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TwinFuzz: Differential Testing of Video Hardware Acceleration Stacks

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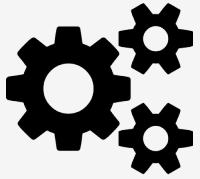
NDSS SYMPOSIUM

NDSS 2025 | CISPA Helmholtz Center for Information Security

Software Fuzzing

image: Flaticon.com

Software Fuzzing



Fuzzer

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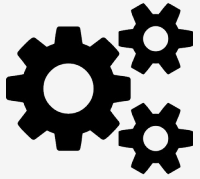

Fuzzer

Instrumented
Binary

image: Flaticon.com

Software Fuzzing

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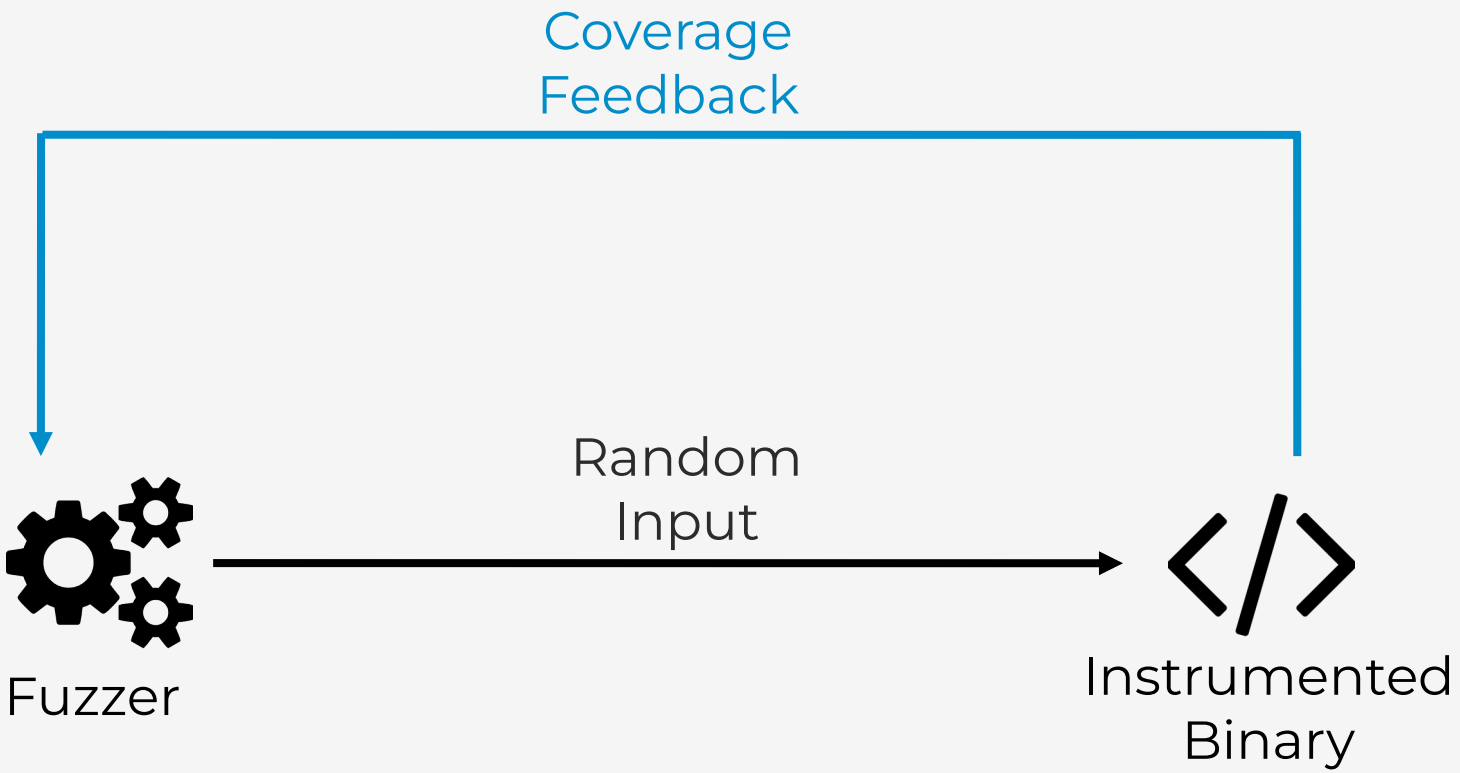

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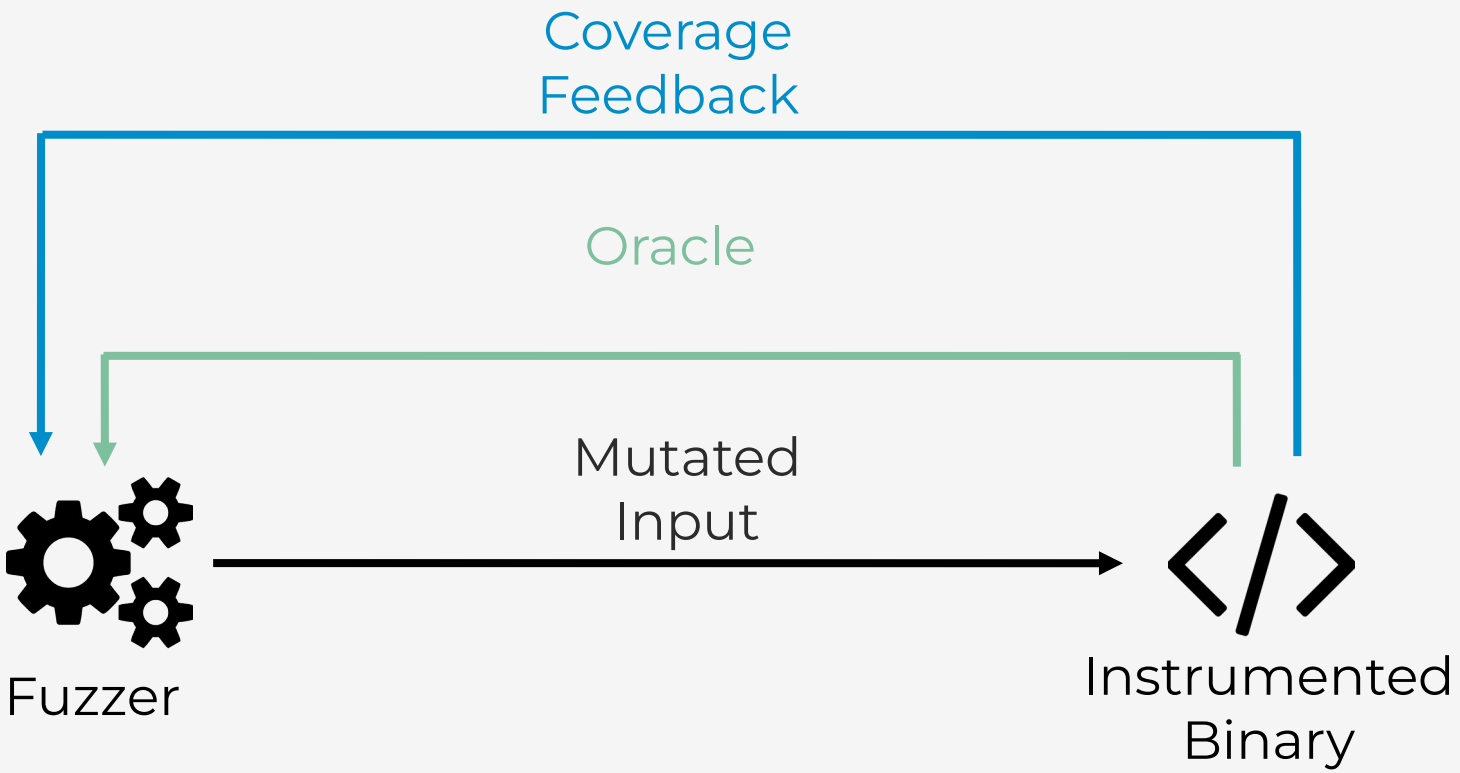

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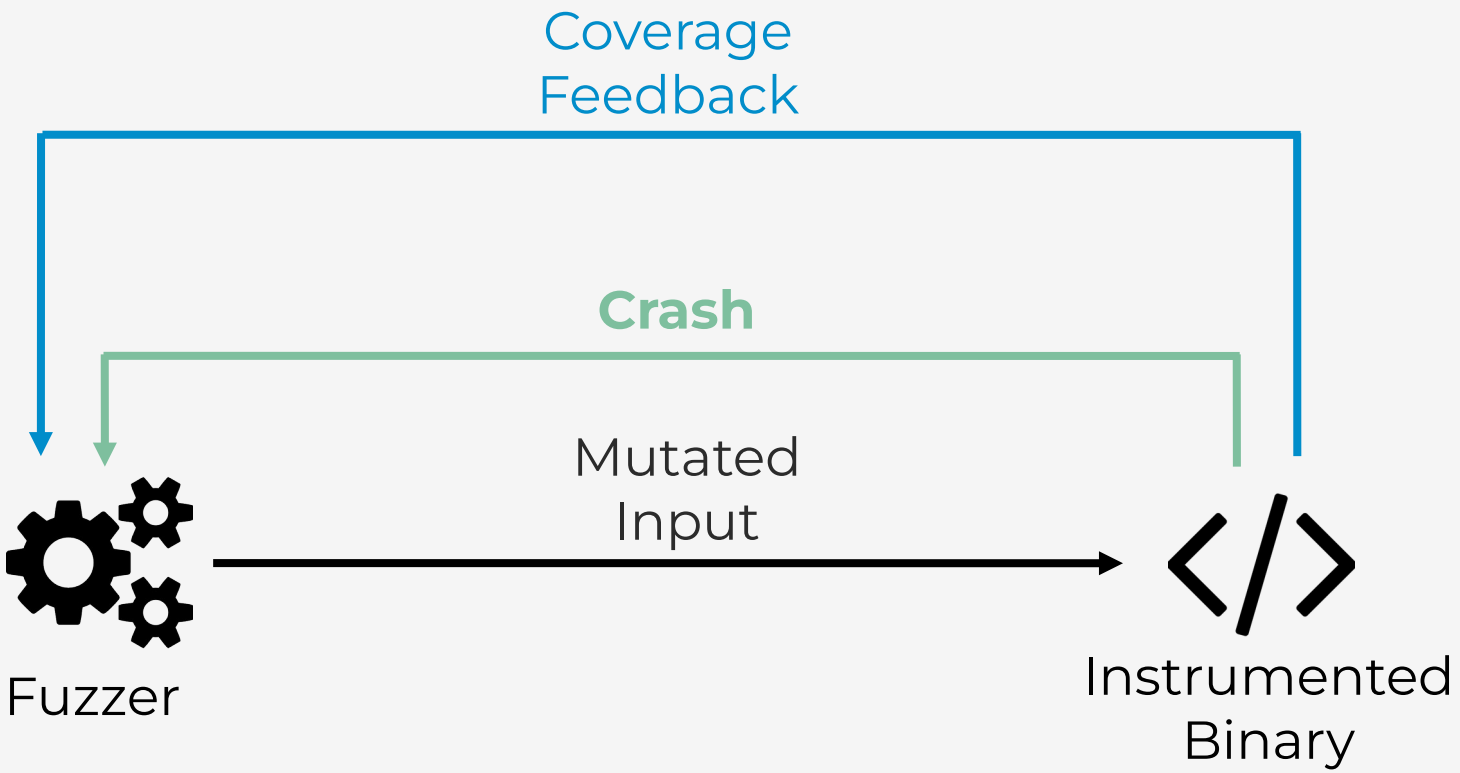

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Hardware Fuzzing

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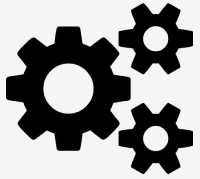

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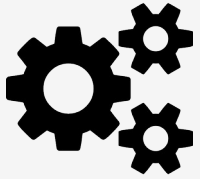

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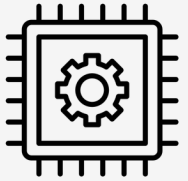

Black-Box
Hardware

image: Flaticon.com

Hardware Fuzzing

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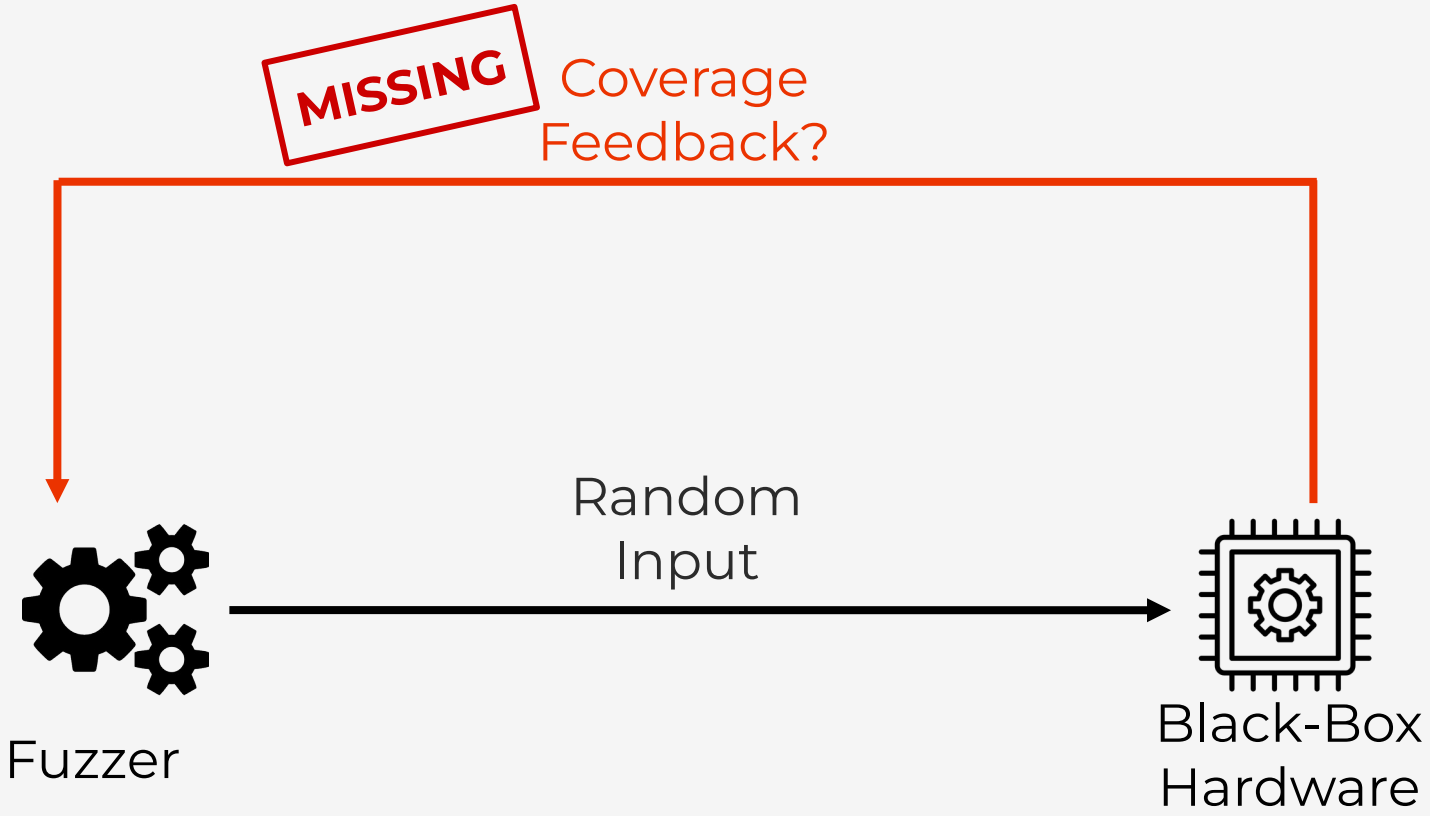

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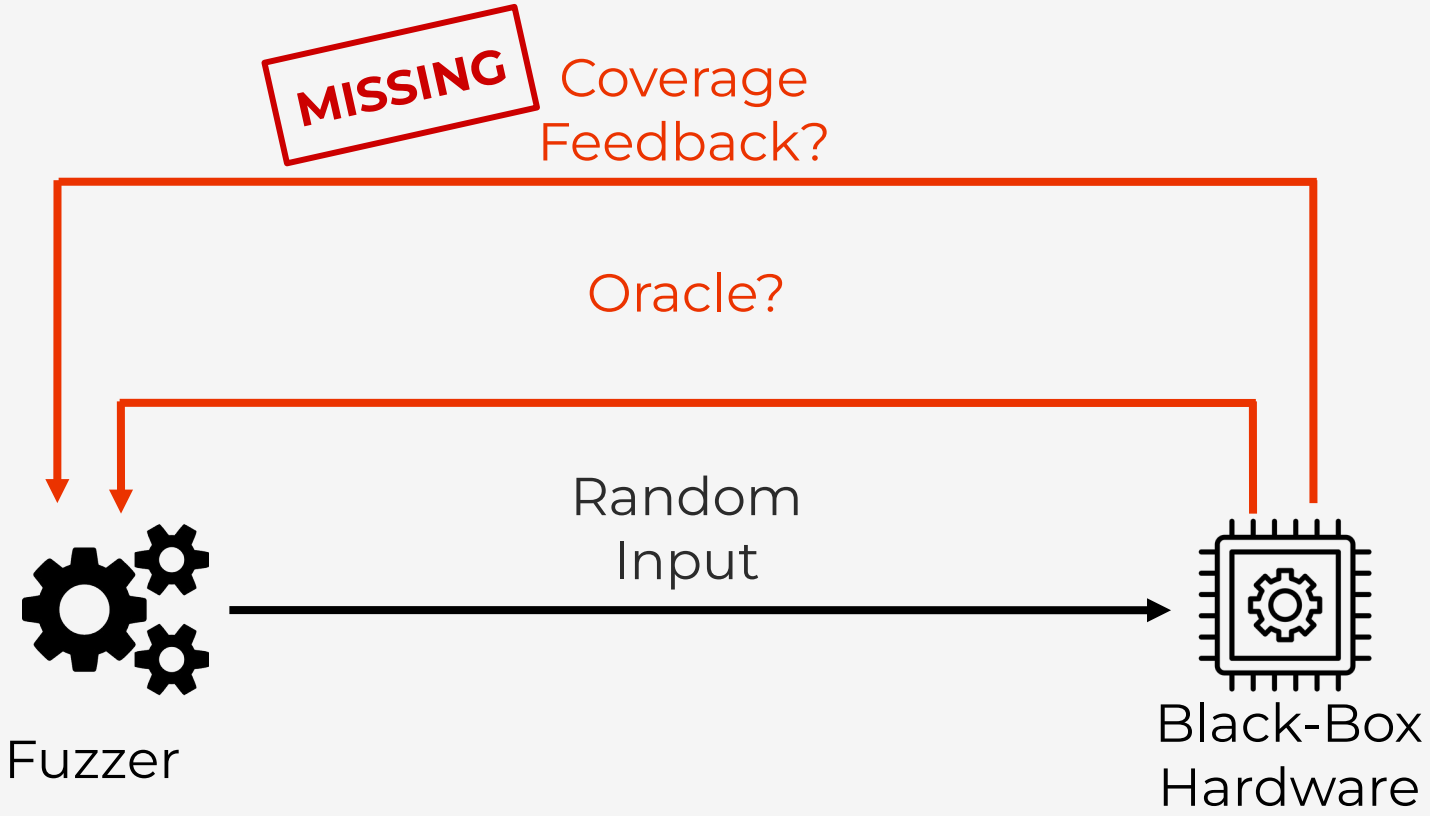

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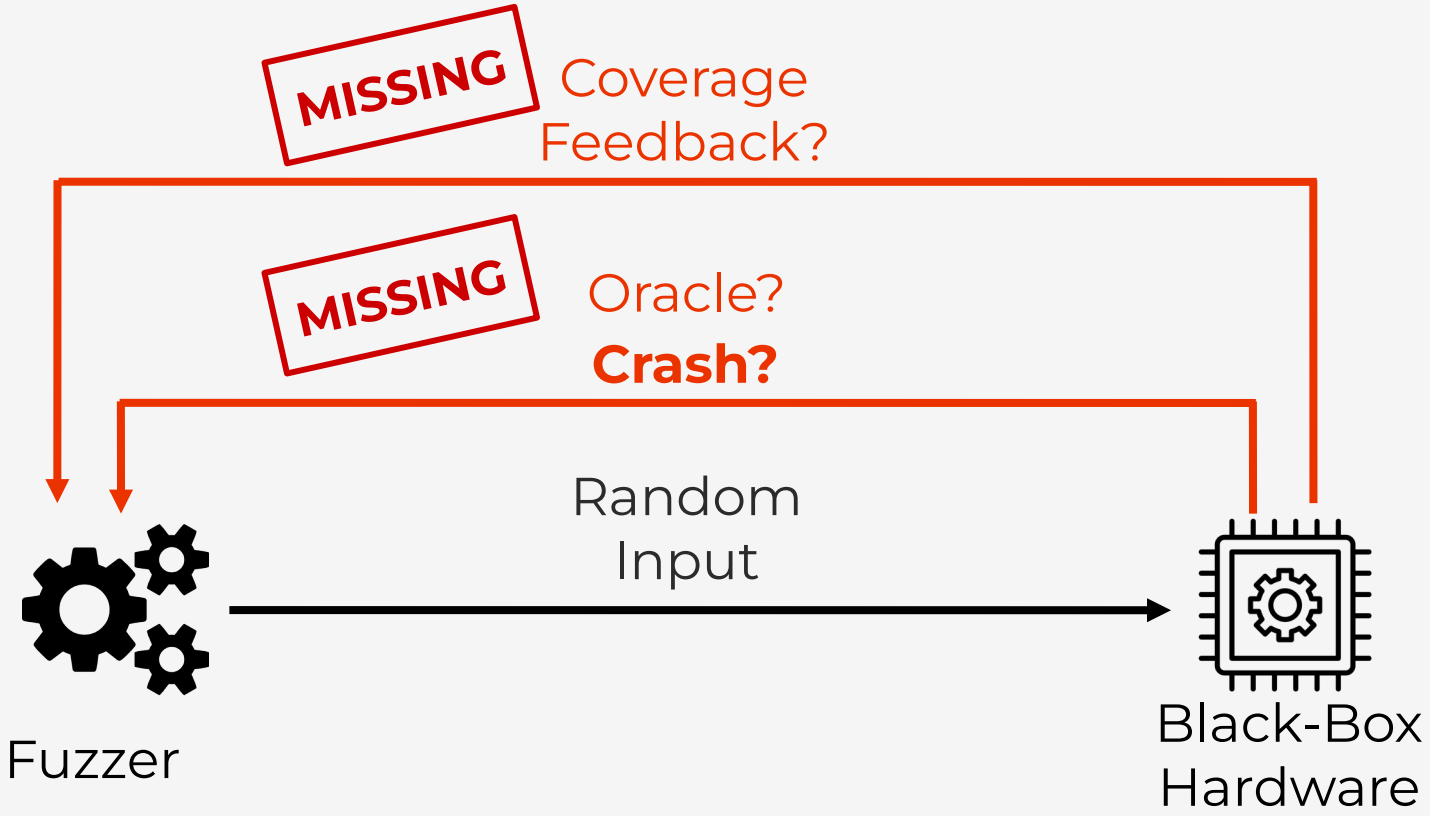

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Differential Testing

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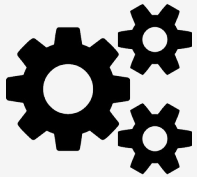

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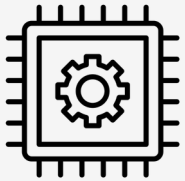

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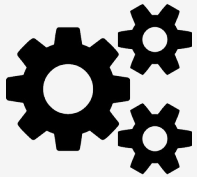

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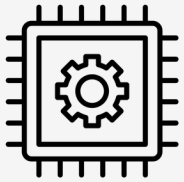

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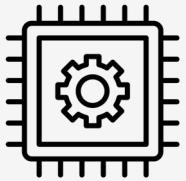

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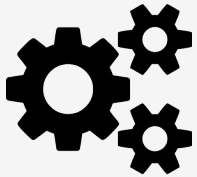
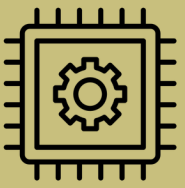


Fuzzer

Reference Model



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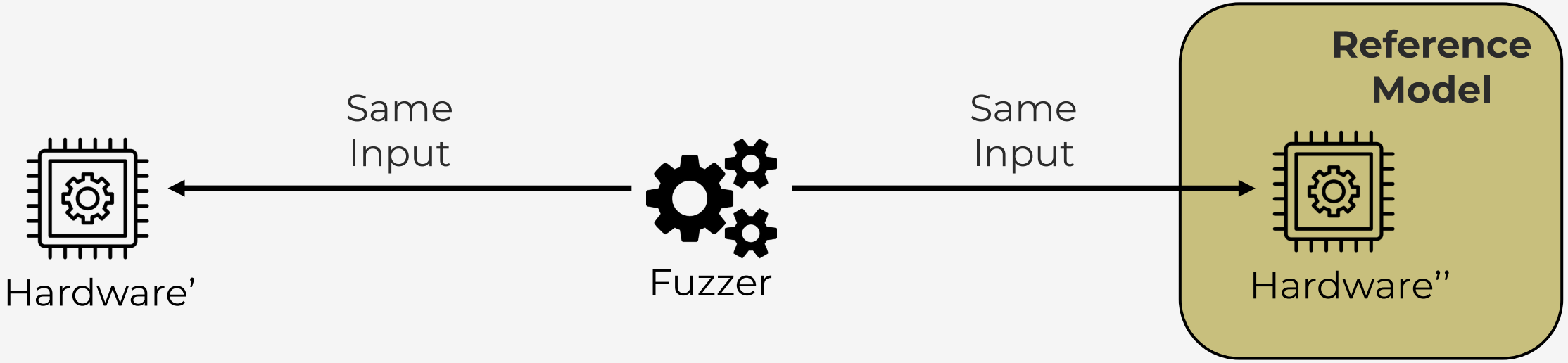
Differential Testing



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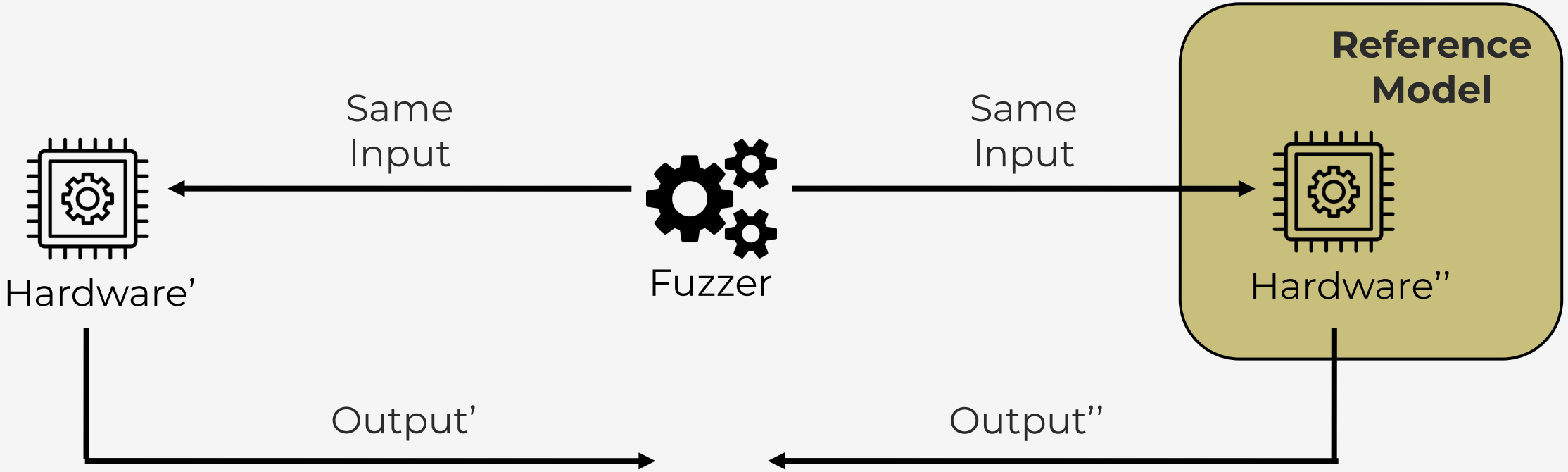

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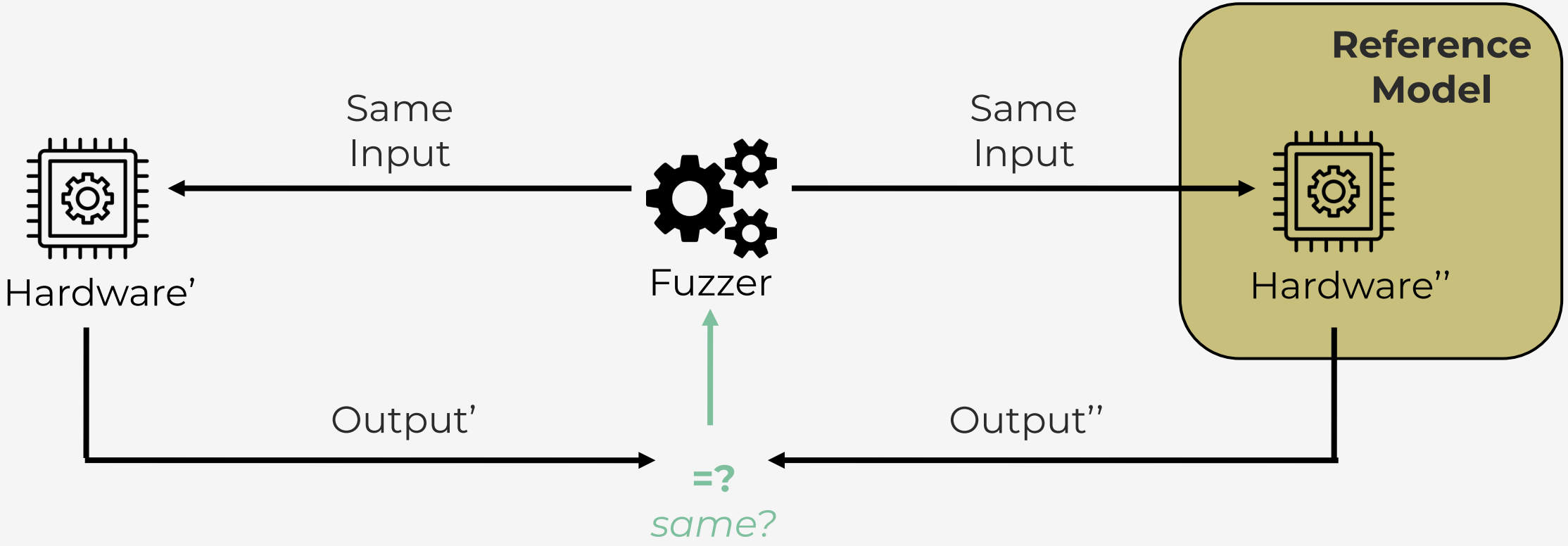

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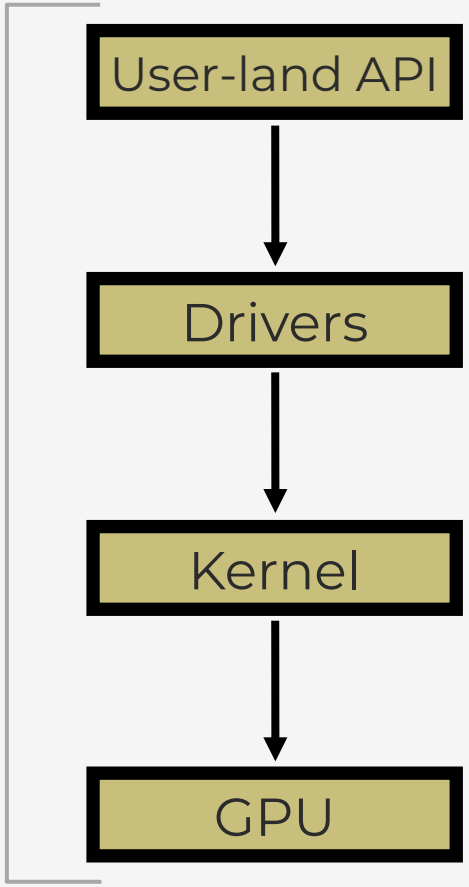
Video Decoding Models

Video Decoding Models

Video Hardware Acceleration Stack



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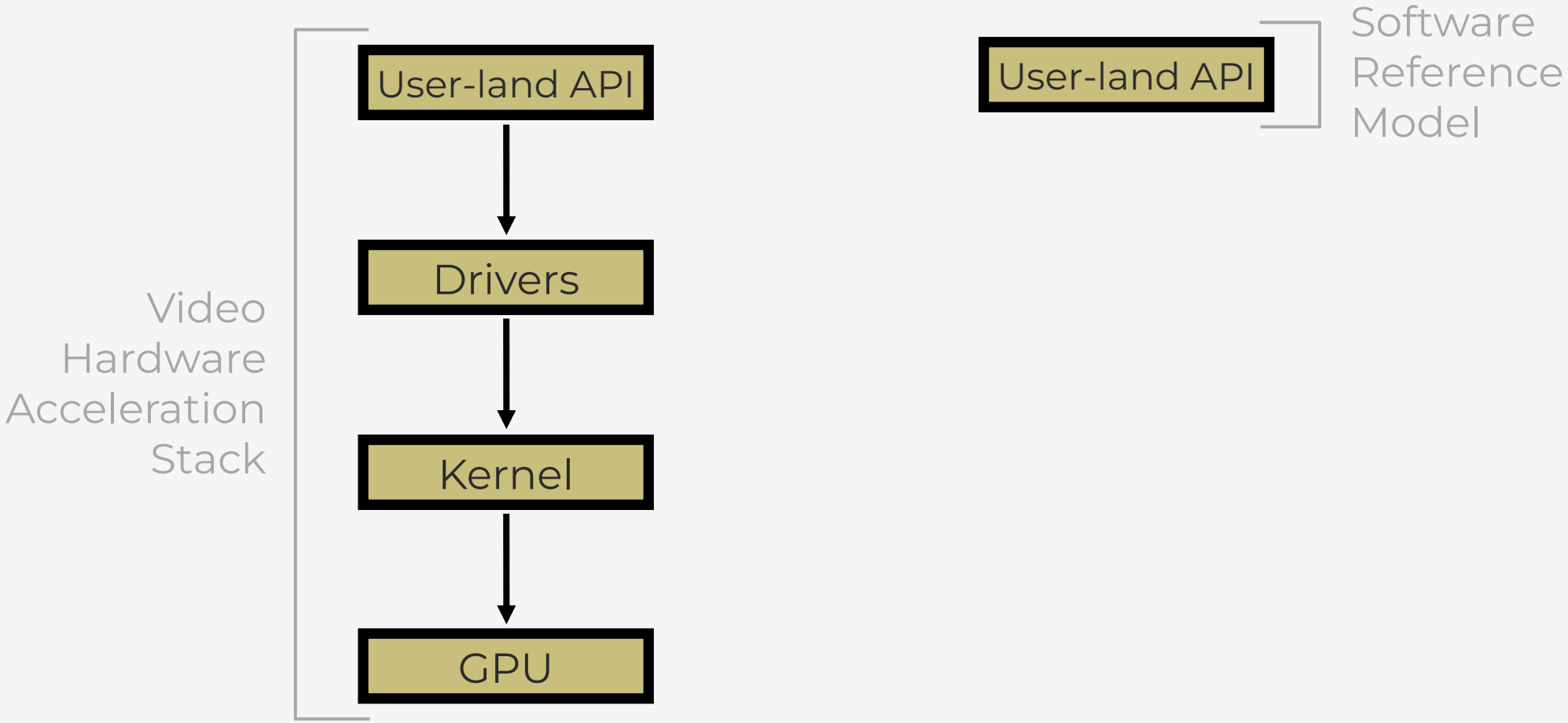

TwinFuzz Challenges

TwinFuzz Challenges

CH 1

Define a **new oracle** for hardware-accelerated stack

TwinFuzz Challenges

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Define a **new oracle** for hardware-accelerated stack

CH 2

Define a **feedback mechanism** for hardware-accelerated stack

TwinFuzz Challenges

CH 1 — Define a **new oracle** for hardware-accelerated stack

CH 2 — Define a **feedback mechanism** for hardware-accelerated stack

CH 3 — Analyze the **observable differences**

CH 1: Differential Oracle for Video Hardware Acceleration Stack

image: Flaticon.com

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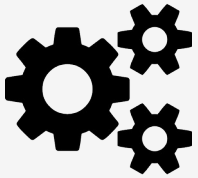

Fuzzer

image: Flaticon.com

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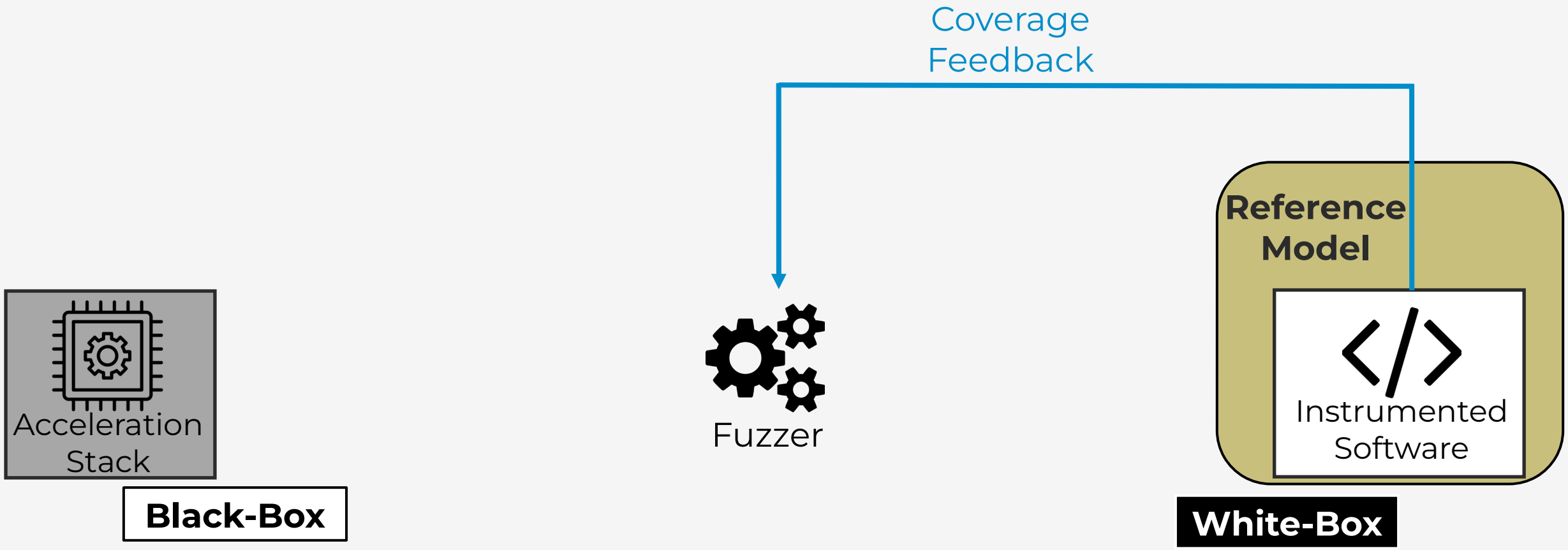

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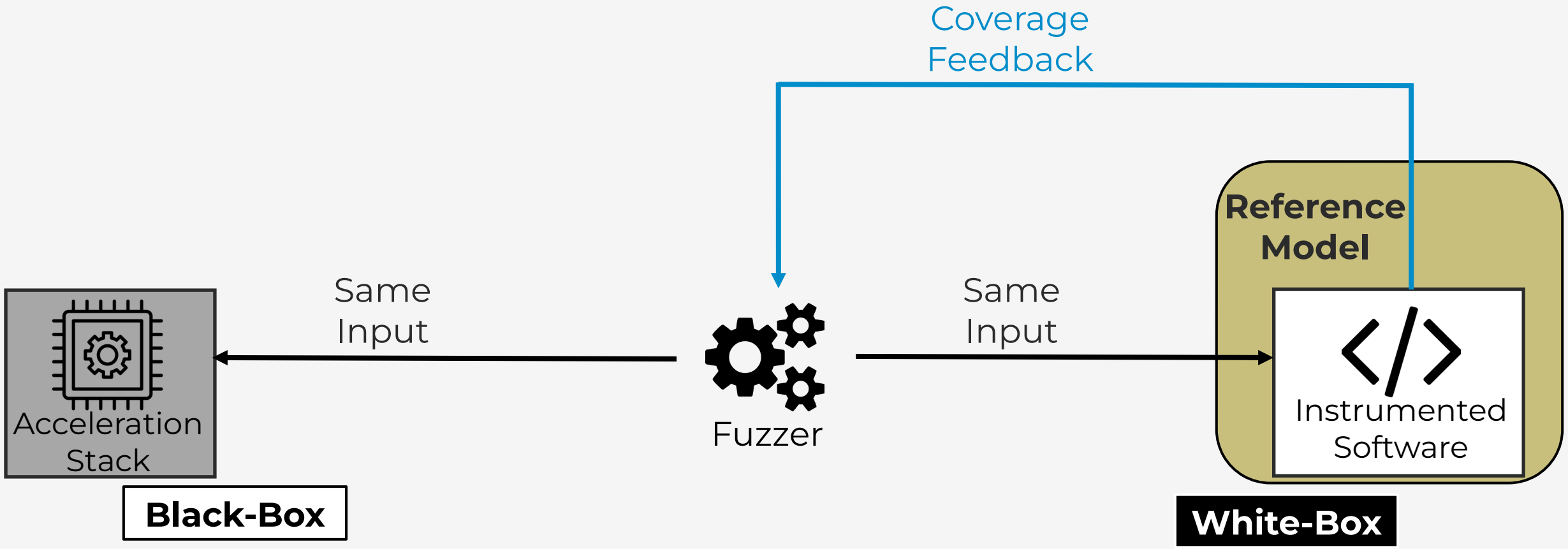

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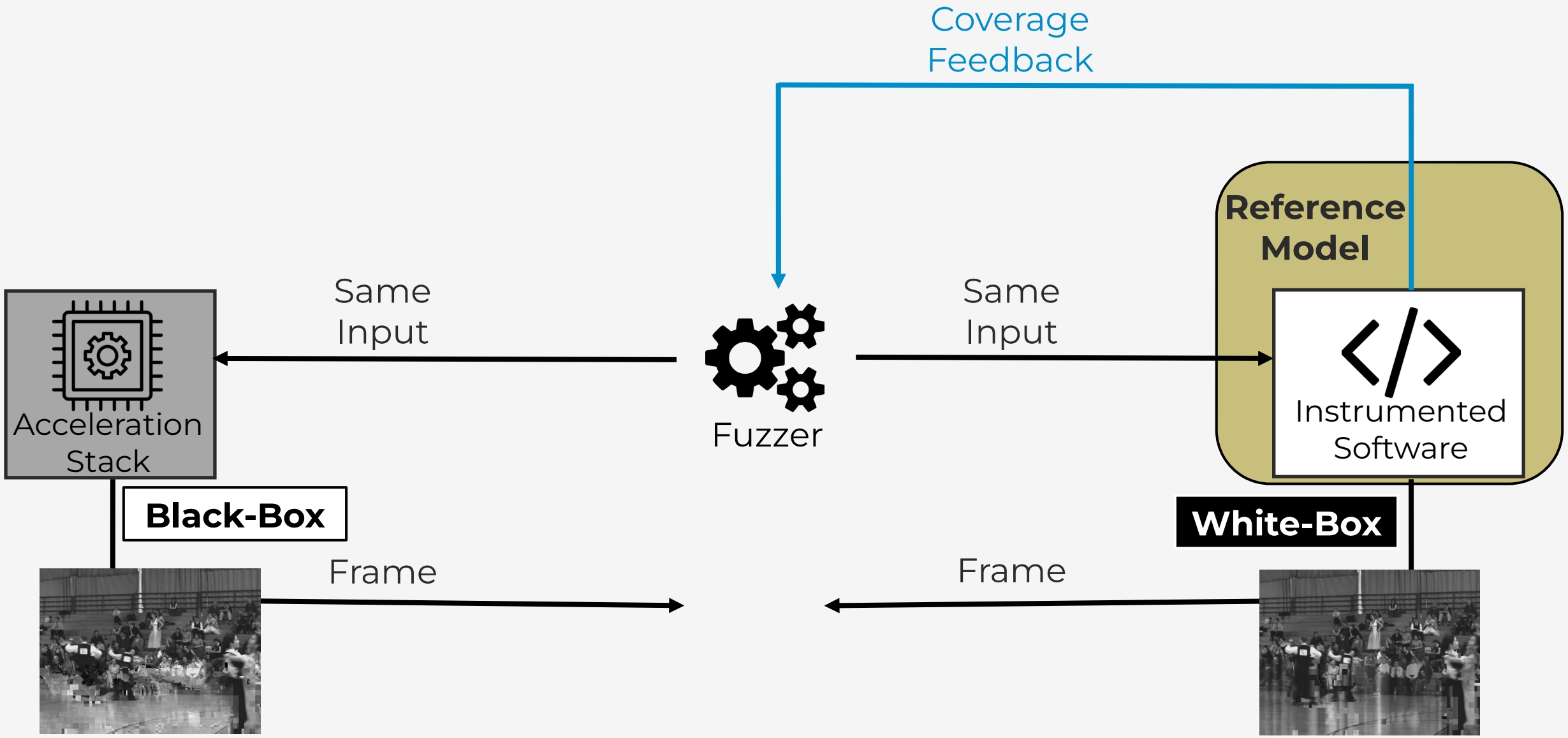

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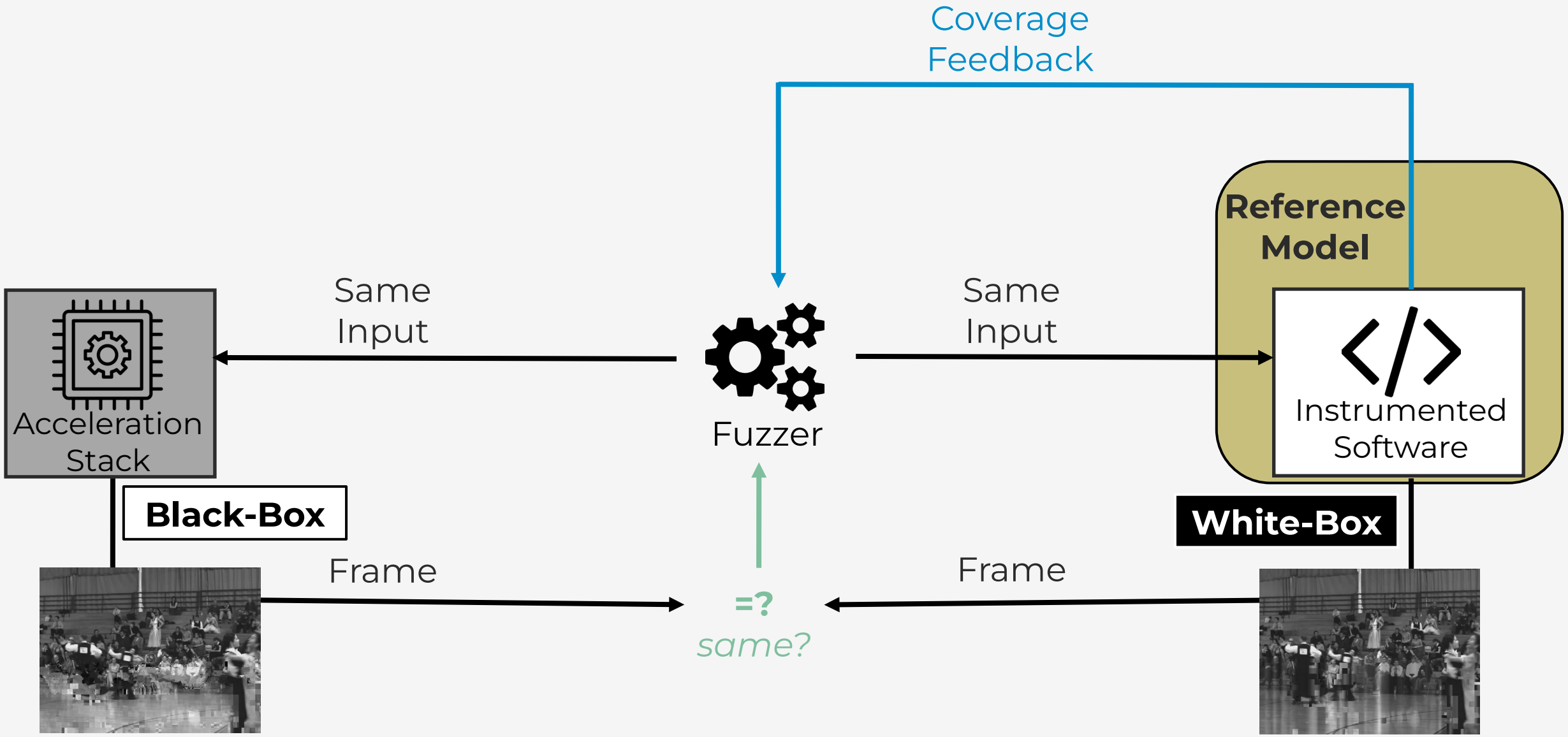

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Observable Differences

Observable Differences

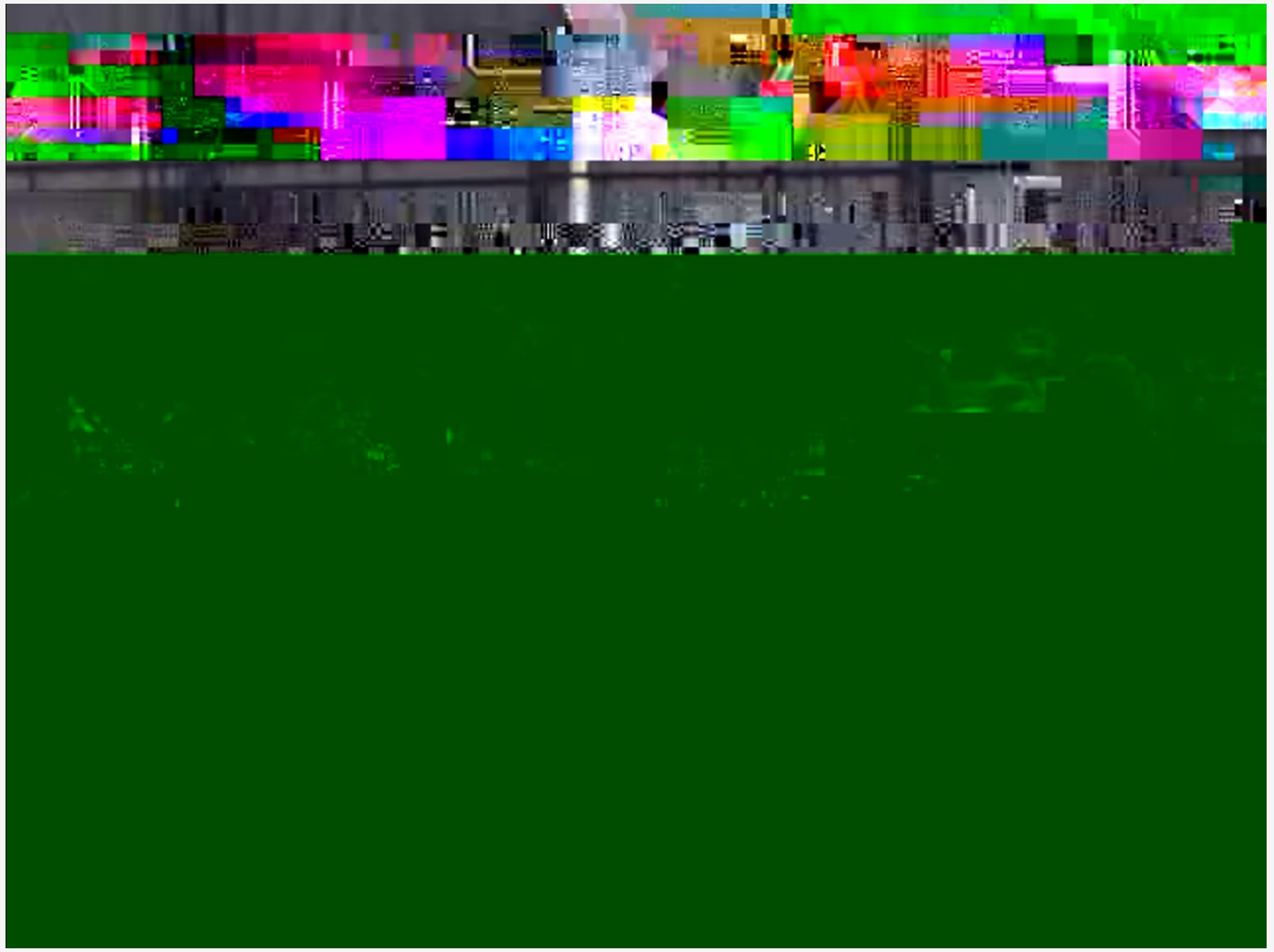
HW Output Frame

Observable Differences

HW Output Frame

SW Output Frame

Frame Rendered in Web Browser



Frame rendered using
hardware acceleration

CH 2: Indirect Proxy Coverage

CH 1

Define a **new oracle** for hardware-accelerated stack

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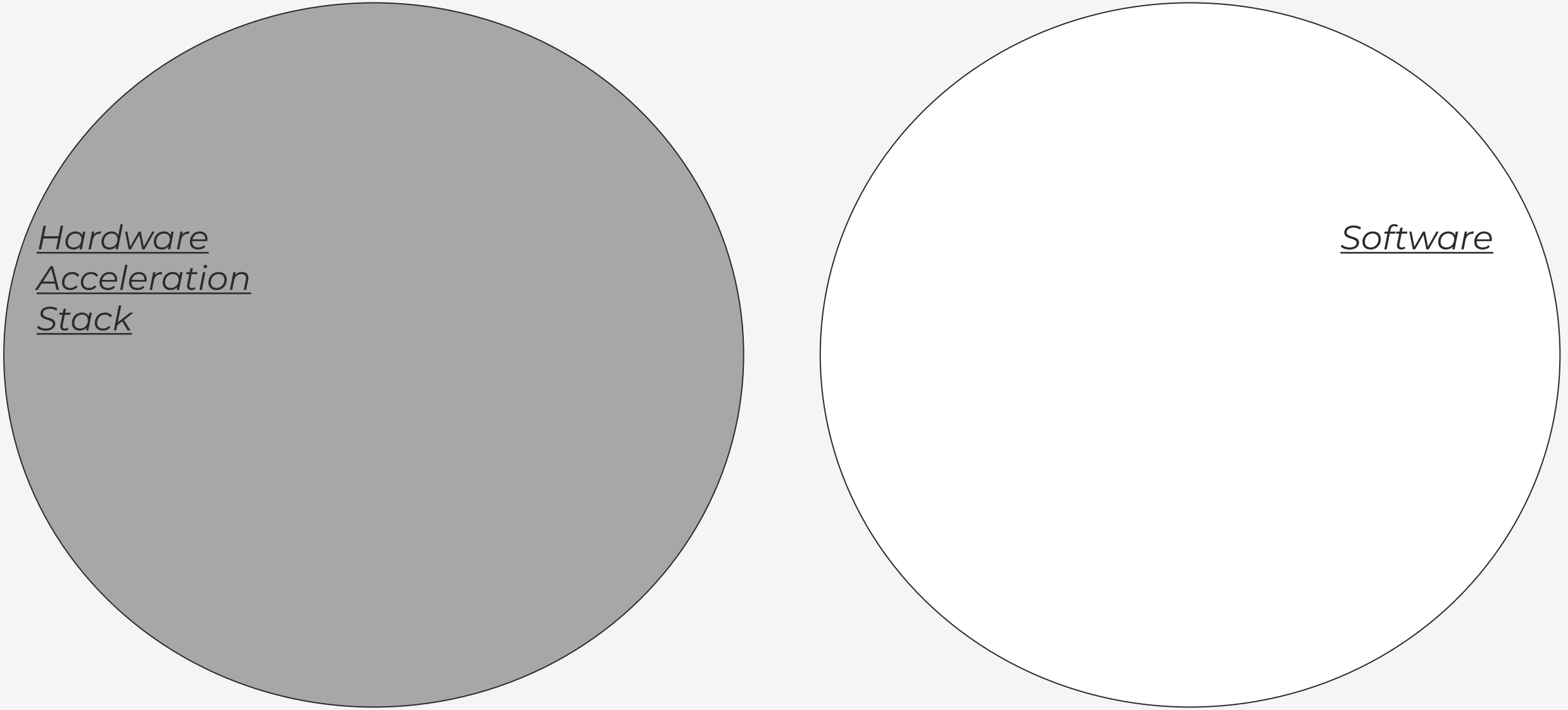

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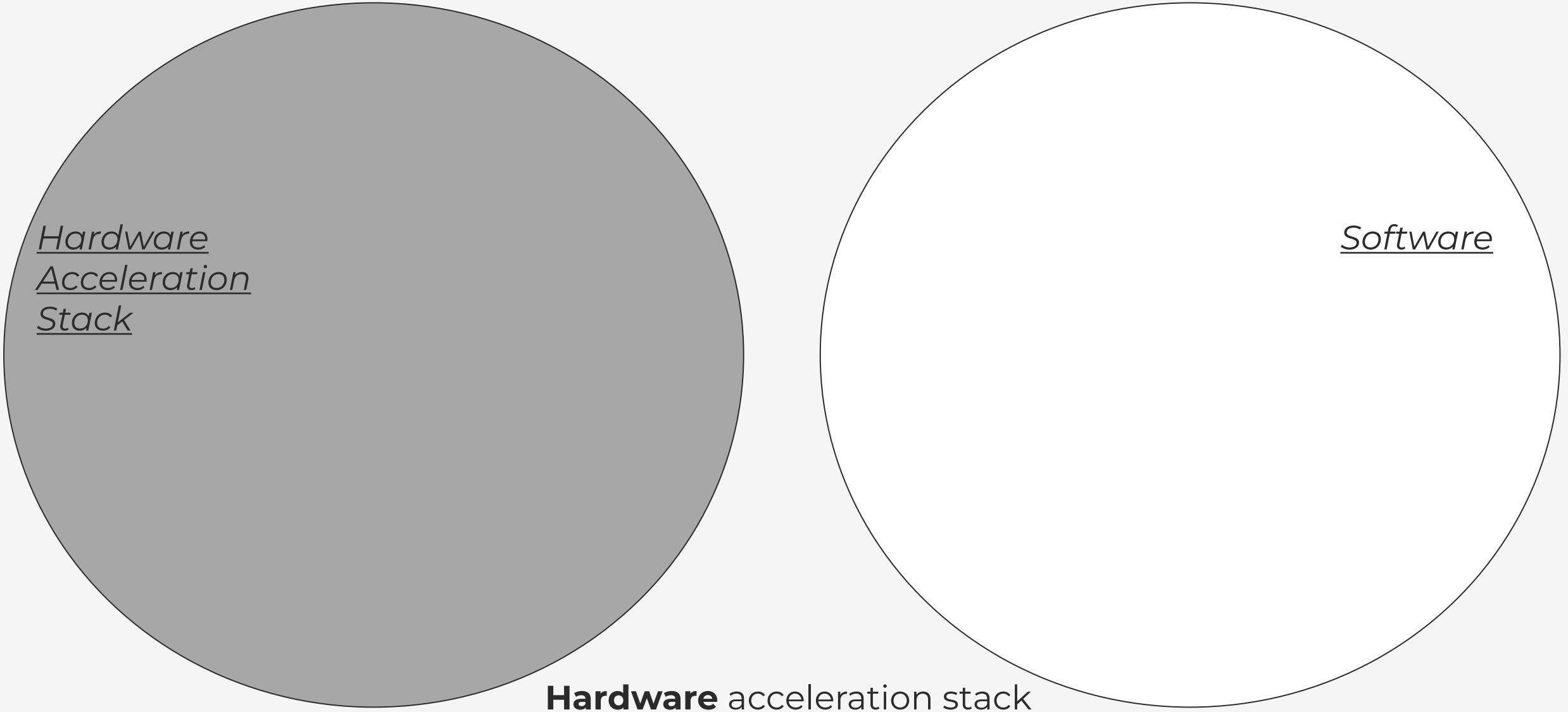

Hardware acceleration stack should **behave as closely** as possible to **software** stack

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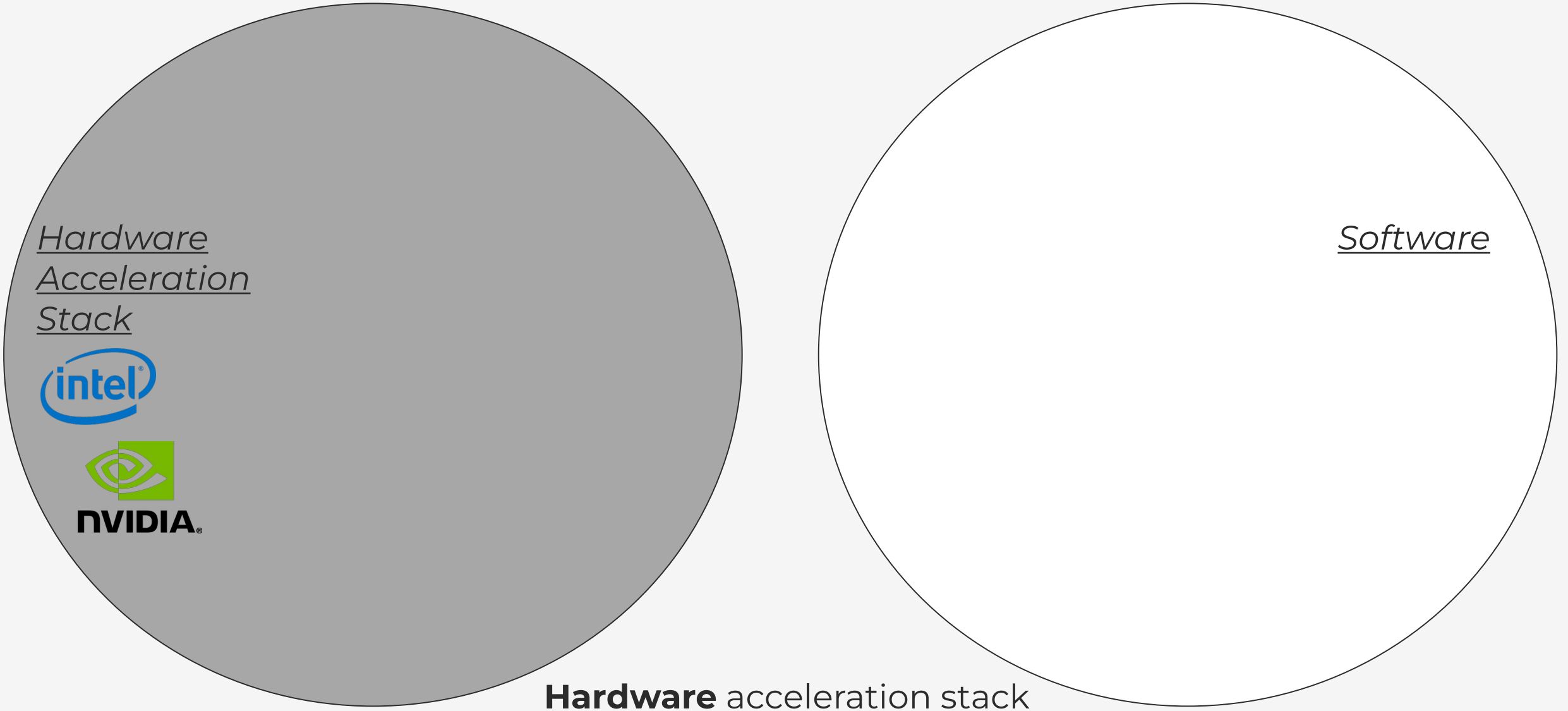

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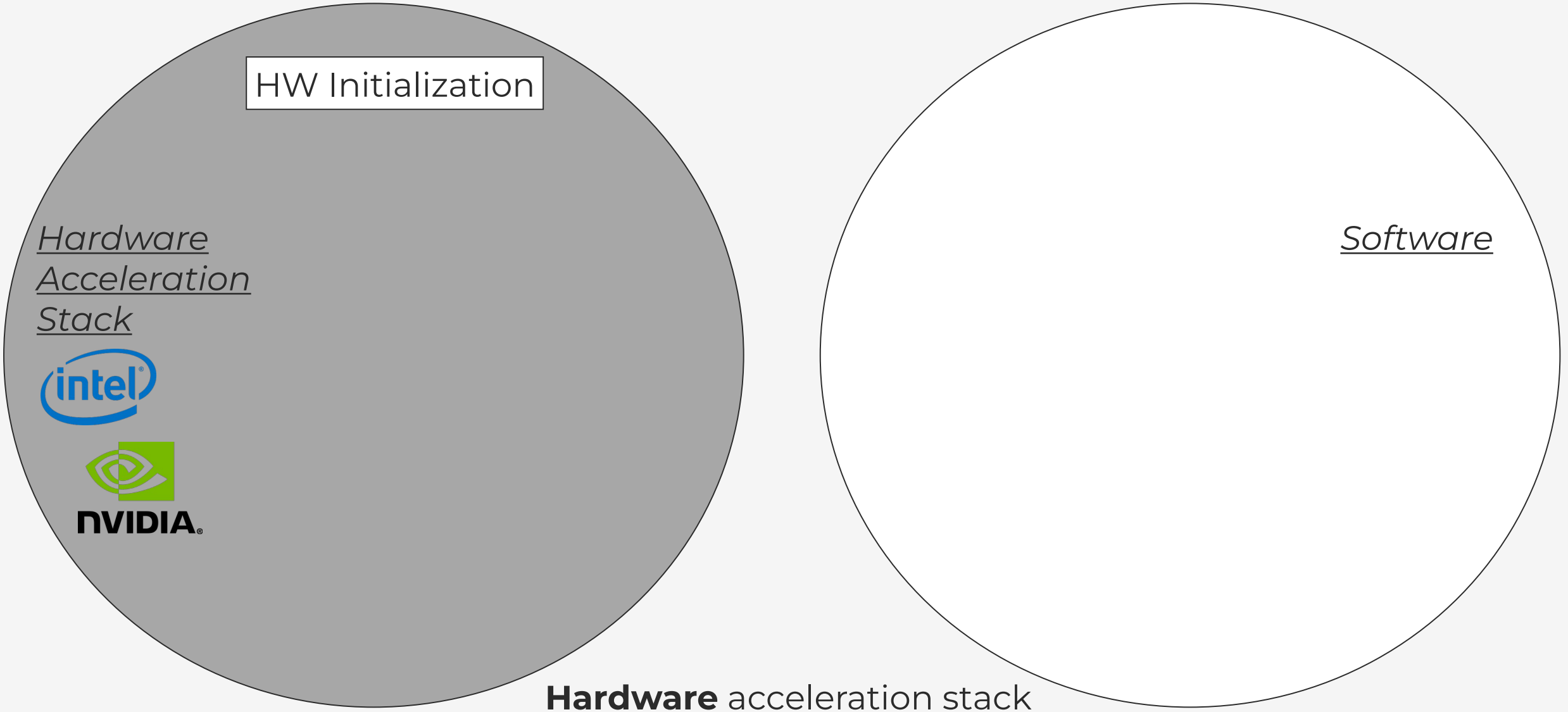

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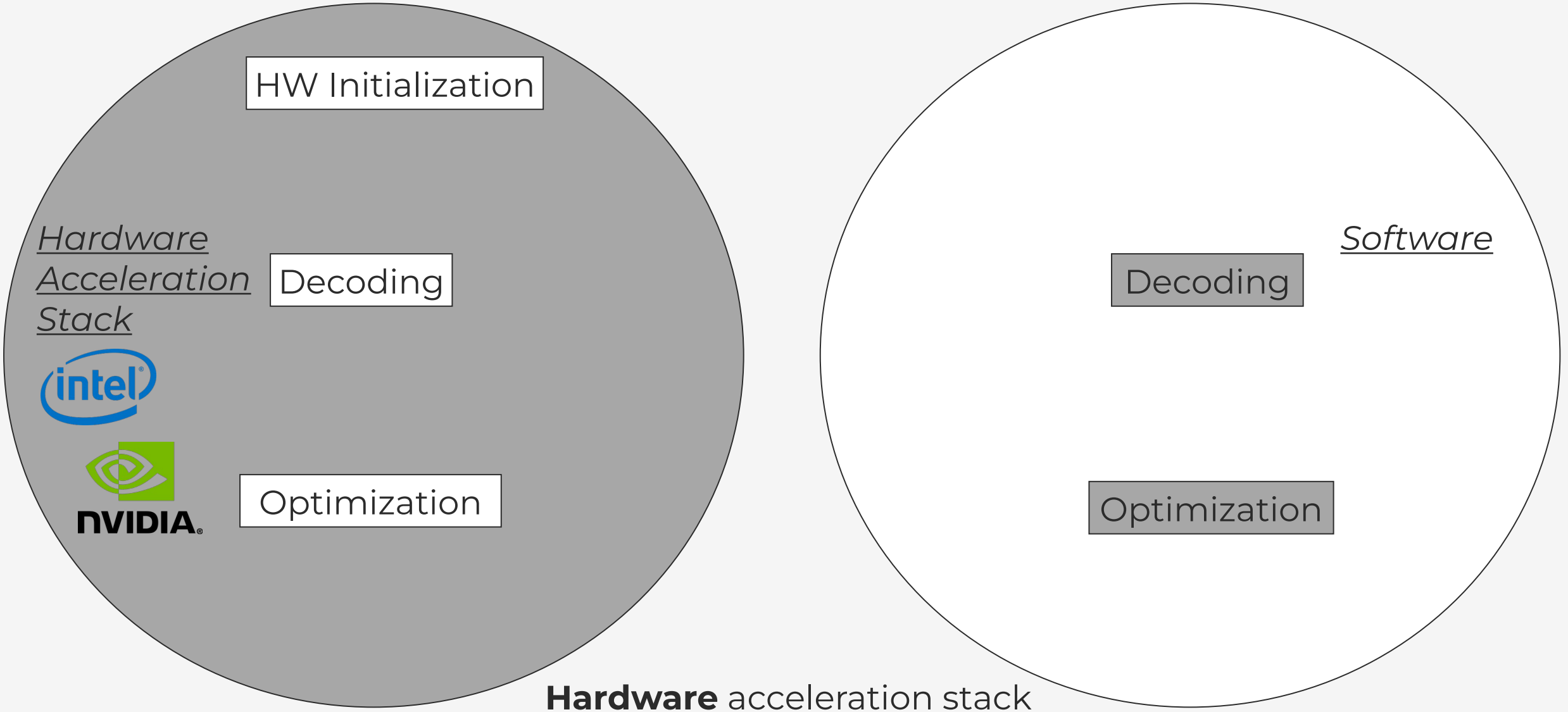

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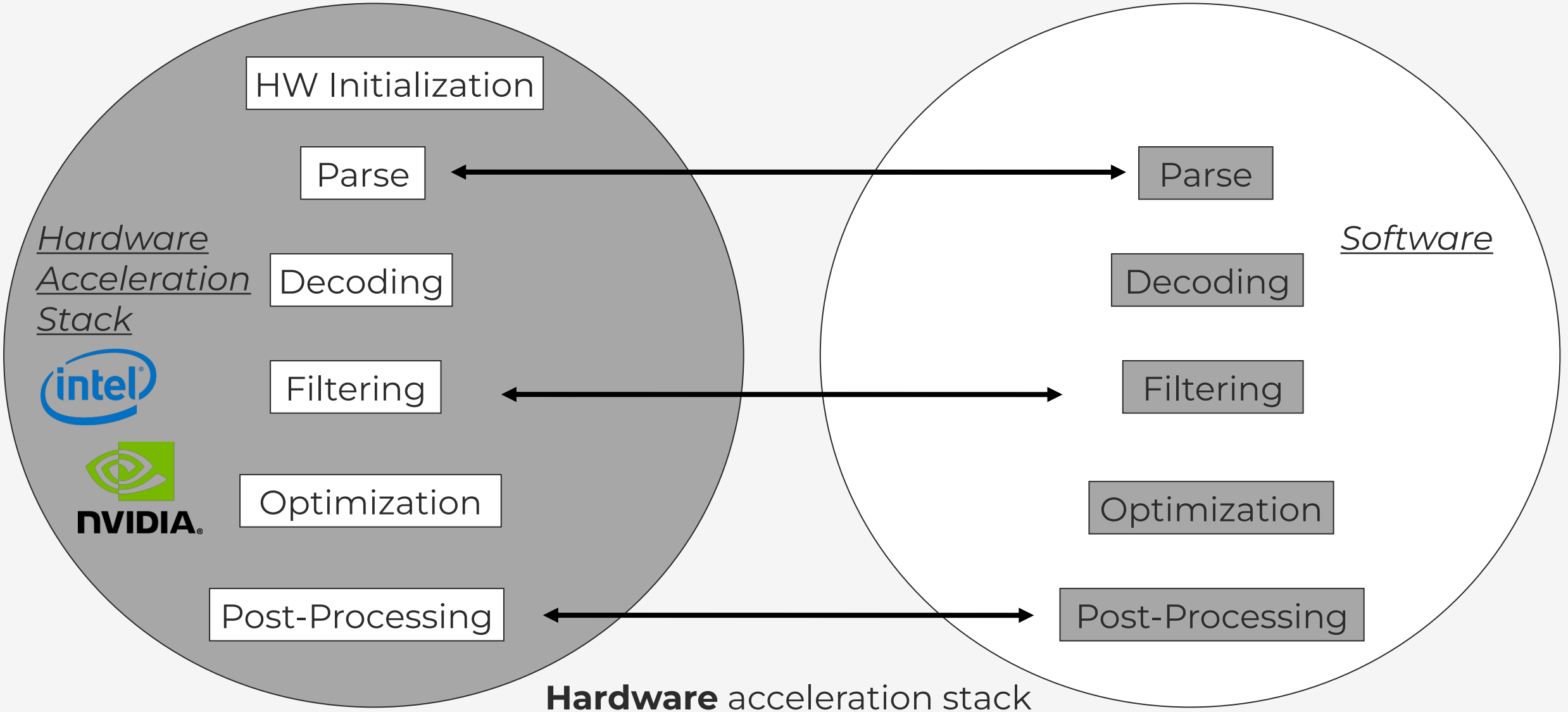

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CH 3: Root Cause with Hardware-accelerated Stack

CH 1 — Define a **new oracle** for hardware-accelerated stack

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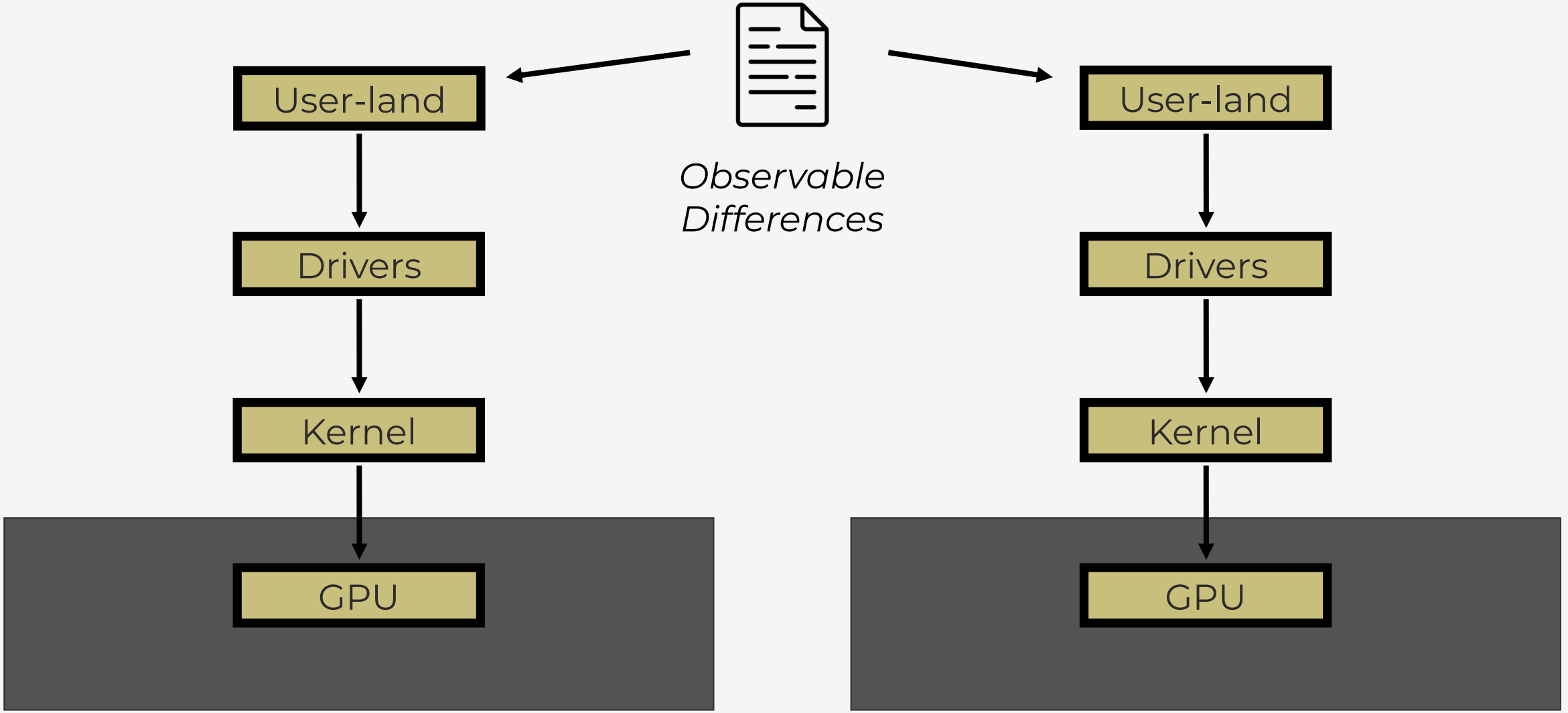

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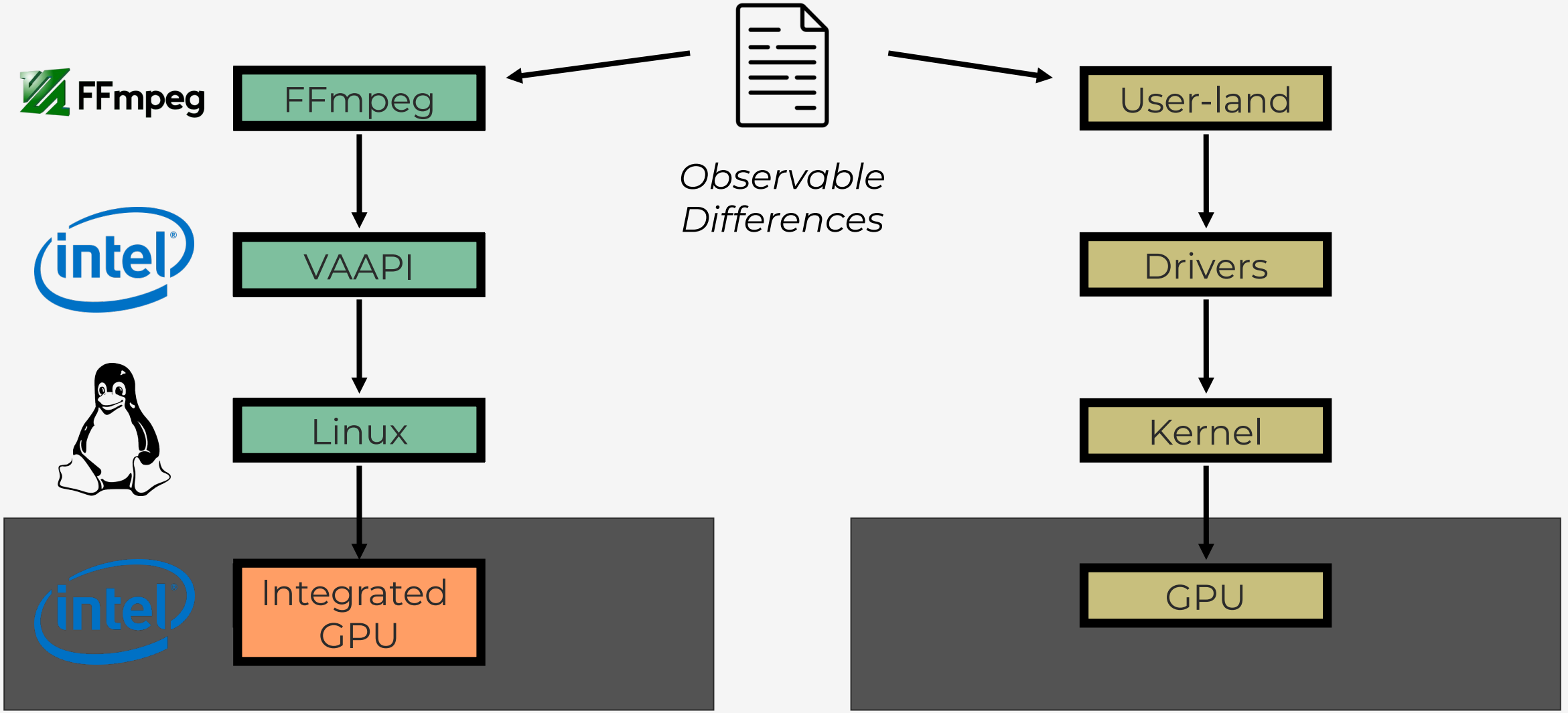

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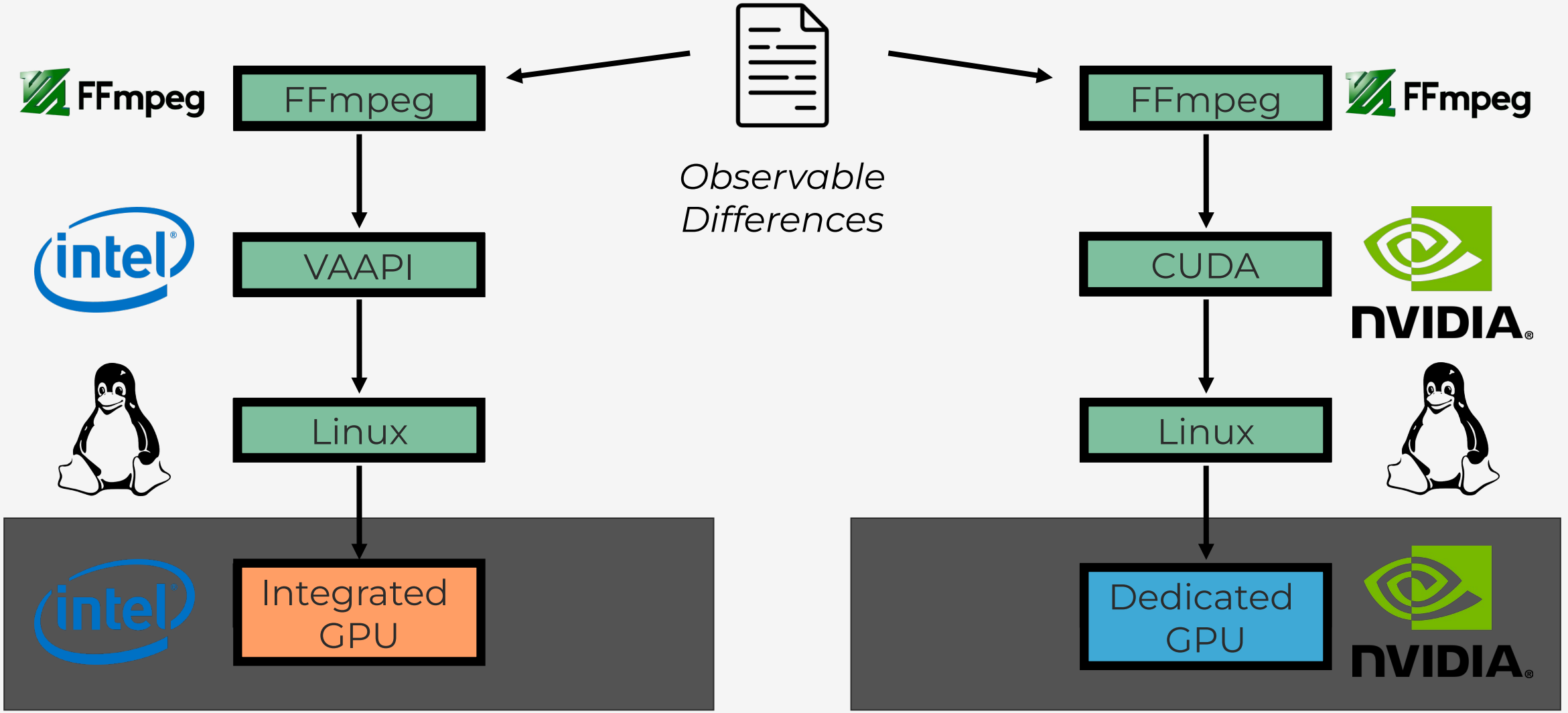

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Bug Findings

Bug ID	Platform	Description	CWE IDs [45]	Layer	Discovery Method	Status
1.a-d	All platforms	Observable difference	204, 474	Undetermined	Fuzzing	Unconfirmed
2	*linux-intel*	Timing-dependent observable difference	204, 362, 474	Undetermined	Fuzzing	Unconfirmed
3	*linux-intel*	Global buffer overflow	126	Application	Fuzzing	Patched
4	*linux-intel*	Heap buffer overflow	122, 787	Driver	Fuzzing	Patched w/ bounty
5	*linux-intel*	Wild pointer dereference	824	Driver	Fuzzing	Disputed
6	*linux-nvidia*	Invalid pointer free	415	Application	Fuzzing	Patched before report
7	*linux-nvidia*	Near-null pointer dereference	824	Application/Driver	Fuzzing	Patched
8	*windows-nvidia*	Information leak on Firefox	908	Application/Driver	Input replay	Confirmed
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Limitations

- ❏ Uses **unspecialized** fuzzer
- ❏ Targets hardware-accelerated **post-silicon video decoding**
- ❏ **Limited** root-cause analysis on observable differences
- ❏ Drivers and GPUs are **bundled**

Take Away

- We present a **new method for testing video hardware acceleration stacks**. We derive a **differential oracle** that may indicate the presence of both correctness and security-relevant faults
- We propose a technique for **indirectly guiding** an unmodified **fuzzer** to abstract **over a hardware acceleration stack** that is otherwise difficult to introspect
- We **implement a prototype called TwinFuzz** capable of fuzzing a specific hardware acceleration stack

https://github.com/CISPA-SysSec/twinfuzz

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