HFL: Hybrid Fuzzing on the Linux Kernel

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Software Security Analysis

- Random fuzzing
  - **Pros**: Fast path exploration
  - **Cons**: Strong branch conditions e.g., *if(i == 0xdeadbeef)*
- Symbolic/concolic execution
  - **Pros**: Generate concrete input for strong branch conditions
  - **Cons**: State explosion

Hybrid Fuzzing in General

- Combining ***traditional fuzzing*** and ***concolic execution***
  - *Fast exploration* with fuzzing (*no state explosion*)
  - *Strong branches are handled* with concolic execution

- State-of-the-arts
  - Intriguer [CCS'19], DigFuzz [NDSS'19], QSYM [Sec'18], etc.
  - Application-level hybrid fuzzers

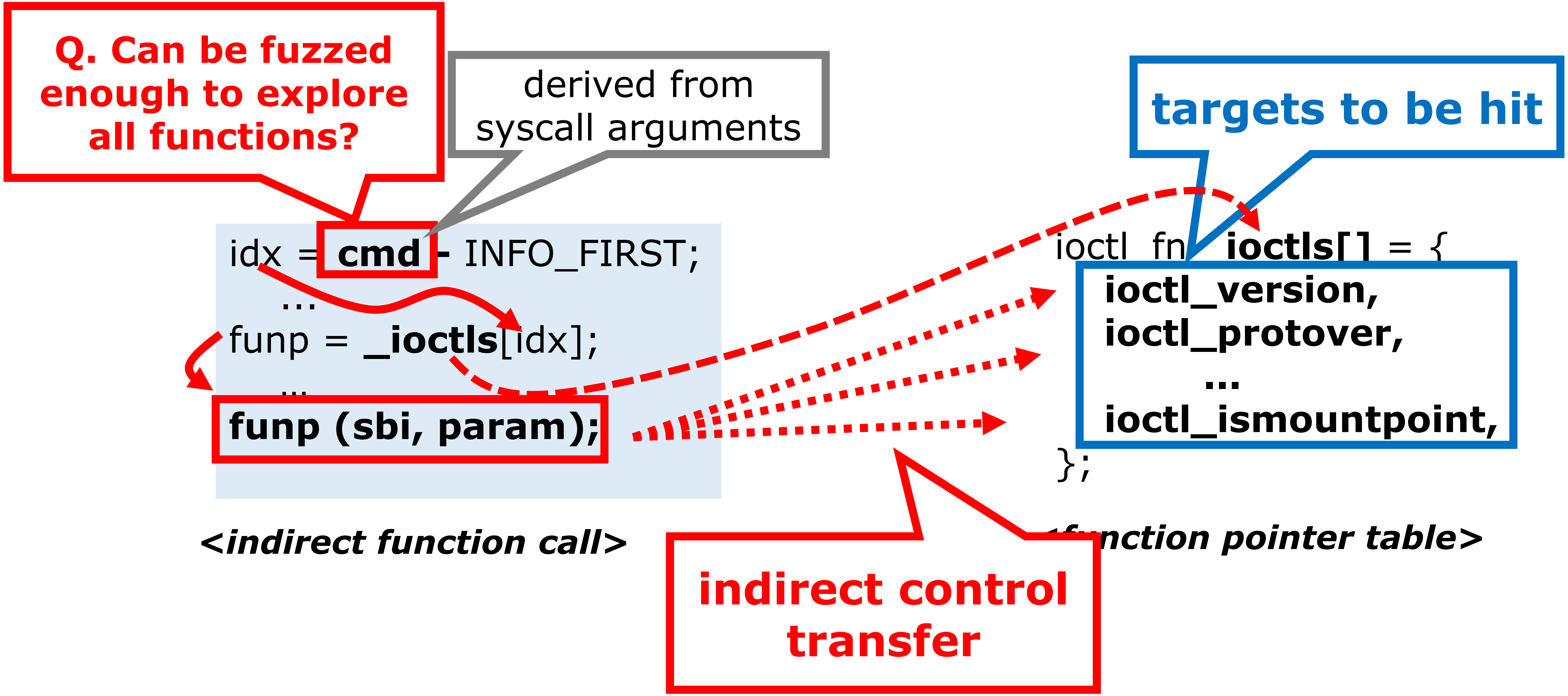
Kernel Testing with Hybrid Fuzzing

- Software vulnerabilities are critical threats to OS

Q. Is hybrid-fuzzing good enough for kernel testing?

- Hybrid-fuzzing can help improve coverage and find more bugs in kernels.
  - A huge number of specific branches e.g., CAB-Fuzz[ATC'17], DIFUZE[CCS'17]

Challenge 1: Indirect Control Transfer



Challenge 2: System Call Dependencies

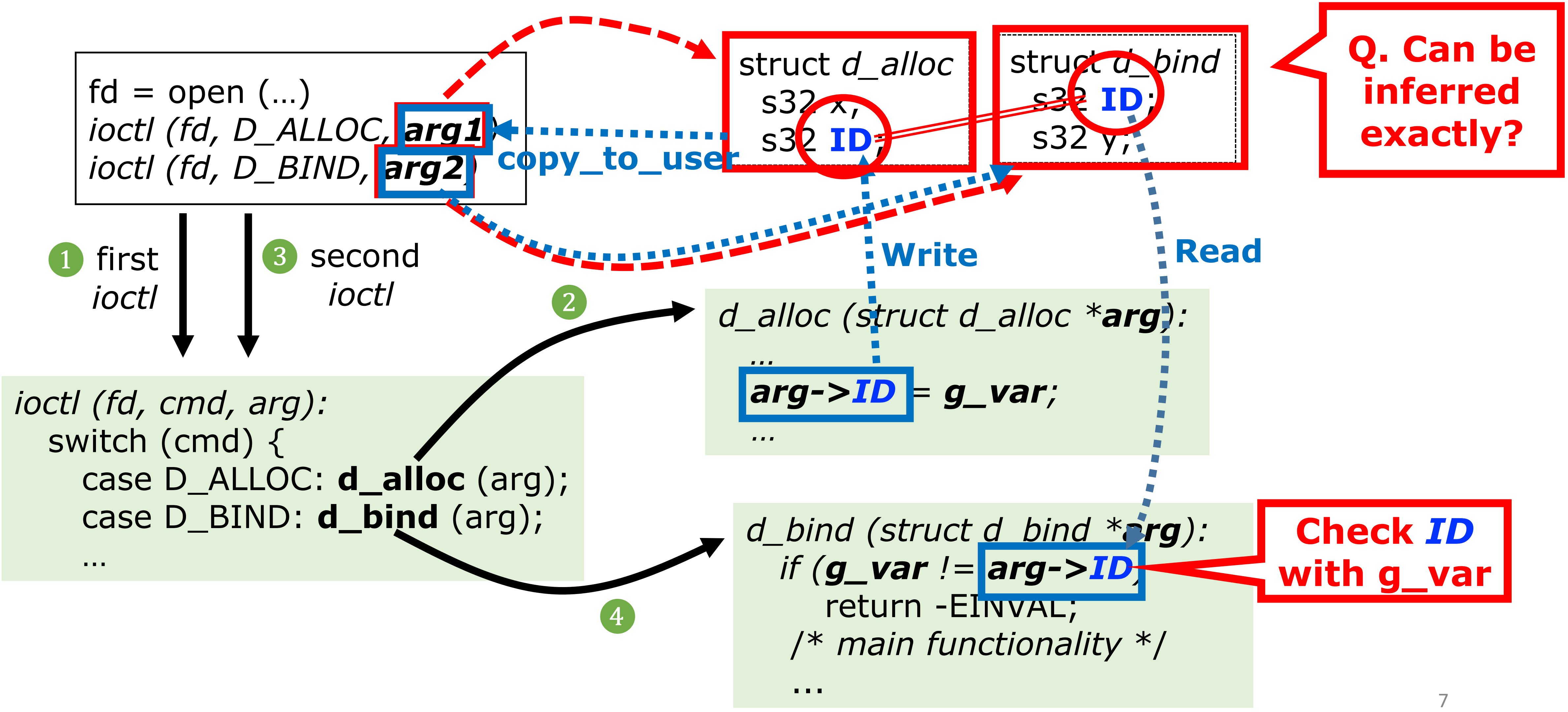
explicit syscall dependencies

*__int__ **open** (const char *pathname, int flags, mode_t mode)*
*ssize_t **write** (__int fd__, void *buf, size_t count)*

***ioctl** (int fd, unsigned long req, void *argp)*
***ioctl** (int fd, unsigned long req, void *argp)*

Q. What dependency behind?

Example: System Call Dependencies



Challenge 3: Complex Argument Structure

unknown type

ioctl (int fd, unsigned long cmd, ***void *argp****)*

write (int fd, ***void *buf****, size_t count)*

unknown type

Example: Nested Arguments Structure

ioctl (fd, USB_X, ***arg****)*

syscall

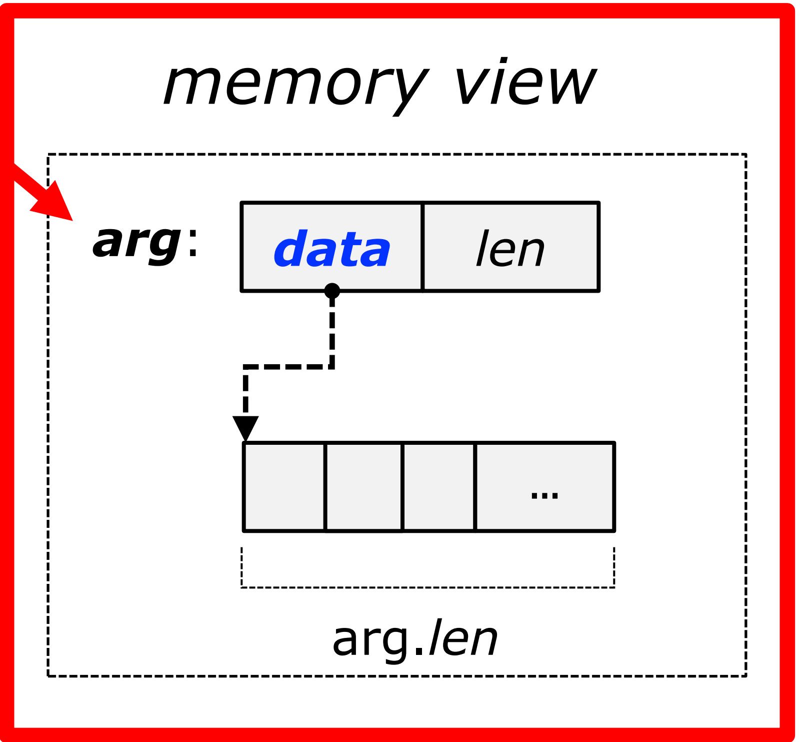
struct *usbdev_ctrl*:
    void ****data***;
    unsigned ***len***;

struct *usbdev_ctrl* ctrl;
uchar ****tbuf***;
    …
copy_from_user *(&ctrl,* ***arg****, sizeof(ctrl))*
    …
copy_from_user *(****tbuf****,* ***ctrl.data****,* ***ctrl.len****)*

/ do main functionality */*
    …

dst addr

src addr



Q. Can be inferred exactly?

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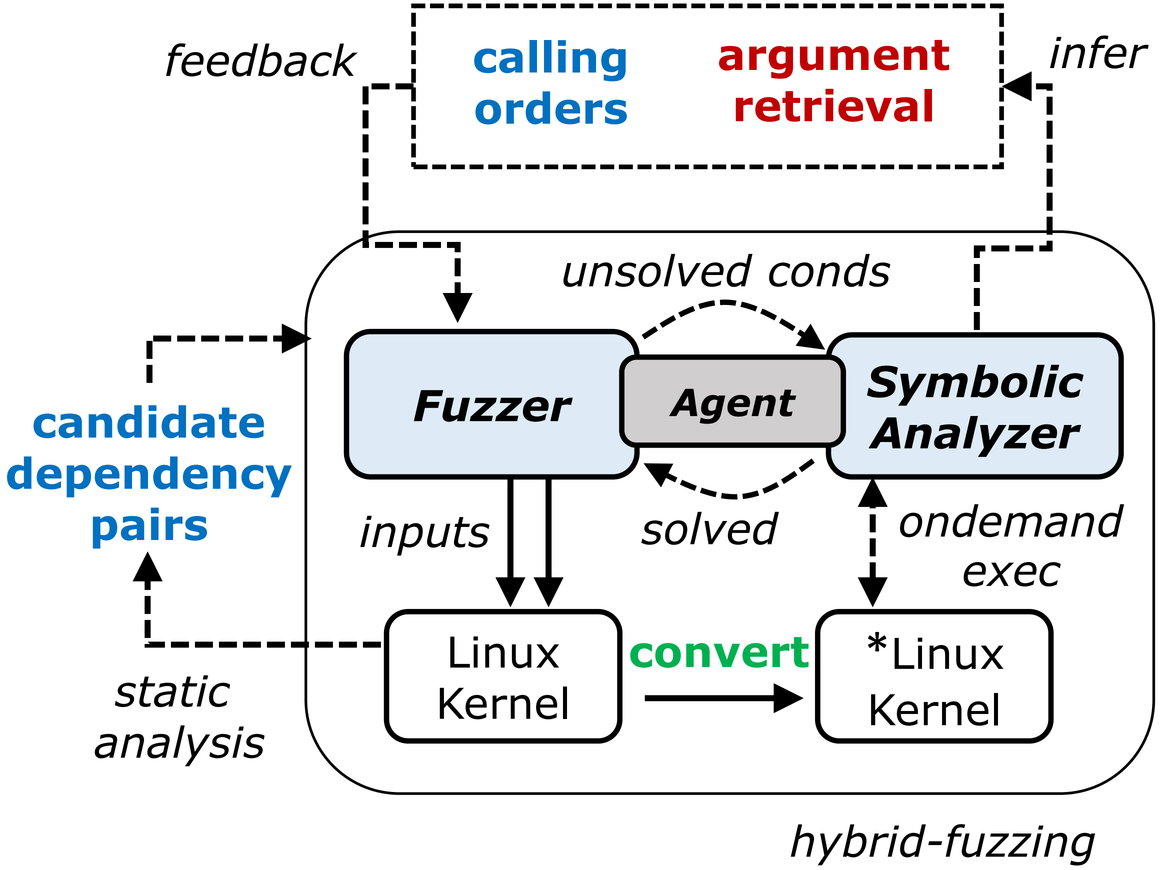


- The *first* hybrid kernel fuzzer
  - Handling the challenges

1. *Implicit control transfer*
   - ***Convert to direct control-flow***
2. *System call dependencies*
   - ***Infer system call dependency***
3. *Complex argument structure*
   - ***Infer nested argument structure***

- Coverage-guided/system call fuzzer
- Hybrid fuzzing
  - Combining fuzzer and symbolic analyzer
  - *Agent* act as a glue between the two components

1. Conversion to Direct Control-flow

<Before>

```
idx = cmd – INFO_FIRST;
    ...
funp = _ioctls[idx];
    ...
funp (sbi, param);
```

Compile time conversion:
***direct* control transfer**

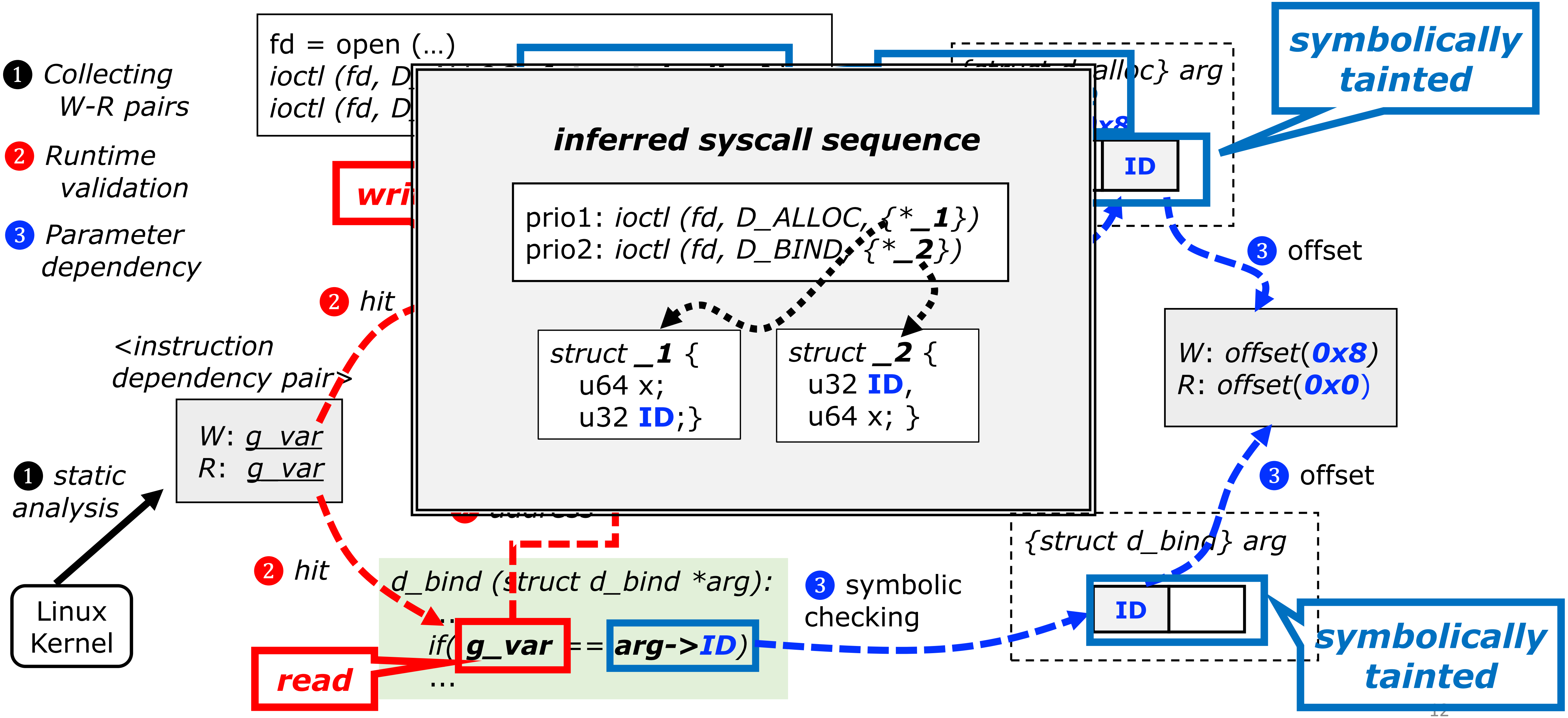
```
ioctl_fn _ioctls[] = {
    ioctl_version,
    ioctl_protover,
          ...
    ioctl_ismountpoint,
};
```

functions

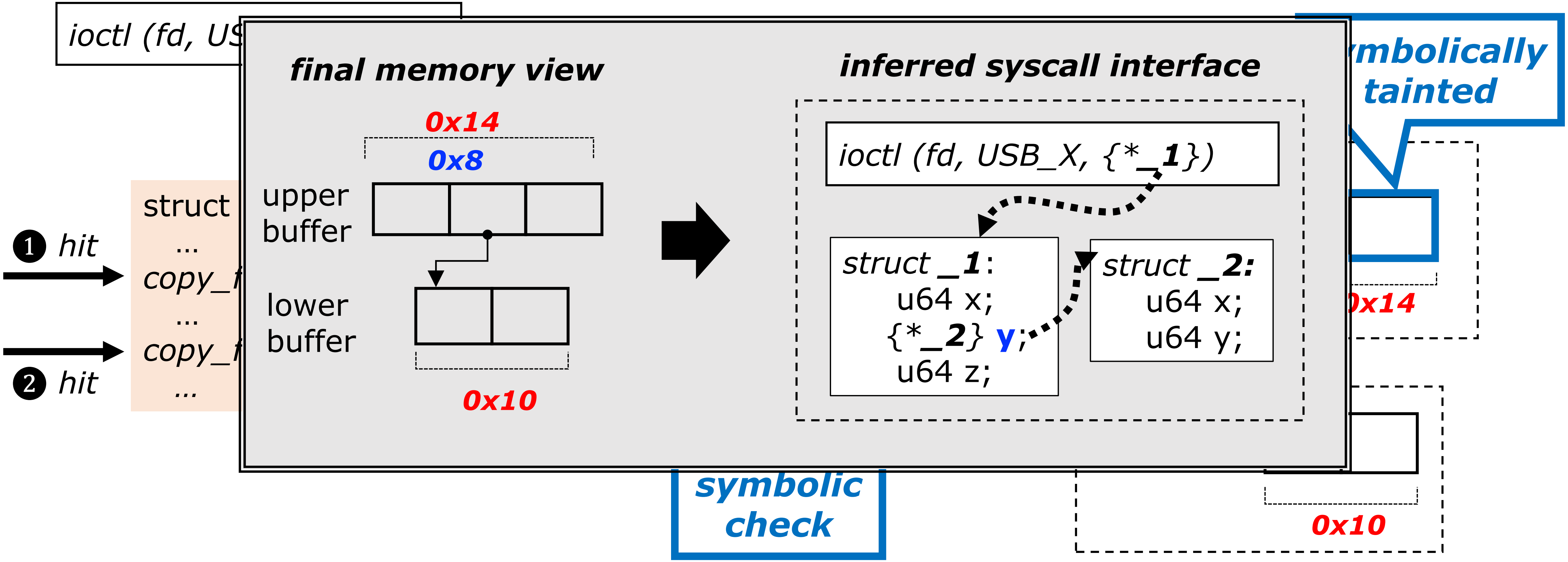
<After>

```
idx = cmd – INFO_FIRST;
    ...
funp = _ioctls[idx];
    ...
if (cmd == IOCTL_VERSION)
     ioctl_version (sbi, param);
else if (cmd == IOCTL_PROTO)
     ioctl_protover (sbi, param);
  ...
     ioctl_ismountpoint (sbi, param)
```

2. Syscall Dependency Inference



3. Nested Argument Format Retrieval



Implementation

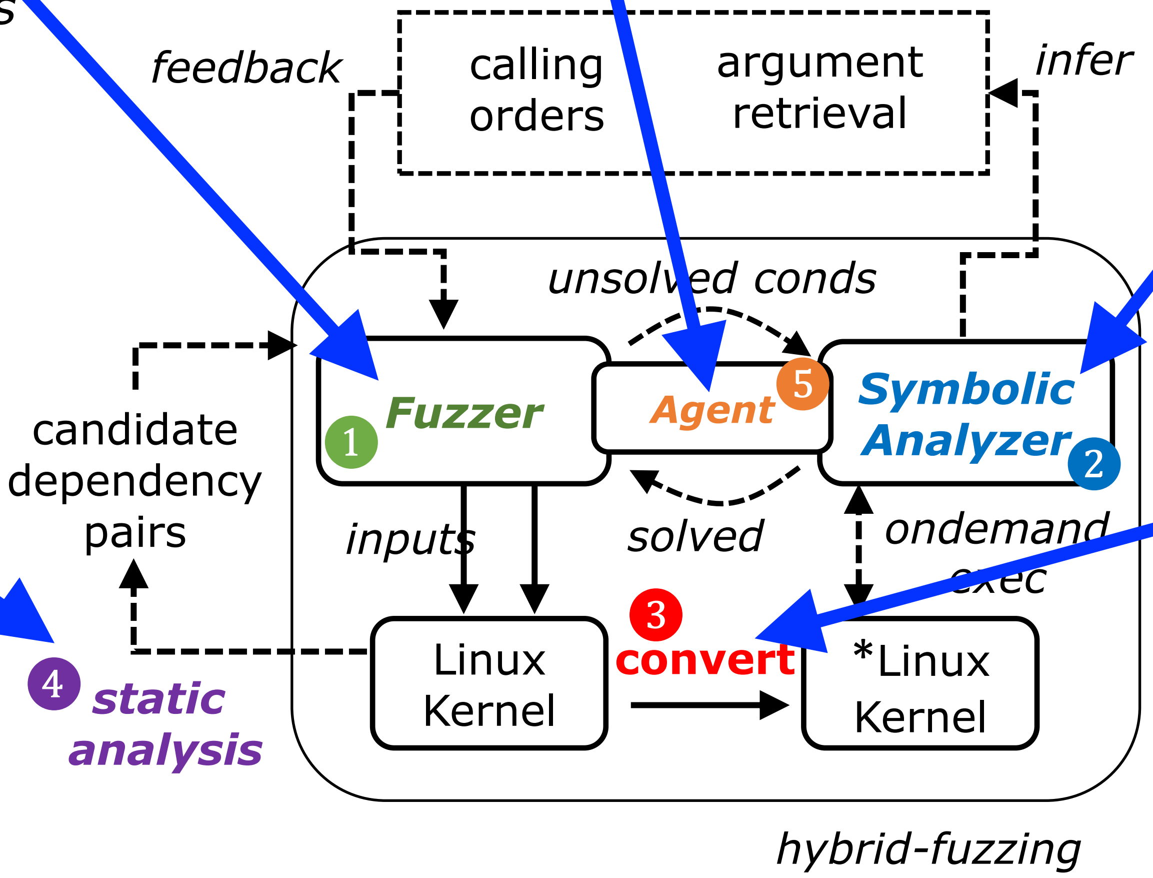
① ***Syzkaller***
- *send unsolved conds*
- *process solved conditions*

⑤ ***Python-based***
- *transfer data*

② ***S2E***
- *constraint solving*
- *symbolic checking*

④ ***SVF/ LLVMLINUX***
- *collect dependency set*

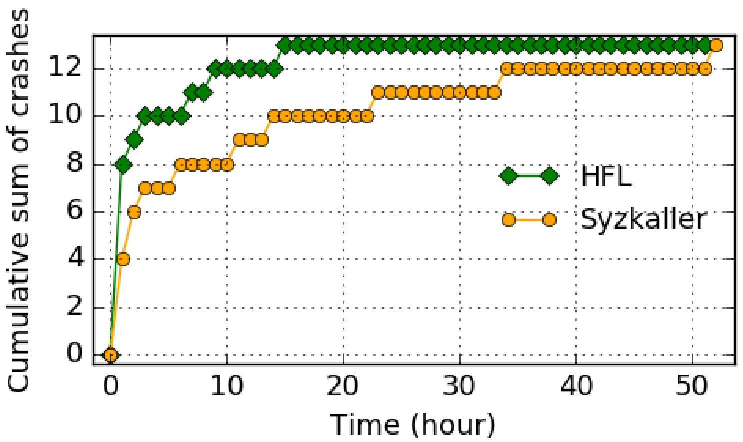
③ ***GCC***
- *convert to direct control-flow*



Vulnerability Discovery

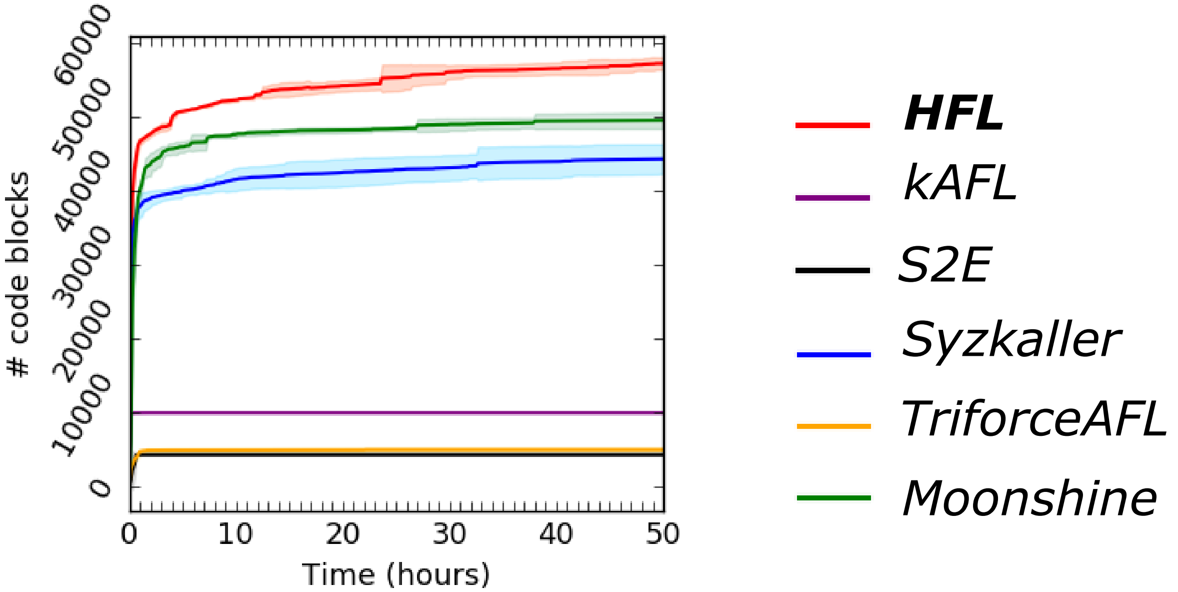
- Discovered new vulnerabilities
  - ***24 new vulnerabilities*** found in the Linux kernels
    - 17 confirmed by Linux kernel community
  - UAF, integer overflow, uninitialized variable access, etc.

- Efficiency of bug-finding capability
  - 13 known bugs for HFL and Syzkaller
  - They were all found by HFL ***3x*** faster than Syzkaller



Code Coverage Enhancement

- Compared with state-of-the-art kernel fuzzers
  - *Moonshine [Sec'18], kAFL [CCS'17], etc.*
- *KCOV*-based coverage measurement
- HFL presents coverage improvement over the others
  - *Ranging from **15%** to **4x***



Conclusion

- HFL is the *first* hybrid kernel fuzzer.
- HFL addresses the crucial challenges in the Linux kernel.
- HFL found 24 new vulnerabilities, and presented the better code coverage, compared to state-of-the-arts.

Thank you