# Introduction to Software Testing
# Chapter 6
# Input Space Partition Testing

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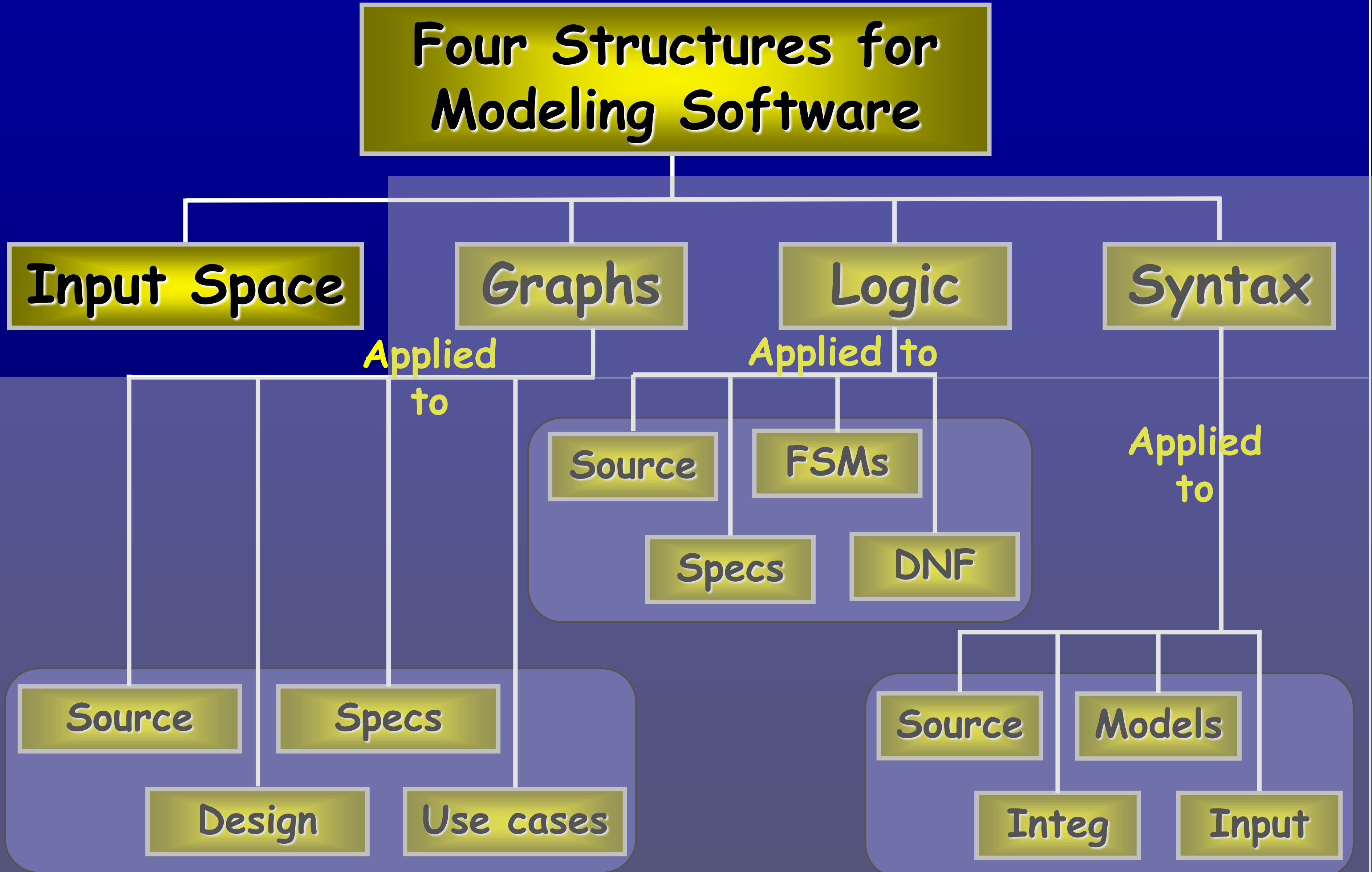
http://www.cs.gmu.edu/~offutt/softwaretest/

# Ch. 6 : Input Space Coverage



# Input Domains

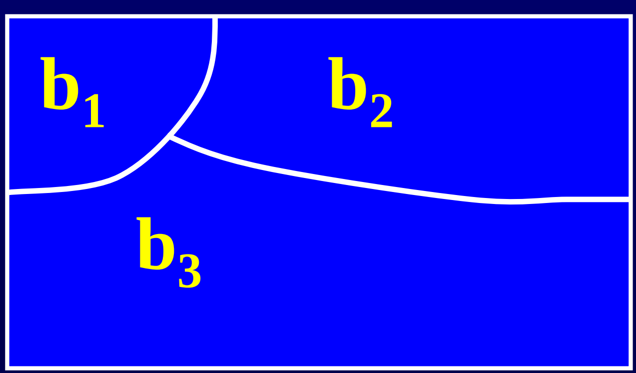
- The input domain for a program contains all the possible inputs to that program
- For even small programs, the input domain is so large that it might as well be infinite
- Testing is fundamentally about choosing finite sets of values from the input domain
- *Input parameters* define the scope of the input domain
  - Parameters to a method
  - Data read from a file
  - Global variables
  - User level inputs
- Domains for input parameters are partitioned into regions
- At least one value is chosen from each region

# Benefits of ISP

- Can be equally applied at several levels of testing
  - Unit
  - Integration
  - System
- Relatively easy to apply with no automation
- Easy to adjust the procedure to get more or fewer tests
- No implementation knowledge is needed
  - Just the input space

# Partitioning Domains

- *Domain* *D*
- *Partition scheme* *q* of *D*
- The partition *q* defines a *set of blocks*, $Bq = b_1, b_2, \ldots, b_Q$
- The partition must satisfy two properties :
  1. Blocks must be *pairwise disjoint* (no overlap)
  2. Together the blocks *cover* the domain *D* (complete)




$$b_i \cap b_j = \Phi, \forall\, i \neq j, b_i, b_j \in B_q$$

$$\bigcup_{b \in Bq} b = D$$

# In-Class Exercise

*Design a partitioning for all integers*

*That is, partition integers into blocks such that each block seems to be equivalent in terms of testing*

*Make sure your partition is valid:*

1) *Pairwise disjoint*
2) *Complete*

# Using Partitions – Assumptions

- Choose a value from each block
- Each value is assumed to be equally useful for testing
- Application to testing
  - Find characteristics in the inputs : parameters, semantic descriptions, …
  - Partition each characteristic
  - Choose tests by combining values from characteristics
- Example Characteristics
  - Input X is null
  - Order of the input file F (sorted, inverse sorted, arbitrary, …)
  - Min separation of two aircraft
  - Input device (DVD, CD, VCR, computer, …)

# Choosing Partitions

- Choosing (or defining) partitions seems easy, but is easy to get wrong
- Consider the characteristic "*order of file F*"

$b_1$ = sorted in ascending order
$b_2$ = sor … der
$b_3$ = arbitrary order

*Design blocks for that characteristic*

but … something's fishy …

What if the file is of length 1?

*Can you find the problem?*

The file … blocks …
That is, disjointness is not satisfied

**Solution:**

**Each characteristic should ad… …rty**

*Can you think of a solution?*

**C1: … ing**
- c1.b1 = true
- c1.b2 = false

**C2: File F sorted descending**
- c2.b1 = true
- c2.b2 = false

# Properties of Partitions

- If the partitions are not complete or disjoint, that means the partitions have not been considered carefully enough
- They should be reviewed carefully, like any design
- Different alternatives should be considered
- We model the input domain in five steps …
  - Steps 1 and 2 move us from the implementation abstraction level to the design abstraction level (from chapter 2)
  - Steps 3 & 4 are entirely at the design abstraction level
  - Step 5 brings us back down to the implementation abstraction level

# Modeling the Input Domain

- Step 1 : Identify testable functions
  - Individual methods have one testable function
  - Methods in a class often have the same characteristics
  - Programs have more complicated characteristics—modeling documents such as UML (use case) can be used to design characteristics
  - Systems of integrated hardware and software components can use devices, operating systems, hardware platforms, browsers, etc.
- Step 2 : Find all the parameters (affecting the behavior of the test function)
  - Often fairly straightforward, even mechanical
  - Important to be complete
  - Methods : Parameters and state (non-local) variables used
  - Components : Parameters to methods and state variables
  - System : All inputs, including files and databases

# Modeling the Input Domain (*cont*)

- Step 3 : Model the input domain
  – The domain is scoped by the parameters
  – The structure is defined in terms of characteristics
  – Each characteristic is partitioned into sets of blocks
  – Each block represents a set of values
  – This is the most creative design step in using ISP
- Step 4 : Apply a test criterion to choose combinations of values
  – A test input has a value for each parameter
  – One block for each characteristic
  – Choosing all combinations is usually infeasible
  – Coverage criteria allow subsets to be chosen
- Step 5 : Refine combinations of blocks into test inputs
  – Choose appropriate values from each block (i.e., remove invalid combinations)

# In-Class Exercise

*Work with 2 or 3 classmates*

*Pick one of the programs from chapter 1 (findLast, numZero, etc)*

*Create an IDM for your program*

# Two Approaches to Input Domain Modeling

1. Interface-based approach
   – Develops characteristics directly from individual input parameters
   – Simplest application
   – Can be partially automated in some situations

2. Functionality-based approach
   – Develops characteristics from a behavioral view of the program under test
   – Harder to develop—requires more design effort
   – May result in better tests, or fewer tests that are as effective

***Input Domain Model* (IDM)**

# 1. Interface-Based Approach

- Mechanically consider each parameter in isolation
- This is an easy modeling technique and relies mostly on syntax
- Some domain and semantic information won't be used
  - Could lead to an incomplete IDM
- Ignores relationships among parameters

# 1. Interface-Based Example

- Consider method *triang()* from class *TriangleType* on the book website :
  - http://www.cs.gmu.edu/~offutt/softwaretest/edition2/java/Triangle.java
  - http://www.cs.gmu.edu/~offutt/softwaretest/edition2/java/TriangleType.java

```
public enum Triangle { Scalene, Isosceles, Equilateral, Invalid }
public static Triangle triang (int Side, int Side2, int Side3)
// Side1, Side2, and Side3 represent the lengths of the sides of a triangle
// Returns the appropriate enum value
```

**The IDM for each parameter is identical**

**Reasonable characteristic : *Relation of side with zero***

# 2. Functionality-Based Approach

- Identify characteristics that correspond to the intended functionality
- Requires more design effort from tester
- Can incorporate domain and semantic knowledge
- Can use relationships among parameters
- Modeling can be based on requirements, not implementation
- The same parameter may appear in multiple characteristics, so it's harder to translate values to test cases (constraints of a single characteristics may affect multiple parameters)

# 2. Functionality-Based Example

- Again, consider method *triang()* from class *TriangleType* :

**The three parameters represent a *triangle***

**The IDM can combine all parameters**

**Reasonable characteristic : *Type of triangle***

# Steps 1 & 2—Identifying Functionalities, Parameters and Characteristics

- A creative engineering step
- More characteristics means more tests
- Interface-based : Translate parameters to characteristics
- Candidates for characteristics :
  - Preconditions and postconditions
  - Relationships among variables
  - Relationship of variables with special values (zero, null, blank, …)
- Should not use program source—characteristics should be based on the input domain
  - Program source should be used with graph or logic criteria
- Better to have more characteristics with few blocks
  - Fewer mistakes and fewer tests

# In-Class Exercise

**public boolean findElement** (List list, Object element)
// Effects: if list or element is null throw NullPointerException
//            else return true if element is in the list, false otherwise

*Work with 2 or 3 classmates*

*Create two IDMs for findElement () :*
*1) Interface-based*
*2) Functionality-based*

# Steps 1 & 2—Interface & Functionality-Based

**public boolean findElement** (List list, Object element)
// Effects: if list or element is null throw NullPointerException
//           else return true if element is in the list, false otherwise

Interface-Based Approach

Two parameters : list, element

Characteristics :

- list is null (block1 = true, block2 = false)
- list is empty (block1 = true, block2 = false)

Functionality-Based Approach

Two parameters : list, element

Characteristics :

- number of occurrences of element in list
  - (0, 1, >1)
- element occurs first in list
  - (true, false)
- element occurs last in list
  - (true, false)

# Step 3 : Modeling the Input Domain

- Partitioning characteristics into blocks and values is a very creative engineering step
- More blocks means more tests
- Partitioning often flows directly from the definition of characteristics and both steps are done together
  - Should evaluate them separately – sometimes fewer characteristics can be used with more blocks and vice versa
- Strategies for identifying values :
  - Include valid, invalid and special values
  - Sub-partition some blocks
  - Explore boundaries of domains
  - Include values that represent "normal use"
  - Try to balance the number of blocks in each characteristic (e.g., each choice)
  - Check for completeness and disjointness

# Interface-Based –*triang()*

- *triang*() has one testable function and three integer inputs

| First Characterization of TriTyp's Inputs | | | |
|---|---|---|---|
| Characteristic | $b_1$ | $b_2$ | $b_3$ |
| $q_1$ = "Relation of Side 1 to 0" | greater than 0 | equal to 0 | less than 0 |
| $q_2$ = "Relation of Side 2 to 0" | greater than 0 | equal to 0 | less than 0 |
| $q_3$ = "Relation of Side 3 to 0" | greater than 0 | equal to 0 | less than 0 |

- A maximum of 3*3*3 = 27 tests
- Some triangles are valid, some are invalid
- Refining the characterization can lead to more tests …

# Interface-Based IDM—*triang*()

**Second Characterization of triang()'s Inputs**

| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|
| $q_1$ = "Refinement of $q_1$" | greater than 1 | equal to 1 | equal to 0 | less than 0 |
| $q_2$ = "Refinement of $q_2$" | greater than 1 | equal to 1 | equal to 0 | less than 0 |
| $q_3$ = "Refinement of $q_3$" | greater than 1 | equal to 1 | equal to 0 | less than 0 |

- A maximum of 4*4*4 = 64 tests
- Complete because the inputs are integers (0 . . 1)

**Possible values for partition $q_1$**

| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|
| Side1 | 2 | 1 | 0 | -1 |

Test boundary conditions

# Functionality-Based *IDM—triang*()

- First two characterizations are based on syntax–parameters and their type
- A semantic level characterization could use the fact that the three integers represent a triangle

Geometric Characterization of *triang*()'s Inputs

| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|
| $q_1$ = "Geometric Classification" | scalene | isosceles | equilateral | invalid |

- Equilateral is also is
- We need to refine t ... cteristics valid

*What's wrong with this partitioning?*

Correct Geometric Characterization of *triang*()'s Inputs

| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|
| $q_1$ = "Geometric Classification" | scalene | isosceles, not equilateral | equilateral | invalid |

# Functionality-Based *IDM—triang*()

- Values for this partitioning can be chosen as

| Possible values for geometric partition $q_1$ | | | | |
|---|---|---|---|---|
| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
| Triangle | (4, 5, 6) | (3, 3, 4) | (3, 3, 3) | (3, 4, 8) |

# Functionality-Based IDM—*triang*()

- A different approach would be to break the geometric characterization into four separate characteristics

| Four Characteristics for *triang*() | | |
|---|---|---|
| Characteristic | $b_1$ | $b_2$ |
| $q_1$ = "Scalene" | True | False |
| $q_2$ = "Isosceles" | True | False |
| $q_3$ = "Equilateral" | True | False |
| $q_4$ = "Valid" | True | False |

- Use constraints to ensure that
  - Equilateral = True implies Isosceles = True
  - Valid = False implies Scalene = Isosceles = Equilateral = False

# Using More than One IDM

- Some programs may have dozens or even hundreds of parameters
- Create several small IDMs
  - A divide-and-conquer approach
- Different parts of the software can be tested with different amounts of rigor
  - For example, some IDMs may include a lot of invalid values
- It is okay if the different IDMs overlap
  - The same variable may appear in more than one IDM

# Step 4 – Choosing Combinations of Values (6.2)

- Once characteristics and partitions are defined, the next step is to choose test values
- We use criteria – to choose effective subsets
- The most obvious criterion is to choose all combinations

**<u>All Combinations (ACoC)</u> : All combinations of blocks from all characteristics must be used.**

- Number of tests is the product of the number of blocks in each characteristic : $\prod_{i=1}^{Q}(B_i)$
- The second characterization of triang() results in 4*4*4 = 64 tests
  - Too many ?

# ISP Criteria – All Combinations

- Consider the "second characterization" of Triang as given before:

| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|
| $q_1$ = "Refinement of $q_1$" | greater than 1 | equal to 1 | equal to 0 | less than 0 |
| $q_2$ = "Refinement of $q_2$" | greater than 1 | equal to 1 | equal to 0 | less than 0 |
| $q_3$ = "Refinement of $q_3$" | greater than 1 | equal to 1 | equal to 0 | less than 0 |

- For convenience, we relabel the blocks:

| Characteristic | $b_1$ | $b_2$ | $b_3$ | $b_4$ |
|---|---|---|---|---|
| A | A1 | A2 | A3 | A4 |
| B | B1 | B2 | B3 | B4 |
| C | C1 | C2 | C3 | C4 |

# ISP Criteria – ACoC Tests

| | | | |
|---|---|---|---|
| A1 B1 C1 | A2 B1 C1 | A3 B1 C1 | A4 B1 C1 |
| A1 B1 C2 | A2 B1 C2 | A3 B1 C2 | A4 B1 C2 |
| A1 B1 C3 | A2 B1 C3 | A3 B1 C3 | A4 B1 C3 |
| A1 B1 C4 | A2 B1 C4 | A3 B1 C4 | A4 B1 C4 |
| A1 B2 C1 | A2 B2 C1 | A3 B2 C1 | A4 B2 C1 |
| A1 B2 C2 | A2 B2 C2 | A3 B2 C2 | A4 B2 C2 |
| A1 B2 C3 | A2 B2 C3 | A3 B2 C3 | A4 B2 C3 |
| A1 B2 C4 | A2 B2 C4 | A3 B2 C4 | A4 B2 C4 |
| A1 B3 C1 | A2 B3 C1 | A3 B3 C1 | A4 B3 C1 |
| A1 B3 C2 | A2 B3 C2 | A3 B3 C2 | A4 B3 C2 |
| A1 B3 C3 | A2 B3 C3 | A3 B3 C3 | A4 B3 C3 |
| A1 B3 C4 | A2 B3 C4 | A3 B3 C4 | A4 B3 C4 |
| A1 B4 C1 | A2 B4 C1 | A3 B4 C1 | A4 B4 C1 |
| A1 B4 C2 | A2 B4 C2 | A3 B4 C2 | A4 B4 C2 |
| A1 B4 C3 | A2 B4 C3 | A3 B4 C3 | A4 B4 C3 |
| A1 B4 C4 | A2 B4 C4 | A3 B4 C4 | A4 B4 C4 |

ACoC yields 4*4*4 = 64 tests for Triang!

This is almost certainly more than we need

Only 8 are valid (all sides greater than zero)

# ISP Criteria – Each Choice

- 64 tests for triang() is almost certainly way too many
- One criterion comes from the idea that we should try at least one value from each block

**<u>Each Choice Coverage (ECC)</u> : One value from each block for each characteristic must be used in at least one test case.**

- Number of tests is the number of blocks in the largest characteristic : $\mathbf{Max}_{i=1}^{Q}(B_i)$

| For *triang*() : | Substituting values: |
|---|---|
| A1, B1, C1 | 2, 2, 2 |
| A2, B2, C3 | 1, 1, 1 |
| A3, B3, C3 | 0, 0, 0 |
| A4, B4, C4 | -1, -1, -1 |

# ISP Criteria – Pair-Wise

- Each choice yields few tests—cheap but maybe ineffective
- Another approach combines values with other values

**<u>Pair-Wise Coverage (PWC)</u> : A value from each block for each characteristic must be combined with a value from every block for each other characteristic.**

- Number of tests is at least the product of two largest characteristics $(\mathrm{Max}_{i=1}^{Q}(B_i)) * (\mathrm{Max}_{j=1,\, j!=i}^{Q}(B_j))$

| | | | | |
|---|---|---|---|---|
| For *triang*() : | A1, B1, C1 | A1, B2, C2 | A1, B3, C3 | A1, B4, C4 |
| | A2, B1, C2 | A2, B2, C3 | A2, B3, C4 | A2, B4, C1 |
| | A3, B1, C3 | A3, B2, C4 | A3, B3, C1 | A3, B4, C2 |
| | A4, B1, C4 | A4, B2, C1 | A4, B3, C2 | A4, B4, C3 |

# ISP Criteria –T-Wise

- A natural extension is to require combinations of *t* values instead of *2*

**t-Wise Coverage (TWC) :A value from each block for each group of t characteristics must be combined.**

- Number of tests is at least the product of *t* largest characteristics
- If all characteristics are the same size, the formula is

$$\left(\mathrm{Max}_{i=1}^{Q}(B_i)\right)^t$$

- If *t* is the number of characteristics *Q*, then all combinations
- That is … *Q-wise = AC*
- *t*-wise is expensive and benefits are not clear

# ISP Criteria – Base Choice

- Testers sometimes recognize that certain values are important
- This uses domain knowledge of the program

**Base Choice Coverage (BCC) : A base choice block is chosen for each characteristic, and a base test is formed by using the base choice for each characteristic. Subsequent tests are chosen by holding all but one base choice constant and using each non-base choice in each other characteristic.**

- Number of tests is one base test + one test for each other block $1 + \sum_{i=1}^{Q} (B_i - 1)$

| For *triang*() : Base | A1, B1, C1 | A1, B1, C2 | A1, B2, C1 | A2, B1, C1 |
|---|---|---|---|---|
| | | A1, B1, C3 | A1, B3, C1 | A3, B1, C1 |
| | | A1, B1, C4 | A1, B4, C1 | A4, B1, C1 |

# Base Choice Notes

- The base test must be feasible
  - That is, all base choices must be compatible
- Base choices can be
  - Most likely from an end-use point of view
  - Simplest
  - Smallest
  - First in some ordering
- Happy path tests often make good base choices
- The base choice is a crucial design decision
  - Test designers should document why the choices were made

# ISP Criteria – Multiple Base Choice

- We sometimes have more than one logical base choice

<u>Multiple Base Choice Coverage (MBCC)</u> : At least one, and possibly more, base choice blocks are chosen for each characteristic, and base tests are formed by using each base choice for each characteristic at least once. Subsequent tests are chosen by holding all but one base choice constant for each base test and using each non-base choice in each other characteristic.

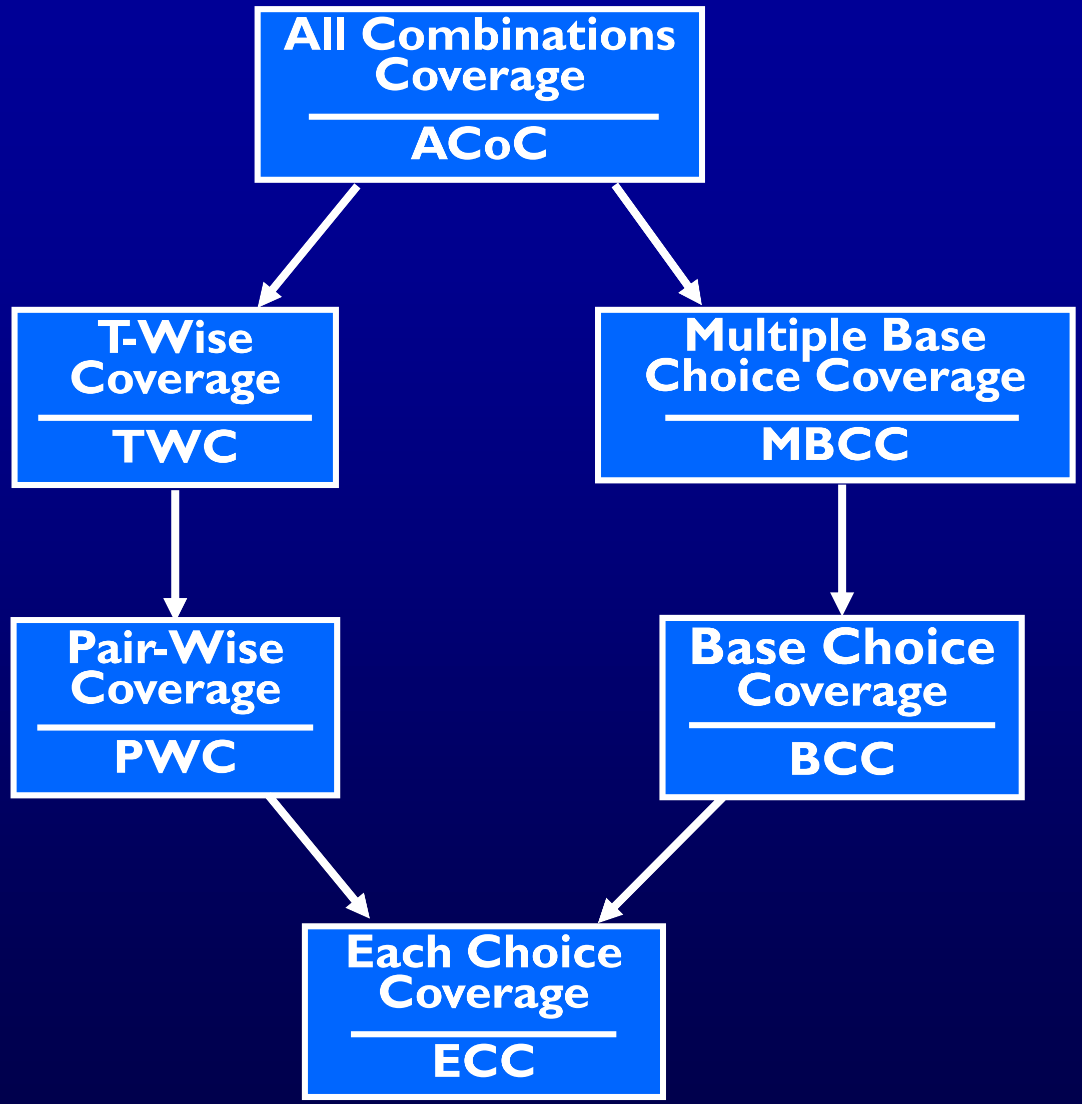
- **If *M* base tests and $m_i$ base choices for each characteristic:**

$$M + \sum_{i=1}^{Q} (M * (B_i - m_i))$$

**For *triang*() :** <u>**Bases**</u>

| | | | |
|---|---|---|---|
| **A1, B1, C1** | **A1, B1, C3** | **A1, B3, C1** | **A3, B1, C1** |
| | **A1, B1, C4** | **A1, B4, C1** | **A4, B1, C1** |
| **A2, B2, C2** | **A2, B2, C3** | **A2, B3, C2** | **C3, B2, C2** |
| | **A2, B2, C4** | **A2, B4, C2** | **C3, B2, C2** |

# ISP Coverage Criteria Subsumption



# Constraints Among Characteristics (6.3)

- Some combinations of blocks are infeasible
  - "less than zero" and "scalene" … not possible at the same time
- These are represented as constraints among blocks
- Two general types of constraints
  - A block from one characteristic cannot be combined with a specific block from another
  - A block from one characteristic can ONLY BE combined with a specific block form another characteristic
- Handling constraints depends on the criterion used
  - ACC, PWC, TWC : Drop the infeasible pairs
  - BCC, MBCC : Change a value to another non-base choice to find a feasible combination

# Example Handling Constraints

- Sorting an array
  - Input : variable length array of arbitrary type
  - Outputs : sorted array, largest value, smallest value

**Characte**
- **Length**
- **Type of**
- **Max val**
- **Min valu**
- **Position**
- **Position**

**Partitions:**
- **Len** { 0, 1, 2..100, 101..MAXINT }
- **Type** { int, char, string, other }
- **Max** { ≤0, 1, >1, 'a', 'Z', 'b', …, 'Y' }
- **Min** { … }
- **Max Pos** { 1, 2 .. Len-1, Len }
- **Min Pos** { 1, 2 .. Len-1, Len }

**Blocks from other characteristics are irrelevant**

**Blocks must be combined**

**Blocks must be combined**

# Example Handling Constraints

public boolean findElement (List list, Object element)

// Effects: if list or element is null throw NullPointerException

// else return true if element is in the list, false otherwise

| Characteristic | Block 1 | Block 2 | Block 3 | Block 4 |
|---|---|---|---|---|
| A : length and contents | One element | More than one, unsorted | More than one, sorted | More than one, all identical |
| B : match | element not found | element found once | element found more than once | |
| Invalid combinations : **(A1, B3)**, **(A4, B2)** | | | | |

**element cannot be in a one-element list more than once**

**If the list only has one element, but it appears multiple times, we cannot find it just once**

# Input Space Partitioning Summary

- Fairly easy to apply, even with no automation
- Convenient ways to add more or less testing
- Applicable to all levels of testing – unit, class, integration, system, etc.
- Based only on the input space of the program, not the implementation

**Simple, straightforward, effective, and widely used**