Input Space Grammars

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Outcomes

At the end of Today's Lecture you will be able to:

- Understand the effects of not validating input
- Understand what input space grammars are
- Understand how to utilize and mutate input space grammars
- Understand the benefits of XML and how to mutate it

Inspiration

“The bitterness of poor quality remains long after the sweetness of meeting the schedule has been forgotten.” – Anonymous

Input Space Grammars

Input Space

The set of allowable inputs to software

- The input space can be **described** in many ways
  - User manuals
  - Unix man pages
  - Method signature / Collection of method preconditions
  - A language
- Most input spaces can be described as **grammars**
- Grammars are usually not provided, but **creating them** is a valuable service by the tester
  - Errors will often be found simply by creating the grammar

Using Input Space Grammars

- Software should **reject** or **handle** invalid data
- Programs often do this **incorrectly**
- Some programs (rashly) **assume** all input data is correct
- Even if it works **today** …
  - What about after the program goes through some **maintenance changes**?
  - What about if the component is **reused** in a new program?
- Consequences can be **severe** …
  - The **database** can be corrupted
  - **Users** are not satisfied
  - Many **security vulnerabilities** are due to unhandled exceptions … from invalid data

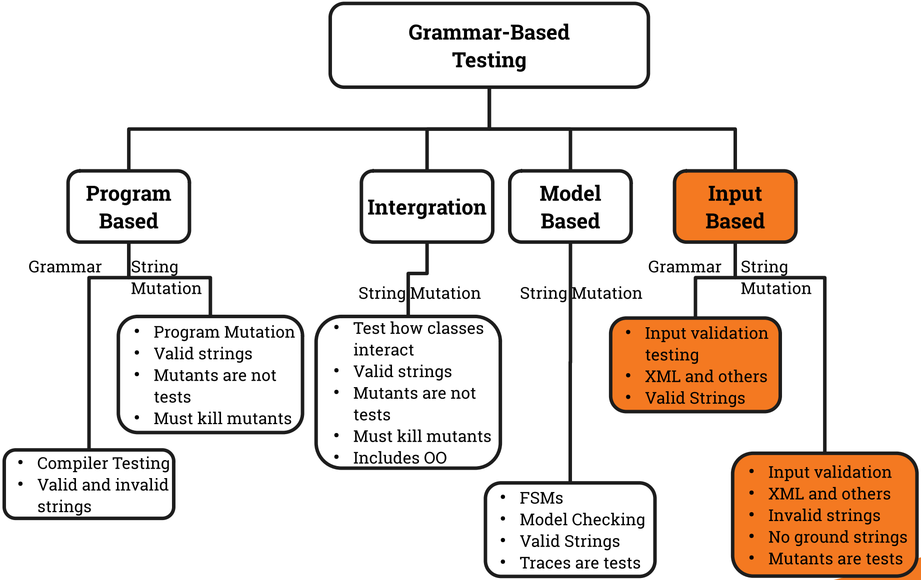
Validating Inputs

Input Validation

Deciding if input values can be processed by this software

- Before starting to process inputs, wisely written programs check that the **inputs are valid**
- How should a program **recognize** invalid inputs?
- What should a program **do with** invalid inputs?
- If the input space is described as a grammar, a **parser** can check for validity automatically
  - This is very **rare**
  - It is easy to write input checkers—but also easy to make mistakes

Instantiating Grammar-Based Testing



Input Space BNF Grammars

- Input spaces can be expressed in many forms
- A common way to use some form of **grammar**
- We will look at **three** grammar-based ways to describe input spaces
  1. Regular expressions
  2. BNF grammars
  3. XML and Schema
- All are **similar** and can be used in different contexts

Regular Expressions

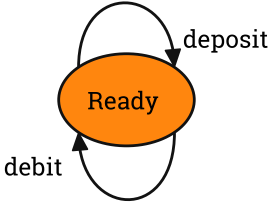
Consider a program that processes a sequence of deposits and debits to a bank

Inputs

deposit 5306 $4.30
debit 0343 $4.14
deposit 5306 $7.29

Initial Regular Expression

```
(deposit account amount | debit account amount)
```



FSM of the Grammar

BNF Grammar for Bank Example

Grammars are more expressive than regular expressions—they can capture more details

```
bank ::= action*
action ::= dep | deb
dep ::= "deposit" account amount
deb ::= "debit" account amount
account ::= digit{4}
amount ::= "$" digit+ "." digit{2}
digit ::= "0" | "1" | "2" | "3" | "4" | "5" | "6" |
          "7" | "8" | "9"
```

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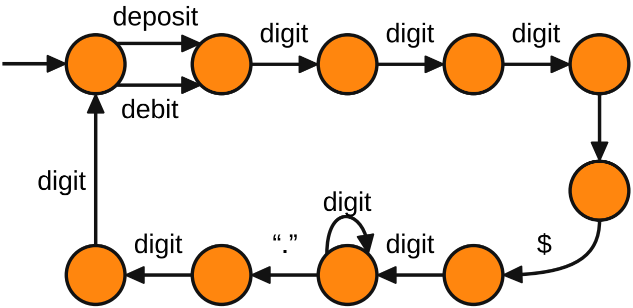
FSM for Bank Grammar

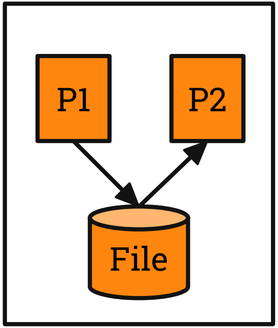


- Derive tests by **systematically replacing** each non-terminal with a production
- If the tester designs the grammar from informal input descriptions, **do it early**
  - In time to **improve** the design
  - **Mistakes** and **omissions** will almost always be found

XML Can Describe Input Spaces

- Software components that pass data must agree on **formats**, **types**, and **organization**
- Web applications have **unique requirements**:
  - very **loose coupling** and **dynamic integration**

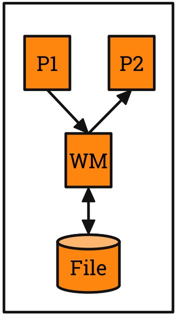
1970s



File storage

- Un-documented format
- Data saved in binary mode
- Source not available

1980s



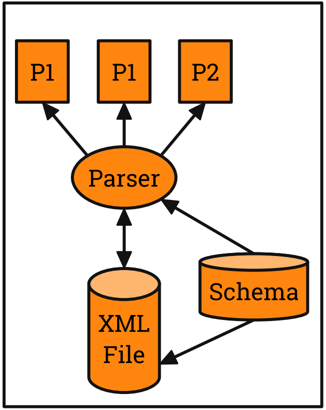
File storage

- Un-documented format
- Data saved as plain text
- Access through wrapper module
- Data hard to validate

XML is Very Loosely Coupled Software

- Data is passed **directly** between components
- XML allows data to be **self-documenting**

2000s



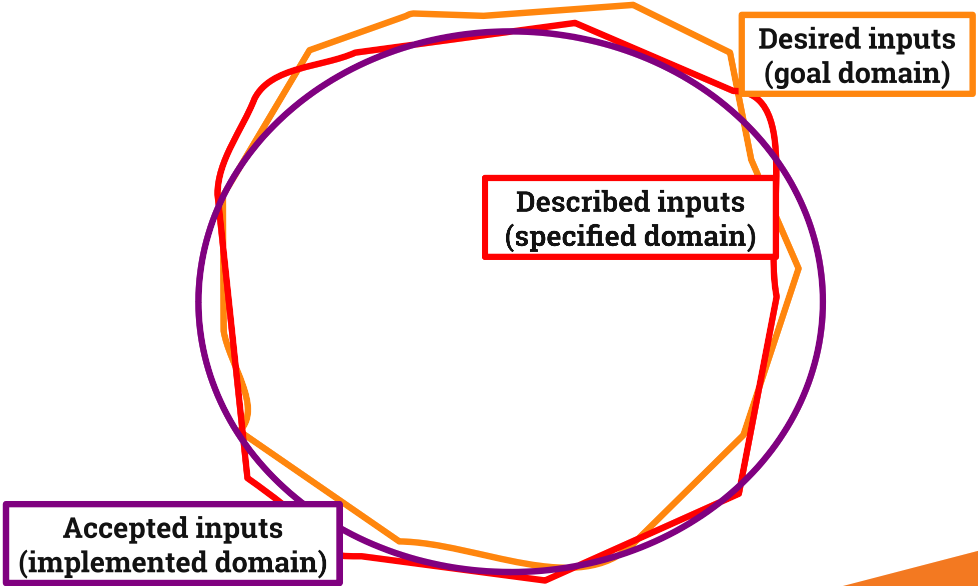
- P1, P2 and P3 can see the format, contents, and structure of the data
- Data sharing is independent of type
- Format is easy to understand
- Grammars are defined in DTDs or Schemas

XML For Book Example

```
<books>
  <book>
    <ISBN>0471043281</ISBN>
    <title>The Art of Software Testing</tittle>
    <author>Glen Myers</author>
    <publisher>Wiley</publisher>
    <price>50.00</price>
    <year>1979</year>
  </book>
</books>
```

- XML messages are defined by **grammars**
  - **Schemas** and DTDs
- Schemas can define many kinds of **types**
- Schemas include "**facets**" which refine the grammar

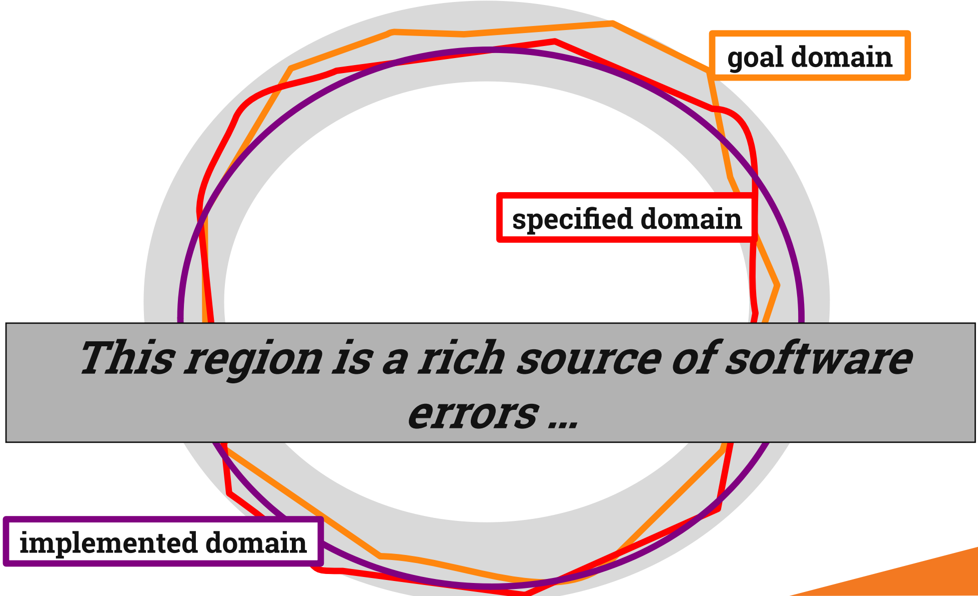
Representing Input Domains



Example Input Domains

- Goal domains are often **irregular**
- **Goal** domain for **credit cards**
  - First digit is the Major Industry Identifier
  - First 6 digits and length specify the issuer
  - Final digit is a “check digit”
  - Other digits identify a specific account
- Common **specified** domain
  - First digit is in {3, 4, 5, 6} (travel and banking)
  - Length is between 13 and 16
- Common **implemented** domain
  - All digits are numeric

Representing Input Domains



This region is a rich source of software errors …

Using Grammars to Design Tests

- This form of testing allows us to focus on **interactions** among the components
  - Originally applied to Web services, which depend on XML
- A **formal model** of the XML grammar is used
- The grammar is used to create **valid** as well as **invalid** tests
- The grammar is **mutated**
- The mutated grammar is used to generate new **XML messages**
- The XML messages are used as **test cases**

Book Grammar Schema

```
<xs:element name="books">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="book" maxOccurs="unbounded">
        <xs:complexType>
          <xs:sequence>
            <xs:element name="ISBN" type="isbnType" minOccurs="0"/>
            <xs:element name="author" type="xs:string"/>
            <xs:element name="title" type="xs:string"/>
            <xs:element name="publisher" type="xs:string"/>
            <xs:element name="price" type="priceType"/>
            <xs:element name="year" type="yearType"/>
          </xs:sequence>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
  </xs:complexType>
</xs:element>
```

Book Grammar Schema

- “xs:string” is a built-in type
- priceType is defined as follows:

```
<xs:simpleType name = "priceType">
  <xs:restriction base="xs:decimal">
    <xs:fractionDigits value="2"/>
    <xs:maxInclusive value="1000.00"/>
  </xs:restriction>
</xs:simpleType>
```

XML Constraints – "Facets"

Boundary Constraints	Non-Boundary Constraints
maxOccurs	enumeration
minOccurs	use
length	fractionDigits
maxExclusive	pattern
maxInclusive	nillable
maxLength	whitespace
minExclusive	unique
minInclusive	
minLength	
totalDigits	

Generating Tests

- **Valid** tests
  - Generate tests as **XML messages** by deriving strings from grammar
  - Take **every production** at least once
  - Take **choices** … `maxOccurs = "unbounded"` means use 0, 1, and more than 1
- **Invalid** tests
  - **Mutate** the grammar in structured ways
  - Create XML messages that are “**almost**” valid
  - This explores the **gray space** on the previous slide

Generating Tests

- The criteria in section 9.1.1 can be used to generate tests
  - **Production** and **terminal symbol** coverage
- The only choice in the books grammar is based on "**minOccurs**"
- Production Coverage (PDC) requires **two tests**
  - ISBN is present
  - ISBN is **not** present
- The facets are used to generate values that are valid
  - We also want values that are **not** valid …

Mutating Input Grammars

- Software should **reject** or **handle** invalid data
- A very **common mistake** is for programs to do this incorrectly
- Some programs (rashly) **assume** that all input data is correct
- Even if it works today …
  - What about after the program goes through some **maintenance changes**?
  - What about if the component is **reused** in a new program?
- Consequences can be **severe** …
  - Most **security vulnerabilities** are due to unhandled exceptions… from invalid data
- To test for invalid data (including security testing), **mutate the grammar**

Mutating Input Grammars

- Mutants are **tests**
- Create **valid** and **invalid** strings
- No **ground strings** – no killing
- Mutation operators listed here are **general** and should be refined for specific grammars

Input Grammar Mutation Operators

1. Nonterminal Replacement

Every nonterminal symbol in a production is replaced by other nonterminal symbols

2. Terminal Replacement

Every terminal symbol in a production is replaced by other terminal symbols

3. Terminal and Nonterminal Deletion

Every terminal and nonterminal symbol in a production is deleted

4. Terminal and Nonterminal Duplication

Every terminal and nonterminal symbol in a production is duplicated

Mutation Operators

- Many strings may **not be useful**
- Use additional **type information**, if possible
- Use **judgment** to throw tests out
- Only apply replacements if “**they make sense**”
- **Examples**...

Examples

Nonterminal Replacement

dep ::= “deposit” account amount

```
dep ::= "deposit" amount amount
dep ::= "deposit" account digit
```

Yields

deposit $1500.00 $3789.88

deposit 4400 5

Terminal Replacement

```
amount ::= "\$" digit+ "." digit{2}
amount ::= "." digit+ "." digit{2}
amount ::= "\$" digit+ "\$" digit{2}
amount ::= "\$" digit+ "1" digit{2}
```

Yields

deposit 4400 .1500.00

deposit 4400 $1500$00

deposit 4400 $1500100

Examples

Terminal and Nonterminal Deletion

```
dep ::= "deposit" account amount
dep ::= account amount
dep ::= "deposit" amount
dep ::= "deposit" account
```

Yields

4400 $1500.00
deposit $1500.00
deposit 4400

Terminal and Nonterminal Duplication

```
dep ::= "deposit" account amount
dep ::= "deposit" "deposit" account amount
dep ::= "deposit" account account amount
dep ::= "deposit" account amount amount
```

Yields

deposit deposit 4400 $1500.00
deposit 4400 4400 $1500.00
deposit 4400 $1500.00 $1500.00

Notes and Applications

- We have more **experience** with program-based mutation than input grammar based mutation
  - Operators are less "**definitive**"

- **Applying** mutation operators
  - **Mutate grammar**, then derive strings
  - Derive strings, **mutate a derivation** "in-process"

- Some mutants give strings in the original grammar (**equivalent**)
  - These strings can **easily be recognized** to be equivalent

Mutating XML

- XML **schemas** can be mutated
- If a schema does not exist, testers should **derive** one
  - As usual, this will help find problems immediately
- Many programs **validate messages** against a grammar
  - Software may still behave correctly, but testers must verify
- Programs are less likely to check all schema **facets**
  - Mutating facets can lead to very effective tests

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Test Generation – Example

```
<xs:simpleType name="priceType">
  <xs:restriction base="xs:decimal">
    <xs:fractionDigits value="2"/>
    <xs:maxInclusive value="1000.00"/>
```

<xs:fractionDigits> Mutants

value = “3”
value = “1”

<xs:maxInclusive> Mutants

value = “100”
value = “2000”

XML from Original Schema

```
<books>
  <book>
    <ISBN>0-201-74095-8</ISBN>
    <price>37.95</price>
    <year>2002</year>
  </book>
```

Mutant XML 1

```
<books>
  <booK>
    <ISBN>0-201-74095-8</ISBN>
    <price>505</price>
    <year>2002</year>
  </book>
```

ROAR

Test Generation – Example

```
<xs:simpleType name="priceType">
  <xs:restriction base="xs:decimal">
    <xs:fractionDigits value="2"/>
    <xs:maxInclusive value="1000.00"/>
```

<xs:fractionDigits> Mutants

value = “3”
value = “1”

<xs:maxInclusive> Mutants

value = “100”
value = “2000”

XML from Original Schema

```
<books>
  <book>
    <ISBN>0-201-74095-8</ISBN>
    <price>37.95</price>
    <year>2002</year>
  </book>
```

Mutant XML 2

```
<books>
  <booK>
    <ISBN>0-201-74095-8</ISBN>
    <price>5</price>
    <year>2002</year>
  </book>
```

Test Generation – Example

```
<xs:simpleType name="priceType">
  <xs:restriction base="xs:decimal">
    <xs:fractionDigits value="2"/>
    <xs:maxInclusive value="1000.00"/>
```

<xs:fractionDigits> Mutants

value = “3”
value = “1”

<xs:maxInclusive> Mutants

value = “100”
value = “2000”

XML from Original Schema

```
<books>
  <book>
    <ISBN>0-201-74095-8</ISBN>
    <price>37.95</price>
    <year>2002</year>
  </book>
```

Mutant XML 3

```
<books>
  <booK>
    <ISBN>0-201-74095-8</ISBN>
    <price>99.00</price>
    <year>2002</year>
  </book>
```

Test Generation – Example

```
<xs:simpleType name="priceType">
  <xs:restriction base="xs:decimal">
    <xs:fractionDigits value="2"/>
    <xs:maxInclusive value="1000.00"/>
```

<xs:fractionDigits> Mutants

value = “3”
value = “1”

<xs:maxInclusive> Mutants

value = “100”
value = “2000”

XML from Original Schema

```
<books>
  <book>
    <ISBN>0-201-74095-8</ISBN>
    <price>37.95</price>
    <year>2002</year>
  </book>
```

Mutant XML 4

```
<books>
  <booK>
    <ISBN>0-201-74095-8</ISBN>
    <price>1500.00</price>
    <year>2002</year>
  </book>
```

Input Space Grammars Summary

- This application of mutation is **fairly new**
- Automated **tools** do not exist
- Can be used **by hand** in an “ad-hoc” manner to get effective tests
- Applications to **special-purpose grammars** very promising
  - XML
  - SQL
  - HTML

Are there any questions?