Grammar Fuzzing

Guillermo Polito

guillermo.polito@inria.fr
@guillep

Goals

- Syntactically valid inputs go further in programs
- Grammars can be used to generate syntactically valid inputs

Remember Fuzzing Date Parser

```
f := PzRandomFuzzer new.
r := PzBlockRunner on: [ :e | e asDate ].
r expectedException: DateError.
f run: r times: 20.
```

- Pharo 11
- String>>asDate
- DateError is an expected error
- 4/20 = 5% of errors

```
PASS "DateError: day is after month ends"
PASS "28 April 2006"
PASS "7 September 2029"
PASS "9 March 1995"
FAIL "SubscriptOutOfBounds: 73"
PASS "DateError: day is after month ends"
FAIL "SubscriptOutOfBounds: 0"
PASS "DateError: day is after month ends"
PASS "6 January 2007"
PASS "9 January 1986"
FAIL "SubscriptOutOfBounds: 0"
FAIL "#isAlphaNumeric was sent to nil"
PASS "DateError: day is after month ends"
PASS "1 September 1989"
PASS "DateError: day is after month ends"
PASS "DateError: day may not be zero or negative"
PASS "5 January 0228"
PASS "DateError: day may not be zero or negative"
PASS "7 September 1996"
PASS "2 January 2008"
```

Parser was too Permissive

- Some inputs PASS but **do not respect the contract**

```
"Answer an instance of created from a string with format
        mm.dd.yyyy or mm-dd-yyyy or mm/dd/yyyy"
```

```
'?(2/=-@=@:4?/(3$3(8"&,!-2/&6&&' asDate.
>> 4 February 2003
```

- Parser is too permissive
- Our runner is too permissive too => we should detect this as an error!

Random Inputs Fail Easily

- We could expect to break something with fully random inputs
- This could be solved with **input sanitizing**

- What if we have *almost correct inputs*?
- Looks like a date, cuacks like a date, parses as a date?

We need to generate syntactically and semantically valid inputs

We need to generate **syntactically** and semantically valid inputs

Date Fuzzer

```
(1 to: 10) collect: [ :e | PzDateFuzzer new fuzz ]
```

```
23 5
7/February-6
7,February0
0/february/7
9 february 0
7 February-9
February 0,1
4/February,4
february/0 7
1January,8
```

Grammars as Input Descriptions

- Grammars describe languages
- Usually used for parsing purposes, but…

- Key idea => structured fuzzing with grammars

Date Grammar

```
ntNumber --> ntDigit, ntNumber | ntDigit.
ntDigit --> ($0 - $9).

ntDate
  --> ntDay, ntSeparator, ntMonth, ntSeparator, ntYear
  | ntMonth, ntSeparator, ntDay, ntSeparator, ntYear
  | ntYear, ntSeparator, ntMonth, ntSeparator, ntDay.
ntSeparator --> '' | ' ' | '-' | ',' | '/'.
ntDay --> ntNumber.
ntMonth
  --> ntNumber
  | 'january' | 'January'
  | 'february' | 'February'.
ntYear --> ntNumber.
```

Grammar Fuzzer

```
(1 to: 10) collect: [ :e | (PzGrammarFuzzer on: PzDateGrammar new) fuzz ]
```

```
23 5
7/February-6
7,February0
0/february/7
9 february 0
7 February-9
February 0,1
4/February,4
february/0 7
1January,8
```

Let’s test some parser

```
f := PzGrammarFuzzer on: PzDateGrammar new.
r := PzBlockRunner on: [ :e | e asDate ].
r expectedException: DateError.
f run: r times: 20.
```

- Pharo 11
- String>>asDate

```
PASS 3 January 2009
PASS 9 February 2006
PASS 4 February 2002
PASS-FAIL DateError: day may not be zero or negative
FAIL #isAlphaNumeric was sent to nil
FAIL Error: Month out of bounds: 26.
PASS 9 January 2001
PASS 4 January 2004
PASS 7 February 2007
PASS 4 February 2007
FAIL #isAlphaNumeric was sent to nil
PASS 4 January 2005
PASS 8 February 2004
PASS 8 February 2009
PASS 8 January 2007
PASS 3 May 2001
PASS 7 February 2001
FAIL #isAlphaNumeric was sent to nil
PASS-FAIL DateError: day may not be zero or negative
PASS 5 February 2006
```

Let’s get more data

```
f := PzGrammarFuzzer on: PzDateGrammar new.
r := PzBlockRunner on: [ :e | e asDate ].
r expectedException: DateError.
f run: r times: 100.
```

Pass	81 %
Expected-Fail	10 %
Fail	9 %

- Simple Date grammar fuzzing has a high success ratio

Looking at the bugs

- Out of 135 bugs fuzzing 1000 cases

method not understood **during parsing**	83 %
Out of bounds **during parsing**	13 %
Validation with generic error **during parsing**	4 %

Building a Grammar Fuzzer

- Example, a number grammar

```
ntNumber --> ntDigit, ntNumber | ntDigit.
ntDigit --> ($0 - $9).
```

Desugarising into simple rules

- Example, a number grammar

```
ntNumber --> ntDigit, ntNumber | ntDigit.
ntDigit --> ($0 - $9).
```

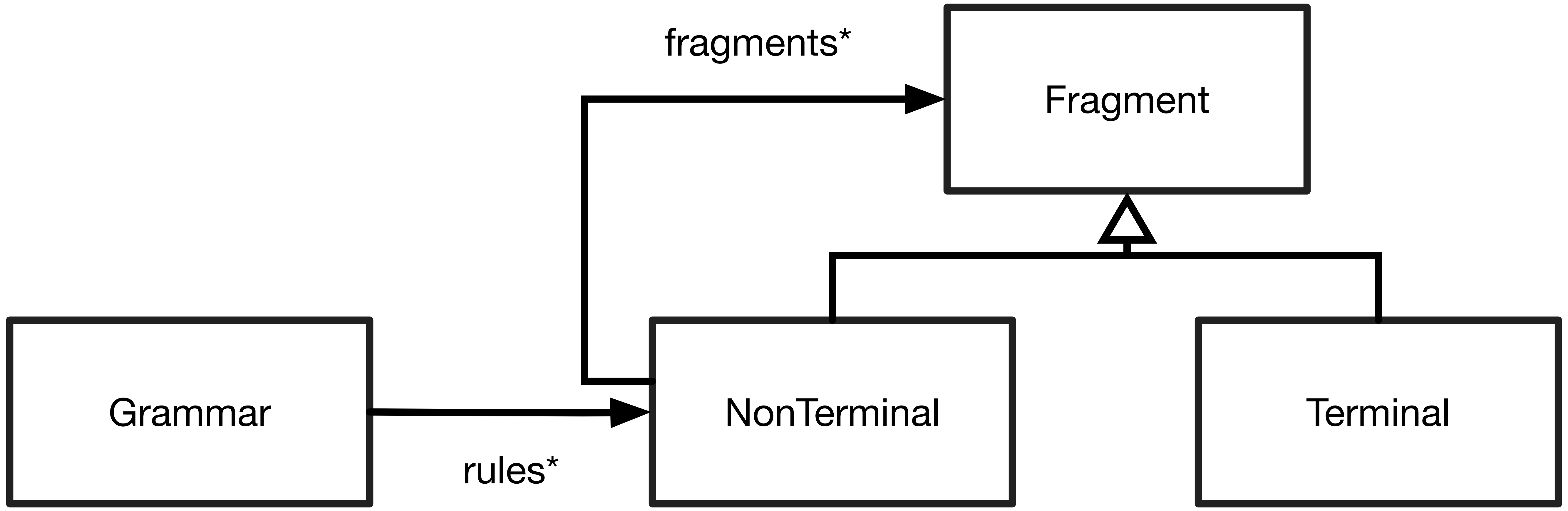
⬇

```
ntNumber --> ntDigit, ntNumber
ntNumber --> ntDigit.
ntDigit --> 0.
ntDigit --> 1.
…
ntDigit --> 8.
ntDigit --> 9.
```

Modelling as a Composite Pattern

- Example, a number grammar

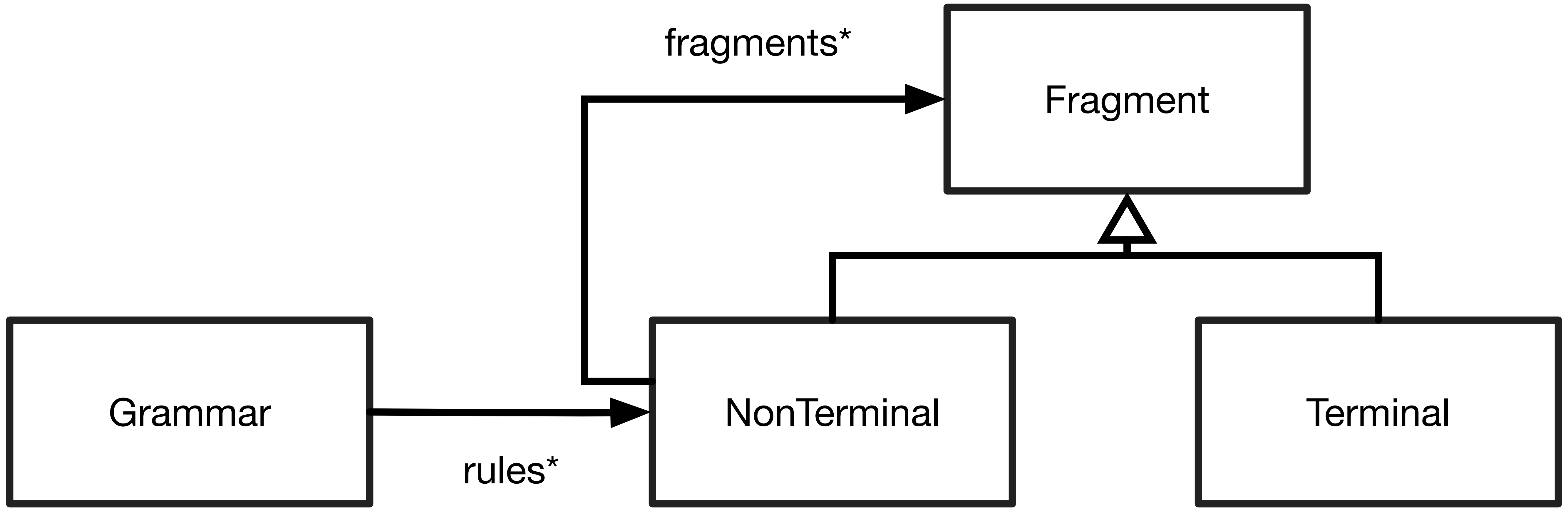
```
ntNumber --> ntDigit, ntNumber
ntNumber --> ntDigit.
ntDigit --> 0.
ntDigit --> 1.
…
ntDigit --> 8.
ntDigit --> 9.
```

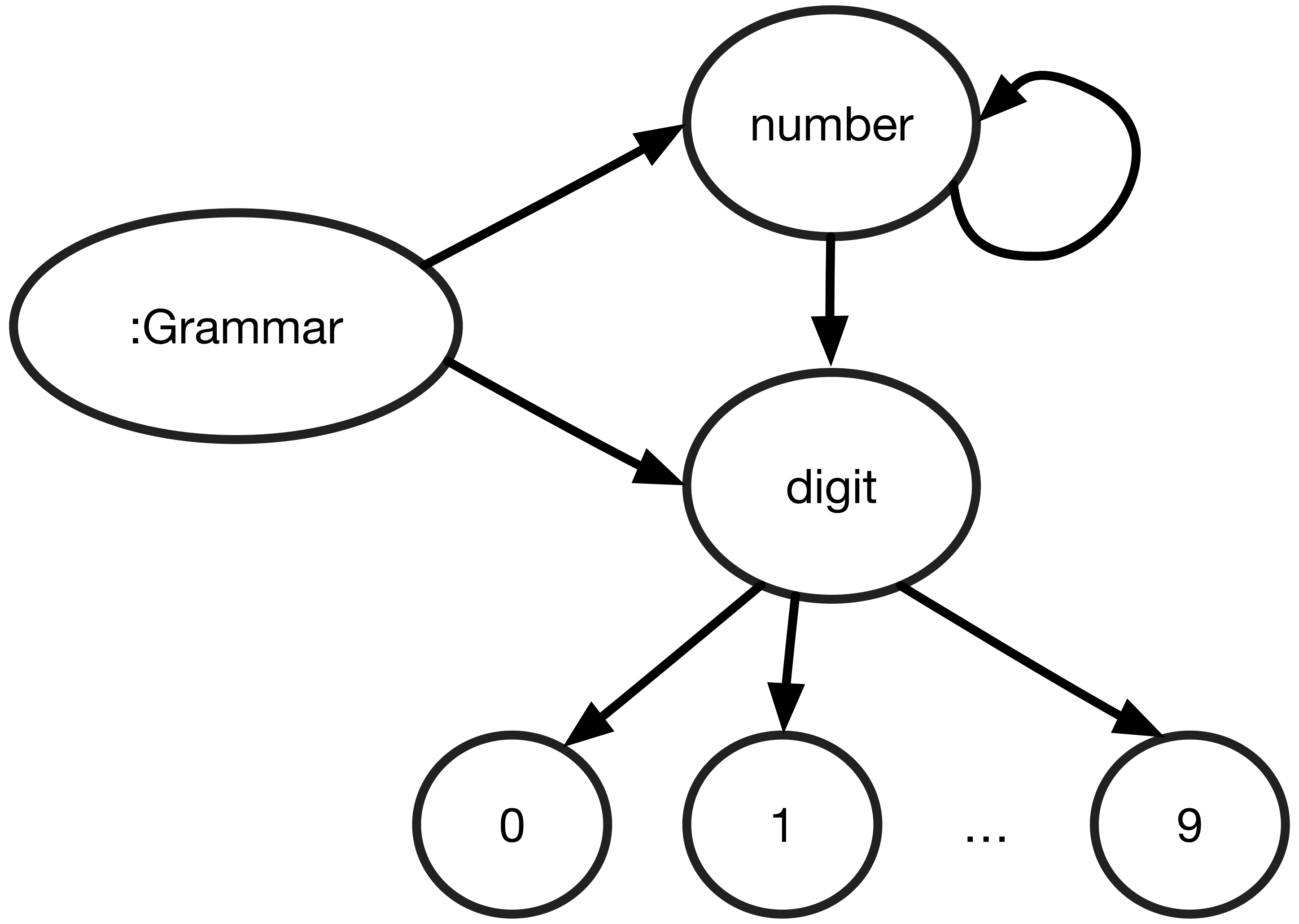


Instantiating the Model

- Example, a number grammar

```
ntNumber --> ntDigit, ntNumber
ntNumber --> ntDigit.
ntDigit --> 0.
ntDigit --> 1.
…
ntDigit --> 8.
ntDigit --> 9.
```





Generation: Visitor Pattern

```
GrammarFuzzer >> visitRule: rule

  ^ rule fragments inject: ‘’ into: [ :accum :each |
     accum , (each visit: self) ].

GrammarFuzzer >> visitTerminal: terminal

  ^ terminal

GrammarFuzzer >> visitNonTerminal: nonTerminal

  | rule |
  rule := self selectRule: nonTerminal rules.
  ^ rule visit: self withSubLevel
```

Generation: Visitor Pattern

```
GrammarFuzzer >> visitRule: rule

  ^ rule fragments inject: ‘’ into: [ :accum :each |
     accum , (each visit: self) ].

GrammarFuzzer >> visitTerminal: terminal

  ^ terminal

GrammarFuzzer >> visitNonTerminal: nonTerminal

  | rule |
  rule := self selectRule: nonTerminal rules.
  ^ rule visit: self withSubLevel
```

Random selection

```
GrammarFuzzer >> selectRule: nonTerminal

  ^ nonTerminal rules atRandom
```

Possible Extensions

- *Limiting* the output, by size, by tree depth
- *Guide* grammar generation by
    - adding *weights* to the derivations
    - grammar *coverage*
    - *genetic algorithms?*

Takeaways

- Structured inputs can help
    - *penetrate* complex programs e.g., compilers
    - bypass validations e.g., syntax validations in parsers
- Grammars describe languages
    - not only parsing!
    - but also generation (goes back to ’67, ’70, ’72!)

Material

- The Fuzzing Book. Grammars Chapter. A. Zeller et al
  https://www.fuzzingbook.org/html/Grammars.html
- Gnocco
  https://github.com/Alamvic/gnocco/