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Building a Linux-compatible Unikernel

How your Application runs on Unikraft

Simon Kuenzer

Lead Maintainer
CTO and Co-Founder
Unikraft GmbH
simon@unikraft.io

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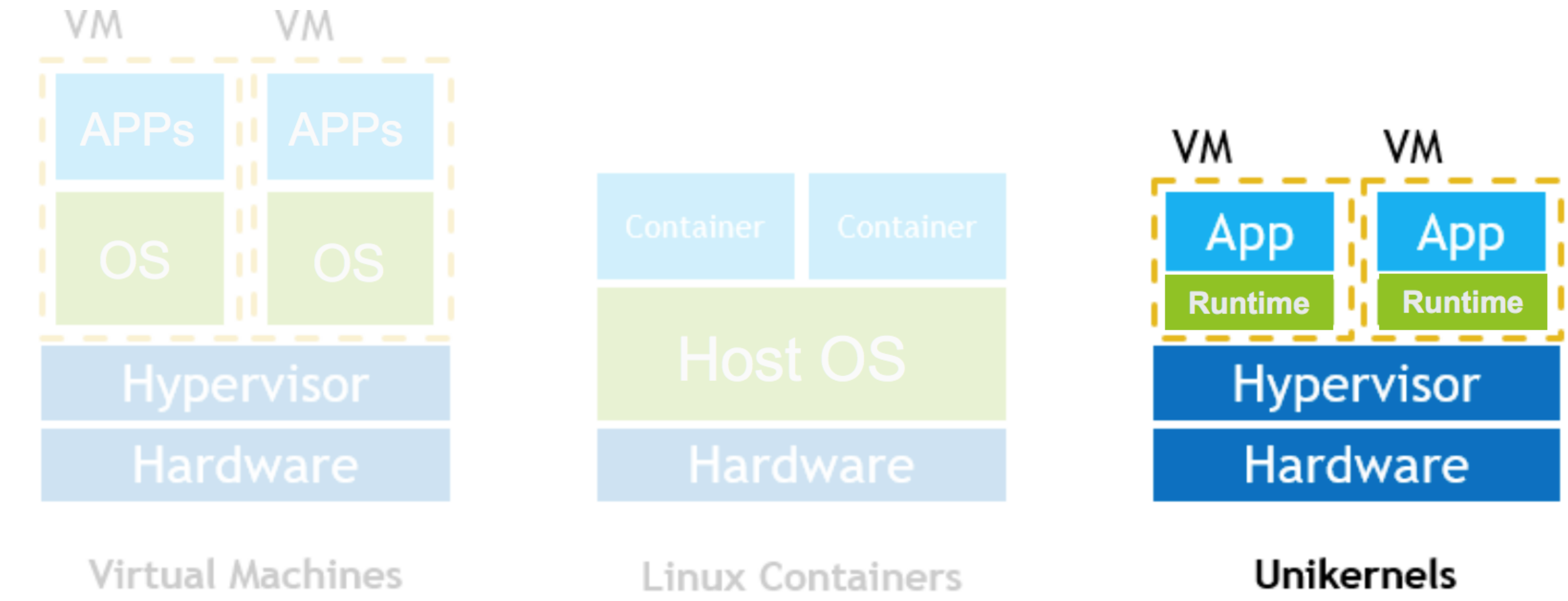
Unikraft: The Unikernel SDK

Unikraft Unikernels



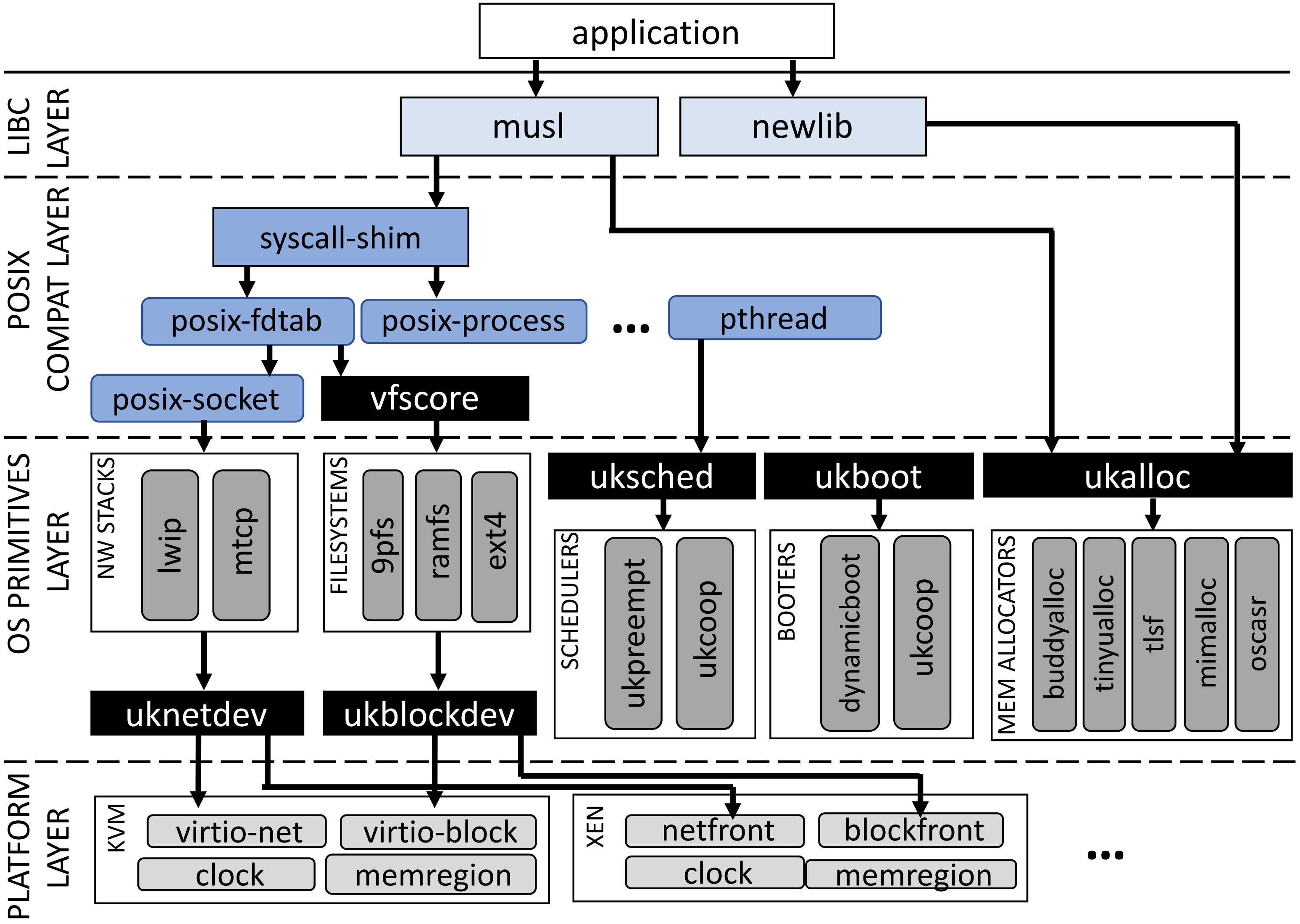
- One application → Flat and single address space
- Single monolithic binary with only necessary kernel components
- Advantages from specialization
  - Performance and efficiency
  - Small TCB and memory footprint

Design Principles

- Specialization as main driving design principle
  - Highly customizable & configurable: KPI-driven specialization
- Philosophy: “Everything is a (micro-)library”
  - Decomposed OS primitives
    - Schedulers, memory allocators, VFS, network stacks, …
  - Architectures, platform support, and drivers
    - Virtualization environments, bare-metal
  - Application interfaces
    - POSIX, Linux system call ABI, language runtimes

→ **(1) Configuration (KConfig) and Build System** | **(2) Library Pool**

The (Micro)-Library Stack



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Linux Application Compatibility

Linux Application Compatibility for Adoption

- Most cloud software is developed for Linux
- People are used to their software
- Remove obstacles for using Unikraft with existing application

VISION

Seamless application support

Applications are automatically ported and benefit from lower boot times, less memory consumption, improved performance, etc.

Linux-compatibility Landscape

Native		Binary compatible	
■ Application* sources are compiled and linked together with Unikraft		■ Application* binaries are externally built	
Unikraft-driven compilation	**Instrumented**	**Build-time linking**	**Runtime linking/loading**
■ Port/convert application build procedure to Unikraft	■ Instrument foreign build system (e.g., cross-compilation)	■ Build objects or static libraries externally and link with Unikraft	■ Support for shared libraries and loading on ELF binaries

Requirements

Native	Binary compatible
API-compatibility	ABI-compatibility

Native — API-compatibility

- POSIX, POSIX, POSIX
- API-compatible libraries and ported libraries
(including libC)

Binary compatible — ABI-compatibility

- ELF format (shared libraries/binaries)
- Binary compatible function interfaces
  - Linux system calls
  - Library functions
- Binary compatible data representation

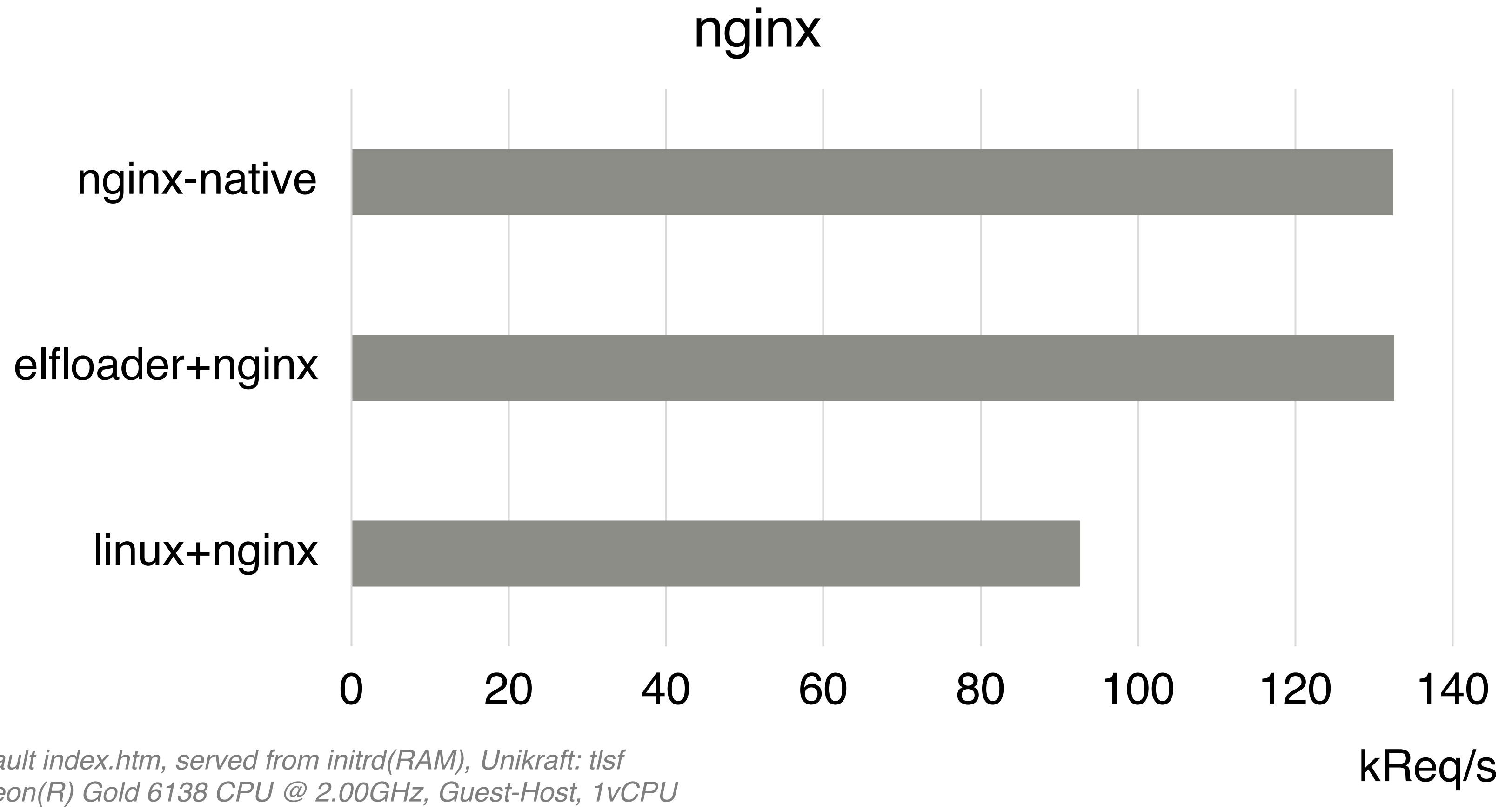
- Compatible system runtime environment
  - E.g., special filesystems and mount points: procfs, sysfs

Pros & Cons

Native (API-compatible)	Binary compatible (ABI-compatible)
+ Performance tuning and specialization of application-kernel interaction naturally possible	+ Source code not required + Applications are compiled the standard way, independent from Unikraft + No modifications to application needed
- Source code of application needed - Compiling of the application is not independent to Unikraft (instrumentation, build system porting)	- Risk of taking over implementation complexity of Linux to Unikraft (e.g., “netlink sockets” for getifaddrs()) - Less opportunities to specialize and tune kernel-application interaction

Binary compatibility vs. Native

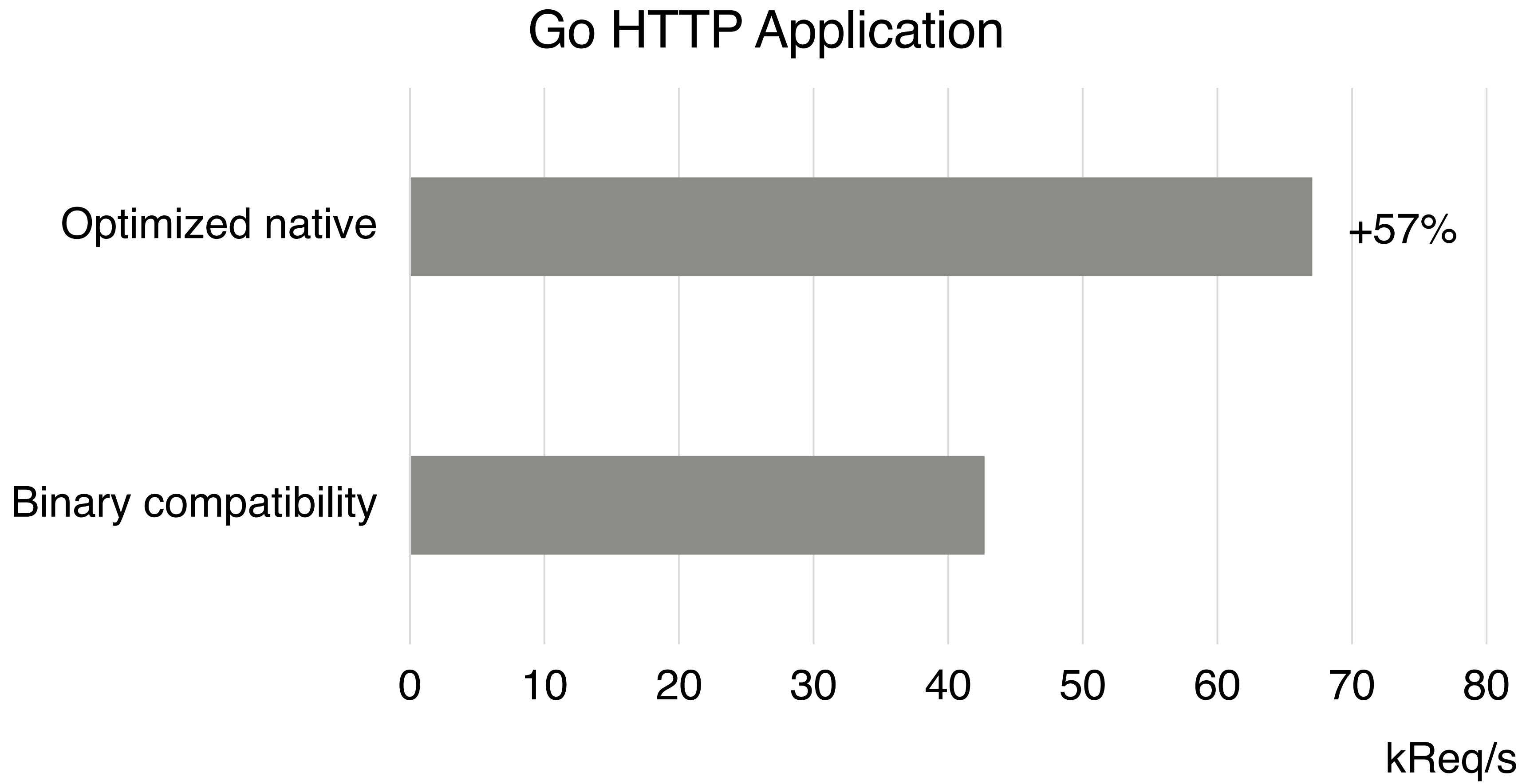
- No extra optimization on native port
- Still Apple&Oranges comparison: musl vs glibc, different heap allocators



Nginx default index.htm, served from initrd(RAM), Unikraft: tlsf
Intel(R) Xeon(R) Gold 6138 CPU @ 2.00GHz, Guest-Host, 1vCPU

Optimization Potential of Native Ports

- Native port patched with improved HTTP processing



Intel(R) Xeon(R) Gold 6138 CPU @ 2.00GHz, Guest-Host, 1vCPU

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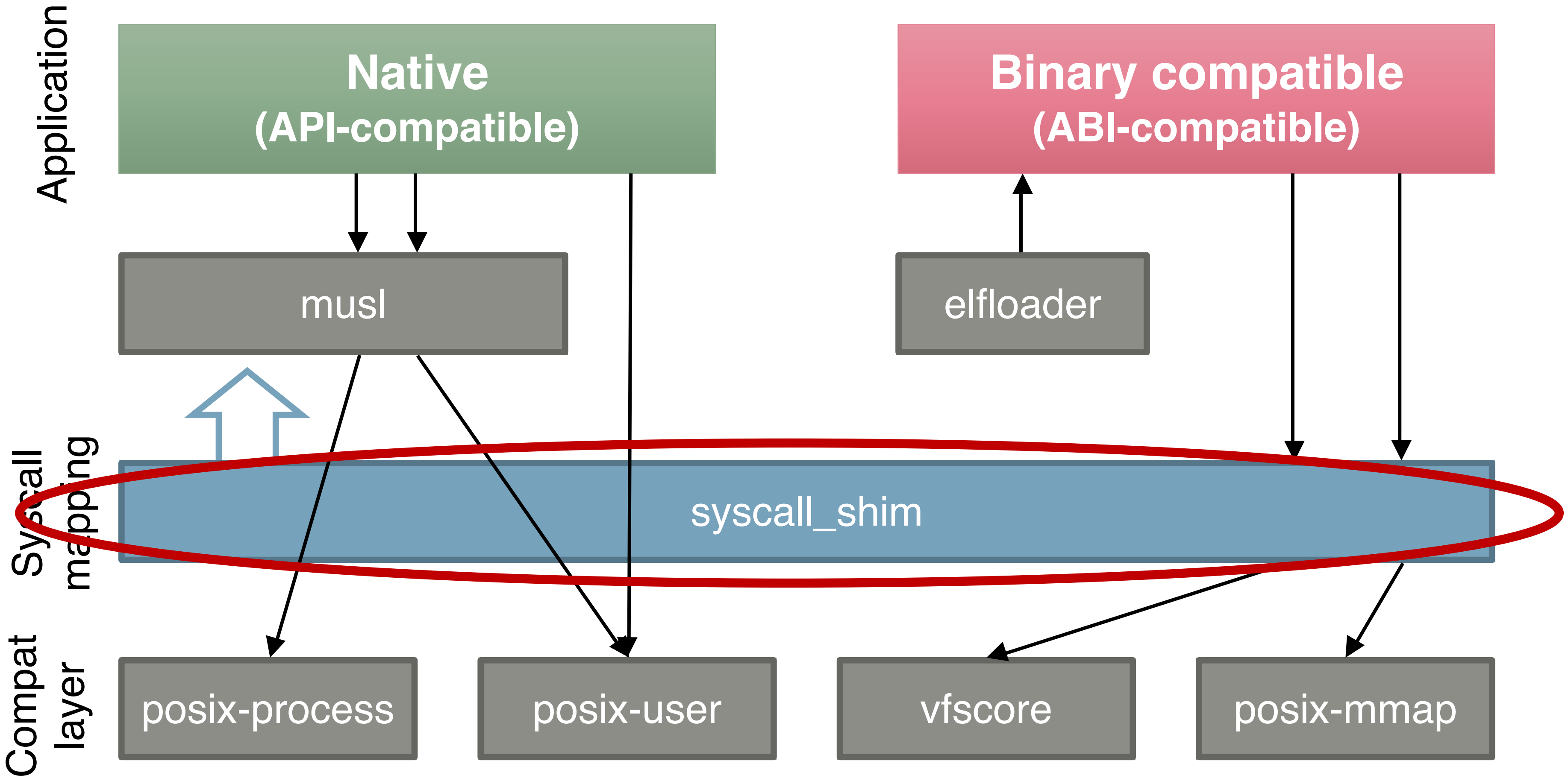
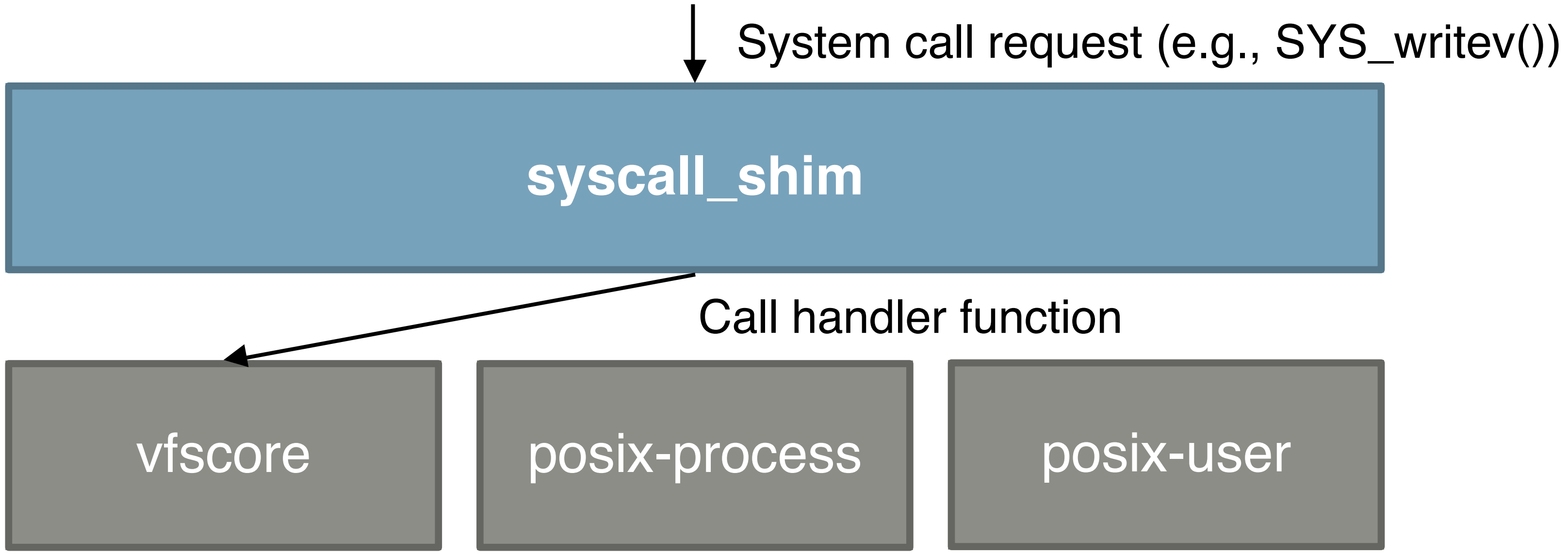
Unikraft's Implementation

Overview

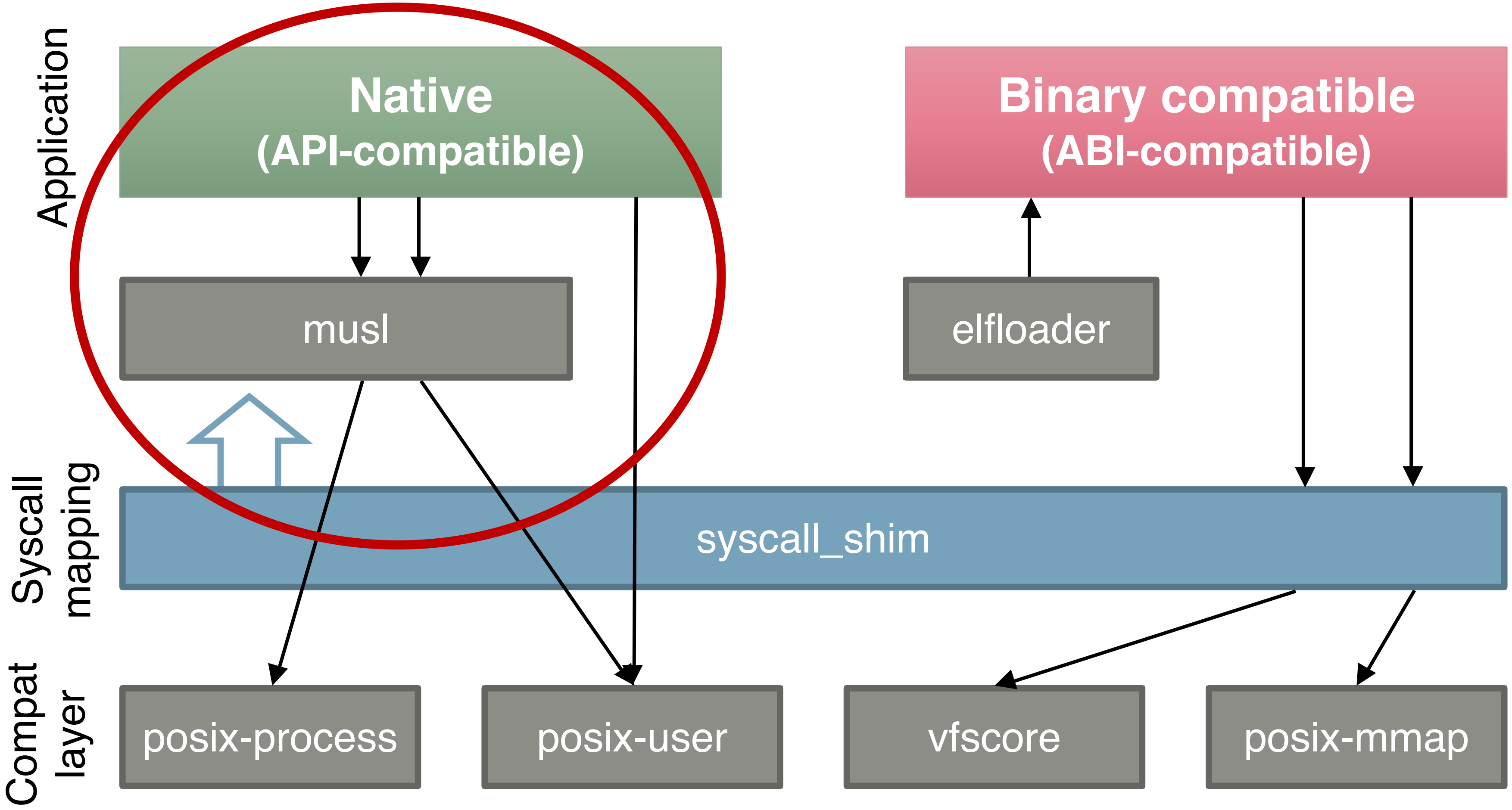

Application
Native
(API-compatible)
Binary compatible
(ABI-compatible)
musl
elfloader
Syscall mapping
syscall_shim
Compat layer
posix-process
posix-user
vfscore
posix-mmap

Syscall Shim



- Libraries register a handler to the shim
- Shim provides two ways to handle/route system calls
  - **Compile-time:** Link application to handler functions (function calls)
  - **Runtime:** Binary system call handler (Linux-style)
- Our aim: Re-use code for both modes

Overview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elfloader
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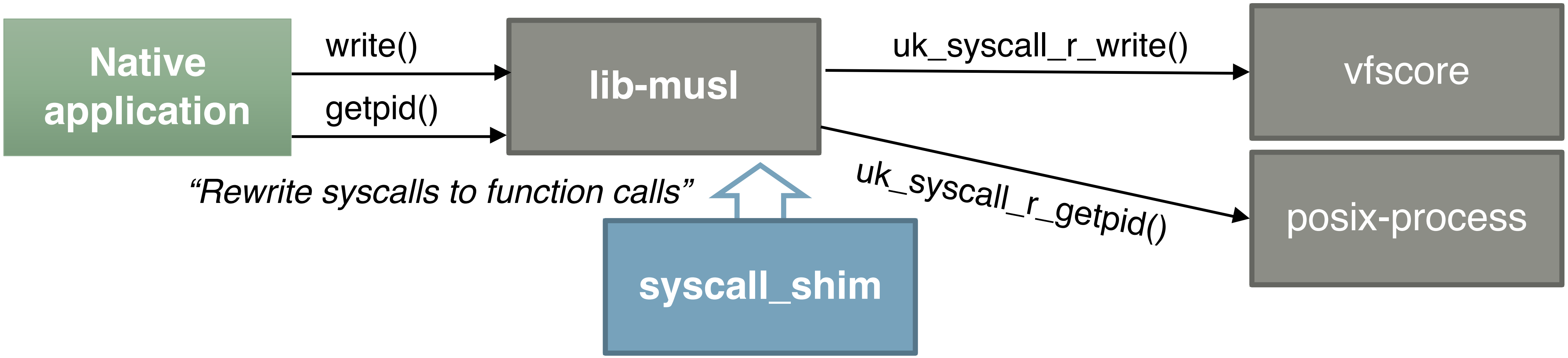
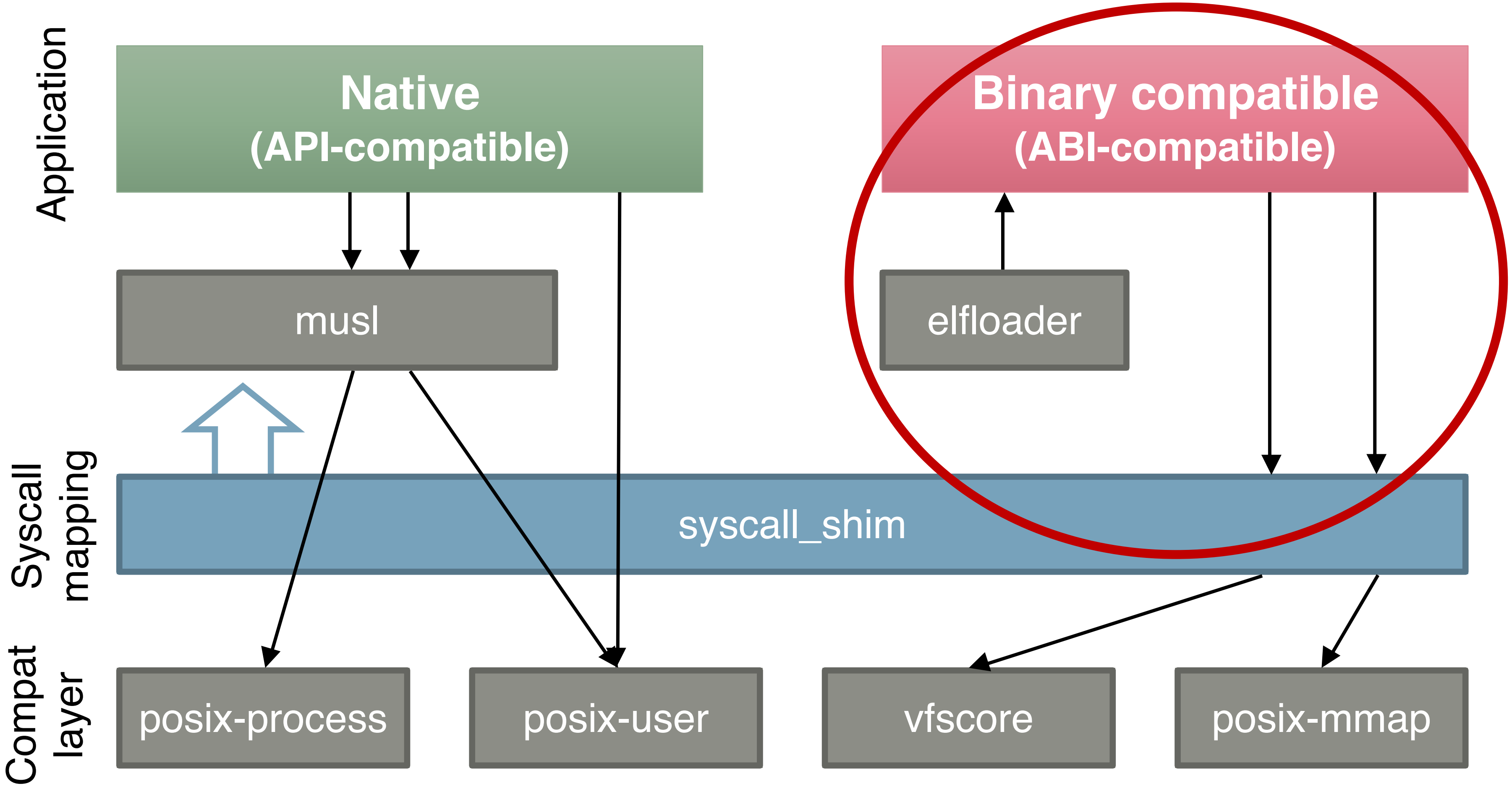
Native: lib-musl



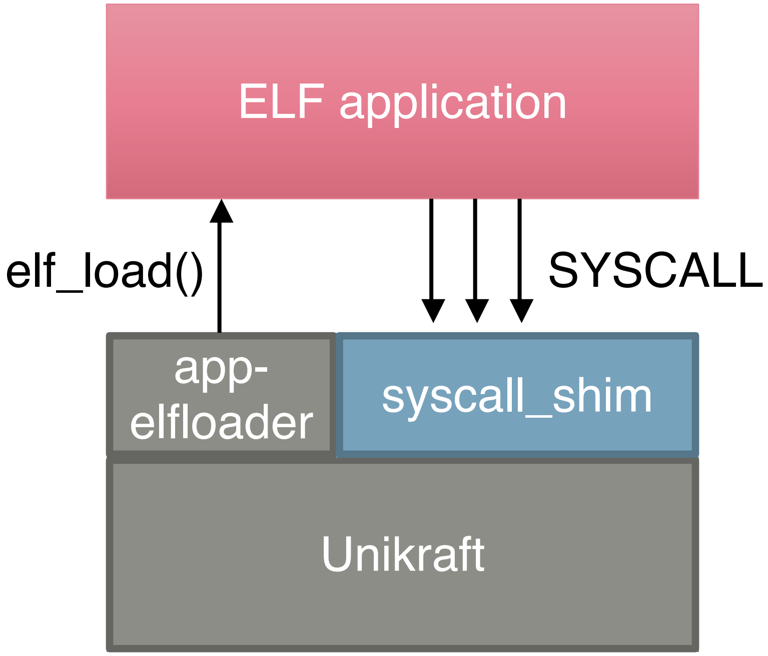
- Musl is compiled natively (build by Unikraft)
- Few patches to replace system call invocation
  - Syscall_shim resolves invocation to functions calls
  - Syscall_shim provides ENOSYS stub for unregistered system calls
- At run-time, syscall shim is out of the way

Overview


Application
Native
(API-compatible)
Binary compatible
(ABI-compatible)
musl
elfloader
Syscall
mapping
syscall_shim
Compat
layer
posix-process
posix-user
vfscore
posix-mmap

Bin. Compat. (1/2): app-elfloader

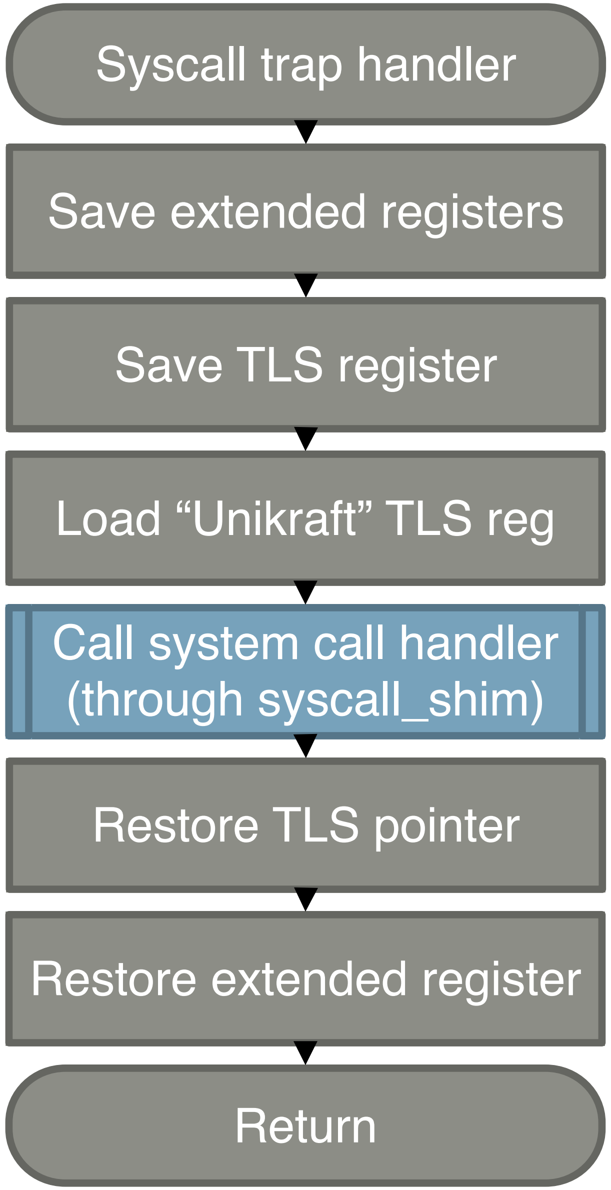
- Loads an Linux ELF application
- Supports (today):
  - static-PIE
  - dynamically-linked using loader (needs posix-mmap)
- System calls are trapped and handled through syscall_shim
- Supported system calls selectable by chosing subsystem libraries
  - e.g., vfscore, posix-process, posix-user



Bin. Compat. (2/2): System Call handler

- syscall trap handler provided by syscall_shim
- No domain switch needed, single AS

- Because of Linux system call calling convention and assumptions:
  - Linux does not use extended registers → we do
    - Save & restore FPU, VU, … state
  - Linux does not use a TLS → we do
    - Save & restore TLS register (application TCB)



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Demo time

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Learned Lessons
Native Application Support

Background

- We avoid linking in multiple libCs to monolithic Unikernel (specialization at compile time)
  - Use a single libC
- Provide multiple libCs:
  nolibc, musl, newlib
- Keep libC as vanilla as possible
  → lower maintenace effort

Learned Lessons with libCs

- Every libC is different
  → Test code with all officially supported libCs
- Namespacing is important
  → Risk of clashing with libC(-internal) definitions
  → avoid plain declarations, like `MIN()`, `MAX()`
  → underscore prefixes may not be enough
- Careful with initialization and dependencies
  - Example: TLS and kernel prints
    → Kernel prints got their own print function
- Circular dependencies can occur
  - Example: getdents64()
  - Learned: Vanilla not always possible → patching

Example: Circular Dependency `getdents64()`

- Circular dependency (syscall_shim → musl → syscall_shim)
- musl defines **`getdents64()`** as macro to **`getdents()`**

  `<dirent.h>`:

```
#define getdents64 getdents
```

- vfscore implements both syscalls with:

```
#include <dirent.h> /* struct dirent, struct dirent64 */

UK_SYSCALL_R_DEFINE(int, getdents, int, fd, struct dirent*,
                    dirp, size_t, count)
{/* ... */}
                              ⚡
UK_SYSCALL_R_DEFINE(int, getdents64, int, fd, struct dirent64 *,
                    dirp, size_t, count)
{/* ... */}
```

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Learned Lessons:
Binary Application Support

Background

- Unikraft makes use of TLS
  - An artifact of supporting applications natively
  - Same register used as in Linux user space (x86: %fsbase segment register)
    → Keep bin. compat working for build-time linking
- Unikraft makes use of extended registers (even drivers)
  - Normally no separation between kernel and application code
    → Monolithic: Everything is a function call

Learned Lessons with binary compatibility

- Linux system calling convention fits for Linux assumptions
- → Need to be able to handle two TLSes (Unikraft TLS and “userland” TLS)
  - Our solution: switch TLS on binary system calls
- → Need to handle extended register context
  - Our solution: Save & restore on binary system calls

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Closing

Upcoming Features

- Improved Linux compatibility
  - posix-signals, posix-netlink, thread exit, join, wait support
- Seamless application support with kraftkit (using elfloader)

Watch out for:

- Seamless integration into kubernetes
- Running Unikraft on your infrastructure provider
- Automatically packaging of your applications

I'd ❤️ to hear your feedback: simon@unikraft.io

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Thank you!

Simon Kuenzer
CTO & Co-Founder
simon@unikraft.io

Unikraft GmbH
Im Neuenheimer Feld 582
69120 Heidelberg
https://unikraft.io