ARCHIE: A QEMU-Based Framework for Architecture-Independent Evaluation of Faults

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Outline

Just Another Fault Tool ...?

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Experimental Verification

Summary

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Fault Analysis in Practice

Laser fault injection into embedded devices [1]

Task: Find "fault candidates", test binary

However:

- No source code available
- Binary varies depending on compiler settings

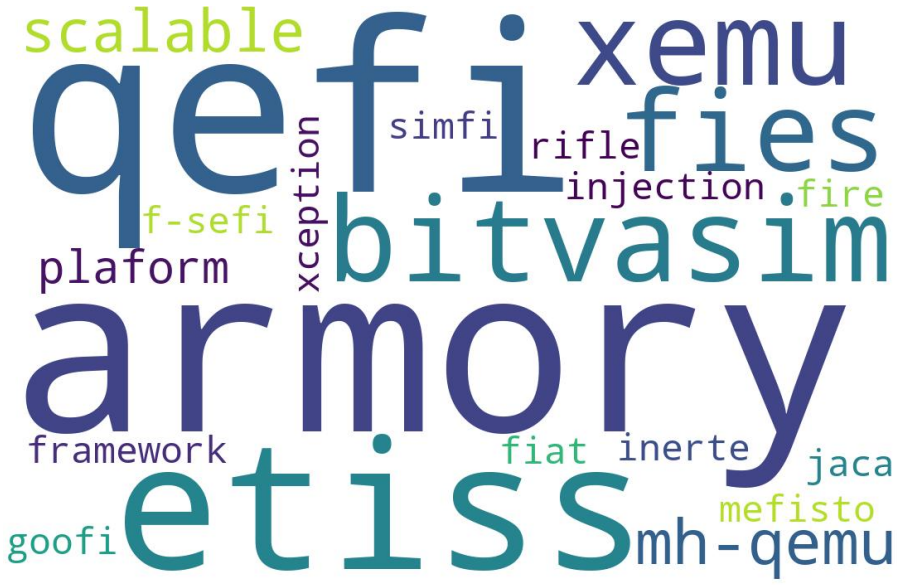
⇒ Manual examination of binary needed

Question: Is there an easier way to do this?

[1] K. Garb, J. Obermaier: Temporary Laser Fault Injection into Flash Memory. IEEE IOLTS 2020

Just Another Fault Tool ...?

The Zoo of Fault Simulation Tools



However:

- Architecture-dependent
- Only specific fault types and models
- Source code mostly non-available
- Old QEMU version

Just Another Fault Tool ...?

Requirements for a Fault Tool

- Support of different architectures
- Support of different fault types
  - Transient and permanent faults
  - Instruction and data faults
  - In registers, RAM, and flash memory
- Automated, parallelized execution
- Open source

$\Rightarrow$ ARCHitecture-Independent Evaluation (ARCHIE) of faults

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QEMU

- Generic and open source machine emulator and virtualizer
- Quick execution time
- Support of 22 different architectures, e.g.,
  - ARM
  - RISC-V
  - x86_64
- Easy to add new machines

⇒ Fulfills requirements

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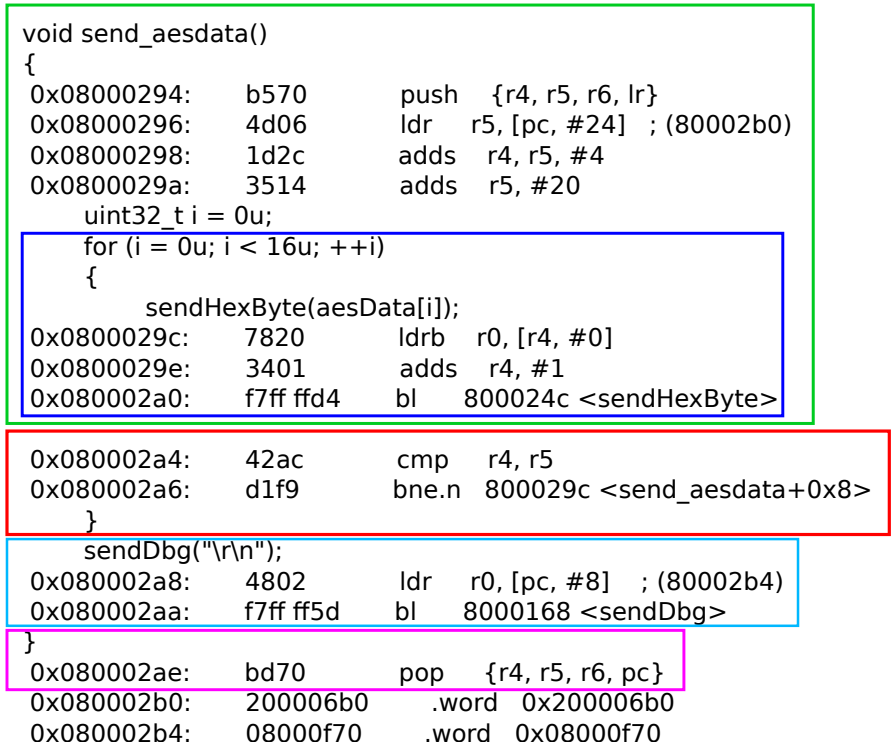
Tiny Code Generator (TCG)

- Execution of guest instructions
- Division of guest instructions into basic blocks
- Translation of basic block into host instructions



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TCG Plugin Interface

TCG plugin interface (since QEMU 4.2, November 2019)
⇒ API for monitoring TCG and read access to low-level guest instructions

Fault injection plugin:

- Minimal extension of TCG plugin interface
- Read and write to guest memory and registers
- Logging of guest behavior

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Experiment, Campaign, Golden Run

Fault
Low-level alteration of a physical state, e.g., one or multiple bit flips

Experiment
One or multiple faults

Campaign
Multiple experiments that follow a high-level goal of testing for failure

Golden Run
binary execution without faults

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Configuration

QEMU configuration: binary, machine

Fault configuration:

- address, type
- model, mask, lifespan
- trigger address and counter

Output:

- difference to golden run
- translation blocks
- memory access

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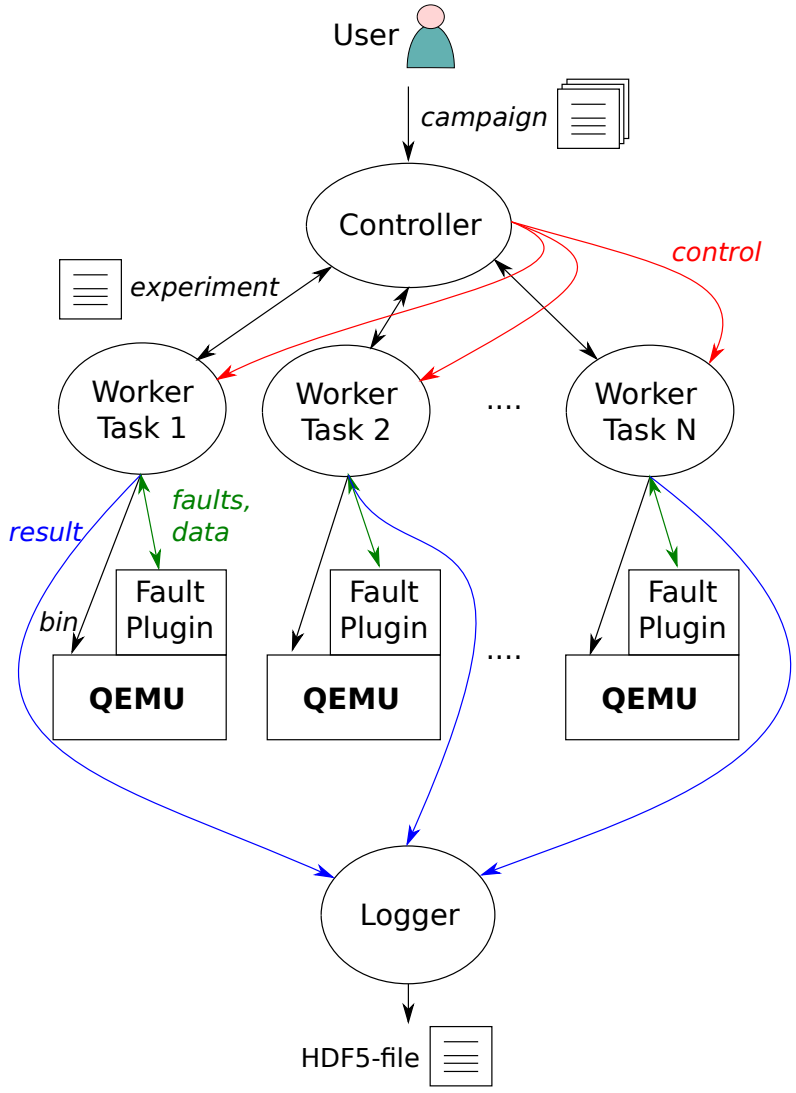
Overview of ARCHIE



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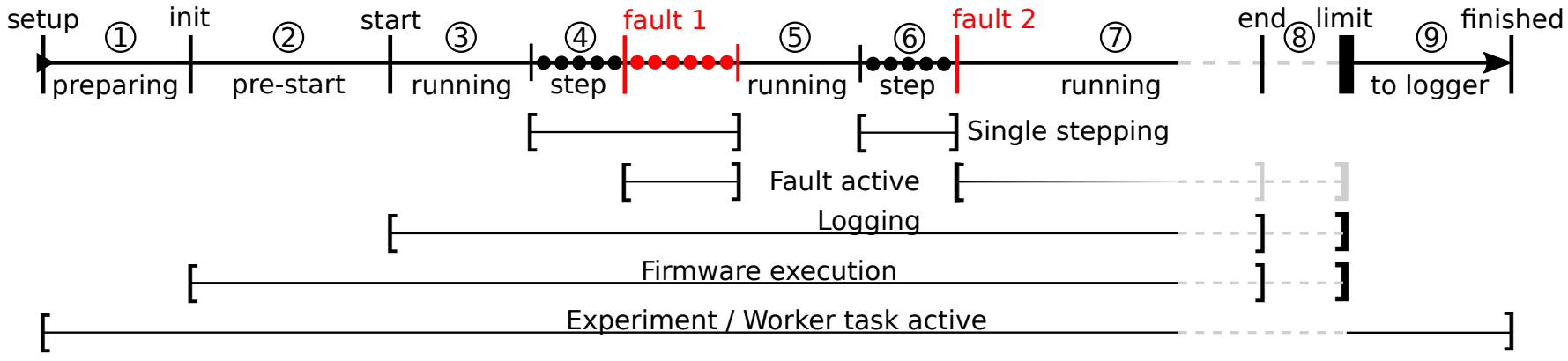
Execution of an Experiment



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Experimental Verification

Experimental Verification

Fault Injection into AES

Laser Fault Injection (LFI) experiment [2]

- target: ARM Cortex-M0 (STM32F0discovery)
- diagonal fault attack on AES S-Box [3]

  $\Rightarrow$ 5 unique faulty ciphertexts

Analysis with ARCHIE

- campaign: transient 1-bit data faults in flash memory ("set1")
- 588 faults leading to exploitable unique faulty ciphertexts

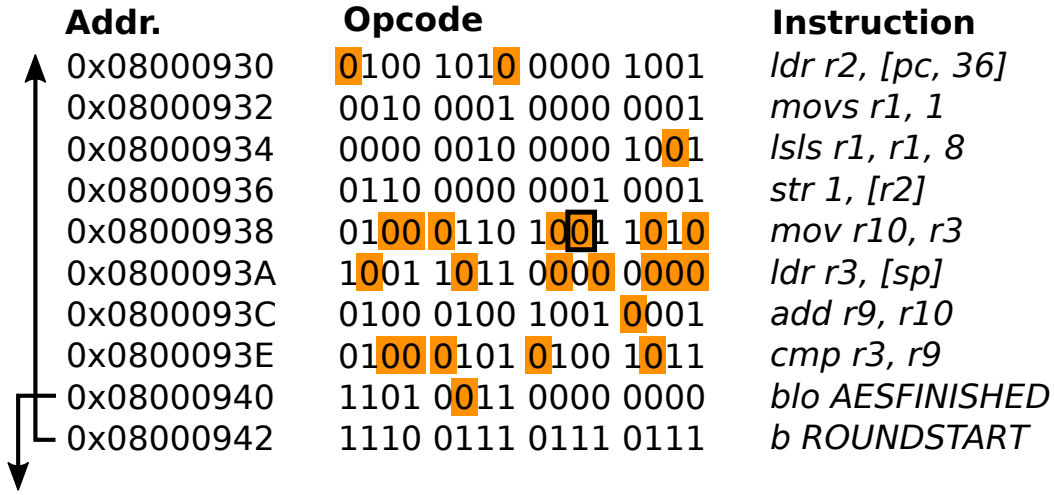
[2] K. Garb, J. Obermaier: Temporary Laser Fault Injection into Flash Memory. IEEE IOLTS 2020

[3] Saha et al., IACR Cryptology ePrint Archive, vol. 2009, p. 581, 2009.

Experimental Verification

Control Flow Manipulation of AES

- LFI attack to skip last round of AES [4] ⇒ 1 fault
- ARCHIE ⇒ 24 exploitable faults
- transient 1-bit instruction faults in flash memory (“set1”)



[4] K. Garb, J. Obermaier: Temporary Laser Fault Injection into Flash Memory. IEEE IOLTS 2020

Experimental Verification

Performance

Measurement was taken with 24,794 faults into TinyAES

Device	OS	CPU	RAM	Storage	Cores / Threads	Worker Tasks	Exec. time
Dell Poweredge Rack Server	Debian 11 via QEMU/KVM	AMD EPYC 7502	192 GB	SAS 7200rpm	32 / 64	64	**6 min 50 s**
Lenovo P52	Ubuntu 20.04	Intel Core i7-8750H	48 GB	SSD	6 / 12	12	**23 min 12 s**
Lenovo P15v	Debian 11 via VirtualBox on Windows 10	Intel Core i7-10750H	32 GB	SSD	6 / 12	12	**24 min 32 s**
Fujitsu Server TX140 S2	Debian 11 via QEMU/KVM	Intel Xeon E3-1230	28 GB	SSD	4 / 8	8	**33 min 12 s**
Supermicro Server	Ubuntu 20.04 via ESXI 6.7	Intel Xeon Silver 4108	16 GB	NAS (HDD)	8 / 8	8	**38 min 41 s**
Supermicro Server	Ubuntu 20.04 via ESXI 6.7	2 x Intel Xeon E5645	32 GB	SAN (HDD)	8 / 9	9	**42 min 21 s**
Cloud Server	Debian 10	Generic Intel Skylake	8 GB	SSD	3 / 3	3	**46 min 44 s**
Lenovo T470s	Debian 10	Intel Core i5-6200U	20 GB	SSD	2 / 4	4	**80 min 19 s**

Experimental Verification

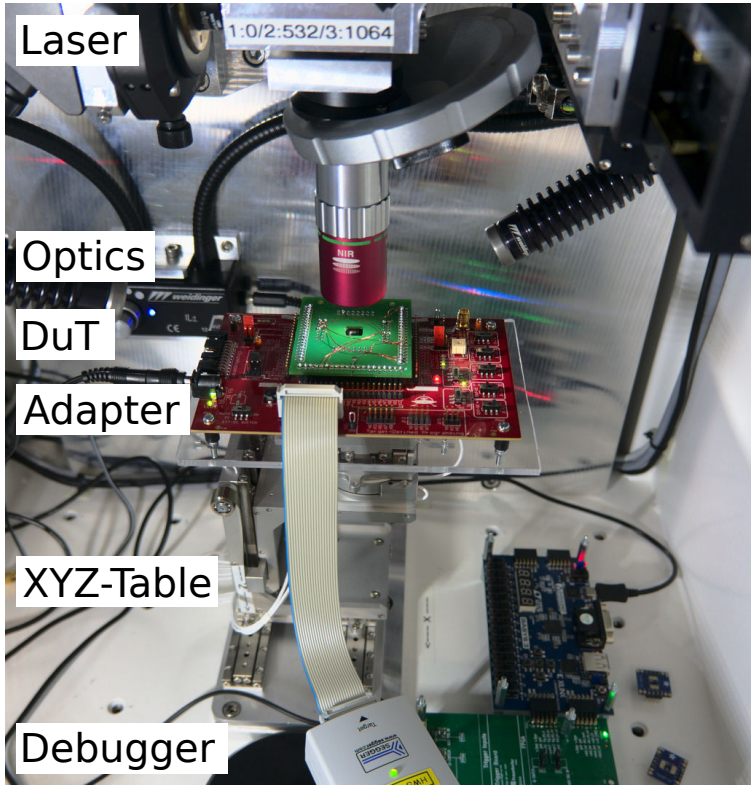
Secure Bootloader

Testing with ARCHIE

- secure bootloader implementation
- test for permanent 1-bit faults

Verification through LFI

- Infineon XMC1400 (ARM Cortex-M0)
- backside attack on SRAM



Experimental Verification

Firmware Testing on RISC-V

- RISC-V processor: 32-bit RV32IMC
- S-Box faulting:
  526 unique exploitable ciphertexts
- Control flow manipulation of AES
  only 2 possible 1-bit faults (instead of 24 for ARM)
- Secure bootloader: identical vulnerability

Summary

Summary

- ARCHIE supports all guest architectures of QEMU

  $\Rightarrow$ Verification for ARM and RISC-V architectures
- Binary testing (AES, bootloader)

  $\Rightarrow$ Large amount of different fault types

  $\Rightarrow$ Identification of new fault candidates
- ARCHIE is available on GitHub:
  `https://github.com/Fraunhofer-AISEC/archie`

Future work

- Further runtime improvements
- Add support for multiprocessor guests

Contact Information

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