Orchestrating a brighter world

NEC

EU H2020 Superfluidity

LINUX FOUNDATION

Xen™

Unleashing the Power of Unikernels with Unikraft

Felipe Huici felipe.huici@neclab.eu
Systems and Machine Learning Group
NEC Laboratories GmbH, Heidelberg

Who am I?

Chief Researcher @

- NEC Laboratories in Heidelberg, Germany
- Systems and Machine Learning Group

The Container Craze

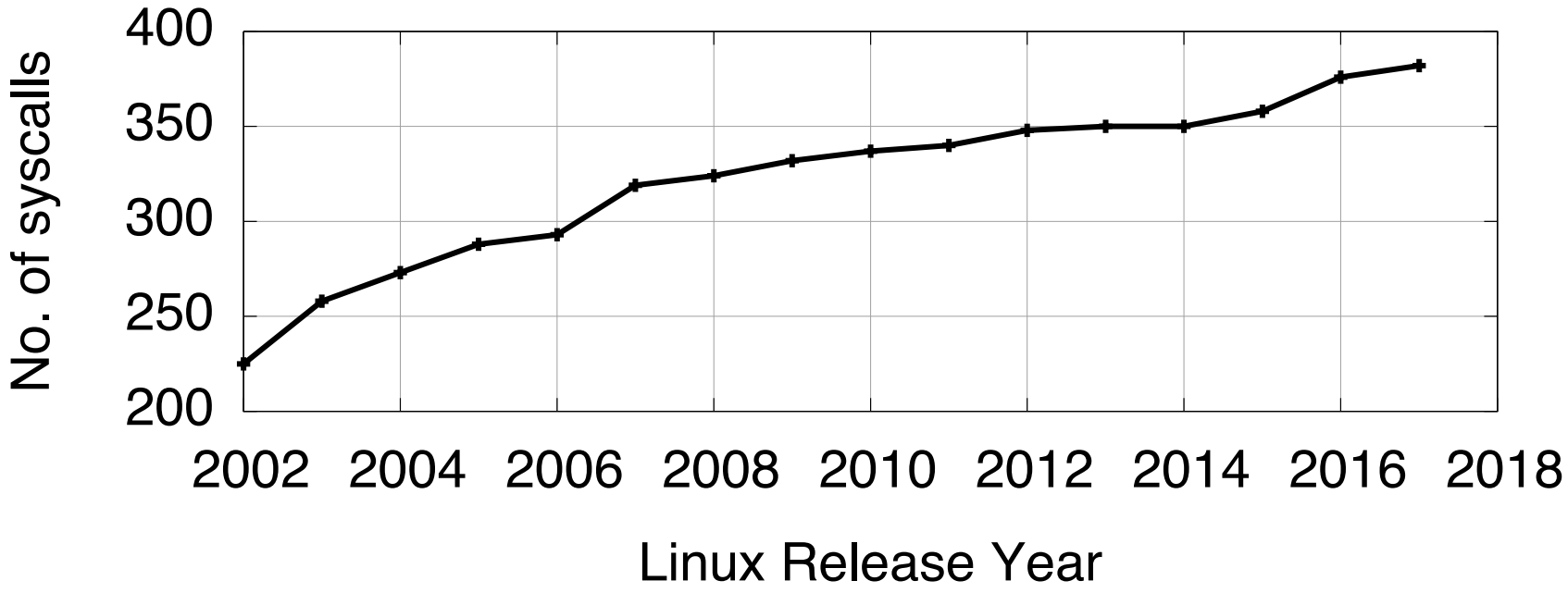
- "Google runs all services in containers"
- Container-as-a-Service services:
  - Amazon Lambda, EC2 Container Service
  - Google Container Engine
  - Azure Container service
  - *and so on…*

The Container Advantage

- Very fast instantiation times
  - 100s ms
- Small per-instance memory footprints
  - 10-100 MBs
- High density
  - 100-1000 instances on same host

The Unsafe Container

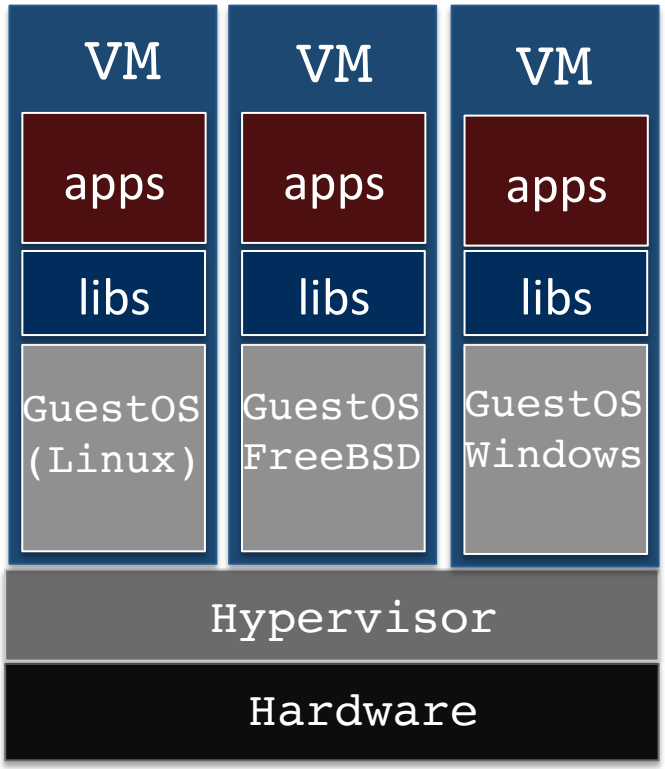
- Kernel API difficult to secure, lots of exploits
- An unsafe container affects all other containers on host
  - This includes DoS/exhaustion attacks (e.g., forkbombs, etc.)



Isolating Workloads

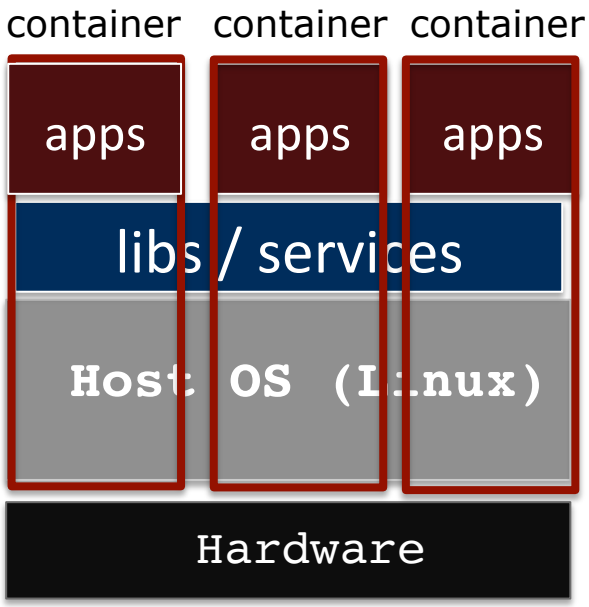
Pick Your Poison

Virtualization



vs.

Containers



✅ Strong isolation

❌ Heavy weight

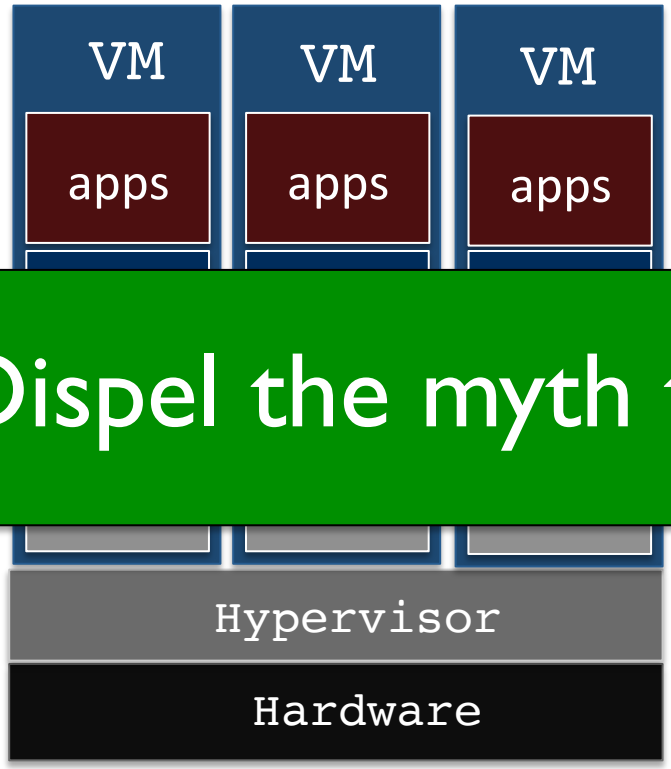
?

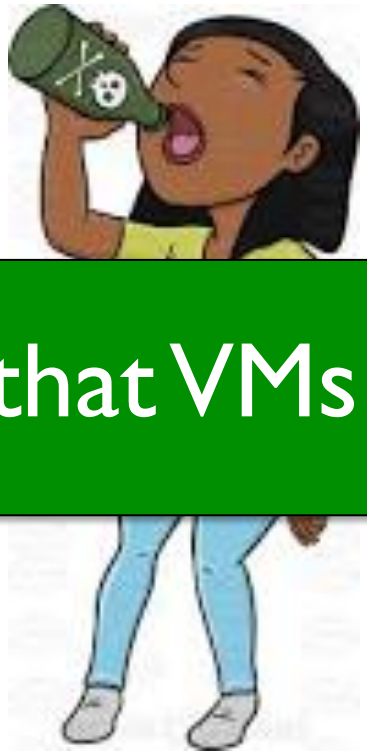
✅ Lightweight

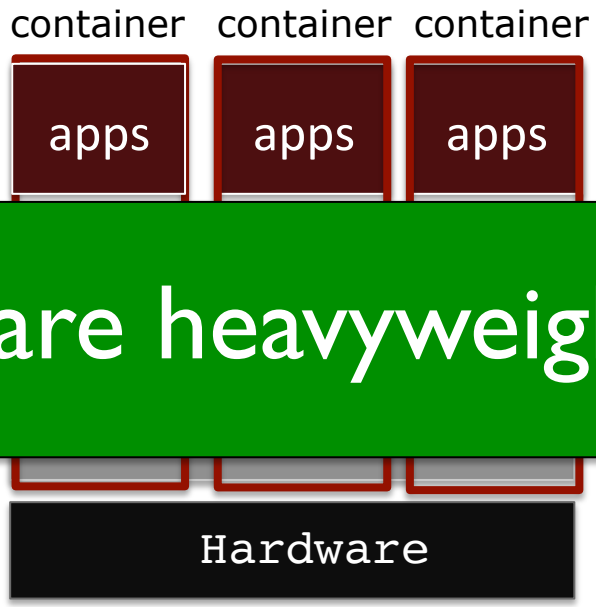
❌ Iffy isolation

Isolating Workloads

Virtualization vs. Containers







Dispel the myth that VMs are heavyweight

✅ Strong isolation

❌ Heavy weight

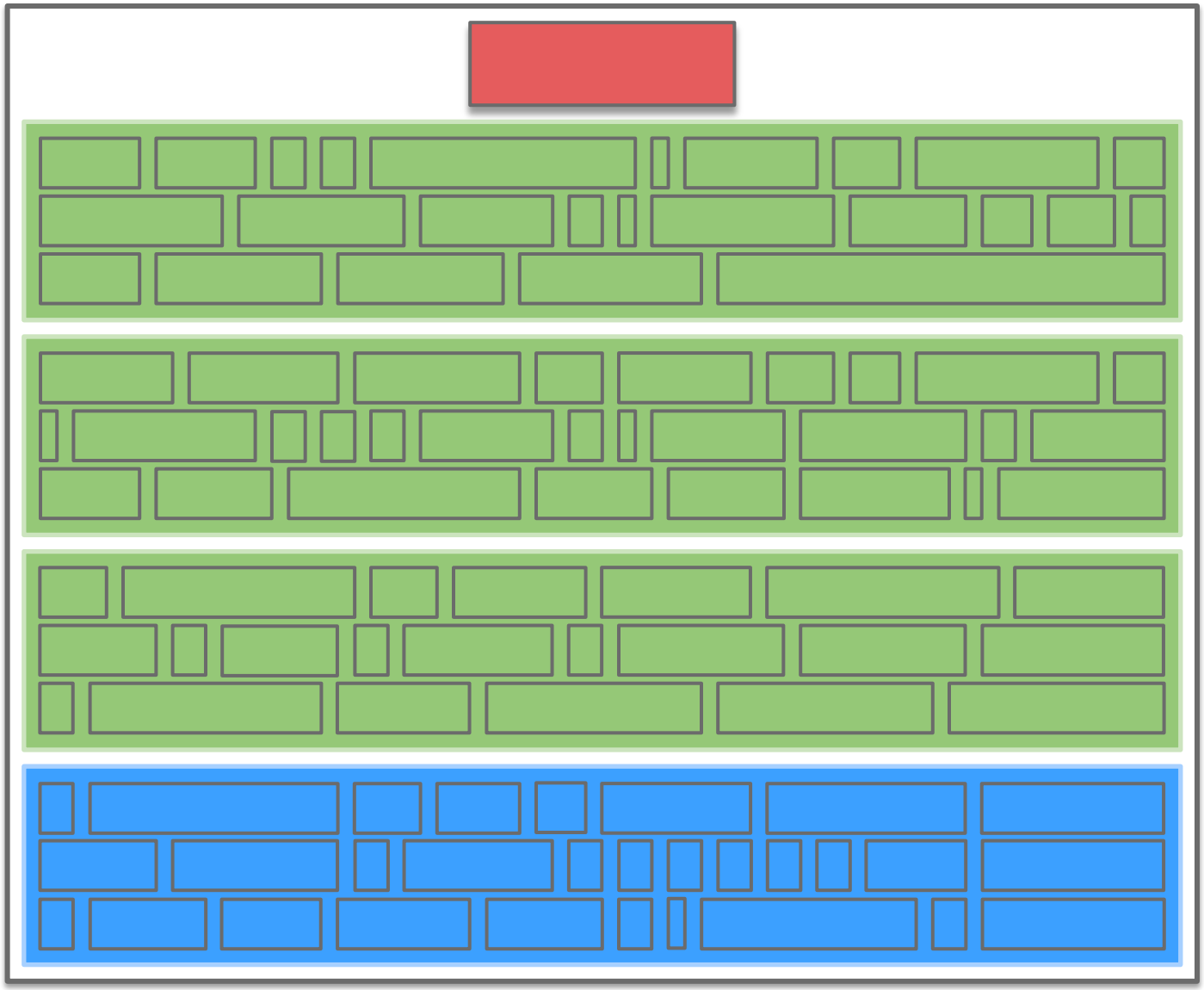
?

✅ Lightweight

❌ Iffy isolation

What's a Unikernel Then?

Standard VM: Application on Top of Distro



User Application(s)

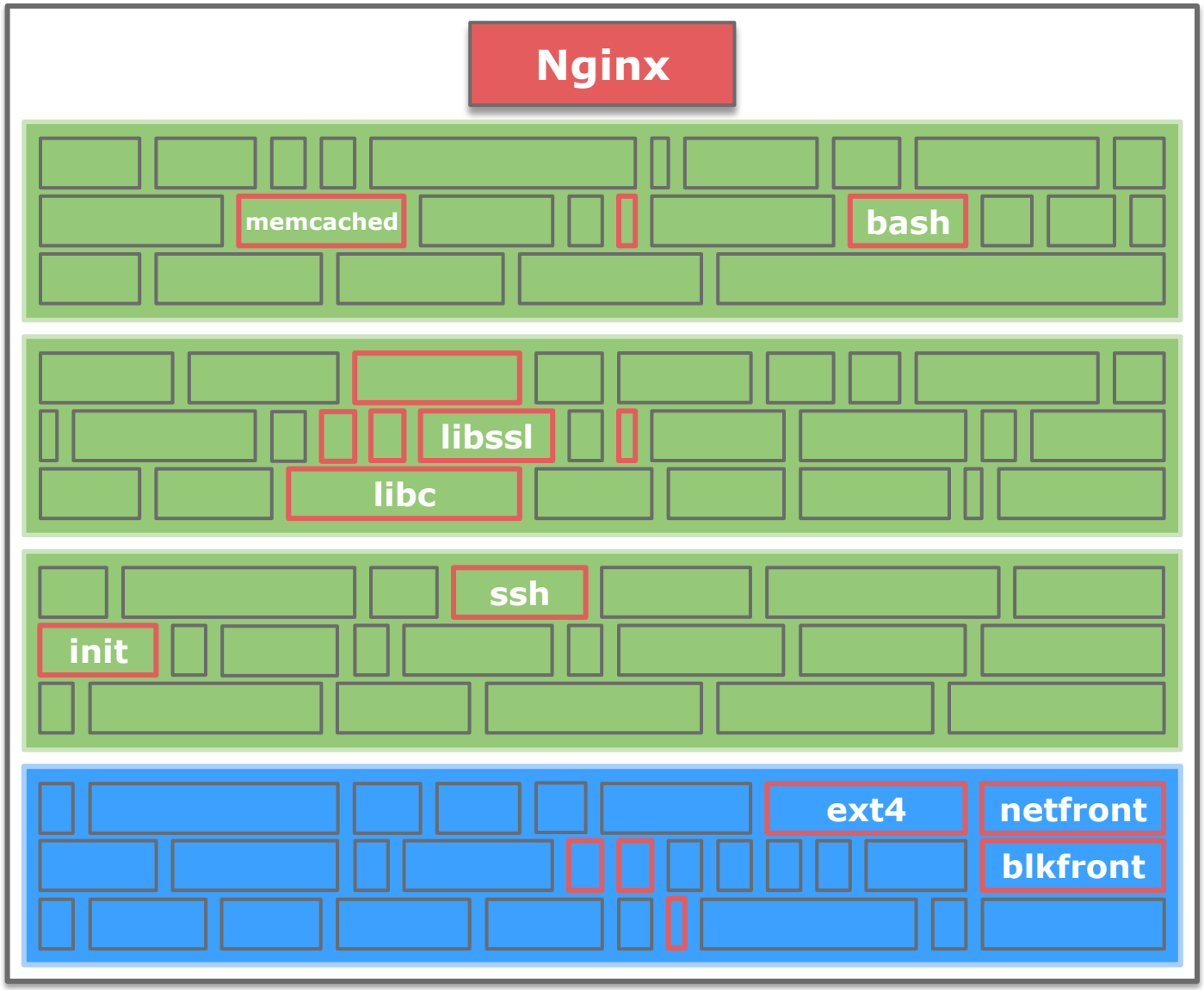
3rd Party Applications

Libraries

Services

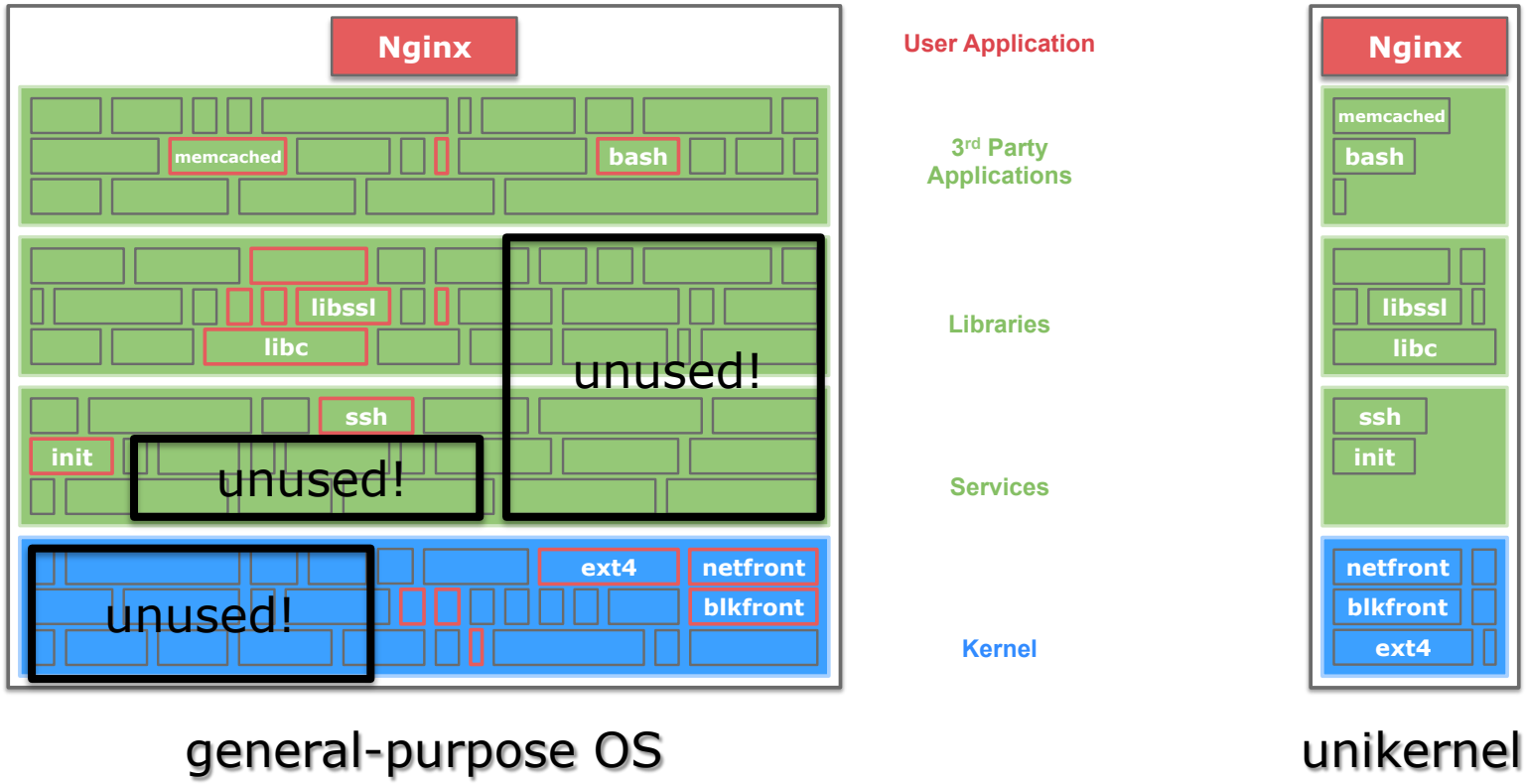
Kernel

Most of the VM not Used…



Specialization in Practice

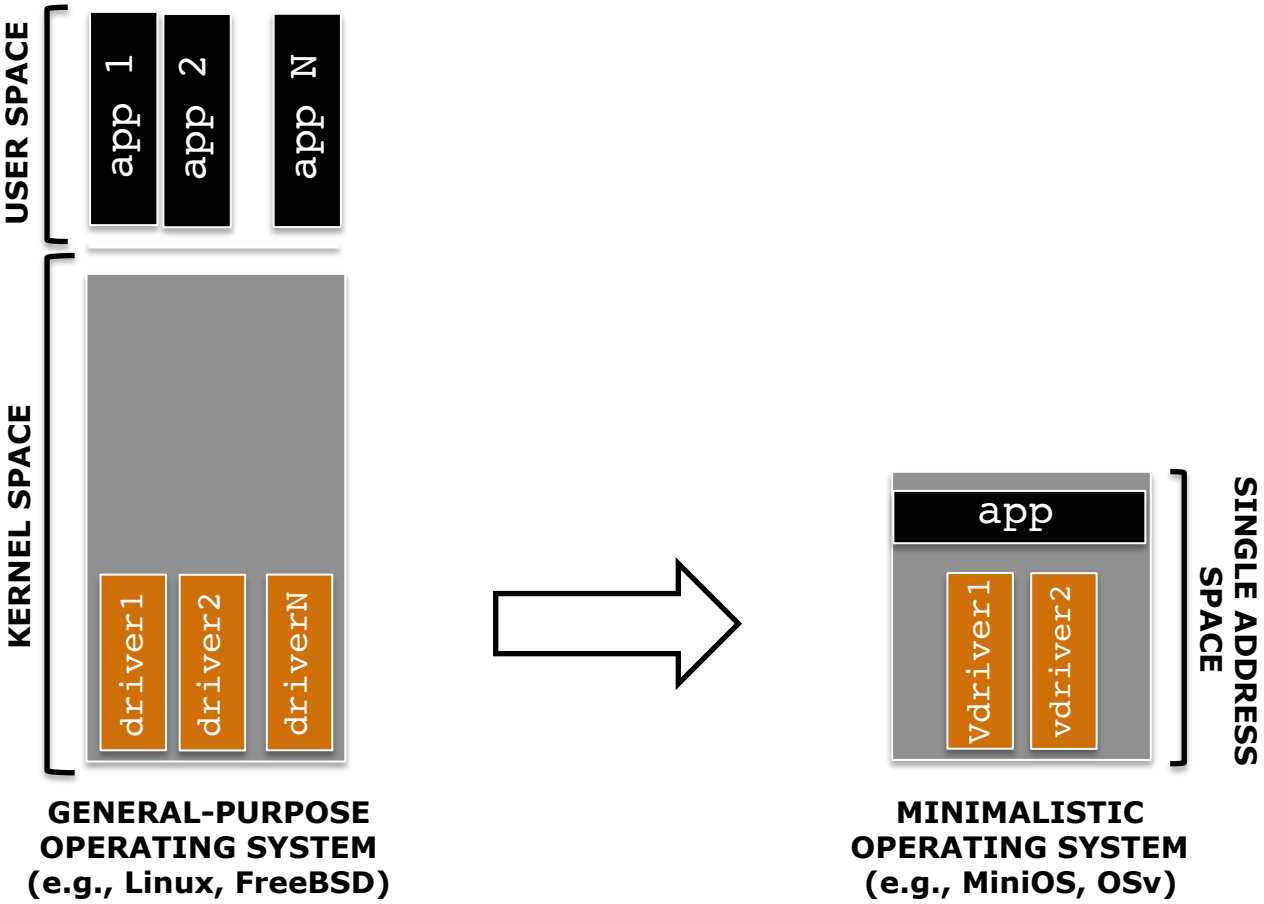
- Standard OS/VM/container: ***lots*** of unnecessary code = ***lots*** of overhead (and potentially bugs/security issues)!
- Unikernel: only what's needed is there



general-purpose OS

unikernel

Unikernels - A Few More Details



When do I want a Unikernel?

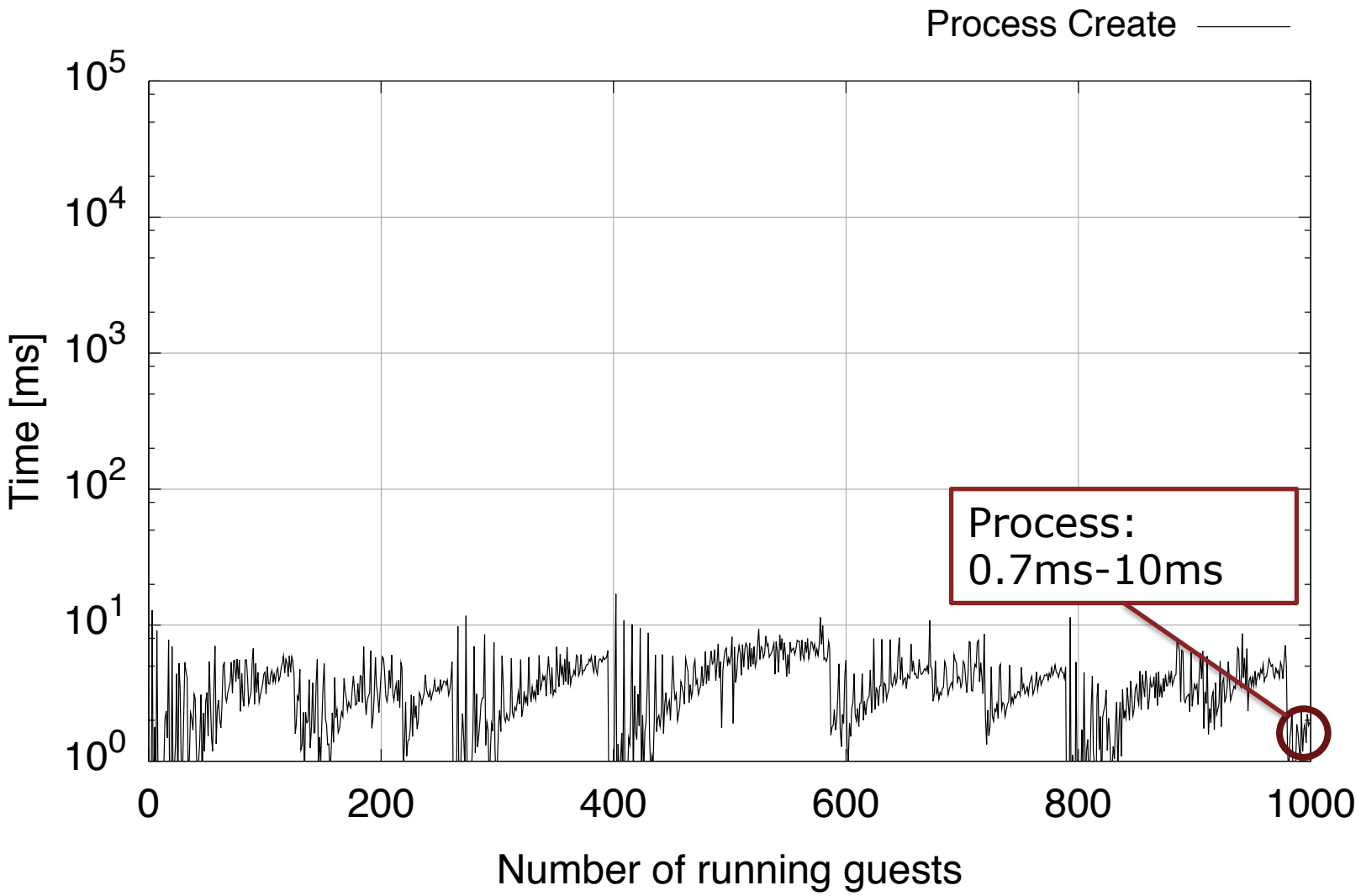
- Unikernels are applicable to many domains!

Some Unikernel Numbers…

My VM is Lighter (and Safer) than your Container
SOSP 2017

In Numbers: Instantiation Times

Server: Intel Xeon E5-1630 v3 CPU@3.7GHz (4 cores), 128GB DDR4 RAM, Xen/Linux versions 4.8



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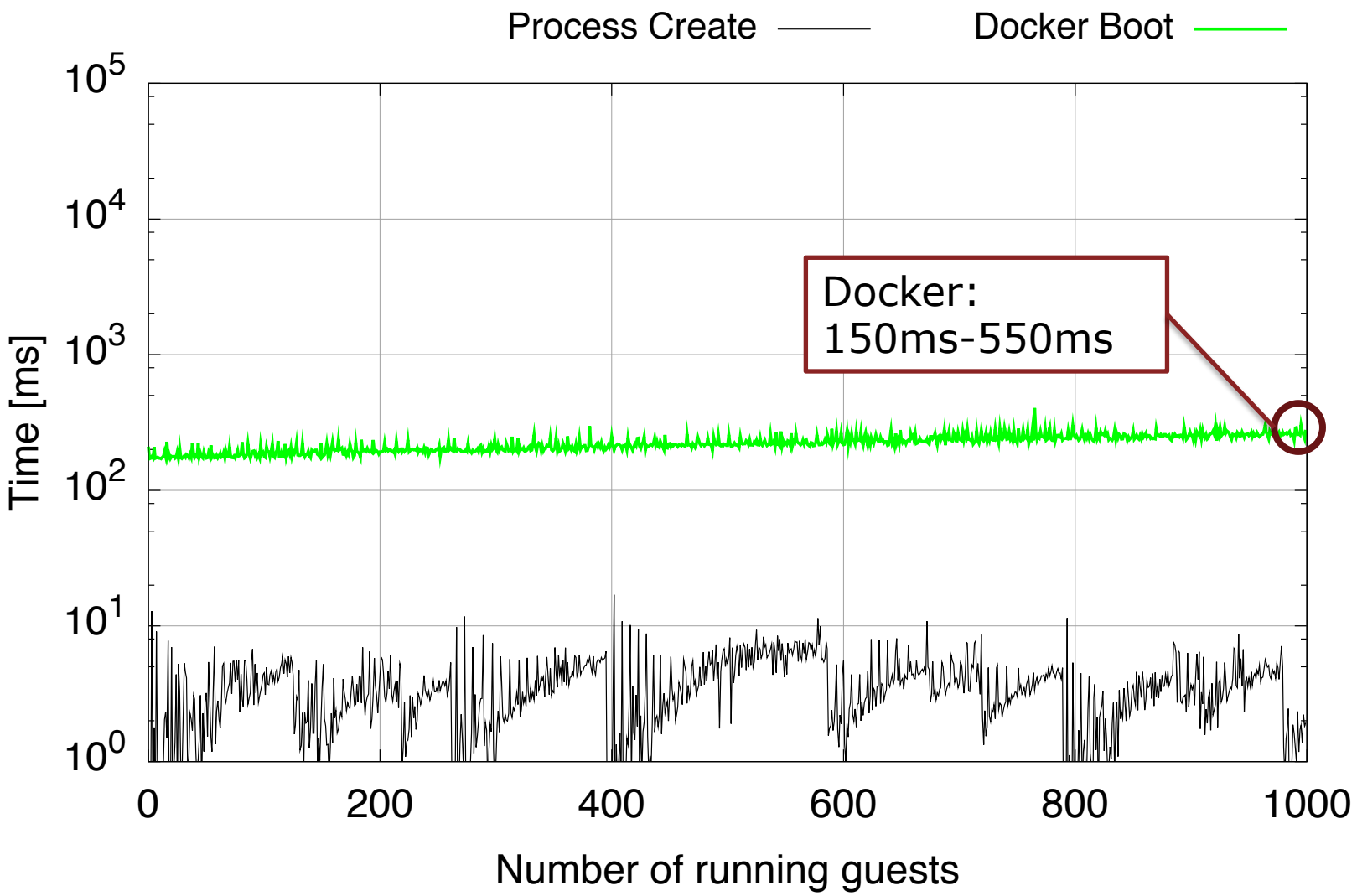

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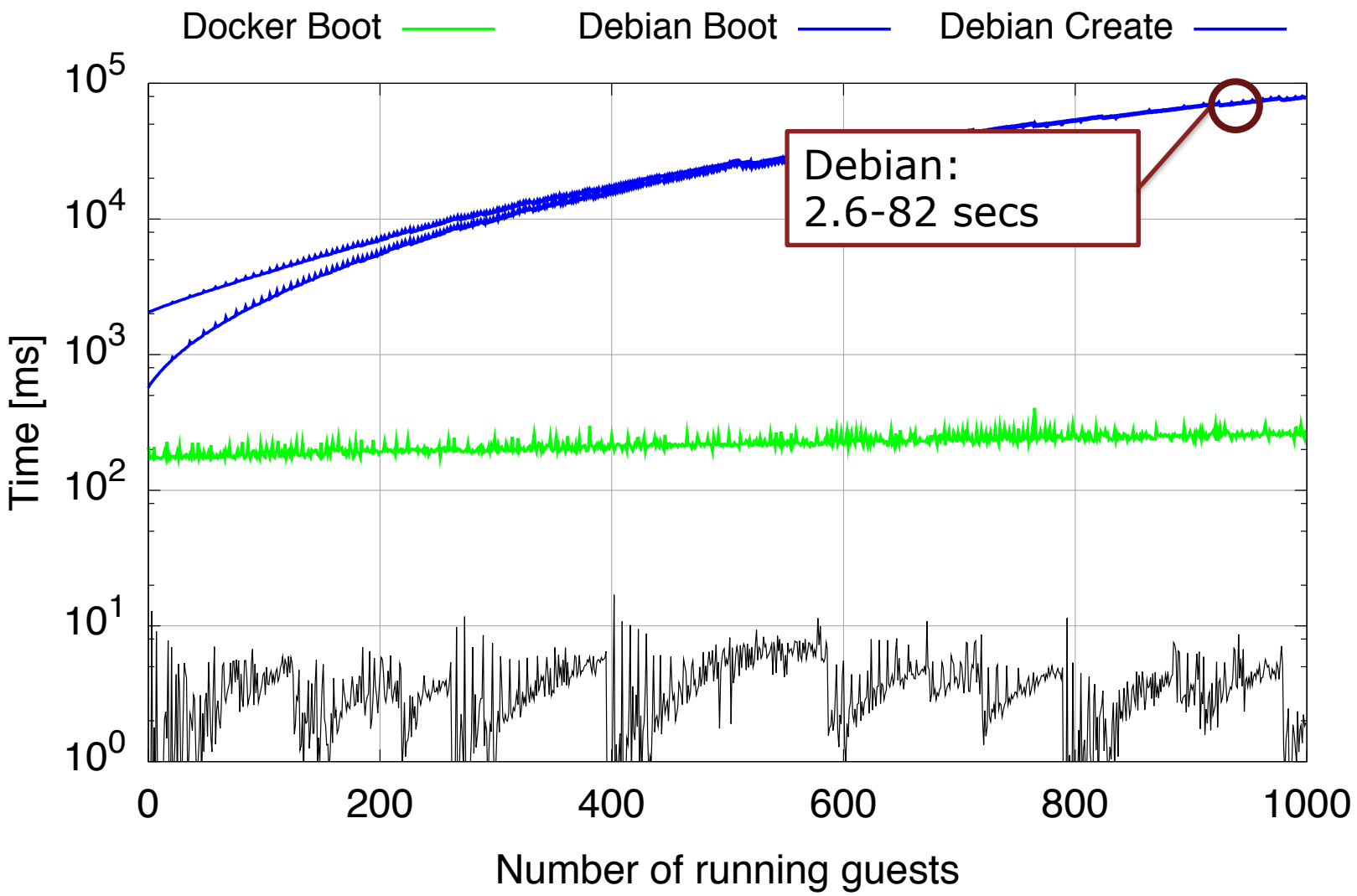

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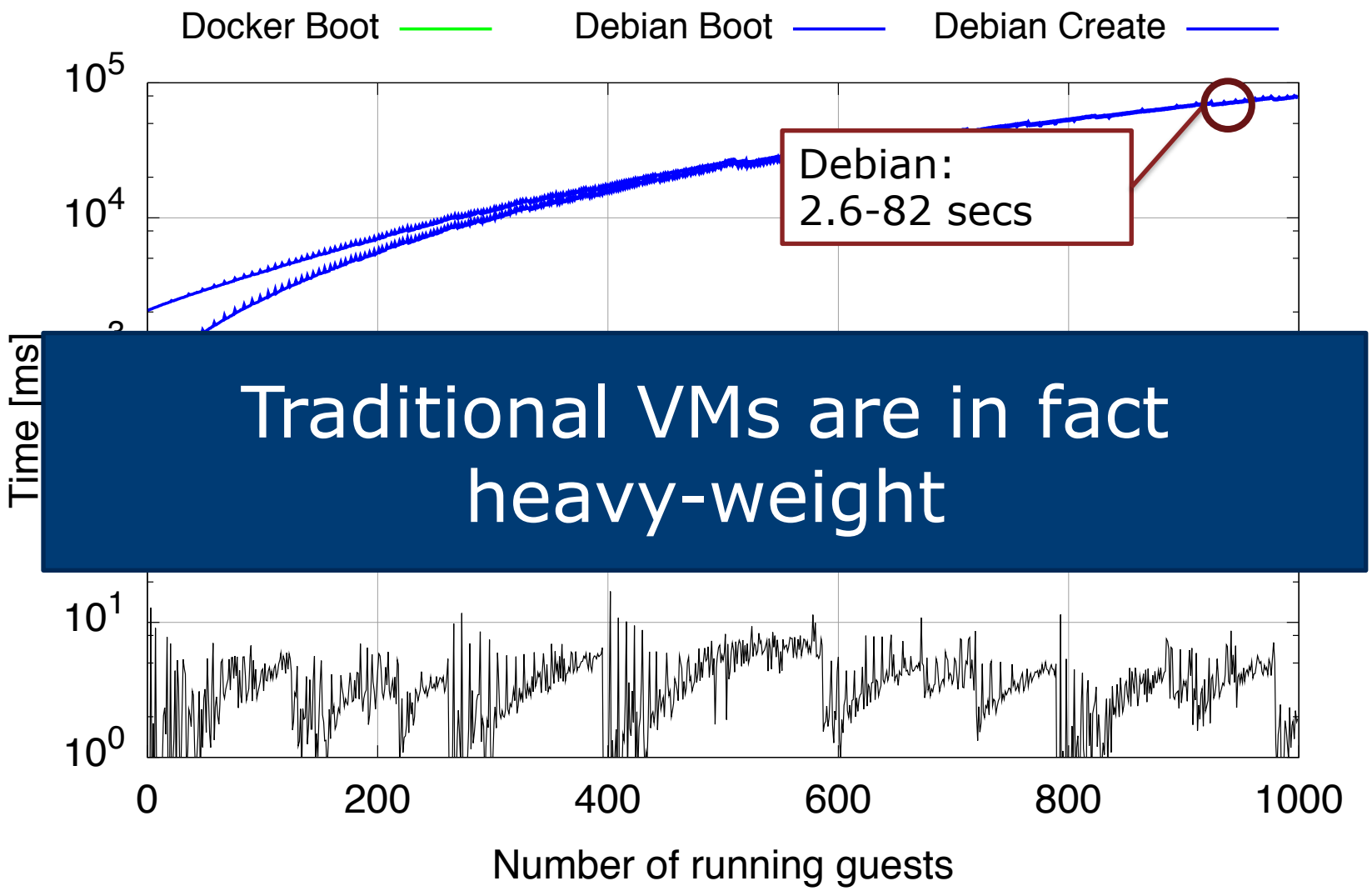

Traditional VMs are in fact heavy-weight

In Numbers: Instantiation Times

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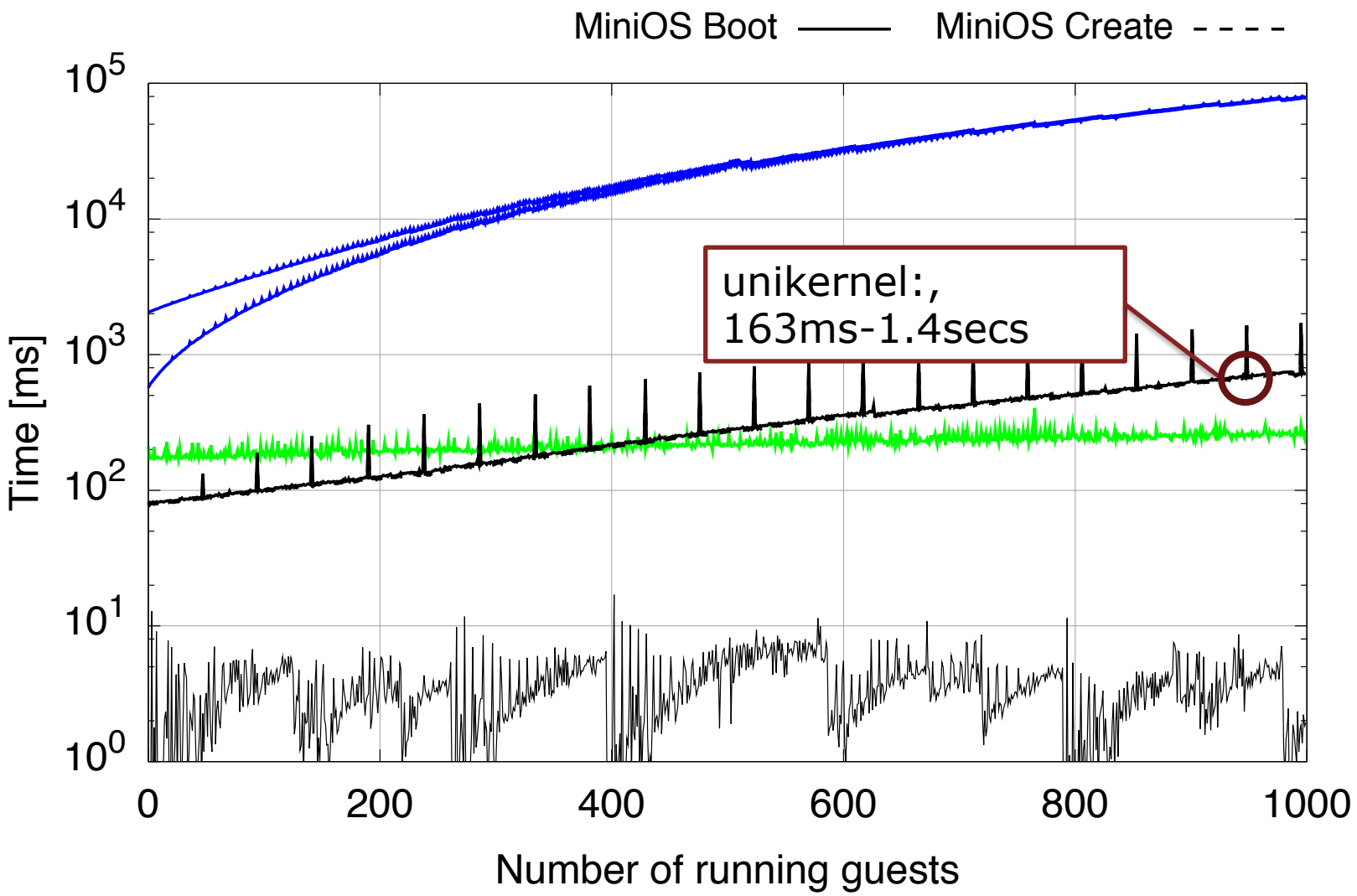

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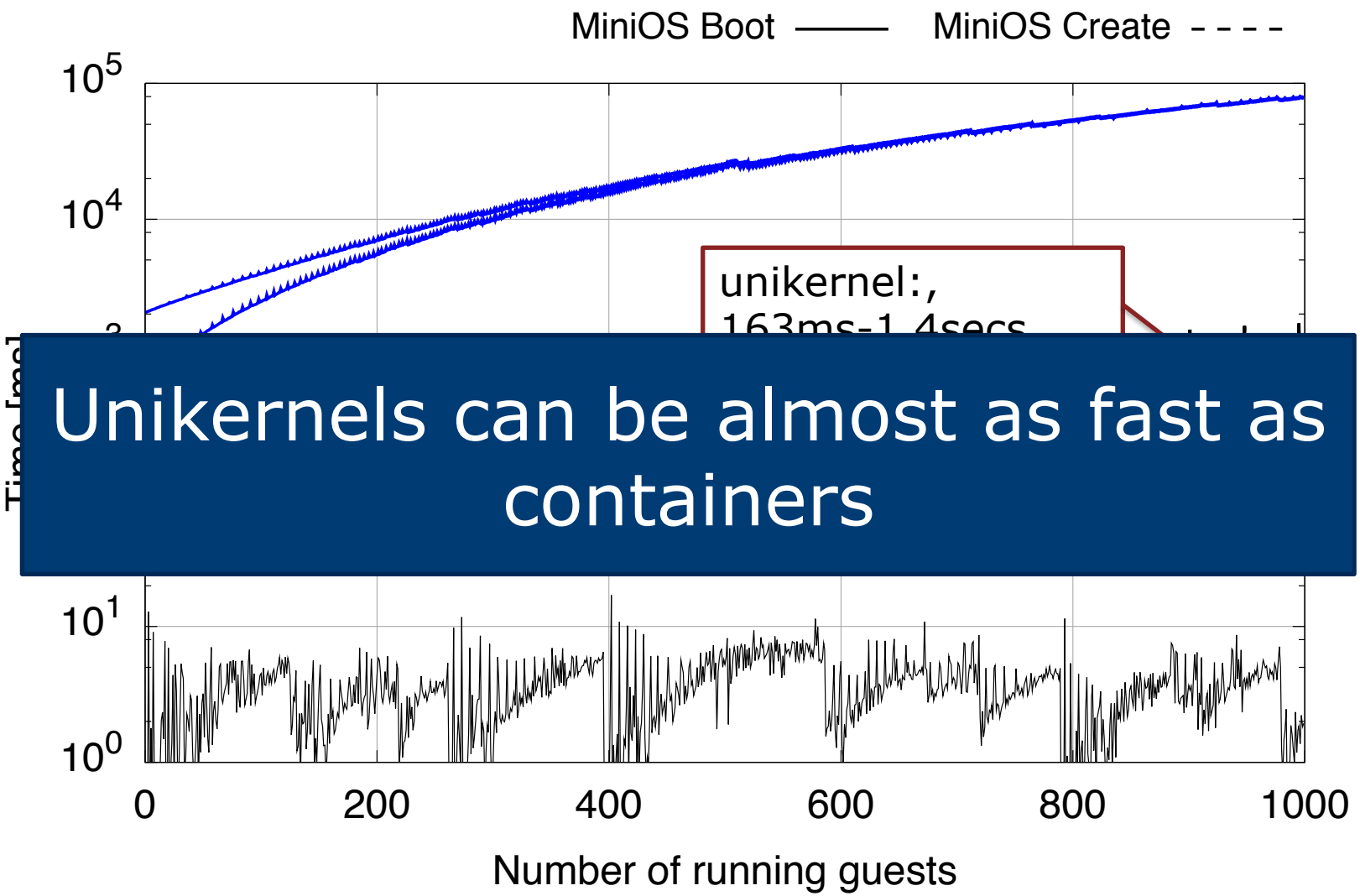

Unikernels can be almost as fast as containers

In Numbers: Instantiation Times

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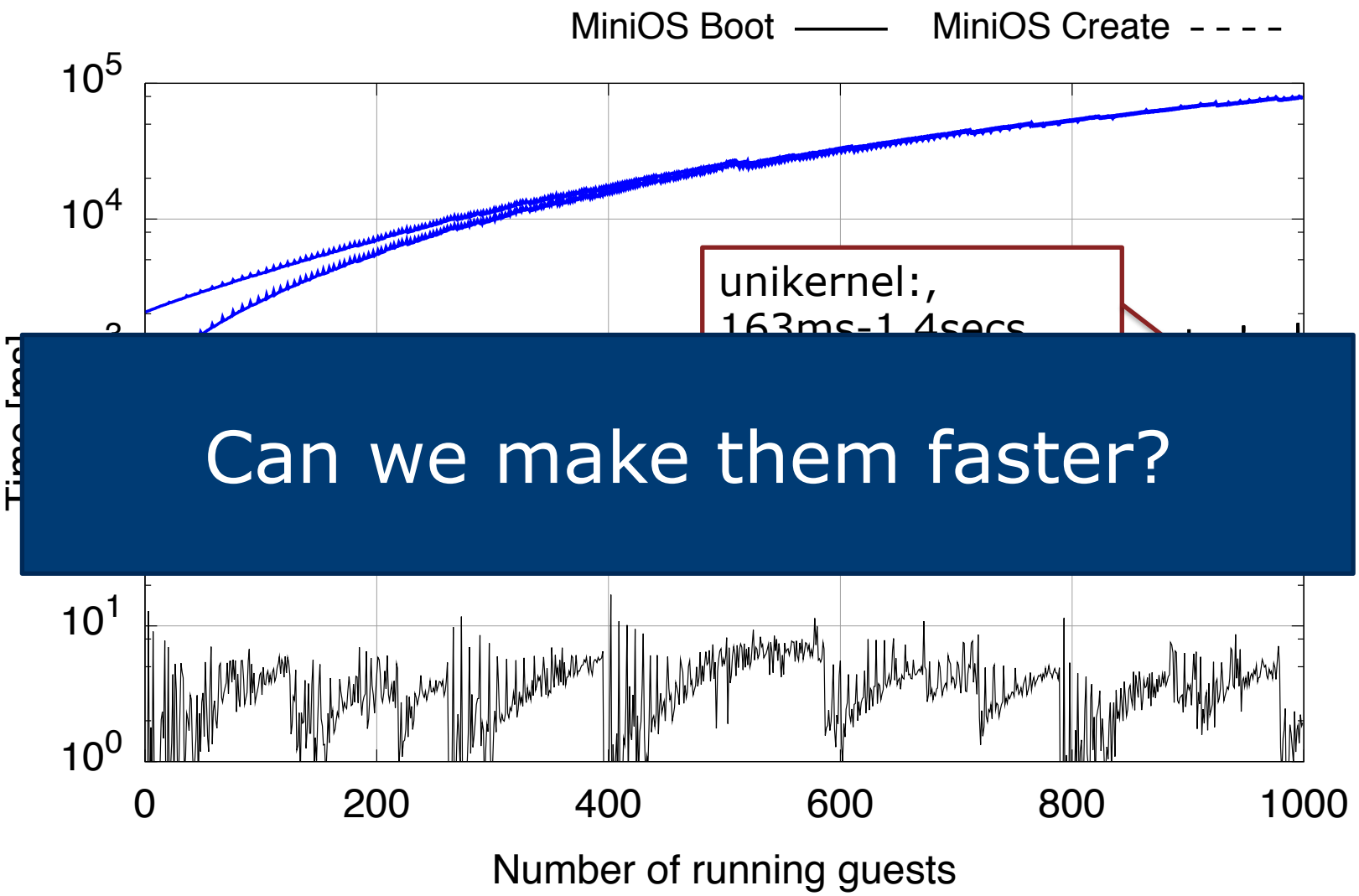
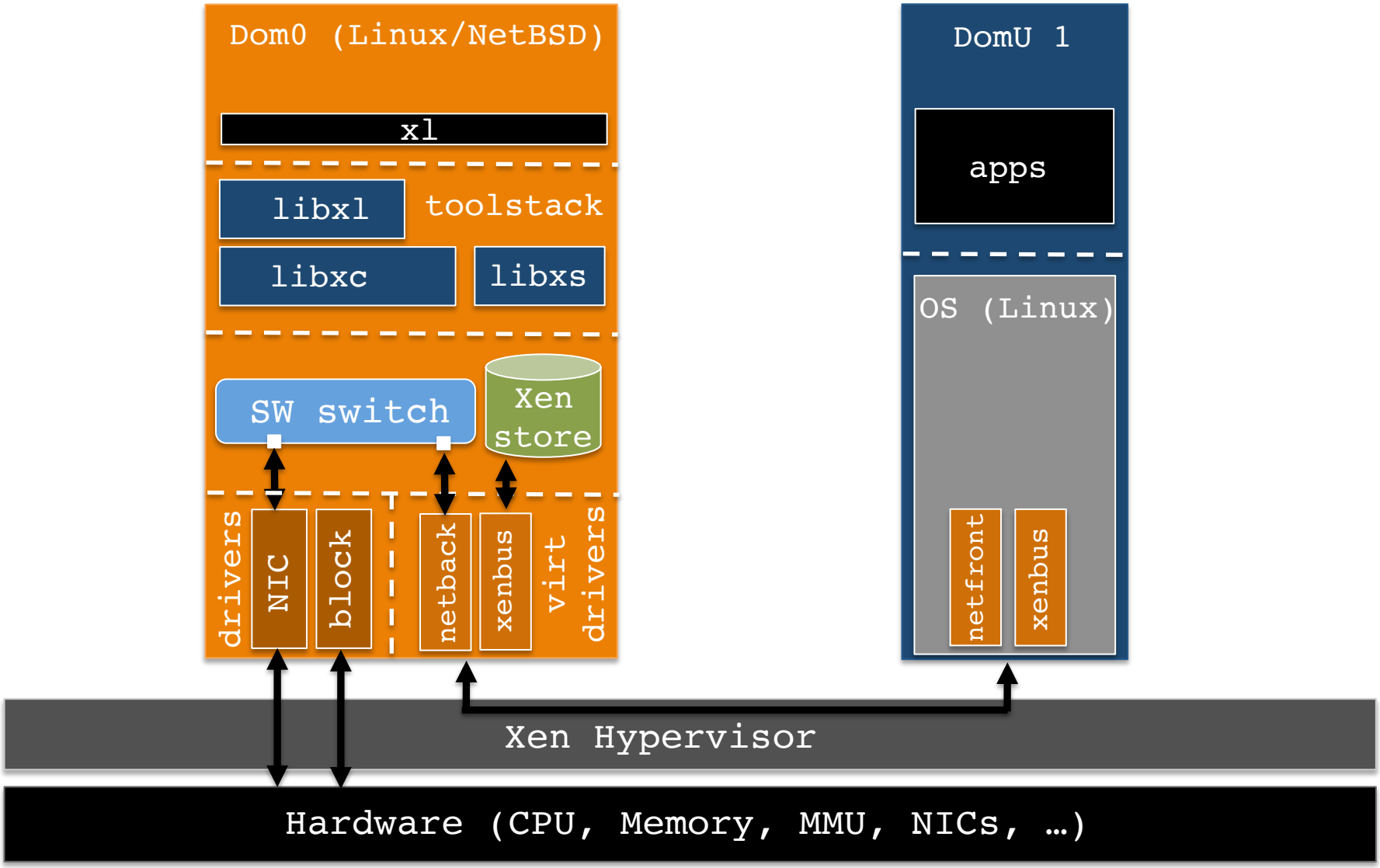


Can we make them faster?

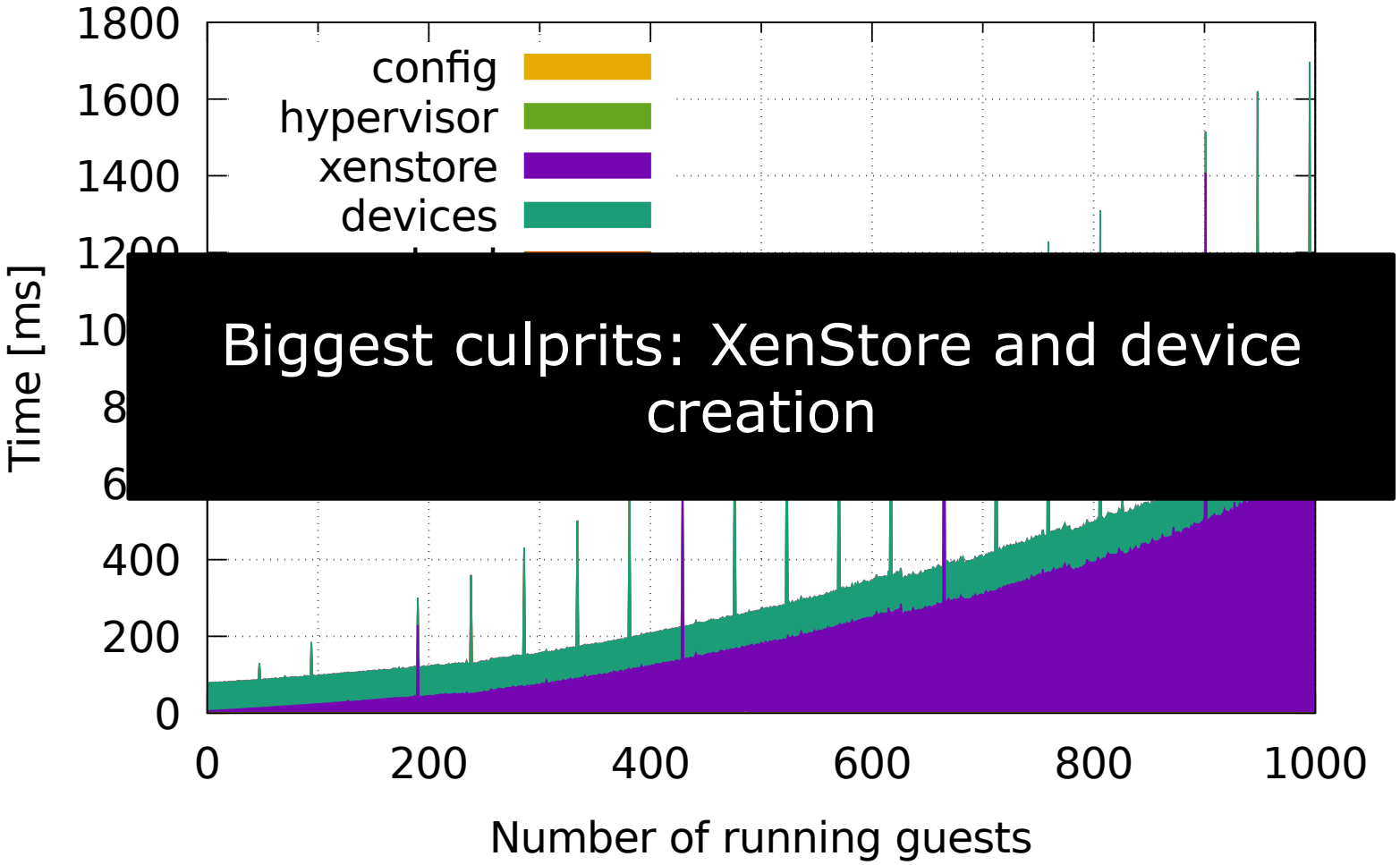
LightVM

A Lightweight Virtualization System

A Quick Xen Primer

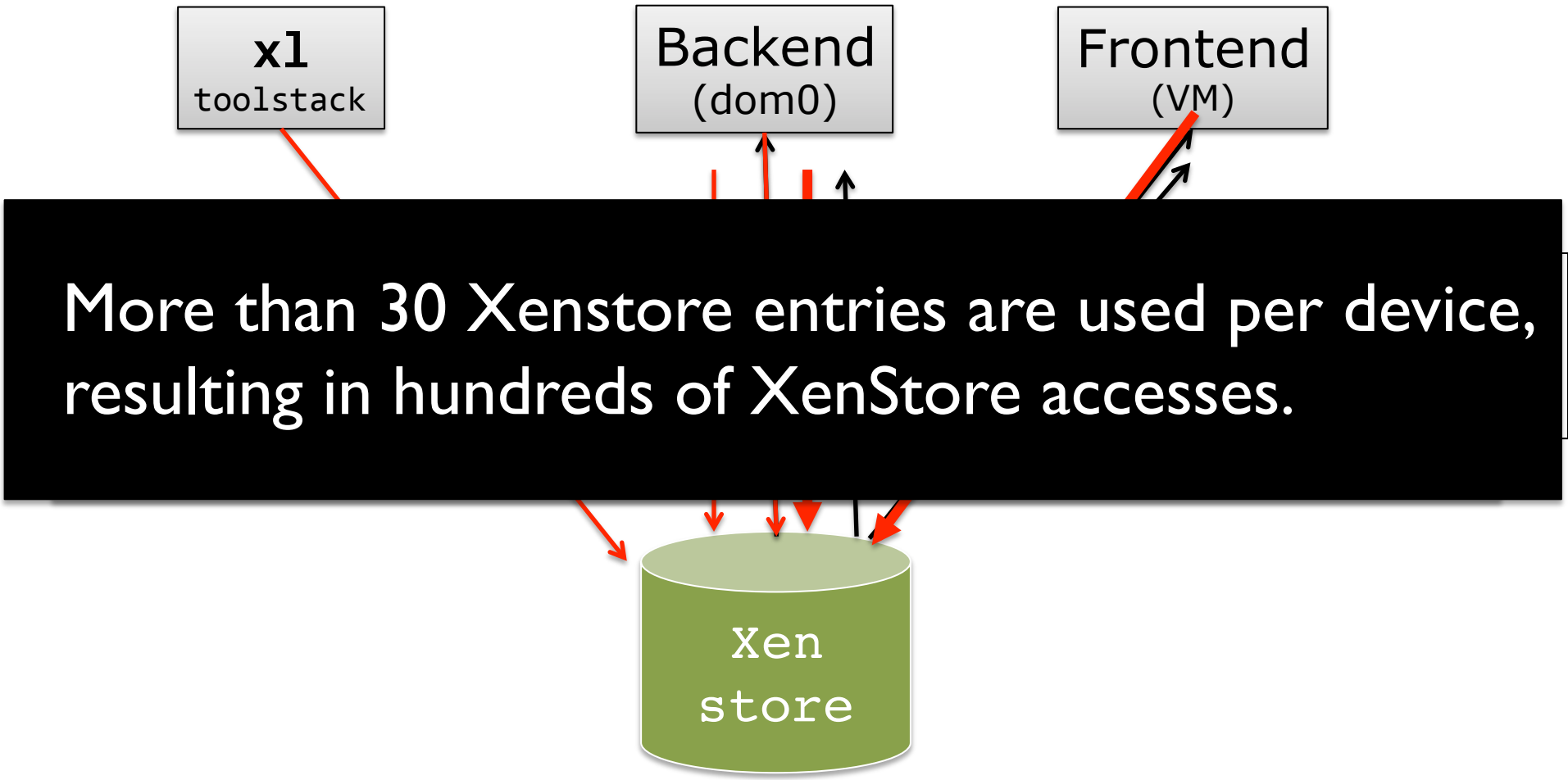


Creation Times – Breakdown (unikernel)

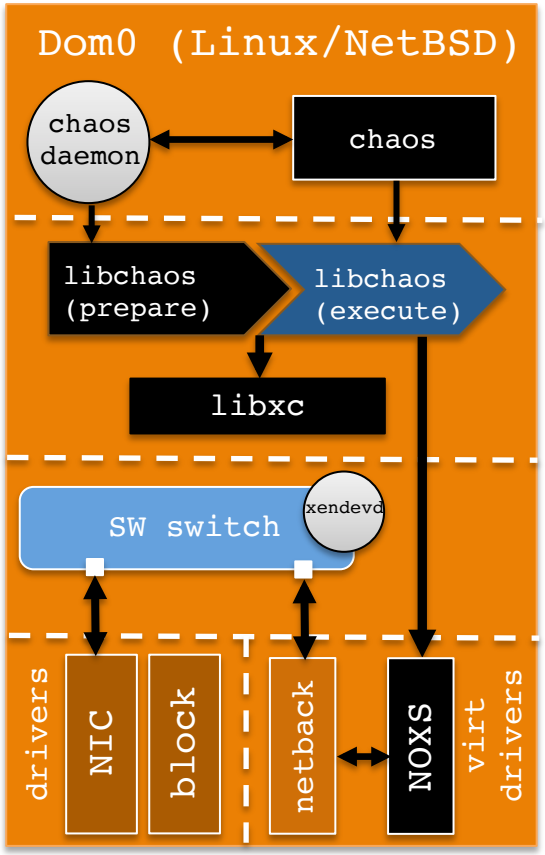


* *Note: Spikes in graph due to XenStore's log rotation*

What's Wrong with the XenStore?



LightVM Architecture

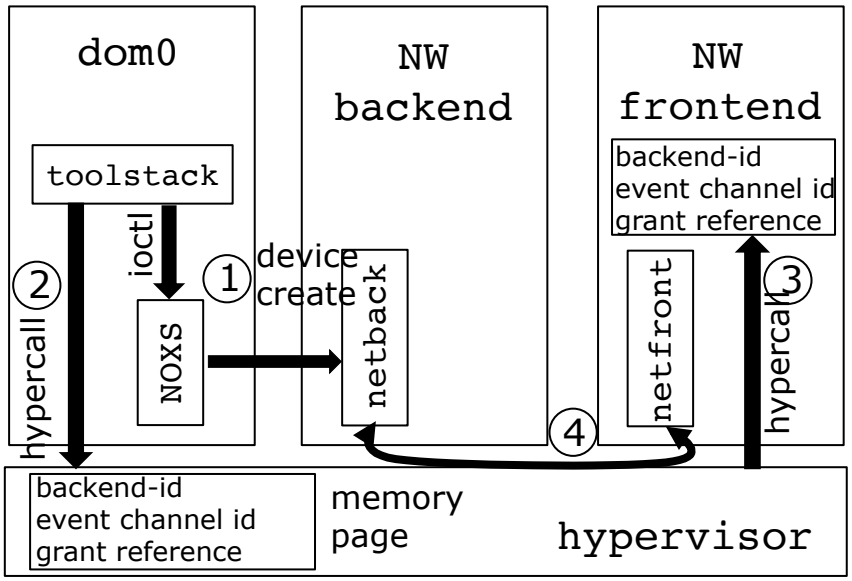


1. **Chaos** – specialized toolstack (xl replacement)
2. **Noxs** - no XenStore
3. **Split toolstack**
4. **Xendevd** – optimized hotplug script

1. Chaos - Specialized Toolstack

- Complete re-write of toolstack for paravirtualized guests
  - Replaces xl → chaos
  - Replaces libxl → libchaos
- Includes framework for easily plugging in different elements of a toolstack (e.g., use the XenStore or not)

2. NoXS – Xen without a XenStore



3. Split Toolstack

Insight: a significant portion of the code does not need to be executed at VM creation time

- Functionality common to all VMs (e.g., mem alloc) can be pre-executed

Split toolstack into two:

- **Pre-create phase:** run by a daemon, periodically
- **Run-time phase:** run when VM creation commands (and others) are issued

4. Xendevd – Hotplug Script

Xen uses either a bash script or udevd to add virtual interfaces to software switch

- Slow: 10s of milliseconds, slows creation/boot times

Replace with xendevd, binary daemon

- Listens to udev events from netback, execute pre-defined setup (e.g., add vif to OVS)

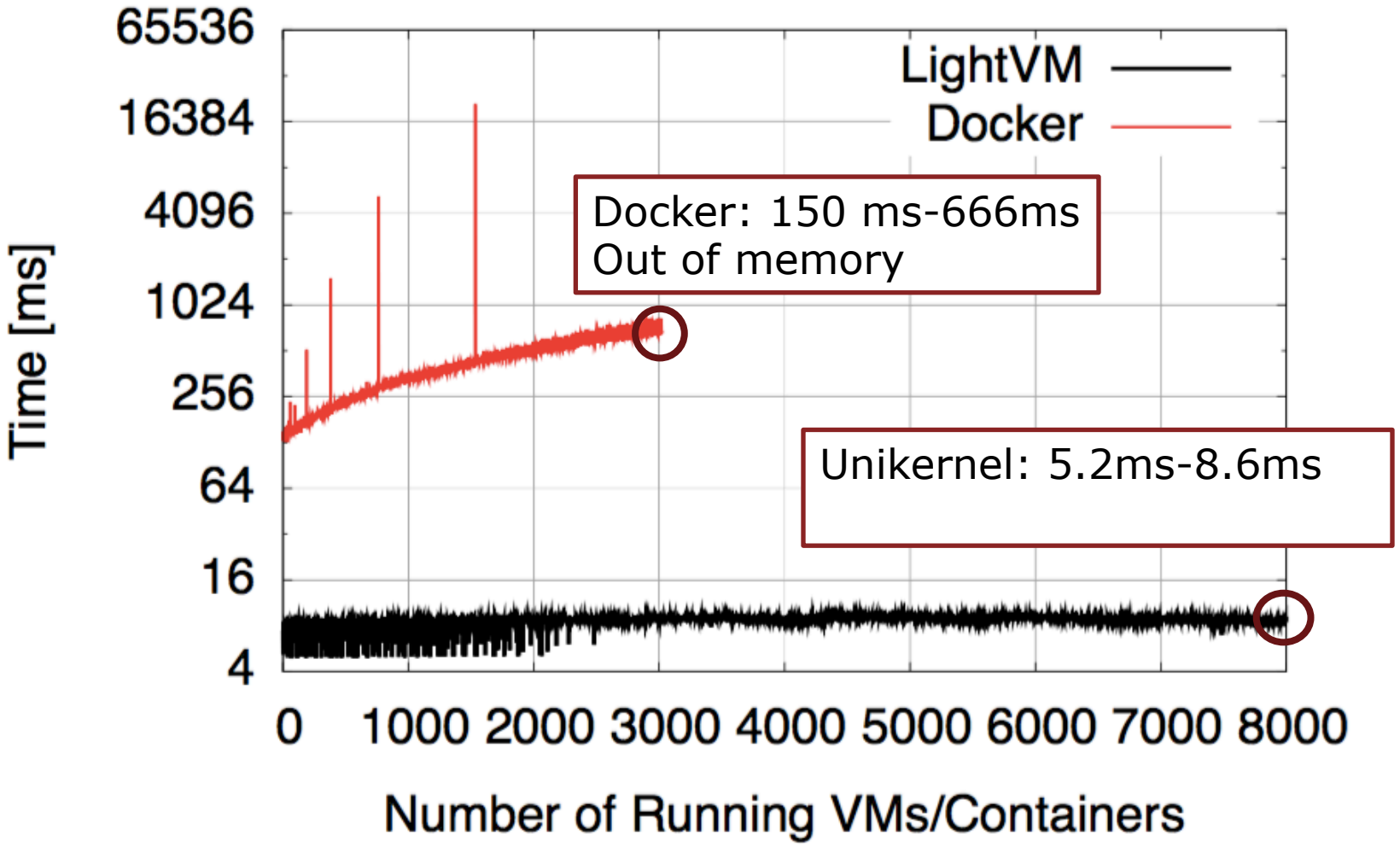
Evaluation – Unikernels We Used

- **Noop unikernel**: self explanatory ☺
- **Daytime unikernel**: TCP server that responds with current time
- **Minipython:** Port of Micropython to MiniOS
- **TLS unikernel:** TLS termination proxy
- **Ping unikernel:** also self-explanatory

Sample sizes:

- **Daytime -** 480KB disk, 3.4MB RAM
- **Minipython -** 3.52MB disk, 8MB RAM
- **TLS** – 3.58MB disk, 8MB RAM

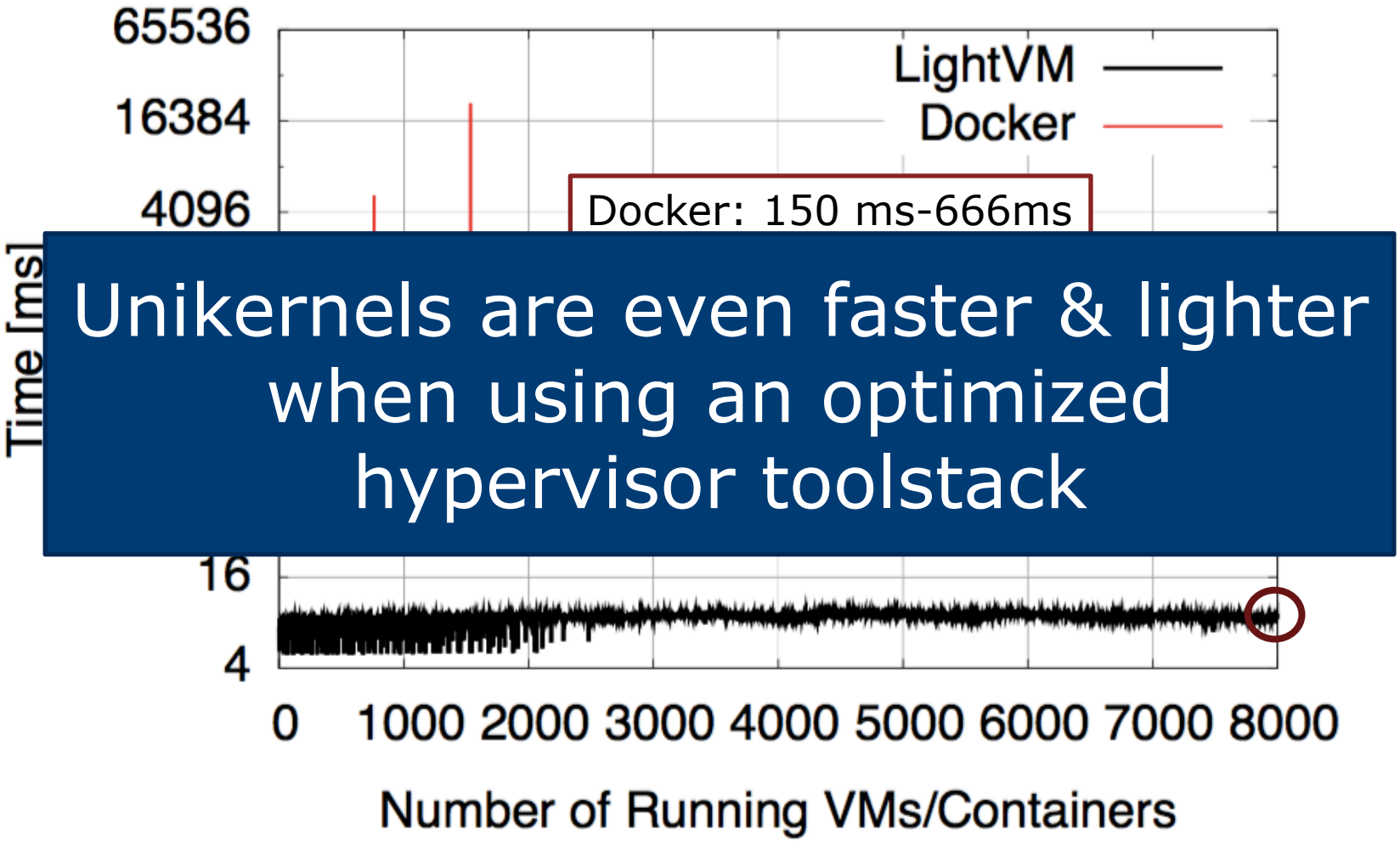
In Numbers: Instantiation Times with LightVM



Server: *4 x AMD Opteron 6376 CPU@2.3GHz (64 cores total), 128GB DDR3 RAM, Xen 4.8/Linux 4.8*
LightVM: http://sysml.neclab.eu/projects/lightvm

Guests: *Noop/Unikernel and Noop Docker image / No devices*

In Numbers: Instantiation Times with LightVM

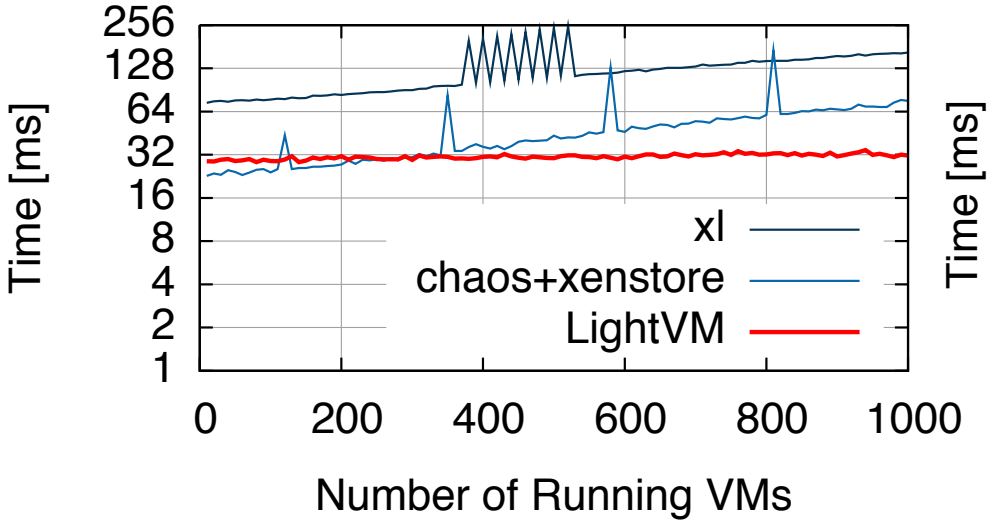


Unikernels are even faster & lighter when using an optimized hypervisor toolstack

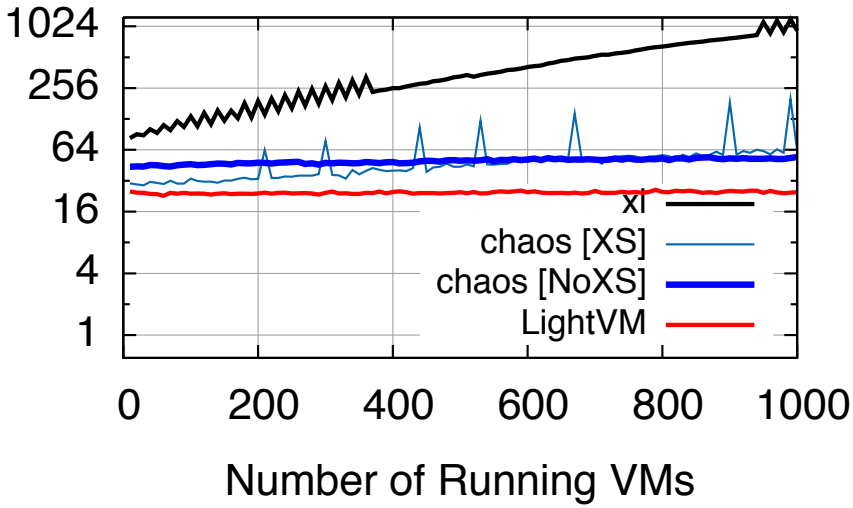
Server: *4 x AMD Opteron 6376 CPU@2.3GHz (64 cores total), 128GB DDR3 RAM, Xen 4.8/Linux 4.8*
LightVM: http://sysml.neclab.eu/projects/lightvm

Guests: *Noop/Unikernel and Noop Docker image / No devices*

Checkpointing – Daytime Unikernel



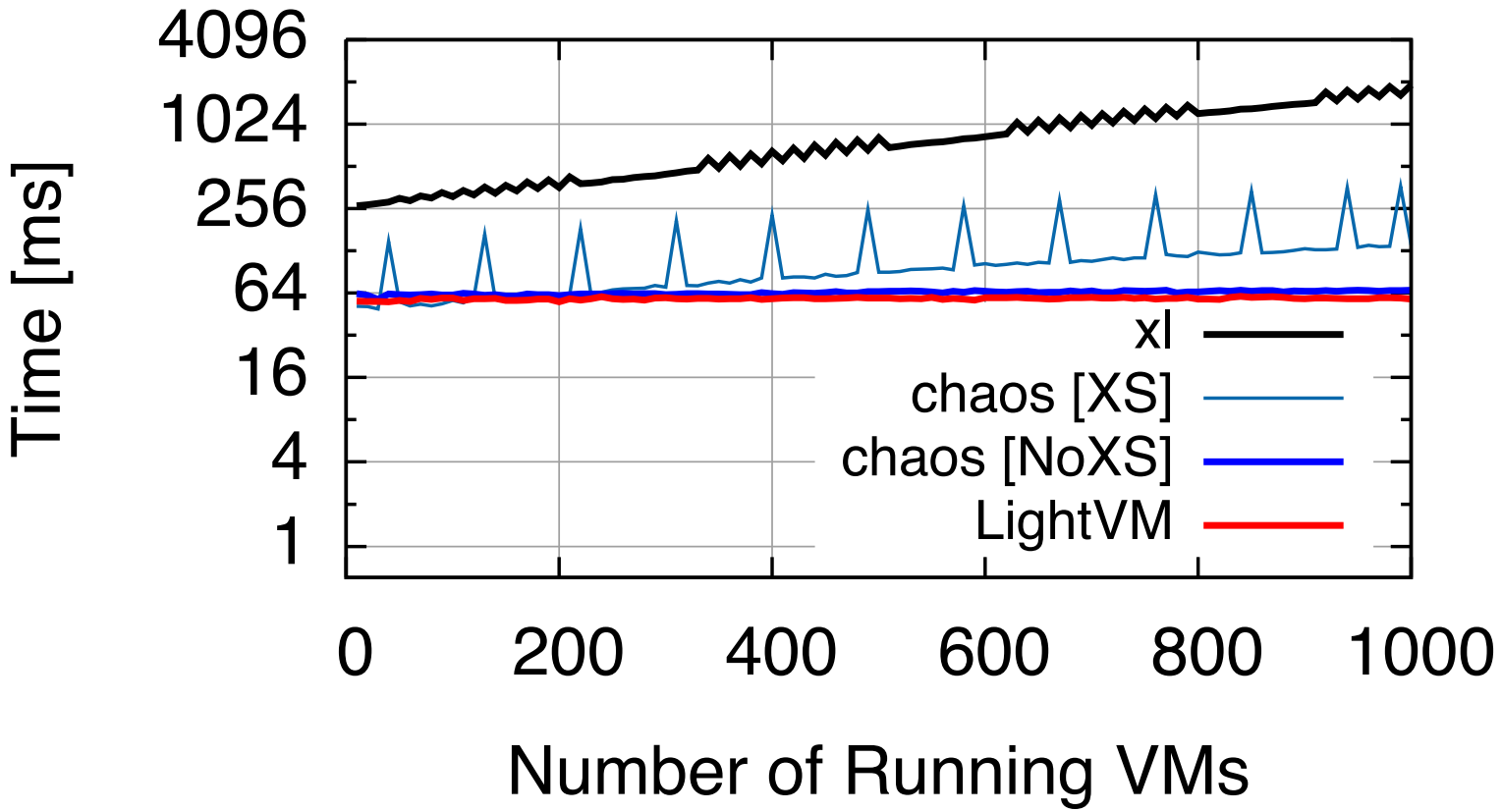
(a) Save



(b) Restore

Server: Intel Xeon E5-1630 v3 CPU@3.7GHz (4 cores), 128GB DDR4 RAM, Xen/Linux versions 4.8

Migration – Daytime Unikernel



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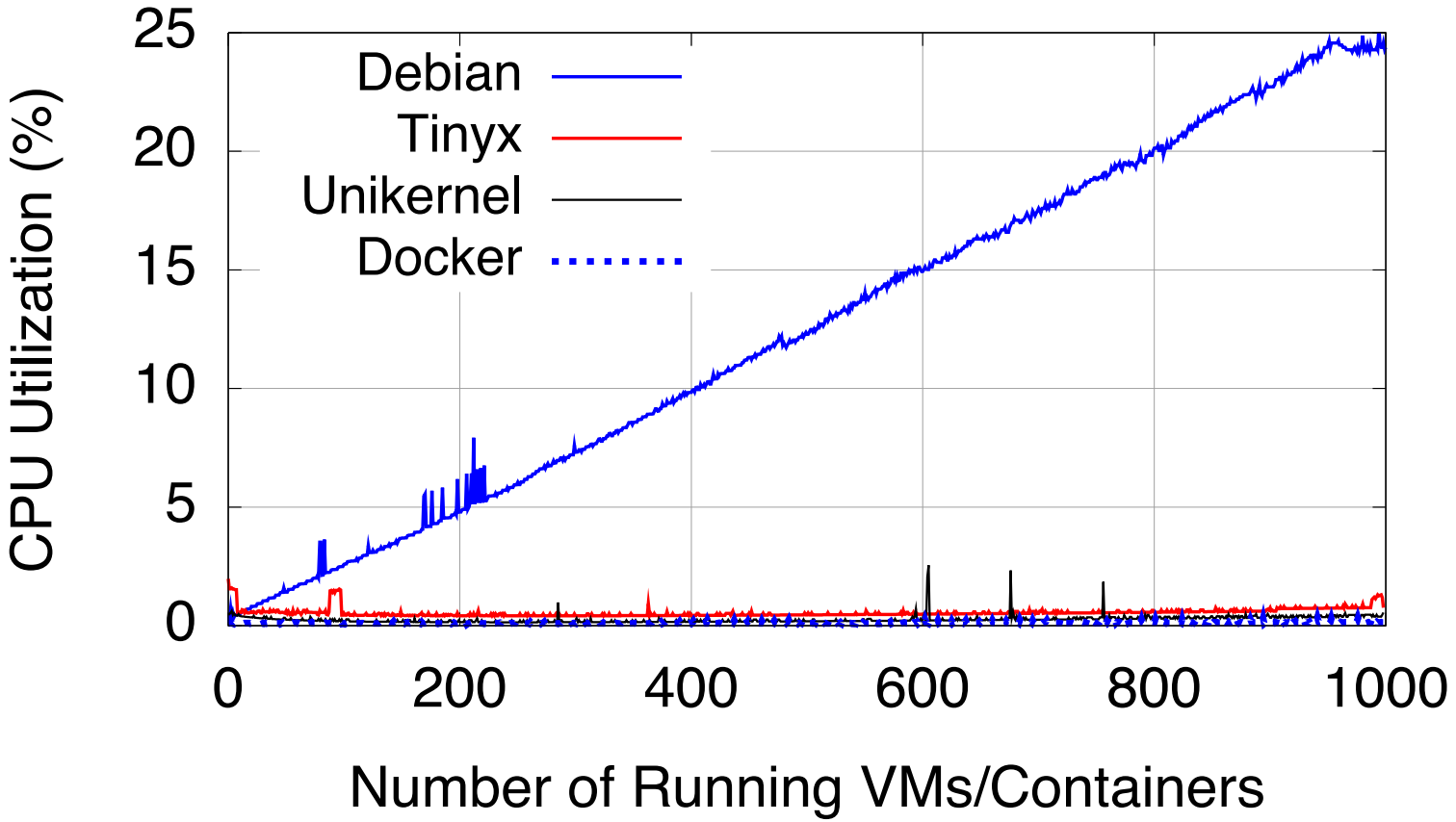
CPU Usage



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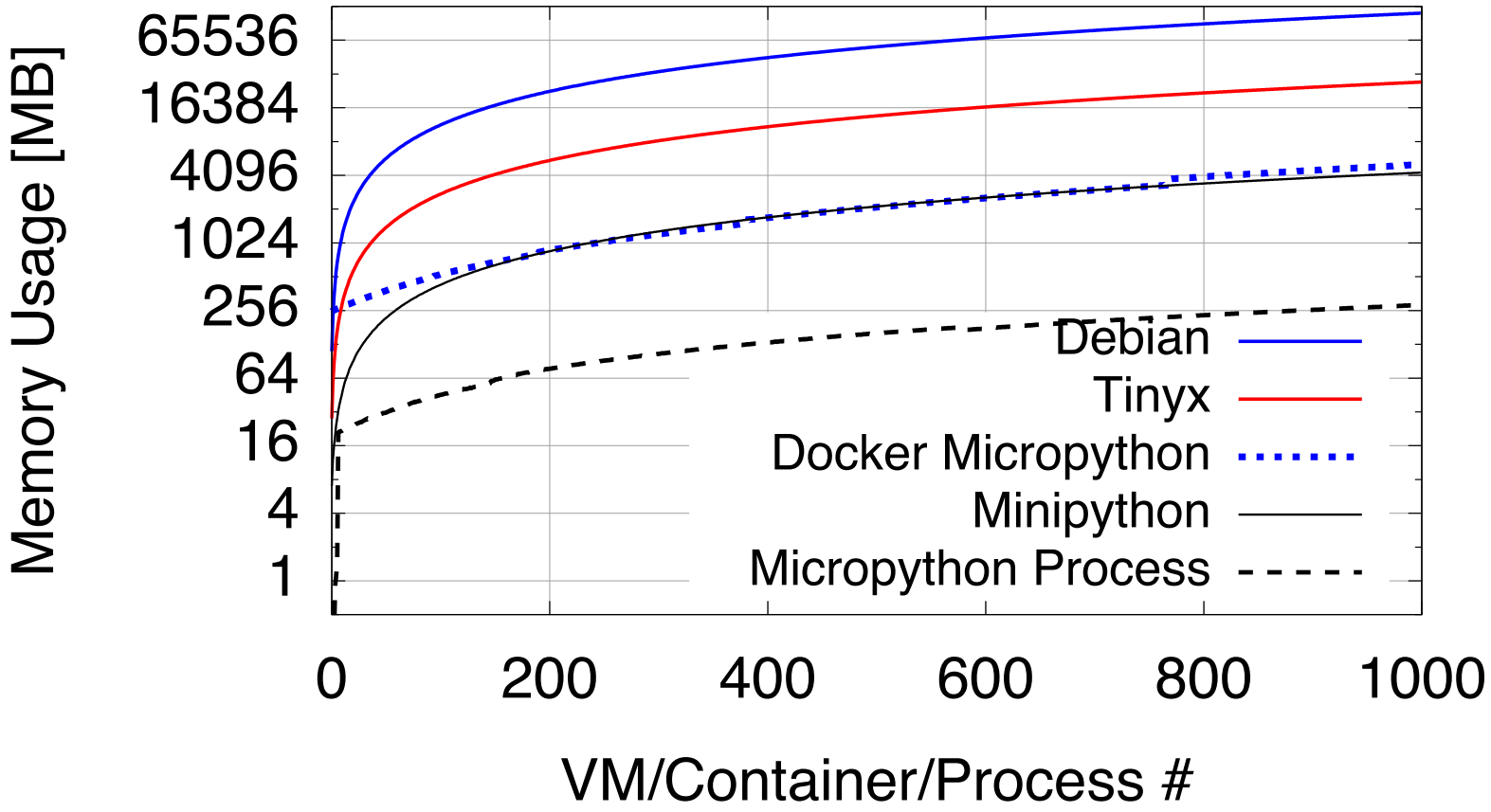
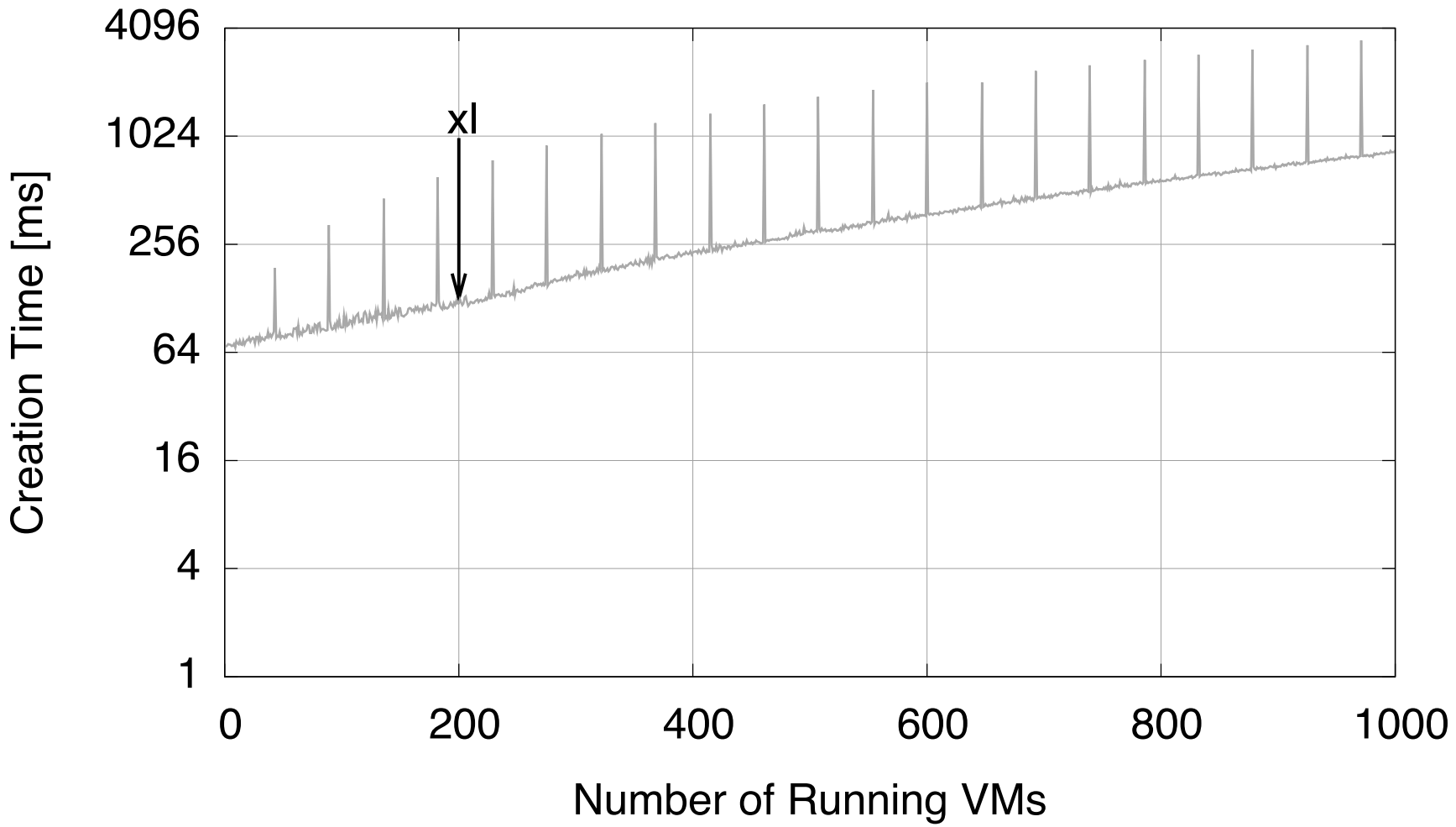
Memory Usage



Server: Intel Xeon E5-1630 v3 CPU@3.7GHz (4 cores), 128GB DDR4 RAM, Xen/Linux versions 4.8

Understanding LightVM's components



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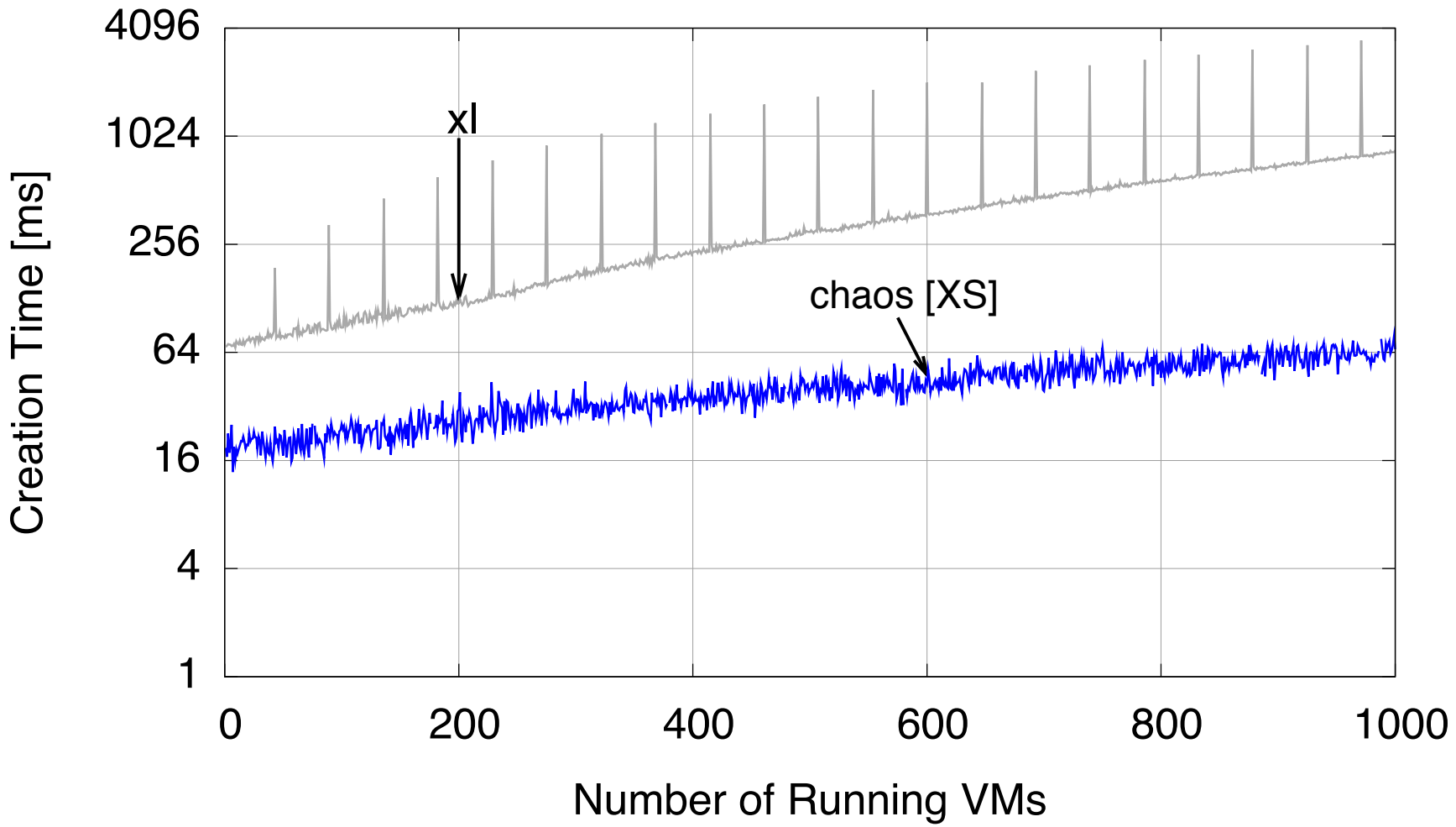

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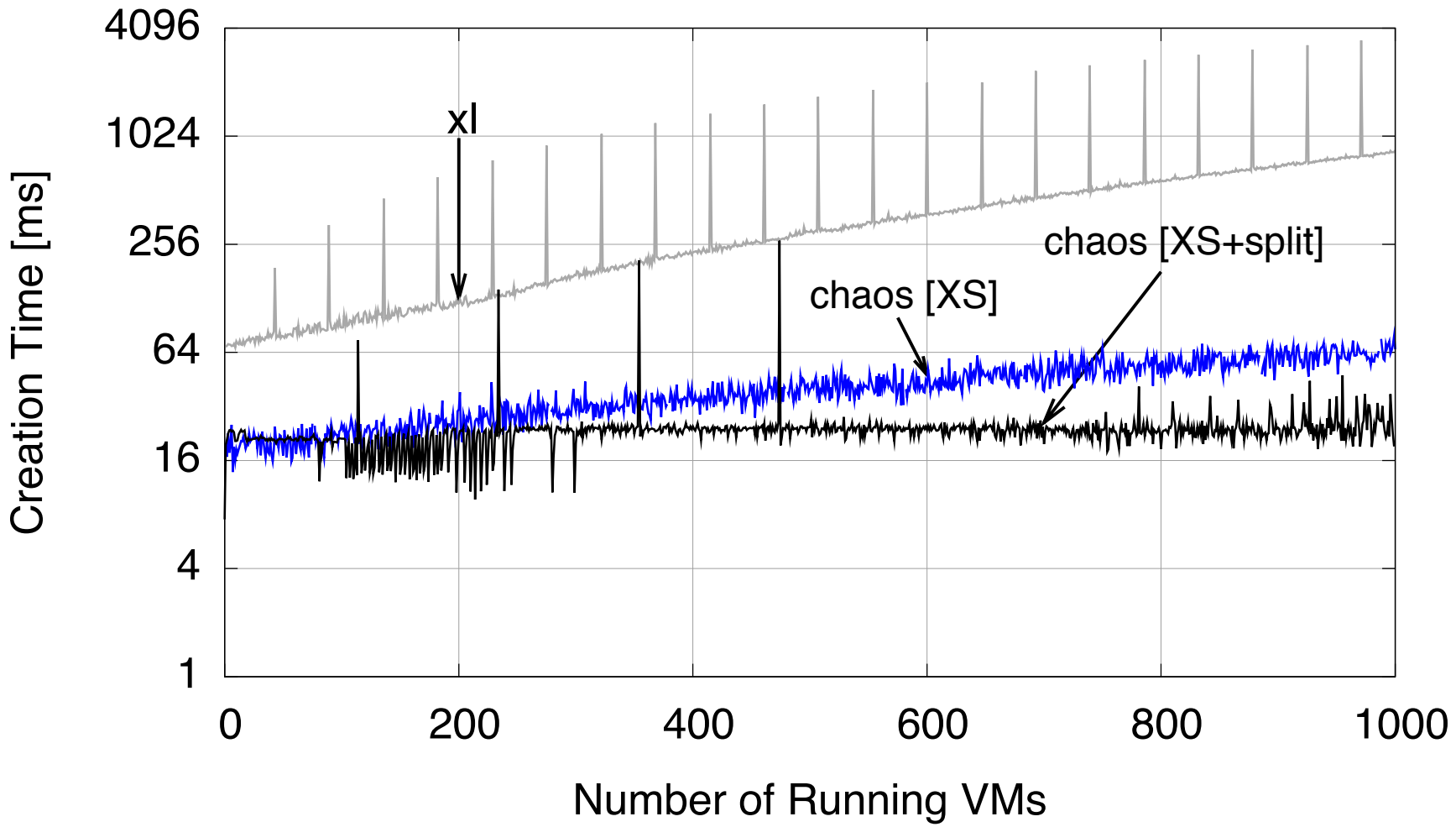

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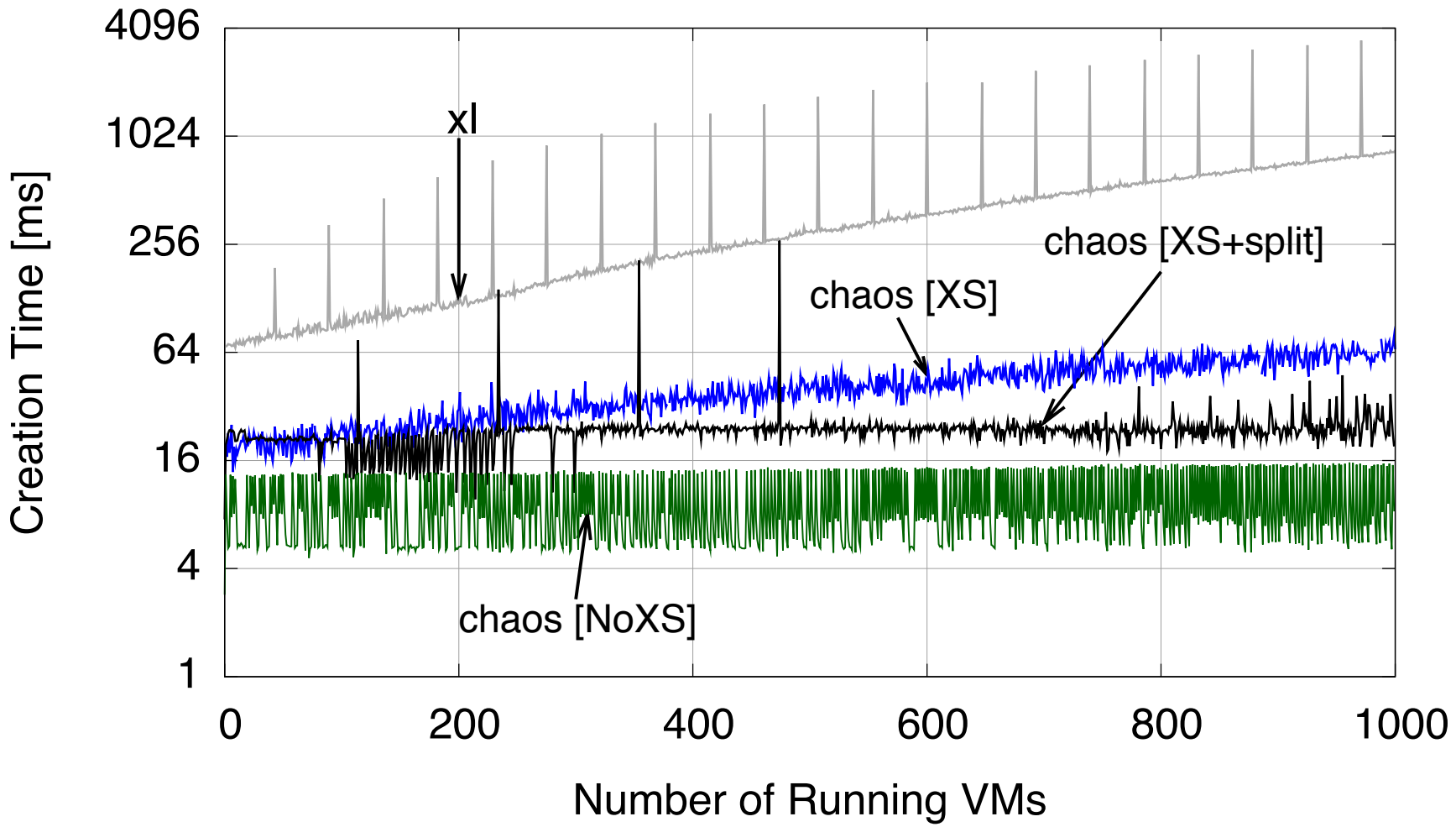

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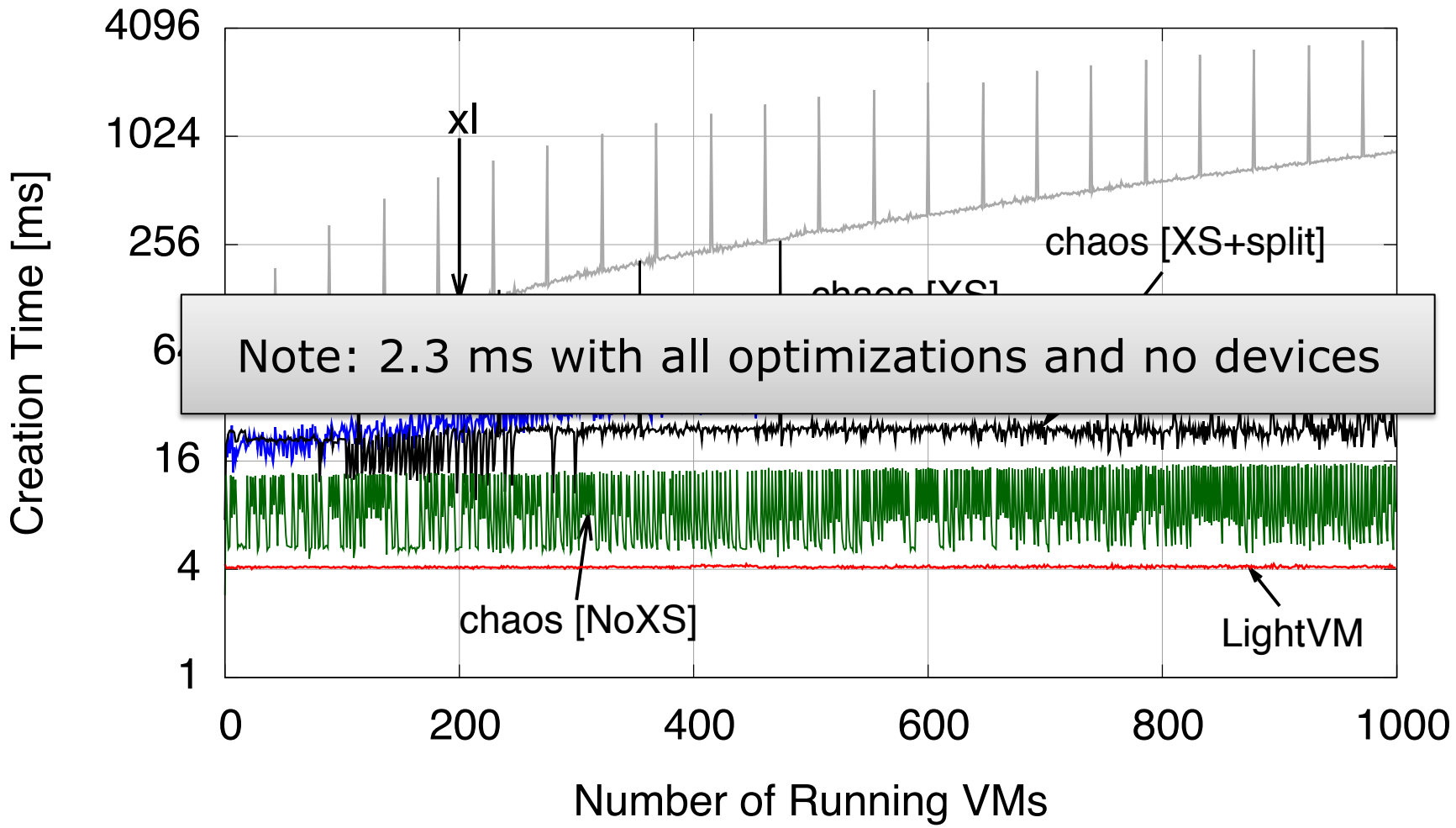


Note: 2.3 ms with all optimizations and no devices

Server: Intel Xeon E5-1630 v3 CPU@3.7GHz (4 cores), 128GB DDR4 RAM, Xen/Linux versions 4.8

The Potential of Unikernels – A Summary

Fast instantiation, destruction and migration time

- 10s of milliseconds or less (and as little as 2.3ms)
  (LigthVM [Manco SOSP 2017], Jitsu [Madhvapeddy, NSDI 2015])

Low memory footprint

- Few MBs of RAM or less *(ClickOS [Martins NSDI 2014])*

High density

- 8k guests on a singlex86 server *(LigthVM [Manco SOSP 2017])*

High Performance

- 10-40Gbit/s throughput with a single guest CPU
  (ClickOS [Martins NSDI 2014], Elastic CDNs [Kuenzer VEE 2017])

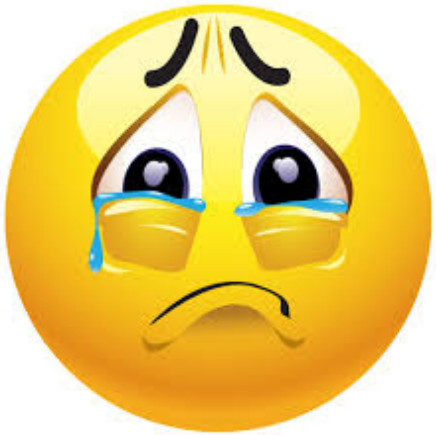
Reduced attack surface

- Small trusted compute base
- Strong isolation by hypervisor

So unikernels are perfect right?

The (Big) Downside with Unikernels

- Each optimized Unikernel is manually built
  - Building takes several months or longer
  - Potentially wash, rinse, repeat for each target application



Unikraft

A Unikernel and Specialized OS Build Framework

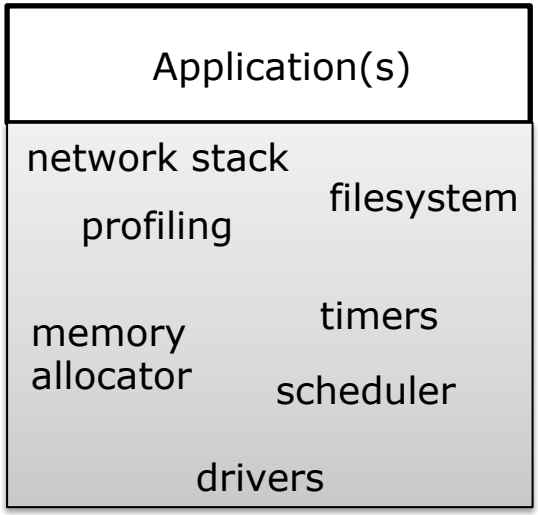
Unikraft Goals

- Severely reduce development time
- Simultaneously target multiple platforms
  - Xen
  - KVM
  - Bare metal (X86_64, ARM32, etc.)
- Allow simple customization of the unikernel *without* having to tweak the actual code

The Unikraft Way

Decompose OSes and libraries into primitives

Recompose them to meet the needs of particular applications



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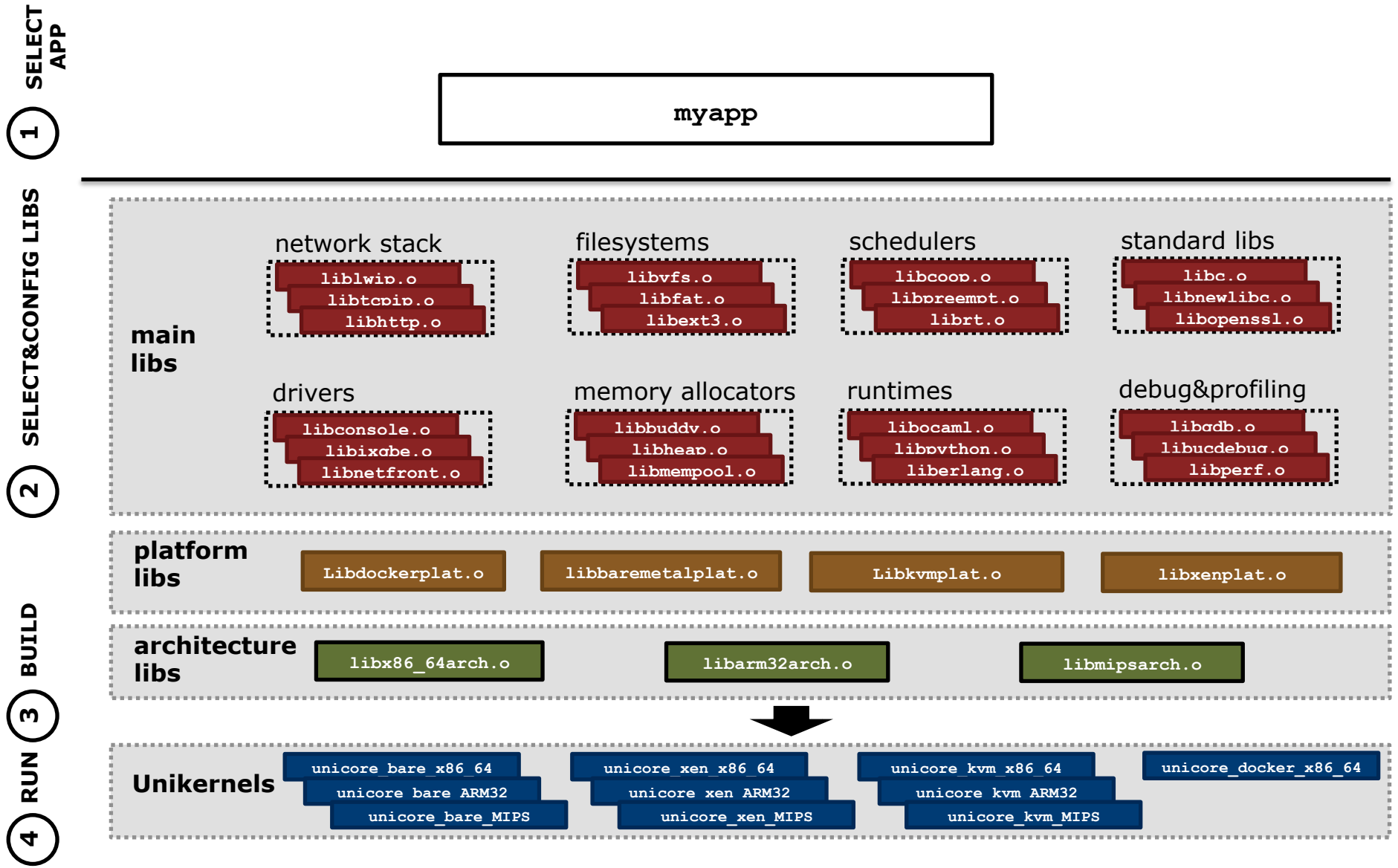
Unikraft Overview – Everything as a Library

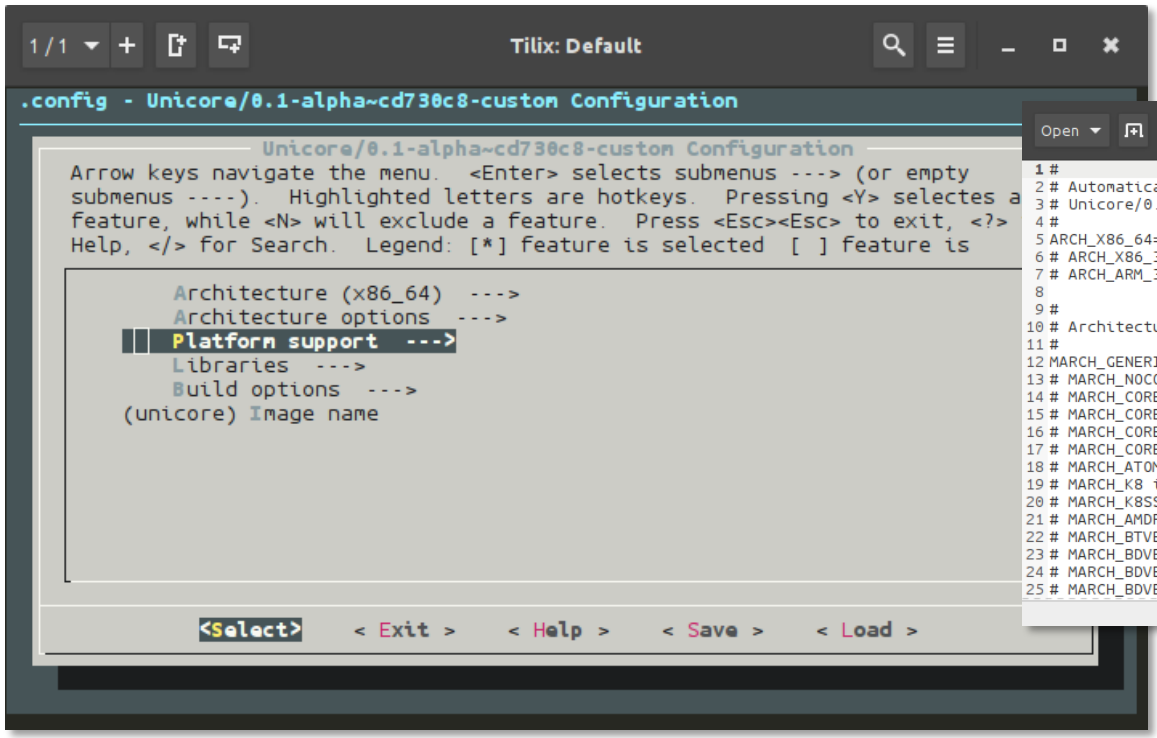


Two Library Types

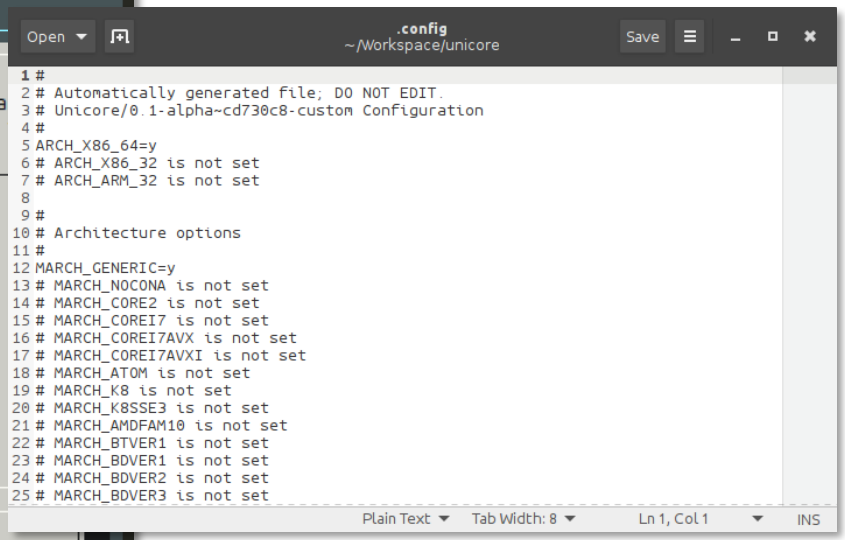
- **Built-in**: functionality specific to Unikraft (e.g., ukboot, ukschedpreempt, etc.)
- **External**: software projects external to Unikraft (e.g., lwip, micropython, etc.)

Putting Things Together – The Unikraft Build Tool

- Kconfig/Makefile based
- Type "`make menuconfig`"
- Choose options in the menu that you want for your application
- Choose your target platform(s)
  - Xen, KVM, bare-metal, Linux
- Save your config and type "`make`"

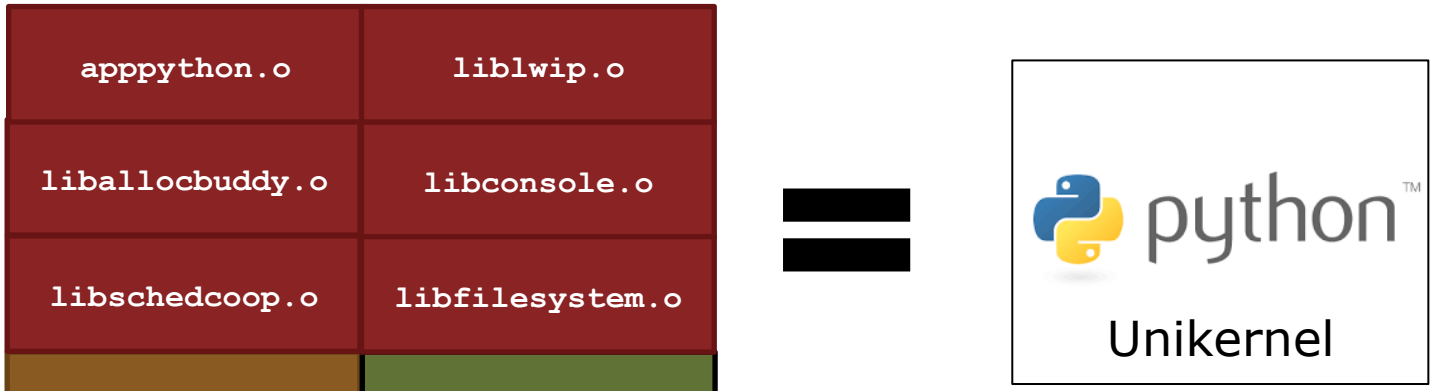


.config



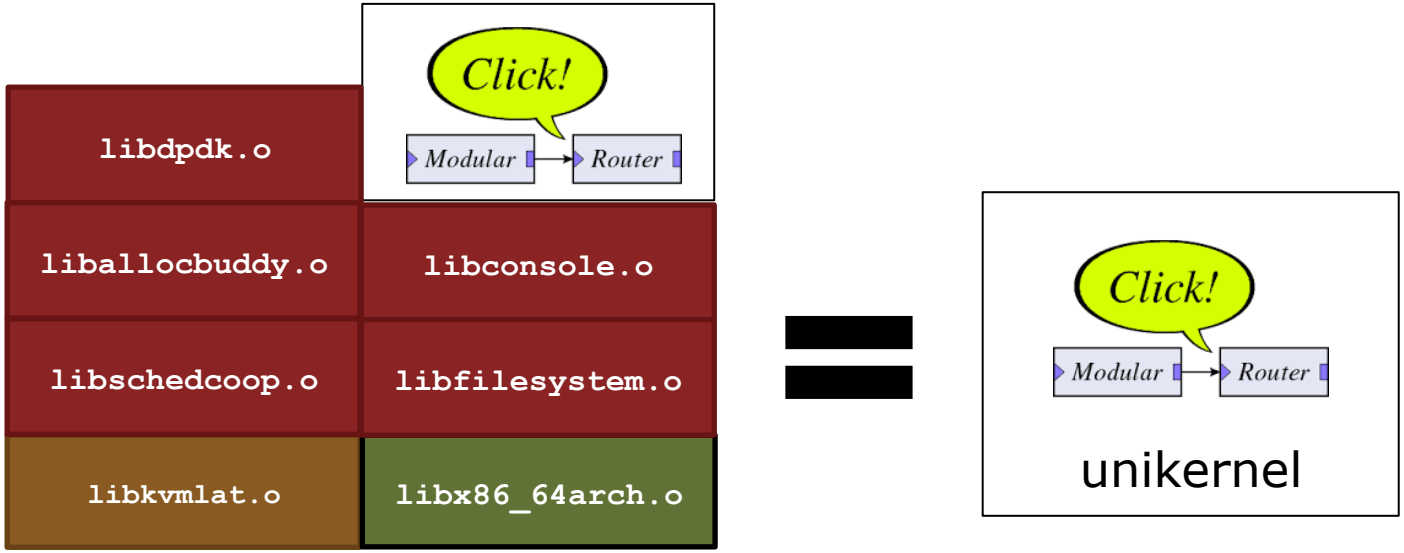
Example System

Python Unikernel for KVM on x86_64



Example System

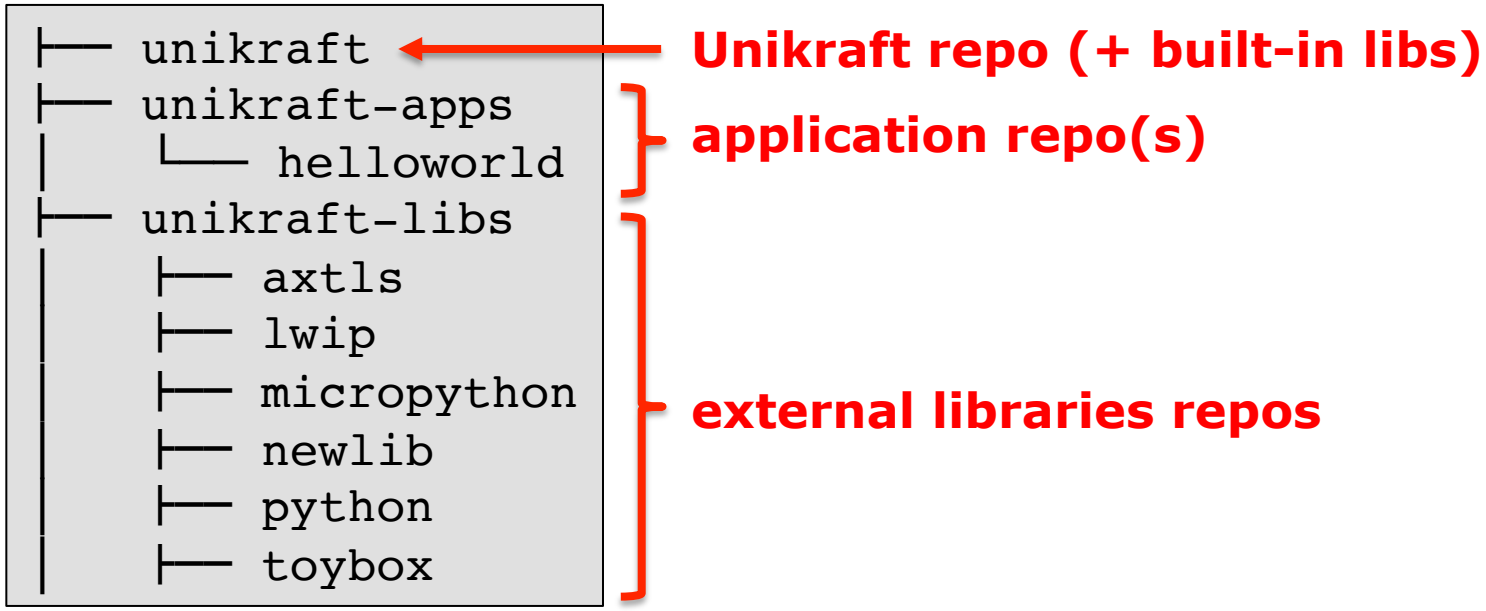
VNF Unikernel for KVM on x86_64



Building a Unikraft Hello World App

Repo Structure

- Clone the main Unikraft repo
- Clone any external library repos
- Create repo for the actual application



Hello World – Four Required Files (I)

Makefile: specify where the main Unikraft repo is, as well as repos for external libraries

```
UK_ROOT ?= $(PWD)/../../unikraft
UK_LIBS ?= $(PWD)/../../unikraft-libs
LIBS := $(UK_LIBS)/newlib

all:
	@make -C $(UK_ROOT) A=$(PWD) L=$(LIBS)

$(MAKECMDGOALS):
	@make -C $(UK_ROOT) A=$(PWD) L=$(LIBS) $(MAKECMDGOALS)
```

← **path to unikraft repo**

← **path to external libs**

← **external libs needed**

Hello World – Four Required Files (II)

Makefile.uk: specifies the sources to build for the application

```
$(eval $(call addlib,apphelloworld))

APPHELLOWORLD_SRCS-y += $(APPHELLOWORLD_BASE)/main.c
```

register app with uk Build system

Add main.c to build

Hello World – Four Required Files (III)

Config.uk: to populate Unikraft's menu with application-specific option

```
### Invisible option for dependencies
config APPHELLOWORLD_DEPENDENCIES
        bool
        default y
        select LIBNOLIBC if !HAVE_LIBC

### App configuration
config APPHELLOWORLD_PRINTARGS
        bool "Print arguments"
        default y
        help
          Prints argument list (argv) to stdout
```

Hello World – Four Required Files (IV)

main.c: source file to provide (at least) a `main()` function

```
#include <stdio.h>

/* Import user configuration: */
#include <uk/config.h>

int main(int argc, char *argv[])
{
        printf("Hello world!\n");

#if APPHELLOWORLD_PRINTARGS
        int i;

        printf("Arguments: ");
        for (i=0; i<argc; ++i)
                printf(" \"%s\"", argv[i]);
        printf("\n");
#endif
}
```

Unikernel entry point after boot

defined by Config.uk

Porting an External Library

How To Port an External Library

- Most of the work revolves around ensuring Unikraft supports your lib's dependencies → we're working on this! ☺
- Write `Makefile.uk` and add the external library source files to it
- Sometimes a bit of *glue* code is needed
  - E.g., in newlib to link POSIX thread creation to Unikraft's thread library

How To Port an External Library – Makefile.uk

```
################################################################################
# Library registration
################################################################################
$(eval $(call addlib_s,libaxtls,$(LIBAXTLS)))

################################################################################
# Sources
################################################################################
# Nothing here: sources are small and included directly in the uk library repo
# Note: sources are from axTLS-2.1.4.tar.gz .

################################################################################
# Library includes
################################################################################
CINCLUDES-y +=    -I$(LIBAXTLS_BASE)/include \
                  -I$(LIBAXTLS_BASE)/crypto  \
                  -I$(LIBAXTLS_BASE)/ssl

################################################################################
# sources
################################################################################
LIBAXTLS_SRCS-y += $(LIBAXTLS_BASE)/crypto/aes.c
LIBAXTLS_SRCS-y += $(LIBAXTLS_BASE)/crypto/bigint.c
…
LIBAXTLS_SRCS-y += $(LIBAXTLS_BASE)/crypto/sha512.c
```

Unikraft 0.2 Titan

Current Status

Available Libraries

Main Libraries

- libfdt
  - Flat device tree parser
- libnolibc
  - A tiny libC replacement
- libnewlib (external)
  - Porting ongoing
- libukalloc
  - Memory allocator abstraction
- libukallocbbuddy
  - Binary buddy allocator for libukalloc
- libukargparse
  - Argument parser library
- libukboot
  - Unikraft bootstrapping
- libukdebug
  - Debug and kernel printing
  - Assertions, hexdump
- libuksched
  - Scheduler abstraction
- libukschedcoop
  - Cooperative scheduler for libsched

Architecture Libraries

- libarmmath
  - 64bit arithmetic on ARMv7

Platform Libraries

- libxenplat
  - Xen (PV)
  - X86_64, ARMv7
- libkvmplat
  - X86_64
- liblinuxu
  - Linux userspace
  - X86_64, ARMv7

Coming Soon

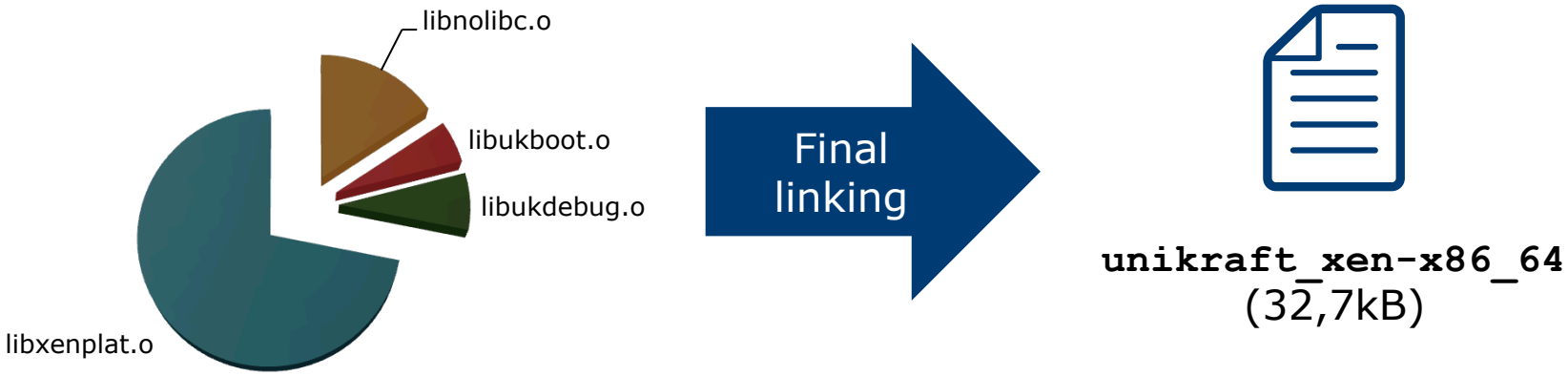
- libukschedpreempt
  - Pre-emptive scheduler
- libukswrand
  - Software random number generator
- libukvirtio
  - Virtio driver
- liblwip (external)
  - Network stack
- libclick (external)
  - The Click modular router (e.g., for NFV)
- libmicropython (external)
  - Micropython (Python for embedded devices)
- libcpython (external)
  - Standard Python
- libaxtls (external)
  - TLS support for embedded devices

More on the way!

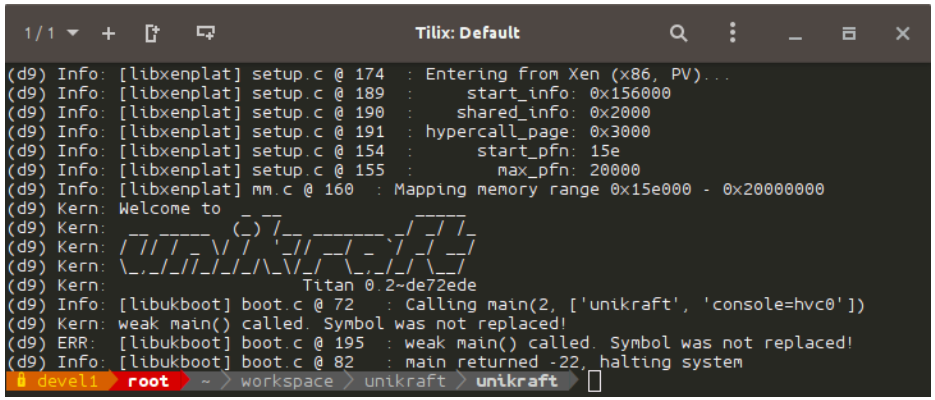
A Baseline Example...

Xen PV x86_64 binary

`unikraft_xen-x86_64.o` (50,2kB)



Boots and prints messages to debug console (with min. 208kB RAM)



Short Video/Demo

It is real!

It’s Open Source – Join Us!

- Recently: Unikraft got released as Xen incubator project
  - OpenSource development under Xen and LinuxFoundation umbrella

- Have look on the Xen Pages and Wiki
  - https://www.xenproject.org/developers/teams/unikraft.html
  - https://wiki.xenproject.org/
- Drop us an mail
  - minios-devel@lists.xen.org
- Join our IRC channel
  - #unikraft on Freenode
- We have plenty of open topics, get in touch with us!
  - http://sysml.neclab.eu

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