Engineering and Physical Sciences Research Council

Digital Security by Design

SFork: Supporting Complex Multi-Process Applications in a Single Address Space OS

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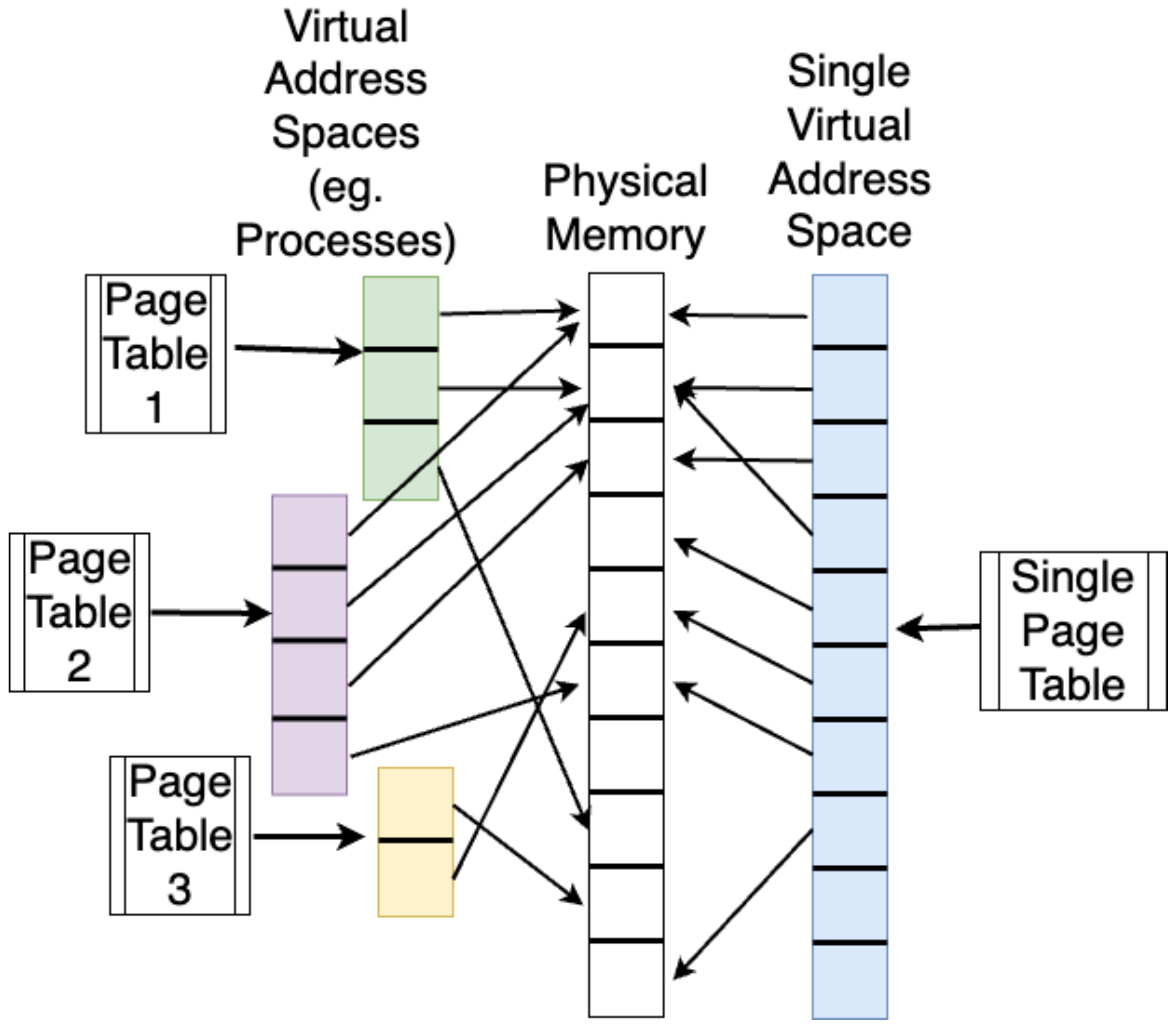
Single Address Space OSes (SASOS)



Virtual Address Spaces (eg. Processes)

Physical Memory

Single Virtual Address Space

Page Table 1

Page Table 2

Page Table 3

Single Page Table

Pros

- ✓ No overhead from switching page tables
- ✓ Fast IPC

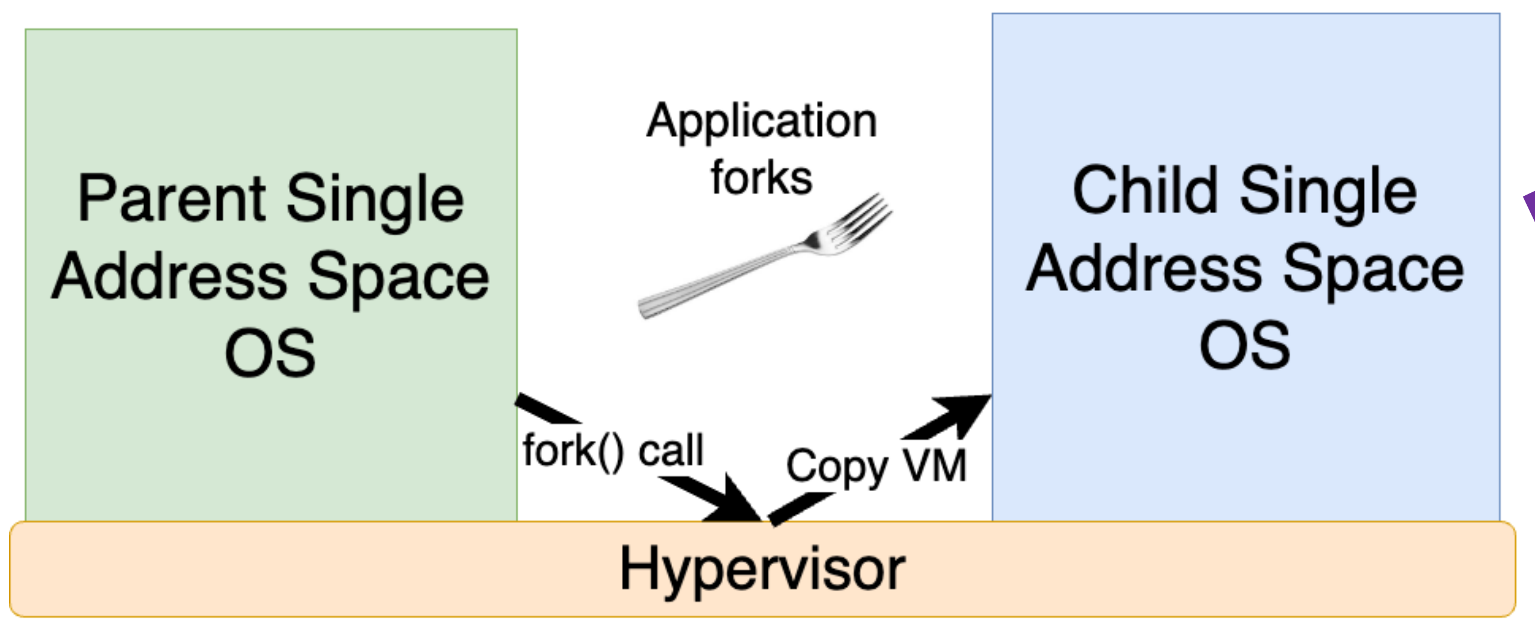
Cons

- ✕ No support for multiple processes through POSIX `fork()`

Problem: Lack of `fork()` Support

SASOSes are incompatible with forking processes which creates a **copy of their address space**.

Most existing solutions treat OS as process and copy entire OS [2,3]



Parent Single Address Space OS

Application forks

fork() call

Copy VM

Child Single Address Space OS

Hypervisor

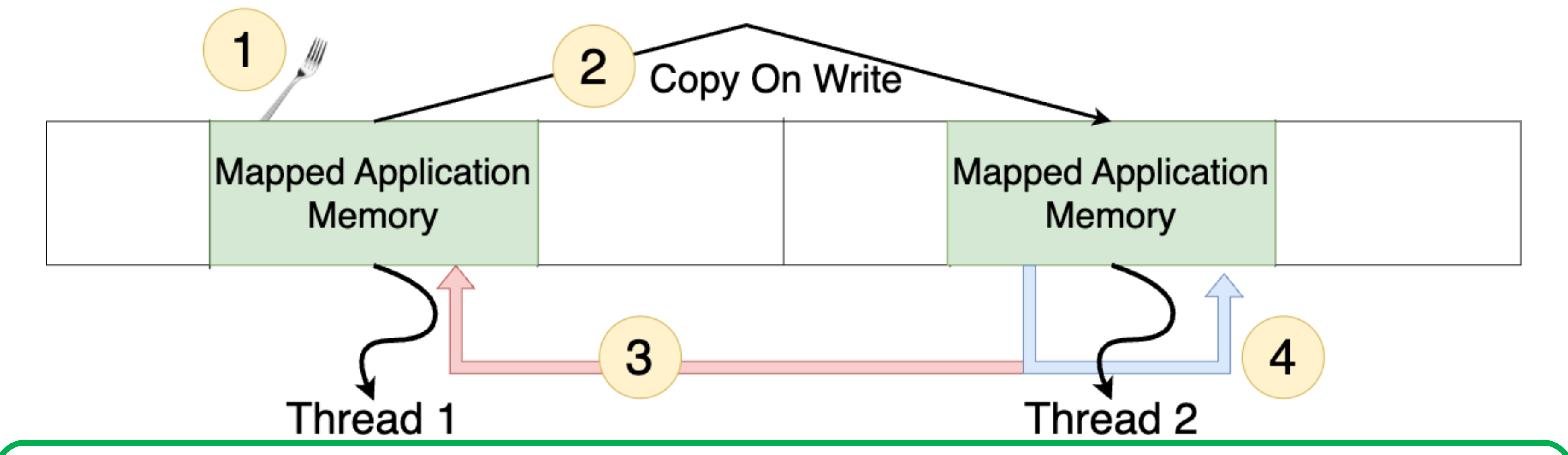
Multiple address spaces!

- ✕ Loses single address space performance advantages by reintroducing multiple address spaces
- ✕ Cloning entire OS is costlier and more resource intensive

Previous attempt at true single address space `fork()` suffers from coarse granularity of memory sharing and no isolation between processes [4]

How can we transparently and securely support POSIX `fork()` in a SASOS without losing the single address space?

SFork: Emulate Processes with Threads in a Single Address Space OS



1

2 Copy On Write

Mapped Application Memory

Mapped Application Memory

3

4

Thread 1

Thread 2

Challenges & Solutions

- Providing isolation between processes
- Ensuring pointers to parent memory are identified and updated in the child

We will solve these problems using CHERI [1]

- In pure capability mode (purecap) all pointers are bounded - processes are restricted to their portion of the address space
- Pointers to parent memory can be identified because capabilities are tagged

Advantages

- ✓ Lower resource consumption than multiple VMs
- ✓ Faster IPCs by using capabilities in the same address space
- ✓ Faster context switches (same page table)
- ✓ Isolation between processes

How SFork Works:

1. Application transparently calls `fork()`
   - New process mapped to another part of the address space
2. Copy On Write
   - Parent process memory copied when modified
3. Identify pointers to parent process
   - Copied memory will contain pointers to parent memory
4. Update pointers to point to child memory

Current Progress (April 2024)

- Unikraft, a popular unikernel, ported to purecap on Morello
- Purecap Unikraft running bare-metal and under bhyve on CHERIBSD host OS
- Paravirtualised I/O (VirtIO) support for purecap Unikraft running under bhyve
- Applications such as SQLite, Redis and a http server running on purecap Unikraft
- Basic `fork()` building blocks implemented with work ongoing

References

[1] *Woodruff, Jonathan, et al. "The CHERI capability model: Revisiting RISC in an age of risk." ISCA 2014*

[2] *Lupu, Costin, et al. "Nephele: Extending Virtualization Environments for Cloning Unikernel-Based VMs." EuroSys 2023*

[3] *Zhang, Yiming, et al. "KylinX: A Dynamic Library Operating System for Simplified and Efficient Cloud Virtualization." USENIX ATC 2018*

[4] *Wilkinson, Tim, et al. Compiling for a 64-bit Single Address Space Architecture Technical Report 1993*