Integrating Unikernel Optimizations in a General Purpose OS

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General Purpose Operating Systems

Advantages

- Rich application support
- Wide hardware support
- Vast ecosystem of tools, utilities
- Community of developers, operators and performance engineers

Limitations

- Designed for the general case
- Overhead of security and resource multiplexing

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Unikernels

Advantages

- Designed to support a single application
- Optimizations include
  - no ring transition overheads
  - zero copy paths
  - custom scheduling and preemption policies
  - direct access to hardware etc.
- Lightweight and resource efficient

Limitations

- Small or non-existent community
- Lack of application and hardware support
- Mostly virtualized, single processor deployment
- Lack of support for utilities and tools
- Untested code base

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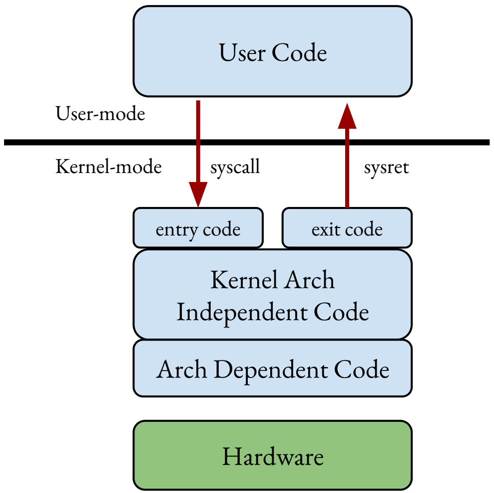
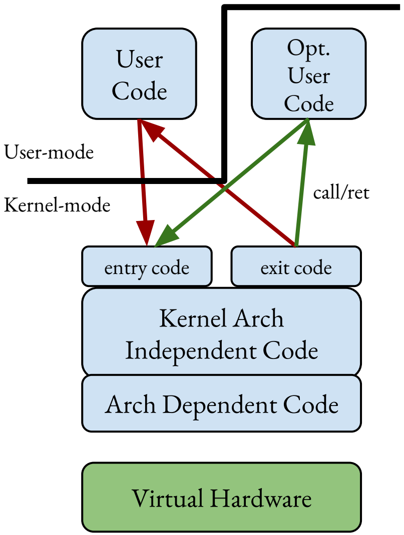
Research Space

General Purpose OS



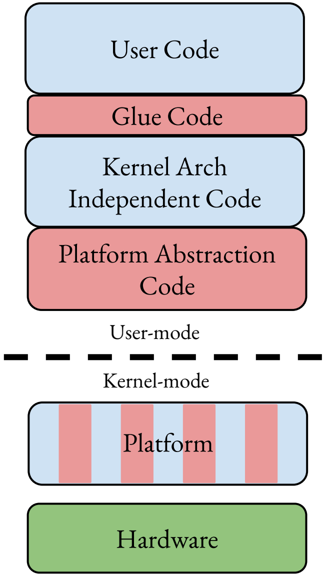
Linux, Windows, NetBSD etc.

Incremental Systems



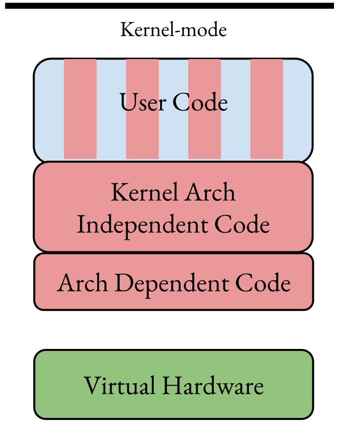
KML, Lupine Linux, X-Containers

Forks of General Purpose OS



LKL, Drawbridge, Rump Kernel

Clean Slate Unikernels

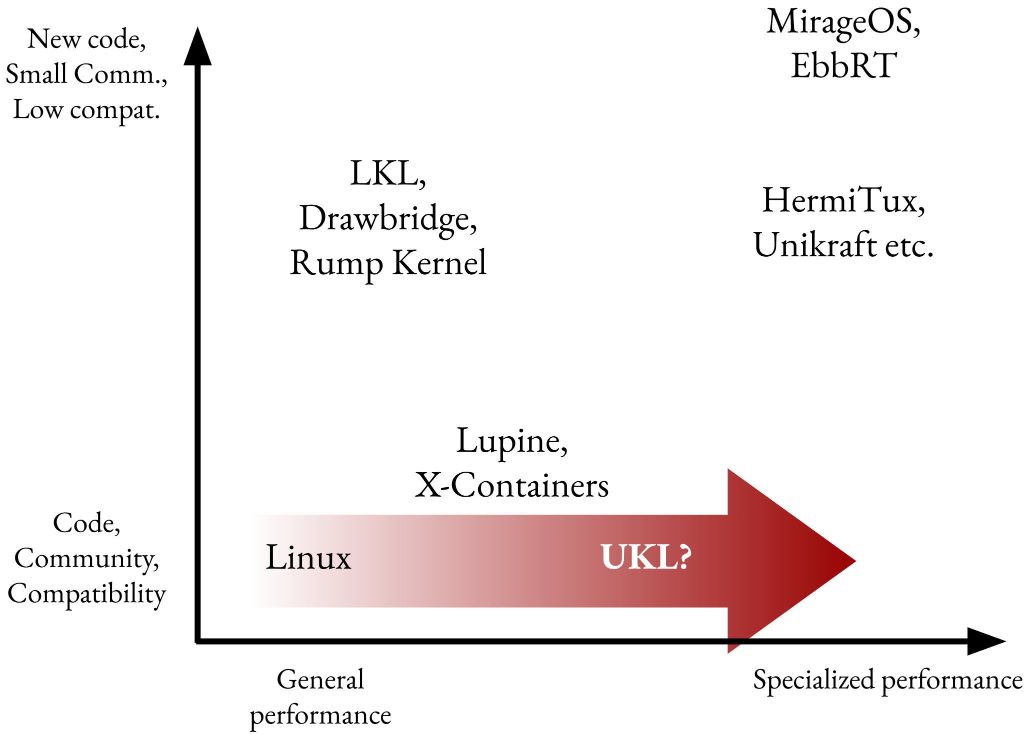


MirageOS, EbbRT, HermiTux, Unikraft etc.

Old code
New code

Motivation

- Is it possible to integrate unikernel optimizations in a general purpose OS without forking the code base?
- Would it be possible to preserve the battle tested code, development community, application and hardware support?
- Would there be any performance benefit?



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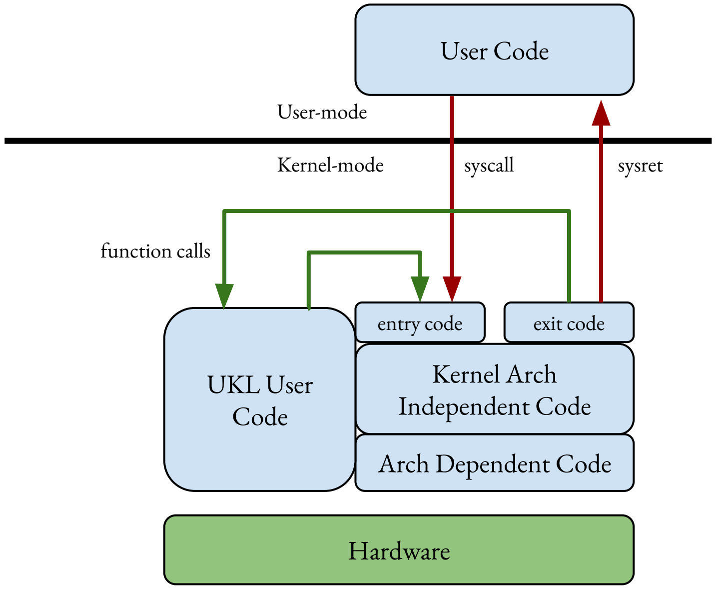
Design: UKL Base Model

- Unikernel-aware version of Linux
- Geared towards functionality and stability, not necessarily performance
- Like unikernels
  - link user code with kernel code
  - replace syscalls with function calls
- Unlike unikernels
  - preserve application and hardware compatibility
  - preserve support for multiple processes
  - preserve address space layout
  - maintain distinct execution models for user code and kernel code



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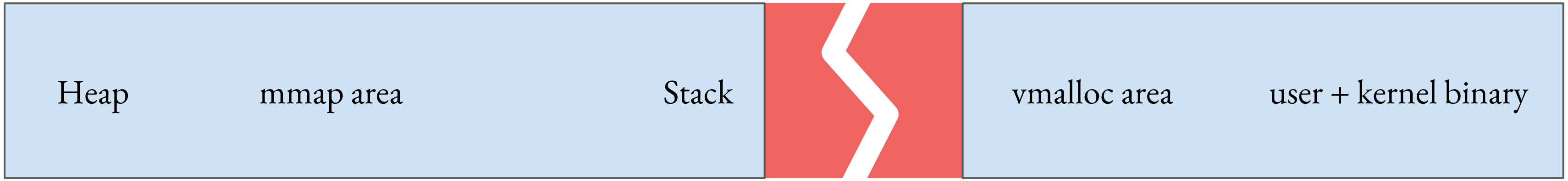
Design: UKL Base Model

- Preserve address space layout
- unmodified user and kernel memory allocators
- UKL user ELF binary is loaded with the kernel



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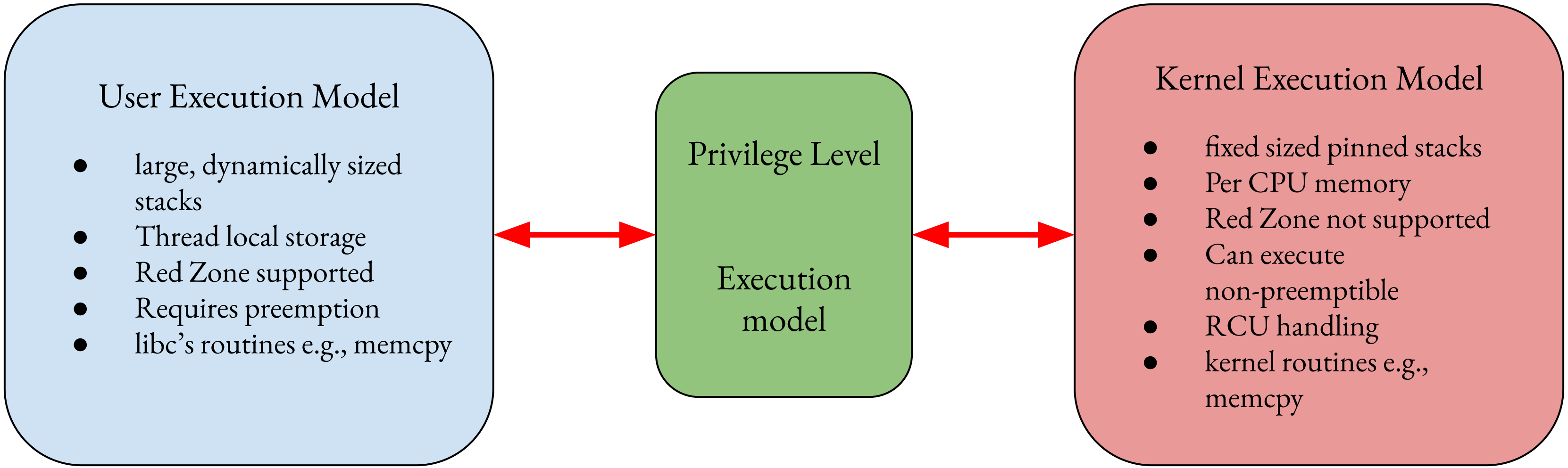
Design: UKL Base Model

- Distinct execution models
- Decouple execution model from privilege level



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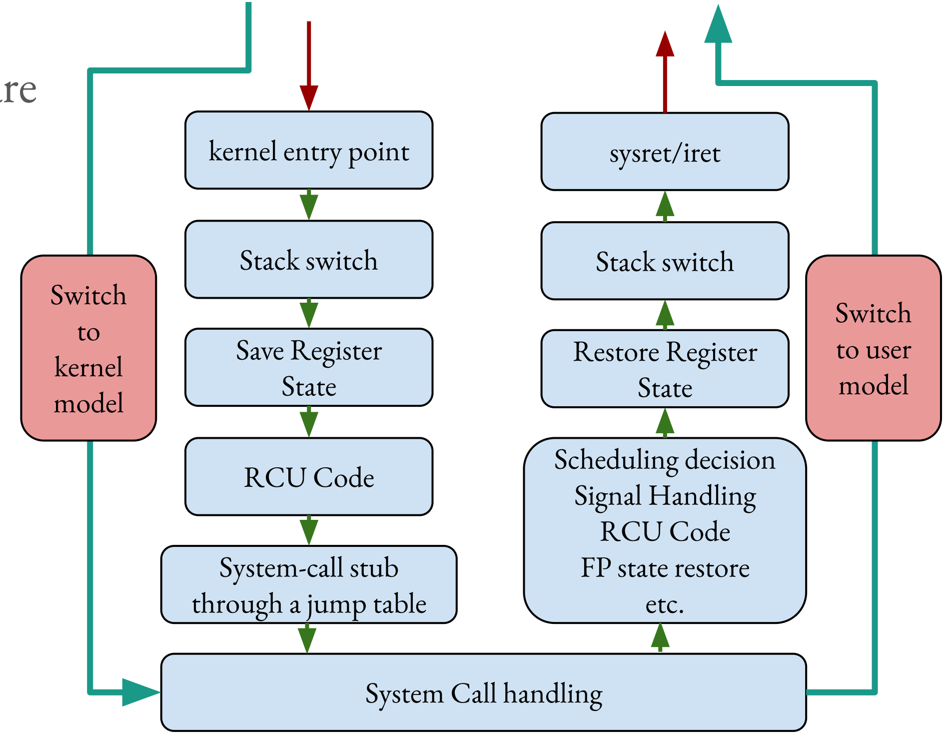
Unikernel Optimizations: Bypassing entry/exit code

- transitions between kernel and user code are expensive
- a configuration option to skip transition code
- do so while keeping a separation between execution models
- ability to selectively execute functionality e.g., stack switch, signal handling etc.
- automatic normal path execution after a number of bypasses



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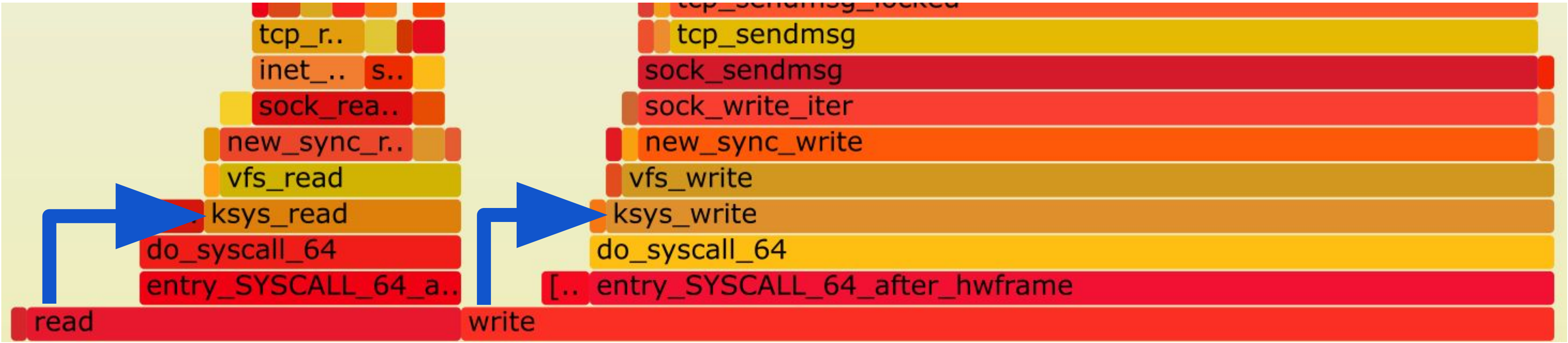
Unikernel Optimizations: Bypassing entry/exit code



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Unikernel Optimizations: Avoid Stack Switches

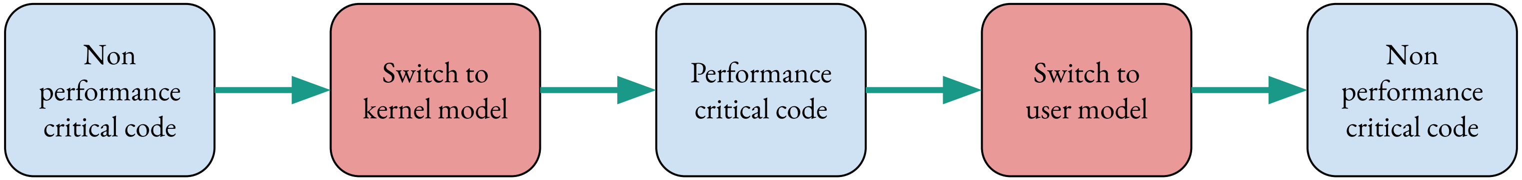
- Assembly code for transition breaks compiler view
- Stops cross layer optimization e.g., LTO
- Avoid stack switches, keep user stack for user and kernel code
- Kernel code cannot take page faults
- User stacks can get page faults
- Stack page fault aware fault handler
- Or use shared kernel stacks

Unikernel Optimizations: `ret` versus `iret`

- `iret` is used for interrupts, exceptions and faults
- an expensive instruction compared to `ret`
- but `iret` guarantees atomicity to
  - switch the stack
  - ring transition
  - update instruction pointer
  - restore flags
- use `ret` instead, while ensuring atomicity

Unikernel Optimizations: Kernel mode execution

- Kernel can run non-preemptible
- Applications can enter kernel mode of execution
- Allows ‘run-to-completion’

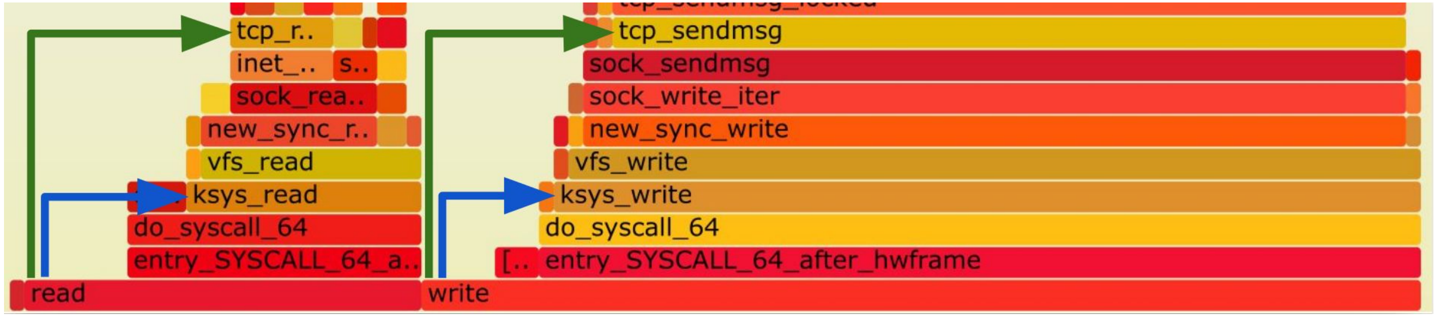


Unikernel Optimizations: Calling kernel routines

- Applications can call any internal kernel functions
- E.g., calling kernel memory allocator instead of user ones
- `vmalloc()` allocates pinned memory from kernel address range

Unikernel Optimizations: Deep shortcuts

- Instead of calling pre-written kernel functions
- Add application specific custom code to the kernel
- Use application knowledge to create custom paths in the kernel



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Implementation

- Modifications to Linux and glibc
- Currently targets x86_64 architecture
- All code is protected by #ifdefs, so UKL can be configured out
- Prefixing all user symbols with `_ukl` to avoid name collisions
- Changes to bootstrapping, process creation and initialization paths
- Execution model tracking in transition code
- UKL base model ~550 LoC modified in Linux
- Total UKL patch to Linux is less than 1400 LoC

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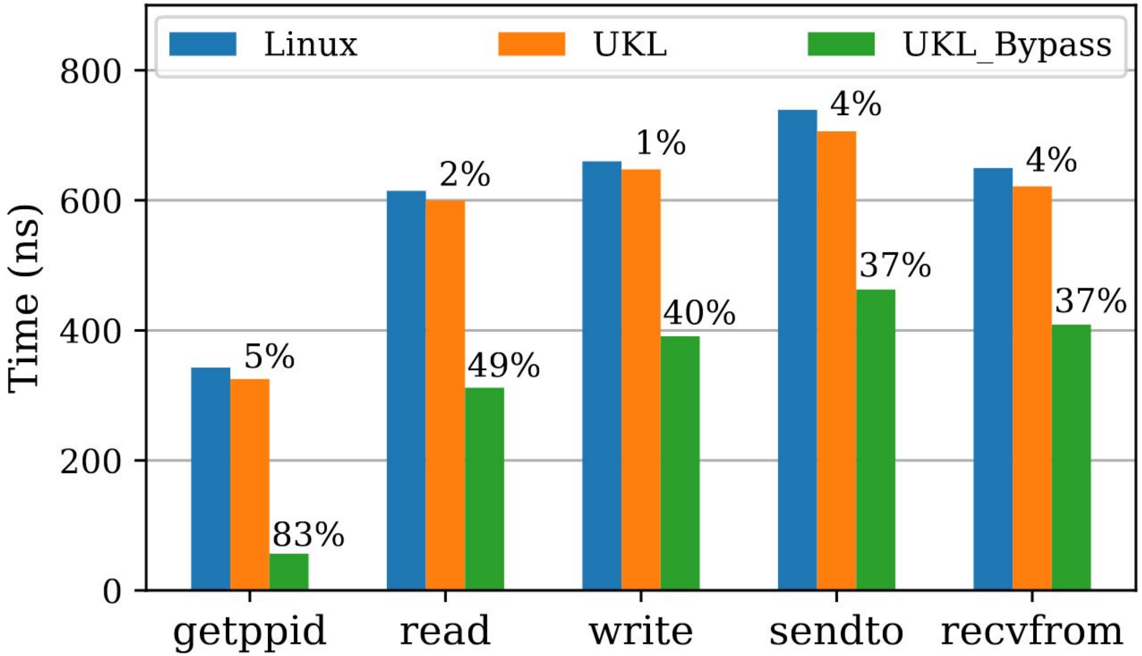
Evaluation: Code, Community and Compatibility

- Application support
- Hardware Support
- Ecosystem Support
- Do not support exec, dynamic loader or proprietary pre-compiled binaries

Evaluation: System call latency



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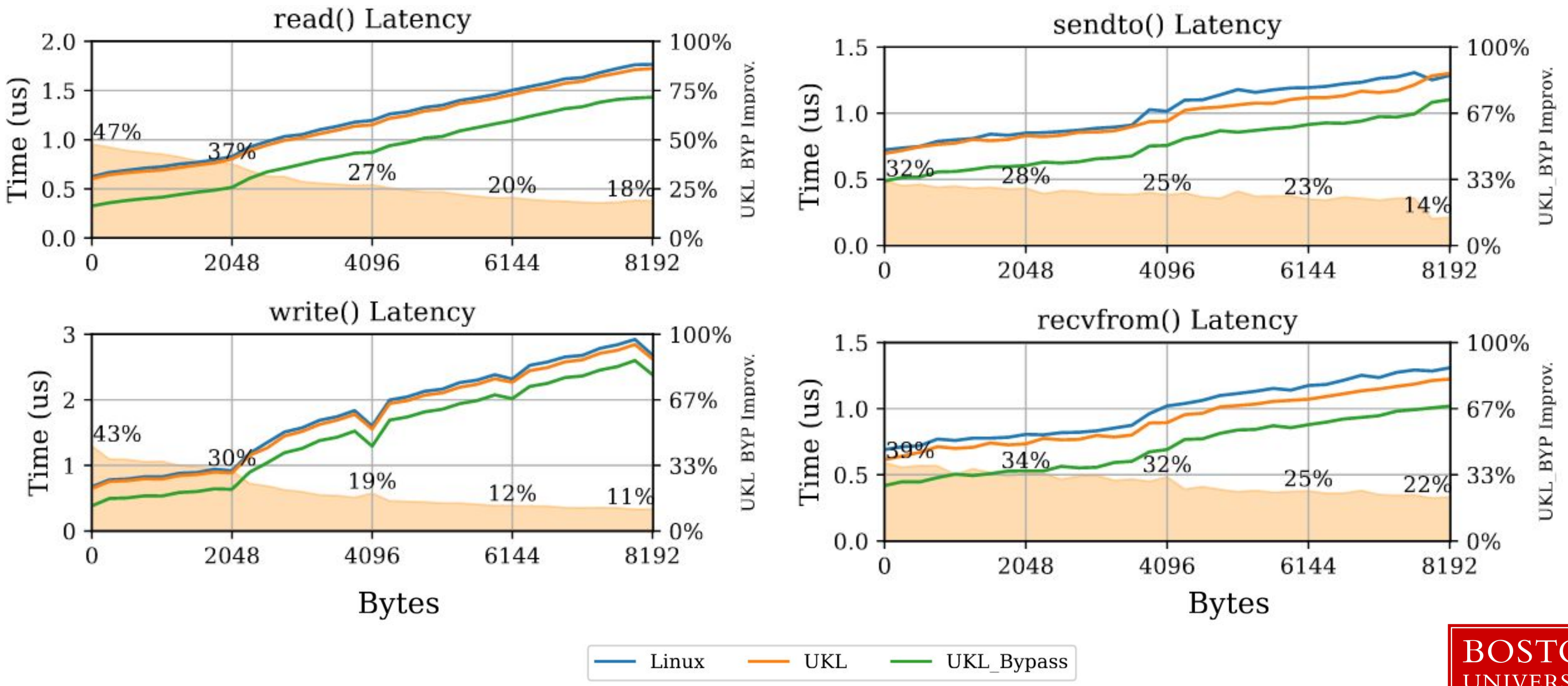
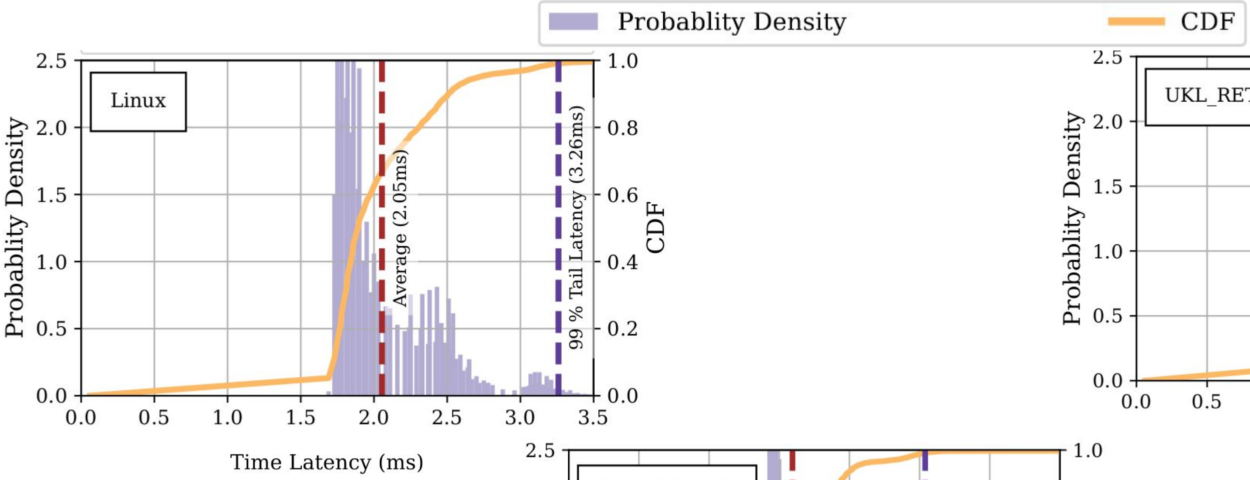
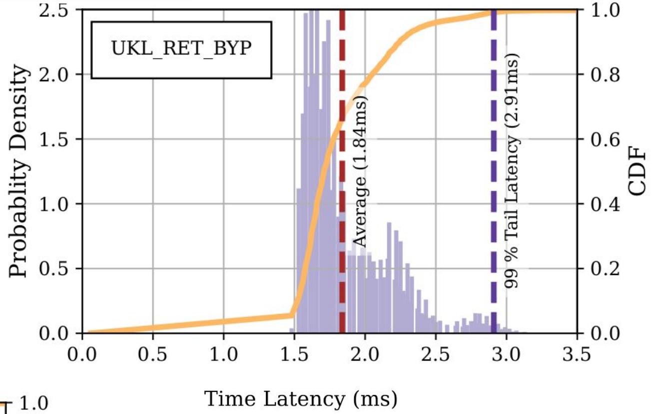
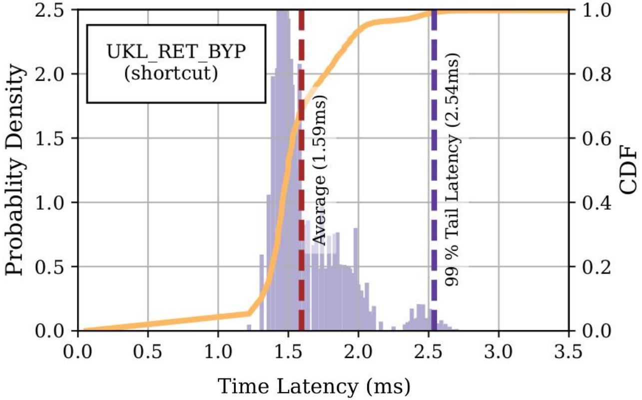
Evaluation: System call latency with larger payloads



Evaluation: Performance







System	99% tail(ms)	tail % improv.	t-put (Kb/s)	t-put % improv.
Linux	3.26	-	6375.20	-
UKL_RET_BP	2.91	11%	7154.68	12%
UKL_RET_BYP (shortcut)	2.54	22%	8022.54	26%

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