What You Corrupt Is Not What You Crash: Challenges in Fuzzing Embedded Devices

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- Embedded devices are becoming increasingly more important
- Vulnerabilities go beyond misconfigurations, weak authentication, hard-coded keys, etc.
- Fuzz testing is a popular and effective method for uncovering *programming errors*
 - A variety of work improves input generation and fault detection for fuzzing

How efficient are we at fuzzing embedded devices? Can we do it better?

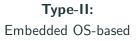
Fuzzing, Corruptions & Crashes

$\mathsf{Corruption} \neq \mathsf{Crash}$

Embedded Devices: A minimalistic classification

Type-I: General purpose OS-based







Type-III: No OS-Abstraction



- Lack of basic features, such as:
 - Memory Management Unit (MMU)
 - Heap consistency checks
 - Canaries
- Often only solution: Basic liveness checks

- Fuzzing greatly benefits from parallelization
 - This would mean 1 device per instance
- Frequent restarts are required
 - Fast for software, slow for full systems

- Hard to retrieve coverage information
- Tools for turning *silent* corruptions into observable ones rarely available
 - Unsupported instruction set architecturess
 - Operation tied to OS-specific features

- Five common types of memory corruptions
- Insertion of artificial bugs in two popular open source programs
 - Expat
 - mbedTLS
- Trigger condition inspired by LAVA [1]
- Vulnerable programs are compiled for four different devices

^[1] Dolan-Gavitt, Brendan, et al. "Lava: Large-scale automated vulnerability addition." IEEE Symposium on Security and Privacy (SP), 2016.

Effects of Corruptions accross different systems

	Platform			
	Desktop	Type-I	Type-II	Type-III
Format String	1	1	×	×
Stack-based buffer overflow	 ✓ 	1	✓ (opaque)	! (hang)
Heap-based buffer overflow	1	<mark>!</mark> (late crash)	×	×
Double Free	1	1	×	X (malfunc.)
Null Pointer Dereference	1	1	✓ (reboot)	X (malfunc.)

- Static Instrumentation
- Binary Rewriting
- Pysical Re-Hosting
- Full Emulation
- Partial Emulation
- Hardware-Supported Instrumentation

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Leveraging (partial) emulation to improve fuzz testing

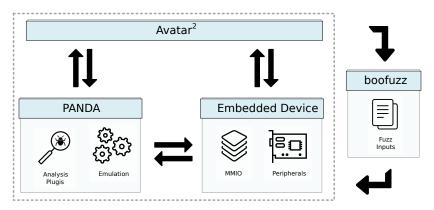
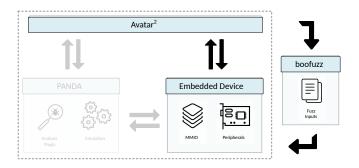


Figure 1: Setup for fuzzing utilizing partial emulation

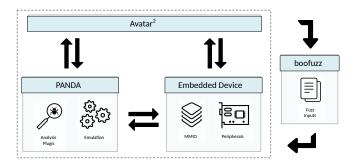
Code will be available at: https://github.com/avatartwo/ndss18_wycinwyc

- The vulnerable expat program, as seen in the last part
- Focus on a Type-III device
- Fuzzed in four different configurations

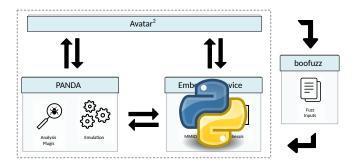


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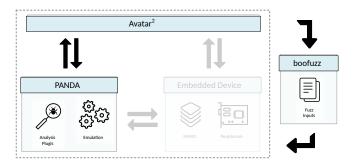
- 2. Partial Emulation with Memory Forwarding (PE/MF)
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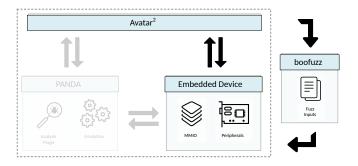


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- boofuzz [2], a python-based fuzzer based on Sulley
- Configured to trigger the corruptions with different ratios
- Used for 100 fuzzing sessions over one hour each



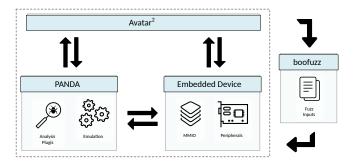
Set-up: Corruption Detection



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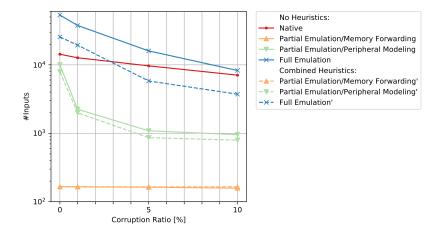
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- 6 simple heuristics, monitoring the execution:
 - 1. Segment Tracking
 - 2. Format Specifier Tracking
 - 3. Heap Object Tracking
 - 4. Call Stack Tracking
 - 5. Call Frame Tracking
 - 6. Stack Object Tracking

Measuring Fuzzing Throughput



Discussion, Future Work & Conclusion

- Liveness checks only is a poor strategy
- Full emulation is good but rarely possible
- Partial emulation can already help
 - But introduces significant performance overhead

- We focused on improving fault detection
 - Other challenges of fuzzing (e.g., input generation) not addressed in this work
- Our experiments focused on artificial vulnerabilities
 - Good for improving our initial understanding
- We investigated solutions based on partial emulation
 - Other approaches still open for research

- Fuzzing embedded devices requires a paradigm shift
- (Partial) emulation can improve fault detection
 - We need good emulators
- Fuzzing of embedded devices needs more investigation