Syntax-based Testing

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Inspiration

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"Just like with everything else, tools won't give you good results unless you know how, when, and why to apply them. If you go out and you buy the most expensive frying pan on the market it's still not going to make you a good chef." – Christin Wiedemann

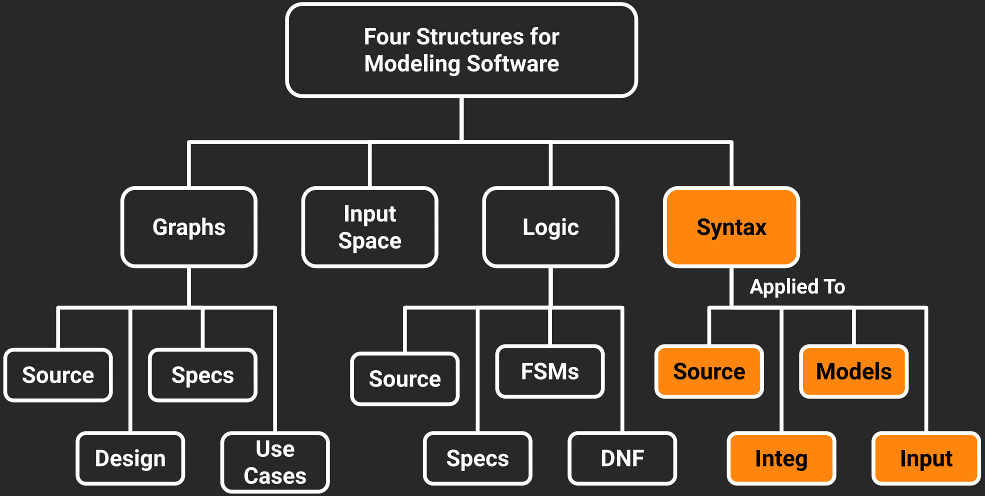
"A fool with a tool is still a fool." – Grady Booch

Outcomes

After today's lecture you will be able to:

- Understand the basics of regular expressions and BNF grammars
- Understand the concepts related to mutants and how to kill them
- Understand basic grammar-based and syntax-based coverage criteria

Syntax Coverage



Using Syntax to Generate Tests

- Lots of software artifacts follow **strict syntax** rules

- The syntax is often expressed as a **grammar**
  - Commonly **BNF**

- **Syntactic descriptions** can come from many sources
  - Programs
  - Integration elements
  - Design documents
  - Input descriptions

- Tests are created with **two general goals**
  - **Cover** the syntax in some way
  - **Violate** the syntax (invalid tests)

Grammar Coverage Criteria

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- Software engineering makes practical use of **automata theory** in several ways
  - **Programming languages** defined in BNF
  - **Program behavior** described as finite state machines
  - **Allowable inputs** defined by grammars
- A simple **regular expression**: `(G s n | B t n)*`
  - `'*'` is closure operator, zero or more occurrences
  - `'|'` is choice, either one can be used
- Any sequence of "**G s n**" and "**B t n**"
- '**G**' and '**B**' could represent commands, methods, or events
- '**s**', '**t**', and '**n**' can represent arguments, parameters or values
- '**s**', '**t**', and '**n**' could represent literals or a set of values

Test Cases from Grammar

- A string that satisfies the derivation rules is said to be "**in the grammar**"
- A test case is a **sequence of strings** that satisfy the regular expression
- Suppose '**s**', '**t**', and '**n**' are numbers

Example

```
G 26 08.01.90
B 22 06.27.94
G 22 11.21.94
B 13 01.09.03
```

Could be one test with four parts or four separate tests, etc.

BNF Grammars

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```
Stream ::= action*
action ::= actG | actB
actG   ::= "G" s n
actB   ::= "B" t n
s      ::= digit{1,3}
t      ::= digit{1,3}
n      ::= digit{2} "." digit{2} "."
           digit{2}
digit  ::= "0" | "1" | "2" | "3" |
           "4" | "5" | "6" | "7" |
           "8" | "9"
```

- `Stream` is called the **start symbol**
- `action` and `actG` are examples of **non-terminals**
- `actB ::= "B" t n` wholly is an example of a **production rule**
- `"5"` is an example of a **terminal**
- `digit{1,3}` means 1 to 3 digits (inclusive)
- `digit{2}` means exactly 2 digits

Using Grammars

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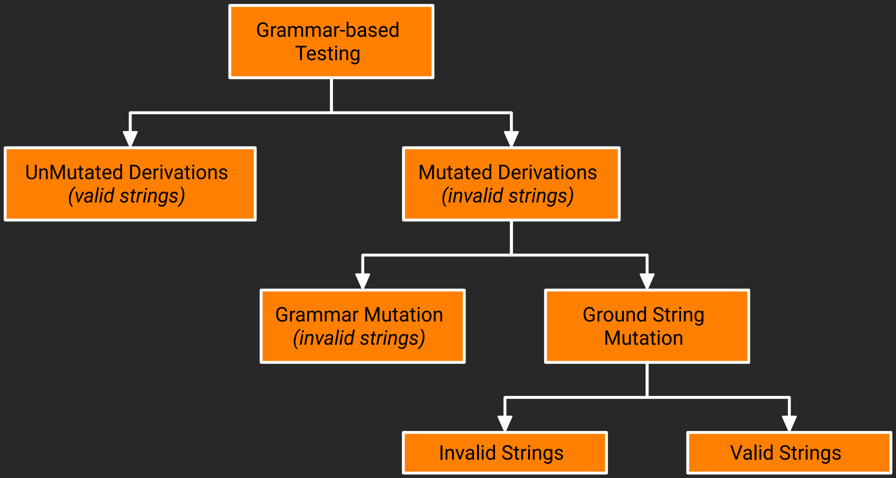
```
Stream ::= action action*
       ::= actG action*
       ::= G s n action*
       ::= G digit{1,3} digit{2} . digit{2} . digit{2} action*
       ::= G digitdigit digitdigit.digitdigit.digitdigit action*
       ::= G 25 08.01.90 action*
  ...
```

- **Recognizer**: Is a string (or test) in the grammar?
  - This is called **parsing**
  - Tools exist to support **parsing**
  - Programs can use them for **input validation**
- **Generator**: Given a grammar, derive strings in the grammar

Mutation as Grammar-Based Testing



ROAR

Grammar-based Coverage Criteria

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- The most common and straightforward criteria use every terminal and every production at least once

  Terminal Symbol Coverage (TSC): *TR* contains each terminal symbol *t* in the grammar *G*.

  Production Coverage(PDC): *TR* contains each production *p* in the grammar *G*.

- PDC subsumes TSC
- Grammars and graphs are interchangeable
  - PDC is equivalent to EC, TSC is equivalent to NC
- Other graph-based coverage criteria could be defined on grammar
  - But have not

Grammar-based Coverage Criteria

- A related criterion is the impractical one of deriving all possible strings

  Derivation Coverage (DC): *TR* contains every possible string that can be derived from the grammar *G*

- The number of **TSC tests** is bound by the number of **terminal symbols**
  - 13 in the stream grammar
- The number of **PDC tests** is bound by the number of **productions**
  - 18 in the stream grammar
- The number of **DC tests** depends on the **details** of the grammar
  - **2,000,000,000** in the stream grammar!
- All TSC, PDC and DC tests are **in the grammar** … how about tests that are **NOT in the grammar**?

Mutation Testing

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- Grammars describe both **valid** and **invalid** strings
- Both types can be produced as **mutants**
- A mutant is a **variation** of a valid string
    - Mutants may be valid or invalid strings
- Mutation is based on "**mutation operators**" and "**ground strings**"

What is Mutation?

General View

We are performing mutation analysis whenever we

- Use well defined **rules**
- defined on **syntactic descriptions**
- to make **systematic changes**
- to the **syntax** or to **objects** developed from the syntax.

What is Mutation?

General View

We are performing mutation analysis whenever we

- Use well defined **mutation operators**
- defined on **grammars**
- to make **applied universally or according to empirically verified distributions**
- to the **grammar** or to **ground strings (tests or programs)** developed from the syntax.

Mutation Testing

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- **Ground string**: A **string** in the grammar
  - The term “ground” is used as an analogy to algebraic ground terms

- **Mutation Operator**: A rule that specifies **syntactic variations** of strings generated from a grammar

- **Mutant**: The result of **one application** of a mutation operator
  - A mutant is a string either in the grammar or very close to being in the grammar

Mutants and Ground Strings

- The key to mutation testing is the **design** of the mutation operators
  - Well designed **operators** lead to powerful testing
- Sometimes **mutant strings** are based on ground strings
- Sometimes they are derived directly **from the grammar**
  - **Ground** strings are used for **valid** tests
  - **Invalid** tests do not need ground strings

Valid Mutants	Ground String Mutants	Invalid Mutants
G 26 08.01.90	B 26 08.01.90	7 26 08.01.90
B 22 06.27.94	B 45 06.27.94	B 22 06.27.1

Questions About Mutation

- Should **more than one operator** be applied at the same time?
  - Should a mutated string contain more than one mutated element?
  - Usually not - multiple mutations can interfere with each other
  - Experience with program-based mutation indicates not
  - Recent research is finding exceptions
- Should **every possible application** of a mutation operator be considered?
  - Necessary with program-based mutation
- Mutation operators have been defined for many **languages**
  - Programming languages (Fortran, Lisp, Ada, C, C++, Java)
  - Specification languages (SMV, Z, Object-Z, algebraic specs)
  - Modeling languages (Statecharts, activity diagrams)
  - Input grammars (XML, SQL, HTML)

Killing Mutants

- When ground strings are mutated to create valid strings, the hope is to exhibit **different behavior** from the ground string
- This is normally used when the grammars are **programming languages**, the strings are **programs**, and the ground strings are **pre-existing** programs
- **Killing Mutants**: Given a mutant $m \in M$ for a derivation D and a test t, t is said to kill m iff the output of t on D is different from the output of t on m
- The derivation D may be represented by the list of productions or by the final string

Syntax-based Coverage Criteria

- Coverage is defined in terms of killing mutants

  Mutation Coverage (MC): For each $m \in M$, TR contains exactly one requirement, to kill m.

- Coverage in mutation equates to number of mutants killed

- The amount of mutants killed is called the **mutation score**

Syntax-based Coverage Criteria

- When creating invalid strings, we just apply the operators
- This results in two simple criteria
- It makes sense to either use every operator once or every production once

Mutation Operator Coverage (MOC): For each mutation operator, *TR* contains exactly one requirement, to create a mutated string *m* that is derived using the mutation operator.

Mutation Production Coverage (MPC): For each mutation operator, *TR* contains several requirements, to create one mutated string *m* that includes every production that can be mutated by that operator.

Example Grammar

```
Stream  ::=  action*
action  ::=  actG  |  actB
actG    ::=  "G" s  n
actB    ::=  "B"  t  n
s       ::=  digit1-3
t       ::=  digit1-3
n       ::=  digit2  "."  digit2  "."  digit2
digit   ::=  "0" | "1" | "2" | "3" | "4" | "5" | "6" |  "7" | "8" | "9"
```

Ground String

```
G 25 08.01.90
B 21 06.27.94
```

Mutants using MOC

```
B 25 08.01.90
B 23 06.27.94
```

Mutation Operators

- Exchange `actG` and `actB`
- Replace digits with all other digits

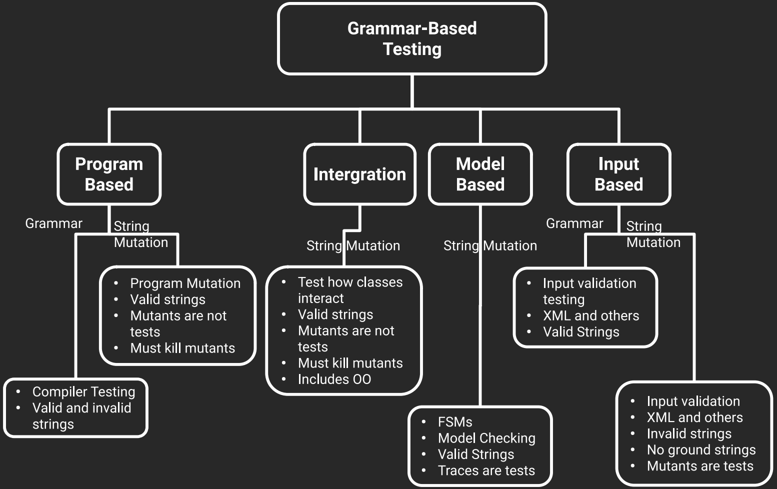
Mutants using MPC

```
B 25 08.01.90   G 21 06.27.94
G 15 08.01.90   B 22 06.27.94
G 35 08.01.90   B 23 06.27.94
G 45 08.01.90   B 24 06.27.94
```

Mutation Testing

- The **number of test requirements** for mutation depends on two things
  - The **syntax** of the artifact being mutated
  - The mutation **operators**
- Mutation testing is very difficult to apply **by hand**
- Mutation testing is very effective – considered the "**gold standard**" of testing
- Mutation testing is often used to **evaluate** other criteria

Instantiating Grammar-Based Testing



Structure of Chapter

	Program-based	Integration	Model-based	Input space
Grammar	**9.2.1**	**9.3.1**	**9.4.1**	**9.5.1**
Grammar	Programming languages	No known applications	Algebraic specifications	Input languages, including XML
Summary	Compiler testing			Input space testing
Valid?	Valid & invalid			Valid
Mutation	**9.2.2**	**9.3.2**	**9.4.2**	**9.5.2**
Grammar	Programming languages	Programming languages	FSMs	Input languages, including XML
Summary	Mutates programs	Tests integration	Model checking	Error checking
Ground?	Yes	Yes	Yes	No
Valid?	Yes, must compile	Yes, must compile	Yes	No
Tests?	Mutants not tests	Mutants not tests	Traces are tests	Mutants are tests
Killing	Yes	Yes	Yes	No
Notes	Strong and weak. Subsumes other techniques	Includes OO testing		Sometimes the grammar is mutated

For Next Time

- Review the Reading
- Review this Lecture
- Come to Class

Are there any questions?