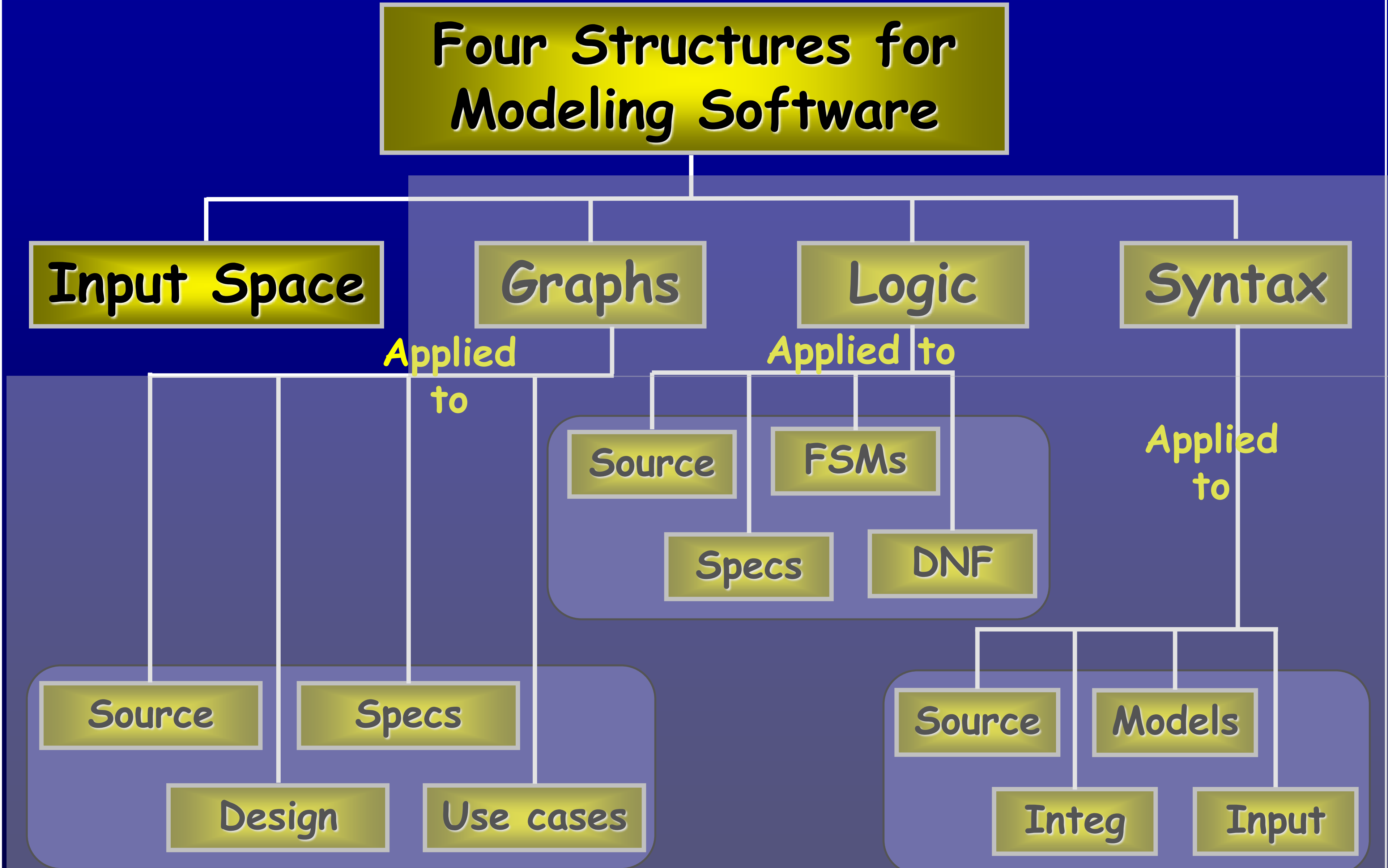
Introduction to Software Testing
Chapter 6
Input Space Partition Testing

Paul Ammann & Jeff Offutt

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

Ch. 6 : Input Space Coverage



Overview: Recall from Chapter 5

- Describe the input domain of the software
  - Identify input parameters
  - Partition each input into finite sets of representative values
  - Choose combinations of values
- Example
  - Parameters *F (int X, int Y)*
  - Possible values X: { *<0, 0, 1, 2, >2* }, *Y* : { *10, 20, 30* }
  - Tests
    - *F (-5, 10), F (0, 20), F (1, 30), F (2, 10), F (5, 20)*

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

Input Domains

- Input domain: all possible values that the input parameters can have
  - Most input domains are so large that they are effectively infinite
- *Input parameters*
  - 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

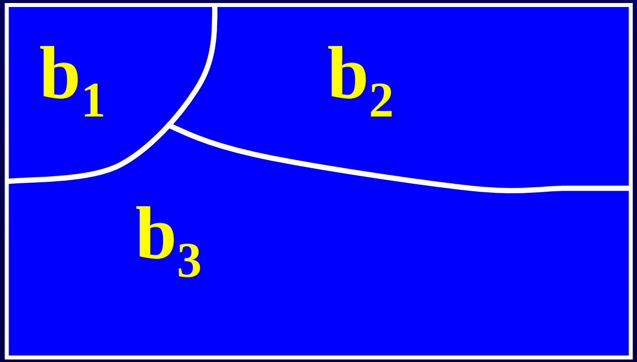
Partitioning Domains

- *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)

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

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

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



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, …)
  - 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

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

Concrete level

- 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

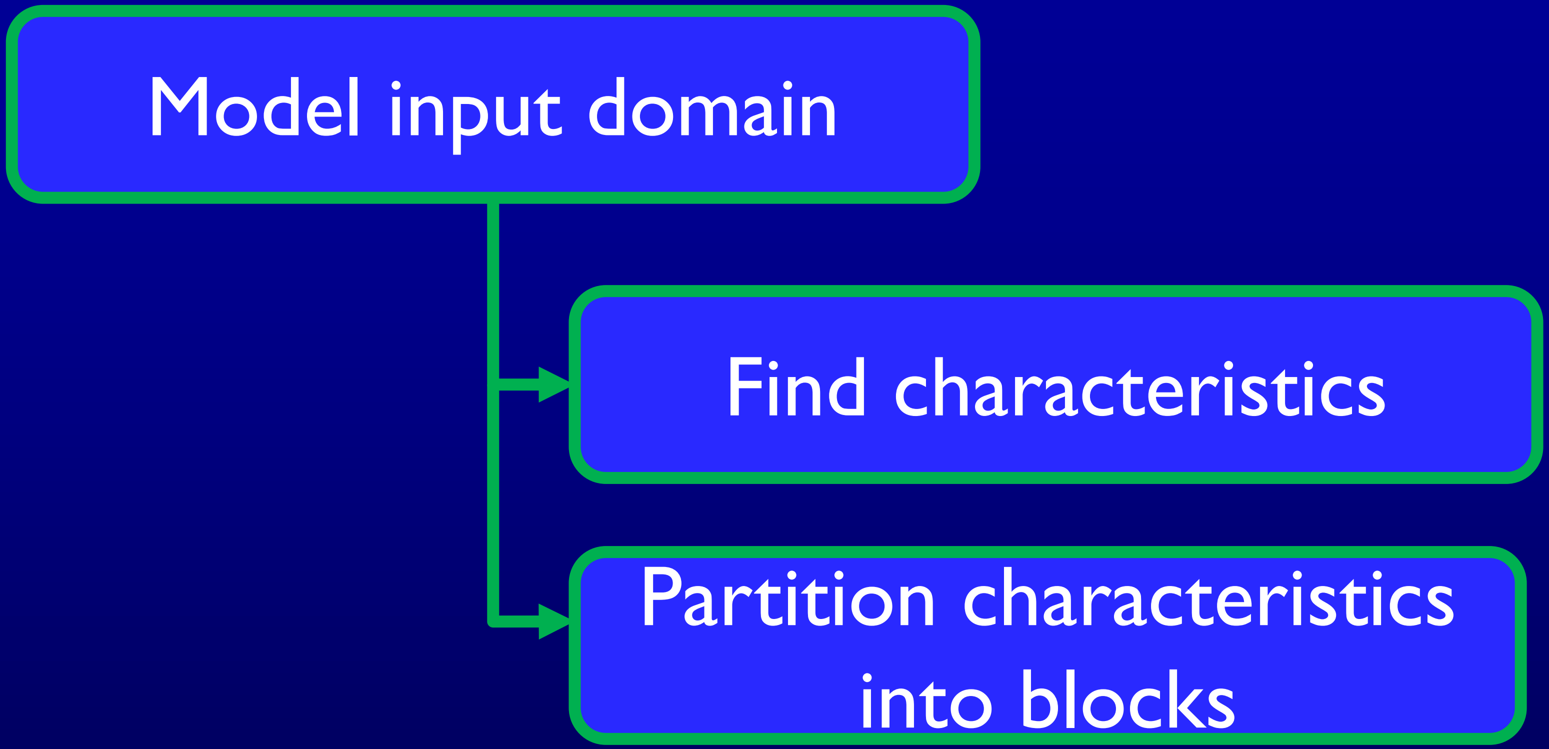
Back to the implementation level

Steps 1 & 2

Identify testable functions

Find input parameters

Step 3


Model input domain
Find characteristics
Partition characteristics into blocks

Two Approaches to Input Domain Modeling (IDM)

1. Interface-based approach
   – Develops characteristics directly from individual input parameters
   – Mechanically consider each parameter in isolation
   – This is an easy modeling technique and relies mostly on syntax
   – Ignores semantic relationships among parameters
2. Functionality-based approach
   – Develops characteristics from a behavioral view (or functionality) of the program under test
   – Incorporates semantic knowledge (i.e., relationships among parameters)
   – Harder to develop—requires more design effort
   – May result in better tests, or fewer tests that are as effective

Example—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

Parameters and Characteristics

Two parameters : list, element

Characteristics based on syntax :

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

Characteristics 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)

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

Relationship of variables with special values (zero, null, blank, …)

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

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

Constraints For triang() IDM

- Complete list of constraints in this example:
  - Scalene = True implies Isosceles = Equilateral = False and Valid = True
  - Scalene = False does not imply anything
  - Isosceles = True implies Scalene = False and Valid = True
  - Isosceles = False implies Equilateral = False
  - Equilateral = True implies Scalene = False and Isosceles = Valid = True
  - Equilateral = False does not imply anything
  - Valid = False implies Scalene = Isosceles = Equilateral = False
  - Valid = True does not imply anything

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

IDM hints (1)

- More characteristics → more tests
- More blocks → more tests
- Do not use program source
  - Use specifications or other documentation instead of program code to develop characteristics
  - The tester should apply ISP by using domain knowledge about the problem, not the implementation
  - In practice, the code may be all that is available
  - Overall, the more semantic information the test engineer can incorporate into characteristics, the better the resulting test set is likely to be

IDM hints (2)

- Design more characteristics with fewer blocks
  - Fewer mistakes
  - Fewer tests
  - More likely to satisfy the disjointness and completeness
- Partition and choose values strategically
  - Valid, invalid, special values (e.g., null, zero, empty, …)
  - Explore boundaries
  - Balance the number of blocks in the characteristics

Strategies for partitioning and choosing values (1)

- Valid, invalid and special values
  – Every partition must allow all values, whether valid or invalid. Special values should be used
- Sub-partition
  – A range of valid values can often be partitioned into sub-partitions (each sub-partition represents a different part of the functionality)
- Boundaries
  – Values at or close to boundaries often cause problems (stress test)
- Normal use (happy path)
  – Include values that represent normal use(not boundary conditions)

Strategies for partitioning and choosing values (2)

- Enumerated types
  - A partition where blocks are a discrete, enumerated set often makes sense. The triangle example uses this approach
- Balance
  - Try to balance the number of blocks in each characteristic
  - It may be cheap or even free to add more blocks to characteristics that have fewer blocks
  - The number of tests sometimes depends on the characteristic with the maximum number of blocks
- Missing blocks and Overlapping blocks
  - Check for completeness and disjointness

Using More than One IDM

- Some programs may have dozens or even hundreds of parameters
- Create several small IDMs than one large
  - A divide-and-conquer approach
- It is okay if the different IDMs overlap
  - The same variable may appear in more than one IDM
- Different parts of the software can be tested with different amounts of rigor (varying levels of coverage)
  - For instance, one IDM may contain only valid values and another IDM may contain invalid values to focus on error handling
  - The valid value IDM may be covered using a higher level of coverage. The invalid value IDM may use a lower level of coverage

Modeling the input domain

- Step 1 : Identify testable functions
- Step 2 : Find all inputs

Concrete level

- 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 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

All combinations criterion (ACoC)

- Number of tests is the product of the number of blocks in each characteristic : $\prod_{i=1}^{Q} (B_i)$
- The syntax characterization of triang()
  - Each side: >1, 1, 0, <1 (four blocks)
  - Results in 4*4*4 = 64 tests
- Most form invalid triangles
  - Only 8 are valid (all sides greater than zero)

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

Each Choice Coverage (ECC) : 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 : $\mathrm{Max}_{i=1}^{Q}(B_i)$

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

Shortcomings of ACoC and ECC

- ECC does not yield very effective tests
- It can be called a relatively "weak" criterion
  - The weakness of ECC can be expressed as not requiring values to be combined with other values
- A natural approach is to require explicit combinations of values
  - ACoC combine values "blindly", without regard for which values are being combined
- The next criterion strengthens ECC in a different
  - bringing in a small but crucial piece of domain knowledge of the program; asking what is the most "important" block for each partition
  - This block is called the base choice

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

Base Choice Example

- Suppose we have three partitions with blocks:
  - [A, B]
  - [1, 2, 3]
  - [x, y]
- Suppose base choice blocks are 'A', '1' and 'x'
- Then the base choice test is (A, 1, x)
- And the following additional tests would be needed:
  - ❖ (B, 1, x)
  - ❖ (A, 2, x)(A, 3, x)
  - ❖ (A, 1, y)

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 block
  - First block 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

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**

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

Triang Example

- 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

triang()– 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)

triang()– ECC Tests

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

For *triang*() : A1, B1, C1	Substituting values: 2, 2, 2
A2, B2, C2	1, 1, 1
A3, B3, C3	0, 0, 0
A4, B4, C4	-1, -1, -1

triang()– BCC Tests

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

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

- Each parameter for triang() has three characteristics with four blocks, thus BCC requires 1 + 3 + 3 + 3 tests

triang()– MBCC Tests

- **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**	**A3, B2, C2**
		A2, B2, C4	**A2, B4, C2**	**A4, B2, C2**

- In this example:
- With M = 2, Bi = 4, and mi = 2 ∀ i, 1 ≤ i ≤ 3:
  - Number of tests: 2 + (2*(4-2)) + (2*(4-2)) + (2*(4-2)) = 14

triang()– MBCC Tests

- Another example:
- For triang(), we may choose to include <u>two base choices for side 1</u>, "greater than 1" (A1) and "equal to 1" (A2)
- With M = 2, m1 = 2, and mi = 1 $\forall$ i, 2 $\leq$ i $\leq$ 3:
  - Number of tests: 2 + (2*(4-2)) + (2*(4-1)) + (2*(4-1)) = 18

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

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

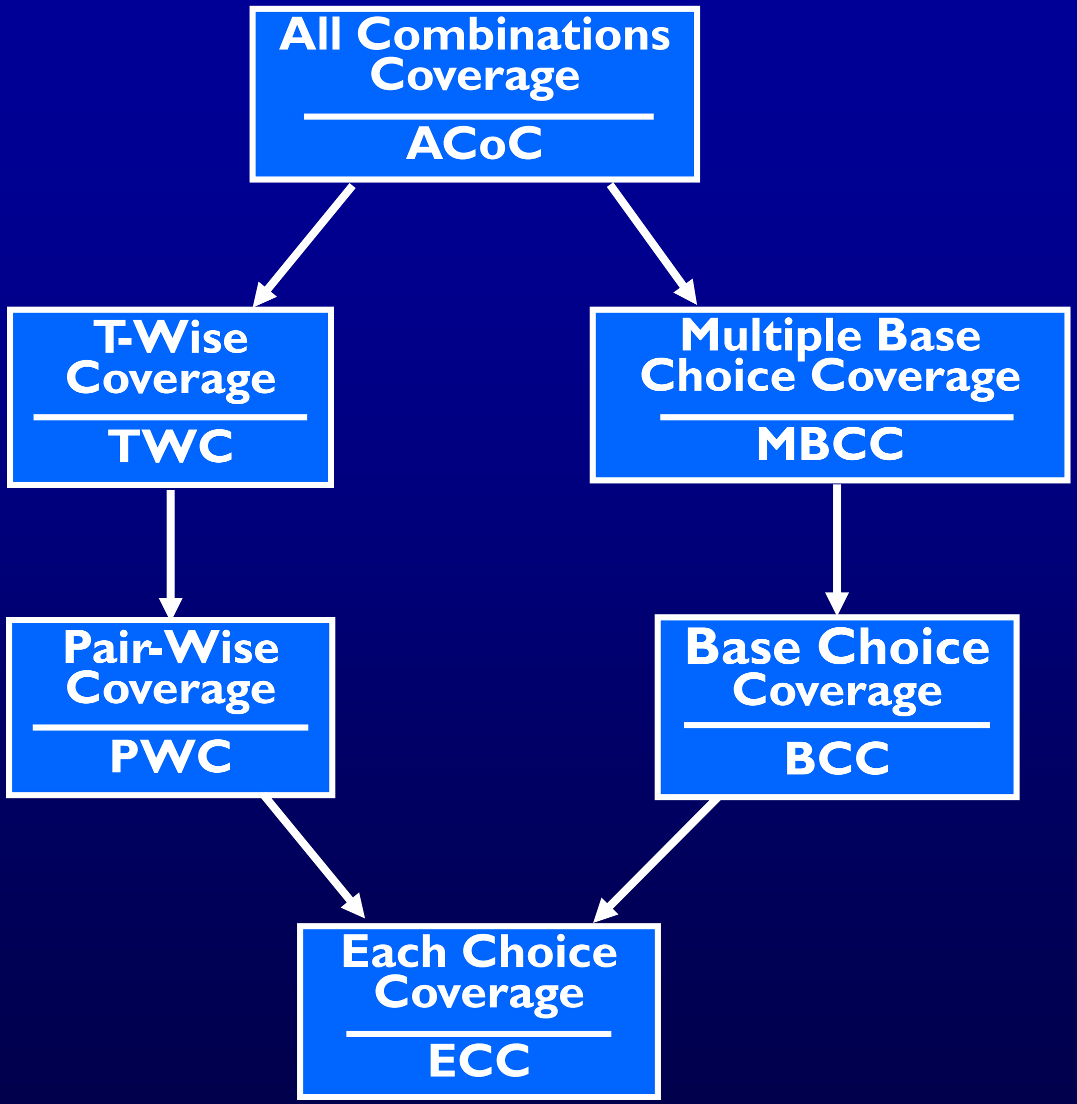
triang()– MBCC Tests

- The MBCC criterion sometimes results in duplicate tests
- For example, (A3, B1, C1) and (A4, B1, C1) both appear twice for triang ()
- Duplicate test cases should be eliminated (which makes the formula for the number of tests an upper bound)

For *triang*() : Bases

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

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 of 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

Example Handling Constraints

- For BCC and MBCC:
- If a particular variation (for example, "less than zero" for "Relation of Side 1 to zero") conflicts with the base case (for example, "scalene" for "Geometric Classification
  - We can change the choice for the base case to make the test requirement feasible
  - In this case, "Geometric Classification" can be changed to "invalid"

base test

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
q_4 = "Geometric Classification"	scalene	isosceles, not equilateral	equilateral	invalid

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

FURTHER READING
PAIR-WISE & T-WISE

ISP Criteria – Pair-Wise

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.

Pair-Wise (An Example)

- Given the example of three partitions with blocks [A, B], [1, 2, 3], and [x, y]:
- PWC needs tests to cover the following 16 combinations:

(A, 1)	(B, 1)	(1, x)
(A, 2)	(B, 2)	(1, y)
(A, 3)	(B, 3)	(2, x)
(A, x)	(B, x)	(2, y)
(A, y)	(B, y)	(3, x)
		(3, y)

- PWC allows the same test case to cover more than one unique pair of values. So the above combinations can be combined in several ways, including:

(A, 1, x)	(B, 1, y)
(A, 2, x)	(B, 2, y)
(A, 3, x)	(B, 3, y)
(A, -, y)	(B, -, x)

- '-' means that any block can be used

ISP Criteria –T-Wise

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

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

- If *t* is the number of characteristics *Q* (i.e., *t* = *Q*, where *Q* is the number of characteristics), then all combinations
  - That is … *Q-wise = AC*
- *t*-wise is expensive and benefits are not clear
  - Experience suggests going beyond pair-wise (that is, t = 2) does not help much