Introduction to Software Testing

(2nd edition)

Chapter 6

Input Space Partition Testing

Instructor: Morteza Zakeri

Slides by: **Paul Ammann & Jeff Offutt**

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

Modified by: **Morteza Zakeri**

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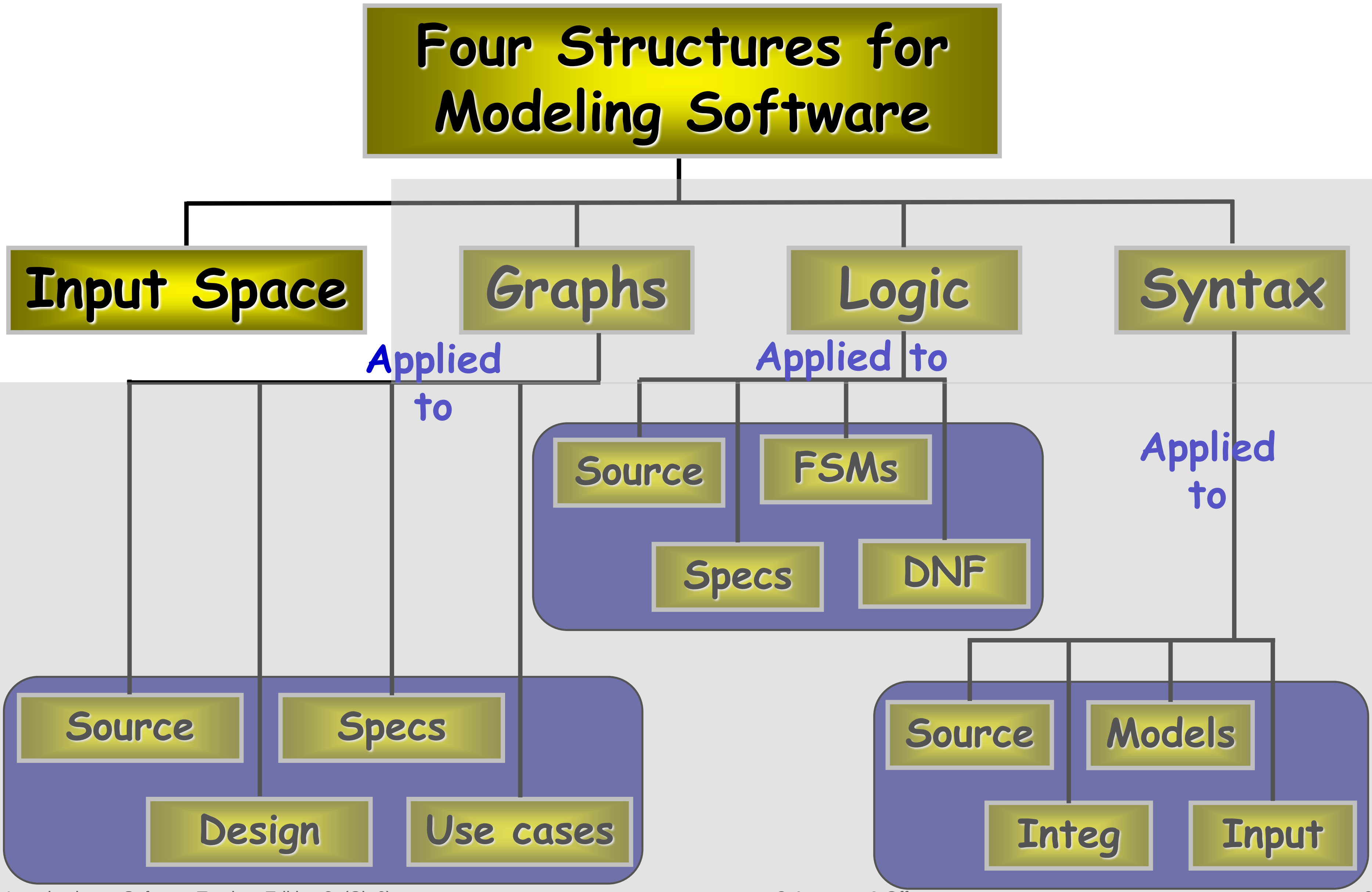
Ch. 6: Input Space Coverage



Benefits of ISP

- Equally applicable at several levels of testing
  - Unit
  - Integration
  - System
- Easy to apply with no automation
- Can adjust the procedure to get more or fewer tests
- No implementation knowledge is needed
  - Just the input space
  - **Blackbox**?

Input Domains

- Input domain: all possible inputs to a program
  - Most input domains are so large that they are effectively infinite
- *Input parameters* define the scope of the input domain
  - Parameter values to a method
  - Data from a file
  - Global variables
  - User inputs
- We partition input domains into regions (called *blocks*)
- Choose at least one value from each block

Input domain: Alphabetic letters

Partitioning characteristic: Case of letter

- Block 1: upper case
- Block 2: lower case

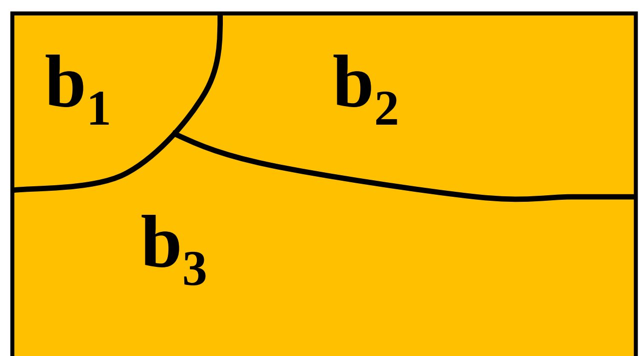
Partitioning Domains

- *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)

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

  2. Together the blocks *cover* the domain *D* (complete)

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



In-Class Exercise

Partitioning for integers

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

What is a characteristic?

"A feature or quality belonging typically to a person, place, or thing and serving to identify it."

Input: people

concrete level

Characteristics: hair color, major

Blocks:

A=(red, black, brown, blonde, other)

B=(cs, swe, ce, math, ist, other)

abstract level

Abstraction:

A = [a1, a2, a3, a4, a5]

B = [b1, b2, b3, b4, b5, b6]

Examples

- Example characteristics
  - Whether X is null
  - Order of the list F (sorted, inverse sorted, arbitrary, …)
  - Min separation of two aircraft
  - Input device (DVD, CD, VCR, computer, …)
  - Hair color, height, major, age
- Partition characteristic into blocks
  - Blocks may be single-value or a set of values
  - Each value in a block should be equally useful for testing
- Each abstract test has one block from each characteristic

Choosing Partitions

- Defining partitions is not hard, but is easy to get wrong
- Consider the "*order of elements in list F*"

b_1 = sorted in ascending order

b_2 = sorted in descending order

b_3 = arbitrary order

but … something's fishy …

Length 1 : [14]

The list will be in all three blocks …

That is, disjointness is not satisfied

Choosing Partitions

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but … something's fishy …

Length 1 : [14]

The list will be in all three blocks …

That is, disjointness is not satisfied

Solution:

Two characteristics that address just one property

C1: List F sorted ascending
- c1.b1 = true
- c1.b2 = false

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

Modeling the input domain

- Step 1 : Identify testable functions
- Step 2 : Find all inputs, parameters, & characteristics

Concrete level

- Step 3 : Model the input domain
  - *input domain model* (*IDM*)

Move from imp level to design abstraction level

- Step 4 : Apply a test criterion to choose combinations of values (6.2)

Entirely at the design abstraction level

- Step 5 : Refine combinations of blocks into test inputs

Back to the implementation abstraction level

Steps 1 & 2

Identify testable functions

Find inputs, parameters, characteristics

Example IDM (syntax)

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

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

IDM for each parameter is identical

Characteristic : *Relation of side with zero*

Blocks: negative; positive; zero

Example IDM (behavior)

- Method *triang()* again :

The three parameters represent a *triangle*

The IDM can combine all parameters

Characteristic : *Type of triangle*

Blocks: Scalene; Isosceles; Equilateral; Invalid

Steps 1 & 2—IDM

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

<u>Parameters and Characteristics</u>

Two <u>parameters</u> : list, element

<u>Characteristics</u> based on **syntax** :
   list is null (block1 = true, block2 = false)
   list is empty (block1 = true, block2 = false)

<u>Characteristics</u> based on **behavior**:
   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

Model input domain

Partition characteristics into blocks

Choose values for blocks

triang(): Relation of side with zero

- 3 inputs, each has the same partitioning

Characteristic	b_1	b_2	b_3
q_1 = "Relation of Side 1 to 0"	positive	equal to 0	negative
q_2 = "Relation of Side 2 to 0"	positive	equal to 0	negative
q_3 = "Relation of Side 3 to 0"	positive	equal to 0	negative

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

Refining *triang()*'s IDM

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	negative
q_2 = "Refinement of q_2"	greater than 1	equal to 1	equal to 0	negative
q_3 = "Refinement of q_3"	greater than 1	equal to 1	equal to 0	negative

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

Values for partition q_1

Characteristic	b_1	b_2	b_3	b_4
Side1	**2**	1	0	**-1**

Test boundary conditions

triang(): Type of triangle

Geometric Characterization of *triang*()'s Inputs

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

What's wrong with this partitioning?

- Equilateral is also isosceles!
- We need to refine the example to make characteristics valid

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

Values for *triang()*

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)

Yet another *triang()* IDM

- 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

IDM hints

- More characteristics → more tests
- More blocks → more tests
- Do not use program source
- Design more characteristics with fewer blocks
  - Fewer mistakes
  - Fewer tests
- Choose values strategically
  - Valid, invalid, special values
  - Explore boundaries
  - Balance the number of blocks in the characteristics

Modeling the input domain

- Step 1 : Identify testable functions
- Step 2 : Find all inputs, parameters, & characteristics
- Step 3 : Model the input domain

Move from imp level to design abstraction level

- Step 4 : Apply a test criterion to choose combinations of values (6.2)

Entirely at the design abstraction level

- Step 5 : Refine combinations of blocks into test inputs

Back to the implementation abstraction level

Step 4 – Choosing combinations of values (6.2)

- After partitioning characteristics into blocks, testers design tests by combining blocks from different characteristics
  - 3 Characteristics (abstract): A, B, C
  - Abstract blocks:
    - A = [a1, a2, a3, a4]; B = [b1, b2]; C = [c1, c2, c3]
- A test starts by combining one block from each characteristic
  - Then values are chosen to satisfy the combinations
- We use criteria to choose effective combinations

All combinations criterion (ACoC)

The most obvious criterion is to choose all combinations

<u>All Combinations</u> (<u>ACoC</u>) : Test with all combinations of blocks from all characteristics.

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 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

# of tests to satisfy ACoC: 4 * 2 * 3 = 24

All combinations criterion (ACoC)

- Number of tests is the product of the number of blocks in each characteristic Q : $$\prod_{i=1}^{Q} (B_i)$$
- The syntax characterization of *triang()*
  - Each side: >1, 1, 0, <1
  - Results in 4*4*4 = 64 tests
- Most form invalid triangles

How can we get fewer tests?

Example

Input: students

Characteristics: Level, Mode, Major, Classification

Blocks:

Level: (grad, undergrad)

Mode: (full-time, part-time)

Major: (cs, swe, other)

Classification: (in-state, out-of-state)

Abstract IDM:

A = [a1, a2] C = [c1, c2, c3]

B = [b1, b2] D = [d1, d2]

In-class exercise

All combinations criterion (ACoC)

Consider this abstract IDM

4 Characteristics: A, B, C, D

Abstract blocks: A = [a1, a2]; B = [b1, b2];

C = [c1, c2, c3]; D = [d1, d2]

How many tests are needed to satisfy ACoC?

In-class exercise (*answer*)

All combinations criterion (ACoC)

4 Characteristics: A, B, C, D

Abstract blocks: A = [a1, a2]; B = [b1, b2];
C = [c1, c2, c3]; D = [d1, d2]

Number of tests: 2*2*3*2 = 24

a1 b1 c1 d1	a1 b2 c1 d1	a2 b1 c1 d1	a2 b2 c1 d1
a1 b1 c1 d2	a1 b2 c1 d2	a2 b1 c1 d2	a2 b2 c1 d2
a1 b1 c2 d1	a1 b2 c2 d1	a2 b1 c2 d1	a2 b2 c2 d1
a1 b1 c2 d2	a1 b2 c2 d2	a2 b1 c2 d2	a2 b2 c2 d2
a1 b1 c3 d1	a1 b2 c3 d1	a2 b1 c3 d1	a2 b2 c3 d1
a1 b1 c3 d2	a1 b2 c3 d2	a2 b1 c3 d2	a2 b2 c3 d2

ISP criteria – each choice

- We should try at least one value from each block

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

- Number of tests is the number of blocks in the largest characteristic:

$$\operatorname{Max}_{i=1}^{Q} (B_i)$$

In-class exercise

Each choice criterion (ECC)

Apply ECC to our previous example

4 Characteristics: A, B, C, D

Abstract blocks: A = [a1, a2]; B = [b1, b2];
C = [c1, c2, c3]; D = [d1, d2]

1. How many tests are needed for ECC?
2. Design the (abstract) tests

In-class exercise (*answer*)

Each choice criterion (ECC)

4 Characteristics: A, B, C, D

Abstract blocks: A = [a1, a2]; B = [b1, b2];
C = [c1, c2, c3]; D = [d1, d2]

Number of tests: max(2,2,3,2) = 3

a1	b1	c1	d1
a2	b2	c2	d2
a1	b1	c3	d1

ISP criteria – base choice (BCC)

- ECC is simple, but very few tests
- The base choice criterion recognizes:
  - Some blocks are more important than others
  - Using diverse combinations can strengthen testing
- Lets testers bring in **domain knowledge** of the program

Base Choice Coverage (BCC): Choose a base choice block for each characteristic. Form a base test by using the base choice for each characteristic. Choose subsequent tests 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

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

In-class exercise

Base choice criterion (BCC)

Apply BCC to our previous example

4 Characteristics: A, B, C, D

Abstract blocks: A = [a1, a2]; B = [b1, b2];
C = [c1, c2, c3]; D = [d1, d2]

1. How many tests are needed for BCC?
2. Pick base values and write one base test
3. Design the remaining (abstract) tests

In-class exercise (*answer*)

Base choice criterion (BCC)

4 Characteristics: A, B, C, D

Abstract blocks: A = [a1, a2]; B = [b1, b2];
C = [c1, c2, c3]; D = [d1, d2]

Number of tests: 1(base)+1+1+2+1 = 6

Base	a1 b1 c1 d1
A	**a2** b1 c1 d1
B	a1 **b2** c1 d1
C	a1 b1 **c2** d1
C	a1 b1 **c3** d1
D	a1 b1 c1 **d2**

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</u> (<u>MBCC</u>): Choose at least one, and possibly more, base choice blocks for each characteristic. Form base tests 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 our example: Two base tests: a1, b1, c1, d1 a2, b2, c2, d2

Tests from a1, b1, c1, d1: a1, b1, c3, d1

Tests from a2, b2, c2, d2: a2, b2, c3, d2

ISP criteria – PWC and TWC

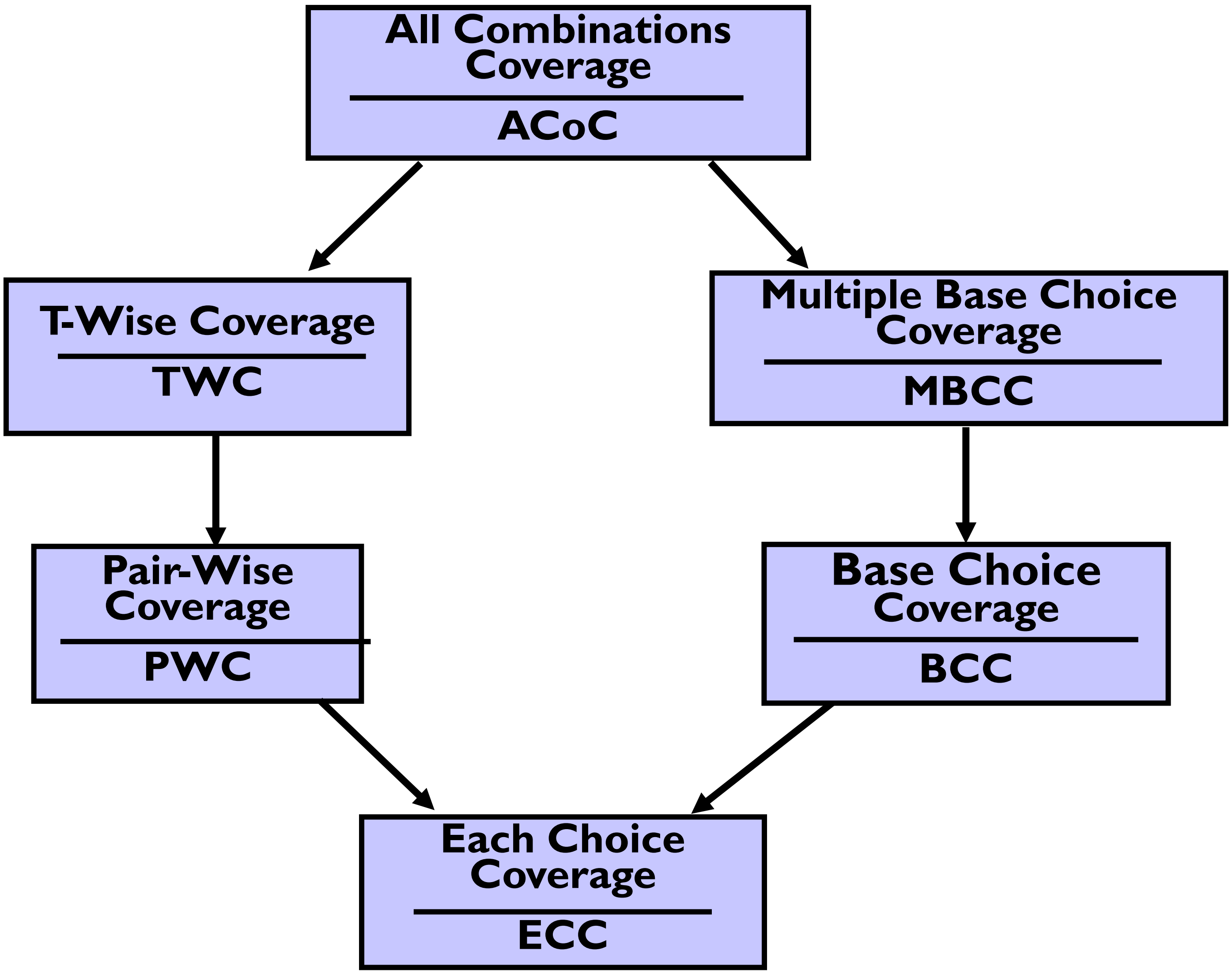
Pair-Wise Coverage (PWC): A value from each block for each characteristic must be combined with a value from every block for each other characteristic.

$$(Max_{i=1}{}^{Q}B_i) * (Max_{i=1,\, j=1}{}^{Q}B_j)$$

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

- Both **Pair-Wise** Coverage and **T-Wise Coverage** combine values "blindly," without regard for which values are being combined.
- The **BCC** and **MBCC** strengthens ECC in a different way by bringing in a small but crucial piece of domain knowledge of the program.

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

```
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