Fuzzing

Martin Kellogg

Reading Quiz: fuzzing

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HW2 thoughts

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“I realized that it would be very time consuming and also difficult for me to manually collect a high coverage test suite…I **wrote a script** that would select an image **if it increases the coverage value**”

- this is an excellent approach to a problem like this!
  - always consider automation if a task is repetitive and manual
  - this student treated coverage as a **fitness function**, much like a mutational fuzzer (more details later)

Fuzzing: agenda

- **story time**
- mutational fuzzing
- grammar-based fuzzing
- fuzzing in the real world
- start symbolic execution (if there is enough time left)

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  - **insight**: just a few bits of random inputs are enough!

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Modern fuzzers combine these two ideas.

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  - But what **else** is “read in” by a program and may influence its behavior?

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  - Many programs (especially student programs) read from a file

What else besides “input” can **influence** program behavior?

- User Input (e.g., GUI)
- Environment Variables, Command-Line Args
- Scheduler Interleavings
- Data from the Filesystem
  - User configuration, data files
- Data from the Network
  - Server and service responses

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3. 1 & 2 imply test input generation must also **control the environment**

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An **implicit oracle** is an oracle that doesn’t require an explicit spec from the programmer, such as “programs should not crash”.

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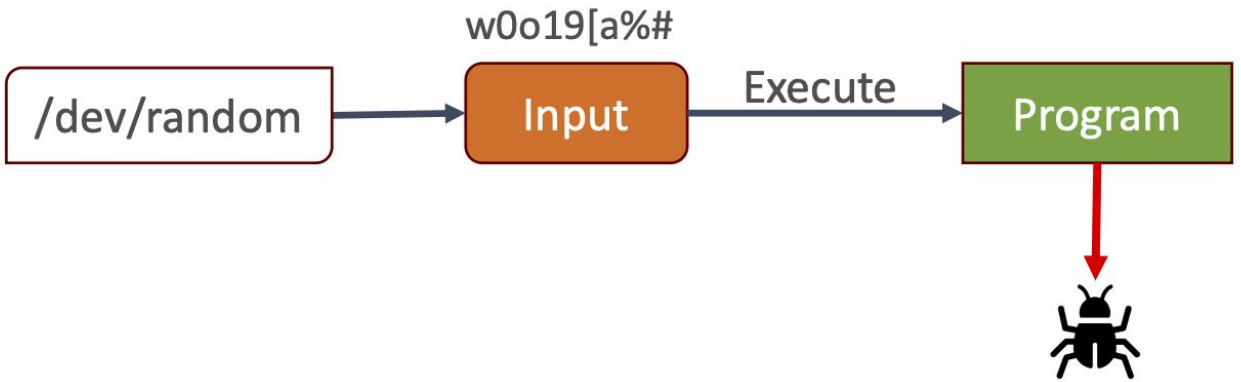

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  - but that rarely works well in practice except to test the code that **reads input** (why?)

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  - **implication**: fuzzing with random input produces tests that have **low coverage**

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- `query` is a list of key/value pairs, such as `q=fuzzing`
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Achieving high coverage

What do you think are the odds of generating a valid URL by choosing random characters?

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  - by using program analysis to find **constraints** on the input that will allow it to pass various checks

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  - repeat until some stopping condition

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    - coverage!

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  - for example, in our URL parsing example, these would be URLs that we know are valid
- the **choice of seed inputs** is one of the most important inputs to the fuzzer
  - “garbage in, garbage out” is very true for this kind of fuzzer
  - can also significantly impact performance
  - HW3 hint: choose seed images carefully

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A ***neutral*** mutation is one that does not impact fitness. E.g., `goggle.com` is also a valid URL.

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- however, statement coverage is actually a bit **too coarse-grained** in practice
- practical fuzzers like AFL (used in HW3) use branch or ***path*** coverage
  - AFL's fitness function rewards an input for **any new path**, even if that path has the same branch coverage
    - this means e.g., that an input that causes a loop to go around **twice instead of once** is rewarded

Mutational fuzzing: power schedules

- consider a new generation of test inputs containing:
  - one input that covered a new branch or path that was created in the last round of mutation
  - *n*-1 inputs that have been in the population for at least a few generations
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  - we implement this intuition via **power schedules**

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    - when a seed is mutated to produce an input that increases fitness, its energy increases
    - when a seed is mutated, but doesn't produce an input that increases fitness, its energy decreases

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    - "unusual" paths are those rarely covered by other seeds
    - this technique can dramatically improve the fuzzer's performance
  - change the power schedule to assign energy based on **distance to some objective**
    - called ***directed fuzzing***

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Population of inputs:

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https://web.njit.edu/~mjk76/
https://calendar.google.com/calendar/u/0/r?cid=bWprNzZAbmppdC5lZHU
http://3.149.230.63:50000
...
```

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Fuzzing: agenda

- story time
- mutational fuzzing
- **grammar-based fuzzing**
- fuzzing in the real world
- start symbolic execution (if there is enough time left)

Grammar-based fuzzing

- Mutating seed inputs is effective in practice to find inputs that are “near” the seeds
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Key idea: provide that structure to the fuzzer, and only select inputs that are valid!

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Grammar-based fuzzing: review of grammars

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- A ***formal grammar*** describes which strings from an alphabet of a formal language are valid according to the language's syntax. [Wikipedia]
- For example, here is a grammar for URLs:

  URL = S :// N / P? `scheme://netloc/path?query#fragment`

  S = http | https | ftp | …

  N = any string

  P = any string / P | P ? Q | ε

  Q = any string | Q # F

  F = any string

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- i.e., the seed inputs are **replaced** with the grammar, and the population is created by sampling from the grammar.
- mutation changes from “change a random character” or similar to “change a part of the **derivation tree** for a term”

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- for such programs, providing a grammar can dramatically improve fuzzing efficiency
  - downside: someone usually has to write the grammar
  - but this is an area of active research!

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Fuzzing in practice

- Fuzzing is **common in industry**
  - AFL (most famous coverage-guided fuzzer) was built at Google
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- Fuzzing is **machine-intensive**
  - most inputs aren't useful (grammars can help)
- Fuzzing **finds real bugs**
  - especially useful for finding security bugs

Fuzzing in practice: security

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- It is straightforward to augment a fuzzer to detect buffer overflows in addition to crashes
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  - fuzzers have detected many important security issues
    - e.g., Heartbleed in OpenSSL

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- note: there is no autograder for this assignment. You only need to turn in a written report (but to write the report, you'll need data from AFL that you can only get by running it on libpng)