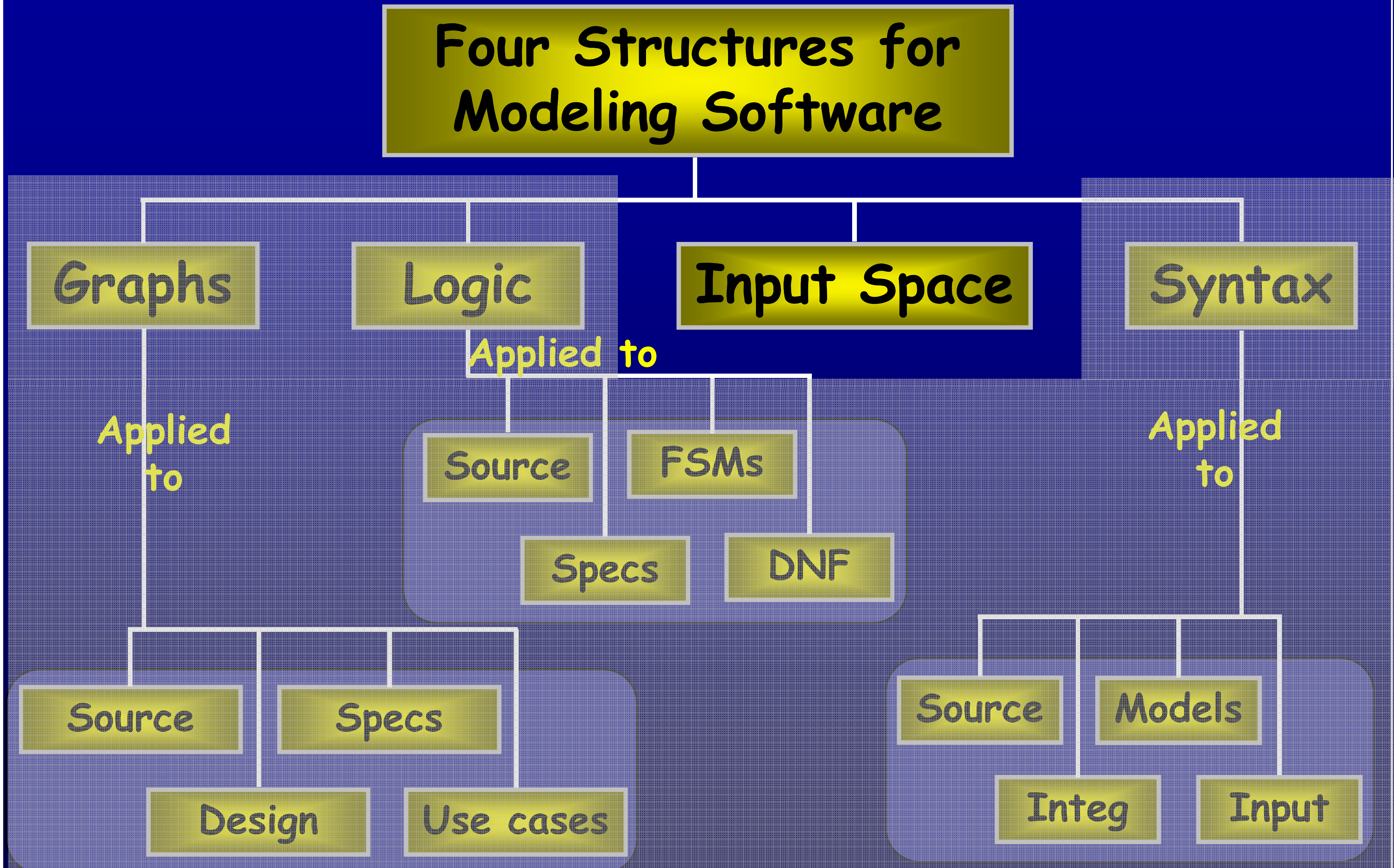
Introduction to Software Testing
Chapter 4
Input Space Partition Testing

Paul Ammann & Jeff Offutt

www.introsoftwaretesting.com

Ch. 4 : Input Space Coverage



Input Domains

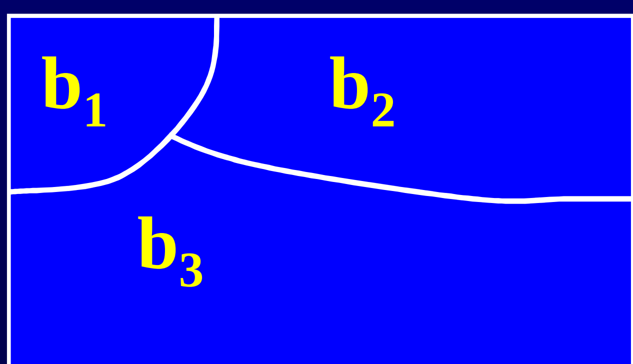
- The **input domain** to a program contains all the possible inputs to that program
- For even small programs, the input domain is so large that it might as well be **infinite**
- Testing is fundamentally about **choosing finite sets** of values from the input domain
- *Input parameters* define the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

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



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

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

Using Partitions – Assumptions

- Choose a value from each partition
- Each value is assumed to be equally useful for testing
- Application to testing
  - Find characteristics in the inputs : parameters, semantic descriptions, …
  - Partition each characteristics
  - 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 "order of file F"

b_1 = sorted in ascending order

b_2 = sorted in descending order

b_3 = arbitrary order

but … something's fishy …

What if the file is of length 1?

The file will be in all three blocks …

That is, disjointness is not satisfied

Solution:

Each characteristic should address just one property

File F sorted ascending

- b1 = true
- b2 = false

File F sorted descending

- b1 = true
- 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 attempt
- Different alternatives should be considered
- We model the input domain in five steps …

Modeling the Input Domain

- **Step 1 : Identify testable functions**
  - Individual methods have one testable function
  - In a class, each method has the same characteristics
  - Programs have more complicated characteristics—modeling documents such as UML use cases 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**
  - 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 applying 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

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

Consider TriTyp from Chapter 3

Three *int* parameters

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

Consider TriTyp again

The three parameters represent a *triangle*

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**

Steps 1 & 2 : Interface vs 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 <u>creative engineering</u> step**
- **More blocks means more tests**
- **The partitioning often flows directly from the definition of characteristics and both steps are sometimes 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**
  - **Check for completeness and disjointness**

Interface-Based IDM – TriTyp

- **TriTyp, from Chapter 3, had 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 – TriTyp (*cont*)

Second Characterization of TriTyp's Inputs

Characteristic			b_3	b_4
q_1 = "Refinement of q_1"			equal to 0	less than 0
q_2 = "Refinement of q_2"			equal to 0	less than 0
q_3 = "Refinement of q_3"			equal to 0	less than 0

- **A maximum of 4*4*4 = 64 tests**
- **This is only 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 – TriTyp

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

<u>Geometric</u> Characterization of TriTyp's Inputs

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

- **Oops … something's fishy … equilateral is also isosceles !**
- **We need to refine the example to make characteristics valid**

<u>Correct</u> Geometric Characterization of TriTyp's Inputs

Characteristic	b_1	b_2	b_3	b_4
q_1 = "Geometric Classification"	scalen[illegible]	[illegible]	equilateral	invalid

Functionality-Based IDM – TriTyp (*cont*)

- **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 – TriTyp (*cont*)

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

Four Characteristics for TriTyp

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

- **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 …**

> **All Combinations (ACoC) : 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 TriTyp results in 4*4*4 = 64 tests – too many ?**

ISP Criteria – Each Choice

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

> **Each Choice (EC) : 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**

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

For TriTyp: 2, 2, 2
1, 1, 1
0, 0, 0
-1, -1, -1

ISP Criteria – Pair-Wise

- **Each choice yields few tests – cheap but perhaps ineffective**
- **Another approach asks values to be combined with other values**

Pair-Wise (PW) : 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**

$$(\text{Max}_{i=1}^{Q}(B_i)) * (\text{Max}_{j=1,\, j!=i}^{Q}(B_j))$$

For TriTyp:				
	2, 2, 2	2, 1, 1	2, 0, 0	2, -1, -1
	1, 2, 1	1, 1, 0	1, 0, -1	1, -1, 2
	0, 2, 0	0, 1, -1	0, 0, 2	0, -1, 1
	-1, 2, -1	-1, 1, 2	-1, 0, 1	-1, -1, 0

ISP Criteria –T-Wise

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

<u>t-Wise (TW)</u> : 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 (BC) : 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 TriTyp: Base			
2, 2, 2	2, 2, 1	2, 1, 2	1, 2, 2
	2, 2, 0	2, 0, 2	0, 2, 2
	2, 2, -1	2, -1, 2	-1, 2, 2

ISP Criteria – Multiple Base Choice

- **Testers sometimes have more than one logical base choice**

Multiple Base Choice (MBC) : One or more base choice blocks are chosen for each characteristic, and base tests are formed by using each base choice for each characteristic. Subsequent tests are chosen by holding all but one base choice constant for each base test and using each non-base choices in each other characteristic.

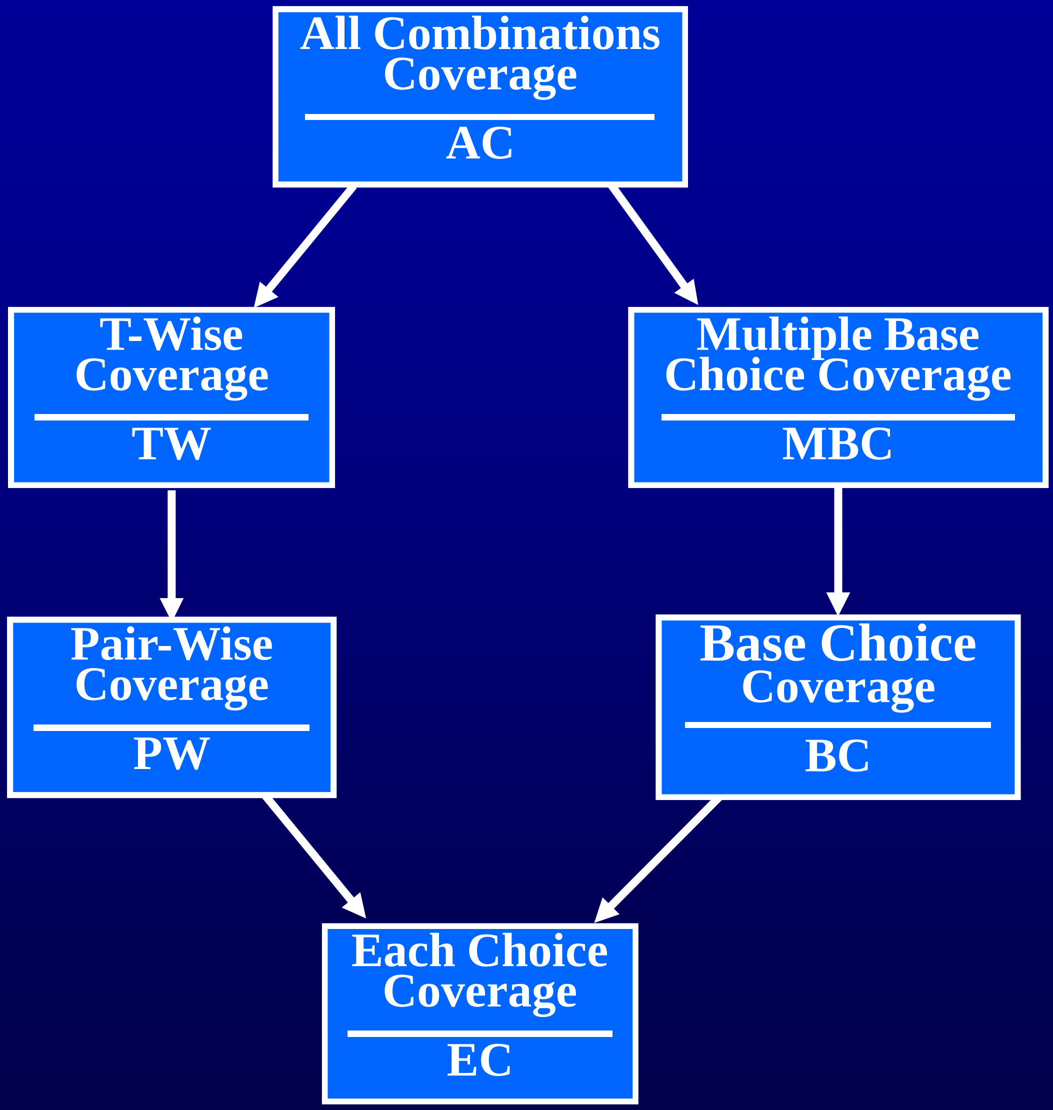
- **If there are *M* base tests and m_i base choices for each characteristic:**

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

For TriTyp: Base

2, 2, 2	2, 2, 0	2, 0, 2	0, 2, 2
	2, 2, -1	2, -1, 2	-1, 2, 2
1, 1, 1	1, 1, 0	1, 0, 1	0, 1, 1
	1, 1, -1	1, -1, 1	-1, 1, 1

ISP Coverage Criteria Subsumption



Constraints Among Characteristics

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

Example Handling Constraints

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

<u>Characte</u>
- Length
- Type of
- Max val
- Min valu
- Position
- Position

<u>Partitions</u>:
- 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

Input Space Partitioning Summary

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