Input Space Partitioning

- Introduction
- Equivalence Partitioning
- Boundary-Value Analysis
- Summary

The Test Selection Problem

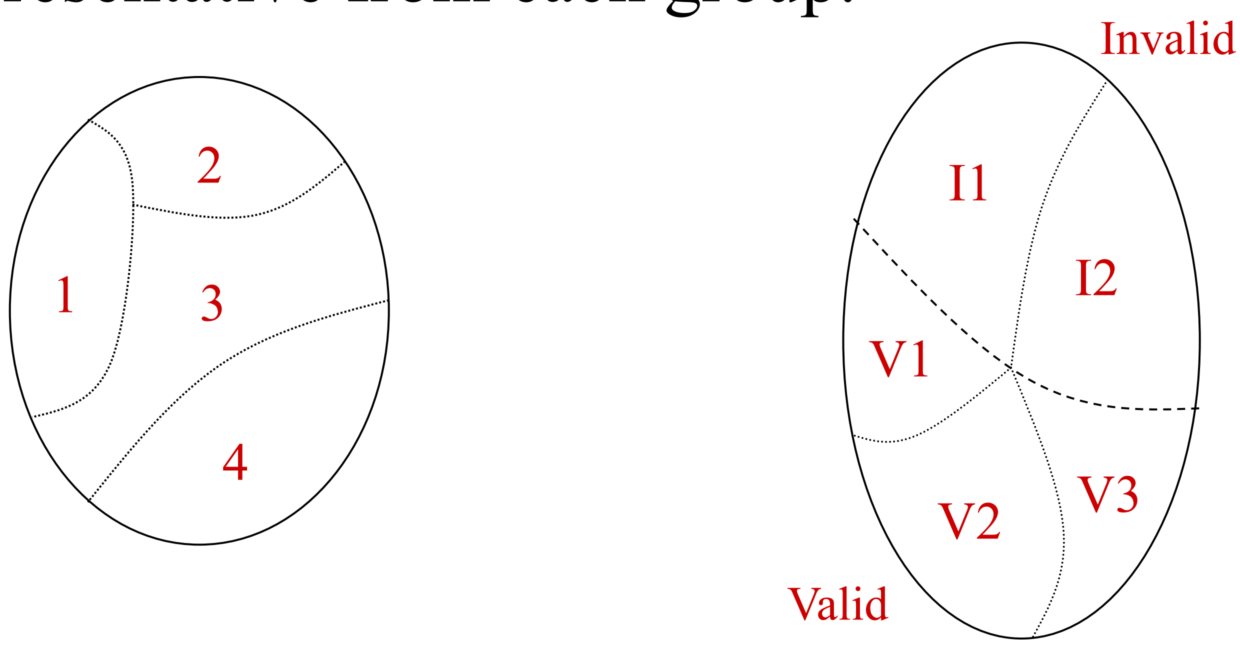
- The input space of a program consists of all possible inputs that could be taken by the program.
- Ideally, the test selection problem is to select a subset T of possible inputs in the input space such that the execution of T will reveal all the faults.
- In practice, the test selection problem is to select a subset T within budget such that it reveals as many faults as possible.

Example

- Consider a program that is designed to sort a sequence of integers into the ascending order.
- What is the input space of this program?

Main Idea

- Partition the input space into a relatively small number of groups, and then select one representative from each group.



Major Steps

- Step 1: Identify the input space
  - Read the requirements carefully and identify all input and output variables, any conditions associated with their use.
- Step 2: Identify equivalence classes
  - For example, partition all the values of a variable into disjoint subsets, based on the expected behavior.
  - In some cases, multiple variables may need to be considered at the same time.
- Step 3: Combine equivalence classes
  - Use some well-defined strategies to avoid potential explosion
- Step 4: Remove infeasible combinations of equivalence classes

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Input Parameter Modeling

- Step 1: Identify testable components, which could be a method, a use case, or the entire system
- Step 2: Identify all of the parameters that can affect the behavior of a given testable component
  - Input parameters, environment configurations, state variables.
  - For example, insert(obj) typically behaves differently depending on whether the object is already in a list or not.
- Step 3: Identify characteristics, and create partitions for each characteristic
- Step 4: Select values from each partition, and combine them to create tests

Partition

- A partition defines a set of equivalent classes, or blocks
  - All the members in an equivalence class contribute to fault detection in the same way
- A partition must satisfy two properties:
  - Completeness: A partition must cover the entire domain
  - Disjoint: The blocks must not overlap
- A partition is usually based on certain characteristic
  - e.g., whether a list of integer is sorted or not, whether a list allows duplicates or not

Interface-Based IPM (1)

- The main idea is to identify parameters and values, typically in isolation, based on the interface of the component under test.
- Advantage: Relatively easy to identify characteristics
- Disadvantage: Not all information is reflected in the interface, and testing some functionality may require parameters in combination

Interface-Based IPM (2)

- Range: one class with values inside the range, and two with values outside the range
  - For example, let speed ∈ [60 .. 90]. Then, we generate three classes {{50}, {75}, {92}}.
- String: one class with an empty string, one class with strings of length 1, one class with strings of length more than 1
  - For example, let s be a string variable. Then, we could generate the following classes: {{ε}, {a}, {abc}}.

Interface-Based IPM (3)

- Enumeration: Each value in a separate class
  - For example, consider auto_color $\in$ {red, blue, green}. The following classes are generated, {{red}, {blue}, {green}}
- Array: One class containing the empty array, one containing arrays of normal size, and one containing arrays larger than normal size
  - For example, consider int[] aName = new int [3]. The following classes are generated: {{[]}, {[-10, 20]}, {[-9, 0, 12, 15]}.

Functionality-Based IPM (1)

- The main idea is to identify characteristics that correspond to the intended functionality of the component under test
- Advantage: Includes more semantic information, and does not have to wait for the interface to be designed
- Disadvantage: Hard to identify characteristics, parameter values, and tests

Functionality-Based IPM (2)

- Preconditions explicitly separate normal behavior from exceptional behavior
  - For example, a method requires a parameter to be non-null.
- Postconditions indicate what kind of outputs may be produced
  - For example, if a method produces two types of outputs, then we want to select inputs so that both types of outputs are tested.
- Relationships between different parameters can also be used to identify characteristics
  - For example, if a method takes two object parameters x and y, we may want to check what happens if x and y point to the same object or to logically equal objects

Example (1)

- Consider a triangle classification program which inputs three integers representing the lengths of the three sides of a triangle, and outputs the type of the triangle.
- The possible types of a triangle include scalene, equilateral, isosceles, and invalid.

int classify (int side1, int side2, int side3)
0: scalene, 1: equilateral, 2: isosceles; -1: invalid

Example (2)

- Interface-based IPM: Consider the relation of the length of each side to some special value such as zero

Partition	b1	b2	b3
Relation of Side 1 to 0	> 0	= 0	< 0
Relation of Side 2 to 0	> 0	= 0	< 0
Relation of Side 3 to 0	> 0	= 0	< 0

T1 = (5, 5, 5)   T2 = (0, 0, 0)   T3= (-3, -3, -3)

Example (3)

- Functionality-based IPM: Consider the traditional geometric classification of triangles

Partition	b1	b2	b3	b4
Geometric classification	Scalene	Isosceles	Equilateral	Invalid

Example (4)

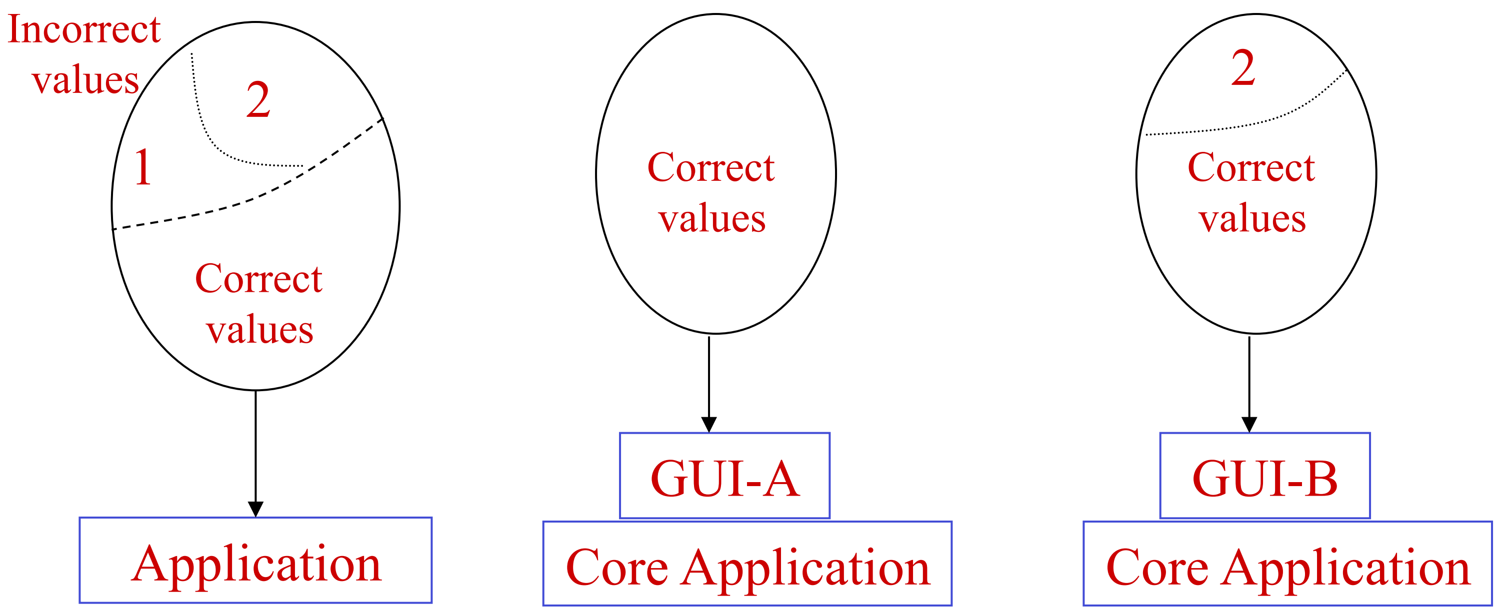
Partition	b1	b2	b3	b4
Geometric classification	Scalene	Isoceles, not equilateral	Equilateral	Invalid

Param	b1	b2	b3	b4
Triangle	(4, 5, 6)	(3, 3, 4)	(3, 3, 3)	(3, 4, 8)

GUI Design (1)

- Suppose that an application has a constraint on an input variable X such that it can only assume integer values in the range 0 .. 4.
- Without GUI, the application must check for out-of-range values.
- With GUI, the user may be able to select a valid value from a list, or may be able to enter a value in a text field.

GUI Design (2)


Incorrect values
2
1
Correct values
Application
Correct values
GUI-A
Core Application
2
Correct values
GUI-B
Core Application

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Motivation

- Programmers often make mistakes in processing values at and near the boundaries of equivalence classes.
- For example, a method M is supposed to compute a function f1 when condition $x <= 0$ and function f2 otherwise. However, M has a fault such that it computes f1 for $x < 0$ and f2 otherwise.
- Can you find an example that shows why a value near a boundary needs to be tested?

Boundary-Value Analysis

- A test selection technique that targets faults in applications at or near the boundaries of equivalence classes.
  - Identify equivalence classes and their boundaries
  - Identify values that are at or near the boundaries
  - Select test data such that each of these values appears in at least one test input

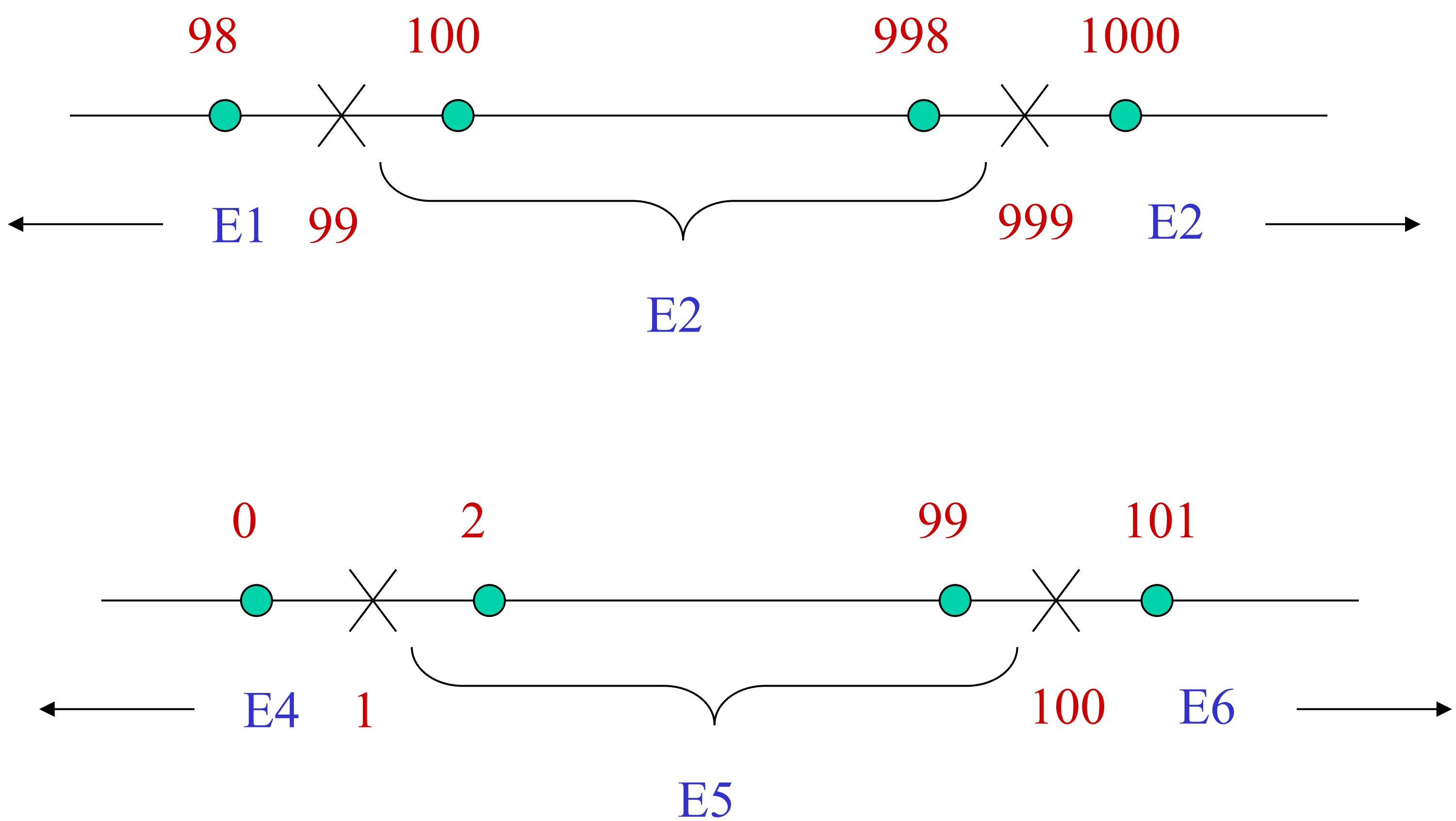
Example

- Consider a method findPrices that takes two inputs, item code (99 .. 999) and quantity (1 .. 100).
- The method accesses a database to find and display the unit price, the description, and the total price, if the code and quantity are valid.
- Otherwise, the method displays an error message and return.

Example (2)

- Equivalence classes for code:
  - E1: Values less than 99
  - E2: Values in the range
  - E3: Values greater than 999
- Equivalence classes for quantity:
  - E4: Values less than 1
  - E5: Values in the range
  - E6: Values greater than 100

Example (3)



Example (4)

- Tests are selected to include, for each variable, values at and around the boundaries
- An example test set is T = { t1: (code = 98, qty = 0), t2: (code = 99, qty = 1), t3: (code = 100, qty = 2), t4: (code = 998, qty = 99), t5: (code = 999, qty = 100), t6: (code = 1000, qty = 101) }

Example (5)

```
public void findPrice (int code, int qty)
{
   if (code < 99 or code > 999) {
      display_error ("Invalid code"); return;
   }
  // begin processing
}
```

Example (6)

- One way to fix the problem is to replace t1 and t6 with the following four tests: t7 = (code = 98, qty = 45), t8 = (code = 1000, qty = 45), t9 = (code = 250, qty = 0), t10 = (code = 250, qty = 101).

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Summary

- Test selection is about sampling the input space in a cost-effective manner.
- The notions of equivalence partitioning and boundary analysis are so common that sometimes we apply them without realizing it.
- Interface-based IPM is easier to perform, but may miss some important semantic information; functionality-based IPM is more challenging, but can be very effective in many cases.
- Boundary analysis considers values both at and near boundaries.