FOSDEM‘24
February 3, 2024

Linux Binary Compatible Unikernels

How your Application runs on Unikraft

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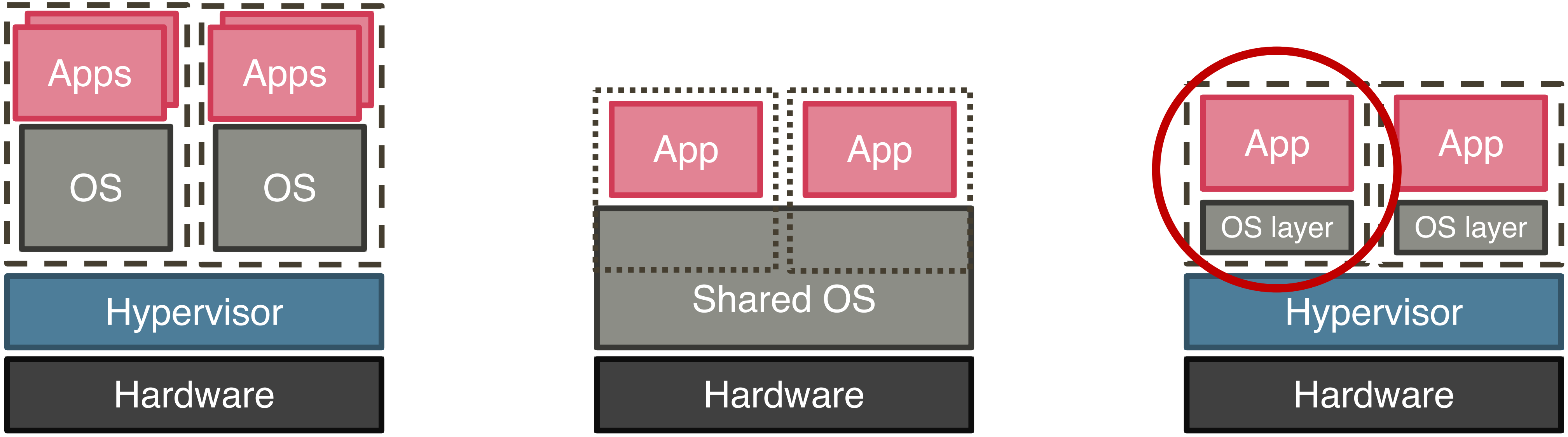
Unikraft: The Unikernel SDK

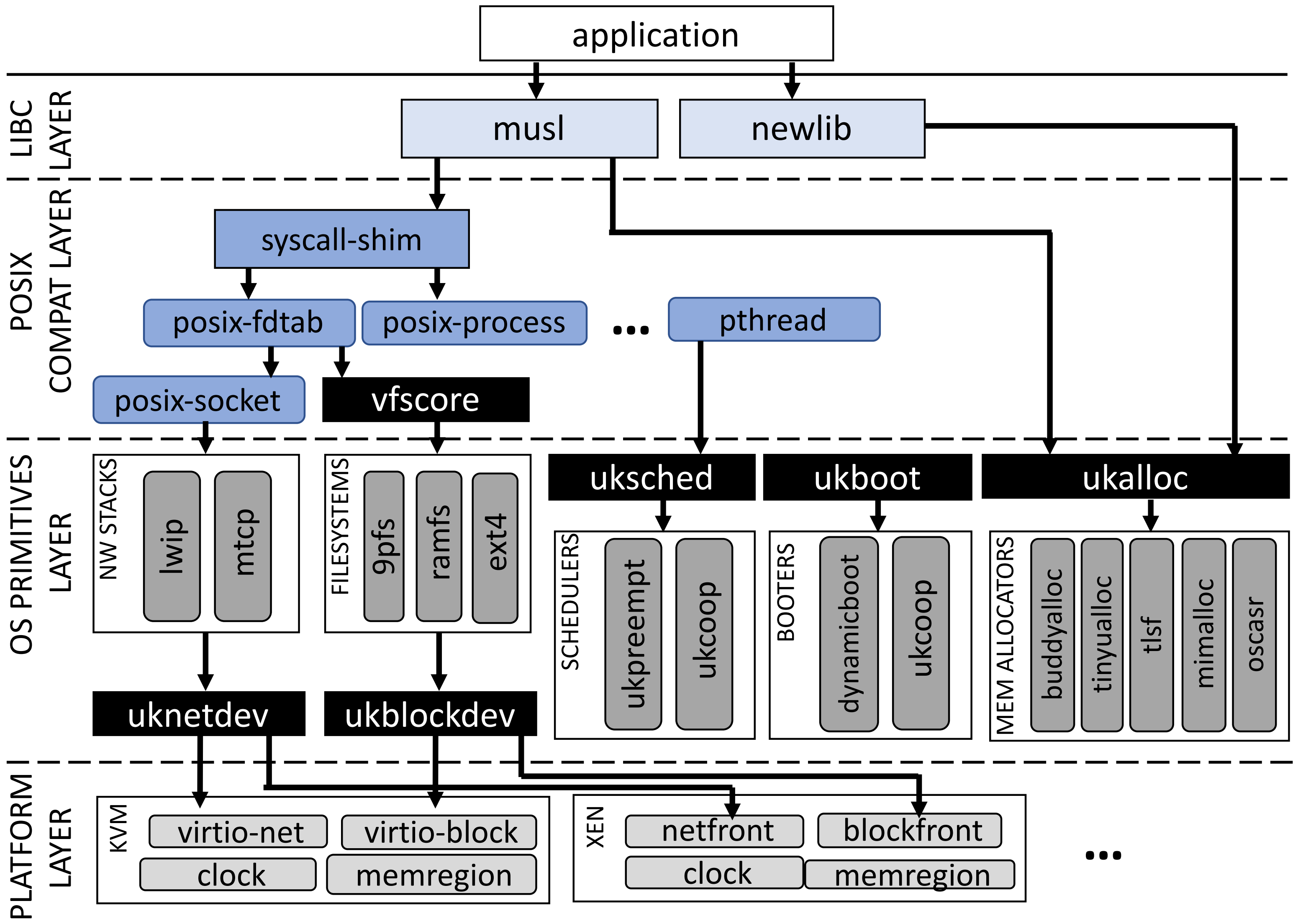
Unikernel Primer



Traditional VMs　　Containers　　Unikernel VMs

- Single purpose: One application & one target platform
  - Flat and single address spac
  - Only necessary kernel components
  - Small TCB and memory footprint

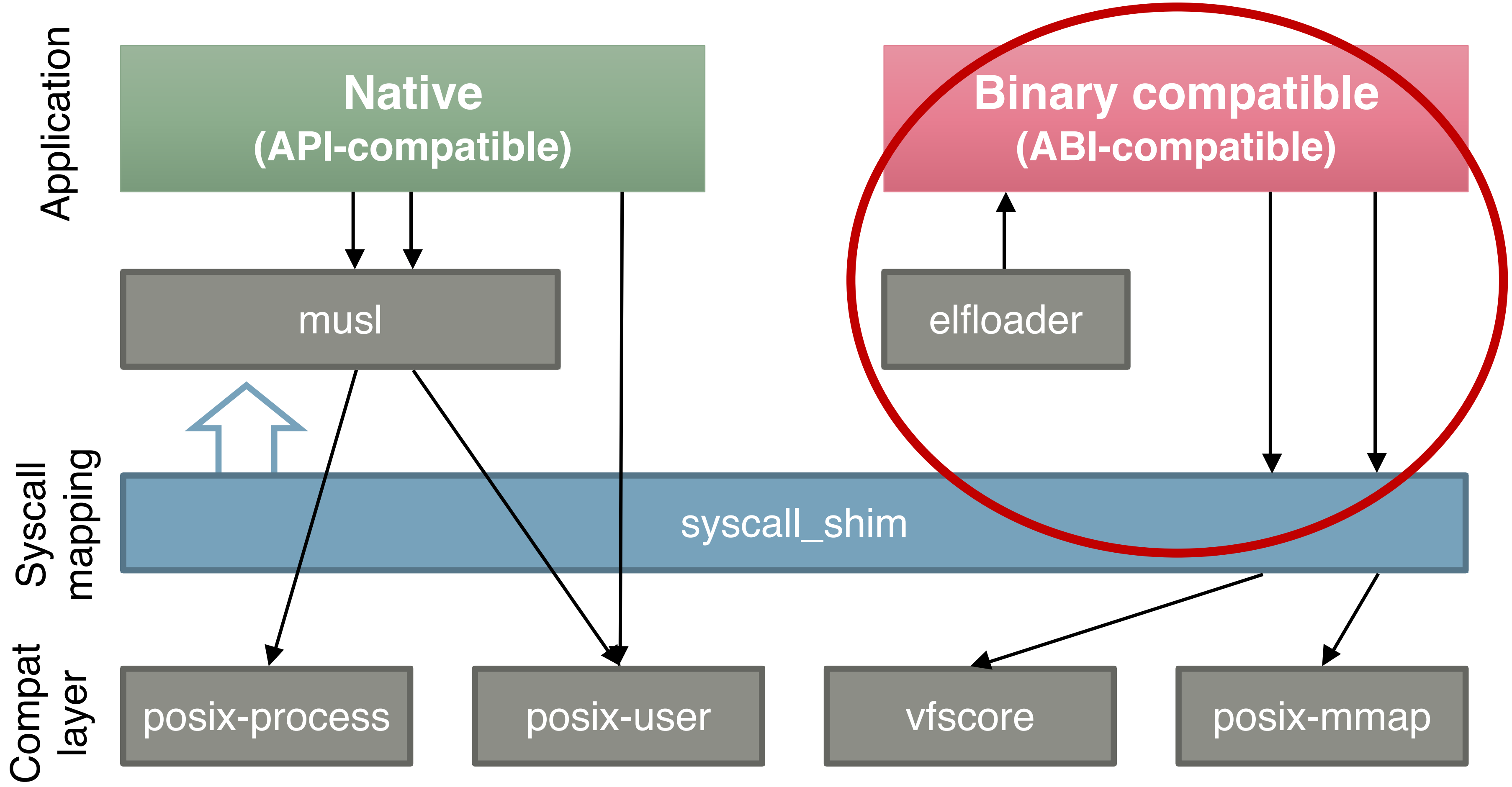
Unikraft's (Micro)-Library Stack



Current project focus: Linux Compatibility

- Our vision: Seamless application support
  - → Most software is developed for Linux
  - → Remove obstacles for running them on Unikraft

The 2 Approaches for Compatibility



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Loading ELF Binaries

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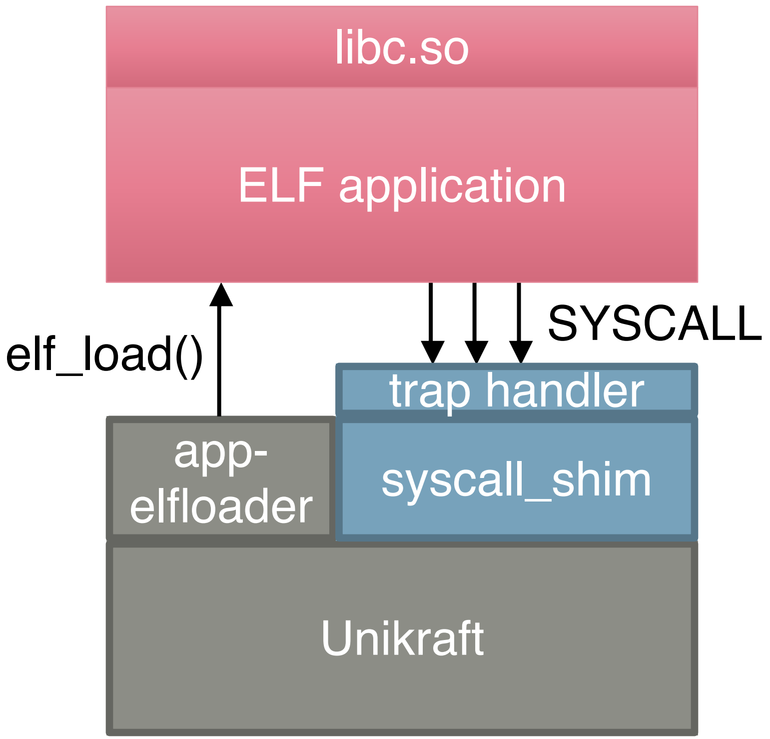
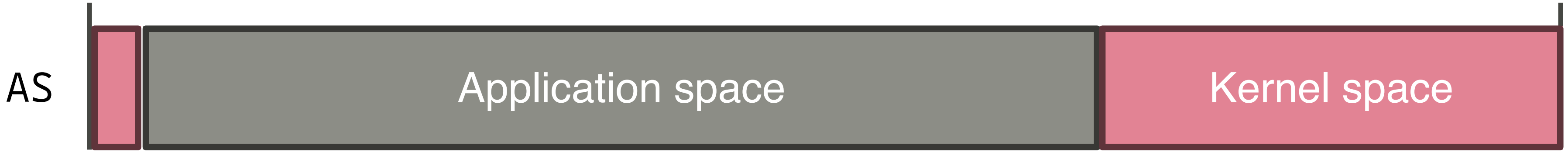
- Straight-forward process:
  1) Parse & load executable/loader
  2) Prepare entrance stack, jump to entrance
  3) Interact with system calls



Challenge PIE vs. Non-PIE Executables

- Non-PIE dictates AS-layout
  - Single AS → only <u>one</u> non-PIE app
  - Limits area where (uni-)kernel relies



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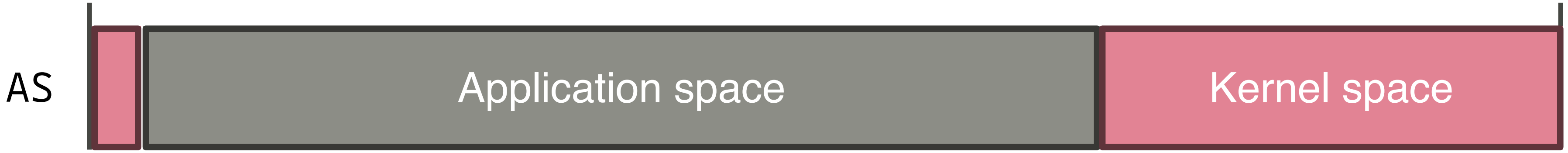

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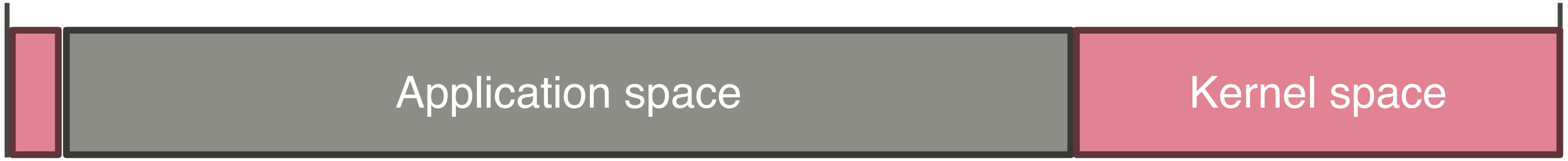

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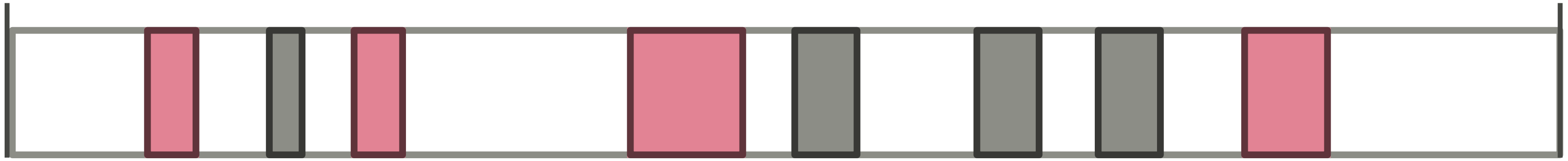

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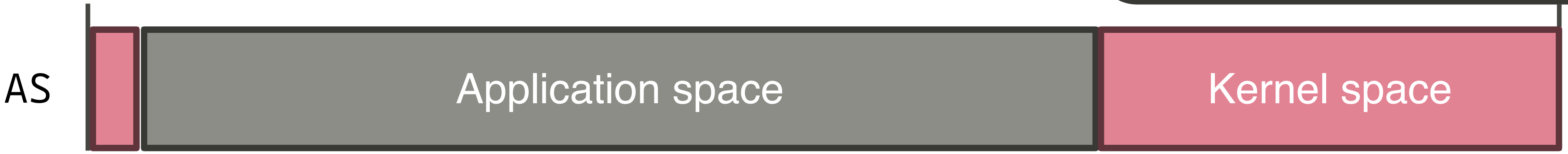

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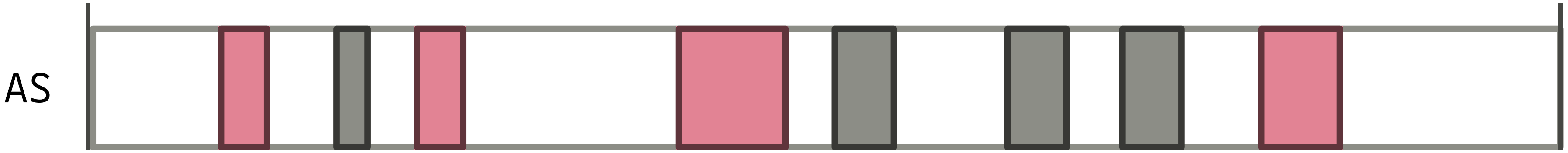

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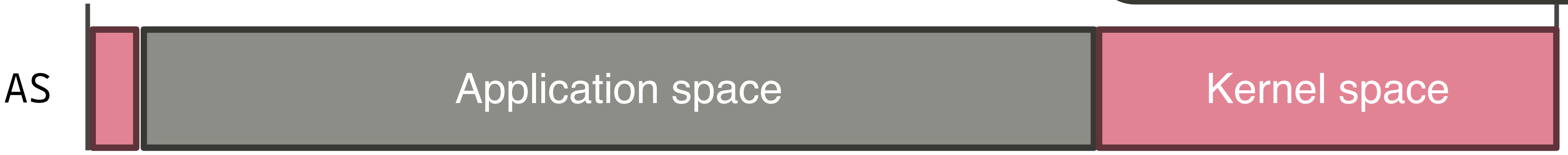

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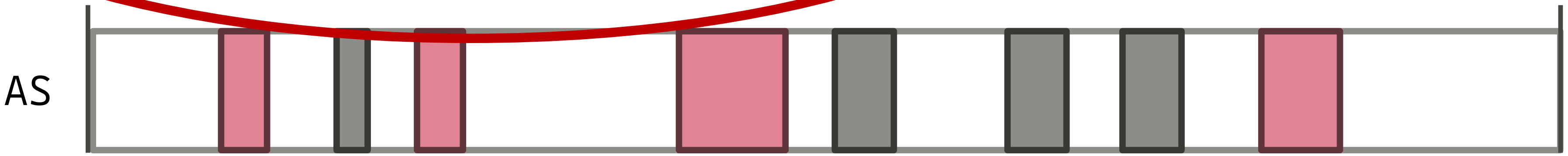

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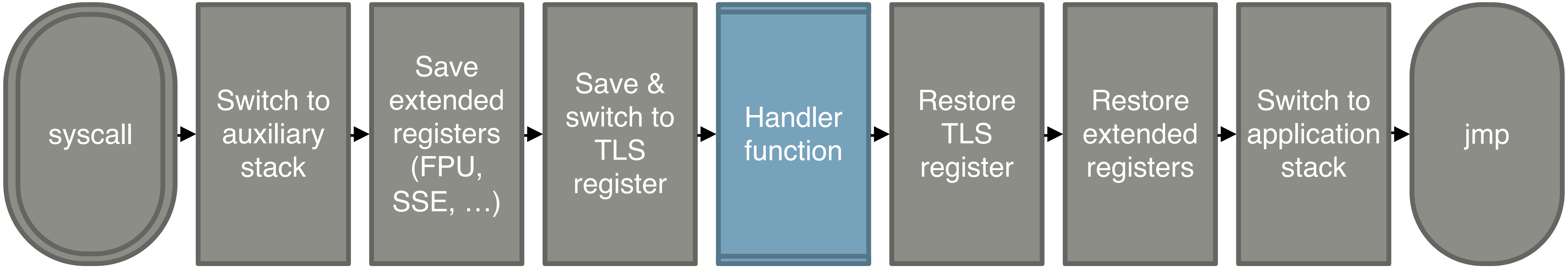
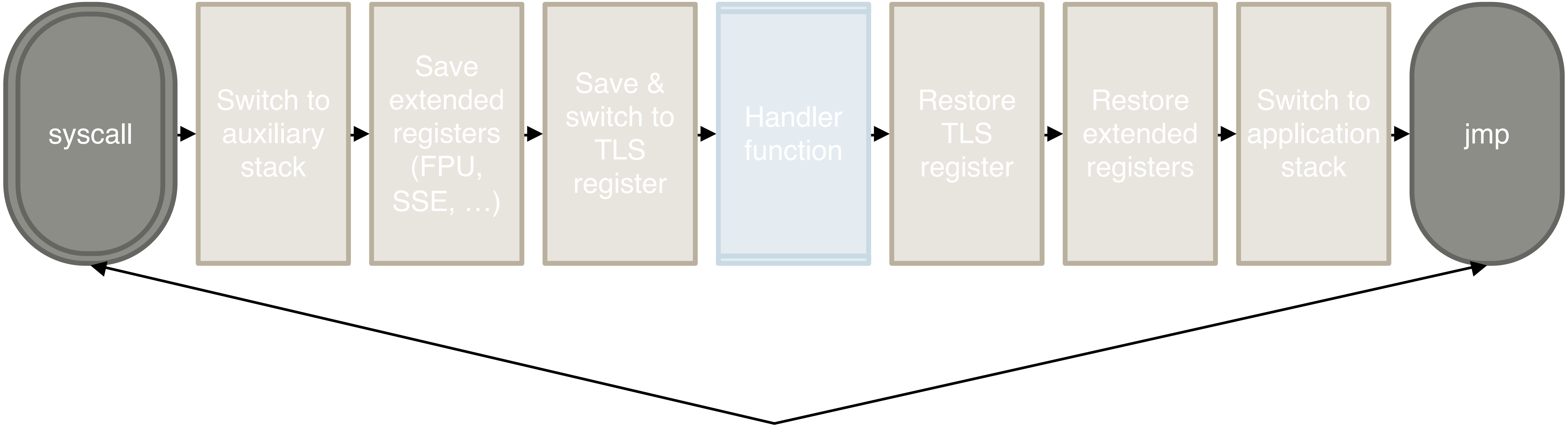
System Calls

System Call Trap Handler



**here: x86_64*

System Call Trap Handler



- Special instruction
  - Takes care of protection domain switch (that we do not need)
- *x86_64:* `jmp` *instead of* `sysret` *because of implicit privilege mode change to ring 3 [1]*

[1] P. Olivier, et al., A binary-compatible unikernel, VEE 2019, https://dl.acm.org/doi/10.1145/3313808.3313817

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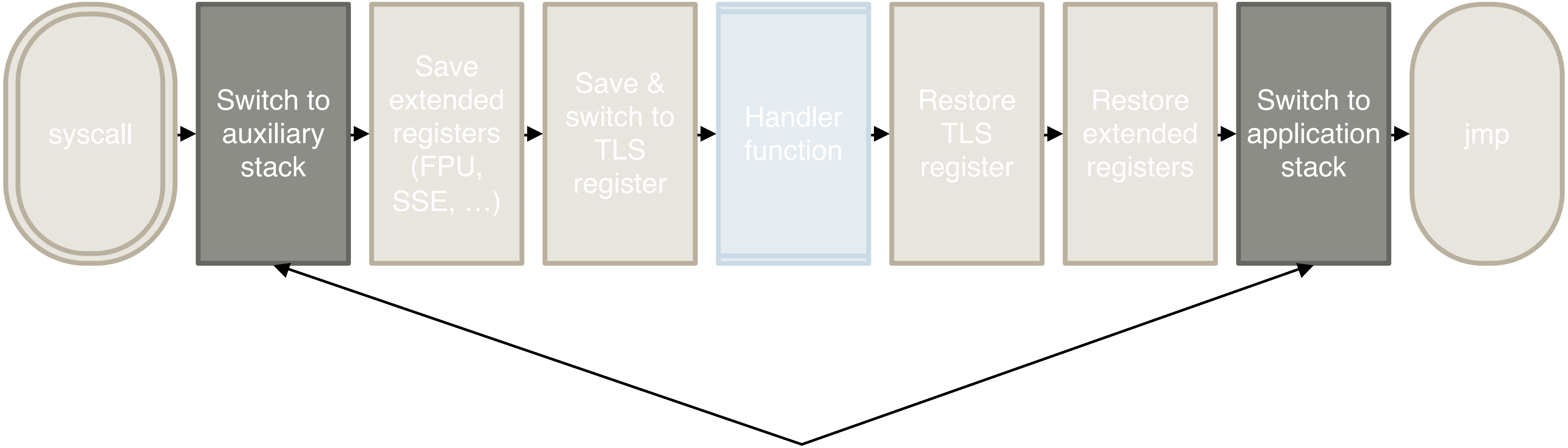
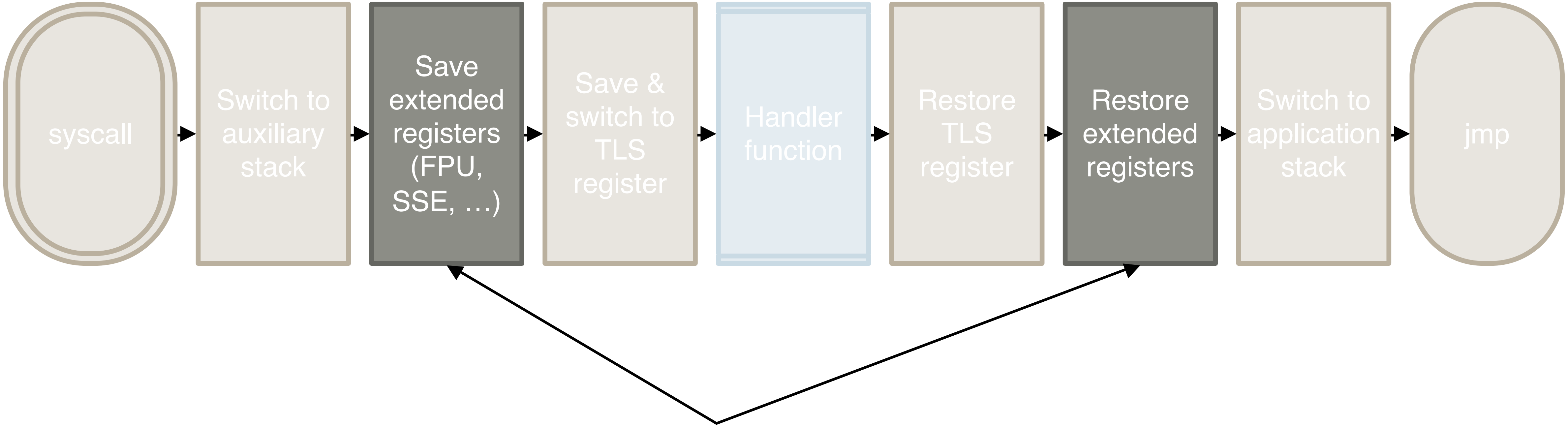


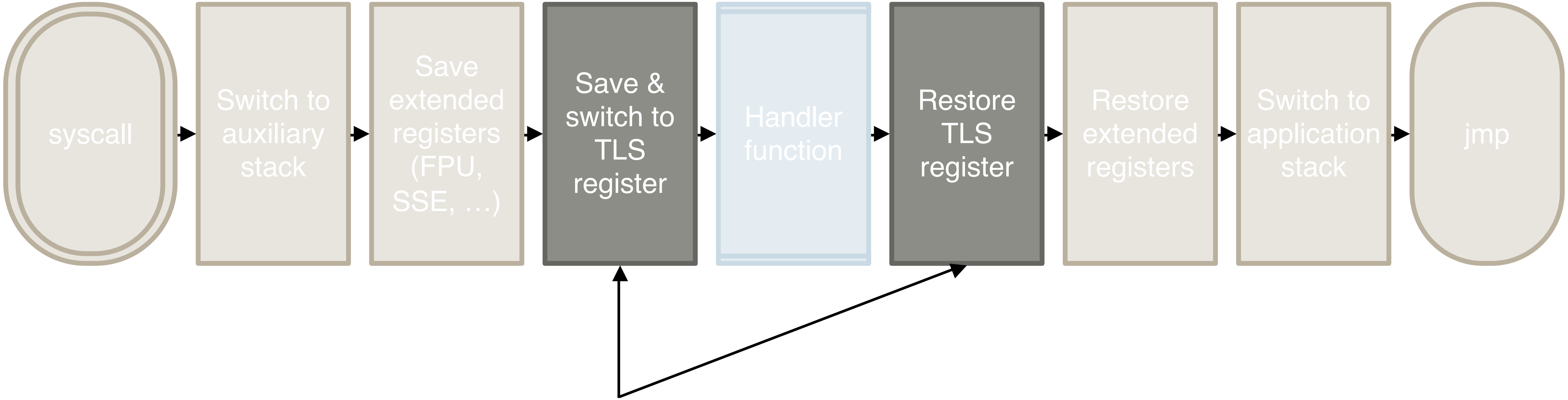
- Needed to be compliant with Linux ABI:
  The system call handler must not require a userland stack
- In reality: Only needed for apps where userland stack is too small (e.g., go)

System Call Trap Handler



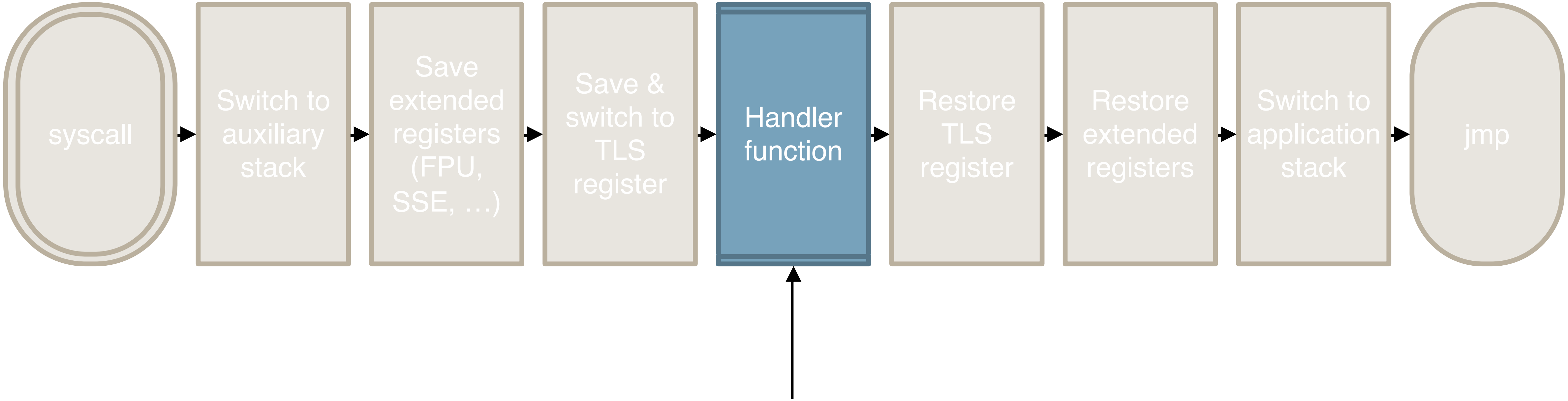
- Needed if we compile Unikraft with full CPU features utilization

System Call Trap Handler



- TLS used as TCB in Unikraft
  - Compartmentalization of library implementations (no central TCB structure definiton needed)

System Call Trap Handler



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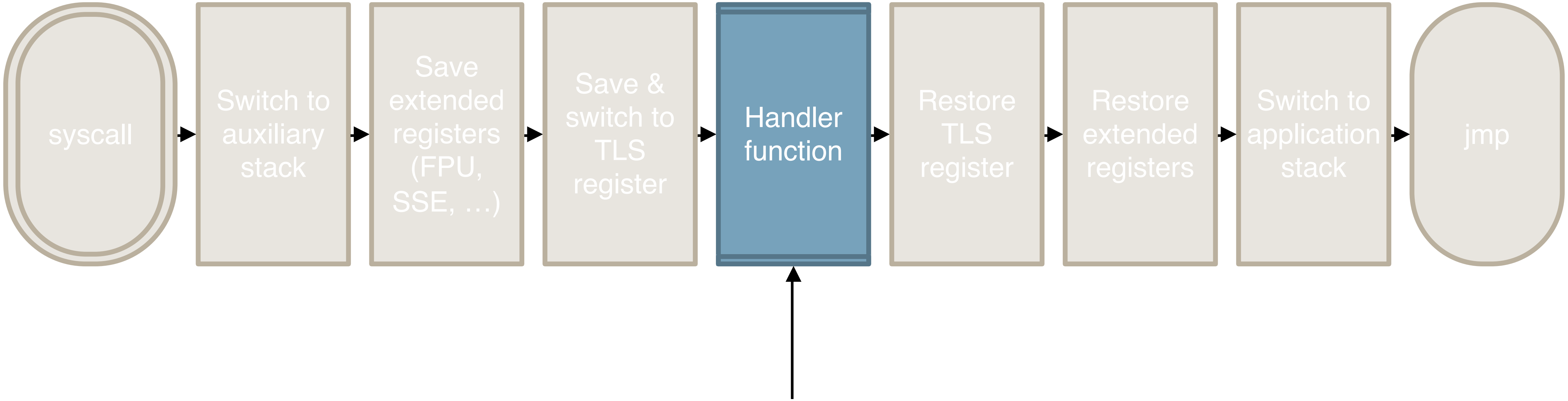

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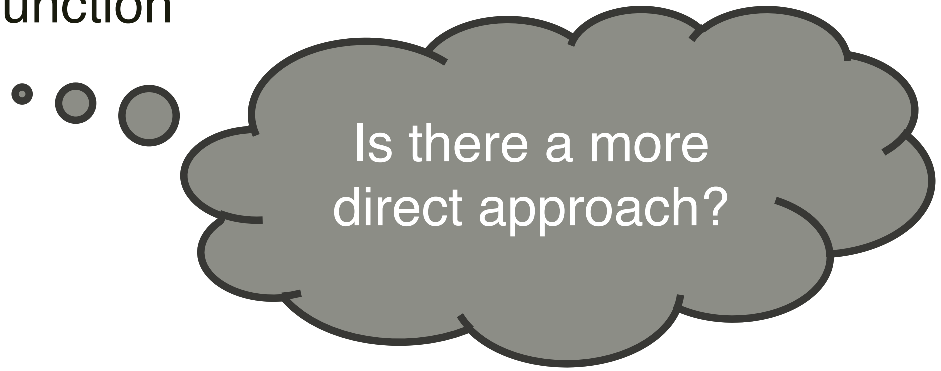
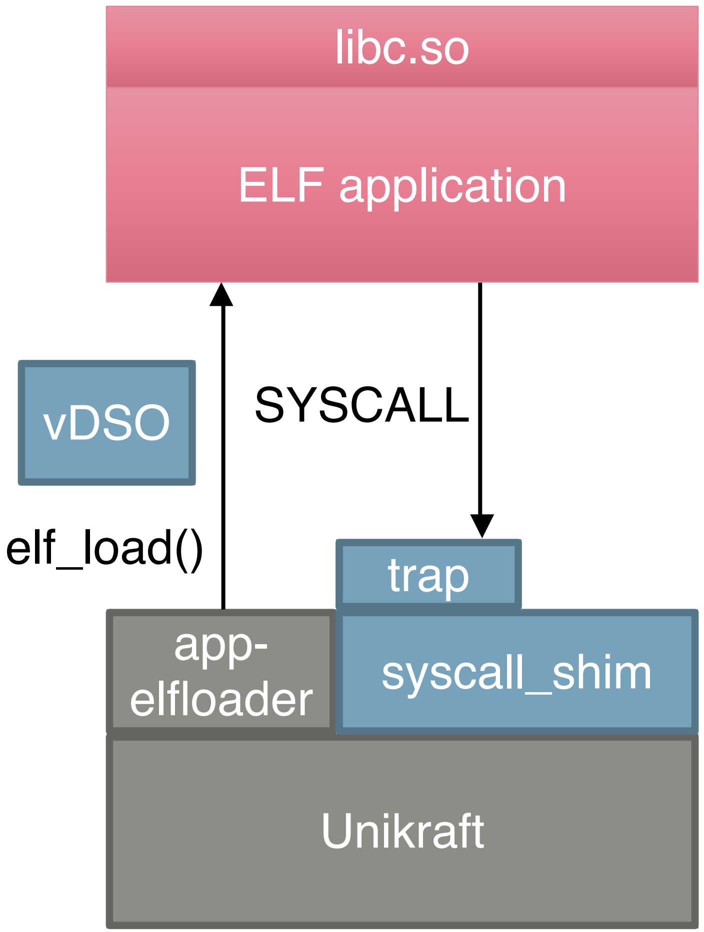


vDSO and __kernel_vsyscall()

- vDSO[1] in Unikraft is a symbol lookup table only
  - Within single-AS/single-protection domain we can directly execute kernel functions



[1] https://man7.org/linux/man-pages/man7/vdso.7.html
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  - *Origin i386: Switch between int_0x80/sysenter/syscall depending on CPU [1]*
  - Idea: Use this mechanism to enter Unikraft
    - Normal function call
    - <u>No</u> trap, interrupt or privilege domain change
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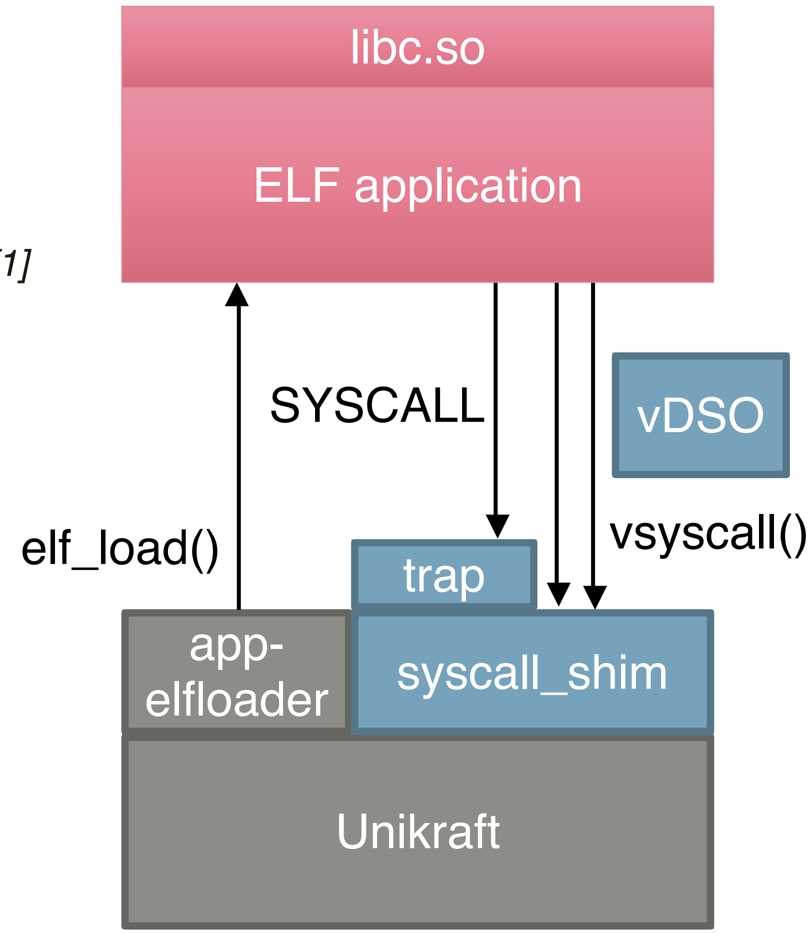

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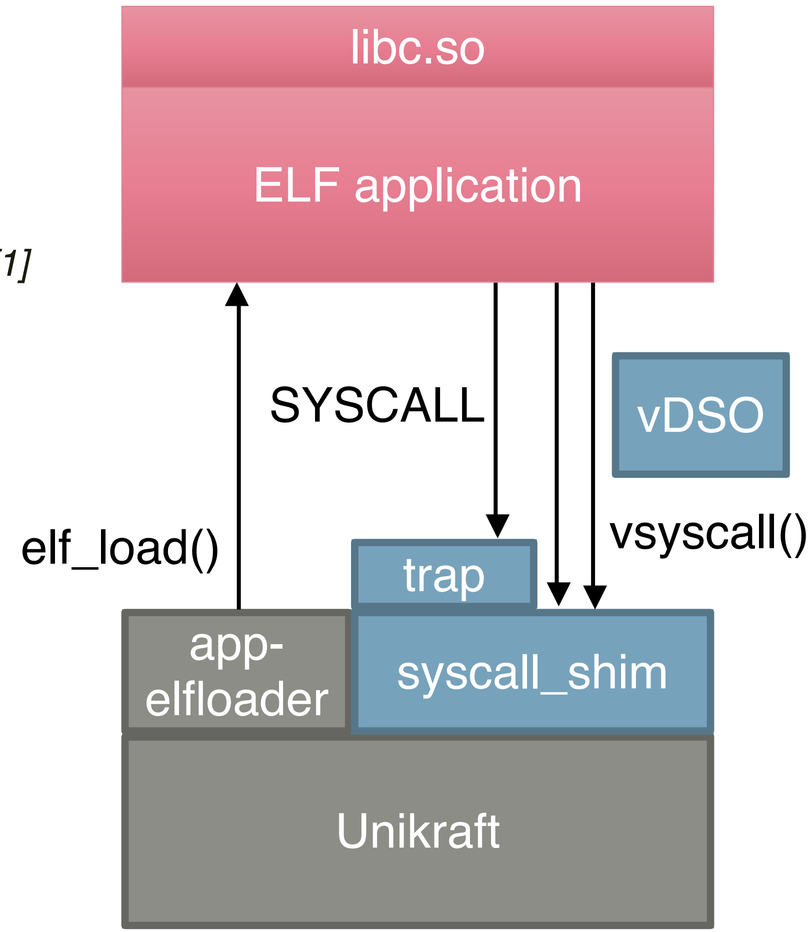
  - Patch application's libc.so
    - Most syscalls done via libc wrappers



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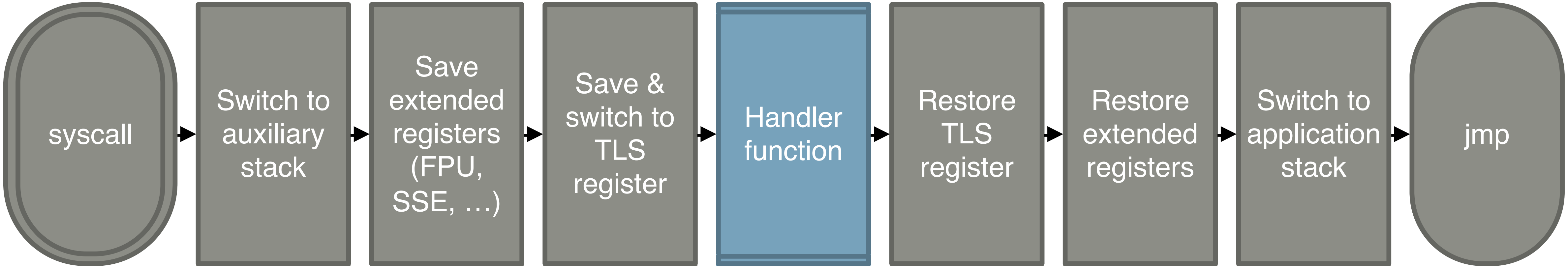

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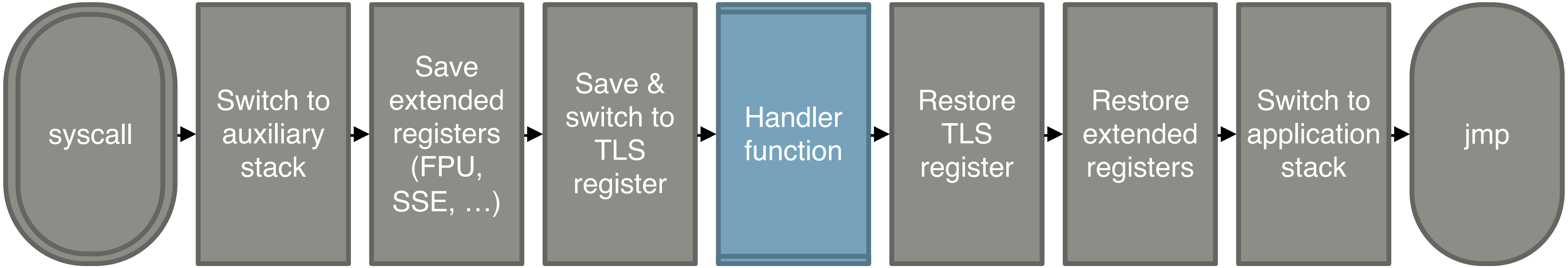
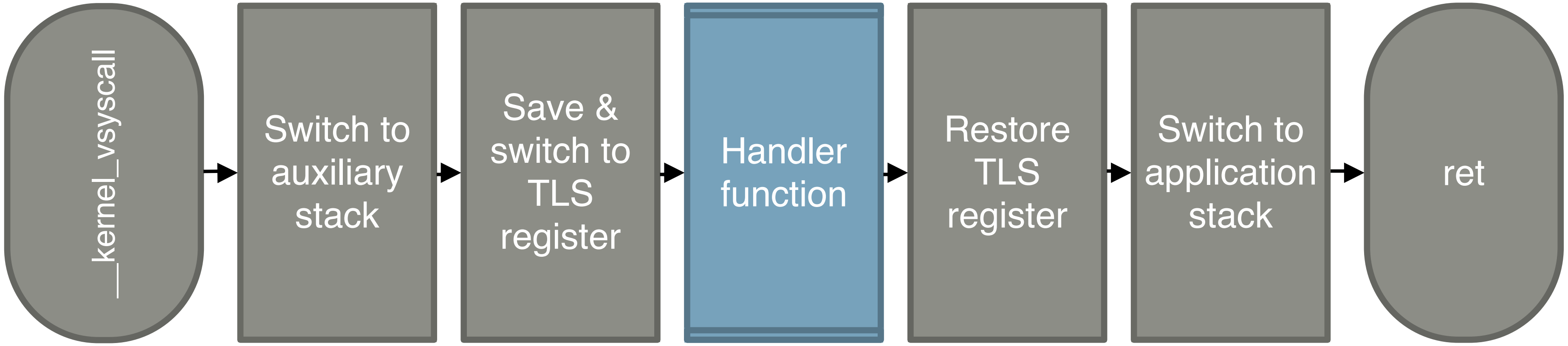


Function call __kernel_vsyscall()



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The **fork** Dilemma

The `fork` Dilemma

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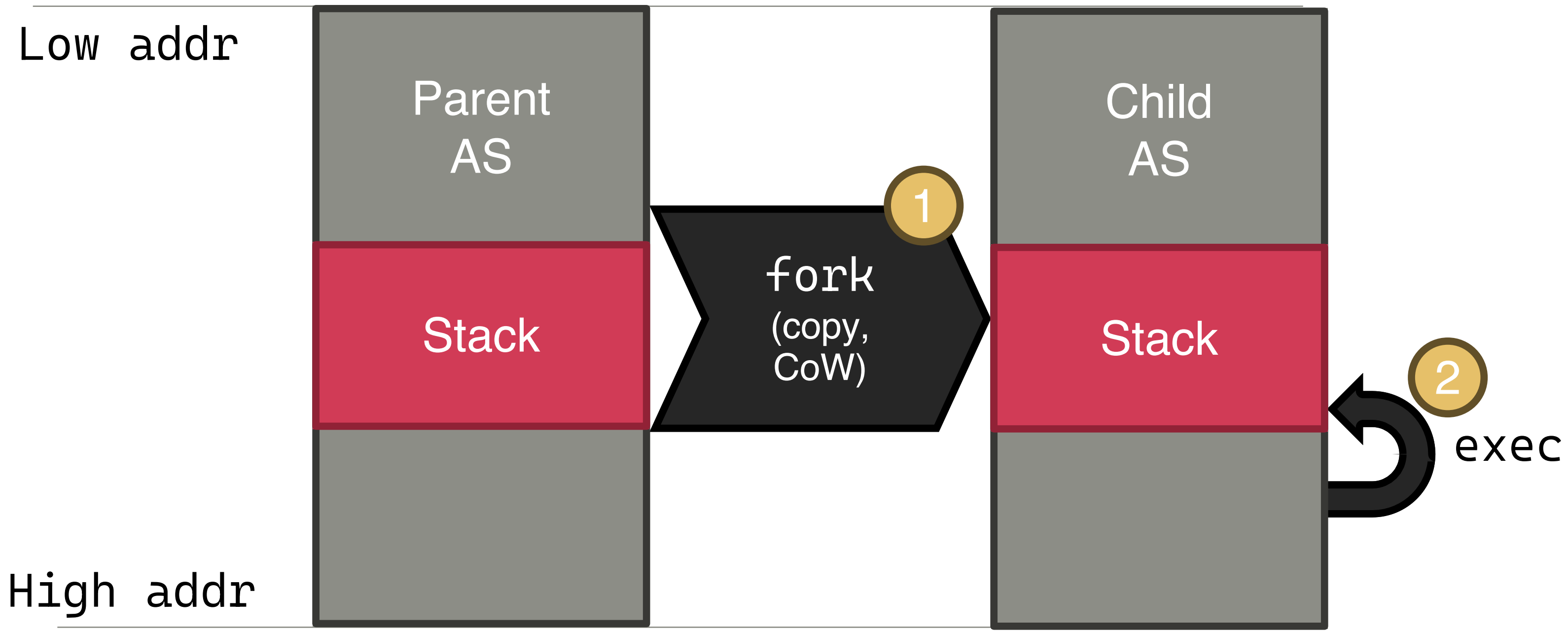
  a) Creating worker processes
  b) Instantiating new applications with `fork` + `exec`



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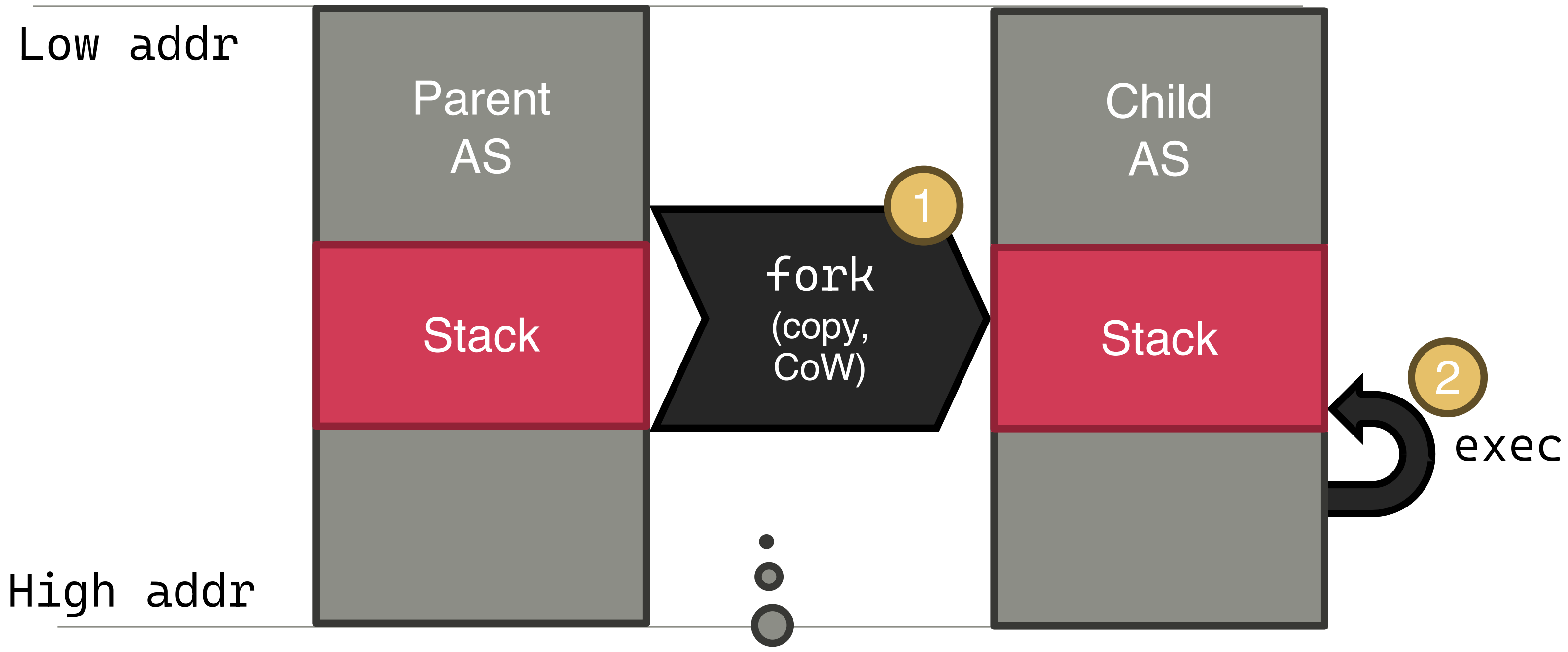
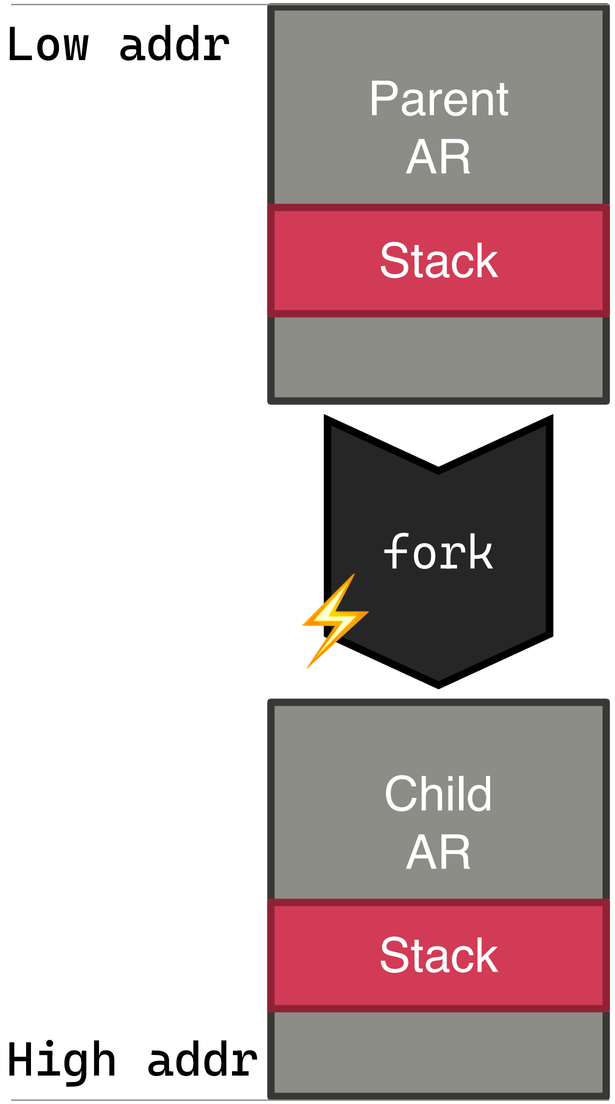


→ Issue: Mechanism relies on per-process ASes

fork in a Unikernel

- Single AS: Child must be located at different address range as the parent
  - Copy&Patching hardly possible without compiler support, e.g.,
    - return addresses on the stack
    - absolute pointers

  → Worker processes cannot be created this way 😢
  luckily, recent software prefer multi-thread model instead



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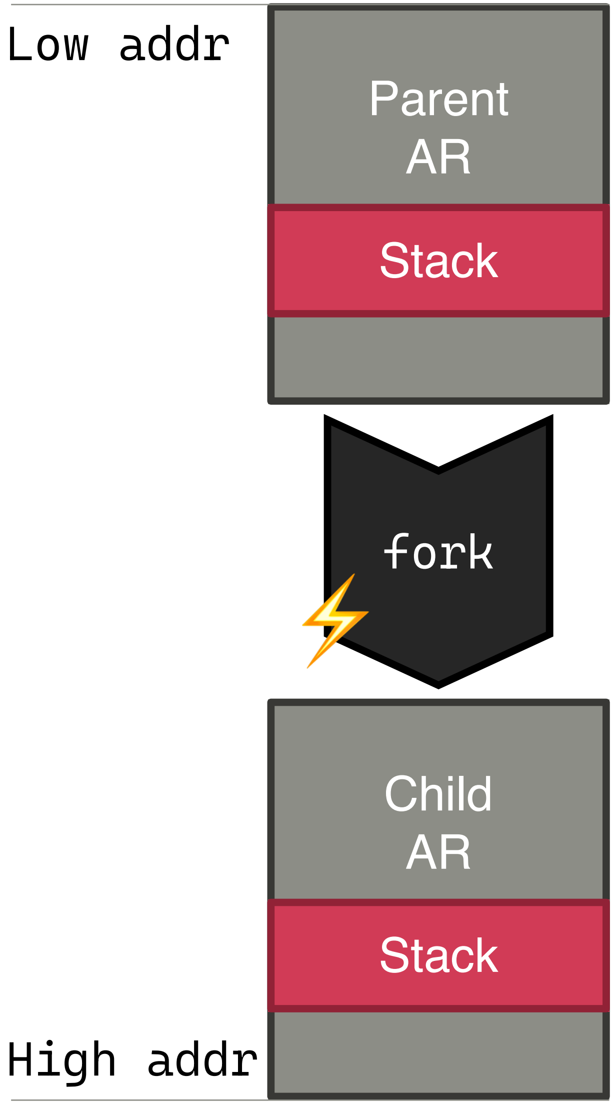

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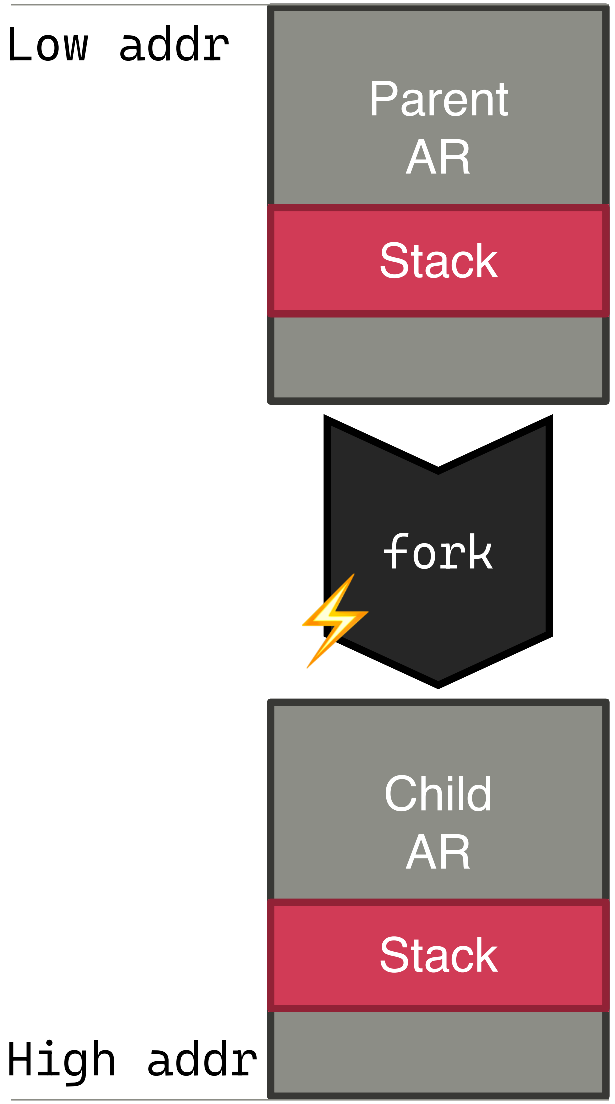
Is fork-exec-model constraining us? [1]



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A Solution: `vfork+exec`

- `vfork` [1]: Shares memory and stack with parent
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- `exec`: will drop current memory image and launch a new one from executable
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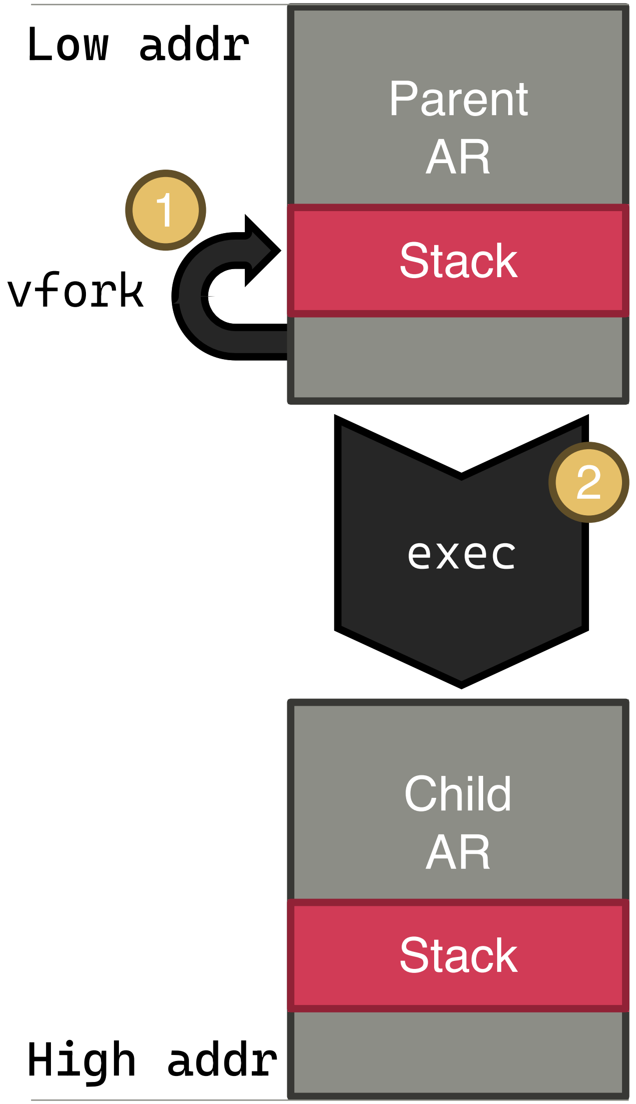

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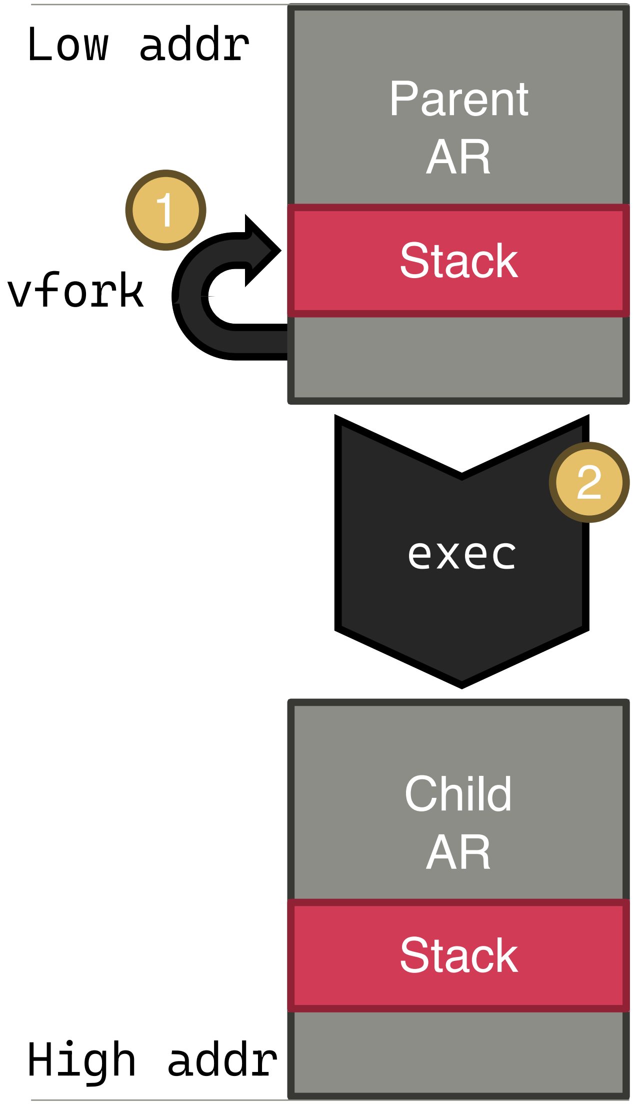
→ Outlook/Trial: Translate `fork+exec` to `vfork+exec`



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- Network interfaces and routing (getifaddr() and co.)
  - Need complex subsystem in between: netlink sockets
  - Alternative: Provide functions directly via the vDSO (trade-off: libc patching)

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- Filesystem Hierarchy Standard [2]:
  - Specific files and file systems (e.g., /proc, /etc) at expected places and behavior
    Many of them can resolved by placing files with meaningful content in the VFS

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Thank you!