Week 10: Lecture A
Hybrid Fuzzing I

Monday, March 18, 2024
How are projects going?

Problems?

Successes?
Recap: Project Schedule

- **Mar. 27th:** in-class project workday

- **Apr. 17th & 22nd:** final presentations
  - 15–20 minute slide deck and discussion
  - What you did, and why, and what results
Questions?
Input Generation Recap
Recap: Model-agnostic Mutation

Random mutation operators
- Bit and byte flips
  - Single, two, or four bits in a row
- Arithmetic operators
  - Additions/subtractions of both endians
- Inject “fun” values (-1, 256, 1024, etc.)
  - Values that often cause weird behavior

11 11 00 11 11 11 11 11

11 11 11 12 11 11 11 11

11 11 11 11 FF 11 11 11
Recap: Model-guided Generation

- **Follow a pre-defined input specification**
  - Pre-defined input grammars
  - Dynamically-learned grammars
  - Domain-specific generators

- **Produces many more valid inputs**
  - Model-agnostic inputs are often discarded because they fail basic input sanity checks
Recap: Symbolic Execution

0. `def f(x, y):
1.     if (x > y):
2.         x = x + y
3.         y = x - y
4.         x = x - y
5.     if (x - y > 0):
6.         assert false
7.     return (x, y)

Possible path constraints:

- `(A > B)` and `(B-A > 0)` = unsatisfiable
- `(A > B)` and `(B-A <= 0)` = satisfiable
- `(A <= B)` = satisfiable
Recap: Taint Tracking

- **Track input bytes’ flow throughout the program**
  - Identify input “chunks” that affect program state
    - Chunks that affect branches
    - Chunks that flow to function calls
  - Mutate these chunks via:
    - Random mutation
    - Insertion of fun or useful tokens
Summary of Input Generation

- **Model-agnostic**: brute-force your way to valid inputs
  - Random insertions, deletions, and splicing

- **Model-guided**: follow a pre-defined input specification
  - Follow “rules” to create highly-structured inputs

- **White-box approaches**:
  - **Symbolic execution**: solve branches as **symbolic** expressions
  - **Concolic execution**: solve branches as **concrete** values
  - **Taint tracking**: infer critical input **“parts”** and mutate those

Source: The Art, Science, and Engineering of Fuzzing: A Survey
Trade-offs

- **Model-agnostic**: great on simple, easy-to-solve branches
  - Need a lot of luck to solve **multi-byte conditionals, checksums**

- **Model-guided**: more valid inputs leads to higher coverage
  - Out of luck if specification is **not defined** or **hard-to-define**

- **White-box approaches**:
  - **Symbolic / concolic exec**: precise solving of multi-byte conditionals
  - **Taint tracking**: easily identifies key data objects, branch constraints
  - Far too **heavyweight** to deploy on all generated inputs

Source: The Art, Science, and Engineering of Fuzzing: A Survey
Recap: *What does your code coverage tell you?*

- **Edge coverage:**
  - Strictly *increases* with time
    - Ideally increases the whole time
  - Always look at *multiple trials*
    - Studies show at least *5 trials*
  - All fuzzers eventually *plateau*
    - *Early plateaus* indicate you are stuck
    - Revisit your approach and try again
      - *Combine multiple techniques*
Recap: What does your code coverage tell you?

- **Edge coverage:**
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  “Hybrid” Fuzzing
Questions?
Hybrid Fuzzing
What is hybrid fuzzing?

- **Combining random fuzzing with smarter fuzzing**
  - E.g., random + concolic execution (Driller, QSYM, Savior)
  - E.g., random + taint tracking (VUzzer, RedQueen, Angora)

- **Goal is to balance strengths of both techniques**
  - Use generic fuzzing for **most test cases**
    - Use **speed** to brute-force easy branches
  - Deploy more elegant approach **selectively**
    - Focus its **precision** on harder branches
Recap: Coverage-guided Fuzzing

Input Generation

Random

Execute and Collect Feedback
(e.g., code coverage)

Interesting!
(new code)

Crashes
(SEGFAULT)

Uninteresting
(no new code)
Recap: Coverage-guided Fuzzing

Input Generation
- Random
- Alternative

Execute and Collect Feedback
(e.g., code coverage)

Interesting!
- (new code)

Uninteresting
- (SEGFAULT)
- (no new code)

Crashes
- (SEGFAULT)
Recap: Coverage-guided Fuzzing

Input Generation

Random (~N inputs)

Alternative (<< N inputs)

Execute and Collect Feedback
(e.g., code coverage)

Interesting!
(new code)

Crashes
(SEGFAULT)

Uninteresting
(no new code)
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL)

Local queue
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL)

Alternative (e.g., symex)
Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL)

- Local queue

Alternative (e.g., symex)

- Local queue

- Sync!
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL):

- Local queue

Alternative (e.g., symex):

- Local queue

Solve!
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL)  

Alternative (e.g., symex)
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL) | Alternative (e.g., symex)
---|---
![Local queue](image1.png) | ![Local queue](image2.png)
Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

- **Random** (e.g., AFL)
- **Alternative** (e.g., symex)
How most hybrid fuzzers work...

- Leverage AFL-style **parallel fuzzing** mode with random fuzzer as parent

Random (e.g., AFL)  

Alternative (e.g., symex)
How most hybrid fuzzers work...

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Random (e.g., AFL)

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Alternative (e.g., symex)

- Local queue

New code coverage?
How most hybrid fuzzers work...

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Random (e.g., AFL)

Alternative (e.g., symex)

New code coverage?
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Random (e.g., AFL)

- **Leverage AFL-style parallel fuzzing mode with random fuzzer as parent**

Alternative (e.g., symex)

Solve!
How most hybrid fuzzers work...

- Leverage AFL-style parallel fuzzing mode with random fuzzer as parent

Random (e.g., AFL)  Alternative (e.g., symex)

**Question:** What could go **wrong**?

short group discussion
What could go wrong?

- **Ineffective seed scheduling**
  - There are fundamental differences in **speed**
    - AFL can solve basic branch conditionals fast
    - Fancier approaches generally are much slower
  - Heavyweight approaches are best applied to a **subset** of paths
    - Invoking on all paths will lead to **path explosion**
    - E.g., by the time it’s solved, fuzzer is already way past
What could go wrong?

- Ineffective seed scheduling
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What could go wrong?

- Ineffective seed scheduling
Solution: Prioritization

- **Idea:** invoke heavier-weight generation only **strategically**
  - **Demand launch** (e.g., Driller): when fuzzer gets “stuck”
    - Perform concolic exec when progress stalls
    - Not stuck? Continue random fuzzing
  - **Cost-based launch** (e.g., DigFuzz): on “costly” paths
    - Prioritize solving rare or unseen branches
    - Infer via lightweight program analysis
Trade-offs

- **Demand launch:** need an accurate way to determine stalling
  - **Time-based:** no new coverage in some time interval
  - **Coverage-based:** rate of change drops below some threshold
  - These heuristics are fundamentally ad-hoc

- **Cost-based launch:** subject to imprecision
  - Observed coverage provides an incomplete picture
    - Rare branches may guard ultimately **fruitless paths**
  - More precise approach is analyzing the entire program
    - Really difficult for large or **closed-source** programs
What (else) could go wrong?

- Discrepancies in program structure
  - Missing branches or paths
    - E.g., from Instrumentation differences
    - Obstructs from **incomplete information**
    - Not a very common problem
  - Disagreeing coverage metrics
    - E.g., basic blocks versus edges
    - Will affect test case **syncing** phase
    - Many test cases won’t be seen as novel
What could go wrong?

- Discrepancies in program structure
Questions?