CMPT 473
Software Quality Assurance

Input Space Partitioning

Nick Sumner
Recall

- Testing involves running software and comparing observed behavior against expected behavior
  - Select an input, look at the output
Recall

- Testing involves running software and comparing observed behavior against expected behavior
  - Select an input, look at the output

- Problem: The *input domain* is infinite or pragmatically infinite.

```python
for test in allPossibleInputs:
    run_program(test)
```
Recall

• Testing involves running software and comparing observed behavior against expected behavior
  – Select an input, look at the output
• Problem: The *input domain* is infinite or pragmatically infinite.
• Testing is about selecting a finite subset of inputs that can help measure quality
Input Space Partitioning

Take the direct approach: Focus on the input!
Input Space Partitioning

- **Input Space Partitioning**
  - Divide (*partition*) the set of possible inputs into equivalence classes
Input Space Partitioning

- *Input Space Partitioning*
  - Divide (*partition*) the set of possible inputs into equivalence classes
  - Test one input from each class
Input Space Partitioning

- Input Space Partitioning
  - Divide (partition) the set of possible inputs into equivalence classes
  - Test one input from each class

e.g. \( \text{abs} \ (x) \)

Input Domain: ..., -3, -2, -1, 0, 1, 2, 3, ...

How many tests if done exhaustively?
Input Space Partitioning

- **Input Space Partitioning**
  - Divide *(partition)* the set of possible inputs into equivalence classes
  - Test one input from each class

E.g. abs(x)

Input Domain: ..., -3, -2, -1, 0, 1, 2, 3, ...

Partitions: ..., -3, -2, -1, 0, 1, 2, 3, ...

What might reasonable partitions be?
Input Space Partitioning

- **Input Space Partitioning**
  - Divide (*partition*) the set of possible inputs into equivalence classes
  - Test one input from each class

**e.g. abs(x)**

Input Domain: ..., -3, -2, -1, 0, 1, 2, 3, ...

Partitions: ...

... , -3, -2, -1, 0, 1, 2, 3, ...
Input Space Partitioning

- **Input Space Partitioning**
  - Divide (*partition*) the set of possible inputs into equivalence classes
  - Test one input from each class

E.g. `abs(x)`

Input Domain: ..., -3, -2, -1, 0, 1, 2, 3, ...

Partitions: ..., -3, -2, -1, 0, 1, 2, 3, ...

How many tests for the partitions?
Input Space Partitioning

- Input Space Partitioning
  - Divide (partition) the set of possible inputs into equivalence classes
  - Test one input from each class

e.g. \( \text{abs}(x) \)

Input Domain: \( \ldots, -3, -2, -1, 0, 1, 2, 3, \ldots \)

Partitions: \( \ldots, -3, -2, -1, 0, 1, 2, 3, \ldots \)

Impressive! How do we do it?
Input Space Partitioning

1) Identify the component
Input Space Partitioning

1) Identify the component

- Whole program
- Module
- Class
- Function
Input Space Partitioning

1) Identify the component
   - Whole program
   - Module
   - Class
   - Function

2) Identify the inputs

What might the inputs be?
Input Space Partitioning

1) Identify the component
   - Whole program
   - Module
   - Class
   - Function

2) Identify the inputs
   - Function/method parameters
Input Space Partitioning

1) Identify the component
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   - File contents
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   - User provided inputs
Input Space Partitioning

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   - Global variables
   - File contents
   - User provided inputs
   - ...
3) Develop an *Input Domain Model*
Input Space Partitioning

3) Develop an *Input Domain Model*
   - A way of *describing* the possible inputs
   - Partitioned by characteristics
Partitioned Input Domain

- **Partition** the domain D on characteristics

![Diagram of partitioned input domain]

D = A ∪ B ∪ C
Partitioned Input Domain

- **Partition** the domain $D$ on *characteristics*

What are *characteristics*?

$D = \{A, B, C\}$
Partitioned Input Domain

- **Partition** the domain D on characteristics
- Must satisfy 2 criteria:
  - Disjoint: \( A \cap B \cap C = \emptyset \)
  - Cover: \( A \cup B \cup C = D \)

![Diagram of partitioned domain]

\[ D = \]
Partitioned Input Domain

- **Partition** the domain D on characteristics
- Must satisfy 2 criteria:
  - Disjoint: $A \cap B \cap C = \emptyset$
  - Cover: $A \cup B \cup C = D$

What do these criteria intuitively provide?
Using Partitions

- Select one input from each block
- Each input in a block is assumed equally useful
Using Partitions

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- How?
  - Identify *characteristics* of the possible inputs (from requirements, types, etc.)
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How?

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Using Partitions

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How many tests might this imply? Might there be more? Fewer?
Using Partitions

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How many tests might this imply? Might there be more? Fewer?

We're hiding some details in this last step. It's not quite right yet.
Using Partitions

- Select one input from each block
- Each input in a block is assumed equally useful
- How?
  - Identify characteristics of the possible inputs (from requirements, types, etc.)
  - Partition into blocks based on each characteristic
  - Create tests by selecting values for each block

- Characteristics:
  - List s is sorted ascending
  - X is null
  - String length
  - ...
Partitioning is Subtle

- Suppose we have:

```python
classifyParallelogram(p1)
```

Characteristic: “The subtype of parallelogram”
Partitioning is Subtle

- Suppose we have:

```markdown
classifyParallelogram(p1)
```

Characteristic: “The subtype of parallelogram”

What are the types of parallelograms?
Partitioning is Subtle

- Suppose we have:

  \[
  \text{classifyParallelogram(p1)}
  \]

  Characteristic: “The subtype of parallelogram”

  - How can we partition based on this characteristic?
  - What problems might arise?
Partitioning is Subtle

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• In class exercise:
  Partitioning a triangle classifying program
Partitioning is Subtle

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Partitioning a triangle classifying program

• It is easy to create overlapping partitions.
  - Care and design required to avoid it.
Partitioning is Subtle

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Characteristic: “The subtype of parallelogram”
– How can we partition based on this characteristic?
– What problems might arise?

• In class exercise:
Partitioning a triangle classifying program

• It is easy to create overlapping partitions.
– Care and design required to avoid it.

Why do disjoint partitions matter?
Process (Reiterated)

3 step process (for now):

1) Find the component / function to test
   methods, classes, programs, functions
Process (Reiterated)

3 step process (for now):

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   - Must identify *everything*
     locals, globals, files, databases, schedules, servers, ...
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3) Model the input domain
   • Identify characteristics
   • Partition the input domain
   • Select values for each region
Process (Reiterated)

3 step process (for now):

1) Find the component / function to test methods, classes, programs, functions

2) Find all test parameters

   Domain knowledge, tactics, and creativity apply here.

3) Model the input domain
   • Identify characteristics
   • Partition the input domain
   • Select values for each region
Approaches to Input Modeling

We still haven't talked about *how* to model input!
Approaches to Input Modeling

2 Main approaches:
Approaches to Input Modeling

2 Main approaches:

1) Interface based
   - Guided directly by identified parameters & domains
Approaches to Input Modeling

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   - Simple
   - Automatable
Approaches to Input Modeling

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1) **Interface based**
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   - Simple
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2) **Functionality/Requirements based**
   - Derived from expected input/output relationship by spec.
Approaches to Input Modeling

2 Main approaches:

1) Interface based
   - Guided directly by identified parameters & domains
   - Simple
   - Automatable

2) Functionality/Requirements based
   - Derived from expected input/output relationship by spec.
   - Requires more design & more thought
   - May be better (smaller, goal oriented, ...)
Interface Based Modeling

- Consider parameters individually
Interface Based Modeling

- Consider parameters individually
  - Examine their types/domains
  - Ignore relationships & dependences
Interface Based Modeling

• Consider parameters individually
  – Examine their types/domains
  – Ignore relationships & dependences

How does this apply to our triangle classifier?
Functionality Based Modeling

- Identify characteristics corresponding to behaviors/functionality in the requirements
Functionality Based Modeling

- Identify characteristics corresponding to behaviors/functionality in the requirements
  - Includes knowledge from the problem domain
Functionality Based Modeling

- Identify characteristics corresponding to behaviors/functionality in the requirements
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  - Accounts for relationships between parameters
Functionality Based Modeling

- Identify characteristics corresponding to behaviors/functionality in the requirements
  - Includes knowledge from the **problem domain**
  - Accounts for **relationships** between parameters
  - Same parameter may appear in multiple characteristics
    - Need to reason about **constraints & conflicts**!
Functionality Based Modeling

- Identify characteristics corresponding to behaviors/functionality in the requirements
  - Includes knowledge from the **problem domain**
  - Accounts for **relationships** between parameters
  - Same parameter may appear in multiple characteristics
    - Need to reason about **constraints & conflicts**!

**How might this apply to our triangle classifier?**
Finding Typical Characteristics

What might typical characteristics be?
Finding Typical Characteristics

What might typical characteristics be?

- Preconditions
- Postconditions
Finding Typical Characteristics

What might typical characteristics be?

- Preconditions
- Postconditions

\{ \text{Invariants} \}
Finding Typical Characteristics

What might typical characteristics be?

- Preconditions
- Postconditions
- Relationships to special values
- Relationships between variables
Finding Typical Values

How might you select values for a block?
Finding Typical Values

How might you select values for a block?

- Expected values (e.g. exampled from spec)
- Invalid, valid, & special values
- Boundary values
Finding Typical Values

How might you select values for a block?

- Expected values (e.g. exampled from spec)
- Invalid, valid, & special values
- Boundary values

Thought experiment:
What do boundary values as a selection approach indicate?
An Interface Based Example

- Consider our triangle classifier
  - Takes 3 integers for sides 1, 2, & 3
An Interface Based Example

- Consider our triangle classifier
  - Takes 3 integers for sides 1, 2, & 3

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>b1</th>
<th>b2</th>
<th>b3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side 1 &lt;?&gt; 0</td>
<td>Side 1 &gt; 0</td>
<td>Side 1 = 0</td>
<td>Side 1 &lt; 0</td>
</tr>
<tr>
<td>Side 2 &lt;?&gt; 0</td>
<td>Side 2 &gt; 0</td>
<td>Side 2 = 0</td>
<td>Side 2 &lt; 0</td>
</tr>
<tr>
<td>Side 3 &lt;?&gt;0</td>
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An Interface Based Example

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</tr>
<tr>
<td>Side 2 &lt;0</td>
<td>Side 2 &gt; 0</td>
<td>Side 2 = 0</td>
<td>Side 2 &lt; 0</td>
</tr>
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How many tests does this create?
An Interface Based Example

- Consider our triangle classifier
  - Takes 3 integers for sides 1, 2, & 3

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</tr>
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<td>Side 2 &lt; 0</td>
</tr>
<tr>
<td>Side 3 &lt;0 &gt;0</td>
<td>Side 3 &gt; 0</td>
<td>Side 3 = 0</td>
<td>Side 3 &lt; 0</td>
</tr>
</tbody>
</table>

How many tests does this create?

What will this test well? What won't this test well?
Refining the Example

- We can subdivide partitions to cover more behavior

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>b1</th>
<th>b2</th>
<th>b3</th>
<th>b4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of side 1</td>
<td>Side 1 &gt; 1</td>
<td>Side 1 = 1</td>
<td>Side 1 = 0</td>
<td>Side 1 &lt; 0</td>
</tr>
<tr>
<td>Value of side 2</td>
<td>Side 2 &gt; 1</td>
<td>Side 2 = 1</td>
<td>Side 2 = 0</td>
<td>Side 2 &lt; 0</td>
</tr>
<tr>
<td>Value of side 3</td>
<td>Side 3 &gt; 1</td>
<td>Side 3 = 1</td>
<td>Side 3 = 0</td>
<td>Side 3 &lt; 0</td>
</tr>
</tbody>
</table>

\{\text{Side } n > 0\} \rightarrow \{\text{Side } n = 1\}, \{\text{Side } n > 1\}
Refining the Example

- We can subdivide partitions to cover more behavior

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<tr>
<td>Value of side 3</td>
<td>Side 3 &gt; 1</td>
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How many tests now?
Refining the Example

- We can subdivide partitions to cover more behavior

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<th>$b_3$</th>
<th>$b_4$</th>
</tr>
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<tr>
<td>Value of side 1</td>
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<td>Side 1 = 0</td>
<td>Side 1 &lt; 0</td>
</tr>
<tr>
<td>Value of side 2</td>
<td>Side 2 &gt; 1</td>
<td>Side 2 = 1</td>
<td>Side 2 = 0</td>
<td>Side 2 &lt; 0</td>
</tr>
<tr>
<td>Value of side 3</td>
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<td>Side 3 = 1</td>
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How many tests now?

Is it still disjoint? Complete?
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- We can subdivide partitions to cover more behavior

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How many tests now?

Is it still disjoint? Complete?

What does it test well? Not well?
A Functionality Based Example

- Consider our triangle classifier again
  - What might our characteristics & partitions be?
A Functionality Based Example

- Consider our triangle classifier again
  - What might our characteristics & partitions be?
  - Are there alternatives?
A Functionality Based Example

- Consider our triangle classifier again
  - What might our characteristics & partitions be?
  - Are there alternatives?
  - Why might you use them?
A Classic Example

• Start with a component / specification:

<table>
<thead>
<tr>
<th>Command</th>
<th>FIND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntax</td>
<td>FIND &lt;pattern&gt; &lt;file&gt;</td>
</tr>
</tbody>
</table>
| Function   | The FIND command is used to **locate one or more instances** of a given **pattern in a text file**. All lines in the file that contain the pattern are written to standard output. A line containing the pattern is **written only once**, regardless of the number of times the pattern occurs on it.

The pattern is any sequence of characters whose **length does not exceed** the maximum length of a line in the file. To include a blank in the pattern, the entire pattern must be **enclosed in quotes ("."**). To include a quotation mark in the pattern, **two quotes in a row (""**) must be used. |
A Classic Example

- Step 1: Analyze the specification
  - What is the component?
  - What are the parameters?
  - What are the characteristics?
A Classic Example

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Parameters:
  Pattern
  Input file (& its contents!)
A Classic Example

- **Step 1: Analyze the specification**
  - What is the component?
  - What are the parameters?
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**Parameters:**
- Pattern
- Input file (& its contents!)

**Characteristics:**
- Pattern
- Input file
- Pattern Size
- Quoting
- Embedded Quotes
- File Name

Environment / System Characteristics:
- # of pattern occurrences in file
- # of occurrences on a particular line:
A Classic Example

- Step 2: Partition the Input Space
  - Guided by intelligence and intuition
  - *Combine* interface and functionality based approaches as necessary
A Classic Example

- Step 2: Partition the Input Space
  - Guided by intelligence and intuition
  - *Combine* interface and functionality based approaches as necessary

Parameters:
- **Pattern Size:**
  - Empty
  - Single character
  - Many characters
  - Longer than any line in the file
- **Quoting:**
  
...

...
A Classic Example

- Familiar Idea:
  - Select one block per characteristic at a time
  - Combine into test *frames* (test case plans)
  - e.g. ...
A Classic Example

- Familiar Idea:
  - Select one block per characteristic at a time
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Pattern size : empty
Quoting : pattern is quoted
Embedded blanks : several embedded blanks
Embedded quotes : no embedded quotes
File name : good file name
Number of occurrences of pattern in file : none
Pattern occurrences on target line : one
A Classic Example

- **Familiar Idea:**
  - Select one block per characteristic at a time
  - Combine into test *frames* (test case plans)
  - e.g.

  Problem?

  Pattern size: empty
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A Classic Example

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  - e.g.

Problem?

- Pattern size: \textit{empty}
- Quoting: pattern is quoted
- Embedded blanks: \textit{several embedded blanks}
- Embedded quotes: no embedded quotes
- File name: good file name
- Number of occurrences of pattern in file: none
- Pattern occurrences on target line: one
A Classic Example

• Step 3: Identify *constraints* among the characteristics & blocks

<table>
<thead>
<tr>
<th>Pattern Size:</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>Empty</td>
</tr>
<tr>
<td>Single character</td>
<td>NonEmpty</td>
</tr>
<tr>
<td>Many characters</td>
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</tr>
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A Classic Example

- Step 3: Identify *constraints* among the characteristics & blocks

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<th>Quoting:</th>
<th></th>
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<tbody>
<tr>
<td>Pattern is quoted</td>
<td>[Property Quoted]</td>
</tr>
<tr>
<td>Pattern is not quoted</td>
<td>[If NonEmpty]</td>
</tr>
<tr>
<td>Pattern is improperly quoted</td>
<td>[If NonEmpty]</td>
</tr>
</tbody>
</table>
A Classic Example

• Step 3: Identify constraints among the characteristics & blocks

| Pattern Size: |                         |
|              | Empty                   |
|              | Single character        |
|              | Many characters         |
|              | Longer than any line in the file |
|              | [Property Empty]        |
|              | [Property NonEmpty]     |
|              | [Property NonEmpty]     |
|              | [Property NonEmpty]     |

| Quoting:     |                         |
|              | Pattern is quoted       |
|              | Pattern is not quoted   |
|              | Pattern is improperly quoted |
|              | [Property Quoted]       |
|              | [If NonEmpty]           |
|              | [If NonEmpty]           |

What should this do to the number of tests? To the quality of tests?
A Classic Example

- Step 4
  - Create tests by selecting values that satisfy the selected blocks for each frame
  - Eliminate tests that cover redundant scenarios
A Classic Example

• Step 4
  – Create tests by selecting values that satisfy the selected blocks for each frame
  – Eliminate tests that cover redundant scenarios

Why might scenarios be redundant?
A Classic Example

- Step 5:
  - Take your generated test cases and automate them