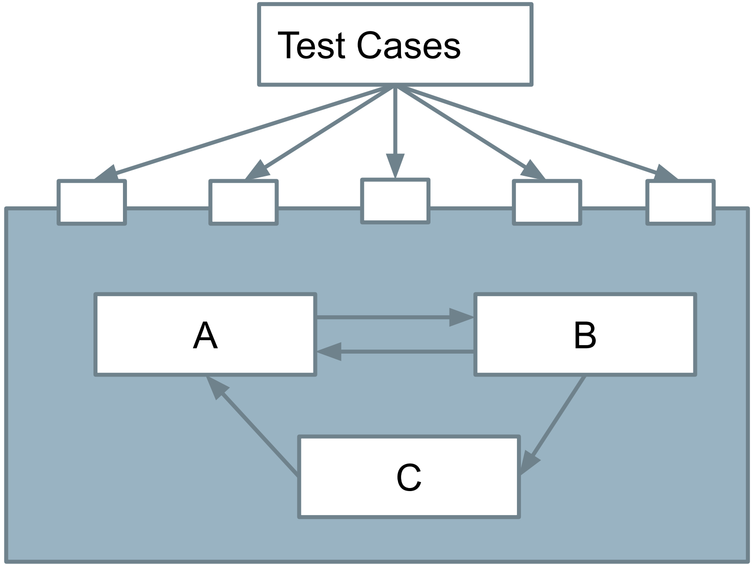
System Testing

- After testing units, test their **integration**.
  - Integrate units in one subsystem.
  - Then integrate the subsystems.
- Test 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.



Unit vs System Testing

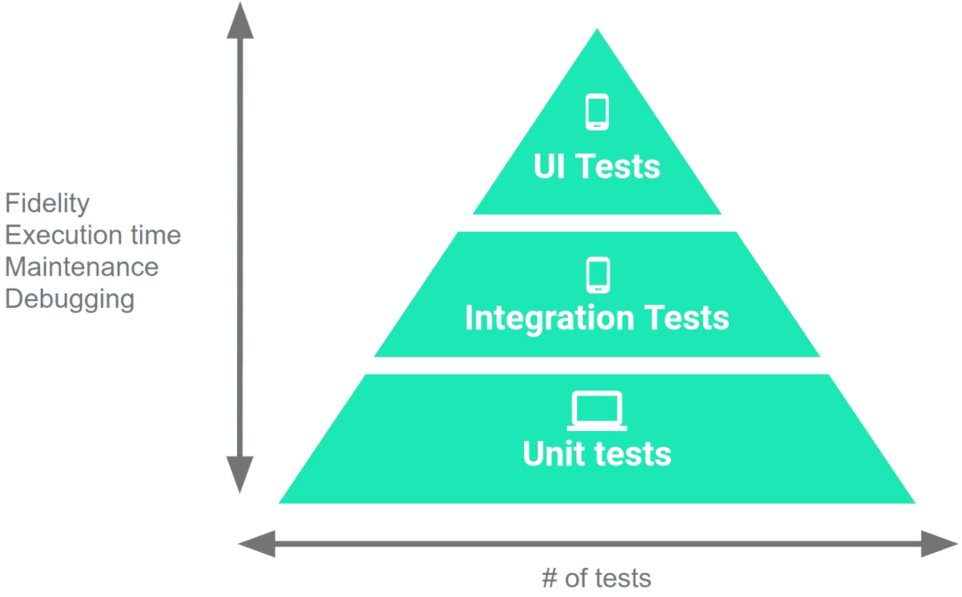
- Unit tests focus on a **single class**.
    - Simple functionality, more freedom.
    - Few method calls.
- System tests **bring many classes together**.
    - Focus on testing through an interface.
    - One interface call triggers many internal calls.
        - Slower test execution.
    - May have complex input and setup.

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.

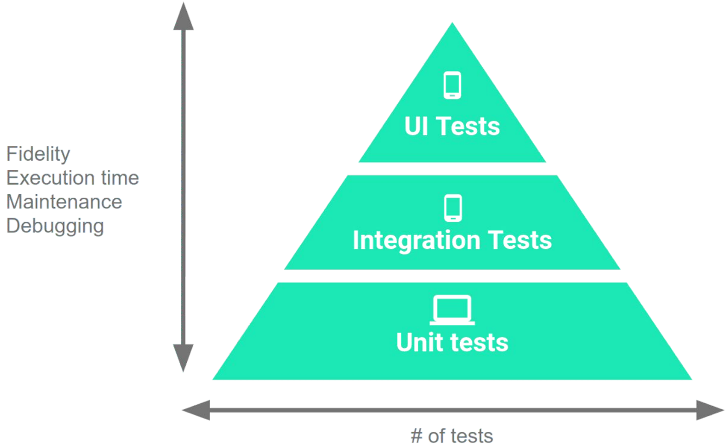
Testing Percentages

- 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.

Writing Integration and UI Tests

- Testing framework depends on language and interface type.
  - Android: JUnit (Integration - AndroidX, UI - Espresso)
  - RESTful API: Postman
  - Browser-based GUI: Selenium

Android UI Test

Uses Espresso testing libraries to interact with Views and Intents. (Part of AndroidX)

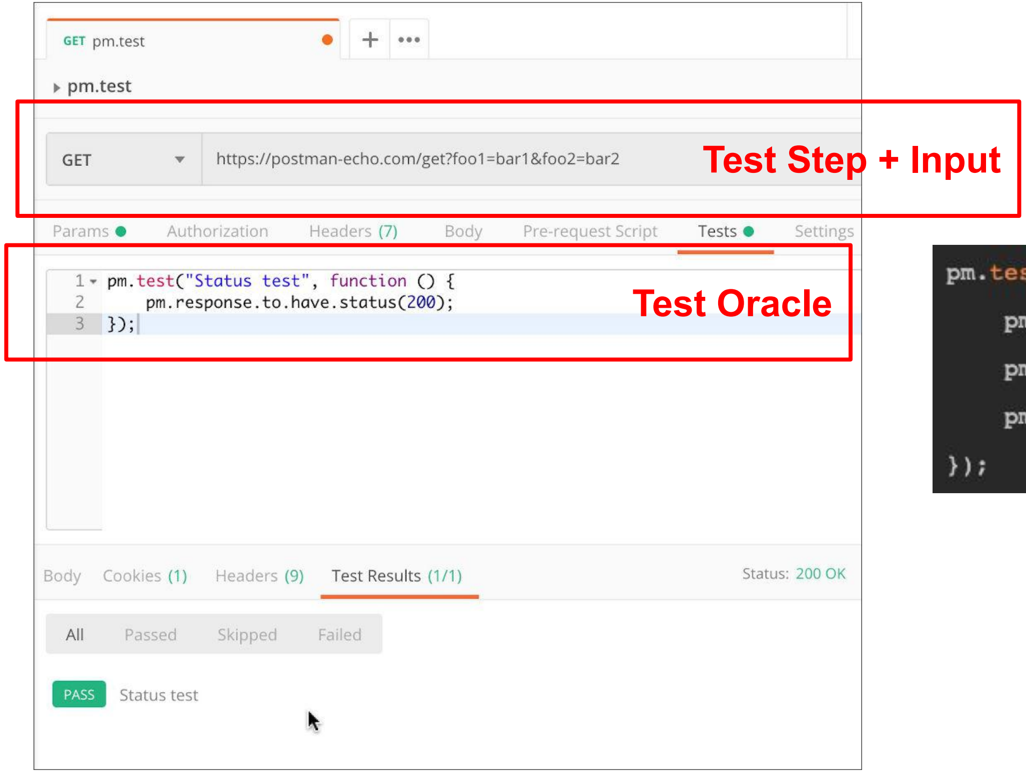
```
@Test
public void successfulLogin() {
    LoginActivity activity =
        ActivityScenario.launch(LoginActivity.class);
    onView(withId(R.id.user_name)).perform(typeText("test_user"));
    onView(withId(R.id.password))
       .perform(typeText("correct_password"));
    onView(withId(R.id.button)).perform(click());
    assertThat(getIntents().first())
        .hasComponentClass(HomeActivity.class);
}
```

Setup

Test Steps + Input

Test Oracle

RESTful API Test - Postman




```
pm.test("response should be okay to process", function () {
    pm.response.to.not.be.error;
    pm.response.to.have.jsonBody("");
    pm.response.to.not.have.jsonBody("error");
});
```

System-Level Tests and SPLs

- Variability is a ***system-level concept***.
  - Feature options tend to be entire classes or subsystems.
- **Unit testing during domain engineering.**
  - Assets tested in isolation.
- Many interaction errors between features, depending on chosen options.
  - **System testing during application engineering.**

Creating System-Level Test Cases

Creating System-Level Tests

Identify an Independently Testable Function

Identify a function that can be tested in (relative) isolation.

Identify Choices

Identify controllable aspects of the input and environment that determine the outcome of the function.

Identify Representative Input Values

Identify types of values for each choice that lead to different function outcomes.

Generate Test Case Specifications

Combine values to form “recipes” for test cases.

Generate Test Cases

Replace representative values with concrete values.

Independently Testable Functionality

- **A well-defined function that can be tested in (relative) isolation.**
  - Based on the “verbs” - what can we do with this system?
  - The high-level functionality offered by an interface.
  - UI - look for user-visible functions.
    - Web Forum: Sorted user list can be accessed.
    - Accessing the list **is** a testable functionality.
    - Sorting the list is **not** (low-level, unit testing target)

Units and “Functionality”

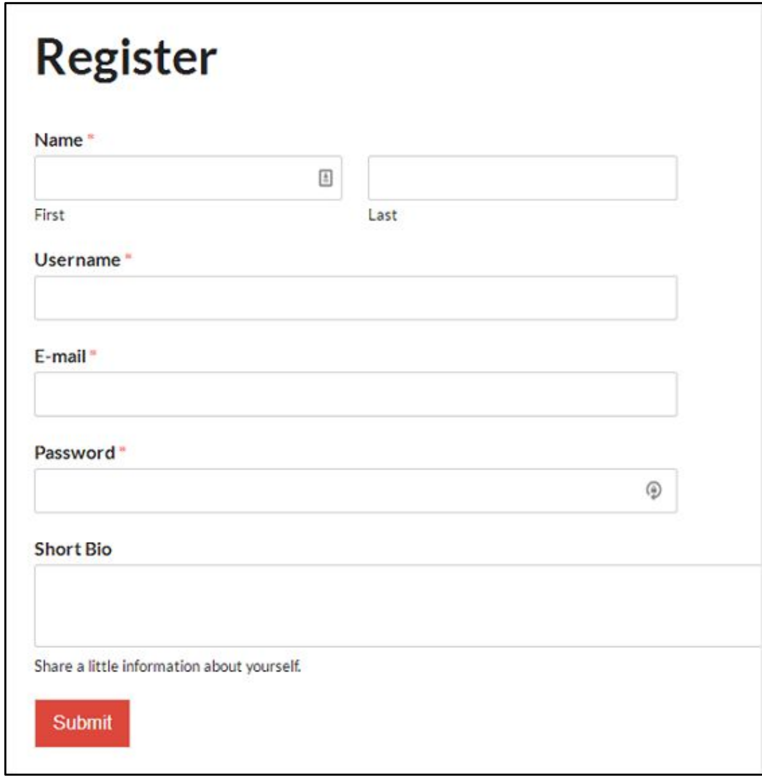
- Many tests written in terms of “units” of code.
- An independently testable function is a *capability* of the software.
  - Can be at class, subsystem, or system level.
  - **Defined by an interface.**

Identify Input Choices

- What choices do we make when using a function?
  - **Anything we control that can change the outcome.**
- What are the ***inputs*** to that feature?
- What ***configuration choices*** can we make?
- Are there ***environmental factors*** we can vary?
  - Networking environment, file existence, file content, database connection, database contents, disk utilization, …

Ex: Register for Website

- What are the inputs to that feature?
  - `(first name, last name, date of birth, e-mail)`
- Website is part of product line with different database options.
  - `(database type)`
- Consider implicit environmental factors.
  - `(database connection, user already in database)`



Parameter Characteristics

- Identify choices by understanding how parameters are used by the function.
- Type information is helpful.
  - `firstName` is string, database contains `UserRecords`.
- … but context is important.
  - Reject registration if in database.
  - … or database is full.
  - … or database connection down.

Parameter Context

- Input parameter split into multiple "choices" based on contextual use.
  - "Database" is an implicit input for User Registration, but it leads to **more than one** choice.
  - "Database Connection Status", "User Record in Database", "Percent of Database Filled" influence function outcome.
    - **The Database "input" results in three input choices when we design test cases.**

Examples

Class Registration System

What are some independently testable functions?

- Register for class
- Drop class
- Transfer credits from another university
- Apply for degree

Example - Register for a Class

What are the choices we make when we design a test case?

- Course number to add
- Student record
- What about a course database? Student record database?
- **What else influences the outcome?**

Example - Register for a Class

- Student Record is an implicit input choice.
- How is it used?
  - Have you already taken the course?
  - Do you meet the prerequisites?
  - What university are you registered at?
  - Can you take classes at the university the course is offered at?

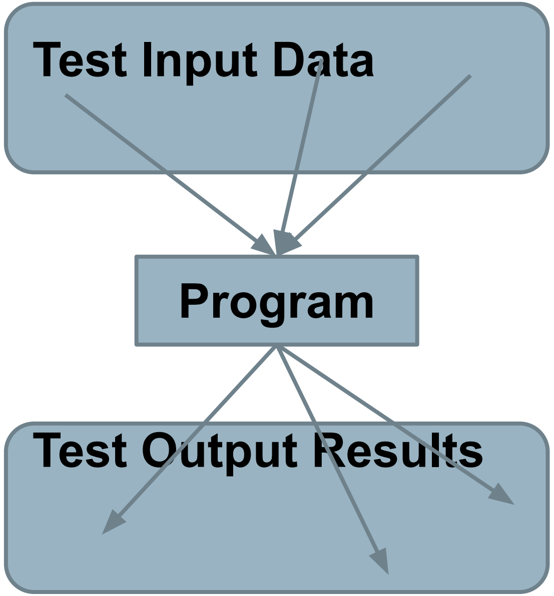
Example - Register for a Class

- Potential Test Choices:
  - Course to Add
  - Does course exist?
  - Does student record exist?
  - Has student taken the course?
  - Which university is student registered at?
  - Is course at a valid university for the student?
  - Can student record be retrieved from database?
  - Does the course exist?
  - Does student meet the prerequisites?

Let’s take a break.

Identifying Representative Values

- We know the functions.
- We have a set of choices.
- What values should we try?
  - For some choices, finite set.
  - For many, near-infinite set.
- **What about exhaustively trying all options?**



Exhaustive Testing

Take the arithmetic function for the calculator:

```
add(int a, int b)
```

- How long would it take to exhaustively test this function?

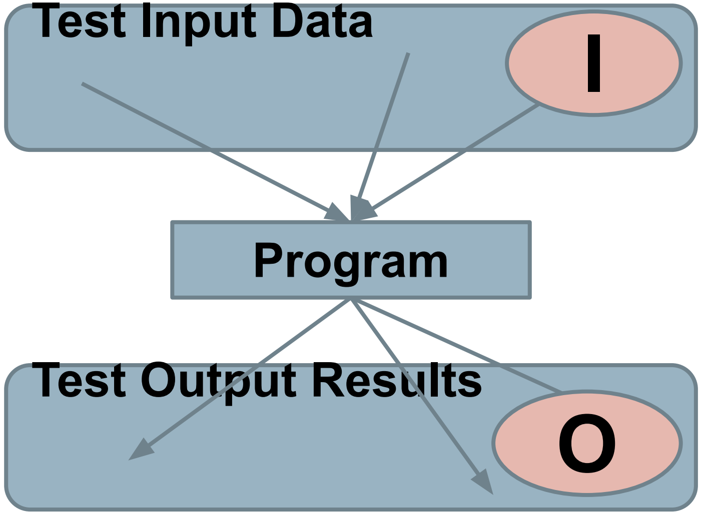
2^{32} possible integer values for each parameter.
$= 2^{32} \times 2^{32} = 2^{64}$ combinations $= 10^{13}$ tests.

1 test per nanosecond
$= 10^{5}$ tests per second
$= 10^{10}$ seconds

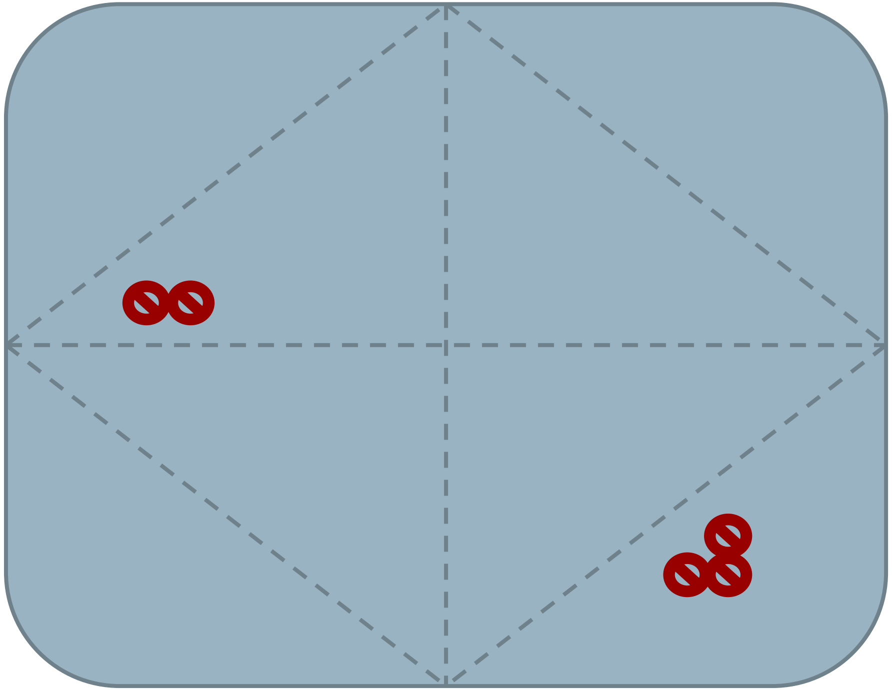
or… about 600 years!

Not all Inputs are Created Equal

- Many inputs lead to same outcome.
- Some inputs better at revealing faults.
  - We can't know which in advance.
  - Tests with different input better than tests with similar input.



Input Partitioning



- Consider possible values for a variable.
- Faults sparse in space of all inputs, but dense in parts where they appear.
  - Similar input to failing input also likely to fail.
- Try input from partitions, hit dense fault space.

Equivalence Class

- Divide the input domain into **equivalence classes**.
  - Inputs from a group interchangeable (trigger same outcome, result in the same behavior, etc.).
  - If one input reveals a fault, others in this class (probably) will too. In one input does not reveal a fault, the other ones (probably) will not either.
- Partitioning based on intuition, experience, and common sense.

Example

`substr(string str, int index)`

What are some possible partitions?

- index < 0
- index = 0
- index > 0
- str with length < index
- str with length = index
- str with length > index
- ...

Choosing Input Partitions

- Equivalent output events.
- Ranges of numbers or values.
- Membership in a logical group.
- Time-dependent equivalence classes.
- Equivalent operating environments.
- Data structures.
- Partition boundary conditions.

Look for Equivalent Outcomes

- Look at the outcomes and group input by the outcomes they trigger.
- Example: **`getEmployeeStatus(employeeID)`**
  - Outcomes include: Manager, Developer, Marketer, Lawyer, Employee Does Not Exist, Malformed ID
  - Abstract values for choice `employeeID`.
    - Can potentially break down further.

Look for Ranges of Values

- Divide based on data type and how variable used.
  - Ex: Integer input. Intended to be 5-digit:
    - < 10000, 10000-99999, >= 100000
    - Other options: < 0, 0, max int
    - Can you pass it something non-numeric? Null pointer?
- Try “expected” values and potential error cases.

Look for Membership in a Group

Consider the following inputs to a program:

- A floor layout
- A country name.

- All can be partitioned into groups.
  - Apartment vs Business, Europe vs Asia, etc.
- Many groups can be subdivided further.
- Look for context that an input is used in.

Timing Partitions

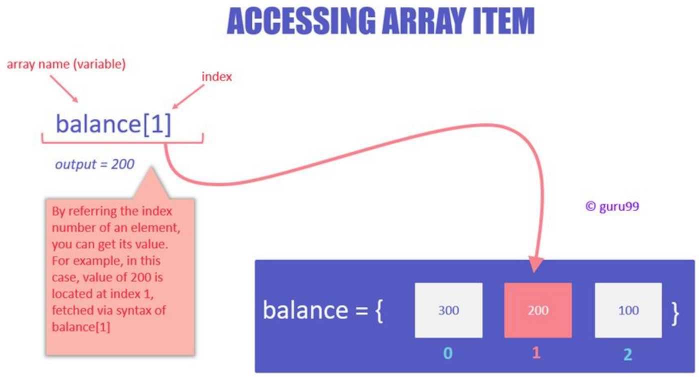
- Timing and duration of an input may be as important as the value.
  - Timing often implicit input.
    - Trigger an electrical pulse 5ms before a deadline, 1ms before the deadline, exactly at the deadline, and 1ms after the deadline.
    - Close program before, during, and after the program is writing to (or reading from) a disc.

Operating Environments

- Environment may affect behavior of the program.
- Environmental factors can be partitioned.
  - Memory may affect the program.
  - Processor speed and architecture.
  - Client-Server Environment
    - No clients, some clients, many clients
    - Network latency
    - Communication protocols (SSH vs HTTPS)

Data Structures

- Data structures are prone to certain types of errors.
- For arrays or lists:
  - Only a single value.
  - Different sizes and number filled.
  - Order of elements: access first, middle, and last elements.



Input Partition Example

What are the input partitions for:

`max(int a, int b) returns (int c)`

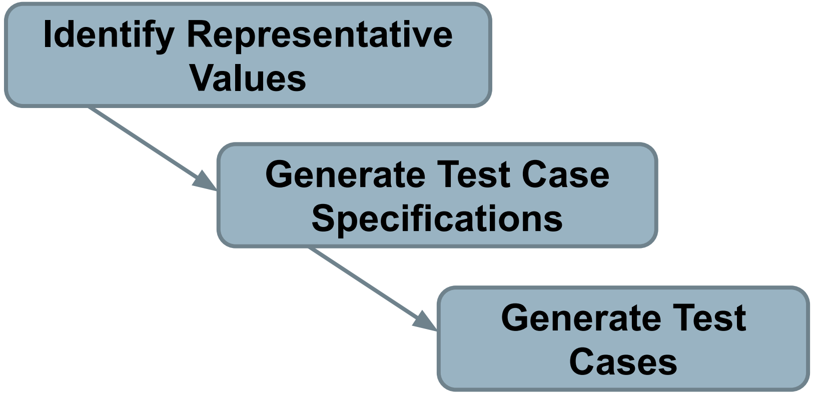
We could consider `a` or `b` in isolation:

`a < 0, a = 0, a > 0`

Consider combinations of `a` and `b` that change outcome:

`a > b, a < b, a = b`

Revisit the Roadmap



For each testing choice for a function, we want to:

1. Partition each choice into representative values.
2. Choose a value for each choice to form a test specification.
3. Assigning concrete values from each partition.

Forming Specification

Function `insertPostalCode(int N, list A)`.

- **Choice:** int N
  - 5-digit integer between 10000 and 99999
  - **Representative Values:** <10000, 10000-99999, >100000
- **Choice:** list A
  - list of length 1-10
  - **Representative Values:** Empty List, List of Length 1, List Length 2-10, List of Length > 10

Forming Specifications

Choose concrete values for each combination of input partitions:

`insertPostalCode(int N, list A)`

`int N`

< 10000
10000 - 99999
> 99999

`list A`

Empty List
List[1]
List[2-10]
List[>10]

Test Specifications:

(3 * 4 = 12 abstract specifications)

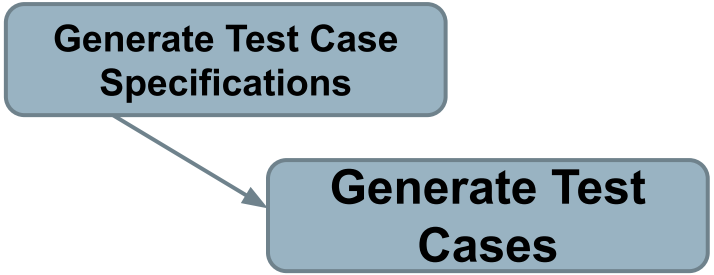
```
insert(< 10000, Empty List)
insert(10000 - 99999, list[1])
insert(> 99999, list[2-10])
...
```

Concrete Test Cases:

(Each specification = 1000s of potential test cases)

```
insert(5000, {})
insert(96521, {11123})
insert(150000, {11123, 98765})
...
```

Generate Test Cases



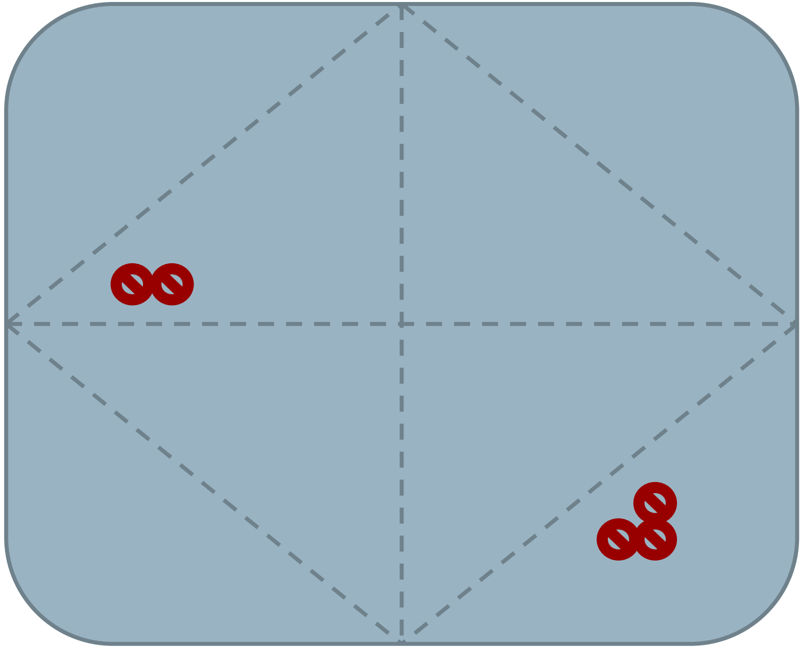
`substr(string str, int index)`

Specification:
`str`: length >=2, contains special characters
`index`: value > 0

Test Case:
`str` = “ABCC!\n\t7”
`index`= 5

Boundary Values

- Errors tend to occur at the boundary of a partition.
- Remember to select inputs from those boundaries.



Boundary Values

Choose test case values at the boundary (and typical) values for each partition.

- If an input is intended to be a 5-digit integer between 10000 and 99999, you want partitions:

<10000, 10000-99999, >100000

0 | 5000 | 9999 | 100000 | 150000 | max int

10000 | 50000 | 99999

Example - Set Microservice

- Microservice related to Sets:
  - `void insert(Set set, Object obj)`
  - `Boolean find(Set set, Object obj)`
  - `void delete(Set set, Object obj)`
- For each **function**, identify **choices**.
- For each choice, identify **representative values**.
- Create **test specifications** with expected outcomes.

Example - Set Microservice

```
void insert(Set set, Object obj)
```

Identify an Independently Testable Function

- What are our choices?

Identify Choices

- **Parameter:** set
  - **Choice 1:** Number of items in the set
- **Parameter:** obj
  - **Choice 2:** Is obj already in the set?
  - **Choice 3:** Type of obj (e.g., valid, invalid, null)

Example - Set Microservice

```
void insert(Set set, Object obj)
```

Identify Representative Input Values

Parameter: set

- **Choice:** Number of items in the set
    - **Representative Values:**
        - Empty Set
        - Set with 1 item
        - Set with 10 items
        - Set with 10000 items

Parameter: obj

- **Choice:** Is obj already in the set?
    - **Representative Values:**
        - obj already in set
        - obj not in set
- **Choice:** Type of obj
    - **Representative Values:**
        - Valid obj
        - Null obj

Example - Set Microservice

Generate Test Case Specifications

Set Size	Obj in Set	Obj Status	Outcome
Empty	No	Valid	Obj added to Set
Empty	No	Null	Error or no change
1 item	Yes	Valid	Error or no change
1 item	No	Valid	Obj added to Set
1 item	No	Null	Error or no Change
10 items	Yes	Valid	Error or no change
10 items	No	Valid	Obj added to Set
10 items	No	Null	Error or no Change
10000	Yes	Valid	Error or no change (may be slowdown)
10000	No	Valid	Obj added to Set(may be slowdown)
10000	No	Null	Error or no Change (may be slowdown)

```
void insert(Set set,
Object obj)
```

- (4 * 2 * 2) = 16 specifications
  - Some are invalid (null in set). Can remove/ignore those.
- Each can become 1+ test cases.

Generate Test Cases

- (1 item, Yes, Valid) becomes:
- `insert({“Bob”}, “Bob”);`

Activity - System-Level Testing

- Microservice related to Sets:
  - void insert(Set set, Object obj)
  - Boolean find(Set set, Object obj)
  - void delete(Set set, Object obj)
- For each microservice, identify choices.
- For each choice, identify the representative values.
- Create four abstract test specifications with expected outcomes.

Solution - Test Specifications

Insert	*Empty/ Object not in Set*	*obj in container*
	One element / Object not in Set	*obj in container*
	Multiple elements / Object not in Set	*obj in container*
	100+ / Object not in Set	*obj in container*
	(any choice) / Object in Set	*Error or no change*
	(any choice) / Null Object	*Error*
Exists	*One element / Object in Set*	*True*
	Empty / Object not in Set	*False*
	100 + / Object in Set	*True*
	100 + / Object not in Set	*False*
	(any choice) / Null Object	*Error*

Delete	*One element / Object in Set*	*obj no longer in set*
	One element / Object not in Set	*no change (or error)*
	(any choice) / Null Pointer	*error*
	100 + / Object in Set	*obj no longer in set*
	Empty / Object not in Set	*no change (or error)*

We Have Learned

- Unit testing focus on a single class.
- System tests focus on high-level functionality, integrating low-level components through a UI/API.
  - Identify an independently testable function.
  - Identify choices that influence function outcome.
  - Partition choices into representative values.
  - Form specifications by choosing a value for each choice.
  - Turn specifications into concrete test cases.

Next Time

- System-level testing and feature interactions
  - Handling infeasible combinations.
  - Selecting a valid subset of representative values.

- Assignment 4 - Dec 12
  - Any questions?

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