embedded conference scandinavia

Fuzzing Hard-to-get-at Embedded Software with Virtual Platforms

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Fuzzing? Why and What?

Software testing technique

Sends “random” inputs to a software component

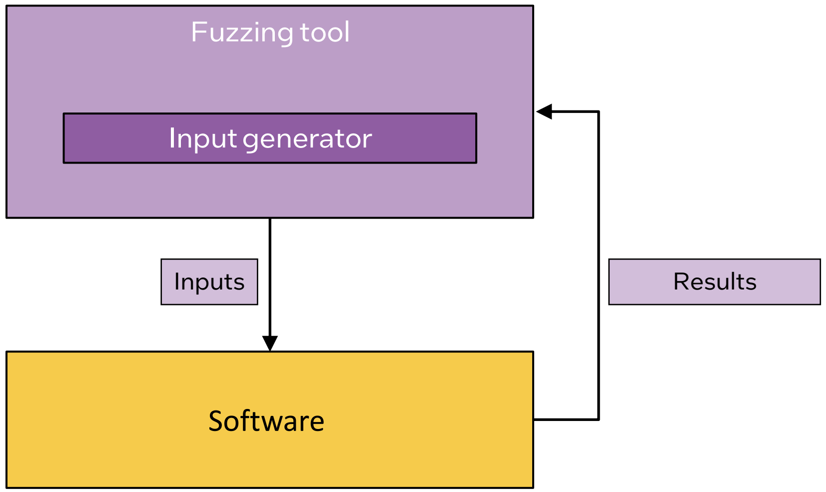
- Inputs should follow the “syntax” of real inputs
- Observe the results, look for errors

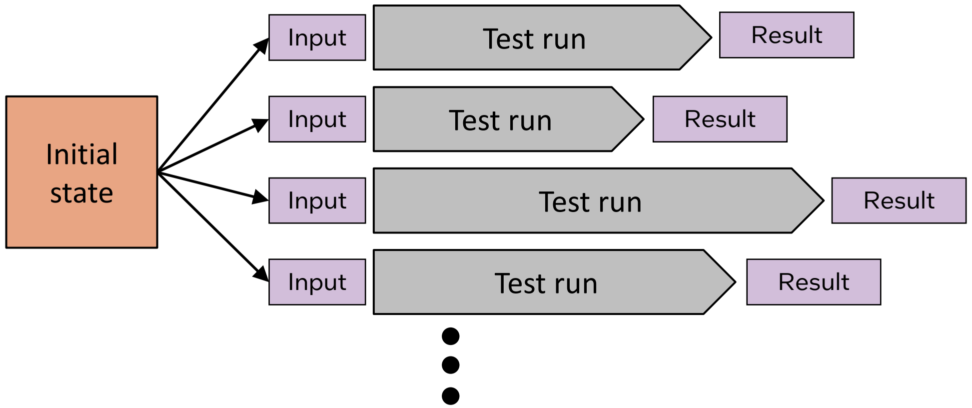
Finds more problems than manually written tests

- Explore corner cases that developers did not think about
- Automation = large volume of variant tests

Iterate tests from the same initial state

Huge area of research today! How can we take advantage of it for hard-to-get-at code?





Coverage-Guided Fuzzing

However... totally random tests are very inefficient – mostly thrashing

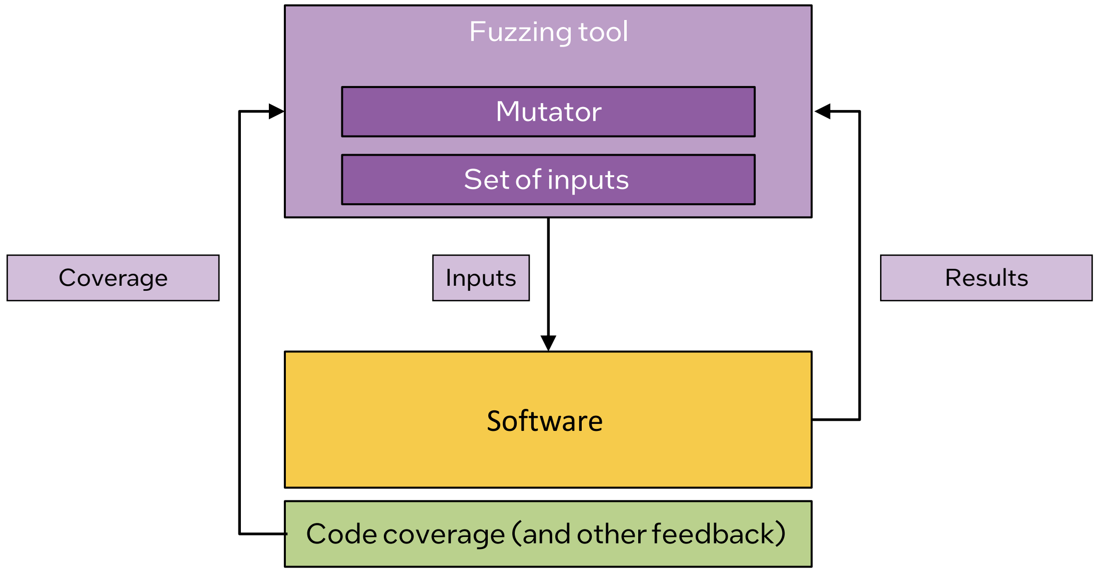
Solution: **coverage-guided fuzzing**

- Discern the code reached by each test
  - I.e., measure the "goodness" of a test case
- Can be done without source code!

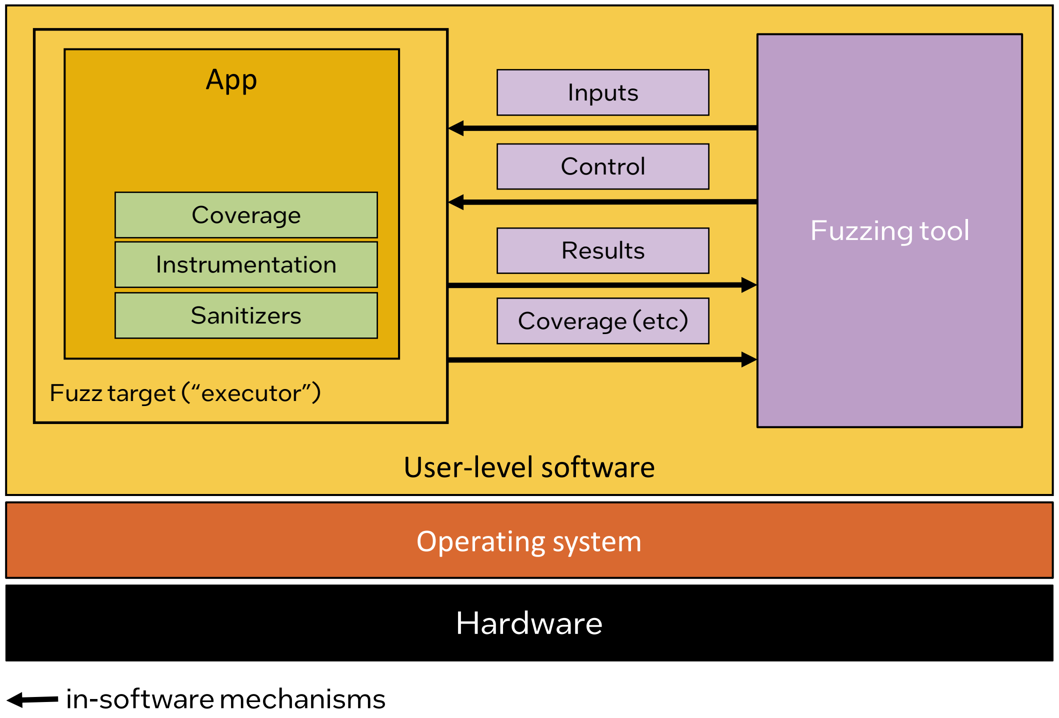
Mutate the set of test cases

- Evolve towards effective tests that are as different from each other as feasible
- Discard tests that do not add coverage

Improves fuzzing effectiveness massively



Standard Coverage-Guided Fuzzing

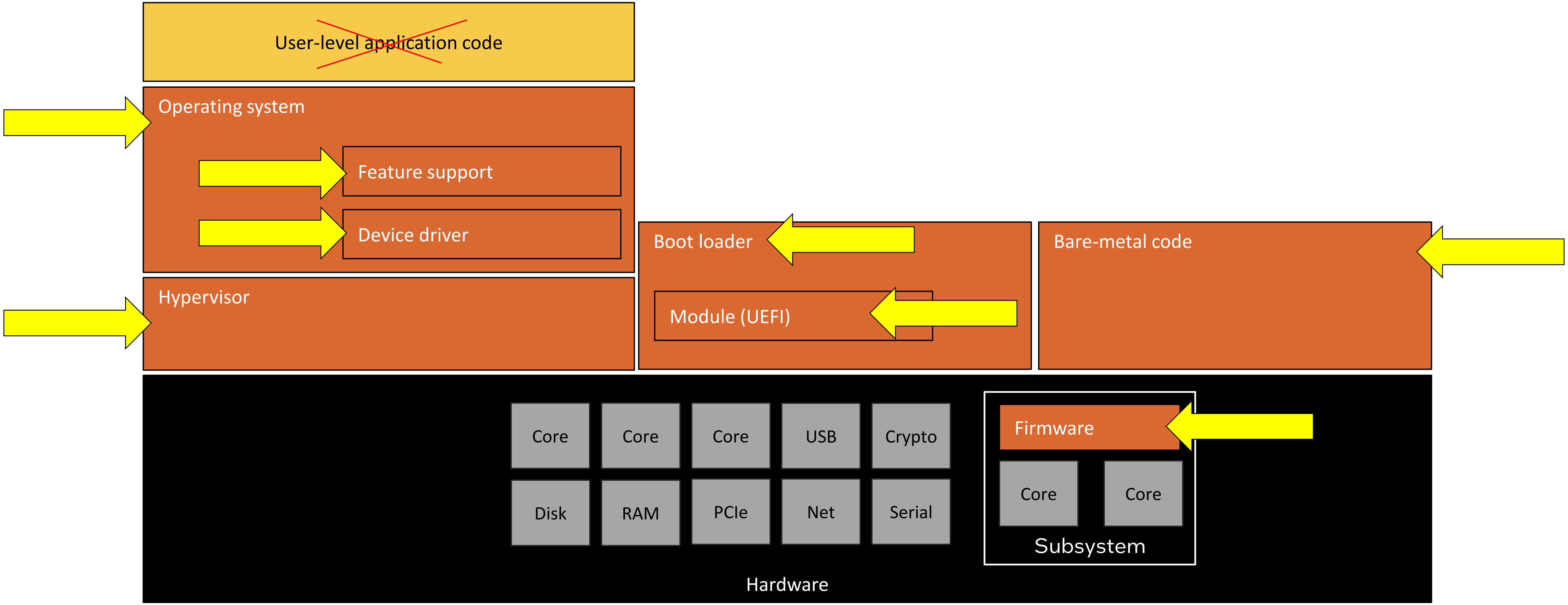


Fuzzer and target run side-by-side on an operating system

- Fuzzer uses host operating-system mechanisms to control and track the target
- Application compiled with instrumentation, coverage, and sanitizers to provide feedback
- On Linux, use "`fork`" to save an initial state to return to for each test

Works well for user-level software

Definition: “Hard-To-Get-At Software”



Hard-To-Get-At Software and Fuzzing

No help from an operating system

- Where do you run the fuzzing tool?
- How do you get inputs into the target from the fuzzing tool?
- How do you detect a failure when there is no OS underneath to help?

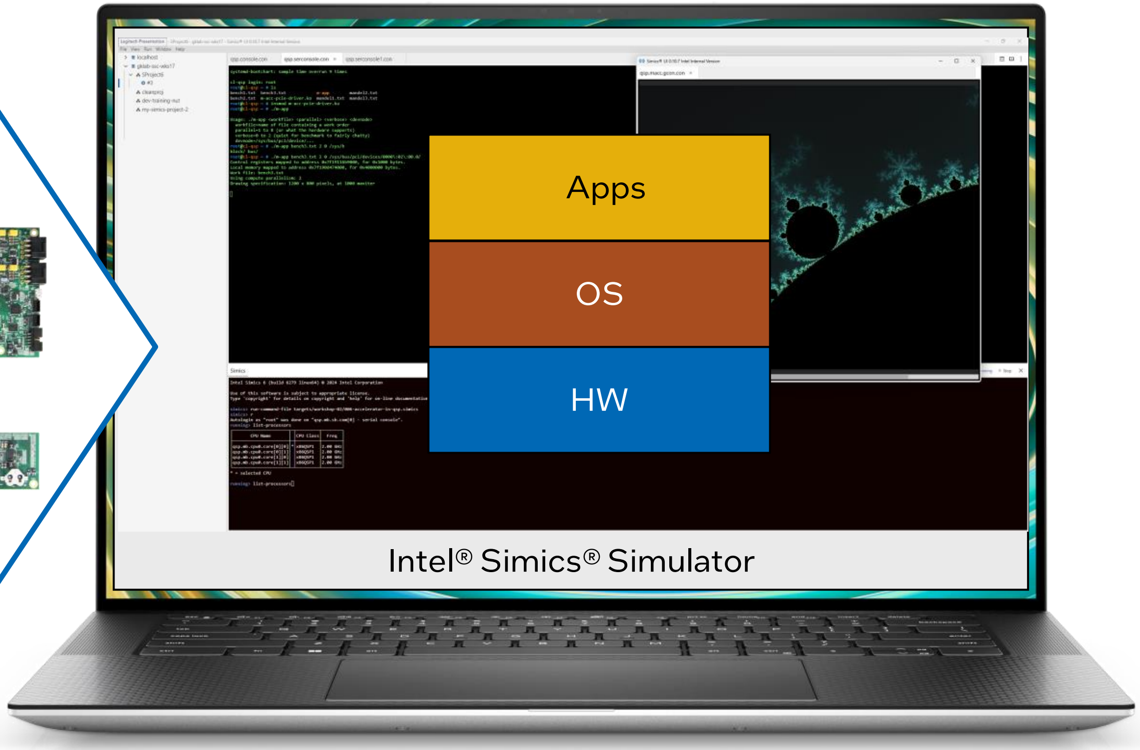
Code insight (coverage) is more difficult to get

- Compilation with instrumentation might be hard (code size, data size, I/O)
- Code runs in protected memory, …

Resetting target state is tricky

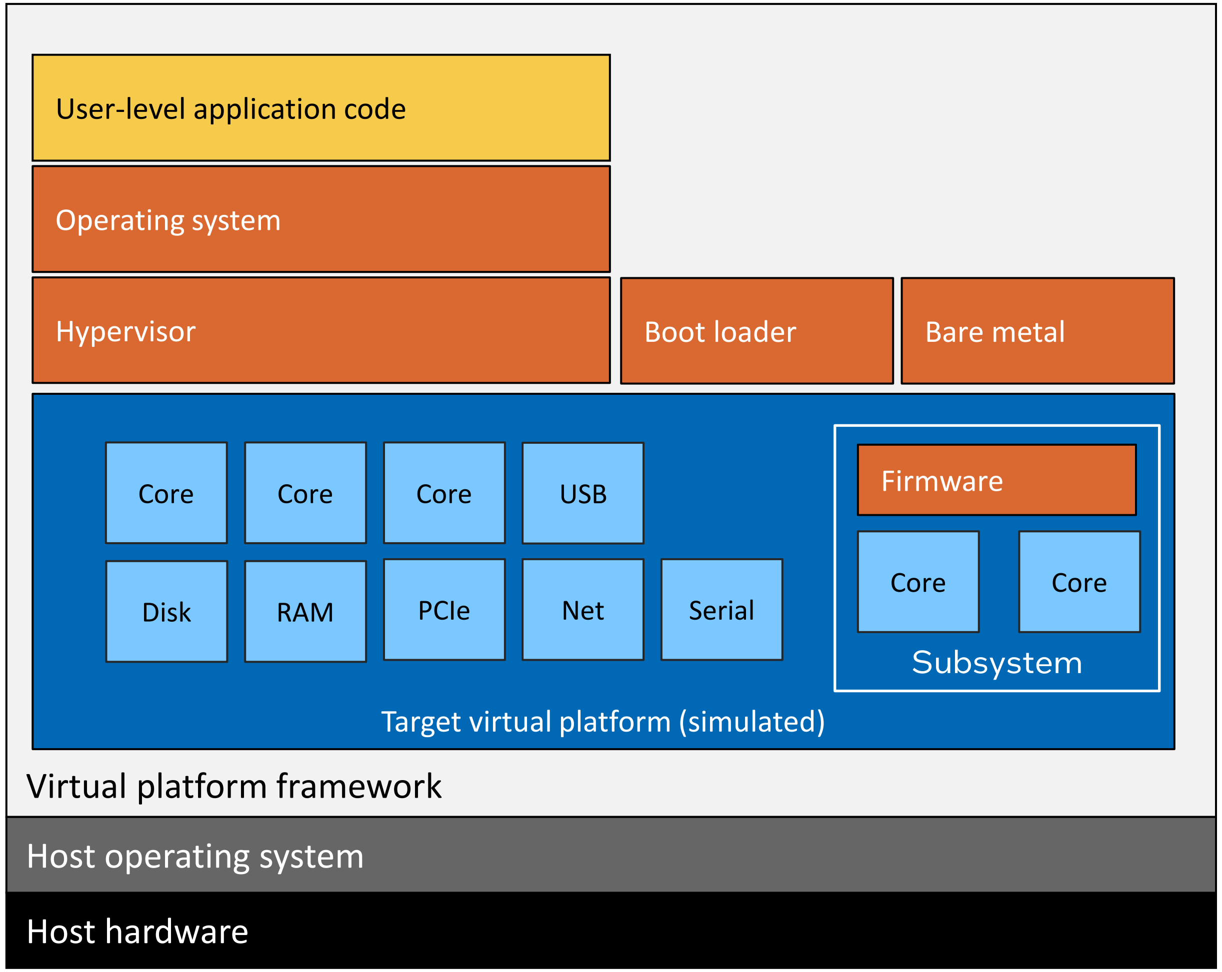
- Code works directly with the hardware – how to rewind hardware registers?
- Operating-system forking is not available

Solution: Virtual Platforms



Run your software without the hardware – on a software model

Virtual Platforms? Why and What?



Technology

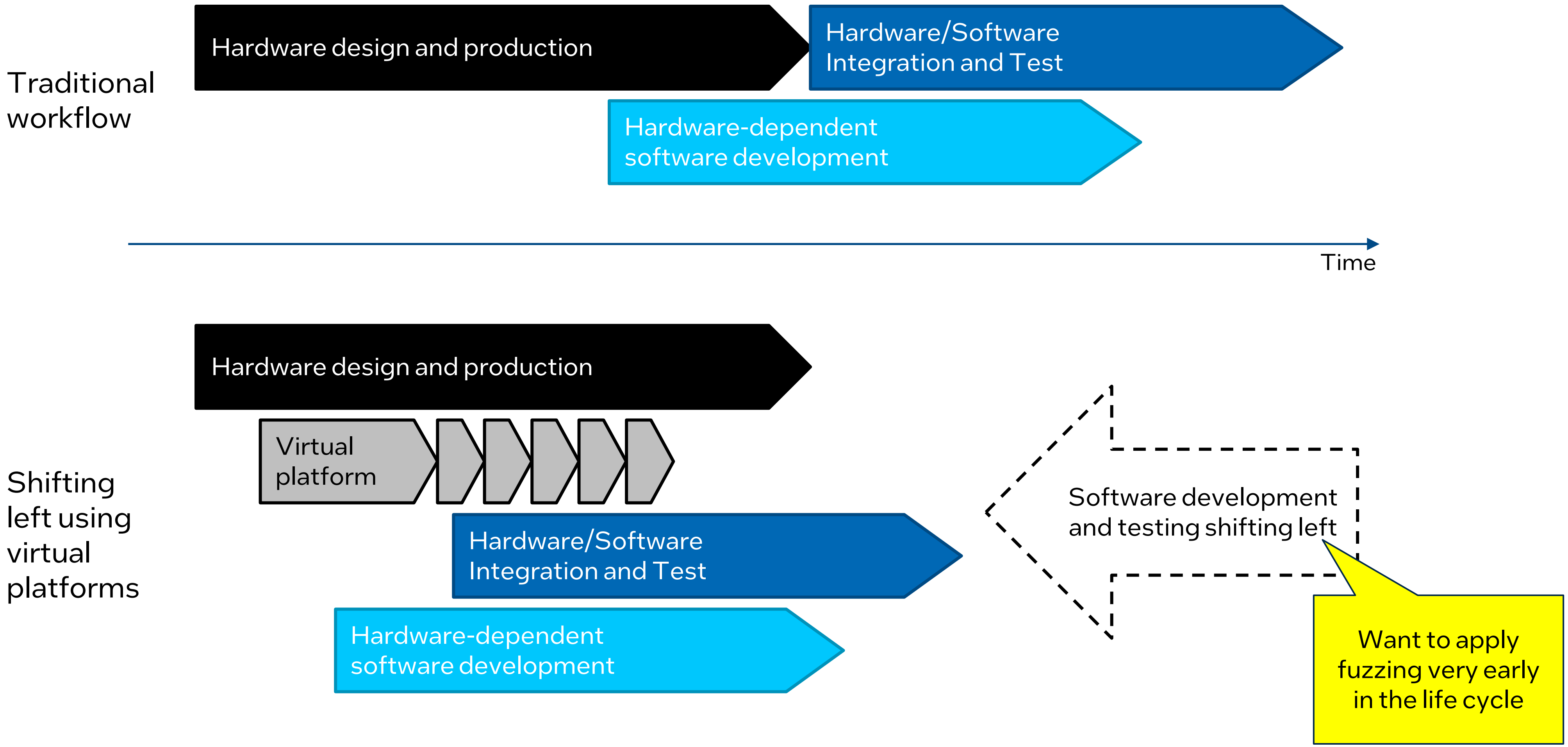
- Software model of hardware
- Run **the same software** as the hardware
  - Same builds, same binaries
- Fast enough to run real workloads

Use case examples

- Explore system architecture
- Develop software early
- Continuous integration of software and hardware
- Debug and test software

Fuzzing is a test technology

Note: Shift-Left = Virtual Platform



Why do Fuzzing on a Virtual Platform?

Fuzz hardware-dependent code

- Fuzz code that interacts closely with hardware
- VP = possible to roll back disk and peripheral device state

Fuzz code with limited interfaces

- Fuzz code that is hard to interface with on real hardware
- VP = access to the platform internals

Shift-left software quality

- Fuzzing increases quality
- Software can run on VP in pre-silicon, why wait for hardware?

Richer fuzzing environment

- VP can observe more types of failures than hardware
- VPs can inject hardware stimuli to provoke software

If you have a VP anyway

- Additional value from existing investment in model
- Avoid constructing complicated setups based on a standard VMs

Alternatives to Virtual Platforms?

Port hard-to-get-at code to run as user-level program

- Requires stubbing/faking/simulating hardware interface
- Not the same code
- Not the same compiler

Use a standard virtual machine (VM)

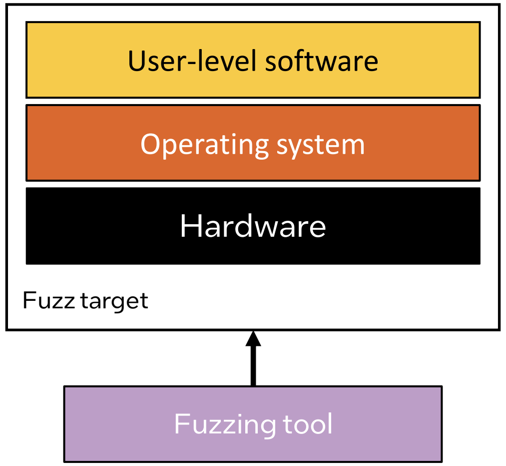
- Modify aspects of the target software to make it work
- Observe execution of code at OS level
- Compile to the VM = compile for the host architecture
- Does not provide the actual target hardware

Use generic instruction-set simulators

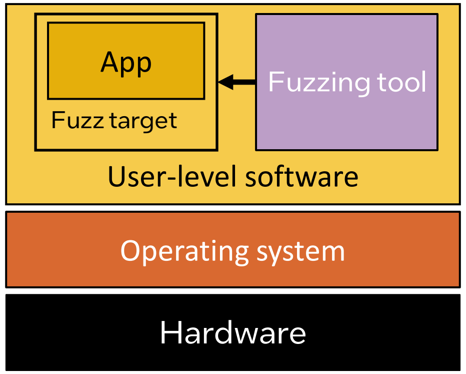
- Fudge the interface to peripherals
- Various generation schemes have been proposed for the peripheral/hardware side

Much easier to just use a virtual platform of the hardware

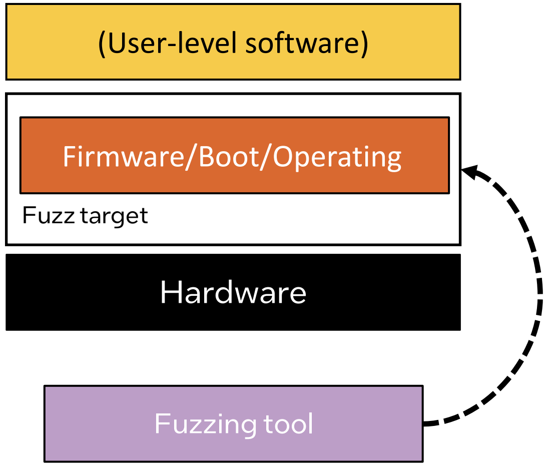
Typical Fuzzing Setups and Virtual Platforms



Black-box fuzzing at target system boundary



Fuzzing individual applications running inside a standard software stack



Fuzzing difficult-to-get-at code that runs directly on the hardware

- VP use: replace the physical hardware with virtual hardware
- Same input/output, standard real-world connections suffice

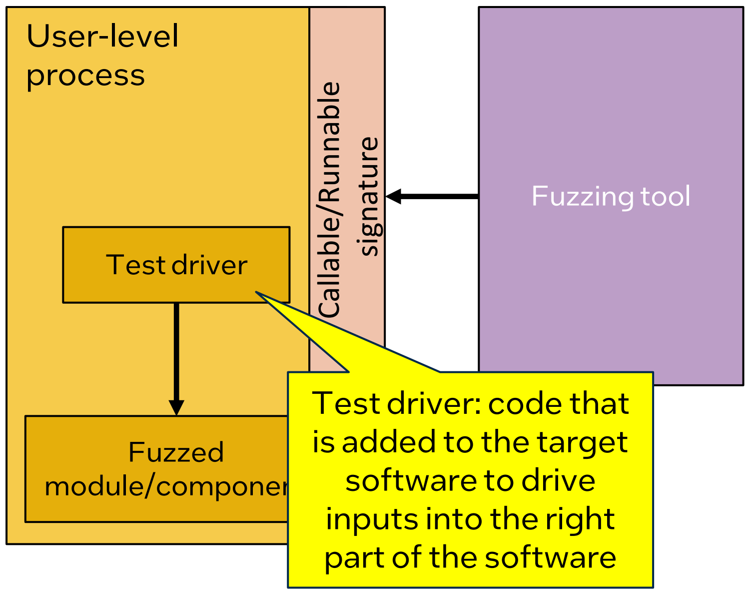
- Easy to do with standard tools
- VP use: when user-level software uses new hardware (instruction sets etc.) – run on VP

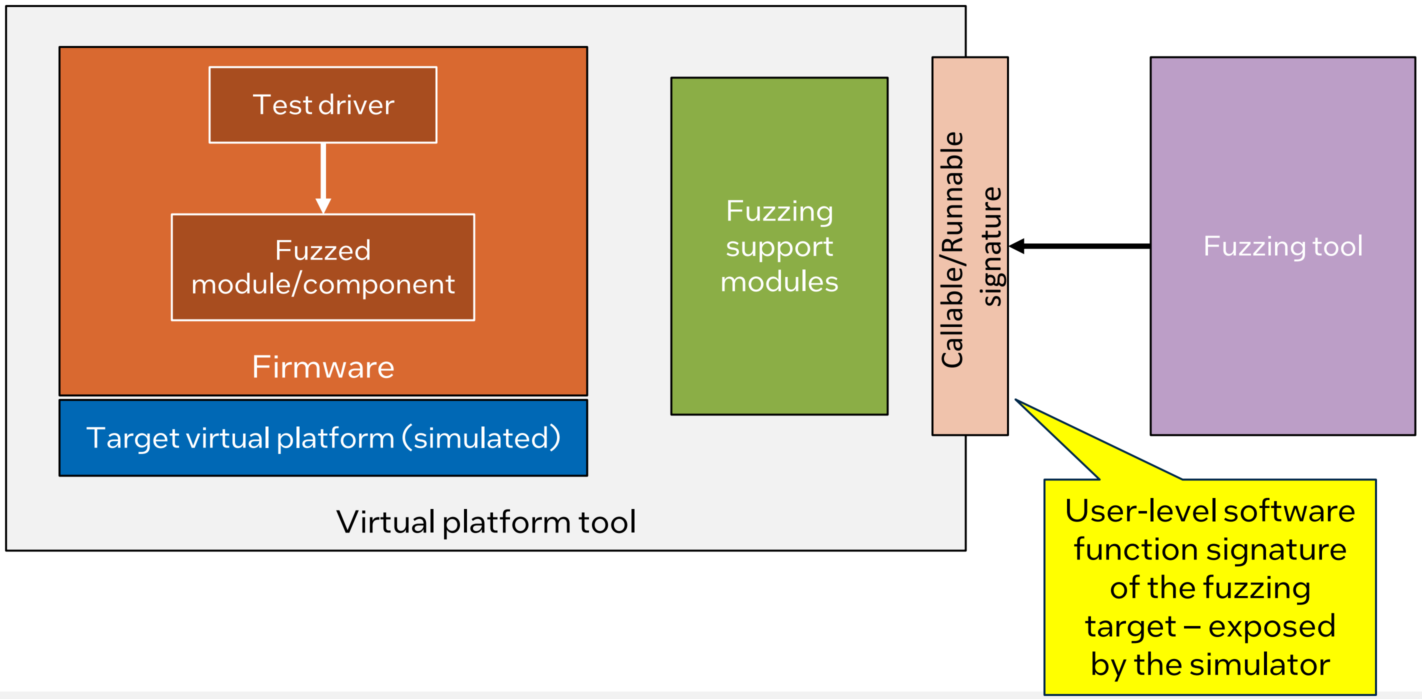
- Not feasible with standard tools
- Requires support in the VP to interface the fuzzer and the software
- Focus of this presentation

Virtual-Platform-Based Guided Fuzzing

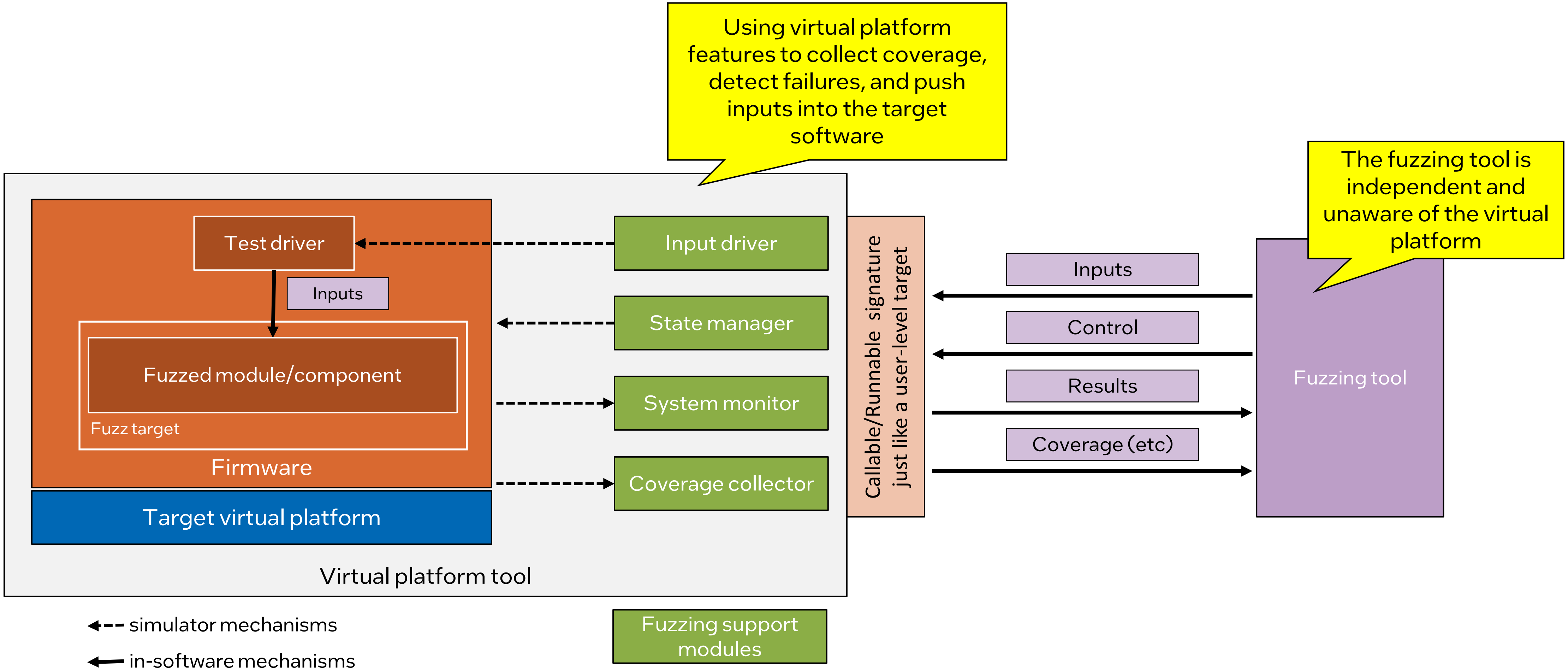
Concept: Make the virtual platform look like a user-level program

- Reuse existing fuzzers and their fuzzing logic as-is…
- … while facilitating access to the software using virtual-platform techniques





Virtual-Platform-Based Guided Fuzzing: Details



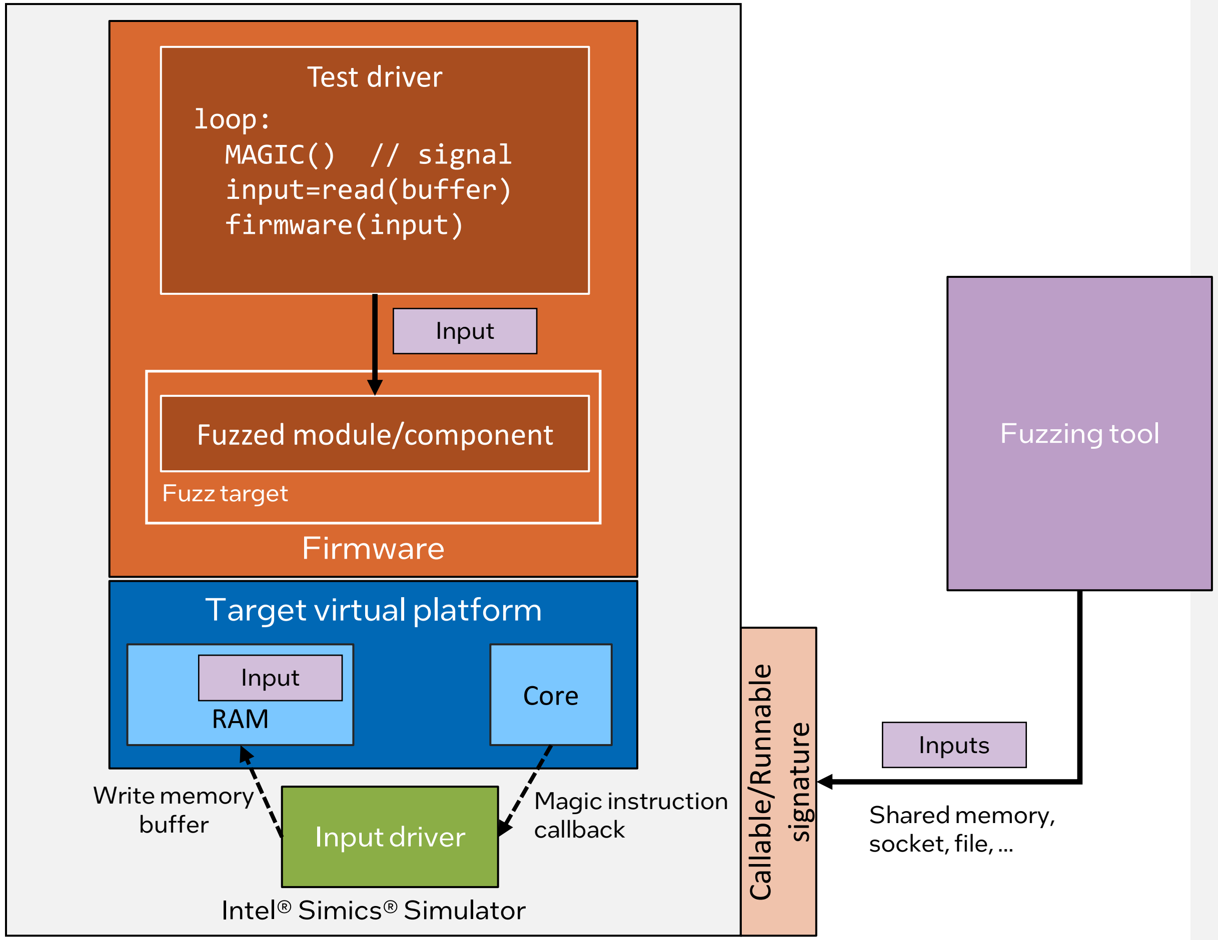
Test Driver and Input Driver

Test driver (target software)

- Depends on target and fuzzing setup
  - Knows how to call into/activate the target
  - Knows how to apply inputs from fuzzer
- **Magic instructions:** key VP trick
  - Test driver issues magic instruction when ready to receive data
  - Input driver catches the magic callback and fills in next test case
- *(Adding to target software stack is the only robust solution; calling into software from VP directly is difficult and brittle)*

Input driver (simulator module)

- Implements the interface towards the fuzzing tool – depends on how the simulator and fuzzer communicate
- Passes data from the fuzzer to the test driver software – dumb pipe



System Monitor

Wait for conditions that indicate success or failure in the system under fuzz

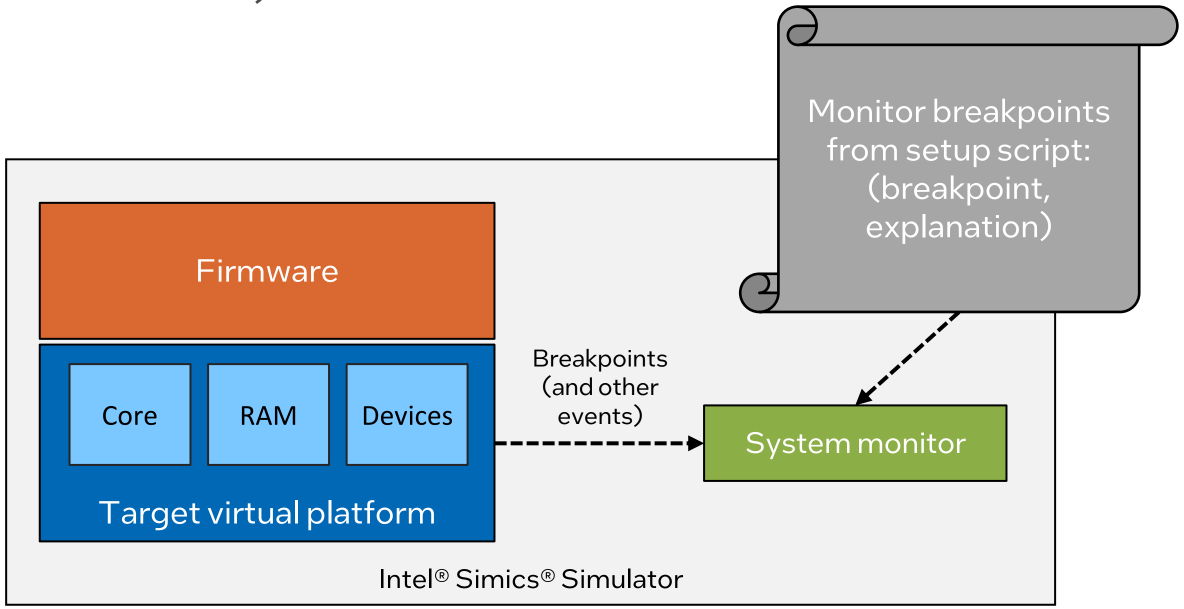
- Watch using breakpoints
- Software is not modified or instrumented
- Success is usually "called function returns OK"

Example conditions:

- Running code outside of allowed ranges
- Memory accesses outside of allowed ranges
- Executing undefined instructions
- Triggering interrupts
- Processor resets and triple faults
- … whatever makes sense …

The set of events to watch depends on the system and software

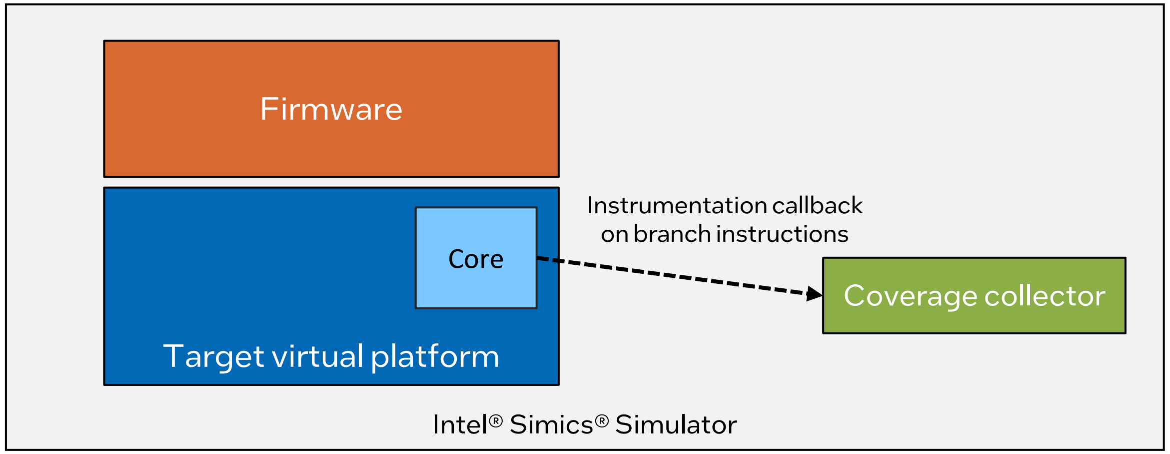
- (It is easier for user-level fuzzing where signals/segmentation faults & sanitizer errors cover most)



Coverage Collection

Current solution: **Branch (edge) coverage**

- The virtual platform processor core simulator reports all branch instructions to a coverage tool
- Coverage data looks like it came from code instrumentation
- Hashing-based algorithms
  - Record all branch instructions
  - Address hashing = no need to know where the code of interest is in memory



This is **"grey-box" fuzzing:** coverage measurement without source code

- Watch the code execution "from the hardware"
- No source code needed
- No compiled-in instrumentation
- ... but still looking at the code flow

Technicality: *note that compiling-in the test driver makes that part of the process "open-box", so the overall approach is not fully grey-box*

State Management: In-Memory Snapshots

Recall, fuzzing = many short test runs starting from a reused common starting point

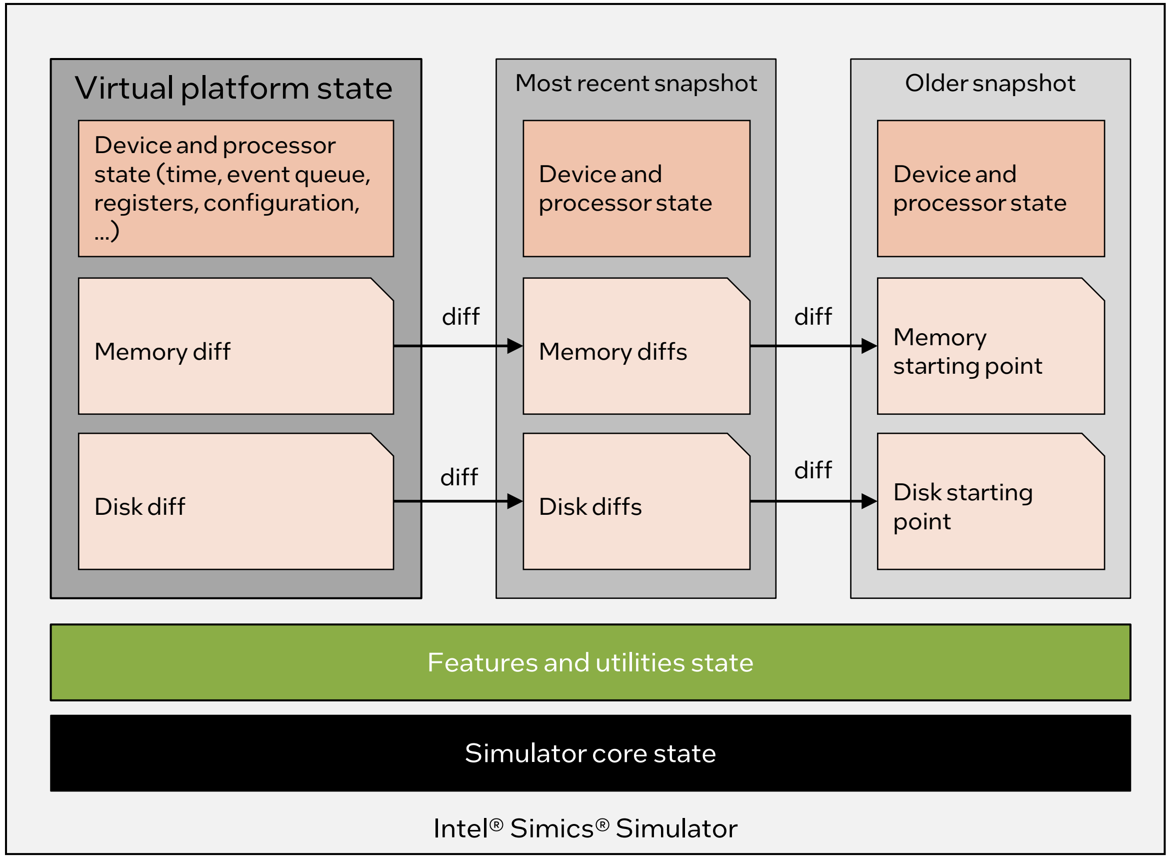
- The system state restore is critical
- Virtual platform = all hardware state is under control

Simulation state is restored using simulator **in-memory snapshots**

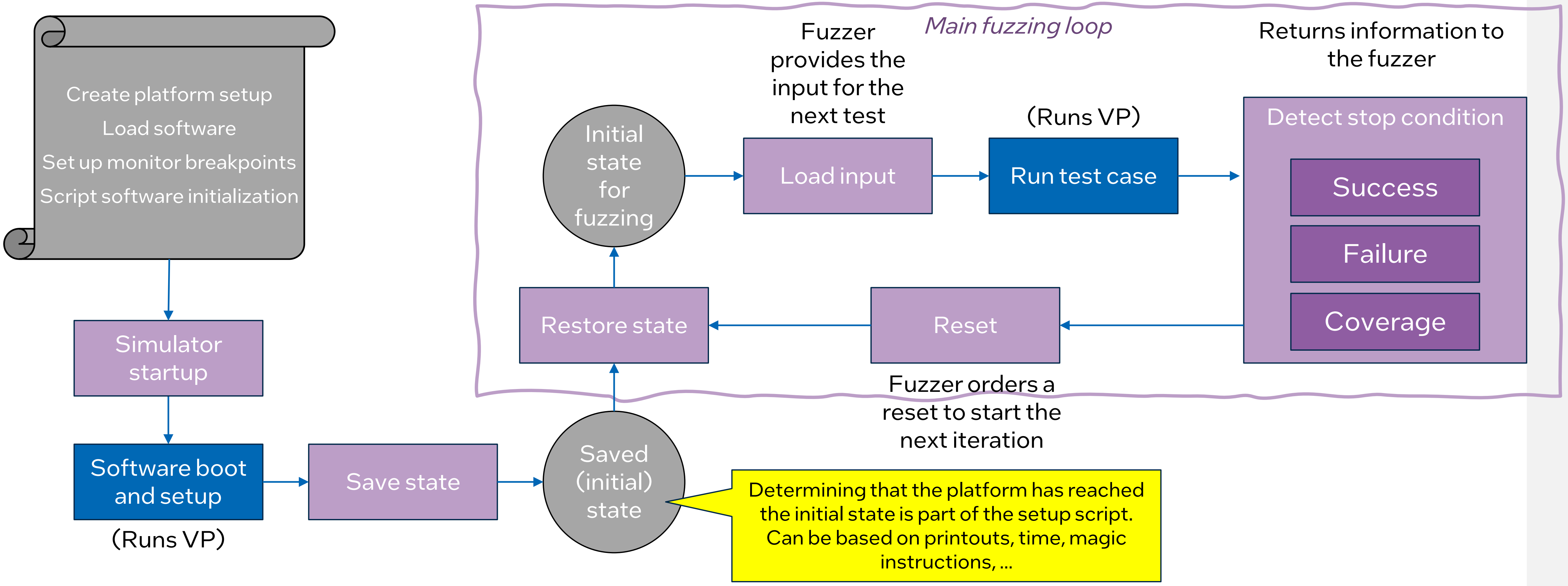
- Processor and device state
- Memory and disk contents
- Not including the simulator core and features

Why not fork the VP process?

- Linux fork does not work well with a threaded simulator
- What to do on Windows hosts?



Complete Fuzzing Flow using a Virtual Platform



Experience

We have applied virtual-platform-based fuzzing internally at Intel

- Cannot talk about concrete application due to sensitivity
- But it has worked

The TSFFS fuzzing setup, https://github.com/intel/tsffs/, is an open-source virtual-platform-based fuzzer for the Intel® Simics® Simulator

- Reports about 200 iterations per second for small virtual platforms

Questions?

Get the Intel® Simics® Simulator
https://developer.intel.com/simics-simulator

Try the TSFFS fuzzing setup (close to what was presented here)
https://github.com/intel/tsffs/

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