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Enabling Syscall Interception on RISC-V

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The European Union's technological sovereignty strategy centers around the RISC-V Instruction Set Architecture, with the European Processor Initiative leading efforts to build production-ready processors. Focusing on realizing a functional RISC-V ecosystem, the BZL initiative from Spain is making an effort to create a software stack along with the hardware. In this poster, we detail the efforts made in porting a widely used syscall interception library, mainly used on AdHocFS (i.e., DAOS, GekkoFS), to RISC-V and how we overcame some of the limitations encountered.

***syscall_intercept* library:**
https://github.com/GekkoFS/syscall_intercept/tree/riscv

***GekkoFS*:**
https://storage.bsc.es/gitlab/hpc/gekkofs

Implementation

Obstacles

1. The relative jump instruction (`jal`) has a **±1 MB reach** which is not enough to jump out of *libc*, unlike x86's `jmp` (±2 GB) or PowerPC (±32 MB).
2. Instructions are naturally better aligned, so **nops are rarely present** in *libc*, eliminating the possibility of using *nop-trampolines*.
3. The Linux kernel on RISC-V **saves the full context** during interrupts, including caller-saved registers. This is relevant for indirect jumps because no register can be overwritten.

These constraints required the use of an indirect jump sequence (`auipc + jalr`), and the calling convention **must be preserved**. This sequence requires 8 bytes, plus prologue/epilogue, **totalling 16 B** when RVC is supported. **x86 requires only 5 or 2 B** (with nop-trampoline).

Solution

Three patching methods:

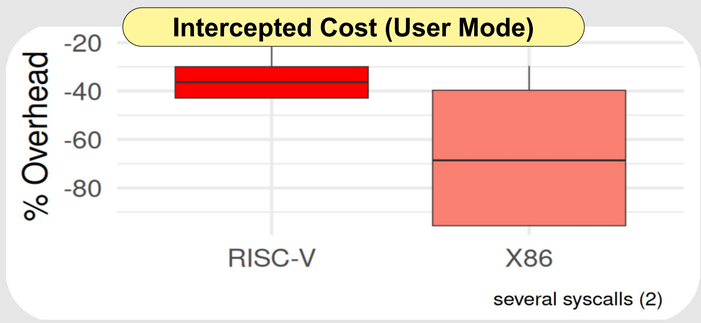
1. **Gateway Patch**: Applied when an *ecall* is surrounded by many relocatable instructions. It creates a ±2 GB jump, serving as the foundation for the library. Smaller patches jump to these gateways to reach the *syscall_intercept* library.
2. **Middle Patch**: Applied when a sufficient number of relocatable instructions are available to preserve the calling convention. It jumps with `jal` to the gateway, where it gets "forwarded" to the *syscall_intercept* library.
3. **Small Patch**: Applied when there is not enough space to preserve the calling convention. Static analysis stores the syscall number (a7) in the patch's structure, allowing `jal` to overwrite it, as its value is restored later inside the library.

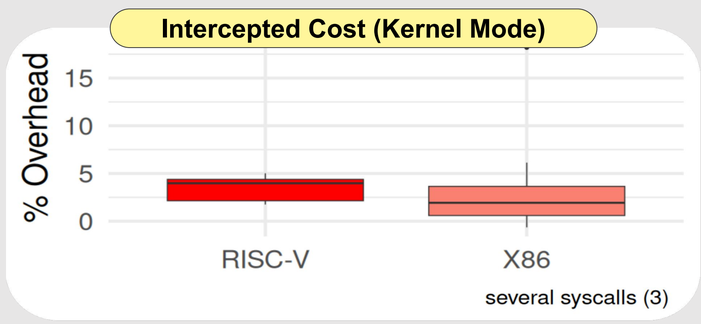
Approximately, *libc* is patched with 40% Gateway, 45% Small, and 15% Middle patch types.

Trade-offs

Less memory is allocated per patch because the library uses an indirect patching approach. Instead of each patch jumping to its own location, all patches redirect to a shared entry point, where they are dynamically identified. This design slightly **increases runtime overhead** (see Overhead), but significantly **reduces overall memory usage**.

Overhead





Platforms: TH1520 RISC-V CPU (4 harts) from Lichee PI 4A
i7-8650U x86 CPU (4 harts) from Dell Latitude

We analyze three distinct cost scenarios:

- **Normal**: The cost of executing the standard *libc* function (e.g., `getpid()`) without interception. These measurements serve as the baseline reference for the overhead charts on the left.
- **Intercepted Cost (User Mode)**: The cost of executing the intercepted *libc* function when the corresponding syscall is bypassed. Since the Linux kernel isn't called to execute the syscall, the overhead is negative in the chart on the left.
- **Intercepted Cost (Kernel Mode)**: The cost of executing the intercepted *libc* function with a call to the corresponding syscall. In this case, the chart shows a positive overhead due to the complexity of patching *libc* and the added indirection to reach the Linux kernel.

Basic examples of patch types

```
f7de0:   addi   sp, sp, -48
f7de2:   sd     ra, 0(sp)
f7de4:   auipc  ra, <offset>
f7de8:   jalr   ra, <offset>(ra)
f7dec:   ld     ra, 0(sp)
f7dee:   addi   sp, sp, 48
```

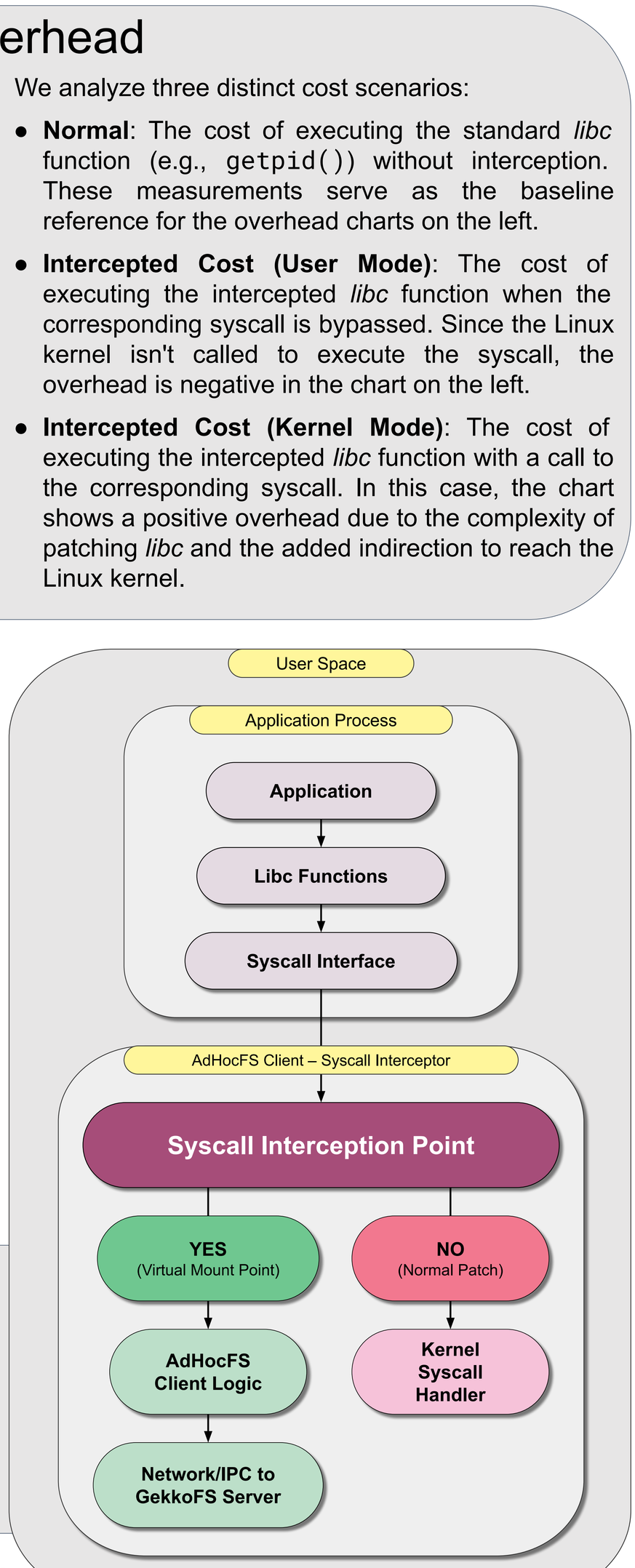
```
e5fa4:   addi   sp, sp, -48
e5fa6:   sd     ra, 8(sp)
e5fa8:   jal    ra, <GW addr offset>
e5fac:   ld     ra, 8(sp)
e5fae:   addi   sp, sp, 48
```

- Case when a register gets set after the ecall:

```
a13ea:   jal    a7, <GW addr offset>
```

- Case when no register gets set after the ecall:

```
a13ea:   jal    a7, <GW addr offset>
a13ec:   li     a7, <syscall number>
```



Use case: GekkoFS

In AdHocFS, the library **reduces** the number of required hooks, improving **compatibility** with *libc* interception. Separate hooks for different `stat()` or `open()` variants are unnecessary. It also enables interception of applications that bypass libc, which would otherwise be difficult to handle and debug.

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