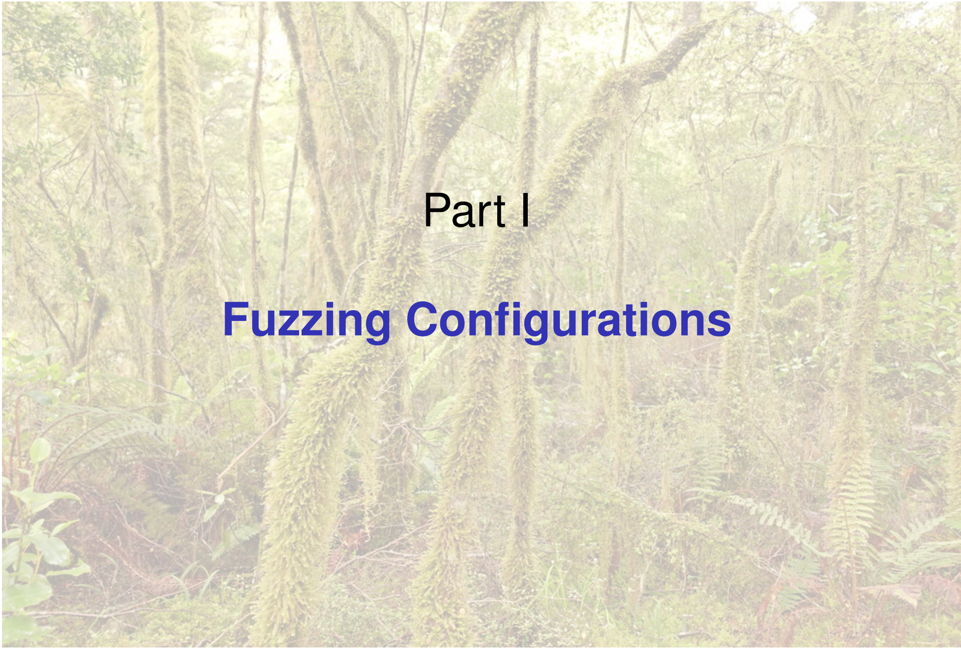
Software Testing, Quality Assurance & Maintenance—Lecture 10

Patrick Lam
University of Waterloo

February 6, 2026



Part I

Fuzzing Configurations

Not Just Inputs

So far: create program inputs through fuzzing (mutation, generation).

Today: instead of inputs, consider program configurations.

Command-line Options as Configurations

```
$ autopep8 --help
usage: autopep8 [-h] [--version] [-v] [-d] [-i]
                [--global-config filename]
                [--ignore-local-config] [-r] [-j n]
                [-p n] [-a] [--experimental]
                [--exclude globs] [--list-fixes]
                [--ignore errors] [--select errors]
                [--max-line-length n]
                [--line-range line line]
                [--hang-closing]
                [--exit-code] [files ...]
  ...
```

could also fuzz config files, registries, etc.

Three Takeaways

1. configurations affect program behaviour;
2. you can automatically construct grammars for configurations;
3. these grammars can be used for fuzzing.

Idea 1: Configurations are Important

```
$ autopep8 --help
...
  --experimental         enable experimental fixes
...
```

Clearly this option affects which code paths are reachable.

Some code paths are only reachable under certain configuration options.

argparse

Options in Python: getopt, optparse, argparse, ...

```
def process_numbers():
    parser = argparse.ArgumentParser
                (description=’Process some integers.’)
    parser.add_argument(’integers’, metavar=’N’, type=
                                    int, nargs=’+’)
    group = parser.add_mutually_exclusive_group(
                                    required=True)
    group.add_argument(’--sum’, dest=’accumulate’,
                       action=’store_const’,
                       const=sum)
    group.add_argument(’--min’, dest=’accumulate’,
                       action=’store_const’,
                       const=min)  # [--max omitted]

    args = parser.parse_args()
    print(args.accumulate(args.integers))
```

Processing numbers

```
$ python3 process-numbers.py --sum 2 4
6
```

A Grammar for Configurations

```
PROCESS_NUMBERS_EBNF_GRAMMAR: Grammar = {
    "<start>": ["<operator> <integers>"],
    "<operator>": ["--sum", "--min", "--max"],
    "<integers>": ["<integer>", "<integers> <integer>"],
    "<integer>": ["<digit>+"],
    "<digit>": crange(’0’, ’9’)
}

assert is_valid_grammar(PROCESS_NUMBERS_EBNF_GRAMMAR)
PROCESS_NUMBERS_GRAMMAR = convert_ebnf_grammar(
                                PROCESS_NUMBERS_EBNF_GRAMMAR)
```

On GrammarCoverageFuzzer

We have seen `GrammarFuzzer`.

We are not talking about `GrammarCoverageFuzzer`, but it ensures that all alternatives are covered.

(it is a drop-in replacement for `GrammarFuzzer`).

Fuzzing process_numbers configurations

```
>>> f = GrammarFuzzer(PROCESS_NUMBERS_GRAMMAR, min_nonterminals
                                                =10)
>>> for i in range(3):
        args = f.fuzz().split()
        print(args)
        process_numbers(args)
['--max', '9', '8', '8', '162', '559606', '07043719933614']
7043719933614
['--sum', '6', '7', '4', '90', '57', '9767']
9931
['--max', '6', '1', '6900', '3637']
6900
```

Can’t we automate this?

We manually proposed a grammar for `process_numbers`.
That works, but is extra work.

Is there a better way?

Insight 2: It’s Already There

The program already instructs `argparse` about which arguments it’ll accept.

Idea: Construct the grammar from the program.

Fuzzing Book approach: dynamic analysis

Observe program's calls to `argparse` to reconstruct the grammar.

Notes:

1. for Python, dynamic analysis probably easier than static analysis;
2. our implementation only works for specifically `argparse`.

Another approach: use a domain-specific language for options,
generate code & grammar from that.

Part II

Mining Configurations

Key idea, again

Use Python tracing infrastructure to
track calls to `argparse`,
recording parameters,
to construct the grammar.

Exploratory code

A tracing function that observes `add_argument` calls:

```
def trace_options(frame, event, arg):
  if event != "call":
      return
  method_name = frame.f_code.co_name
  if method_name != "add_argument":
      return
  locals = frame.f_locals
  print(locals[’args’])
```

Exploring

Let’s exercise our code.

```
>>> sys.settrace(trace_options)
>>> process_numbers(["--sum", "1", "2", "3"])
('-h', '--help')
('integers',)
('--sum',)
('--min',)
('--max',)
6
>>> sys.settrace(None)
```

We can indeed see the arguments being added.

Implementation highlights

The *Fuzzing Book* exhaustively presents `OptionGrammarMiner`'s implementation. We won't.

```
class OptionGrammarMiner:
    def __init__(self, function: Callable, log: bool = False):
        self.function = function
        self.log = log

    def mine_ebnf_grammar(self):
        # ...
```

Usage:

1. create an `OptionGrammarMiner` with the function that calls `argparse`,
2. trigger it by calling its `mine_ebnf_grammar()` method.

mine_ebnf_grammar highlights

mine_ebnf_grammar() enables tracing & calls provided function.

function runs until parse_args() called.

mine_ebnf_grammar's tracer

Tracer watches calls to add_argument, add_mutually_exclusive, and add_argument_group.

For instance, add_argument may call

```
    def add_str_rule(self):
        self.grammar["<str>"] = ["<char>+"]
        self.grammar["<char>"] = srange(
            string.digits
            + string.ascii_letters
            + string.punctuation)
```

mine_ebnf_grammar in action

```
>>> miner = OptionGrammarMiner(process_numbers, log=True)
>>> process_numbers_grammar = miner.mine_ebnf_grammar()
>>> print (process_numbers_grammar)
...
{'<start>': ['<group>(<option>)*<arguments>'],
 '<option>': [' -h', ' --help'],
 '<arguments>': ['( <integers>)+'],
 '<int>': ['(-)?<digit>+'],
 '<digit>': ['0', '1', '2', '3', '4', '5', '6', '7', '8', '9'],
 '<integers>': ['<int>'],
 '<group>': [' --sum', ' --min', ' --max']}
```

Part III

Fuzzing Mined Grammars

Yes, we can…

…fuzz mined options grammars.

```
>>> grammar = convert_ebnf_grammar(process_numbers_grammar)
>>> assert is_valid_grammar(grammar)
>>> f = GrammarFuzzer(grammar)
>>> for i in range(10):
>>>     print(f.fuzz())
 --sum -h 19
 --max -09 4
 --min -685 -8
 --max 73 4731240
 --max --help --help -h 0 0 -34
 --min --help 57
 --max -6820 8
 --sum 96
 --min 7 -76 -61
 --max --help 56
```

Another example: autopep8

```
>>> autopep8_miner = OptionGrammarMiner(autopep8)
>>> autopep8_ebnf_grammar = autopep8_miner.mine_ebnf_grammar()
>>> print (autopep8_ebnf_grammar["<option>"])
[’ -h’, ’ --help’, ’ --version’, ’ -v’, ’ --verbose’, ’ -d’, ’
                                --diff’, ’ -i’, ’ --in-place’,
                                ’ --global-config <filename>’,
                                ’ --ignore-local-config’, ’ -r’
                                , ’ --recursive’, ’ -j <n>’, ’
                                --jobs <n>’, ’ -p <n>’, ’ --
                                pep8-passes <n>’, ’ -a’, ’ --
                                aggressive’, ’ --experimental’,
                                 ’ --exclude <globs>’, ’ --list
                                -fixes’, ’ --ignore <errors>’,
                                ’ --select <errors>’, ’ --max-
                                line-length <n>’, ’ --line-
                                range <line> <line>’, ’ --range
                                 <line> <line>’, ’ --indent-
                                size <int>’, ’ --hang-closing’,
                                 ’ --exit-code’]
```

autopep8 extracted grammar

Extracts correct types for lines and files:

```
>>> print (autopep8_ebnf_grammar["<line>"])
['<int>']
>>> print (autopep8_ebnf_grammar["<arguments>"])
['( <files>)*']
>>> print (autopep8_ebnf_grammar["<files>"])
['<str>']
```

Fuzzing extracted `autopep8` grammar

```
>>> autopep8_grammar = convert_ebnf_grammar(
                                      autopep8_ebnf_grammar)
>>> assert is_valid_grammar(autopep8_grammar)
>>> f = GrammarFuzzer(autopep8_grammar, max_nonterminals=4)
>>> for i in range(10):
>>>     print(f.fuzz())
 foo.py
 --range 9 9 foo.py
 --diff --help foo.py
 foo.py
 --jobs -64621 foo.py
 foo.py
 foo.py
 --indent-size -8 --list-fixes foo.py
 foo.py
 foo.py
```

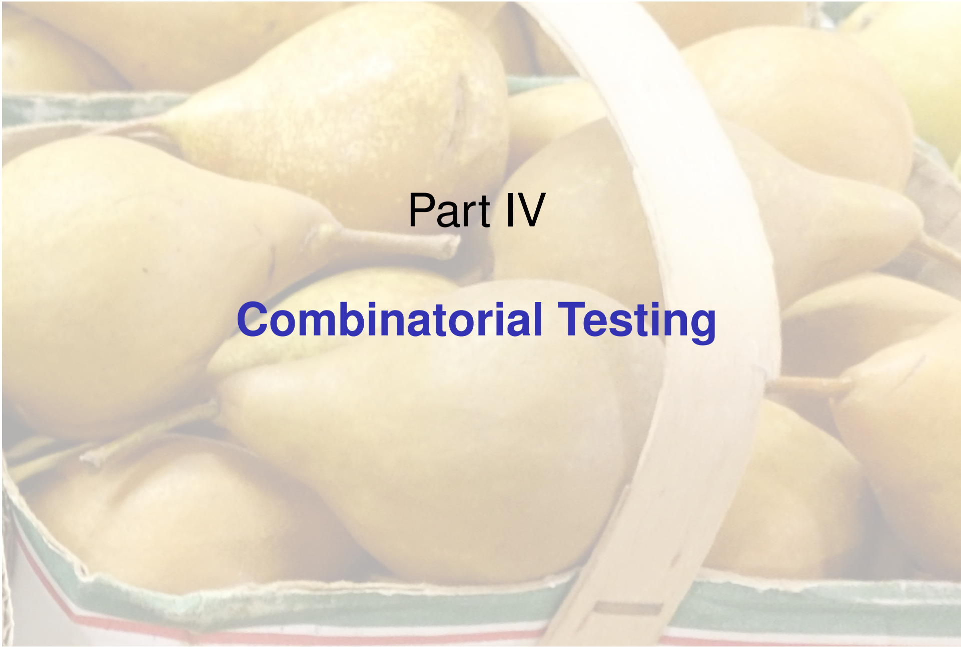
`GrammarCoverageFuzzer` would be much better, oh well.

Could run `autopep8` with these inputs.

Not shown: yet more examples

With some machinery to run arbitrary Python programs (that use `argparse`), carry out configuration fuzzing for:

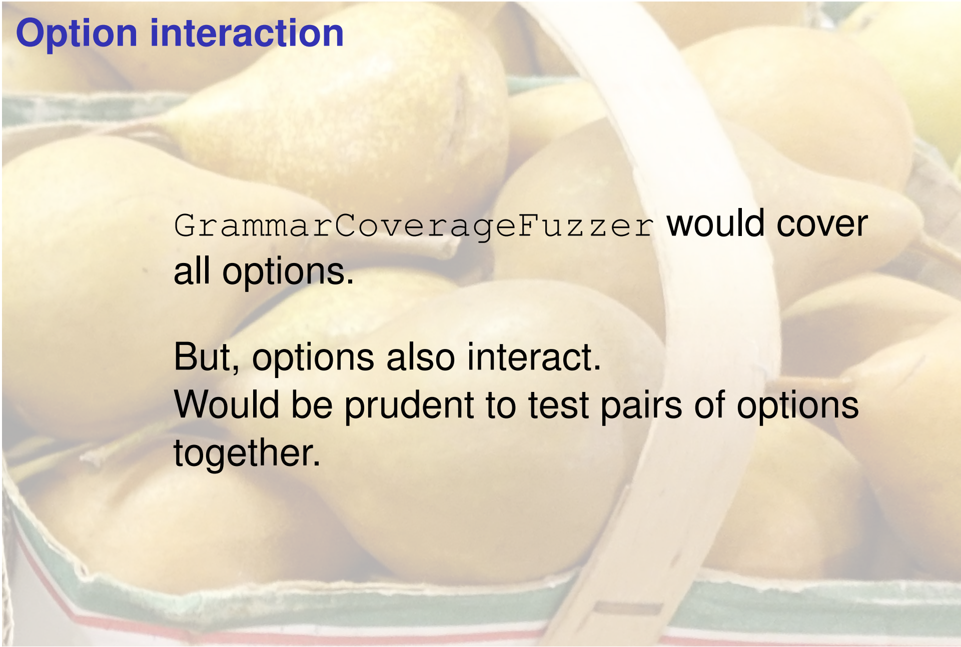
- `mypy` static type checker
- `notedown` Notebook to Markdown converter.



Part IV

Combinatorial Testing

Option interaction



`GrammarCoverageFuzzer` would cover all options.

But, options also interact.
Would be prudent to test pairs of options together.

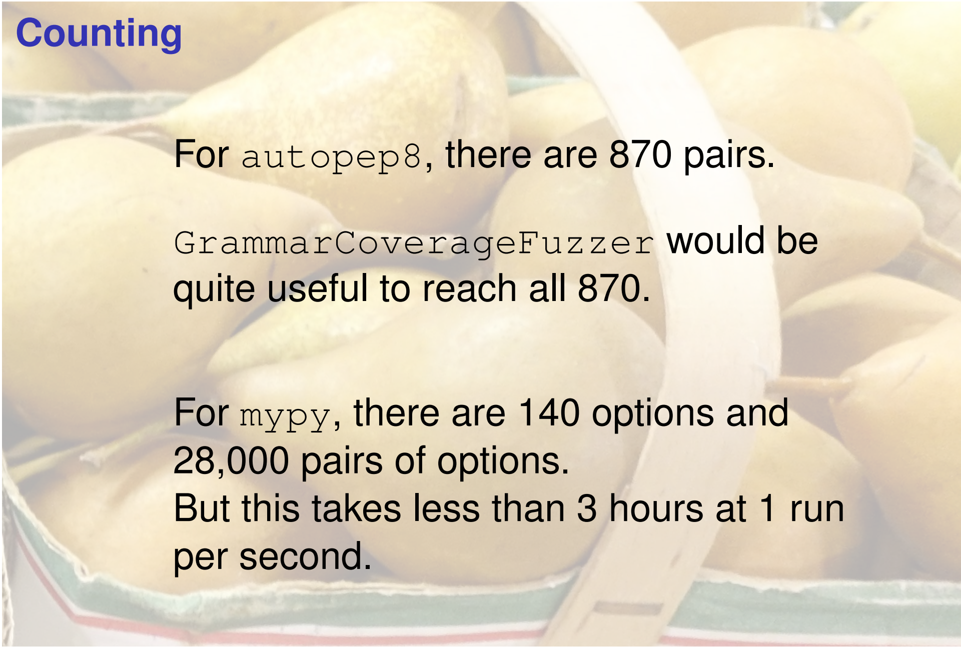
All pairs

```
>>> autopep8_miner = OptionGrammarMiner(autopep8)
>>> autopep8_ebnf_grammar = autopep8_miner.mine_ebnf_grammar()
>>> option_list = autopep8_ebnf_grammar["<option>"]
>>> pairs = list(combinations(option_list, 2))
>>> print (len(pairs))
435
>>> print (pairs[:20])
[(’ -h’, ’ --help’), (’ -h’, ’ --version’), (’ -h’, ’ -v’), (’
                               -h’, ’ --verbose’), (’ -h’, ’ -
                               d’), (’ -h’, ’ --diff’), (’ -h’
                               , ’ -i’), (’ -h’, ’ --in-place’
                               ), (’ -h’, ’ --global-config <
                               filename>’), (’ -h’, ’ --ignore
                               -local-config’), (’ -h’, ’ -r’)
                               , (’ -h’, ’ --recursive’), (’ -
                               h’, ’ -j <n>’), (’ -h’, ’ --
                               jobs <n>’), (’ -h’, ’ -p <n>’),
                                (’ -h’, ’ --pep8-passes <n>’),
                                (’ -h’, ’ -a’), (’ -h’, ’ --
                               aggressive’), (’ -h’, ’ --
                               experimental’), (’ -h’, ’ --
                               exclude <globs>’)]
```

Pairs grammar

```
>>> def pairwise(option_list):
        return [option_1 + option_2
                for (option_1, option_2) in combinations(
                                                option_list, 2)]

>>> pairwise_autopep8_grammar=extend_grammar(autopep8_grammar)
>>> pairwise_autopep8_grammar["<option>"] = pairwise(
                                    autopep8_grammar["<option>"])
>>> assert is_valid_grammar(pairwise_autopep8_grammar)

>>> pairwise_autopep8_fuzzer = GrammarFuzzer(
                                    pairwise_autopep8_grammar,
                                    max_nonterminals=4)
>>> for i in range(10):
        print (pairwise_autopep8_fuzzer.fuzz())

 FYZcX s
 Y u C
 =kD
 -h --in-place }

 C ap
```

Counting



For `autopep8`, there are 870 pairs.

`GrammarCoverageFuzzer` would be quite useful to reach all 870.

For `mypy`, there are 140 options and 28,000 pairs of options.
But this takes less than 3 hours at 1 run per second.

Generalization to Inputs

We've seen grammar inference and fuzzing for configurations.

Can do something similar for some inputs as well.

See *Fuzzing Book* under "Mining Input Grammars", and also the paper by Bettscheider & Zeller.