From Browser to Kernel:
Exploring a Lightweight Sandboxed Approach for Unikernel Extensions

Martin Kröning, Jonathan Klimt, Stefan Lankes, Antonello Monti

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What? Why?

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  - single-process,
  - single-address-space, and
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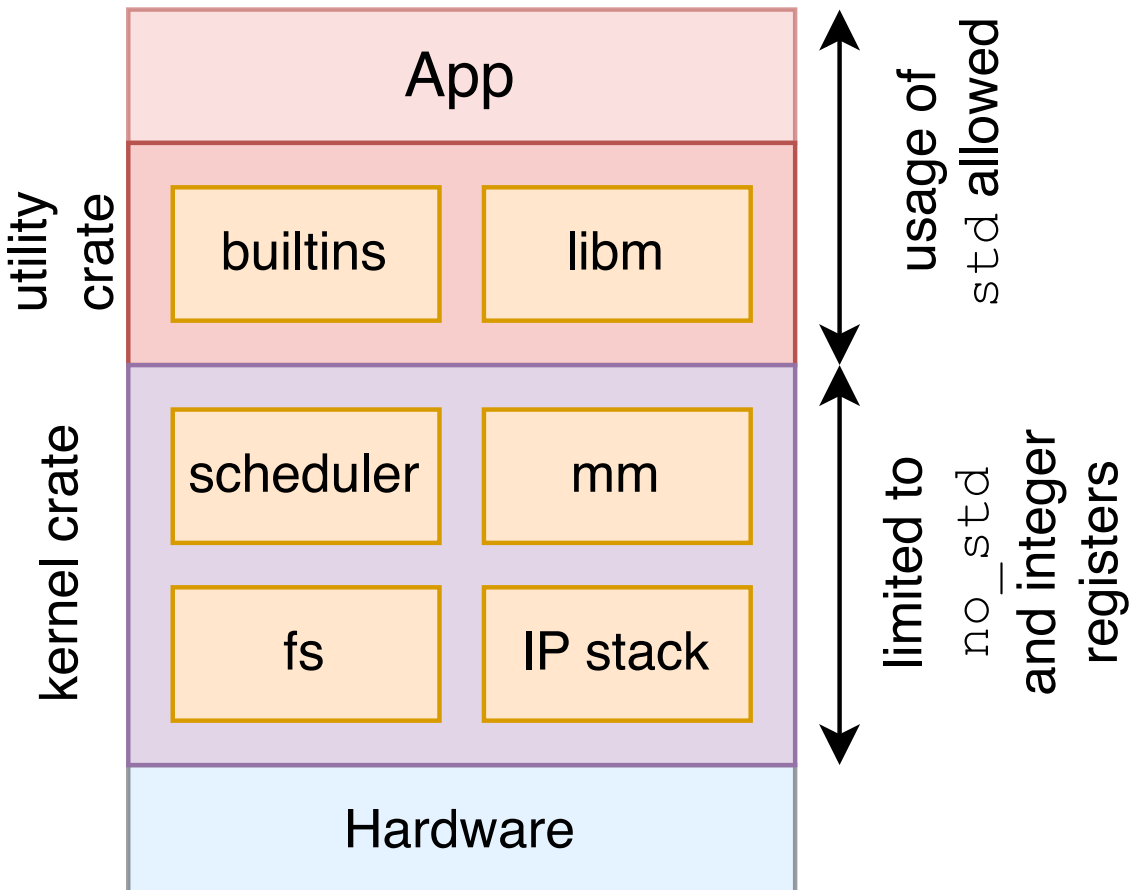
$\Longrightarrow$ Let's use Webassembly in a sandbox using Wasmtime

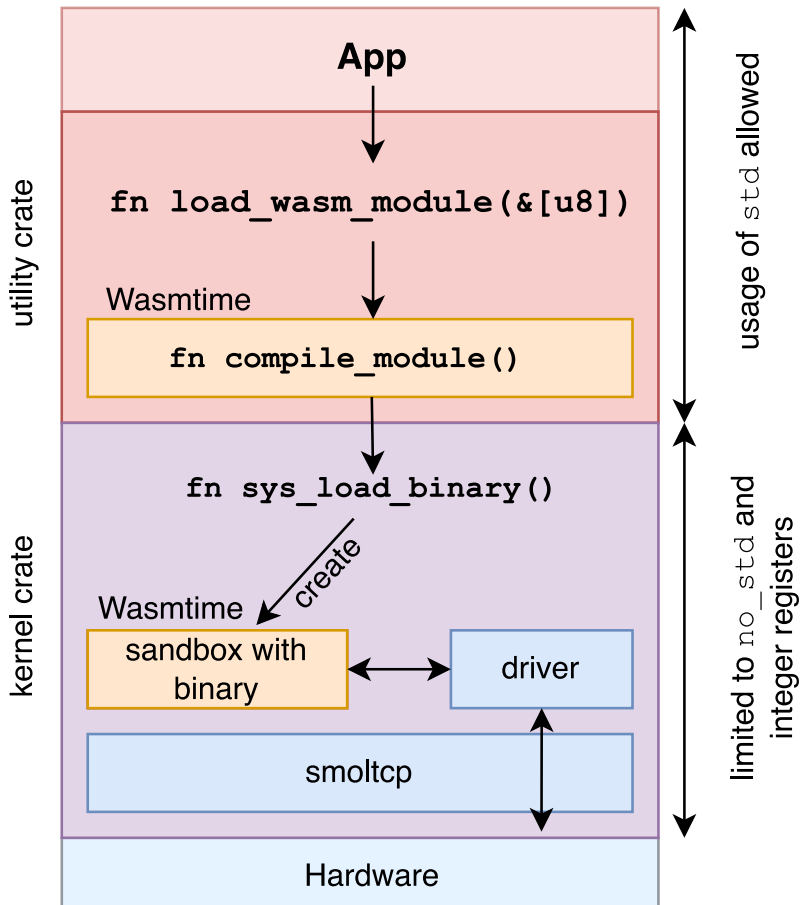
What? Why?

- Extending OS kernels at runtime is great
  - Code injection
  - Network packet tracing
  - Custom drivers
- The Go-to solution: eBPF
  - 👍 Static code analysis by in-kernel verifier
  - 👎 Code has to pass in-kernel verifier
    - = Cannot easily run arbitrary programs

Design of the Hermit libOS



Loading a Wasm Module



Connecting Wasm Space and Kernel Space

```
let mut linker = Linker::new(...);
linker
    .func_wrap("env", "now", || now())
    .unwrap();
```

Connecting Wasm Space and Kernel Space

```
static PCAP_FILE: Mutex<File> = ...;

#[no_mangle]
extern "C" fn handle_pcap() {
    let mut buffer = vec![0; ETHR_SIZE];
    let n = io::stdin().read(&mut buffer)
        .unwrap();

    PcapSink::packet(
        &mut *PCAP_FILE.lock(),
        Instant::ZERO,
        &buffer[..n],
    );
}
```

Key Performance Characteristics of the Wasm Sandbox

- Test platform:
  - AMD EPYC 9354P 32-core processor and 128 GB RAM
  - Hyperthreading was disabled in the BIOS

Benchmark	Result

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Call Wasm NOP function from kernel	127 ns

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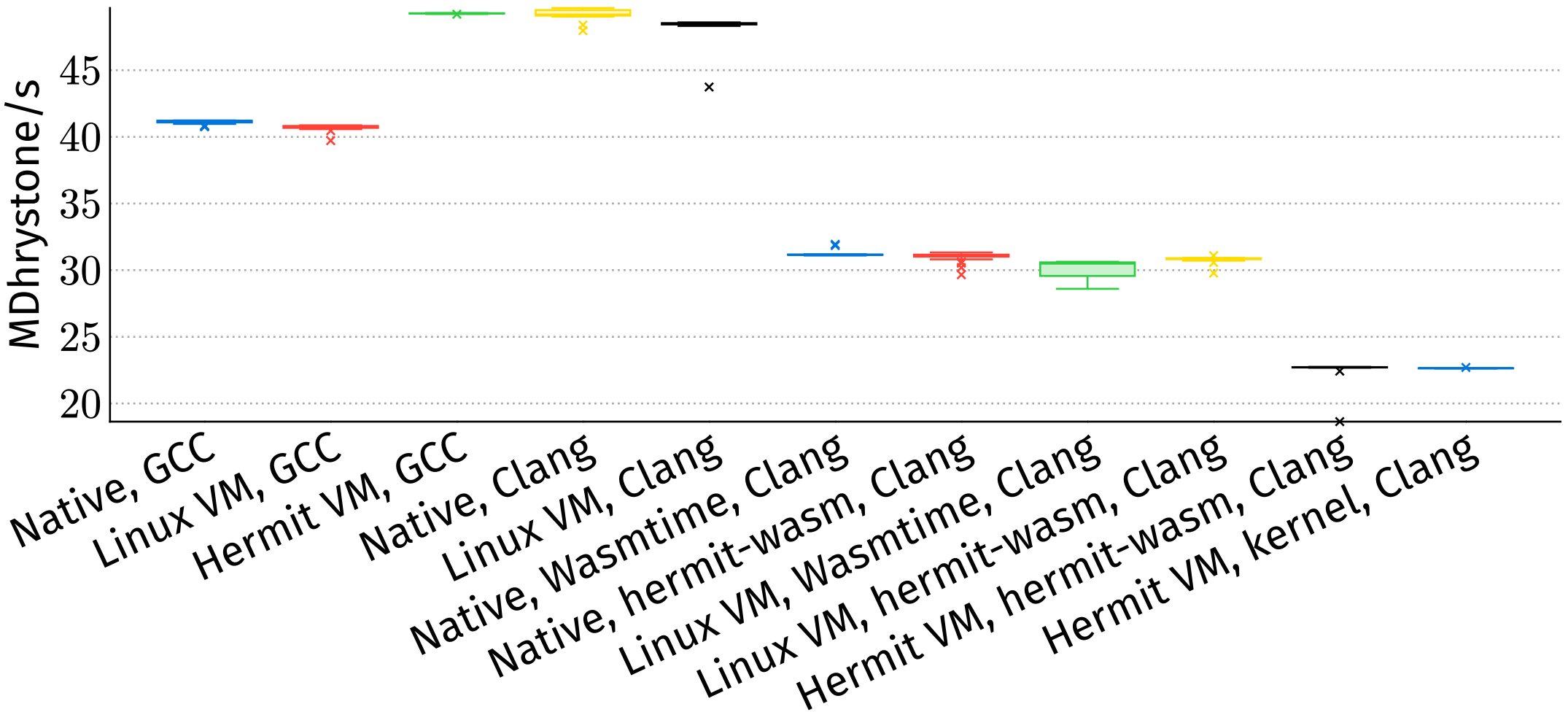
Compile a small Wasm module	940 µs
Instantiate a new sandbox	125 µs
Call Wasm NOP function from kernel	127 ns
Call native NOP function from kernel	0.26 ns

Dhrystone

- Integer arithmetic benchmark form 1988
- Is able to run in kernel and user space
- Wasmtime checks missuage of C functions ⟹ Runtime error

```
@@ -384,7 +384,7 @@
 #define CLOCK_TYPE "time()"
 #undef HZ
 #define HZ     (1) /* time() returns time in seconds */
-extern long     time(); /* see library function "time"  */
+extern long long    time(); /* see library function "time"  */
 #define Too_Small_Time 2 /* Measurements should last at least 2 seconds */
 #define Start_Timer() Begin_Time = time ( (long *) 0)
 #define Stop_Timer()  End_Time   = time ( (long *) 0)
```

Dhrystone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Native, GCC
Linux VM, GCC
Hermit VM, GCC
Native, Clang
Linux VM, Clang
Native, Wasmtime, Clang
Native, hermit-wasm, Clang
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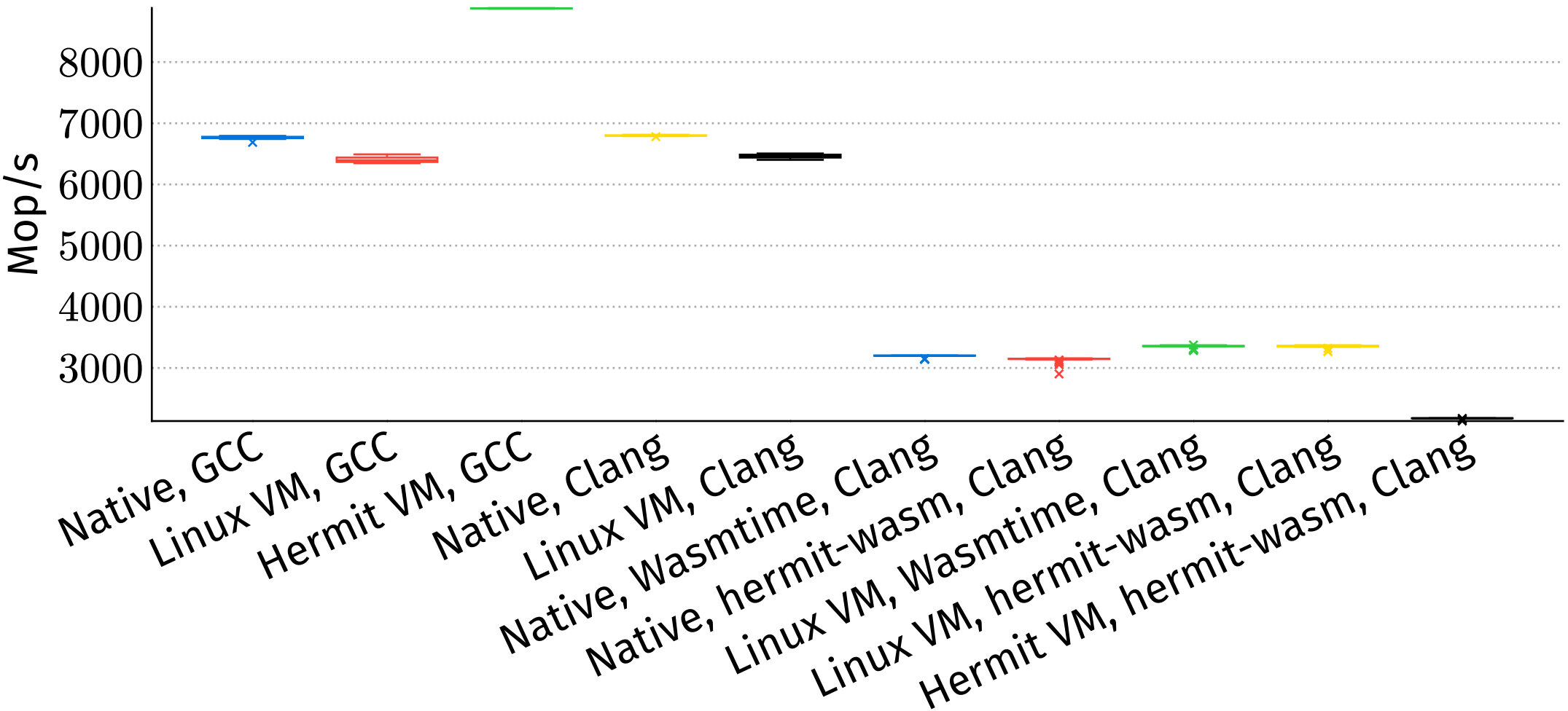
Hermit VM, kernel, Clang

SNU-NPB MG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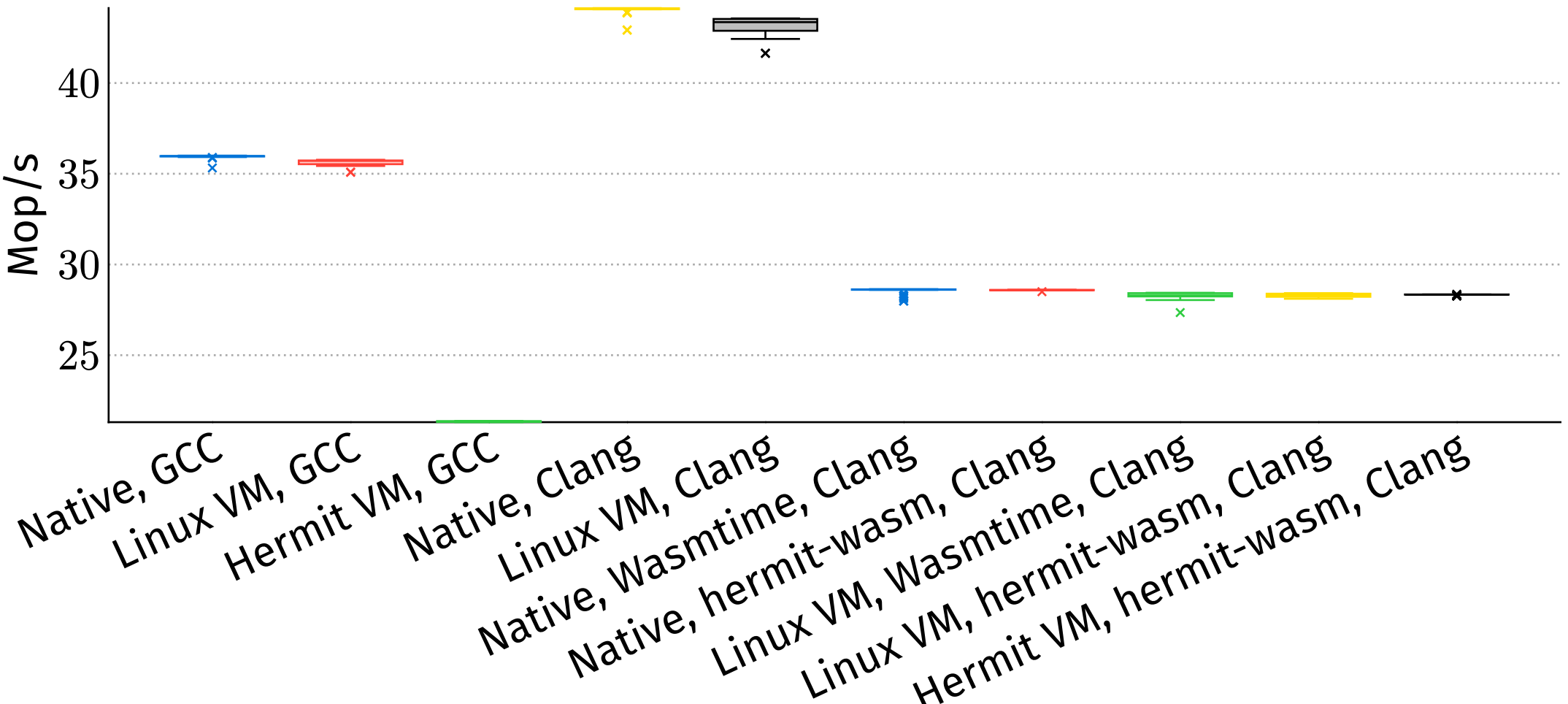
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- OS extensions with eBPF
  - have to be verified statically,
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Our work

- OS extensions with WebAssembly
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  - are the flexible choice for single-process OSes.
- Performance is not terrible! (thanks to Wasmtime)

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  - Device drivers
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Thanks for listening! 😊

Acknowledgments

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Martin Kröning, Jonathan Klimt, Stefan Lankes, Antonello Monti – slankes@eonerc.rwth-aachen.de

Institute for Automation of Complex Power Systems
E.ON Energy Research Center, RWTH Aachen University
Mathieustraße 10
52074 Aachen

www.acs.eonerc.rwth-aachen.de

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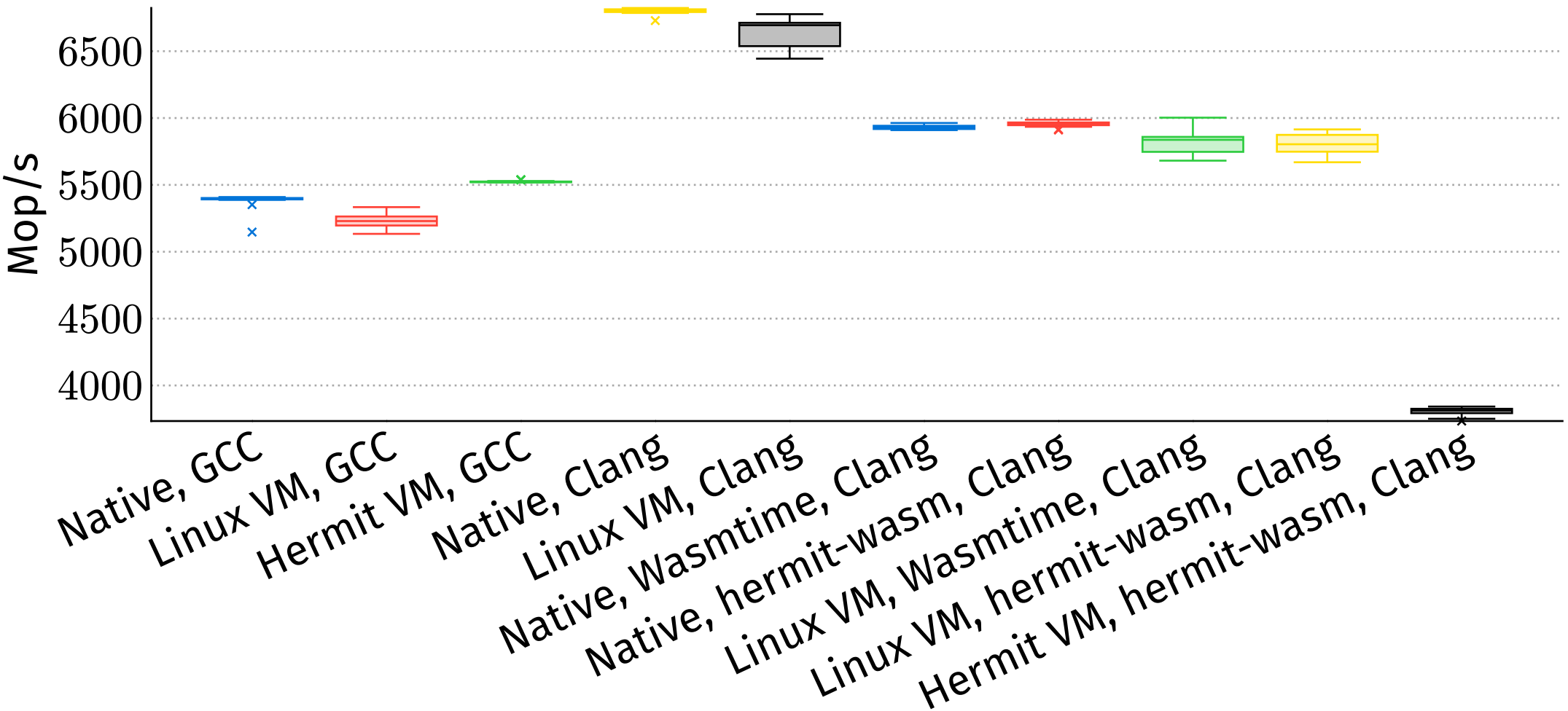
Backup Slides

SNU-NPB BT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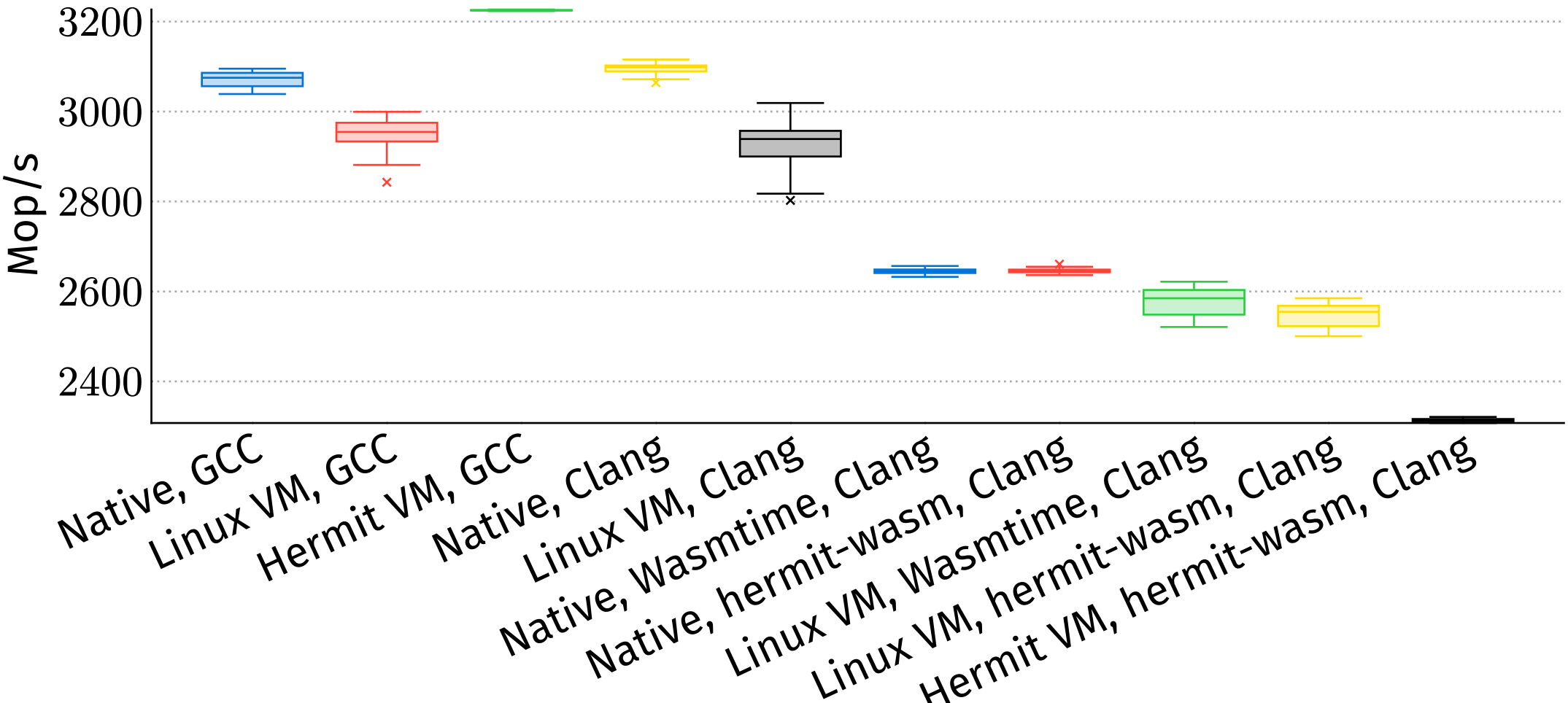
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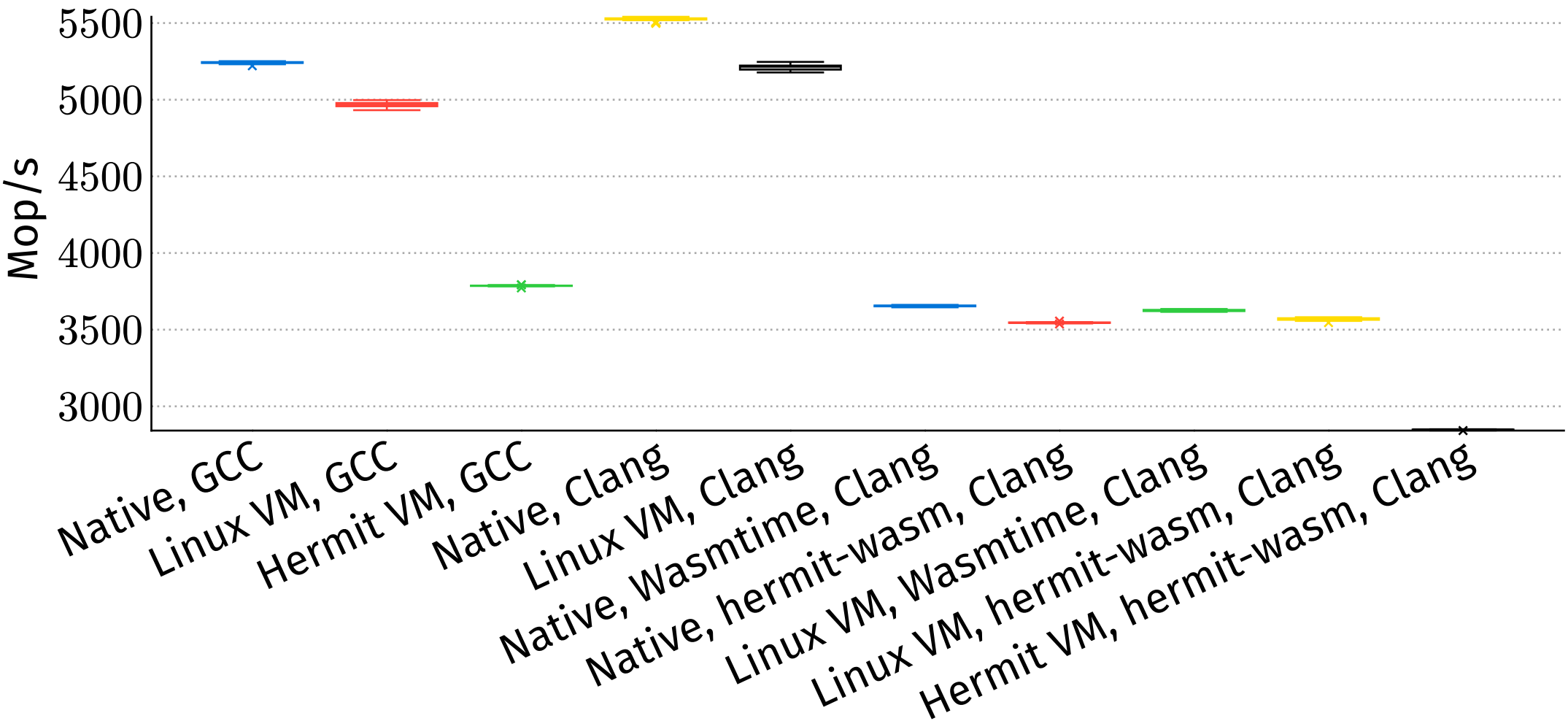
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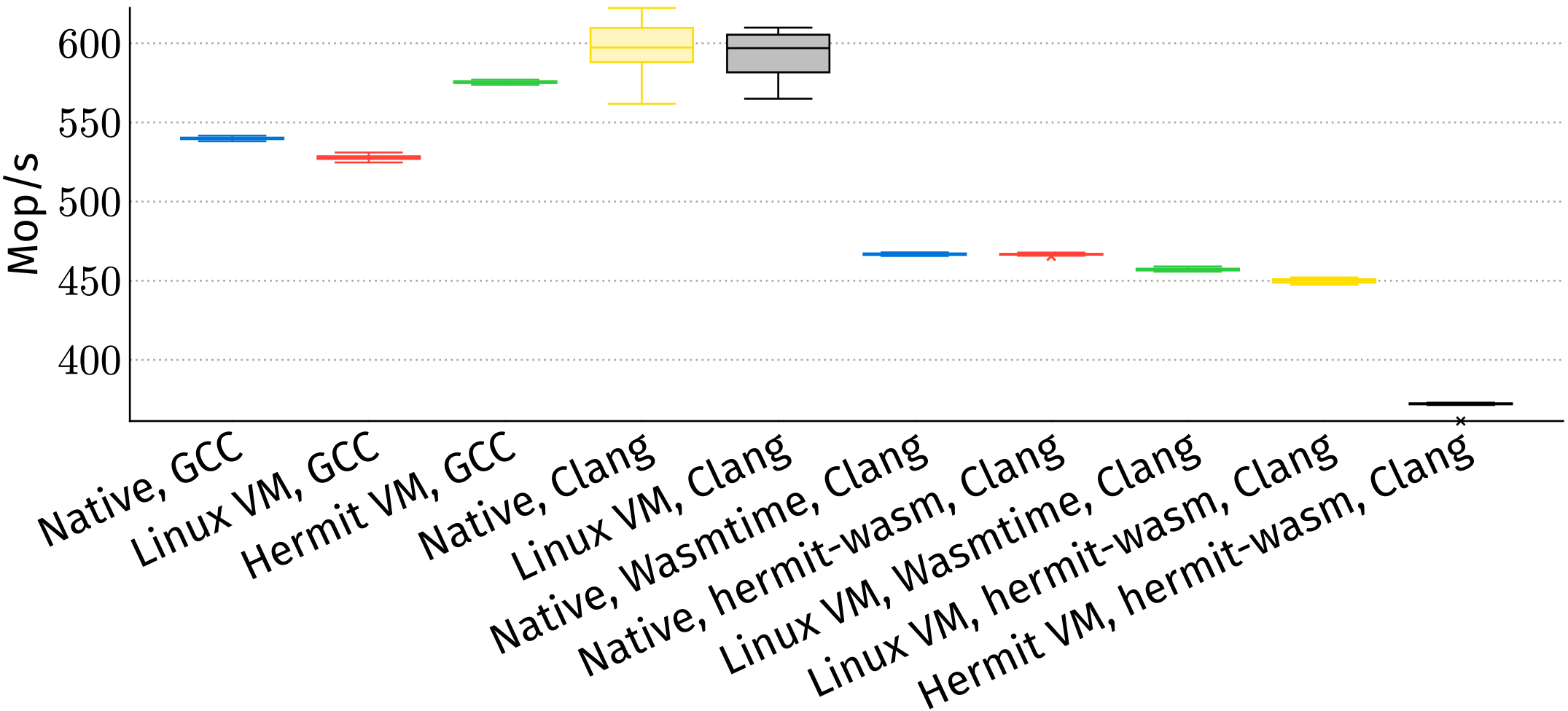
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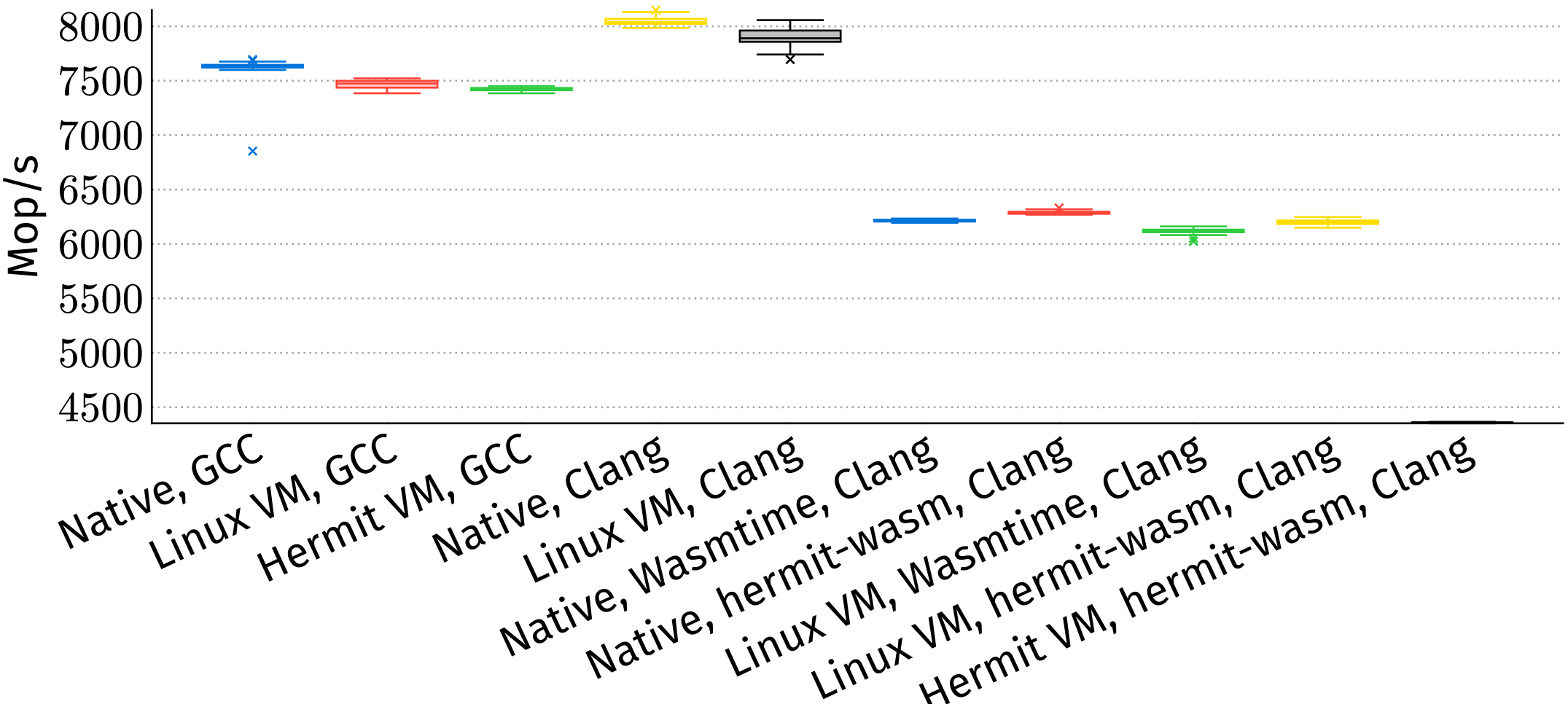
SNU-NPB SP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