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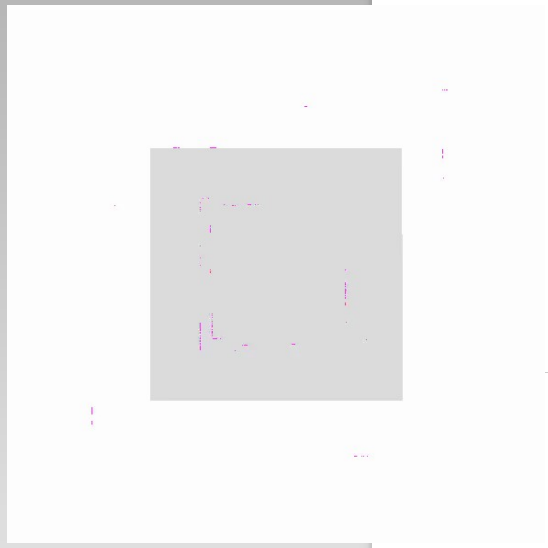
Improving Linux-Kernel Tests for LockDoc with Feedback-driven Fuzzing



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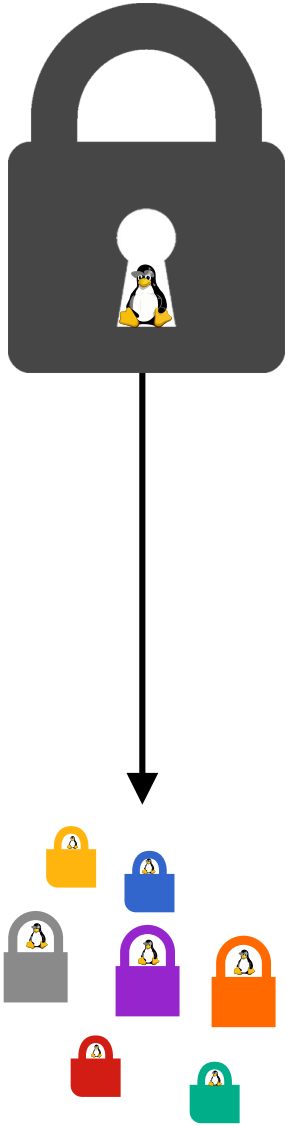
Locking the Linux Kernel



- Shift from **Big Kernel Lock** to a **fine-grained locking scheme** [1]
  - **Reduce** lock **contention**
  - **Better scaling** on multi-core platforms
  - Needs **good documentation** for developers
- Locking Documentation …
  - is usually scattered throughout the source code
  - does not use a well-defined syntax
  - is ambiguous or even conflicting

→ Inefficiencies, deadlocks, crashes, silent data corruptions

What is LockDoc?

- Tracks **locking pattern** and **data-structure** accesses
- Validates/generates documentation, and locates locking bugs
- **Recording** performed under a **load**
  - Relies on how system is put under load
  - **Wants** to reach even **remote parts** of the code

- LockDoc study [2]
  - Focuses on *Virtual File System* (VFS) subsystem
  - Uses filesystem-specific subset of *Linux Test Project* (LTP)

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→ How much source code is covered?

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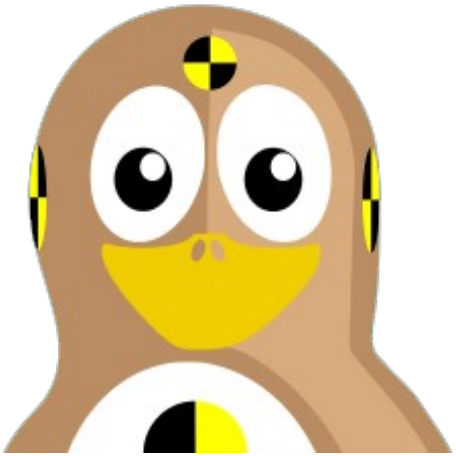
What is the L(inux) T(est) P(roject)?

- LTP “validate(s) the reliability, robustness, and stability of Linux” [3]
- **Framework** for Linux **Kernel Tests** via the **System Call Interface**
- Collection of **manually crafted regression tests** for various subsystems, e.g., IPC, VFS, scheduling, ...
- Individual tests are composed to test suites, e.g., *syscalls*



Code Coverage by LTP – A Breakdown

- Run test suites related to VFS
- Measure basic block coverage
- Linux 4.10
  - Total BBs: 342,732
  - VFS BBs: 75,531
- Only **~35%** of kernel's basic blocks are executed by **all VFS-related testsuites** of LTP

Test Suite	#Tests	Covered VFS BBs	(%)
dio	30	8312	11.0%
fcntl-locktests	1	2420	3.2%
filecaps	1	2518	3.3%
fs	65	17495	23.2%
fs_ext4	4	13081	17.3%
fs_perms_simple	18	5081	6.7%
fsx	1	6572	8.7%
io	2	6817	9.0%
syscalls	1181	24217	32.1%
Total	1302	26229	34.7%

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→ How can we cover more code?

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What is syzkaller?

- Coverage-guided kernel fuzzer [4]
- Wants to **trigger kernel bugs**
- Fuzzes Linux kernel by **randomly generating user programs**:

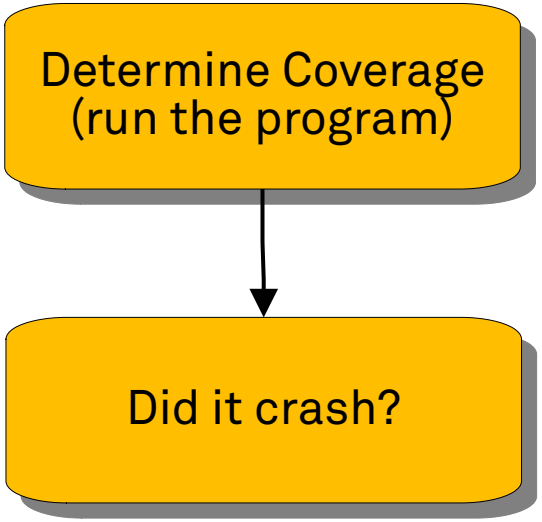
```
int main(void)
{
  syscall(__NR_mmap, 0x1ffff000, 0x1000, 0, 0x32, -1, 0);
  syscall(__NR_mmap, 0x20000000, 0x1000000, 7, 0x32, -1, 0);
  syscall(__NR_mmap, 0x21000000, 0x1000, 0, 0x32, -1, 0);

  *(uint32_t*)0x20002480 = 0x20000340;
  memcpy((void*)0x20000340, "\x12", 1);
  *(uint32_t*)0x20002484 = 1;
  *(uint32_t*)0x20002488 = 0;
  syz_read_part_table(0, 1, 0x20002480);
  return 0;
}
```

How does syzkaller work?

Determine Coverage
(run the program)

How does syzkaller work?



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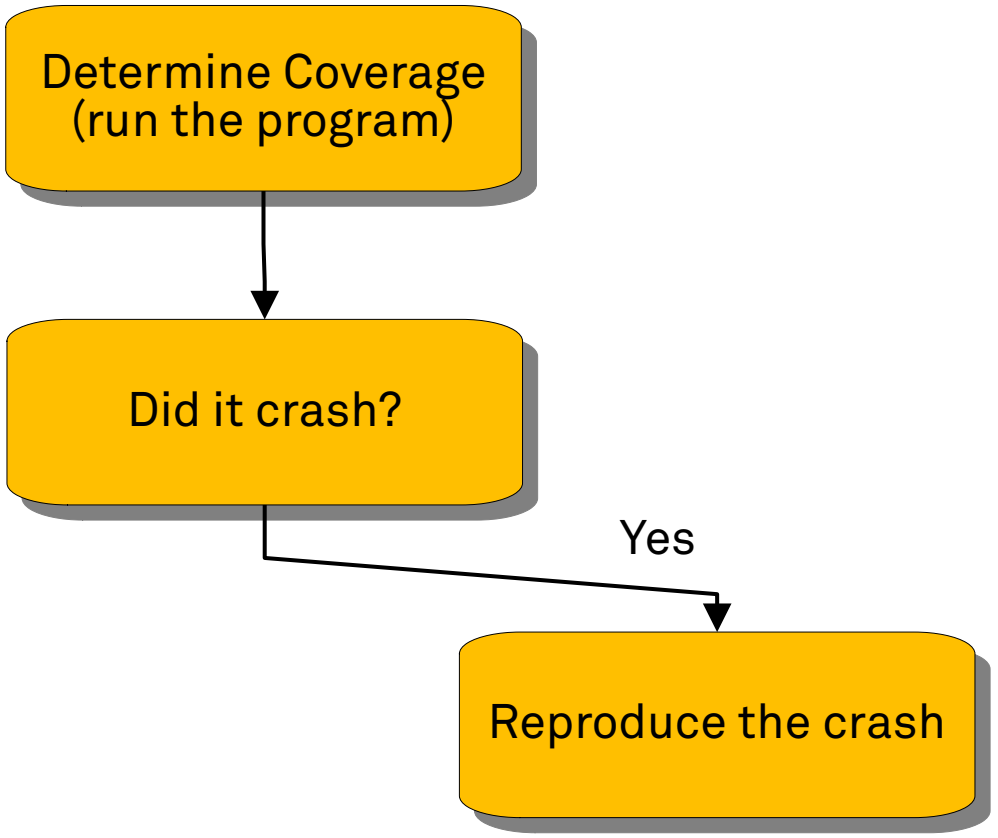

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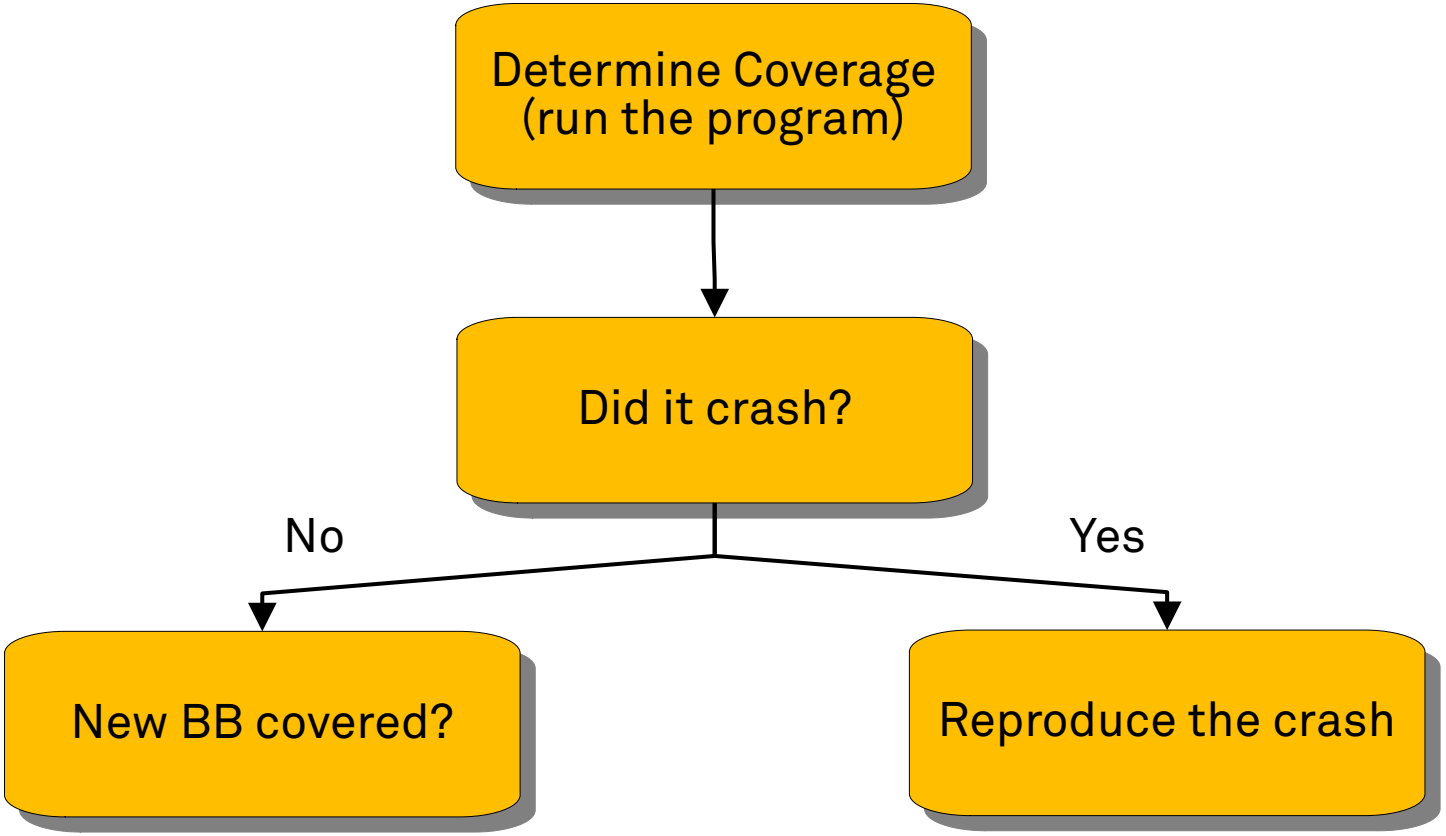

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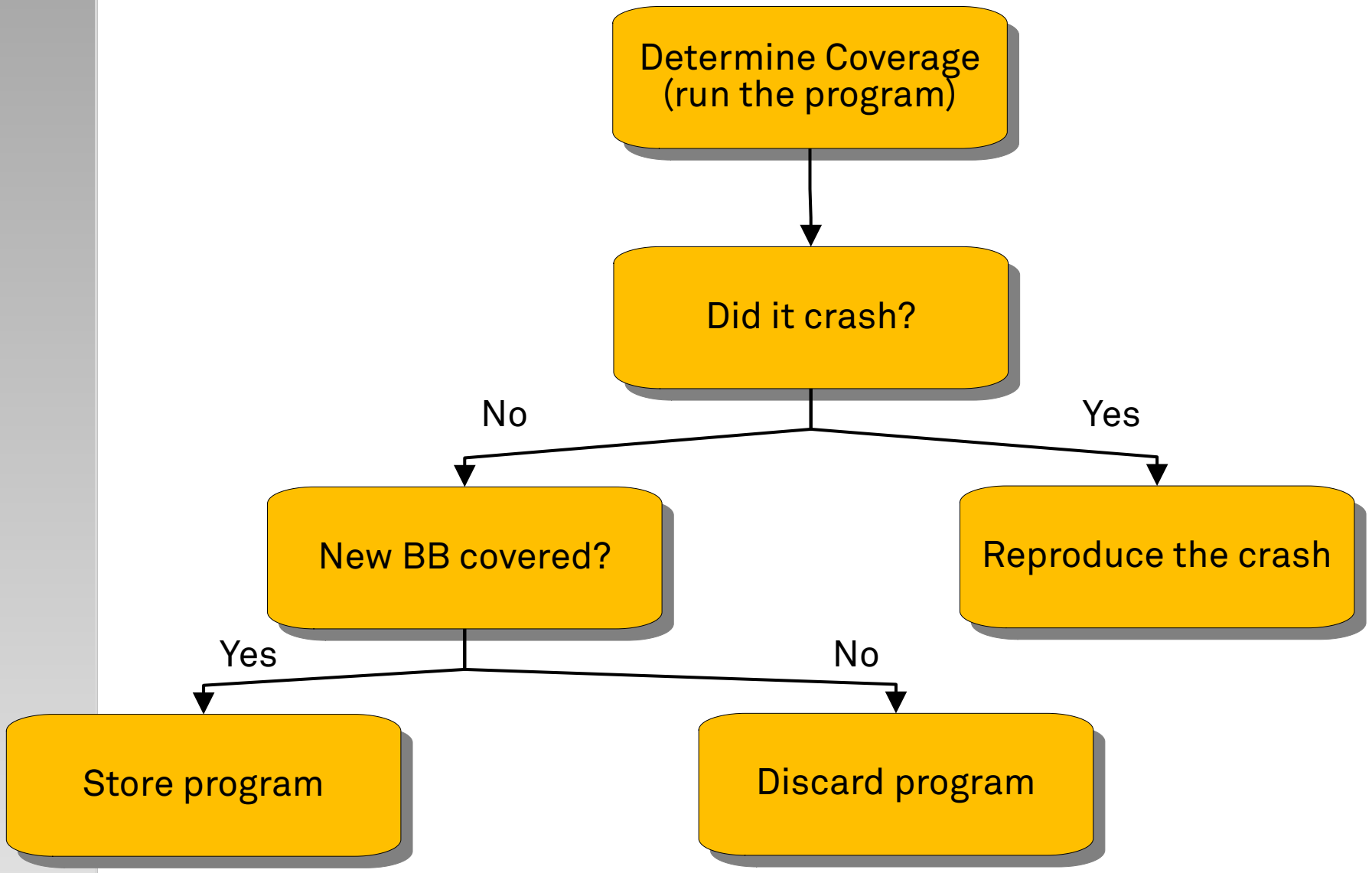

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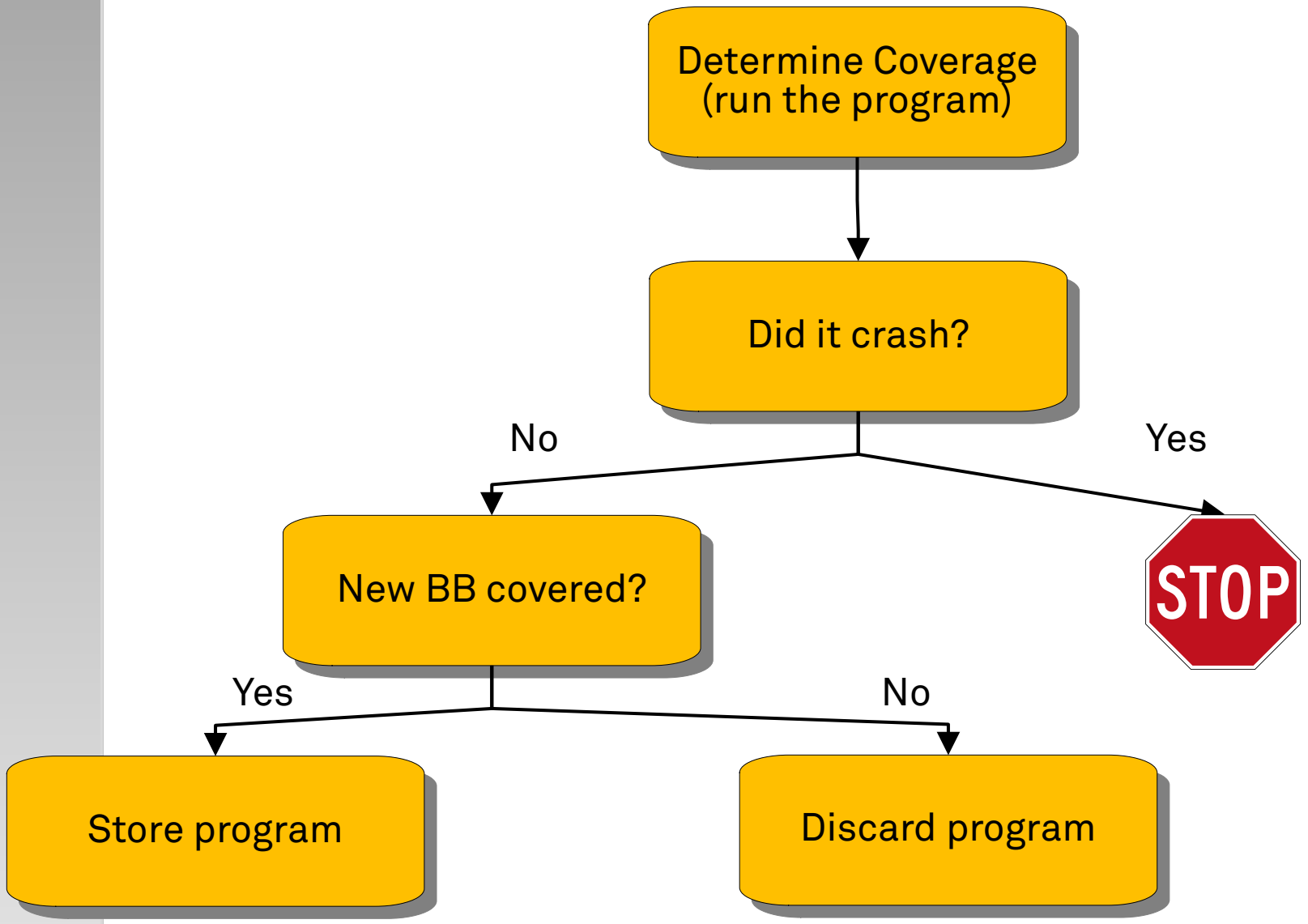

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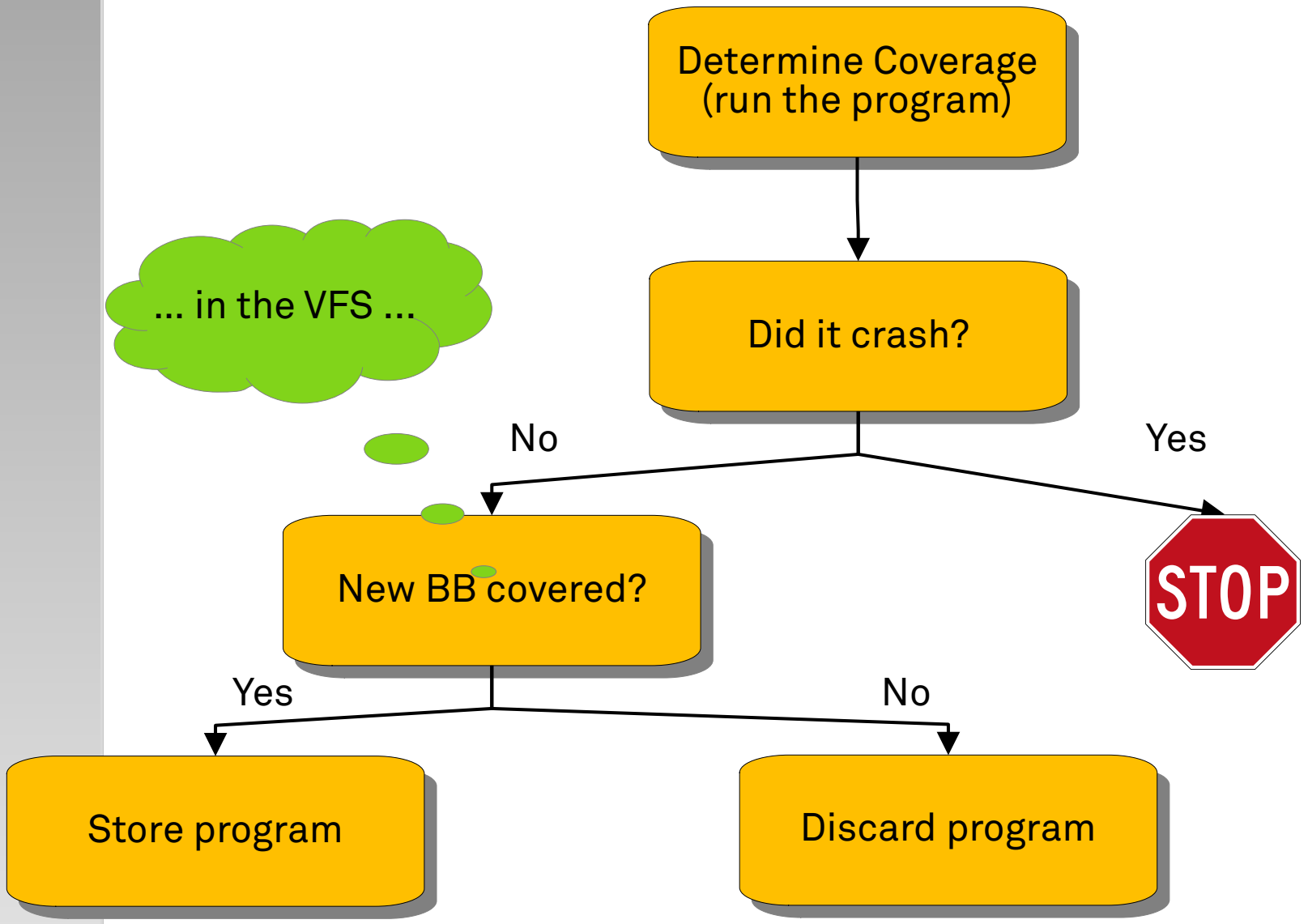
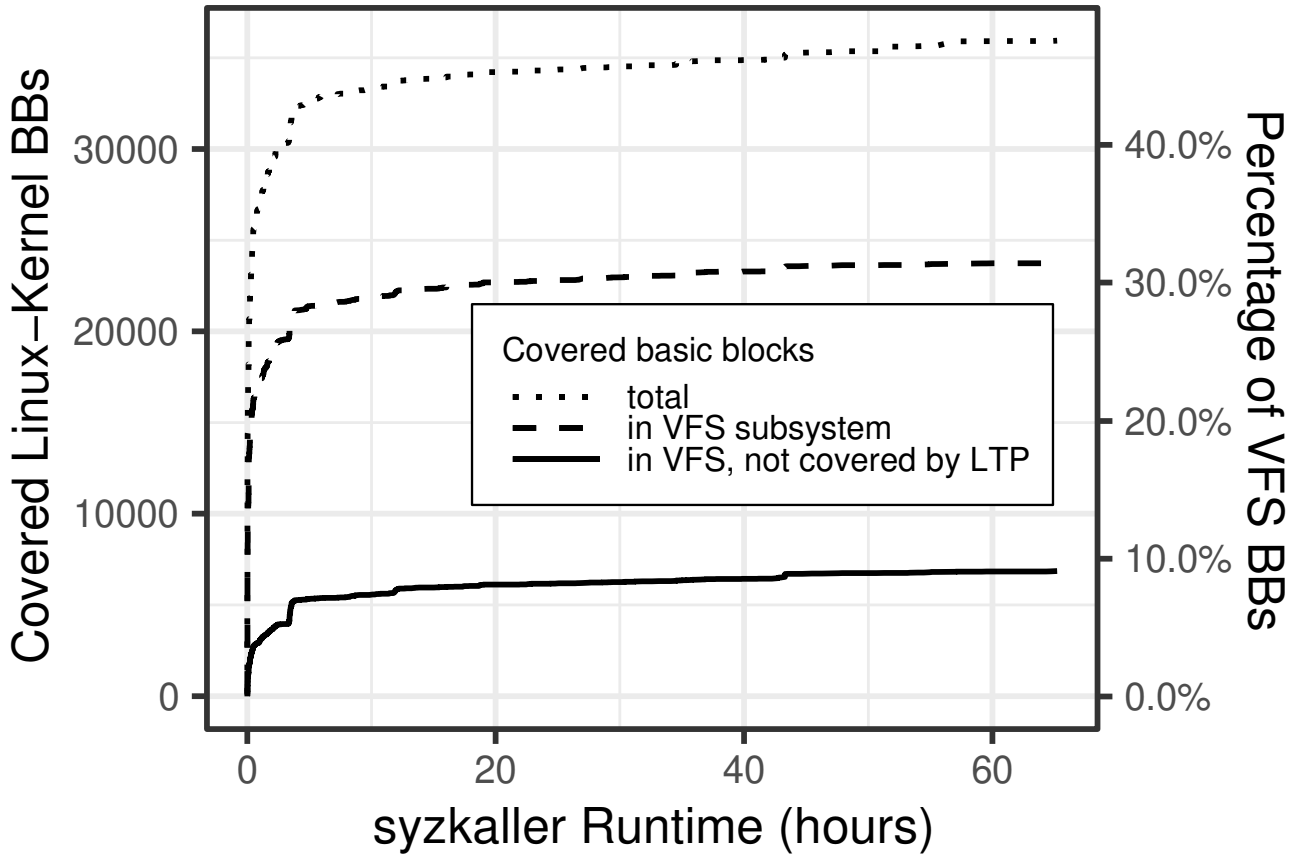


Evaluation Setup

- Linux Kernel 4.10 x86 64-bit
  - Without module support
  - Minimal configuration: Network support, essential drivers for root fs and for a paravirtualized environment
- Record executed basic blocks via Vyukov's KCOV [5]
- Use of LD_PRELOAD to collect covered BBs for a process hierarchy
- Convert BB to source code via *addr2line*
- Filtering using regex: */fs/|/mm/|fs\.h|mm\.h*

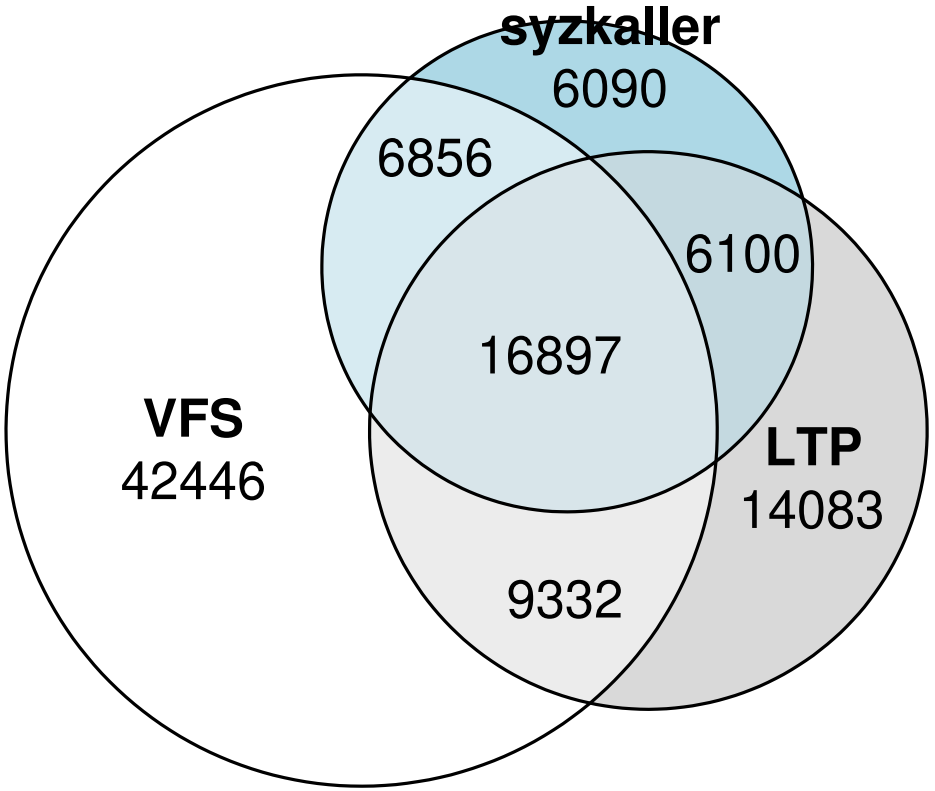
syzkaller Activity

Results (1)



- 65-hour run: syzkaller generated 2278 programs
- BB coverage: 10% of whole kernel, 31.4% of VFS
- 9.1% of VFS BBs covered that are not covered by LTP

Results (2)



- Relation between BBs: VFS vs. syzkaller vs. LTP
- Absolute numbers of basic blocks shared among intersecting sets

Summary

- Basic-block coverage of VFS by LTP is limited
- Used modified syzkaller to reach more VFS-related code
- Increased basic-block coverage by 9.1 % to 43.8%
- More observations (mem. accesses/lock ops.) for LockDoc to analyze → Increased quality
- Outlook
  - Use *Moonshine* [6] approach to improve code coverage
  - Generate full-fledged regression tests, sent them back to LTP?

References

[1] Robert Love. 2010. *Linux Kernel Development (3rd ed.)*.

[2]Alexander Lochmann, Horst Schirmeier, Hendrik Borghorst, and Olaf Spinczyk. 2019. *LockDoc: Trace-Based Analysis of Locking in the Linux Kernel*. EuroSys‘19.

[3] https://github.com/linux-test-project/ltp

[4] https://github.com/google/syzkaller

[5]https://www.kernel.org/doc/html/latest/dev-tools/kcov.html

[6]Shankara Pailoor, Andrew Aday, and Suman Jana. 2018. *MoonShine: Optimizing OS Fuzzer Seed Selection with Trace Distillation*. USENIX Security Symposium 2018.