Intro to Software Testing

chapter 6

Input Space Coverage
(continued)

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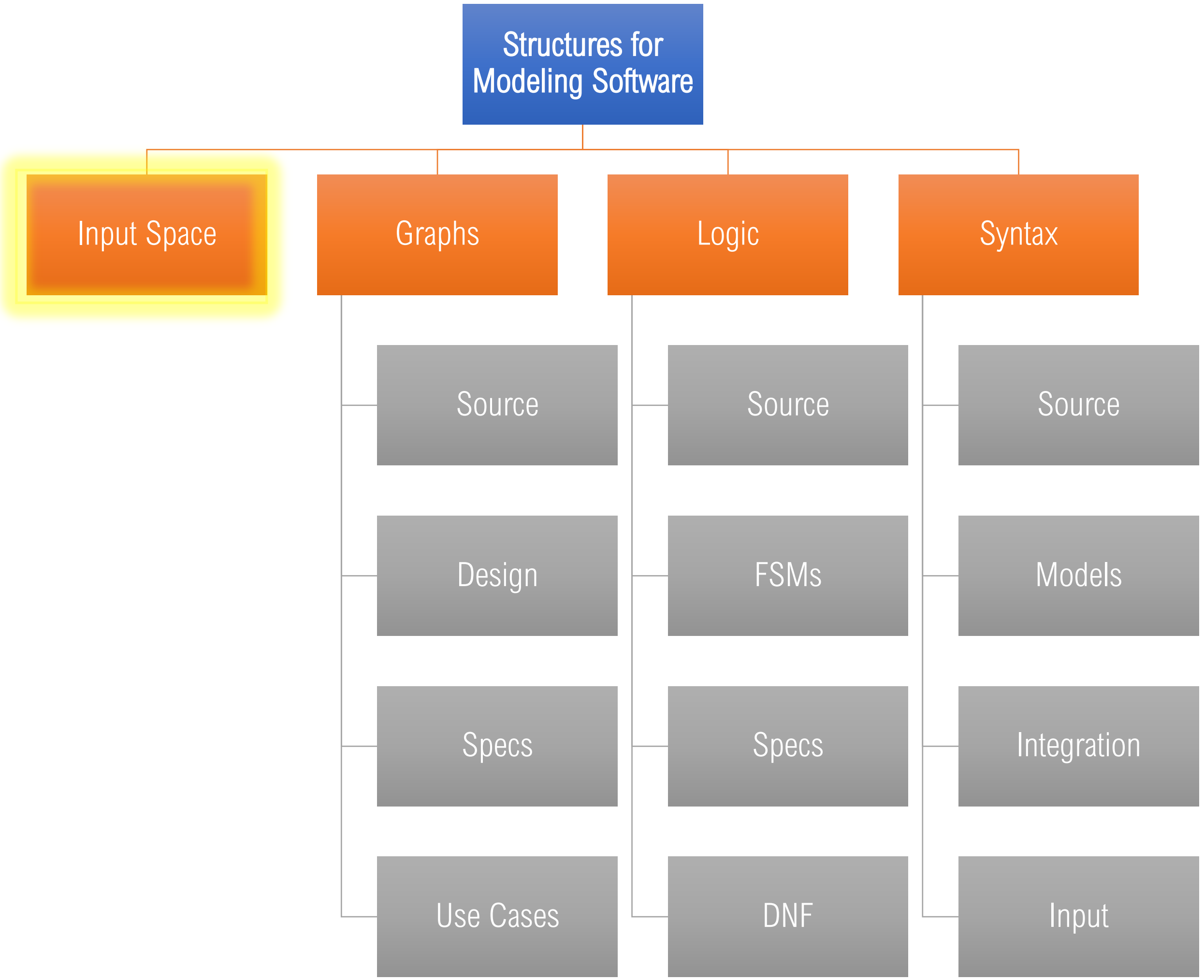
(Dr. B for short)

https://go.gmu.edu/SWE637

Adapted from slides by Jeff Offutt and Bob Kurtz

Input Space Coverage



Input Domains

Input domain: all possible inputs to a program

- most domains are so large they are effectively **infinite**

Input parameters define the scope of the input domain

- parameter values to a method
- data from file
- global variables
- user inputs

We **partition** input domains into regions called ***blocks***

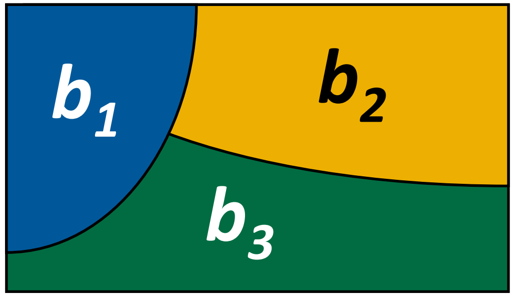
Choose at least **one value** from each block

Input domain: Alphabetic letters
Partitioning characteristic: Case of letter
Block 1: upper case
Block 2: lower case

Partitioning Input Domains

Given domain ***D***, there is a partition scheme ***q*** of ***D*** such that:

- Partition ***q*** defines a set of blocks
  Bq = b_1, b_2, …, ***bQ***
- The partition must satisfy two properties
  - Blocks must be ***disjoint*** (no overlaps)
  - Blocks must be ***complete*** (cover the domain D)



Input Characteristics

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

Input: people

Concrete

Characteristics: hair color, major
Blocks:
A = (1) red, (2) black, (3) brown, (4) blonde, (5) other
B = (1) cs, (2) swe, (3) ce, (4) math, (5) ist, (6) other

Abstraction

A = [a1, a2, a3, a4, a5]
B = [b1, b2, b3, b4, b5, b6]

Modeling the input domain

Step 1: Identify testable functions

Step 2: Find all inputs, parameters, & characteristics

Step 3: Model the input domain

Step 4: Apply a test criterion to choose combinations of values

Step 5: Refine combinations of blocks into test inputs

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 like UML can be used to design characteristics
- *Systems* of integrated hardware and software components can have many testable functions – devices, operating systems, hardware platforms, browsers, etc.

Modeling the input domain

Step 2: Find all the *parameters*

- Often straightforward or mechanical
  - Preconditions and postconditions
  - Relationships among variables
  - Special values (zero, null, etc.)
- Do not use program source code, characteristics should be based on the *input domain*
- *Methods*: parameters and state variables
- *Components*: parameters to methods and state variables
- *Systems*: all inputs, including files and databases

Modeling the input domain

Step 3: Model the *input domain*

- The domain is scoped by the *parameters*
- The structure is defined by *characteristics*
- Each characteristic is partitioned into *sets of blocks*
- Each block represents a *set of values*
- This is the most creative design step in ISP
  - Better to have more characteristics and fewer blocks; leads to fewer tests
  - Strategies include valid/invalid/special values, boundary values, “normal” values

Modeling the input domain

Step 4: Apply a *test criterion* to choose *combinations* of values

- A test input has *one value* for each parameter
- There is *one block* for each characteristic
- Choosing *all combinations* is usually infeasible
  - Coverage criteria allow subsets to be chosen

Modeling the input domain

Step 5: Refine combinations of blocks into *test inputs*

- Choose *appropriate values* for each block
- Combinatorial test optimization tools can help

  These tools dramatically reduce the number of tests

Choosing 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**

Choosing values (6.2)

DEFINITION

All Combinations Coverage (ACoC) – all combinations of blocks from all characteristics must be covered

DEFINITION

Each Choice Coverage (ECC) – one value from each characteristic must be used in at least one test

DEFINITION

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.

PWC Criterion for Choosing Values

We can combine values from one block with values from other blocks

DEFINITION

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

PWC Example

Characteristic	Blocks		
A	a1	a2	a3
B	b1	b2	--
C	c1	c2	--

TR = { (a1, b1, c*), (a1, b2, c*),
(a1, b*, c1), (a1, b*, c2),
(a2, b1, c*), (a2, b2, c*),
(a2, b*, c1), (a2, b*, c2),
(a3, b1, c*), (a3, b2, c*),
(a3, b*, c1), (a3, b*, c2),
(a*, b1, c1), (a*, b1, c2),
(a*, b2, c1), (a*, b2, c2) }

We can satisfy all these TRs with optimized combinations:
TR = { (a1, b1, c1),
(a1, b2, c2),
(a2, b2, c1),
(a2, b1, c2),
(a3, b1, c2),
(a3, b2, c1) }
(other combinations are possible)

BCC Criterion for Choosing Values

Use *domain knowledge* of the program to identify important values

DEFINITION

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.

BCC Criterion for Choosing Values

The base test must be *feasible,* that is, all values in the base choice must be compatible

Base choices can be:

- The most likely or most common values
- The simplest values
- The smallest values
- The first values in some logical ordering

Happy path tests make good base choices

The base choice is a *crucial design decision*

- Test designers should document why the base choice was selected
- A poor base choice can result in many infeasible combinations

BCC Example

Characteristic	Blocks		
A	a1	a2	a3
B	b1	b2	--
C	c1	c2	--

Base choices: a1, b1, c1

TR = { **(a1, b1, c1)**, — Base test
(**a2**, b1, c1),
(**a3**, b1, c1), — Variations on A
(a1, **b2**, c1), — Variation on B
(a1, b1, **c2**) } — Variation on C

MBCC Criterion for Choosing Values

There can sometimes be more than one logical base choice for each characteristic

DEFINITION

Multiple Base Choice Coverage (MBCC) – 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 and using each non-base choice in each other characteristic.

MBCC Example

Multiple base choices

Characteristic	Blocks		
A	a1	a2	a3
B	b1	b2	--
C	c1	c2	--

TR = { **(a1, b1, c1),** — Base choice #1
(**a2**, b1, c1), — Variations on A
~~(**a3**, b1, c1),~~
(a1, **b2**, c1), — Variation on B
~~(a1, b1, **c2**),~~ — Variation on C
(a3, b1, c2), — Base choice #2
~~(**a1**, b1, c2),~~ — Variations on A
(**a2**, b1, c2),
(a3, **b2**, c2), — Variation on B
~~(a3, b1, **c1**)~~ } — Variation on C

Substituting a3 in place of a1 is not necessary because a3 is also a base choice and will show up in a later TR

Constraints Among Characteristics

Some combinations are **infeasible**

- Can’t have “less than zero” and “scalene”

This is represented as **constraints**

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 from another

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

Constraints Example

```
public boolean findElement (List list, Object element) {
   // Effects: if list or element is null throw NullPointerException
   //          else element is in list return true
   //          else return false
   ...
}
```

Characteristic	b_1	b_2	b_3	b_4	b_5	b_6
A: size and contents	list=null	size=0	size=1	size>1 varied unsorted	size>1 varied sorted	size>1 all same
B: match	Element not found	Element found once	Element found more than once	--	--	--
Infeasible combinations: (Ab_1, Bb_2), (Ab_1, Bb_3), (Ab_2, Bb_2), (Ab_2, Bb_3), (Ab_3, Bb_3), (Ab_6, Bb_2)						

Element cannot be in a null list once (or more than once)

Element cannot be in a 0-element list once (or more than once)

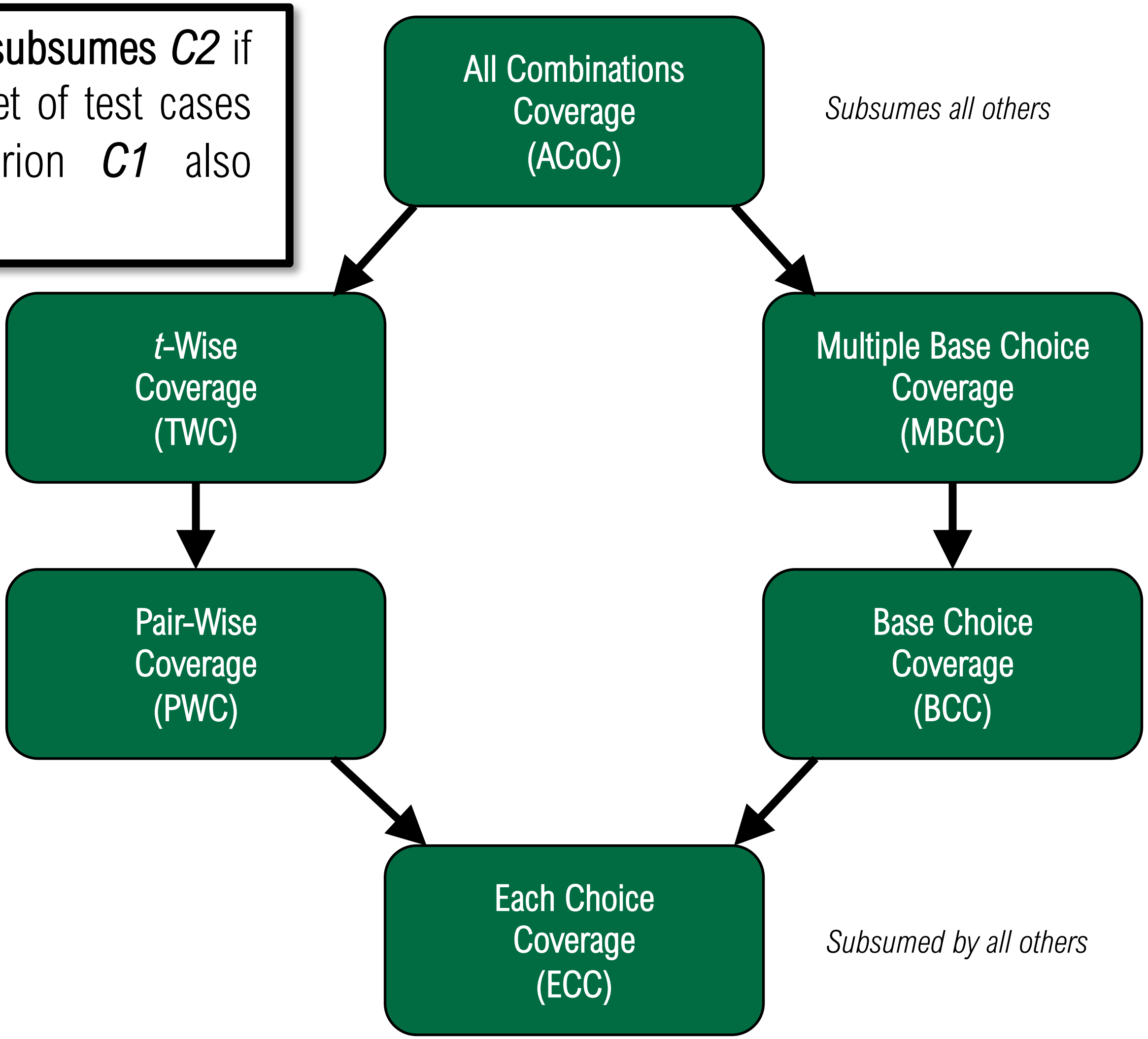
Element cannot be in a 1-element list more than once

If a list has many of the same element, we can't find it just once

ISP Criteria Subsumption

DEFINITION

A test criterion *C1* **subsumes** *C2* if and only if every set of test cases that satisfies criterion *C1* also satisfies *C2*



ISP Summary

Fairly easy to apply, even with no automation

Convenient ways to increase or decrease test cases

Applicable to all levels of testing

Based on the input space of the program, not the implementation

Simple, straightforward, effective, and widely used!

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Input Space Coverage
Extended Exercise

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Today's Exercise

Textbook chapter 6.4

Design an input domain model (IDM) for the Java 7 Iterator interface

https://docs.oracle.com/javase/7/docs/api/java/util/Iterator.html has the full version

Note that there may be some differences in the way I solve this exercise as compared to the textbook – input domain modeling is a creative exercise!

Java 7 Iterator

```
public interface Iterator<E> {
   /**
    * Returns true if the iteration has more elements. (In other words,
    *  returns true if next() would return an element rather than throwing
    *  an exception.)
    * @return true if the iteration has more elements
    */
    boolean hasNext();

   /**
    * Returns the next element in the iteration.
    * @return the next element in the iteration
    * @throws NoSuchElementException - if the iteration has no more elements
    */
    E next();

   /**
    * Removes from the underlying collection the last element returned by
    *  this iterator (optional operation). This method can be called only once
    *  per call to next(). The behavior of an iterator is unspecified if the
    *  underlying collection is modified while the iteration is in progress in
    *  any way other than by calling this method.
    * @throws UnsupportedOperationException - if the remove operation is not
    *  supported by this iterator
    * @throws IllegalStateException - if the next method has not yet been
    *  called, or the remove method has already been called after the last call
    *  to the next method
    */
    void remove();
}
```

Task 1 – Determine characteristics

Step 1 – Identify characteristics in **Table A**

Step 2 – Develop characteristics

Step 3 – Associate methods and characteristics in **Table B**

Step 4 – Design a partitioning

Step 1. Identify Characteristics

Identify characteristics by considering

- Functional units
- Parameters
- Return types and values
- Exceptional behavior

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by

Step 1. Identify Characteristics

`hasNext()` – returns true if collection has more elements

`E next()` – returns next element

- Exception – `NoSuchElementException` if at end

`void remove()` – removes the most recent element returned by the iterator

- Exception – `UnsupportedOperationException`
- Exception – `IllegalStateException`
- *Note that the void return challenges us to verify the behavior indirectly*

Parameters – internal state of the iterator

- Internal state changes with `next()` and `remove()`
- Modifying the underlying collection directly also changes the iterator state

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext							

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state						

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false				

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--			

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--

Step 1. Identify Characteristics

`hasNext()` – returns true if collection has more elements

`E next()` – returns next element

- Exception – `NoSuchElementException` if at end

`void remove()` – removes the most recent element returned by the iterator

- Exception – `UnsupportedOperationException`
- Exception – `IllegalStateException`
- *Note that the void return challenges us to verify the behavior indirectly*

Parameters – internal state of the iterator

- Internal state changes with `next()` and `remove()`
- Modifying the underlying collection directly also changes the iterator state

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next							

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state						

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	?	?	?	?

Let's leave this to your groups…

Step 1. Identify Characteristics

`hasNext()` – returns true if collection has more elements

`E next()` – returns next element

- Exception – `NoSuchElementException` if at end

`void remove()` – removes the most recent element returned by the iterator

- Exception – `UnsupportedOperationException`
- Exception – `IllegalStateException`
- *Note that the void return challenges us to verify the behavior indirectly*

Parameters – internal state of the iterator

- Internal state changes with `next()` and `remove()`
- Modifying the underlying collection directly also changes the iterator state

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	?	?	?	?
remove							

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	?	?	?	?
remove	state						

Step 1. Document in Table A

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	?	?	?	?
remove	state	--	--	?	?	?	?

Let's leave this to your groups…

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	?	?	?	?
remove	state	--	--	?	?	?	?

Hint – think about both normal and exceptional conditions; each method can have *more than one row* for Exception, Characteristic, ID, and Covered By:

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
Method	Params	Returns	Values	Normal	…	…	…
				Ex1	…	…	…
				Ex2	…	…	…

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values				

Add or remove rows to the table as needed

Step 3. Associate Characteristics

How can we partition each characteristic?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values				

Add or remove rows to the table as needed

Exercise 1

20 minutes to work

- Develop characteristics
- Associate characteristics with methods
- Partition characteristics into blocks

15 minutes for debrief and discussion

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	?	?	?	?
remove	state	--	--	?	?	?	?

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	--	Returns a non-null object	C2	--
remove	state	--	--	?	?	?	?

This characteristic forces useful TRs for retrieving a non-null object and a null object

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	--	Returns a non-null object	C2	--
remove	state	--	--	?	?	?	?

What about exceptions for next()?

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	--	Returns a non-null object	C2	--
				NoSuch Element	--	--	C1
remove	state	--	--	?	?	?	?

What about exceptions for remove()?

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	--	Returns a non-null object	C2	--
				NoSuch Element	--	--	C1
remove	state	--	--	Unsupported Op	Remove is supported	C3	--

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	--	Returns a non-null object	C2	--
				NoSuch Element	--	--	C1
remove	state	--	--	Unsupported Op	Remove is supported	C3	--
				IllegalState	Remove constraint is satisfied	C4	--

meaning that next() has been called and remove() has not already been called.

Step 2. Develop Characteristics

Table A							
Method	Params	Returns	Values	Exception	Characteristic	ID	Covered by
hasNext	state	boolean	true, false	--	has more values	C1	--
next	state	E	E, null	--	Returns a non-null object	C2	--
				NoSuch Element	--	--	C1
remove	state	--	--	Unsupported Op	Remove is supported	C3	--
				IllegalState	Remove constraint is satisf	C4	--

These are the characteristics of our IDM.

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values				

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	

Does remove() care whether there are more objects? Maybe… we might think that removing the last object is functionally different from removing an earlier object and wish to explicitly test that case.

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object				

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object		X	X	

Here we mean that remove() cares about whether next() *previously returned* a non-null object.

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object		X	X	
C3	Remove is supported				

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object		X	X	
C3	Remove is supported			X	

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object		X	X	
C3	Remove is supported			X	
C4	Remove constraint is satisfied				

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object		X	X	
C3	Remove is supported			X	
C4	Remove constraint is satisfied			X	

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	
C2	Returns a non-null object		X	X	
C3	Remove is supported			X	
C4	Remove constraint is satisfied			X	

Step 3. Associate Characteristics

Which characteristics are relevant for which methods?

Table B					
ID	Characteristic	hasNext()	next()	remove()	Partition
C1	Has more values	X	X	X	{true, false}
C2	Returns a non-null object		X	X	{true, false}
C3	Remove is supported			X	{true, false}
C4	Remove constraint is satisfied			X	{true, false}

Important: Partitions are *not always* true/false, it just happens to make sense with these.

END OF EXERCISE 1

Task 2 – Define Test Requirements

Step 1 – Select a coverage criterion, we'll use **base choice** (BCC)

Step 2 – Identify a *happy-path* test for the base case in **Table C**

Step 3 – Identify test requirements (TRs)

Step 4 – Identify infeasible TRs

Step 5 – Refine TRs to remove infeasible cases

How to Refine Infeasible TRs

Assume the following characteristics:

Characteristic	b_1	b_2	b_3
Protein	Chicken	Fish	Lamb
Vegetable	Asparagus	Eggplant	Squash
Starch	Bread	Rice	Potato

Applying base choice coverage, we might select a base test
{ **C**hicken, **S**quash, **R**ice }

BCC requires that we vary each characteristic:
{F,S,R}, {L,S,R}, {C,A,R}, {C,E,R}, {C,S,B}, {C,S,P}

Assume that {F,S,R} is infeasible – BCC requires that we have a test with Fish, so keep Fish and try changing one (or both) of the other characteristics – is {F,A,R} feasible? Is {F,S,P}? Maybe {F,S,B}?

If we can't find *any* feasible combination that includes Fish, then we discard the TR

Exercise 2

15 minutes to work

- Create a happy-path base test
- Build a set of base choice tests
- Identify infeasible test requirements
- Develop replacement test requirements for any infeasib

10 minutes for debrief and discussion

Step 2: Base Coverage Criterion

Create a happy-path base test for each method, then create additional tests to satisfy base-choice coverage.

Table C			
Method	Characteristics	TRs	Infeasible TRs
hasNext()	Fill in from table B		
next()	Fill in from table B		
remove()	Fill in from table B		

Step 2: Base Coverage Criterion

Identify infeasible TRs

- Are there invalid combinations? Refine them to create feasible substitutes

Table C			
Method	Characteristics	TRs	Infeasible TRs
hasNext()	Fill in from table B		Inf.TR --> f.TR
next()	Fill in from table B		Inf.TR --> f.TR
remove()	Fill in from table B		Inf.TR --> f.TR

Step 2: Base Coverage Criterion

Create a happy-path base test for each method, then create additional tests to satisfy base-choice coverage.

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C			
Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1		
next()	C1, C2		
remove()	C1, C2, C3, C4		

Recall that for remove(), C2 means that next() *previously returned* a non-null object.

Step 2: Base Coverage Criterion

Create a happy-path base test for each method, then create additional tests to satisfy base-choice coverage.

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C

Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1	T	
next()	C1, C2	TT	
remove()	C1, C2, C3, C4	TTTT	

Step 3: Base Coverage Criterion

Add additional tests to satisfy base-choice coverage

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C			
Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1	T	
next()	C1, C2	TT	
remove()	C1, C2, C3, C4	TTTT	

Remember that you create additional tests by taking the base test and iterating through other values for each of the characteristics

Step 4: Base Coverage Criterion

Identify infeasible TRs

Are there invalid combinations?

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C

Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1	{ T, F }	
next()	C1, C2	{ TT, FT, TF }	
remove()	C1, C2, C3, C4	{ TTTT, FTTT, TFTT, TTFT, TTTF }	

Step 4: Base Coverage Criterion

Identify infeasible TRs

Are there invalid combinations?

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C

Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1	{ T, F }	--
next()	C1, C2	{ TT, FT, TF }	FT
remove()	C1, C2, C3, C4	{ TTTT, FTTT, TFTT, TTFT, TTTF }	FTTT

If C1=false indicates "no more values", then C2 "returned a non-null object" can not be true.

Step 5: Base Coverage Criterion

Refine the test requirements to eliminate infeasible cases

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C

Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1	{ T, F }	--
next()	C1, C2	{ TT, FT, TF }	FT
remove()	C1, C2, C3, C4	{ TTTT, FTTT, TFTT, TTFT, TTTF }	FTTT

Follow the process described before the exercise

Step 5: Base Coverage Criterion

Refine the test requirements to eliminate infeasible cases

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C

Method	Characteristics	TRs	Infeasible TRs
hasNext()	C1	{ T, F }	--
next()	C1, C2	{ TT, FT, TF }	FT -> FF
remove()	C1, C2, C3, C4	{ TTTT, FTTT, TFTT, TTF TTT	FTTT -> FFTT

In test case "FT" we are varying C1 to false, so we want to keep C1=F and change other characteristics to try to make the test feasible.

Step 5: Base Coverage Criterion

Replace infeasible TRs with feasible TRs

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C				
Method	**Characteristics**	**TRs**	**Infeasible TRs**	**Refined TRs**
hasNext()	C1	{ T, F }	--	
next()	C1, C2	{ TT, FT, TF }	FT -> FF	
remove()	C1, C2, C3, C4	{ TTTT, FTTT, TFTT, TTFT, TTTF }	FTTT -> FFTT	

Step 5: Base Coverage Criterion

Replace infeasible TRs with feasible TRs

ID	Characteristic
C1	Has more values
C2	Returns a non-null object
C3	Remove is supported
C4	Remove constraint is satisfied

Table C				
Method	Characteristics	TRs	Infeasible TRs	Refined TRs
hasNext()	C1	{ T, F }	--	{ T, F }
next()	C1, C2	{ TT, FT, TF }	FT -> FF	{ TT, FF, TF }
remove()	C1, C2, C3, C4	{ TTTT, FTTT, TFTT, TTFT, TTTF }	--	{TTTT, FFTT, TFTT, TTFT, TTTF}

END OF EXERCISE 2

Task 3 – Automate Tests

We need an *implementation* of Iterator because Iterator is merely an interface

- `ArrayList` implements `Iterator`, so we can use `ArrayList` for our testing

Create a test fixture with two variables

- List of strings
- Iterator for strings

`@Before setup()`

- Creates a list with two strings
- Initializes an iterator

Task 3 – Automate Tests

Example implementation framework

```
public class IteratorTest {

   private List<String> list;             // test fixture list
   private Iterator<String> itr;          // test fixture iterator

   @Before public void setUp()            // set up test fixture
   {
      list = new ArrayList<String>();     // create new ArrayList
      list.add ("cat");                   // append "cat"
      list.add ("dog");                   // append "dog"
      itr = list.iterator();              // initialize the iterator
   }

   ...    // test implementations to be defined on upcoming slides
}
```

Exercise 3

10 minutes to work

- Write tests for `hasNext()`
- Write tests for `next()`
- Write tests for `remove()`

No debrief, but answers will be posted

Task 3 – Automate Tests

Write tests for **hasNext()**

2 test cases

```
// Test 1 of hasNext(): testHasNext_BaseCase():  C1=T
@Test public void testHasNext_BaseCase()
{
   ...
}

// Test 2 of hasNext(): testHasNext_C1(): C1=F
@Test public void testHasNext_C1()
{
   ...
}
```

Task 3 – Automate Tests

Write tests for **hasNext()**

2 test cases

```
// Test 1 of hasNext(): testHasNext_BaseCase():  C1=T
@Test public void testHasNext_BaseCase()
{
     assertTrue (itr.hasNext()); // list is not empty
}

// Test 2 of hasNext(): testHasNext_C1(): C1=F
@Test public void testHasNext_C1()
{
   itr.next (); // consume "cat"
   itr.next(); // consume "dog"
   assertFalse (itr.hasNext()); // now list is empty

}
```

Task 3 – Automate Tests

Write tests for **`next()`**

- 3 test cases

```
// Test 1 of next(): testNext_BaseCase(): C1=T, C2=T
@Test public void testNext_BaseCase()
{
    ...
}

// Test 2 of next(): testNext_C1(): C1=F, C2=F
@Test(expected=NoSuchElementException.class)
public void testNext_C1()
{
    ...
}

// Test 3 of next(): testNext_C2(): C1=T, C2=F
@Test public void testNext_C2()
{
    ...
}
```

Task 3 – Automate Tests

Write tests for **next()**

- 3 test cases

```
// Test 1 of next(): testNext_BaseCase(): C1=T, C2=T
@Test public void testNext_BaseCase()
{
   assertEquals ("cat", itr.next()); // list is not empty
}

// Test 2 of next(): testNext_C1(): C1=F, C2=F
@Test(expected=NoSuchElementException.class)
public void testNext_C1()
{
   itr.next(); // consume “cat”
   itr.next();      // consume “dog”
   itr.next(); // throws NSE because list is empty
}

// Test 3 of next(): testNext_C2(): C1=T, C2=F
@Test public void testNext_C2()
{
   list = new ArrayList<String>(); // create a new empty list
   list.add (null); // add a null object
   itr = list.iterator(); // reinitialize the iterator
   assertNull (itr.next()); // verify that it is null
}
```

Task 3 – Automate Tests

Write tests for **`remove()`**

- 5 test cases (1-3 shown)

```
// Test 1 of remove(): testRemove_BaseCase(): C1=T, C2=T, C3=T, C4=T
@Test public void testRemove_BaseCase()
{
    ...
}

// Test 2 of remove(): testRemove_C1(): C1=F, C2=F, C3=T, C4=T
@Test public void testRemove_C1()
{
    ...
}

// Test 3 of remove(): testRemove_C2(): C1=T, C2=F, C3=T, C4=T
@Test public void testRemove_C2()
{
    ...
}
```

Task 3 – Automate Tests

Write tests for **remove()**

5 test cases (1-3 shown)

```
// Test 1 of remove(): testRemove_BaseCase(): C1=T, C2=T, C3=T, C4=T
@Test public void testRemove_BaseCase()
{
   itr.next(); // consume “cat”
   itr.remove(); // remove “cat”
   assertFalse (list.contains ("cat")); // verify list does not contain “cat”
}

// Test 2 of remove(): testRemove_C1(): C1=F, C2=F, C3=T, C4=T
@Test public void testRemove_C1()
{
   itr.next(); // consume “cat”
   itr.next(); // consume “dog”
   itr.remove(); // remove “dog”
   assertFalse (list.contains ("dog")); // verify list does not contain “dog”
}

// Test 3 of remove(): testRemove_C2(): C1=T, C2=F, C3=T, C4=T
@Test public void testRemove_C2()
{
   list.add (null); // append a null object to the list
   list.add ("elephant"); // append “elephant” to the list
   itr = list.iterator(); // reinitialize the iterator
   itr.next(); // consume “cat”
   itr.next(); // consume “dog”
   itr.next(); // consume null; iterator not empty
   itr.remove(); // remove null from list
   assertFalse (list.contains (null)); // verify list does not contain null
}
```

Task 3 – Automate Tests

Write tests for **`remove()`**

- 5 test cases (4-5 shown)

```
// Test 4 of remove(): testRemove_C3(): C1=T, C2=T, C3=F, C4=T
@Test(expected=UnsupportedOperationException.class)
public void testRemove_C3()
{
    ...
}

// Test 5 of remove(): testRemove_C4(): C1=T, C2=T, C3=T, C4=F
@Test (expected=IllegalStateException.class)
public void testRemove_C4()
{
    ...
}
```

Task 3 – Automate Tests

Write tests for **remove()**

- 5 test cases (4-5 shown)

```
// Test 4 of remove(): testRemove_C3(): C1=T, C2=T, C3=F, C4=T
@Test(expected=UnsupportedOperationException.class)
public void testRemove_C3()
{
   list = Collections.unmodifiableList (list); // does not support remove()
   itr = list.iterator(); // reinitialize the iterator
   itr.next(); // consume “cat” so C4=true
   itr.remove(); // remove “cat”, throws UOE
}

// Test 5 of remove(): testRemove_C4(): C1=T, C2=T, C3=T, C4=F
@Test (expected=IllegalStateException.class)
public void testRemove_C4()
{
   itr.remove(); // invalid remove, throws ISE
}
```

END OF EXERCISE 3