Unikernels as Processes

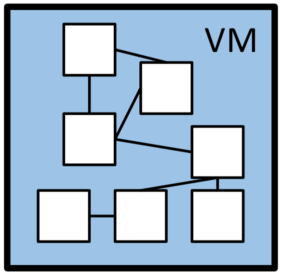
Dan Williams, Ricardo Koller (IBM Research)

Martin Lucina (robur.io/Center for the Cultivation of Technology)

Nikhil Prakash (BITS Pilani)

What is a unikernel?

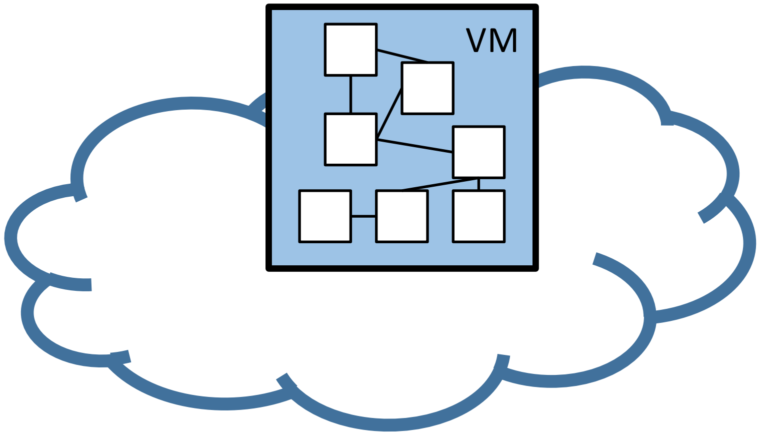
- An application linked with **library OS** components
- Run on **virtual hardware** (like) abstraction



- Language-specific
  - MirageOS (OCaml)
  - IncludeOS (C++)
- Legacy-oriented
  - Rumprun (NetBSD-based)
    - Can run nginx, redis, node.js, python,etc..

Why unikernels?

- **Lightweight**
  - Only what the application needs
- **Isolated**
  - VM-isolation is the “gold standard”
- Well suited for the **cloud**
  - Microservices
  - Serverless
  - NFV



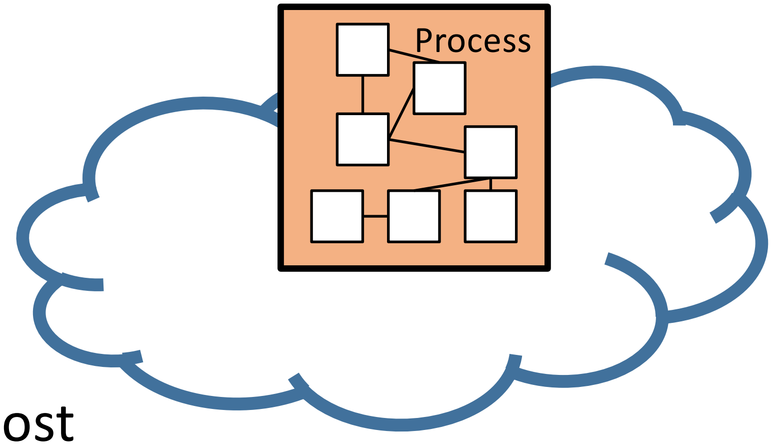
Virtualization is a mixed bag

- Good for **isolation**, but…

- **Tooling** for VMs not designed for lightweight (e.g., lightVM)
- How do you debug **black-box** VMs?
- Poor VM **performance** due to `vmexits`
- **Deployment** issues on already-virtualized infrastructure

Why not run unikernels as processes?

- Unikernels are a **single process** anyway!
- Many benefits as a process
  - Better **performance**
  - Common tooling (gdb, perf, etc.)
  - ASLR
  - Memory sharing
  - Architecture independence
- **Isolation** by limiting process interface to host
  - 98% reduction in accessible kernel functions



Outline

- Introduction
- Where does unikernel isolation come from?
- Unikernels as processes
- Isolation evaluation
- Performance evaluation
- Summary

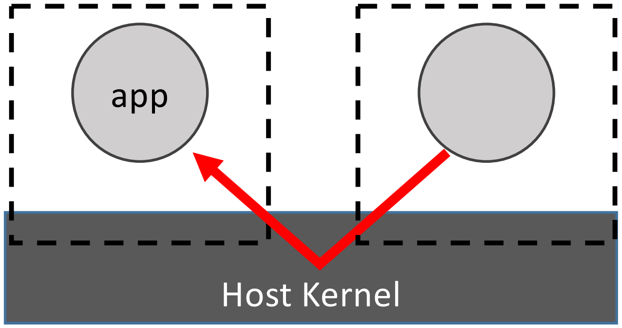
Isolation: definitions and assumptions

- **Isolation**: no cloud user can read/write state or modify its execution

- Focus on **software deficiencies** in the host
  - Code reachable through interface is a metric for attack surface

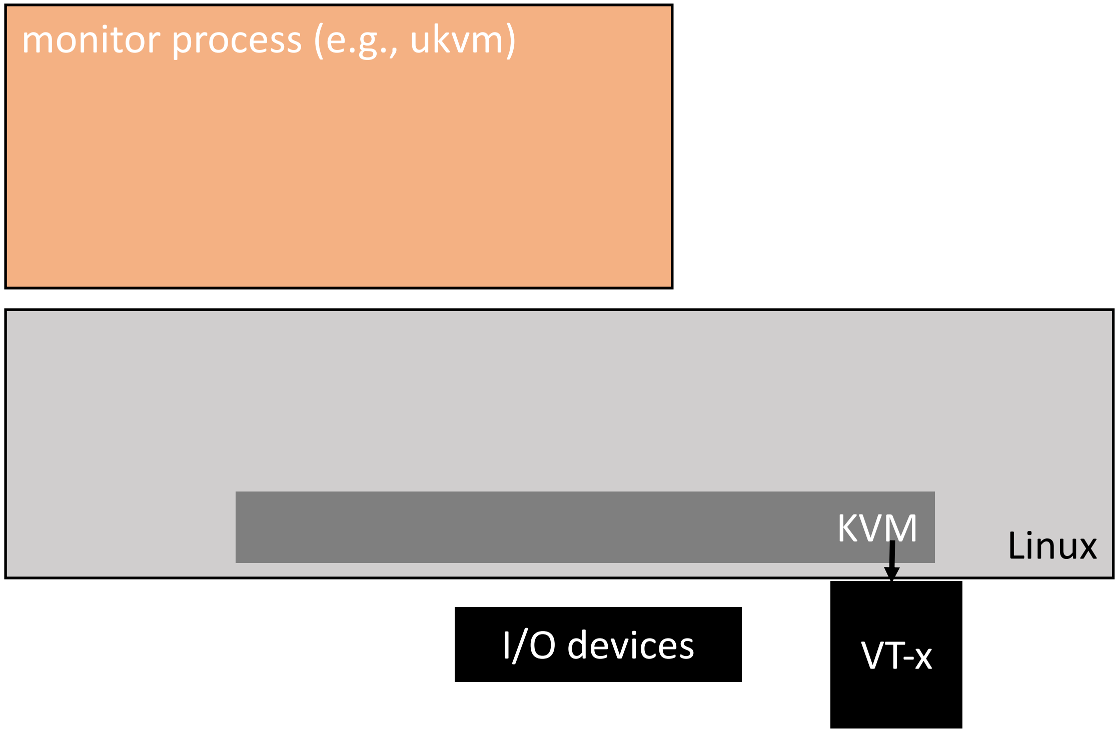
- We **trust HW** isolation (page tables, etc.)

- We do not consider covert channels, timing channels or resource starvation



Unikernel architecture

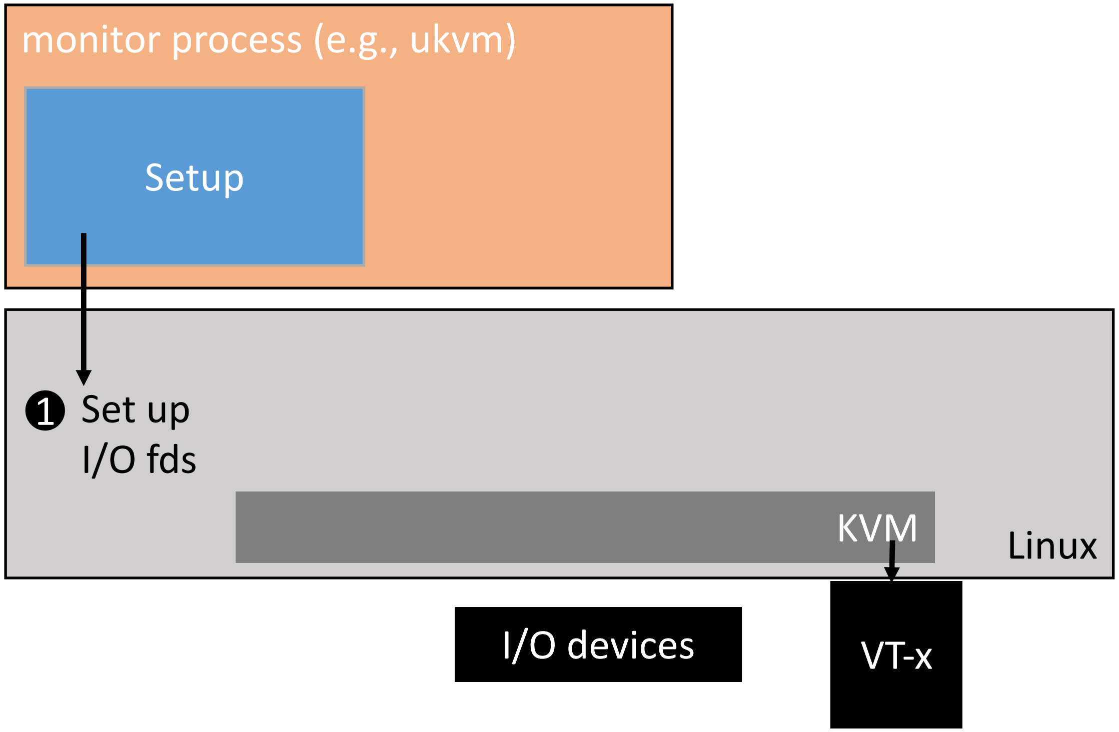
- ukvm unikernel monitor
  - Userspace process
  - Uses Linux/KVM
- Setup and loading
- Exit handling



Unikernel architecture

- ukvm unikernel monitor
  - Userspace process
  - Uses Linux/KVM

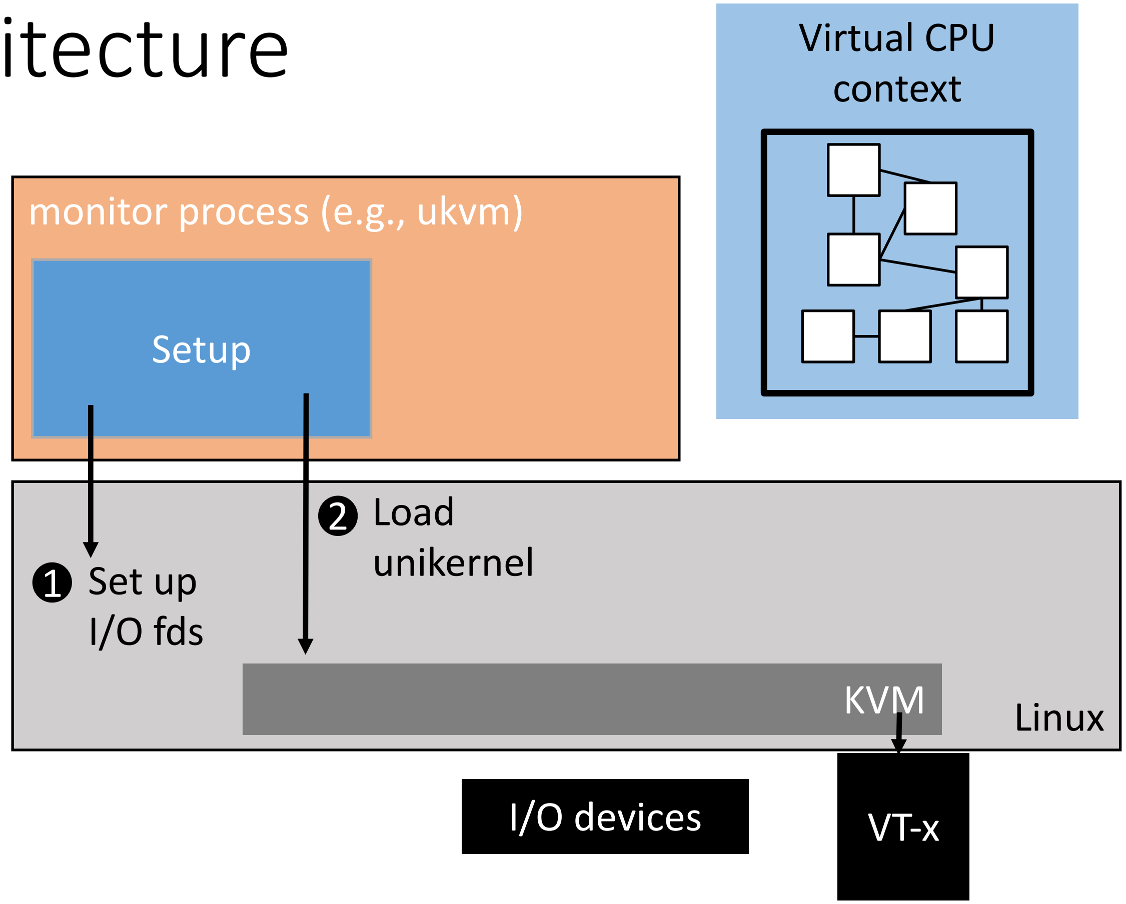
- Setup and loading
- Exit handling



Unikernel architecture

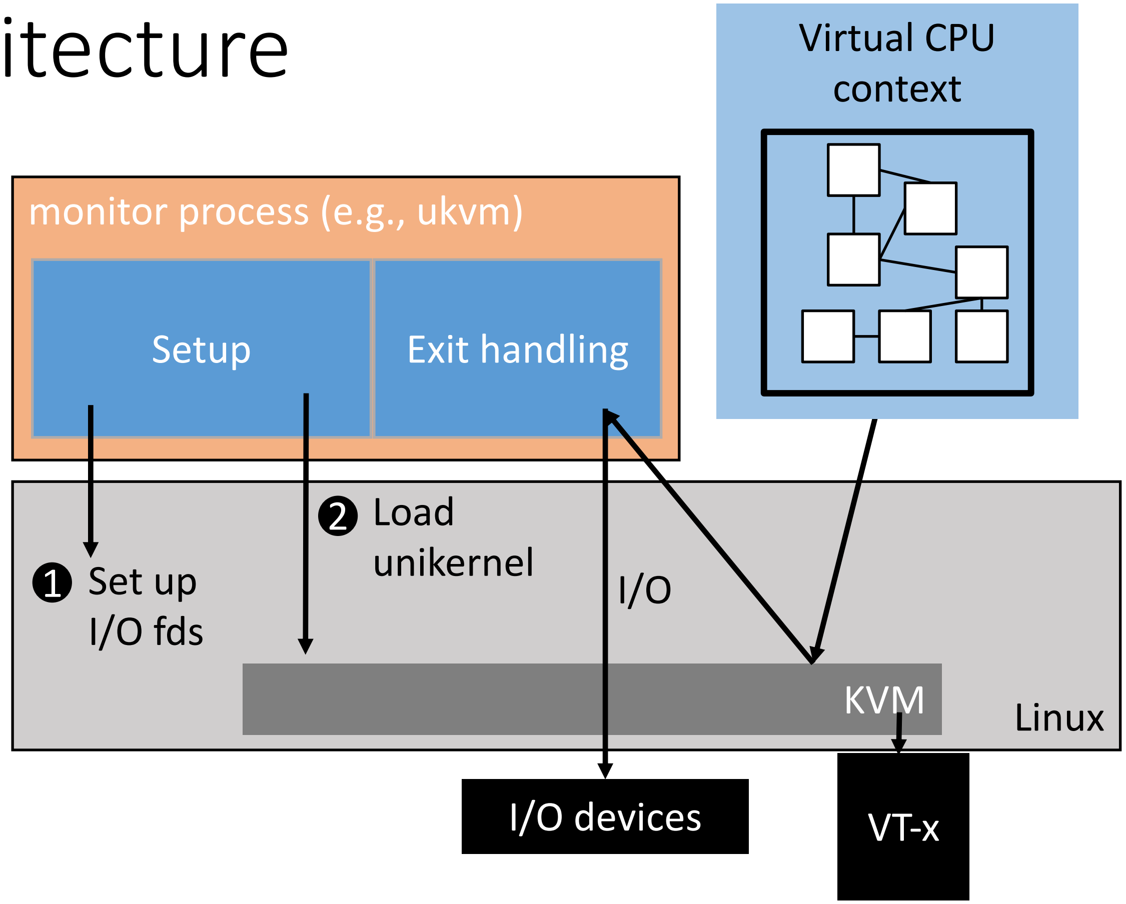
- ukvm unikernel monitor
  - Userspace process
  - Uses Linux/KVM

- Setup and loading
- Exit handling



Unikernel architecture

- ukvm unikernel monitor
  - Userspace process
  - Uses Linux/KVM
- Setup and loading
- Exit handling



Unikernel isolation comes from the interface

- 10 hypercalls

- 6 for I/O
  - Network: packet level
  - Storage: block level

- vs. >350 syscalls

Hypercall
`walltime`
`puts`
`poll`
`blkinfo`
`blkwrite`
`blkread`
`netinfo`
`netwrite`
`netread`
`halt`

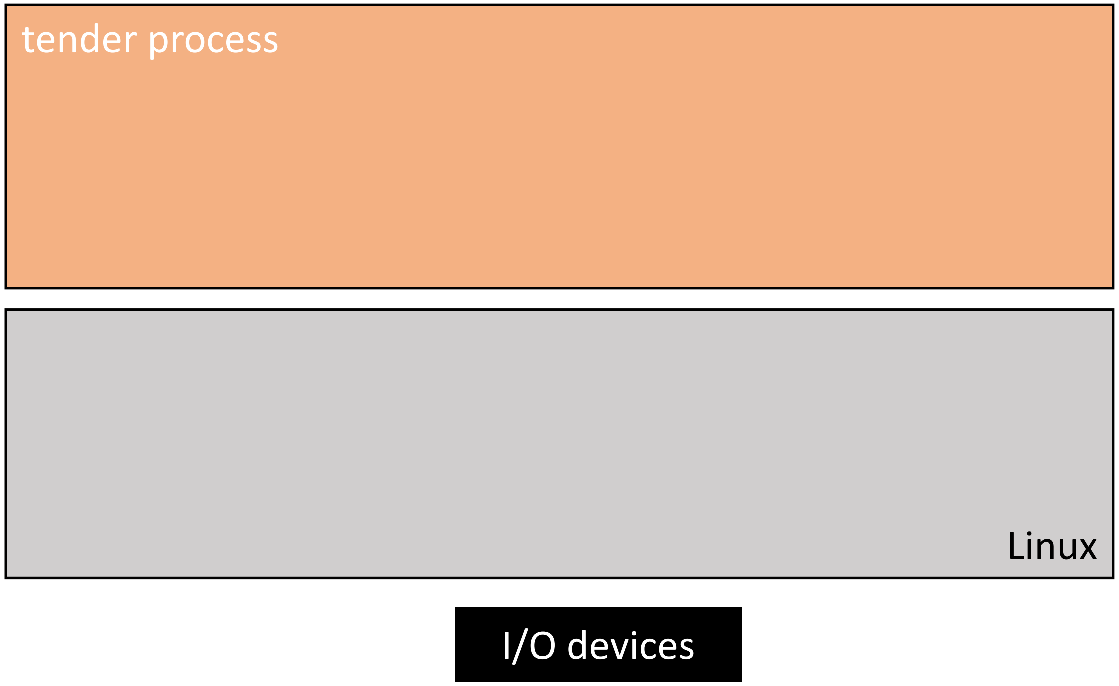
Observations

- Unikernels are not kernels!
  - No page table management after setup
  - No interrupt handlers: cooperative scheduling and poll
- The ukvm monitor doesn't "do" anything!
  - One-to-one mapping between hypercalls and system calls
- Idea: maintain isolation by **limiting syscalls** available to process

Unikernel as process architecture

- **Tender**: modified ukvm unikernel monitor
  - Userspace process
  - Uses **`seccomp`** to restrict interface

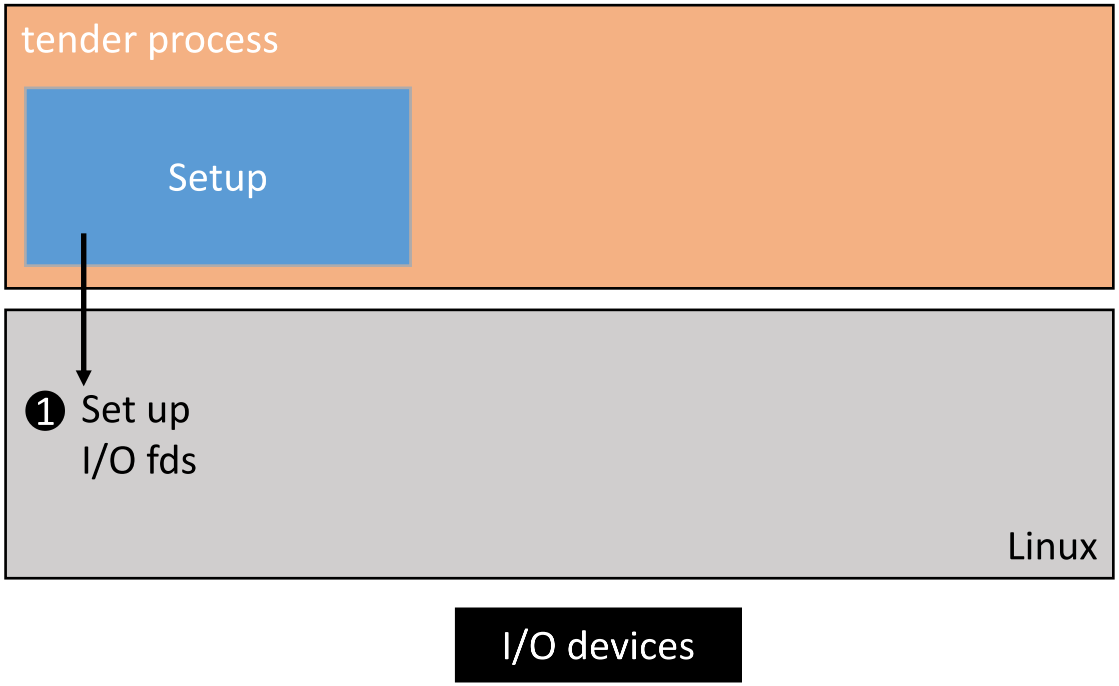
- Setup and loading



Unikernel as process architecture

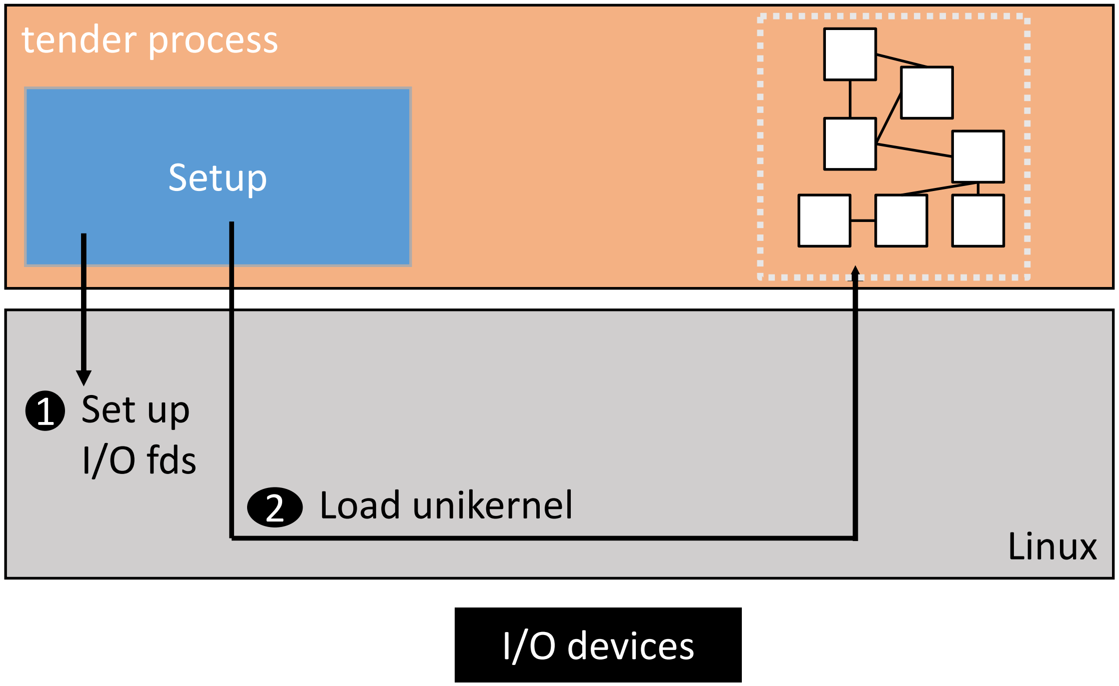
- **Tender**: modified ukvm unikernel monitor
  - Userspace process
  - Uses **`seccomp`** to restrict interface

- Setup and loading



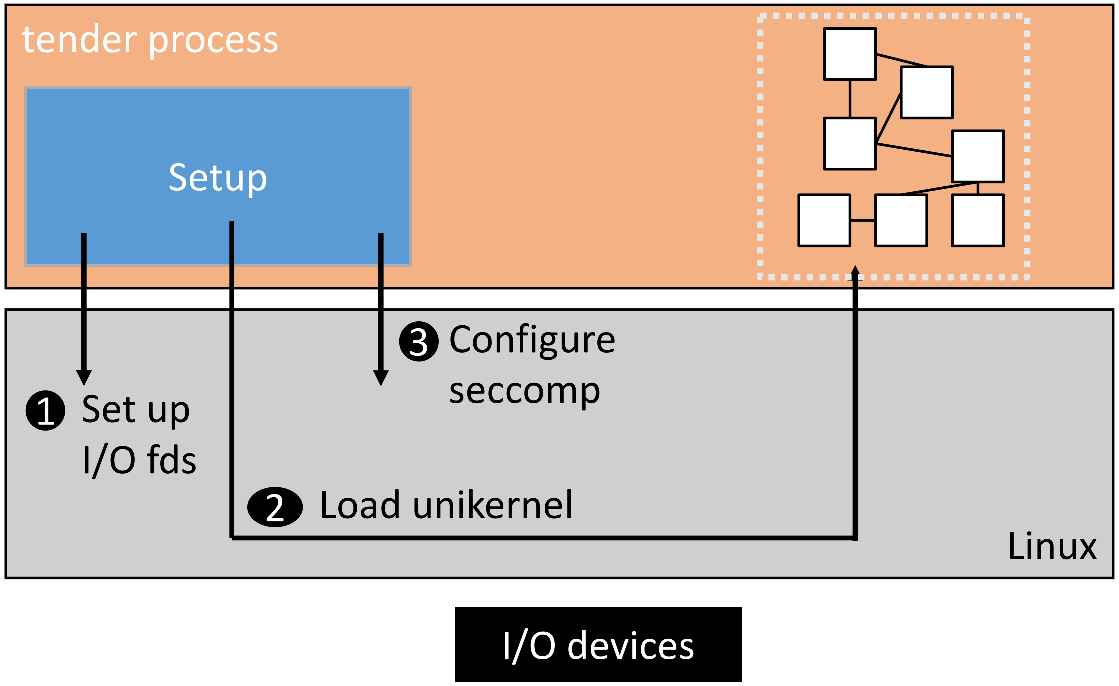
Unikernel as process architecture

- **Tender**: modified ukvm unikernel monitor
  - Userspace process
  - Uses **`seccomp`** to restrict interface
- Setup and loading



Unikernel as process architecture

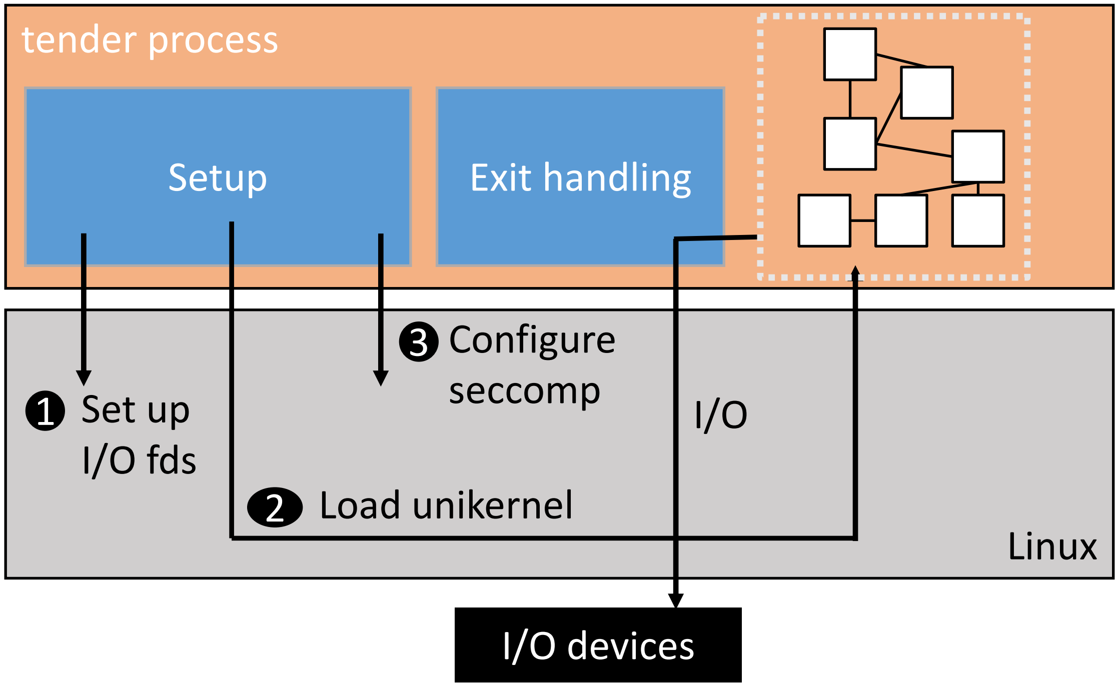
- **Tender**: modified ukvm unikernel monitor
  - Userspace process
  - Uses **`seccomp`** to restrict interface
- Setup and loading



Unikernel as process architecture

- **Tender**: modified ukvm unikernel monitor
  - Userspace process
  - Uses **`seccomp`** to restrict interface

- Setup and loading
- “Exit” handling



Unikernel isolation comes from the interface

- 10 hypercalls

- 6 for I/O
  - Network: packet level
  - Storage: block level

- vs. >350 syscalls

Hypercall
`walltime`
`puts`
`poll`
`blkinfo`
`blkwrite`
`blkread`
`netinfo`
`netwrite`
`netread`
`halt`

Unikernel isolation comes from the interface

- Direct mapping between 10 hypercalls and system call/resource pairs

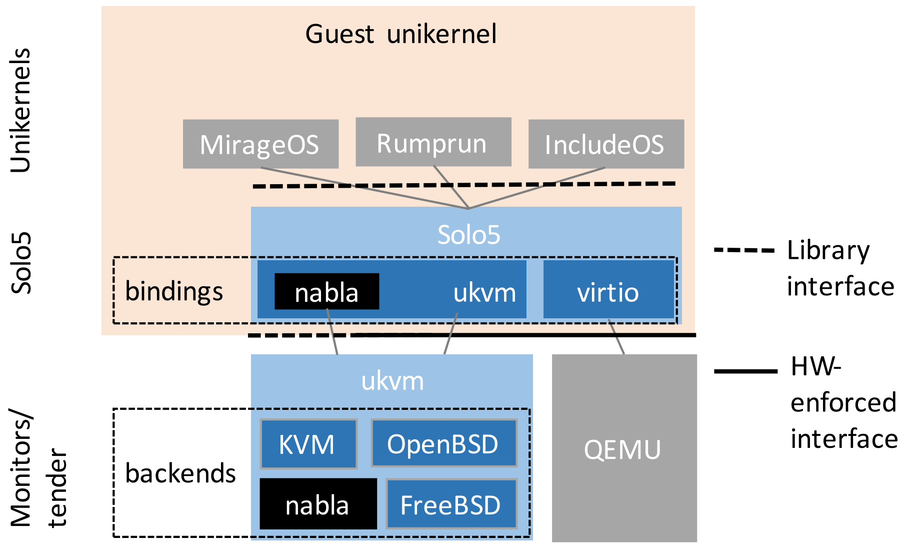
- 6 for I/O
  - Network: packet level
  - Storage: block level

- vs. >350 syscalls

Hypercall	System Call	Resource
walltime	clock_gettime	
puts	write	*stdout*
poll	ppoll	*net_fd*
blkinfo		
blkwrite	pwrite64	*blk_fd*
blkread	pread64	*blk_fd*
netinfo		
netwrite	write	*net_fd*
netread	read	*net_fd*
halt	exit_group	

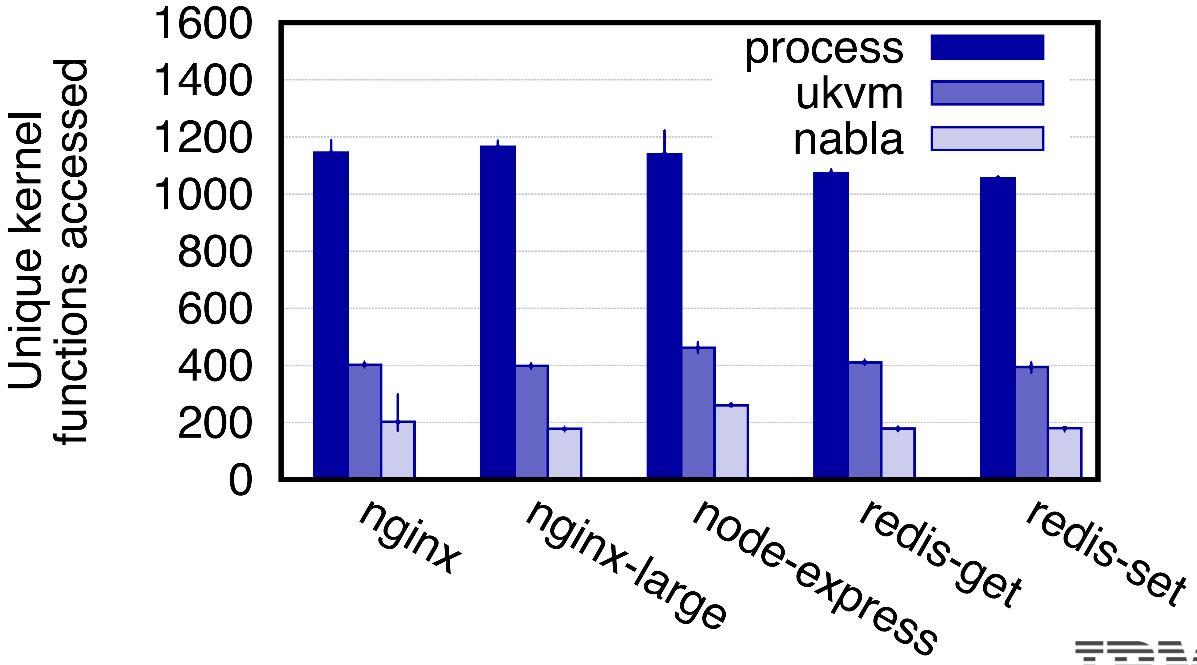
Implementation: nabla ∇

- Extended Solo5 unikernel ecosystem and ukvm
- Prototype supports:
  - MirageOS
  - IncludeOS
  - Rumprun
- https://github.com/solo5/solo5



Measuring isolation: common applications

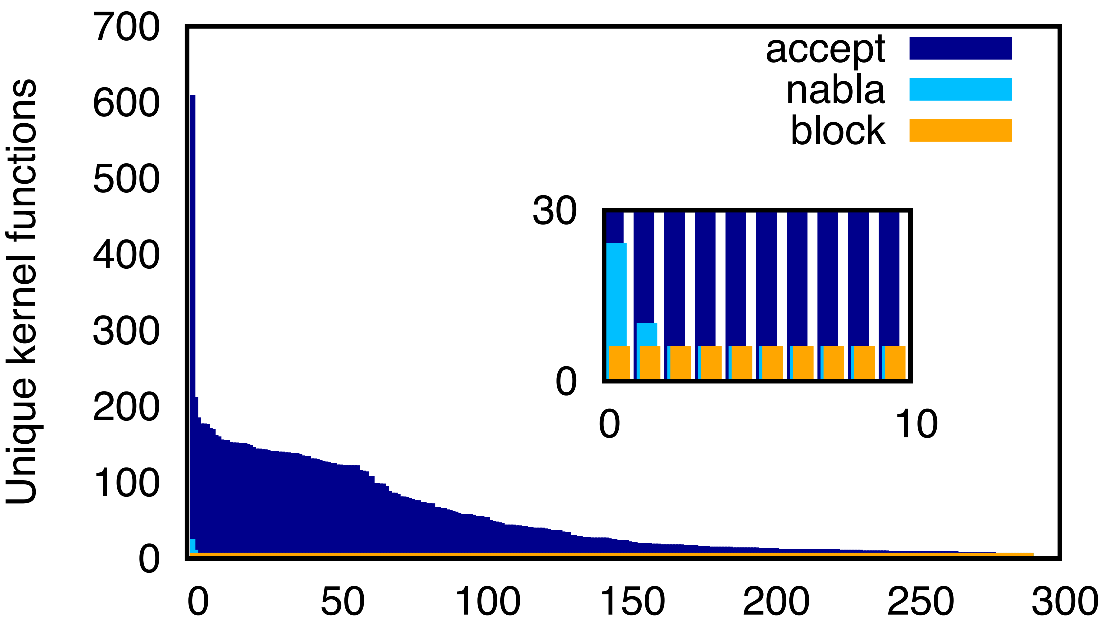
- Code reachable through interface is a metric for attack surface
- Used kernel **`ftrace`**
- Results:
  - Processes: 5-6x more
  - VMs: 2-3x more



Measuring isolation: fuzz testing

- Used kernel **`ftrace`**
- Used **`trinity`** system call fuzzer to try to access more of the kernel

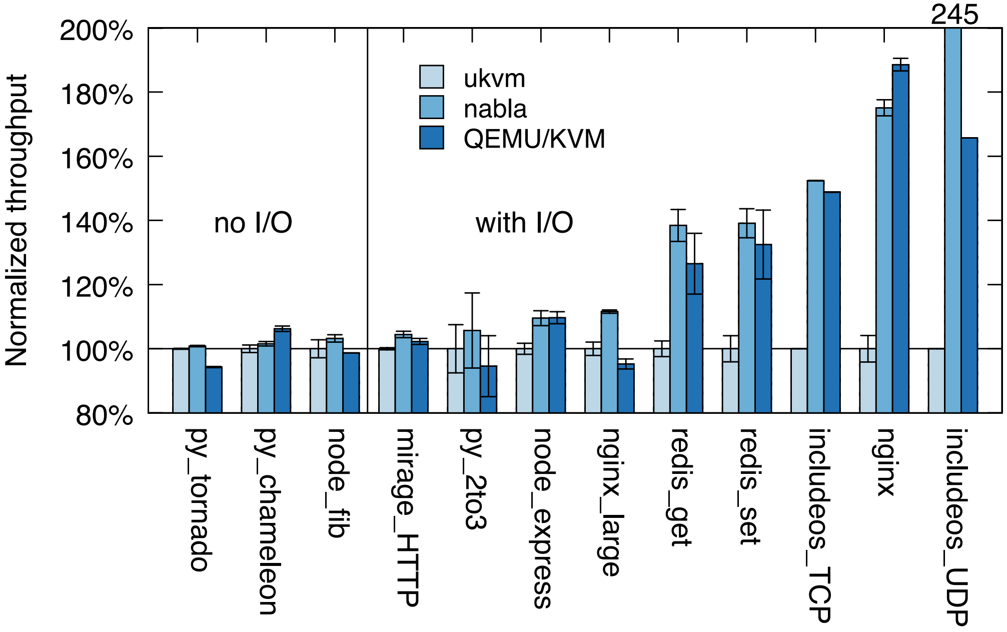
- Results:
  - Nabla policy reduces by 98% over a "normal" process



Measuring performance: throughput

- Applications include:
  - Web servers
  - Python benchmarks
  - Redis
  - etc.

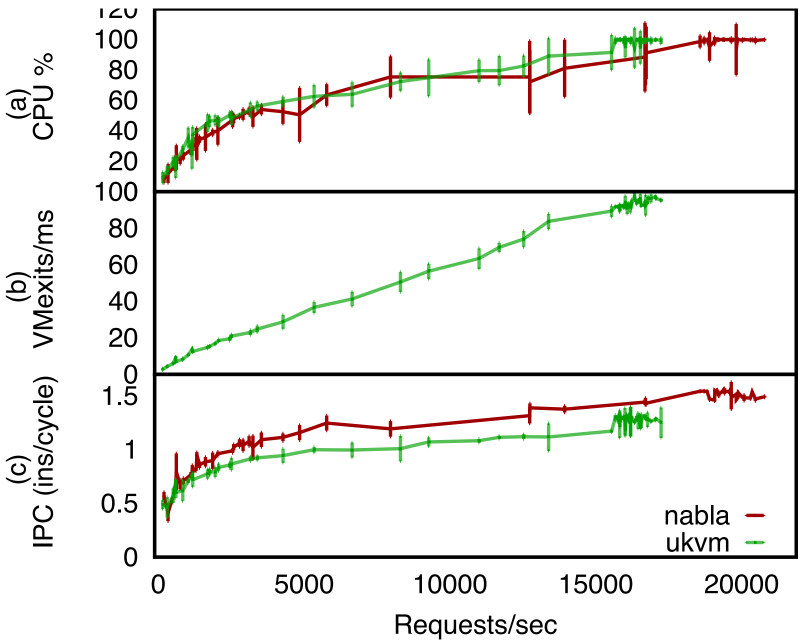
- Results:
  - 101%-245% higher throughput than ukvm



Measuring performance: CPU utilization

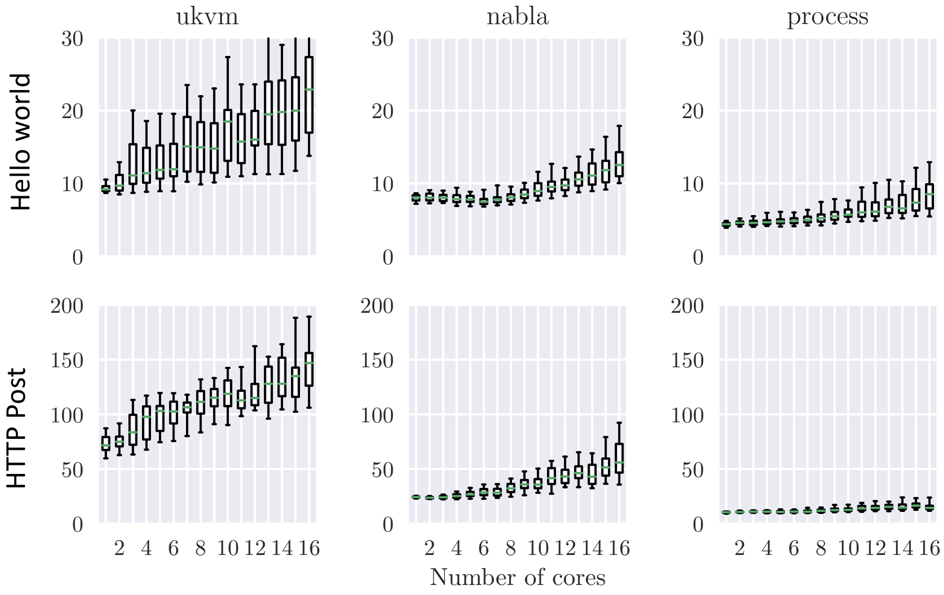
- `vmexits` have an effect on instructions per cycle

- Experiment with MirageOS web server
- Results:
  - 12% reduction in cpu utilization over ukvm



Measuring performance: startup time

- Startup time is important for serverless, NFV
- Results:
  - Ukvm has 30-370% higher latency than nabla
- Mostly due avoiding KVM overheads



Summary and Next Steps

- Unikernels should run as processes!
  - Maintain isolation via thin interface
  - Improve performance, etc.

- Next steps: can unikernels as processes be used to improve container isolation?
  - Nabla containers
  - https://nabla-containers.github.io/