THE LINUX FOUNDATION
OPEN SOURCE SUMMIT
EUROPE

From Handcraft to Unikraft:
Simpler Unikernelization of Your Application

Florian Schmidt

Research Scientist, NEC Labs Europe

This work has received funding from the European Union's Horizon 2020 research and innovation program under grant agreements no. 675806 ("5G CITY") and 761592 ("5G ESSENCE"). This work reflects only the author's views and the European Commission is not responsible for any use that may be made of the information it contains.

THE LINUX FOUNDATION

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- "Containers are much easier to create and deploy.
  I just write this Dockerfile and I'm done."

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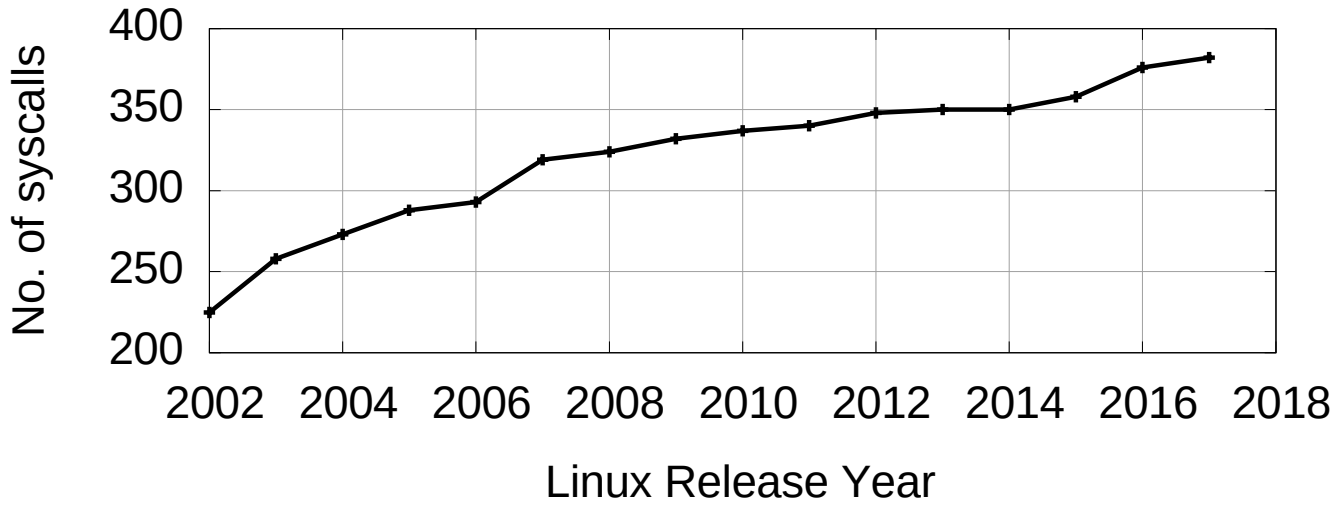

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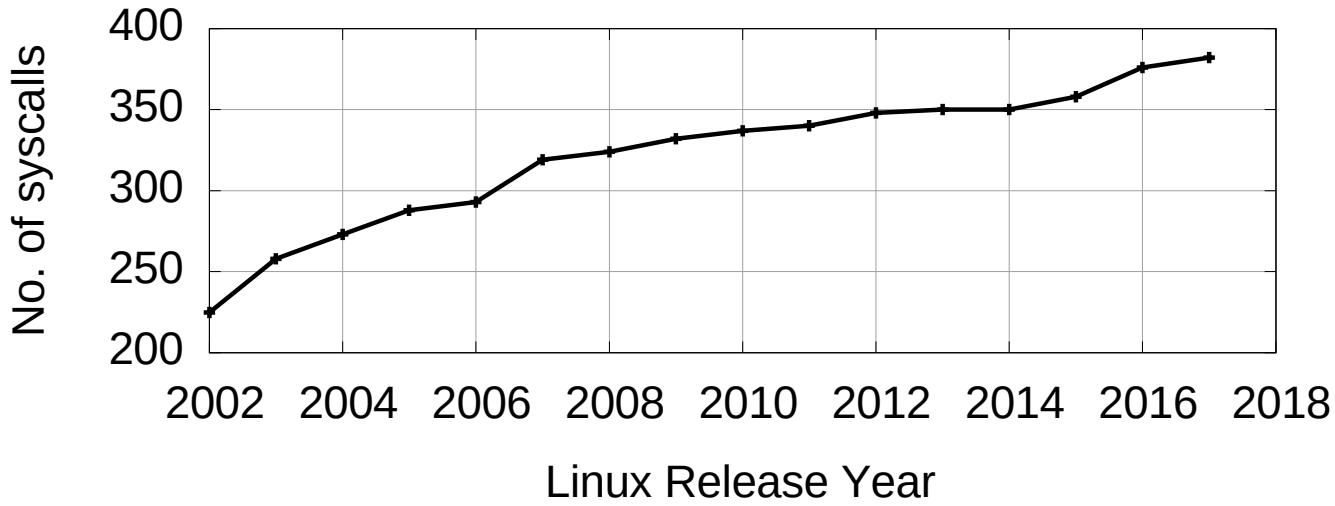

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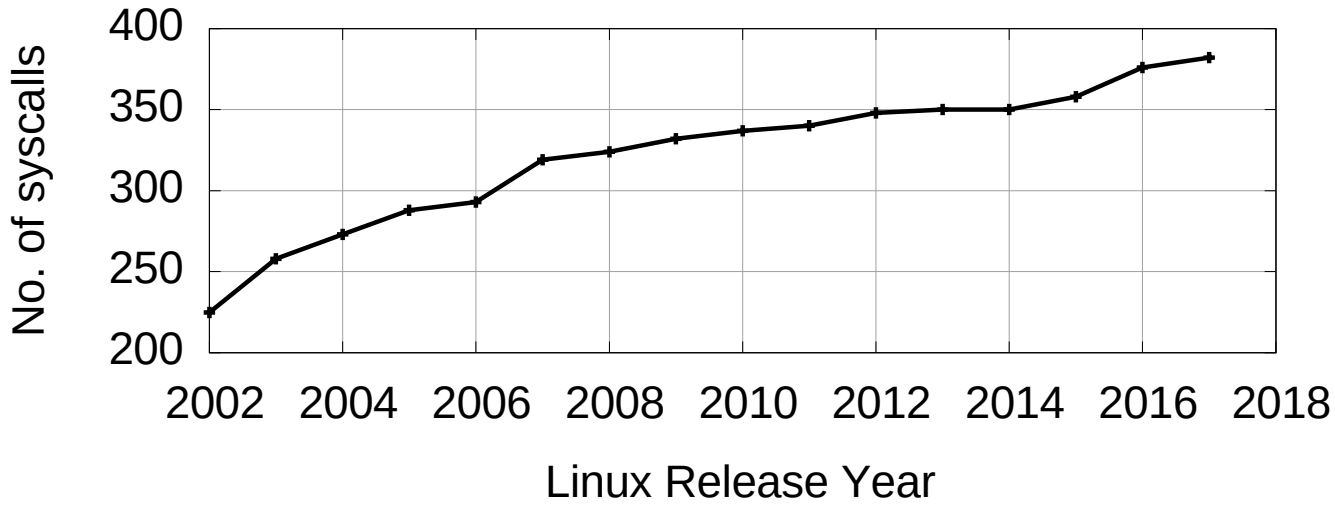

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  - This is where unikernels come in

Traditional VMs vs. Unikernels

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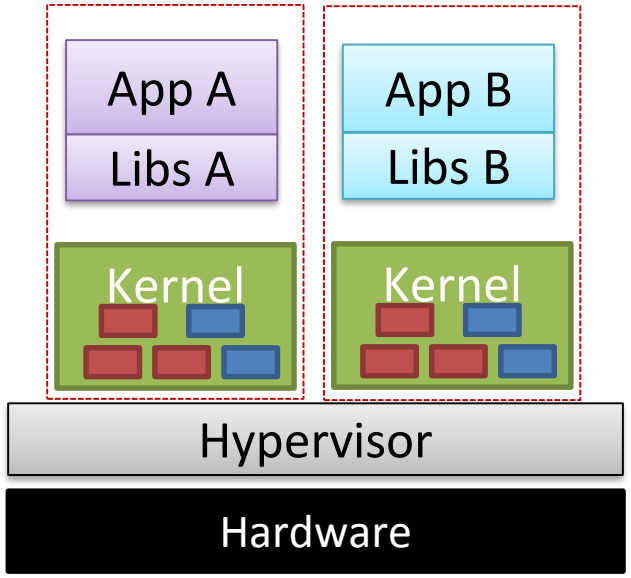

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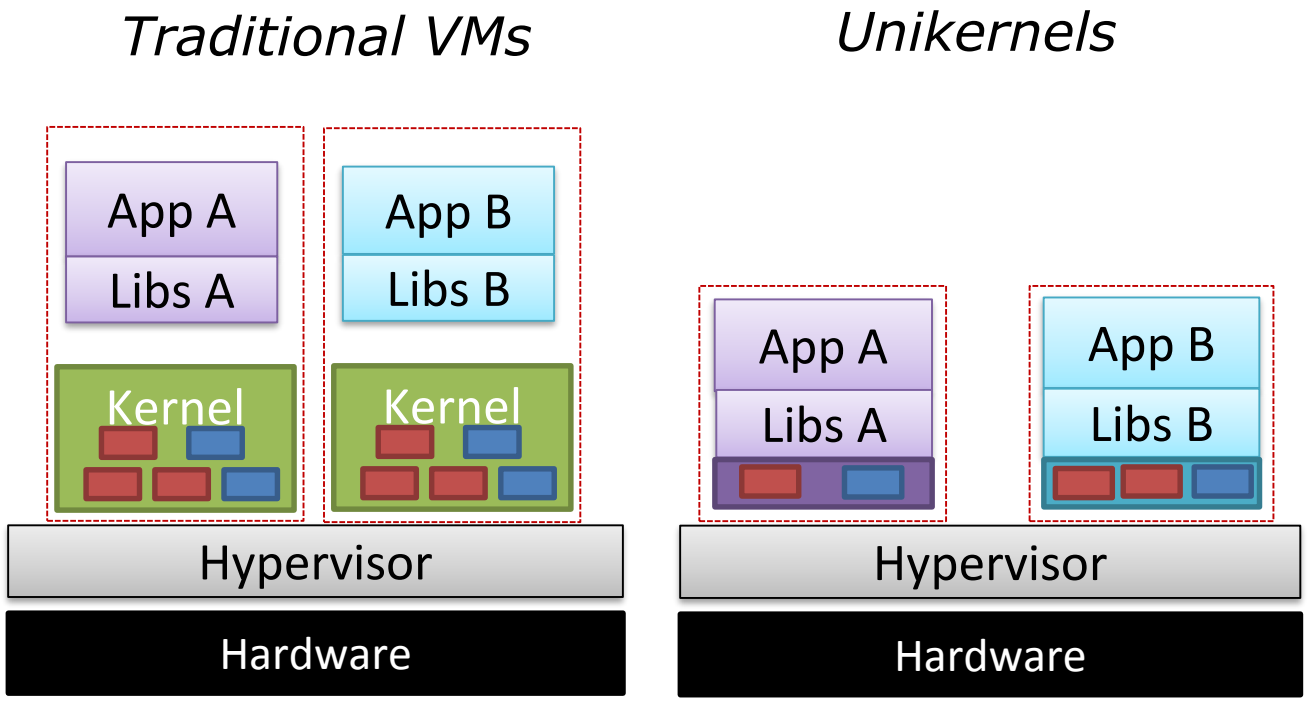

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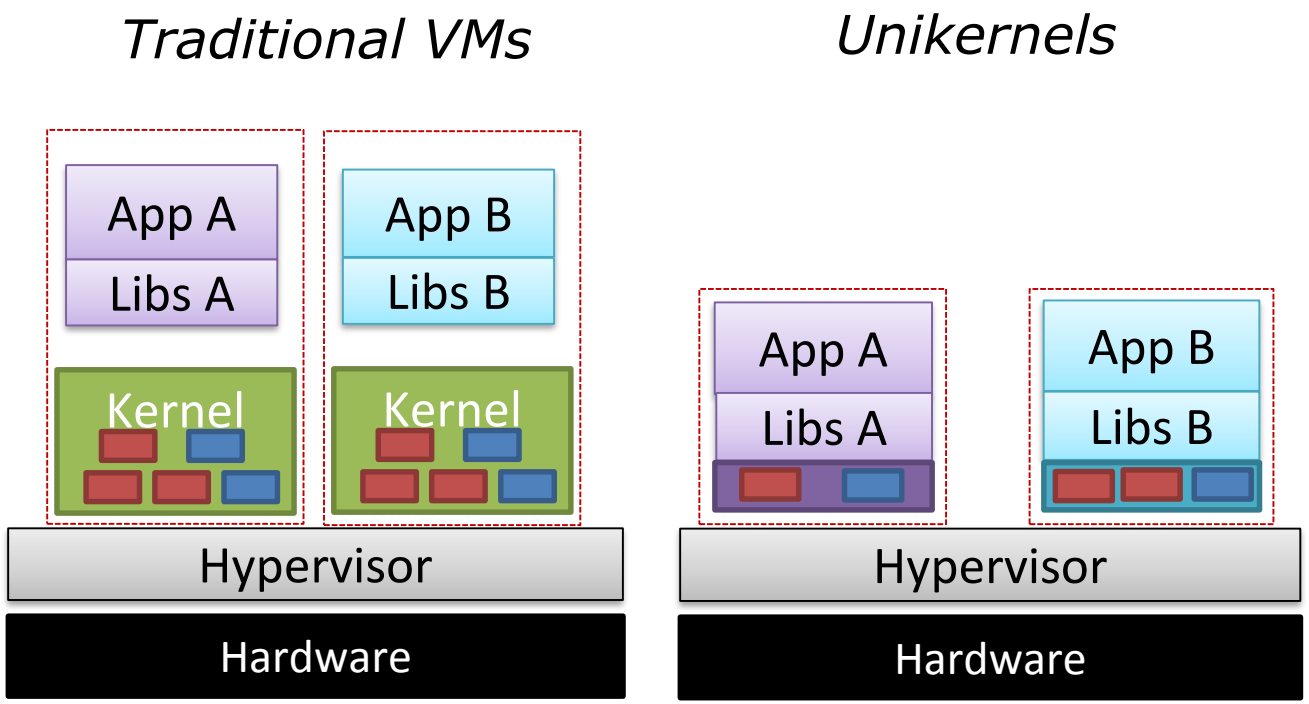

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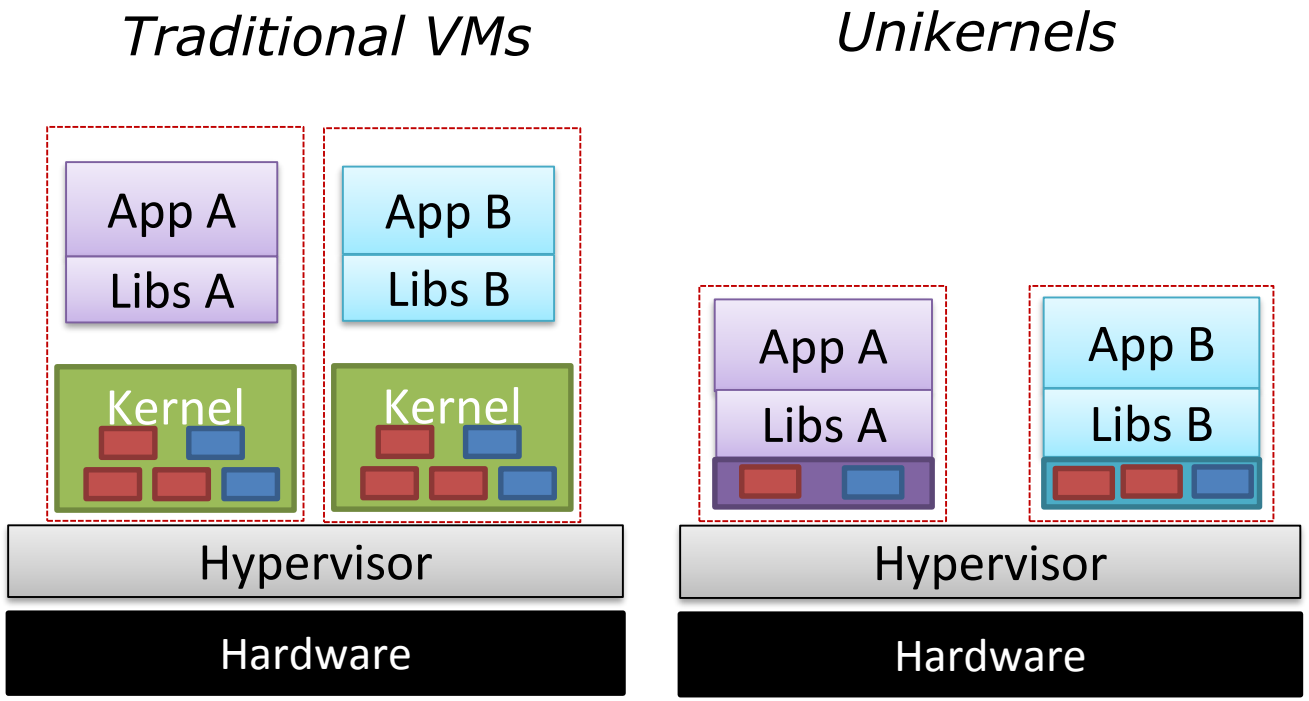

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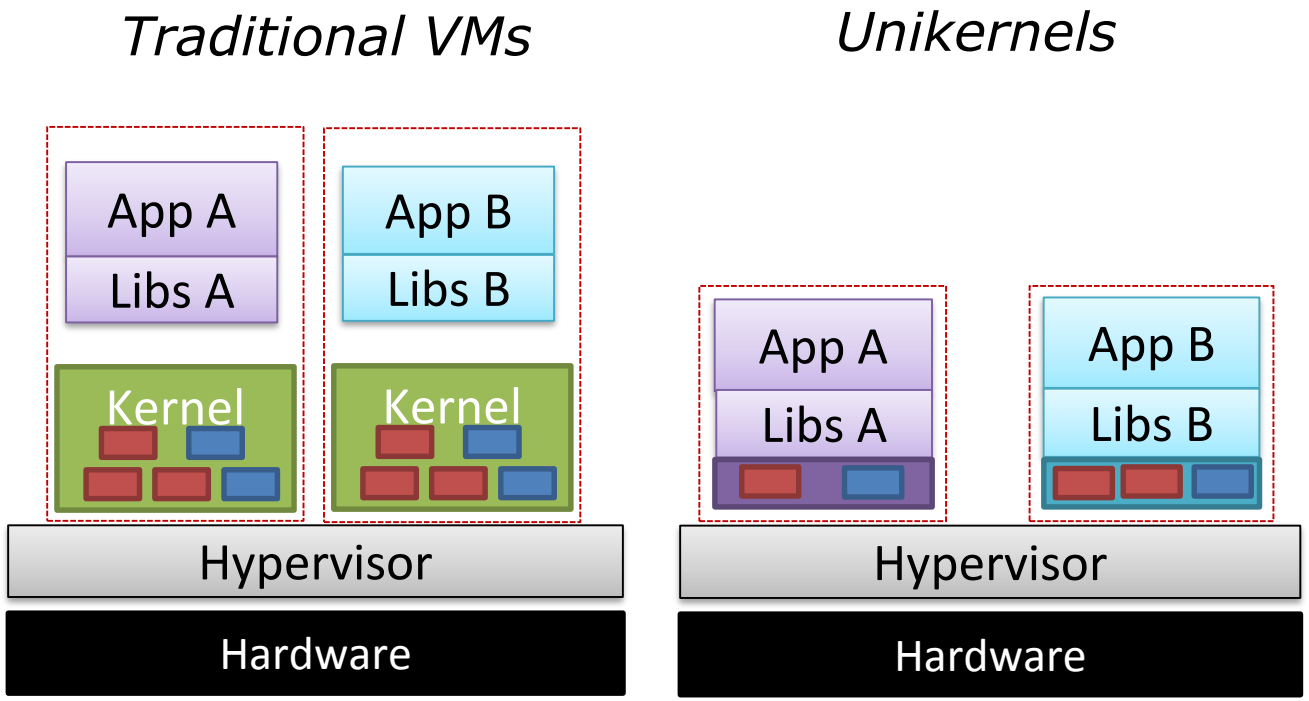

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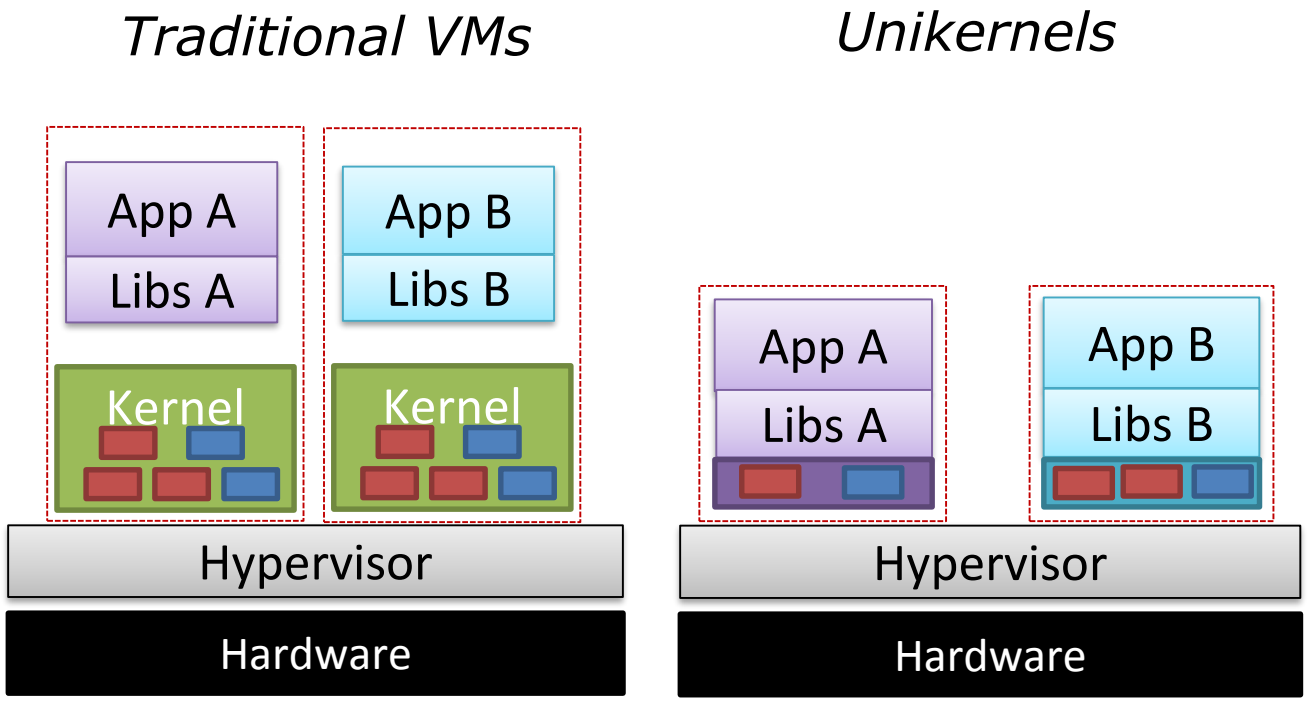

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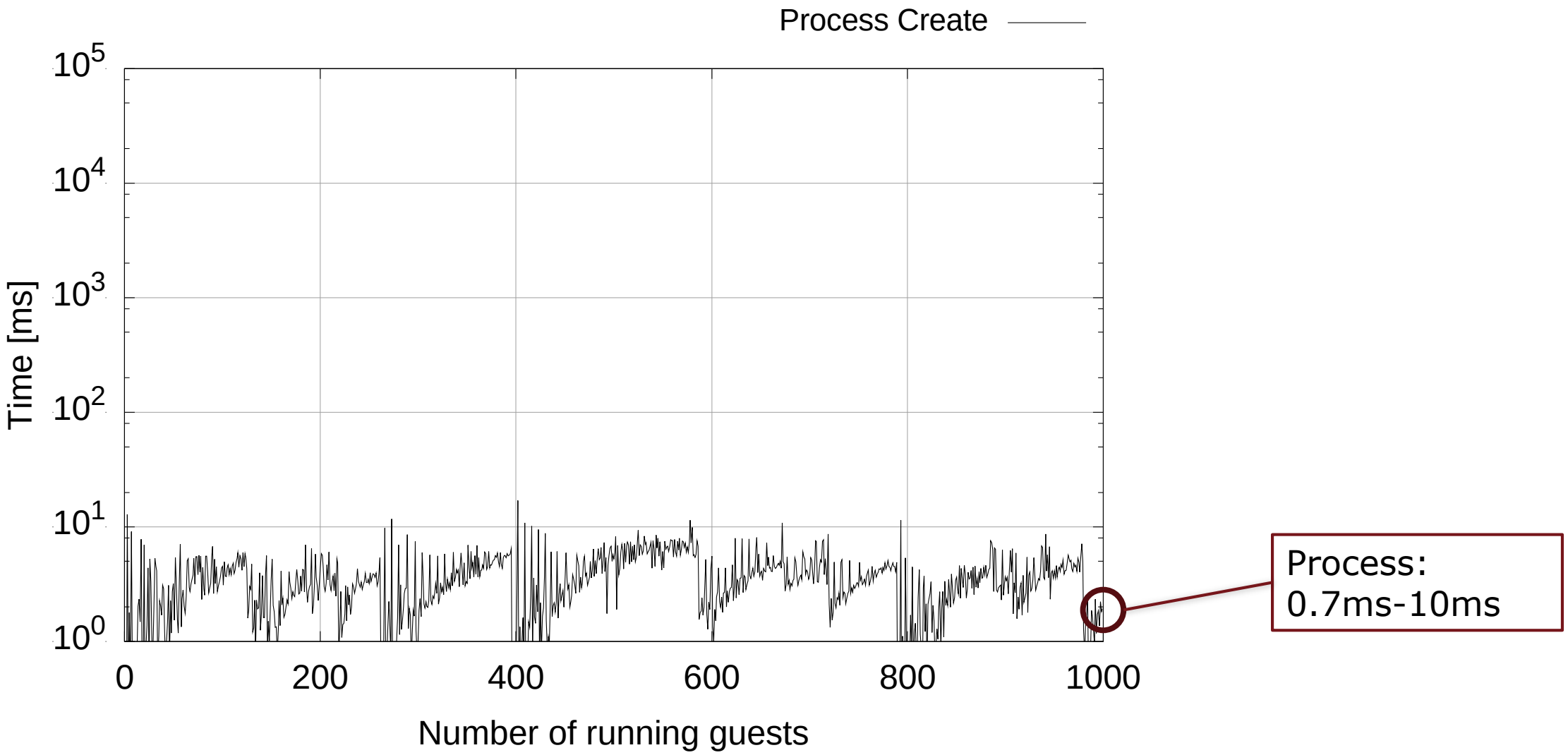

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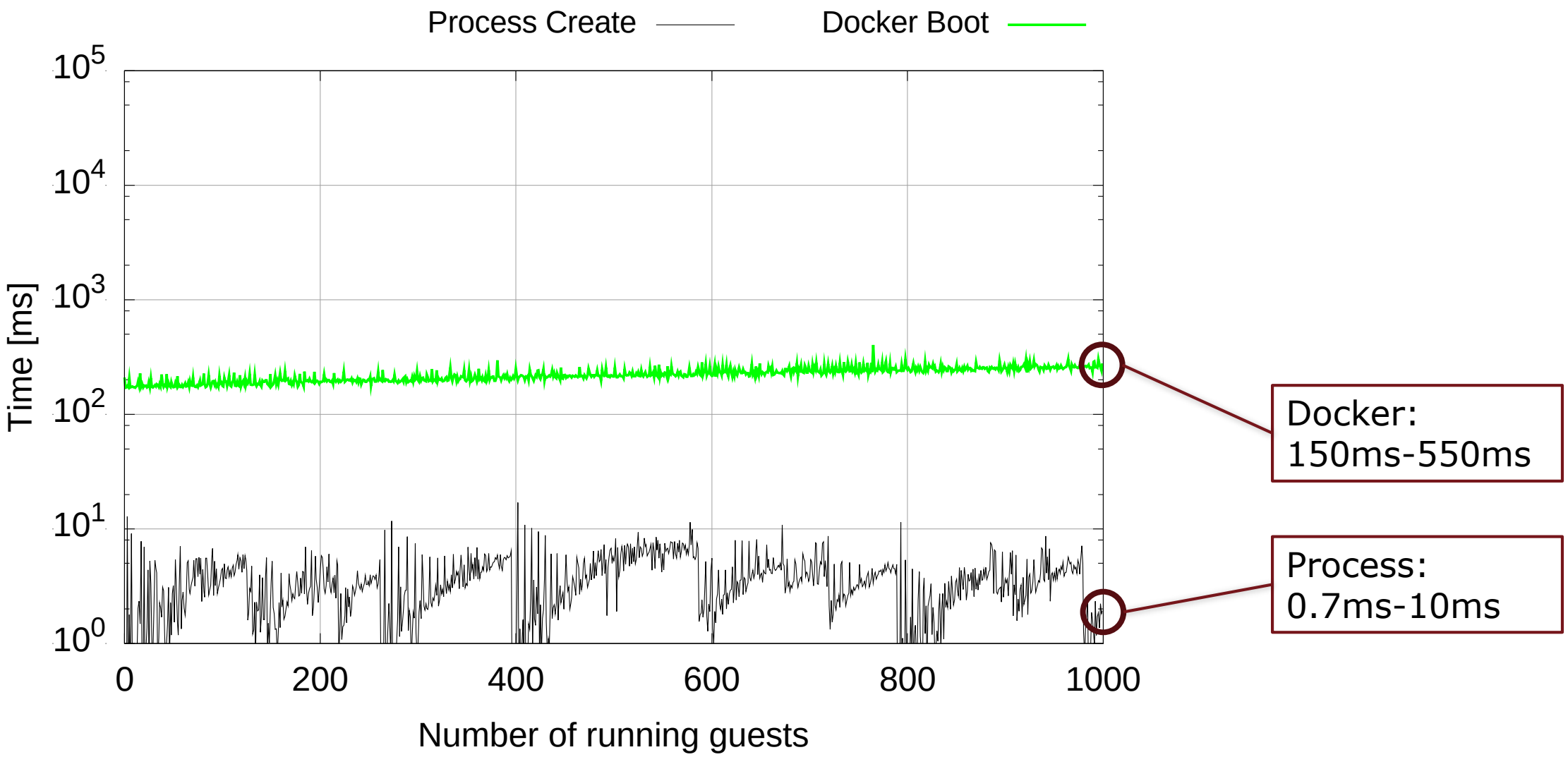

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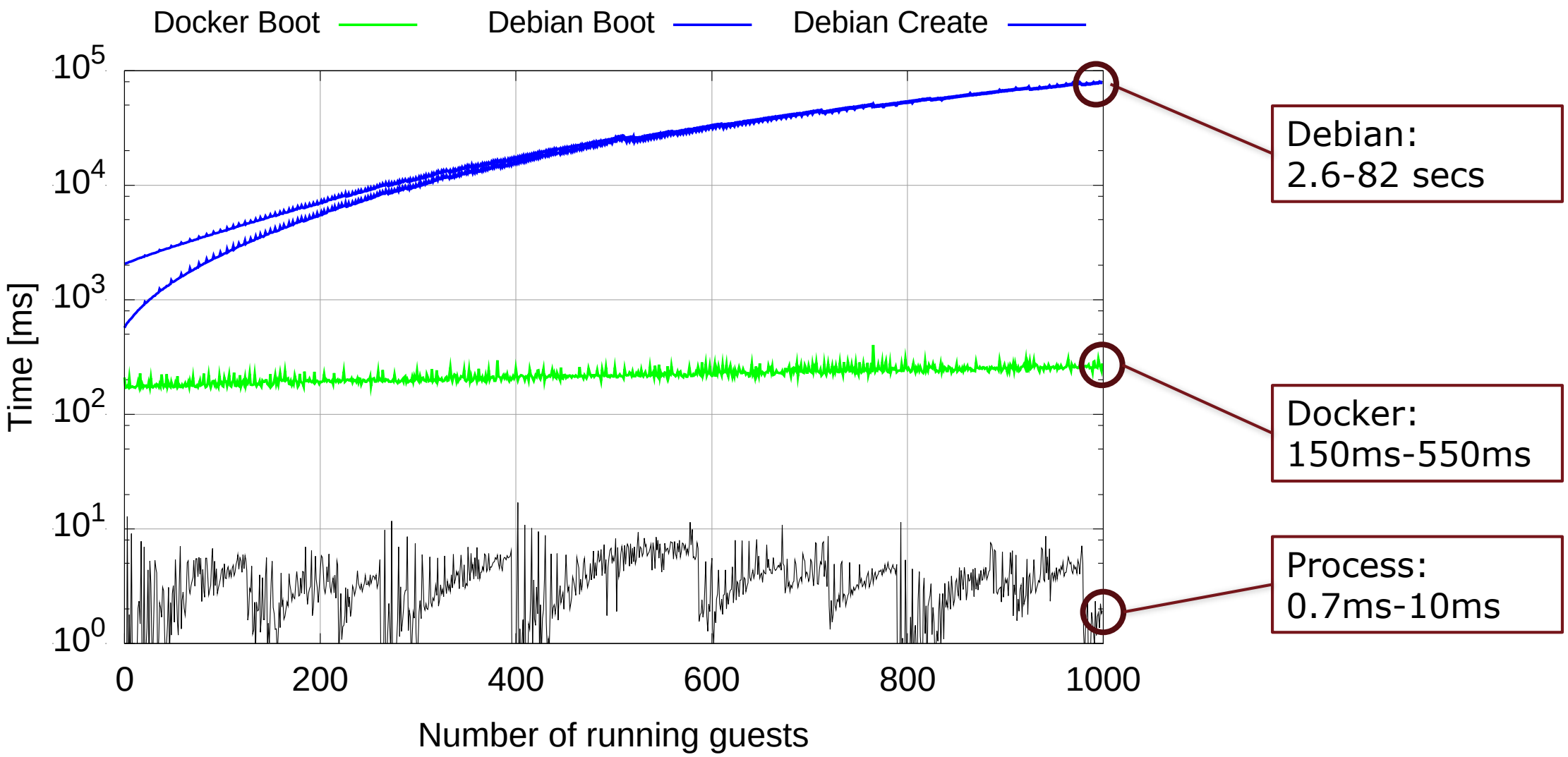

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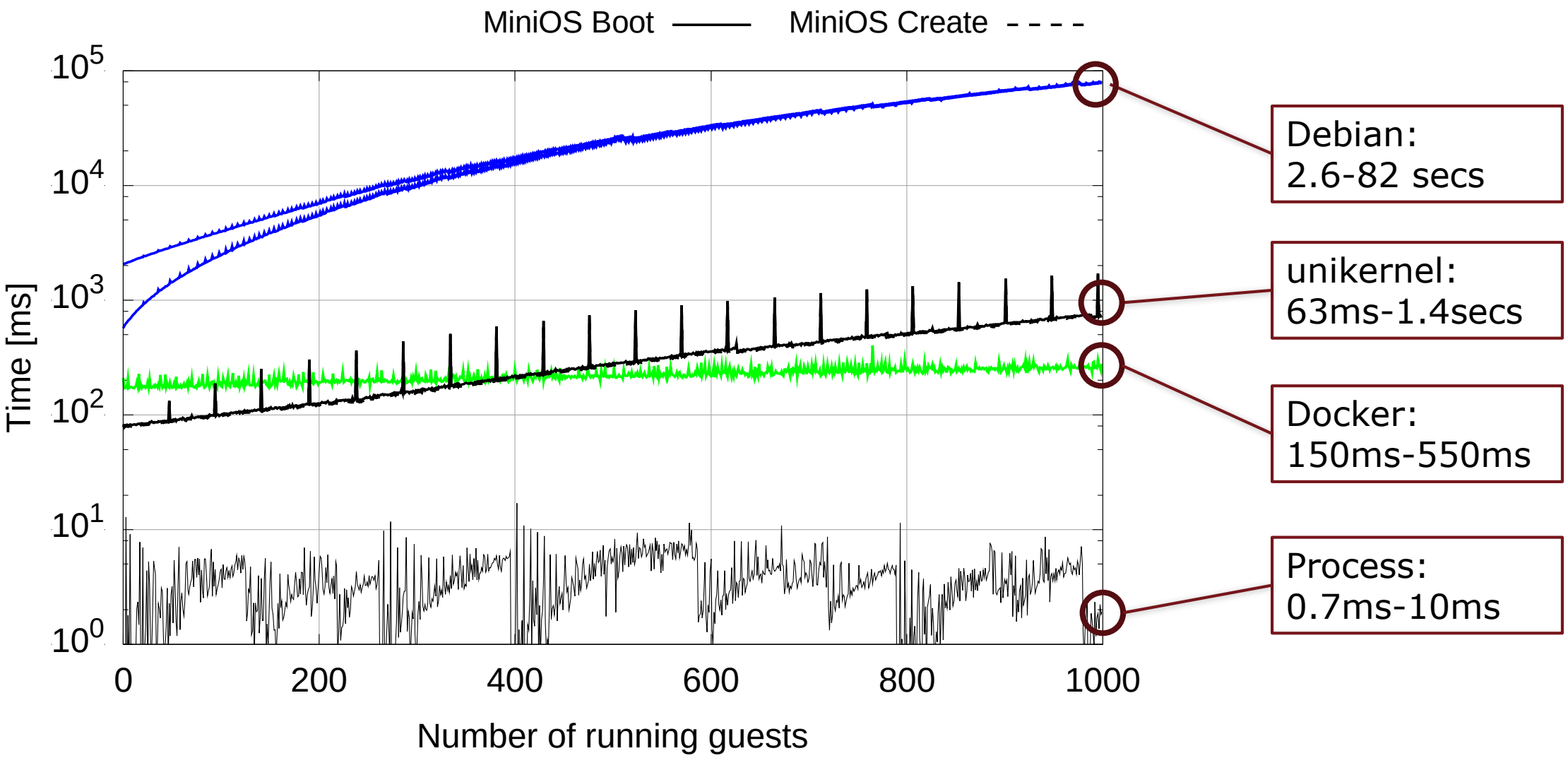

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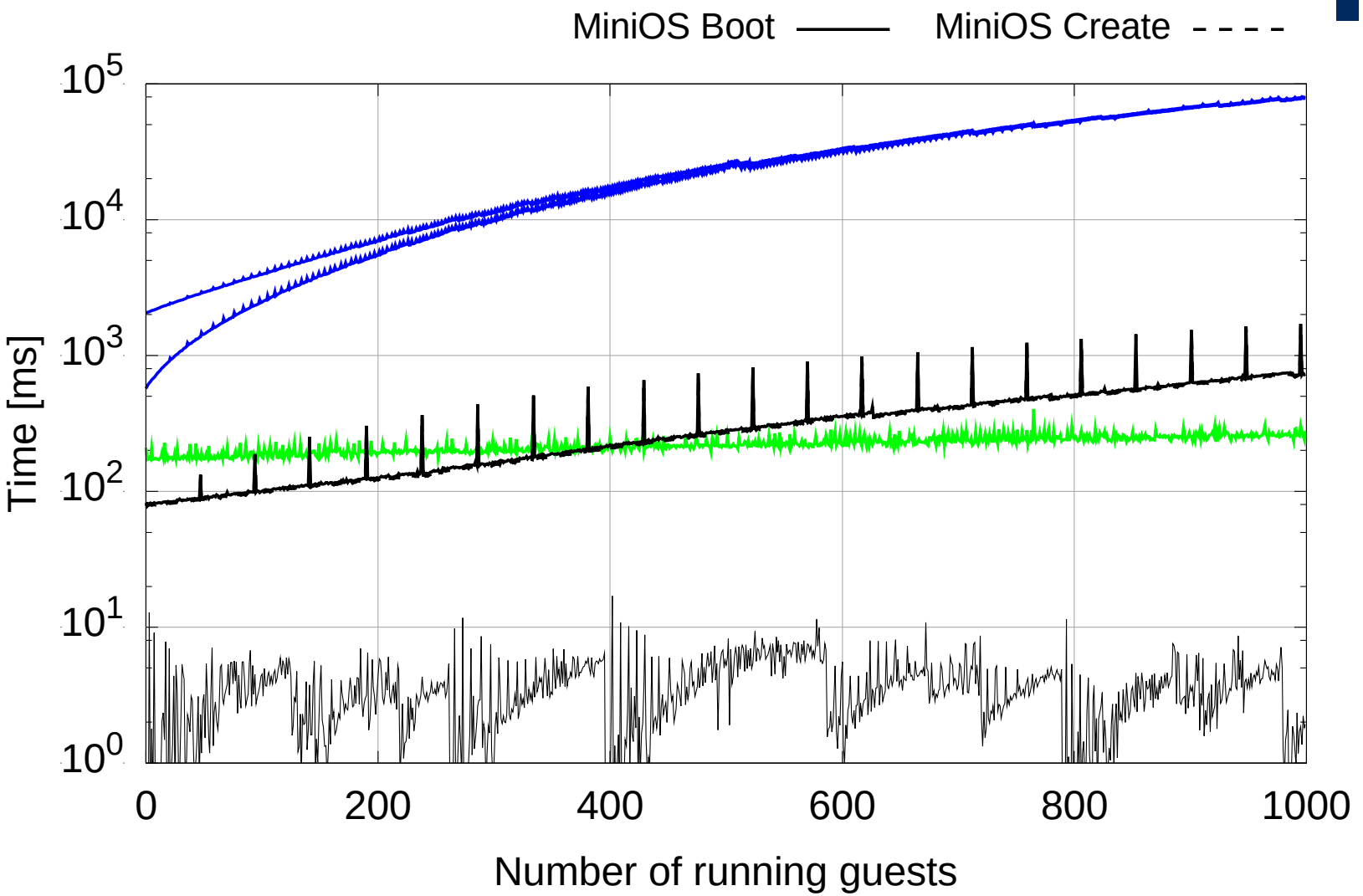

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Unikernels can instantiate as fast as containers

- Often faster
- Except when many are colocated
  - Speaking of which, what is going wrong there?!
  - If you're interested, talk to me later
  - Bottom line: this is a solvable implementation problem

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- That's not an effective way of doing things

Unikraft - A Unikernel Framework

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Motivation

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- Provide common code base for unikernel development
- Simplify building and optimizing
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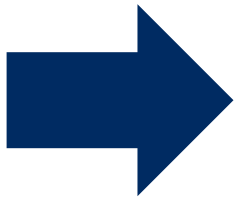

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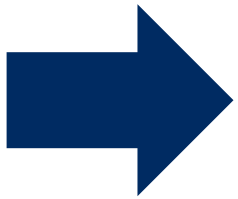

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- Decompose OS functionality into libraries
- Unikraft's two components:
  - Library Pool
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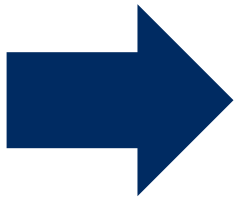

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- Started as an internal project at NEC Labs in early 2017
- Made public early on
  - Discussed ideas at Xen Summit 2017
  - Accepted as a Xen incubator project in October 2017
  - First public code release in December 2017

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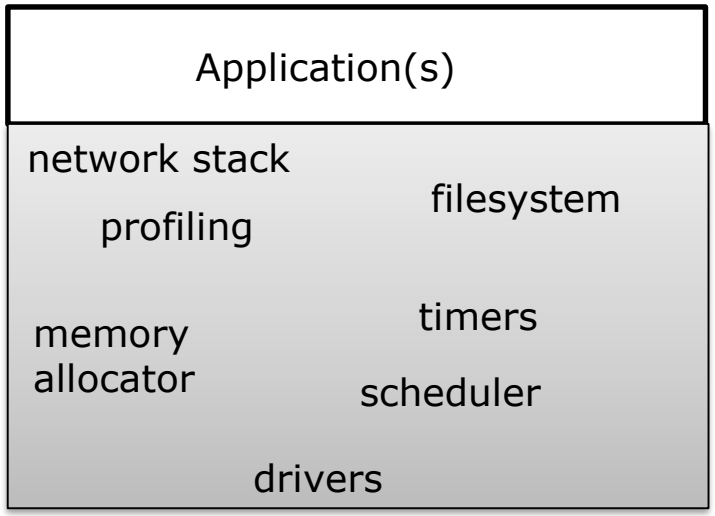

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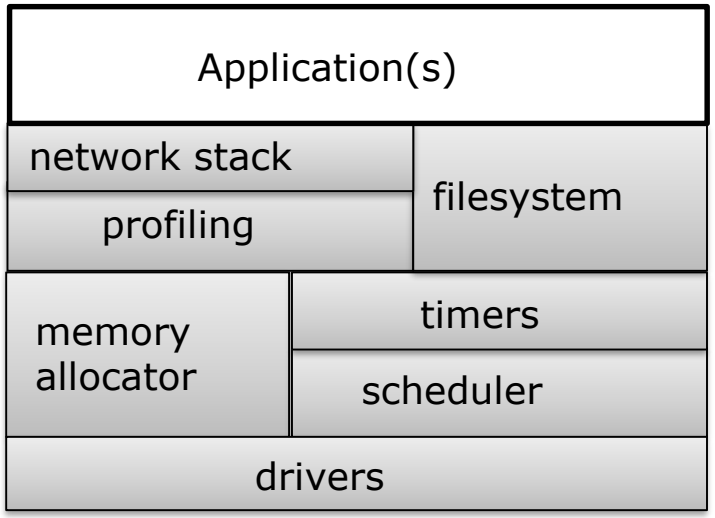

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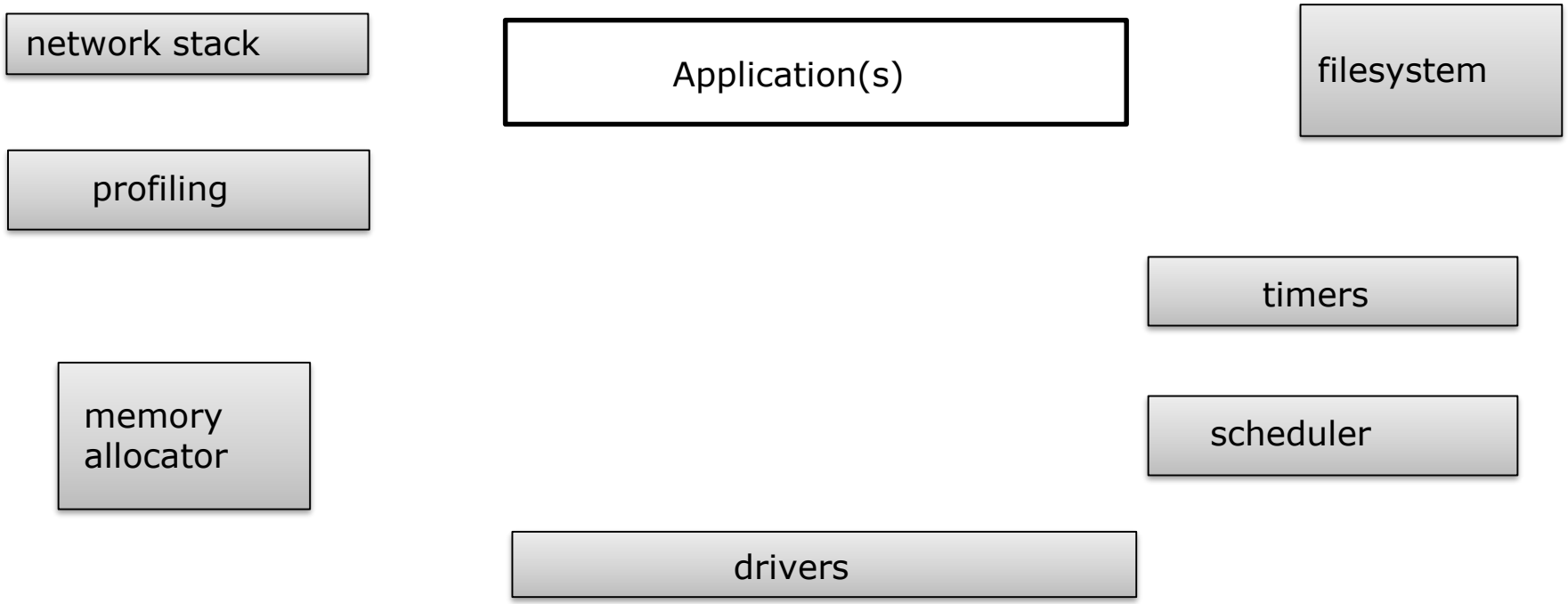

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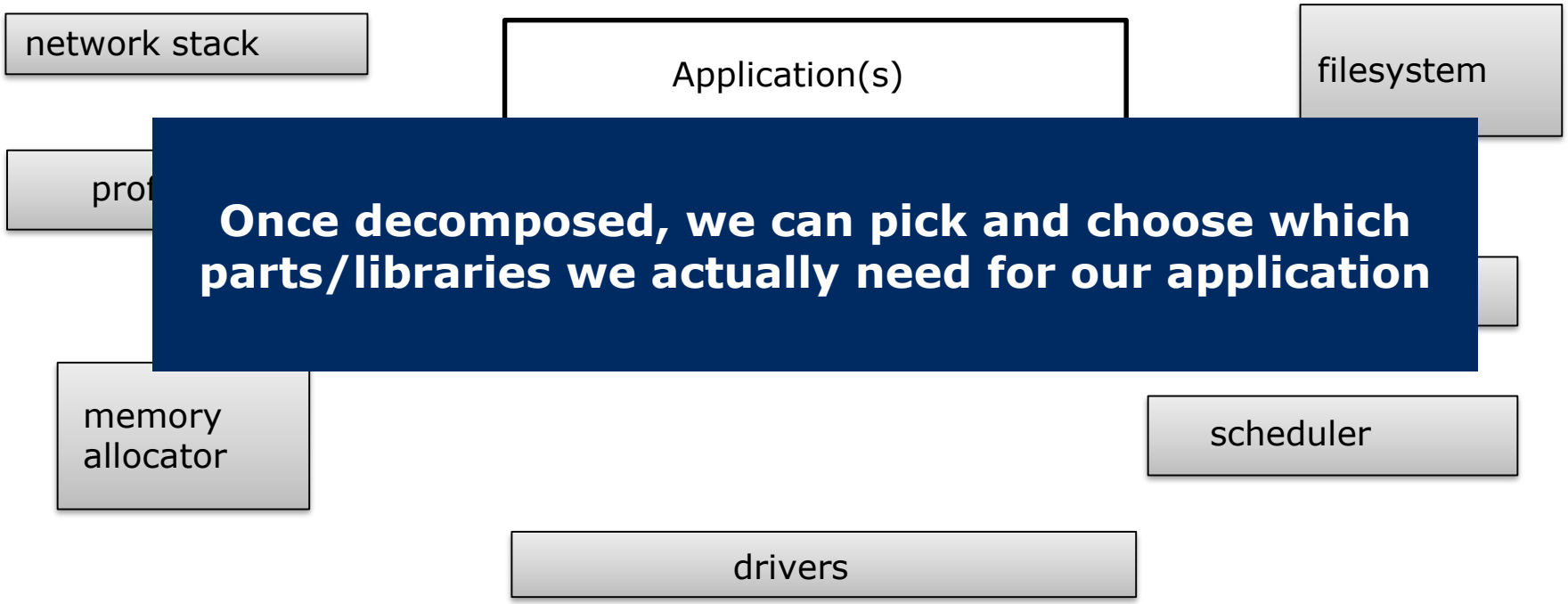

Unikraft Overview – Everything as a Library

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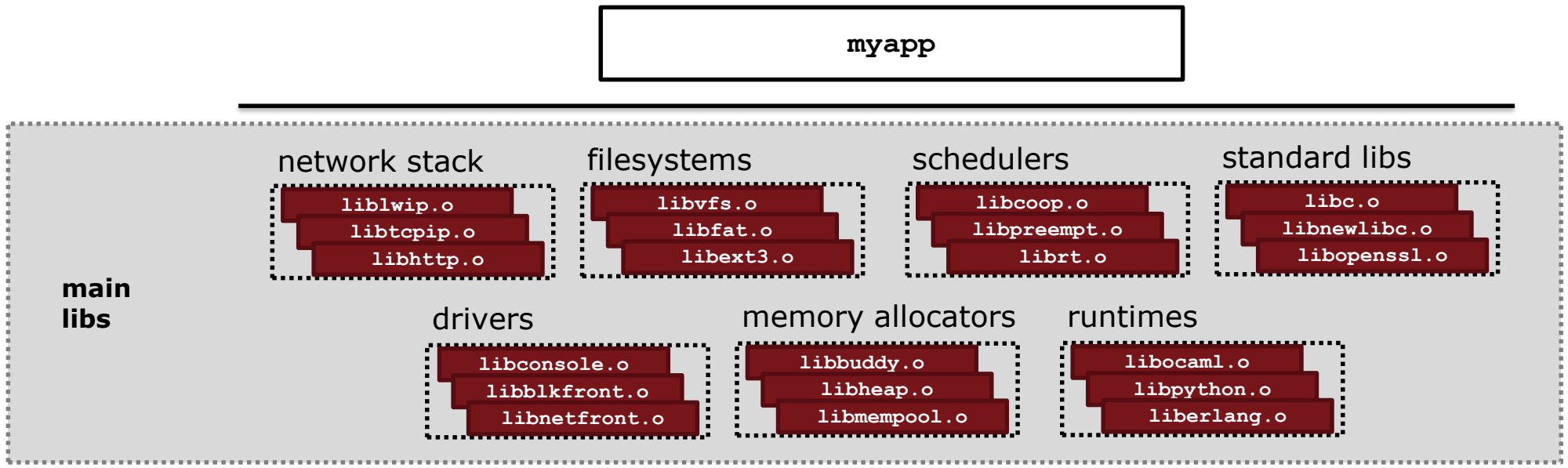

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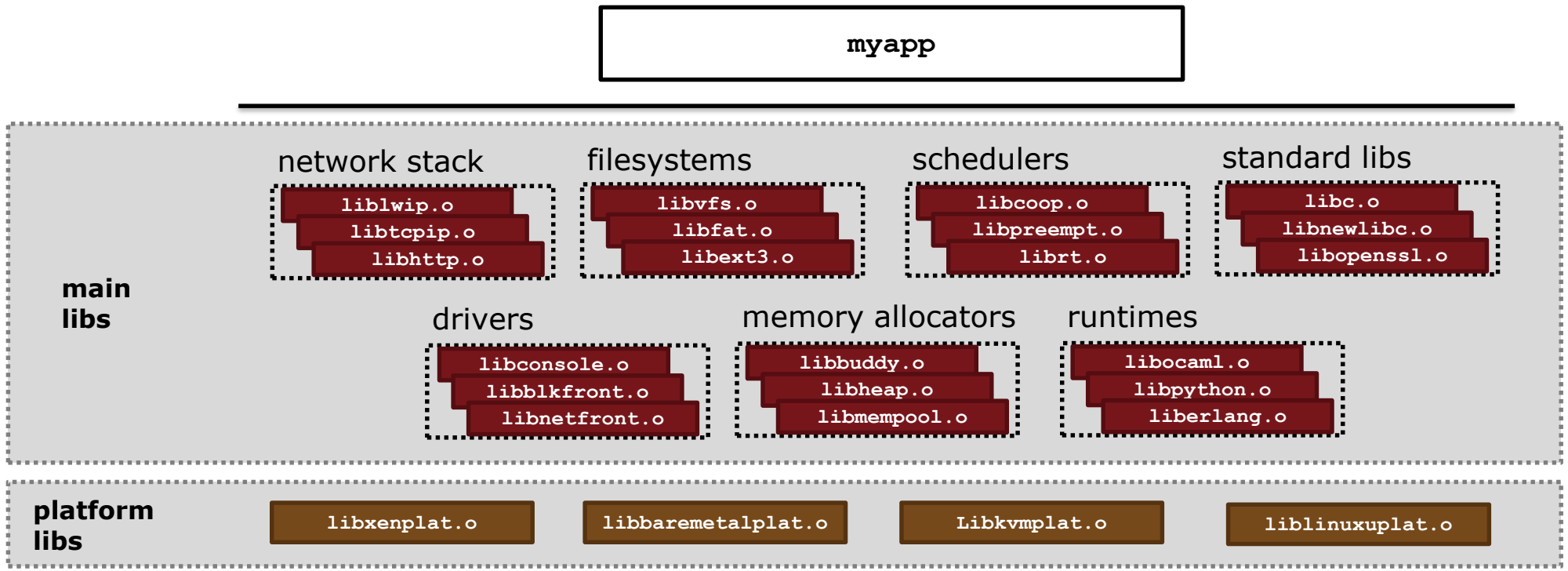

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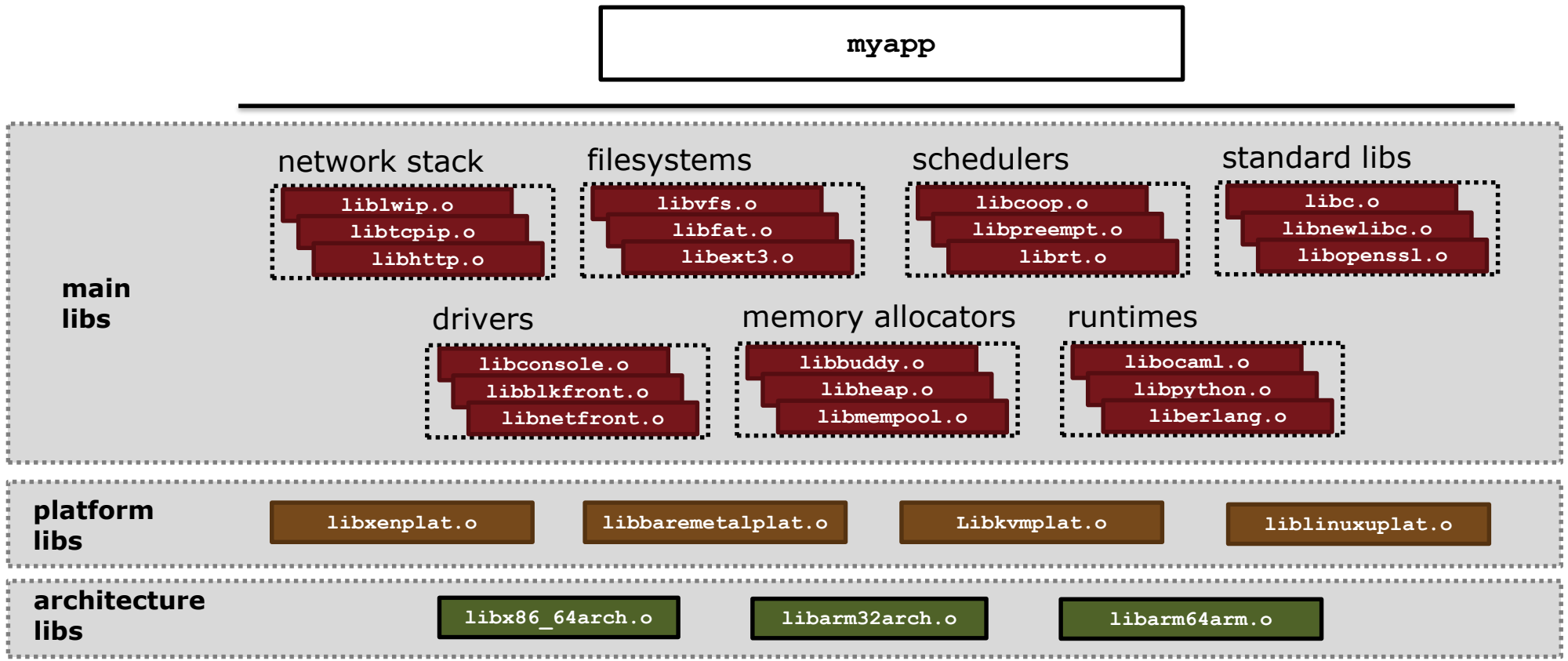

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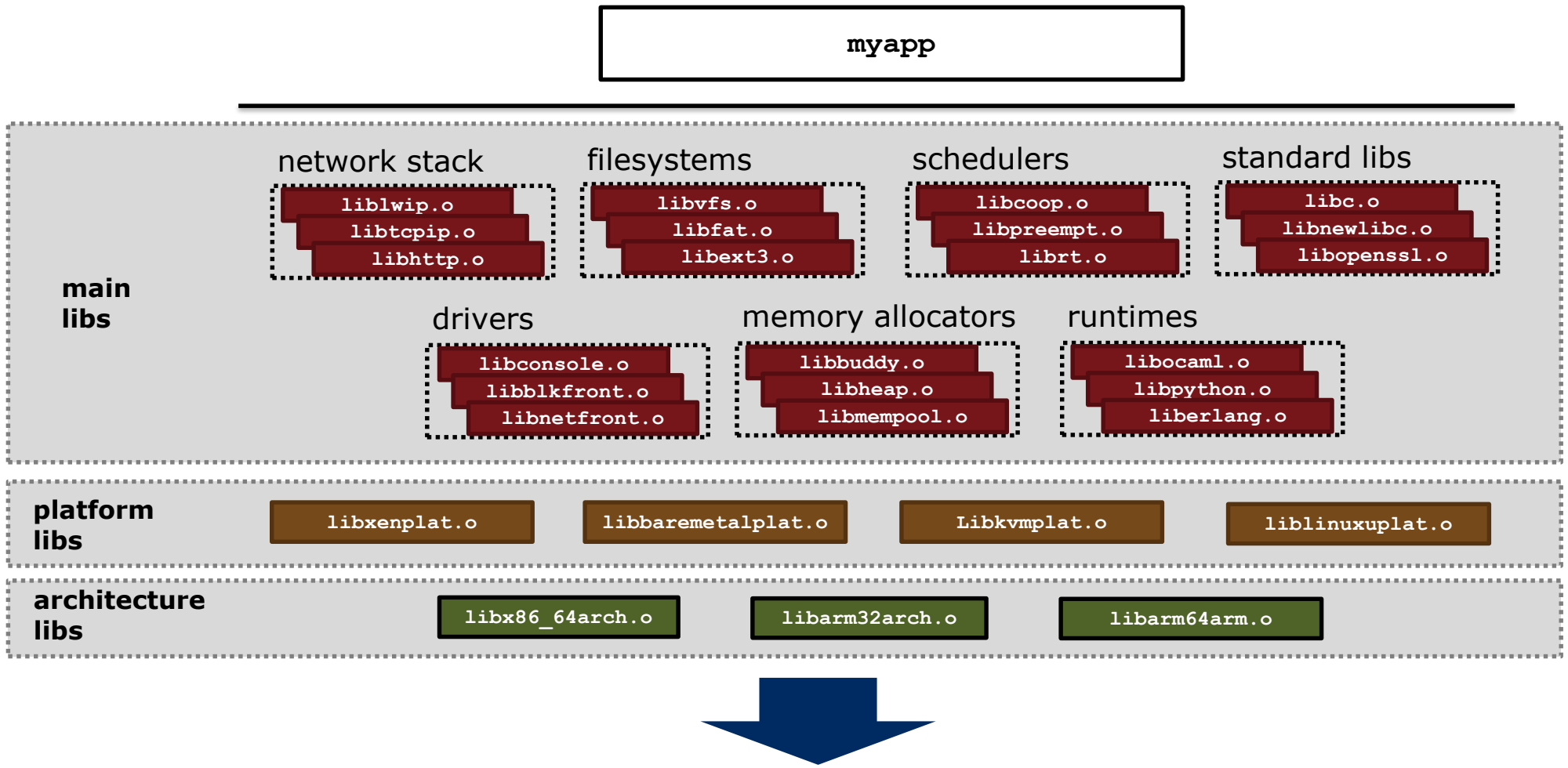

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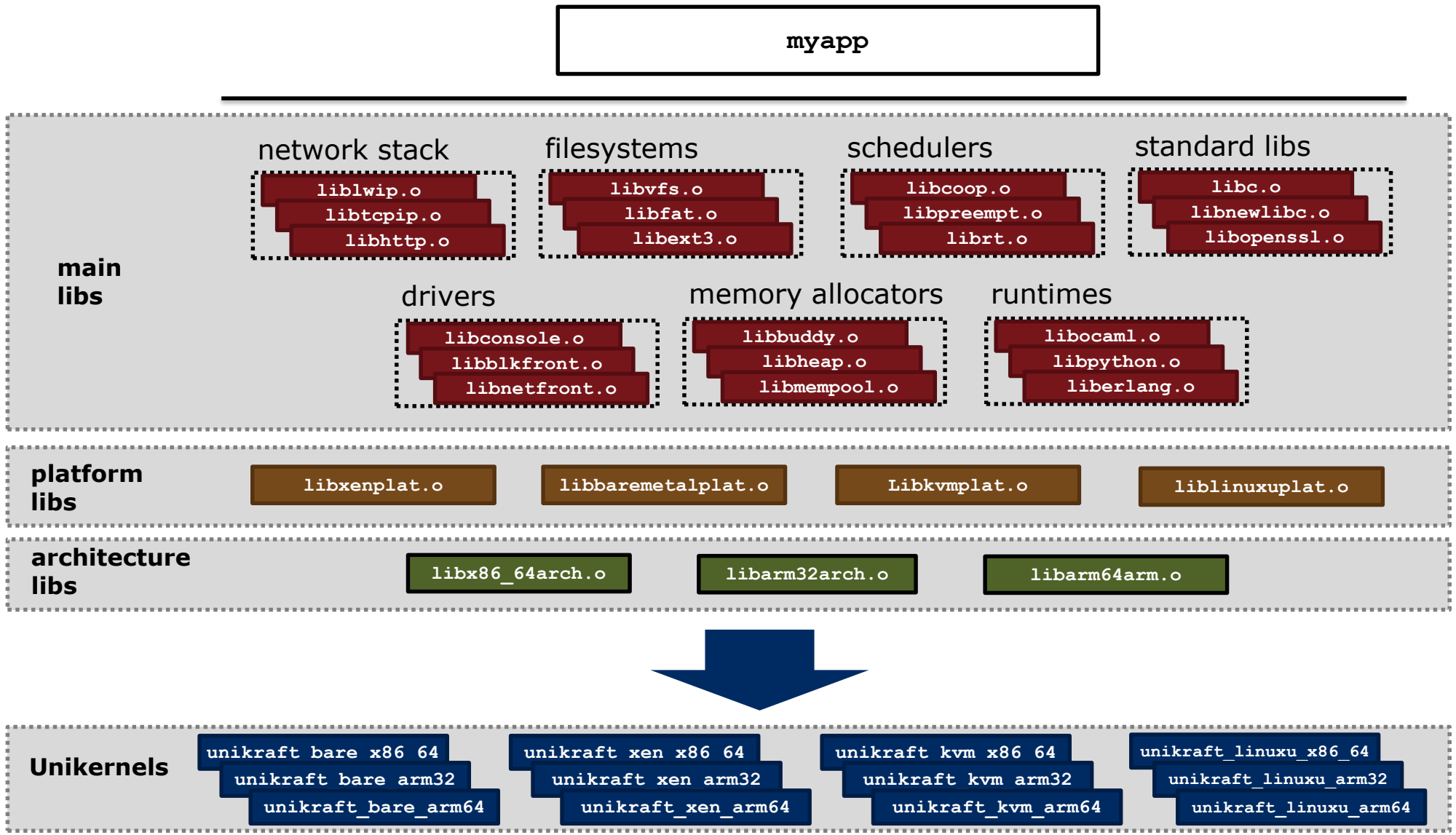

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External: software projects external to Unikraft, have their own unikraft-lib repos

- lwip
- micropython
- …

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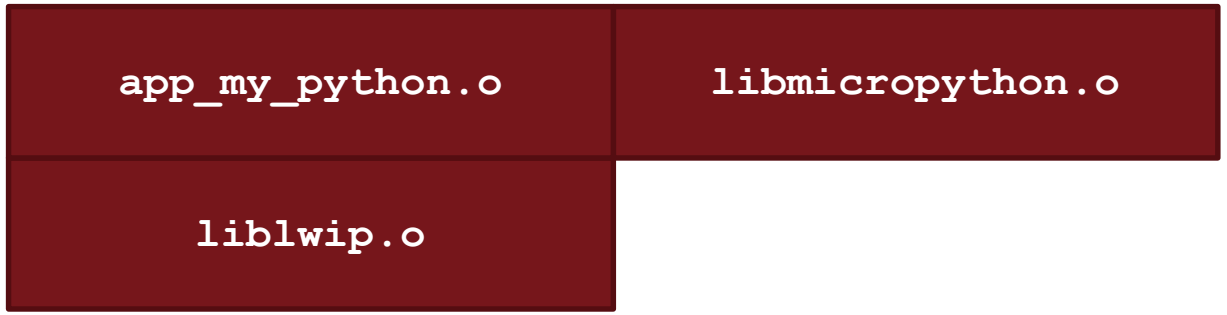

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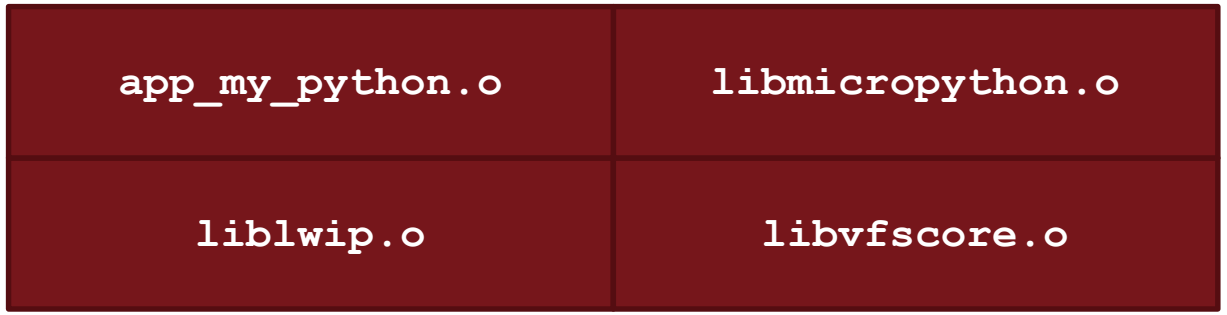

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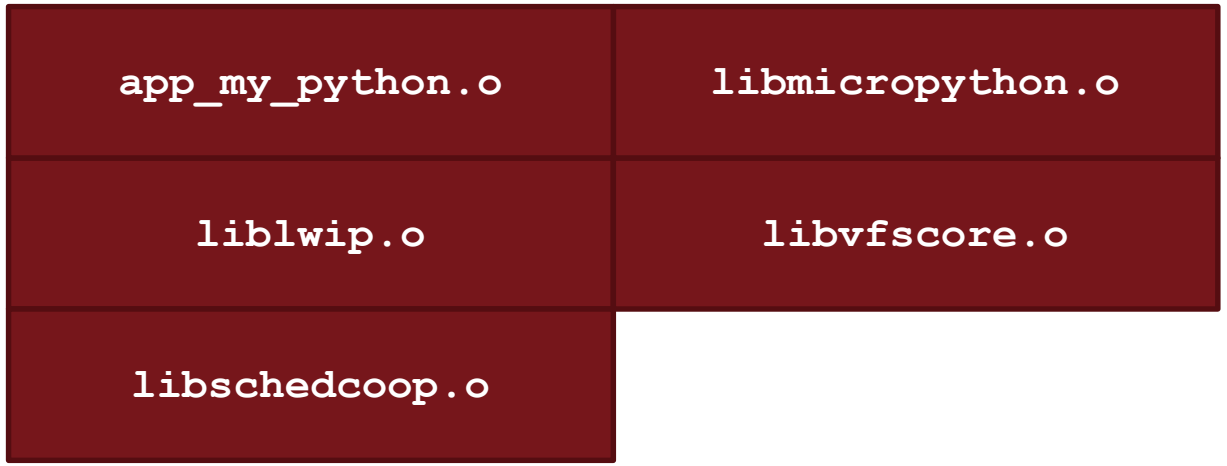

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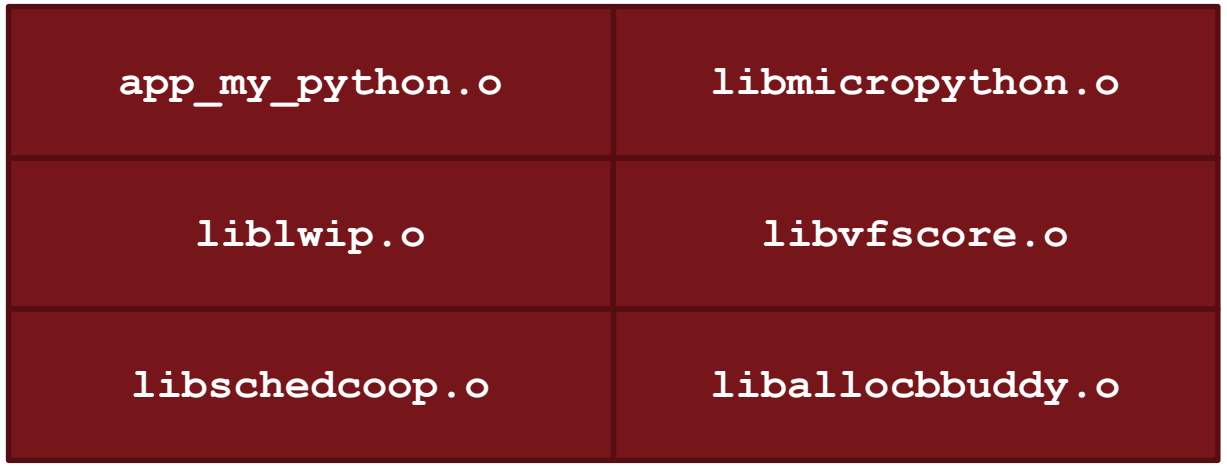

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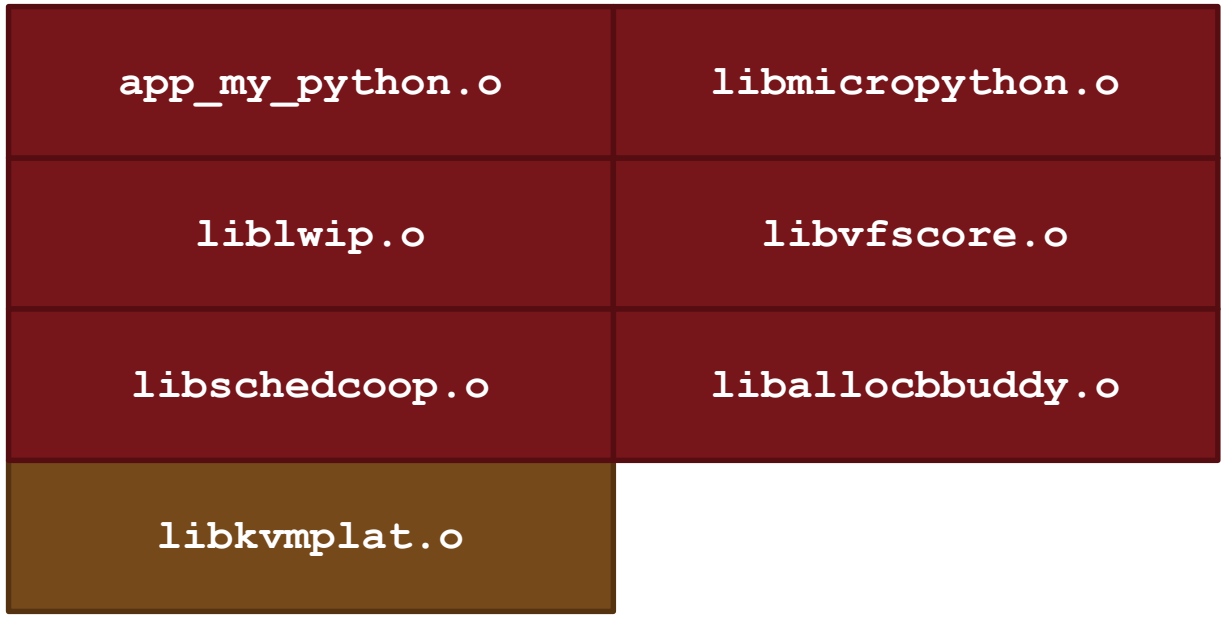

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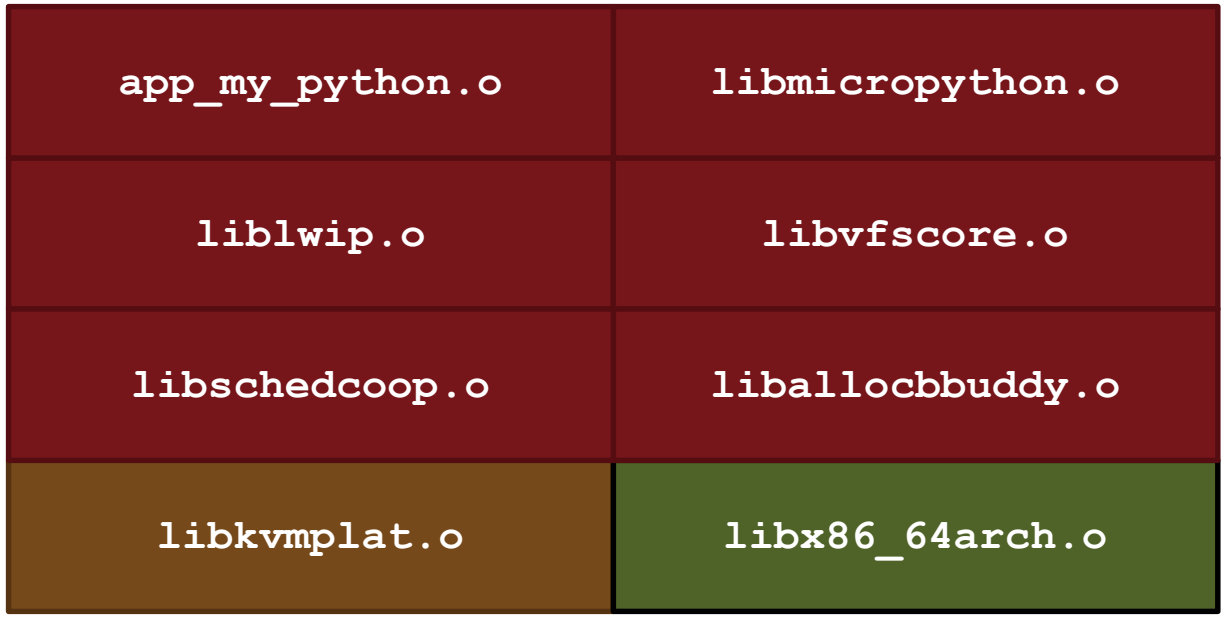

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app_my_python.o	libmicropython.o
liblwip.o	libvfscore.o
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libkvmplat.o	libx86_64arch.o

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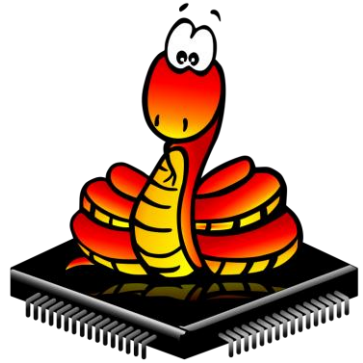

Unikernel

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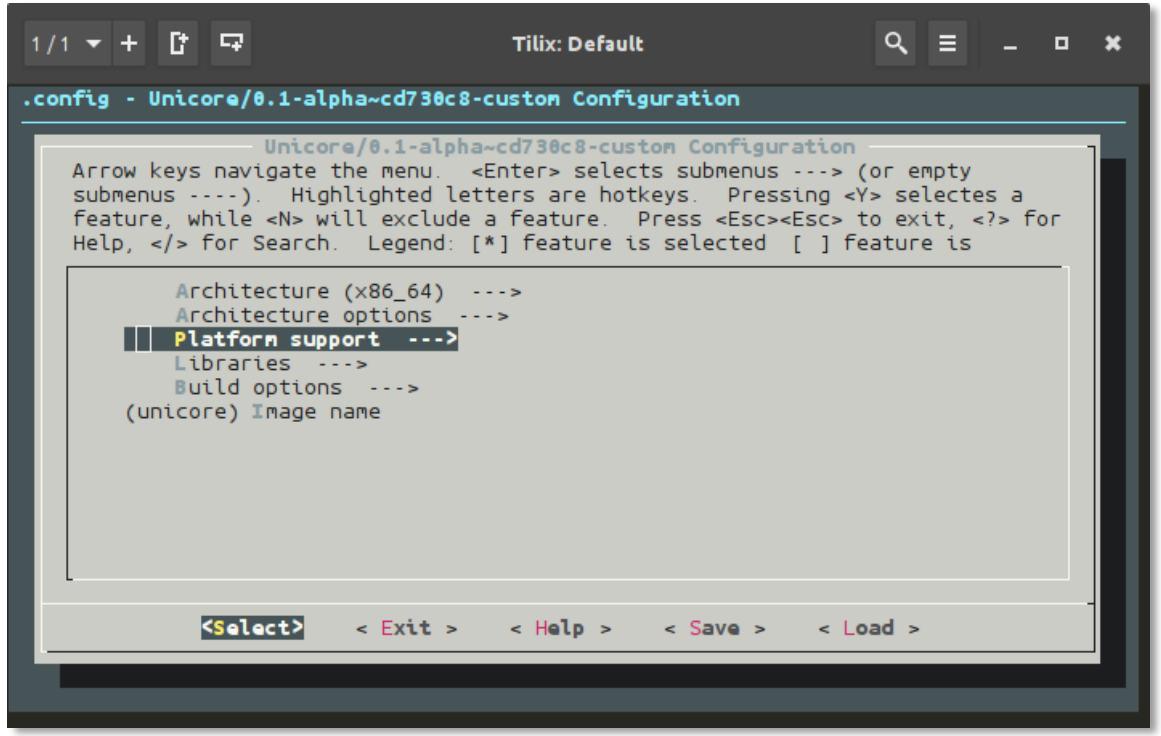

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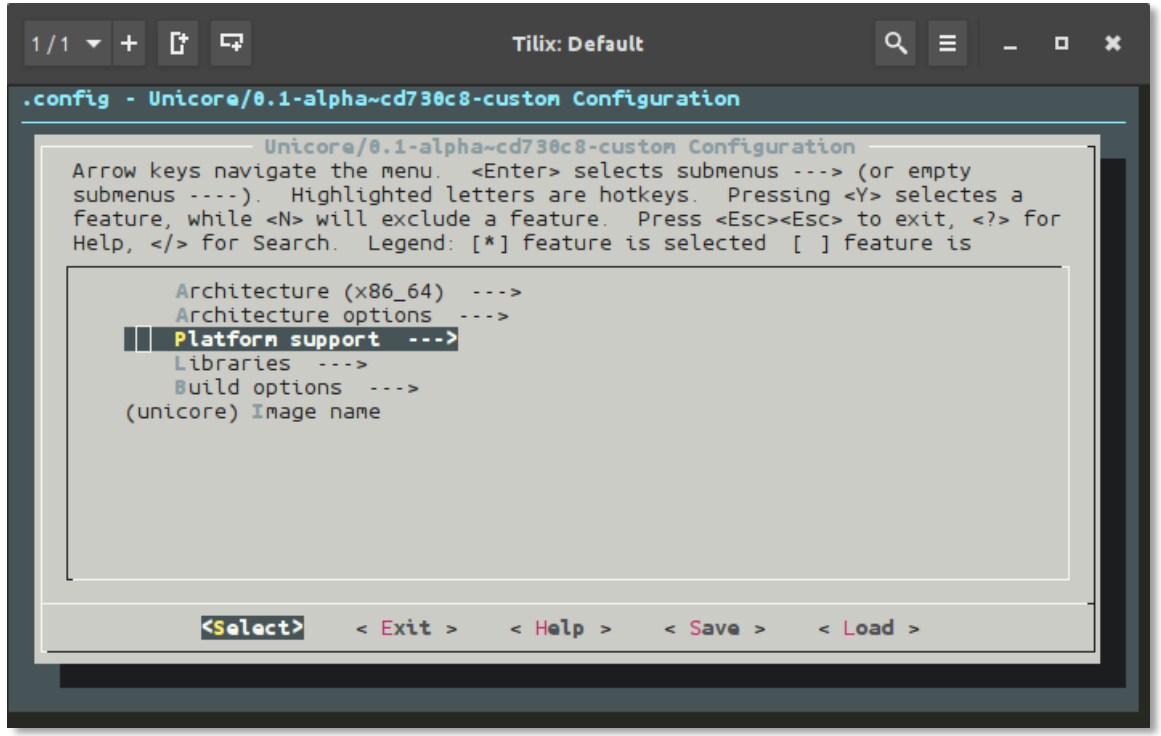

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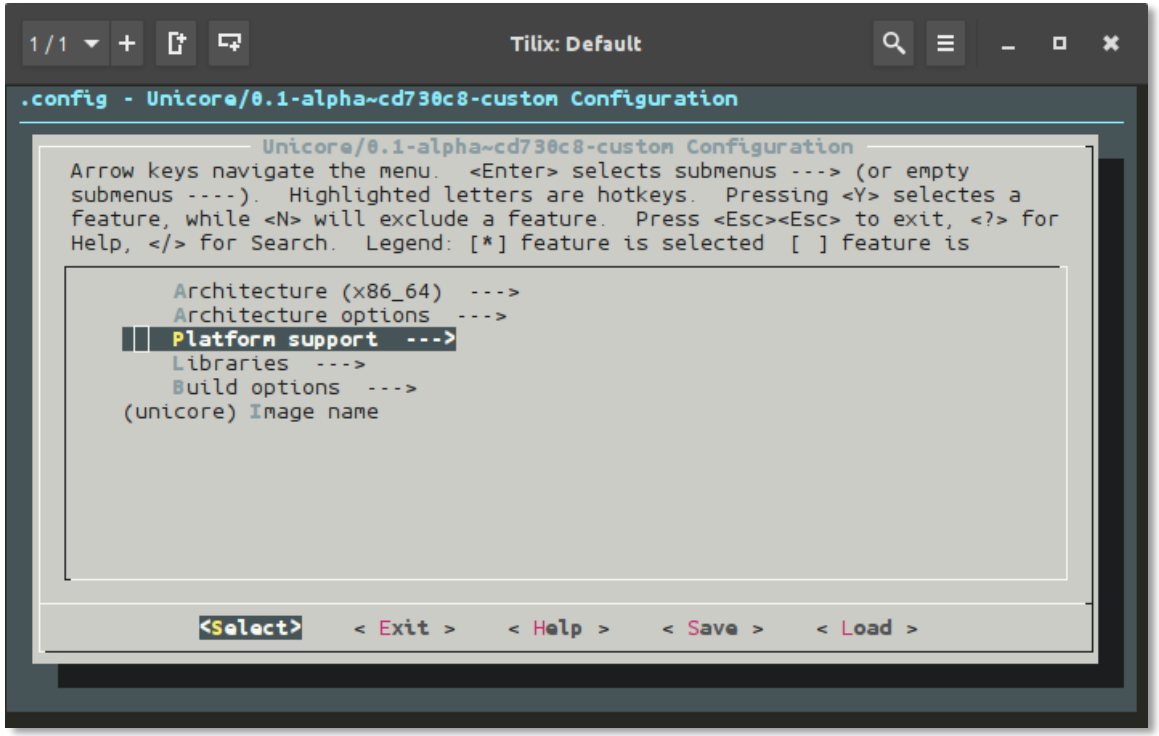

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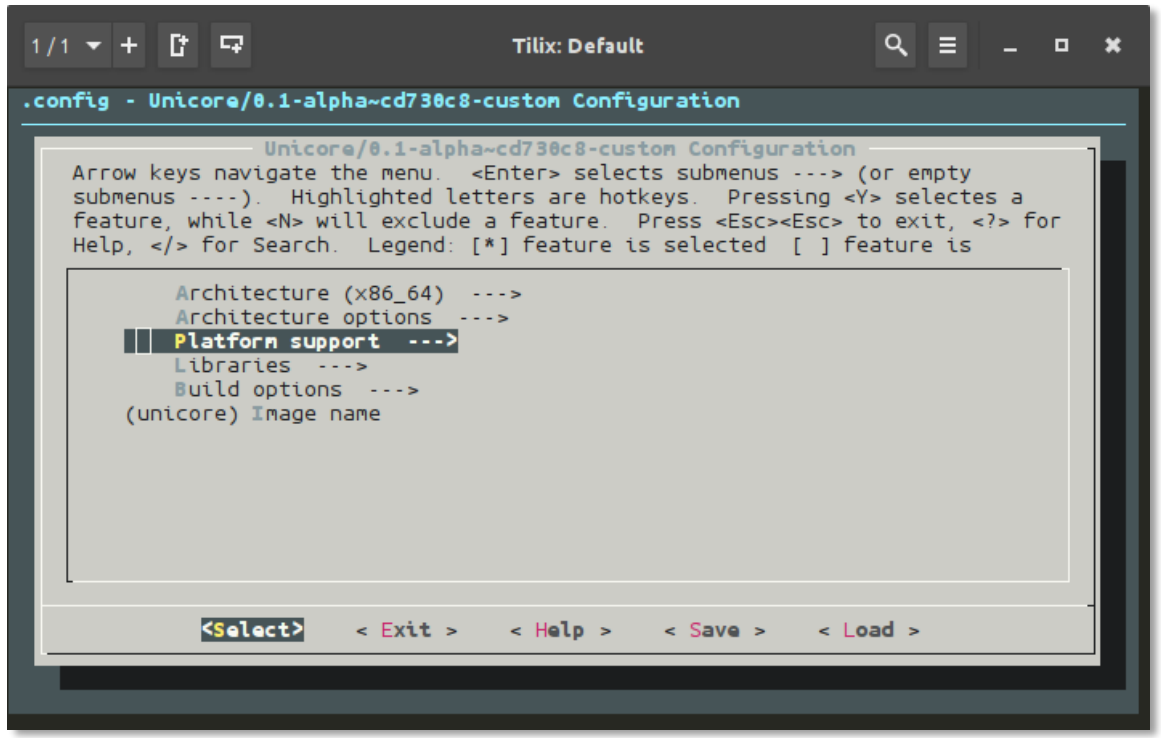
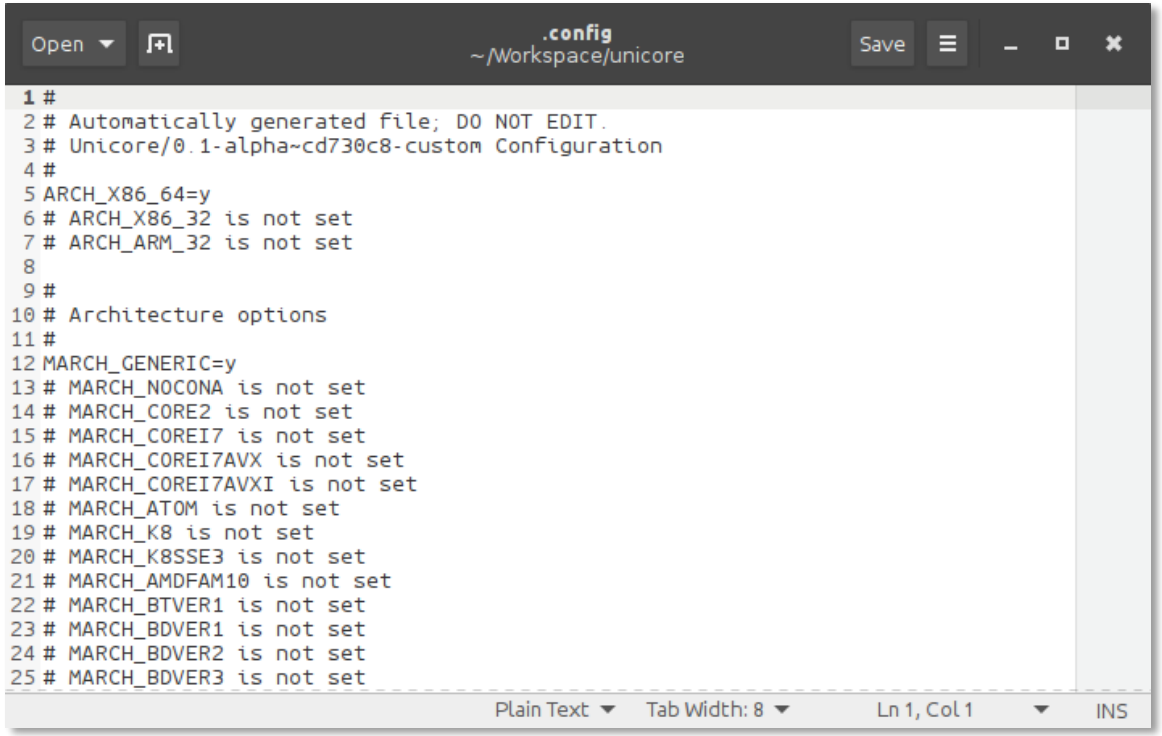
  - Choose options in the menu that you want for your application
  - Choose your target platform(s) (currently: Xen, KVM, Linux) and architectures
- Save config and `make`



.config



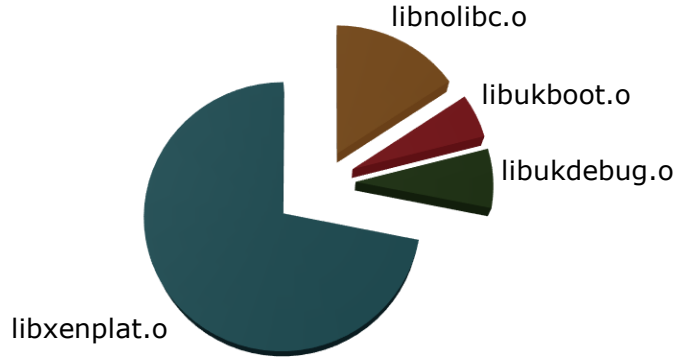
A Baseline Example…

- *Xen PV x86_64 binary*

A Baseline Example…

Xen PV x86_64 binary

unikraft_xen-x86_64.o



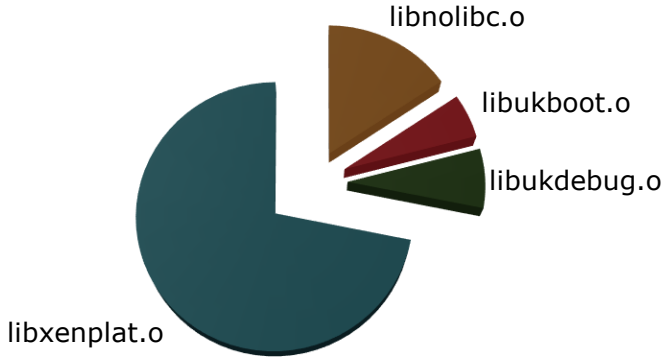
Final linking

unikraft_xen-x86_64
(32,7kB)

A Baseline Example…

Xen PV x86_64 binary

unikraft_xen-x86_64.o



Final linking

unikraft_xen-x86_64
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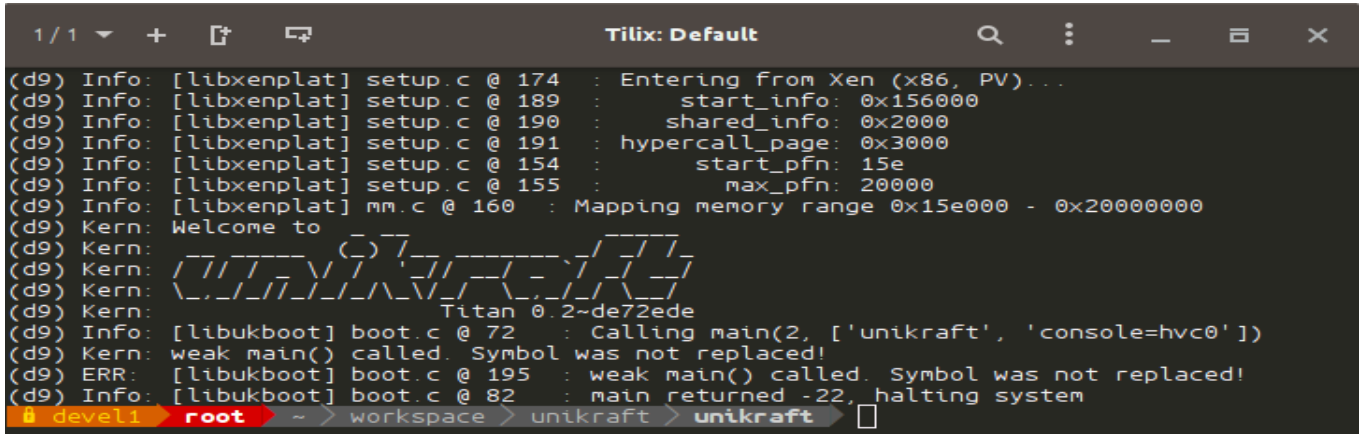
Boots and prints messages to debug console (with min. 208kB RAM)



A Baseline Example…

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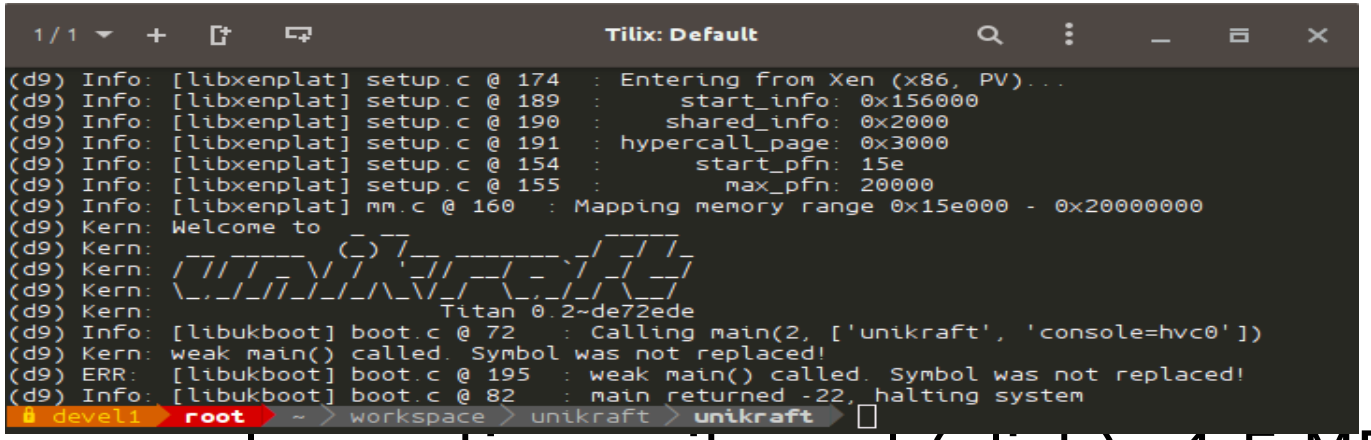

- More functional example: routing unikernel (click): 4.5 MB (8 MB RAM)

Building a Unikraft Hello World App

Repo Structure

- Clone the main Unikraft repo

```
git clone git://xenbits.xen.org/unikraft/unikraft.git
```

- Clone any external library repos

```
git clone git://xenbits.xen.org/unikraft/libs/newlib.git
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- Create repo for the actual application

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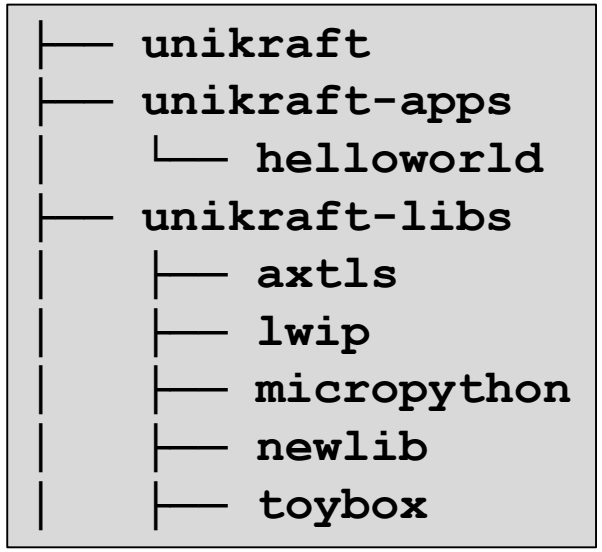

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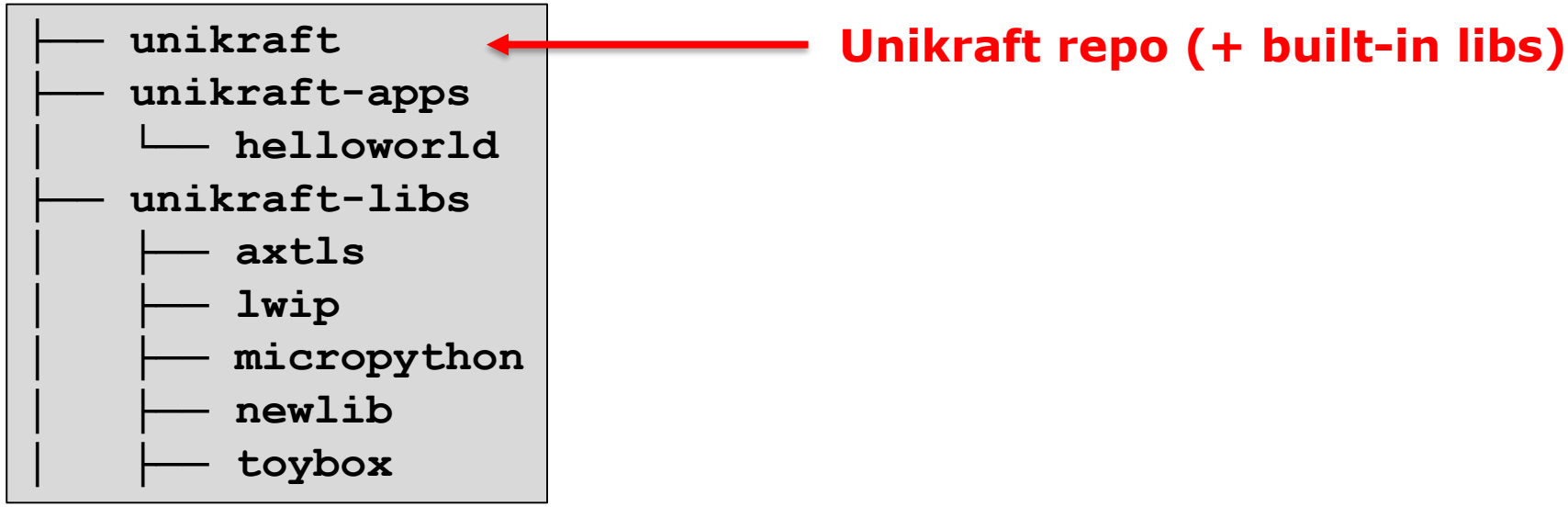

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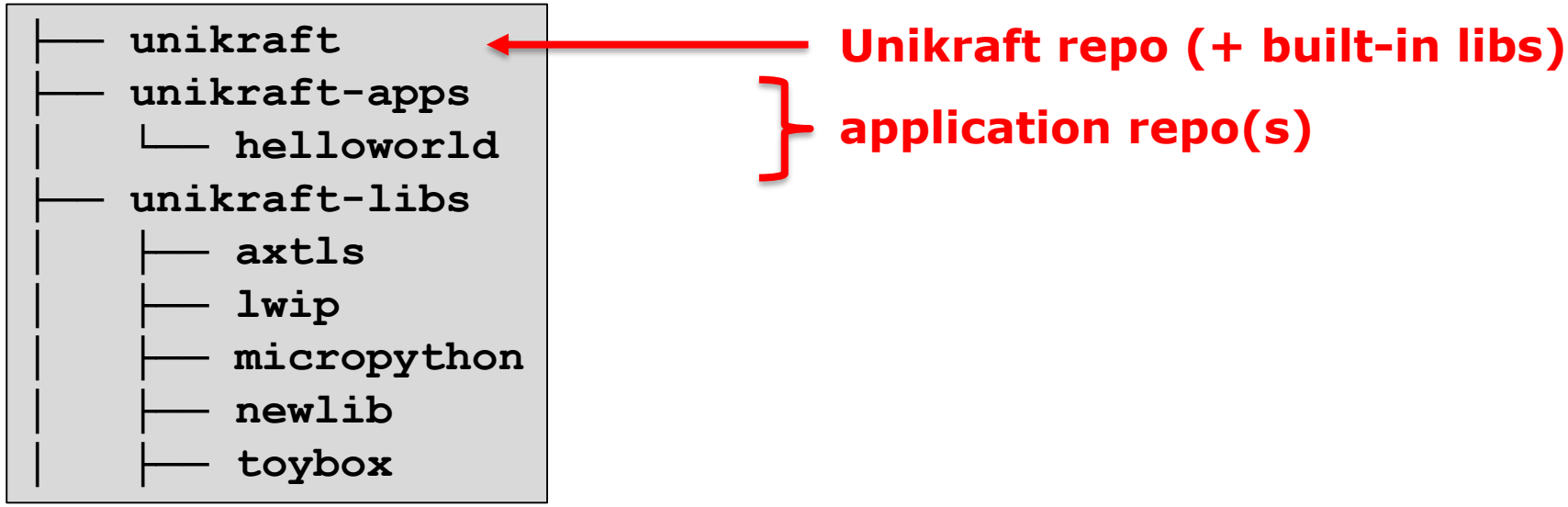

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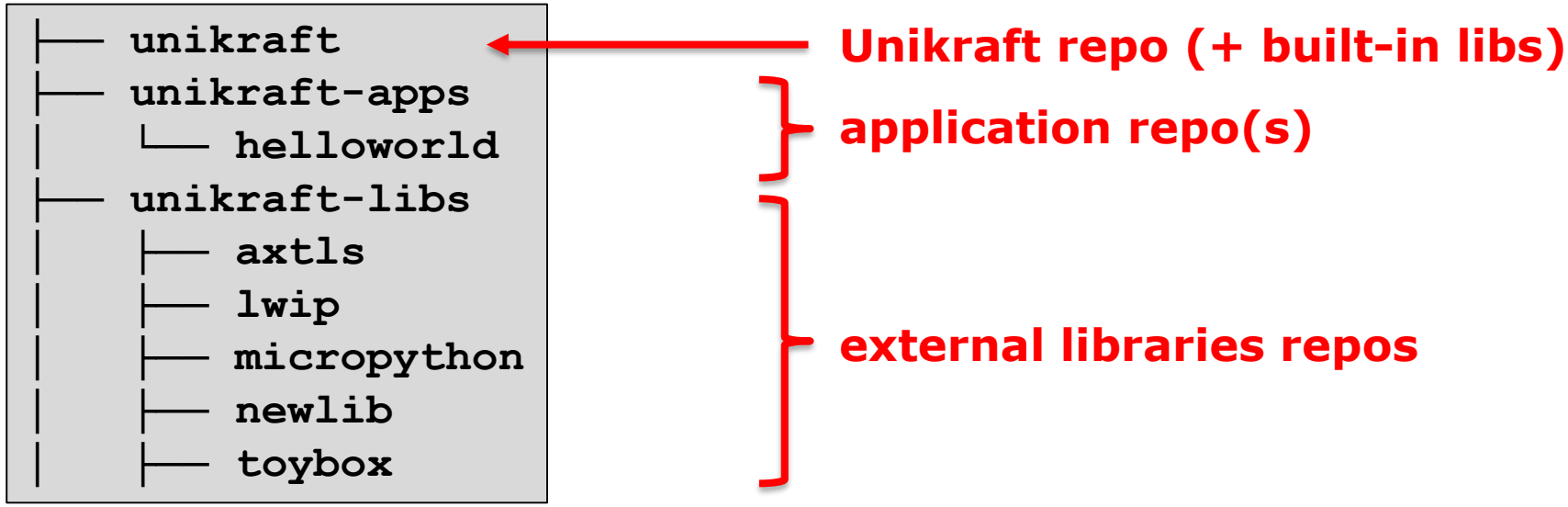

Hello World – Four Required Files (I)

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)
```

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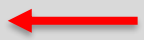

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← path to unikraft repo

← path to external libs

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LIBS := $(UK_LIBS)/newlib

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

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	@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
```

Hello World – Four Required Files (II)

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

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$(eval $(call addlib,apphelloworld))

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register app with unikraft build system

Hello World – Four Required Files (II)

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

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

Hello World – Four Required Files (IV)

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

```
#include <stdio.h>
/* Import user configuration: */
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int main(int argc, char *argv[])
{
        printf("Hello world!\n");
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        int i;
        printf("Arguments:s");
        for (i=0; i<argc; ++i)
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        printf("\n");
#endif
}
```

Unikernel entry point after boot

Hello World – Four Required Files (IV)

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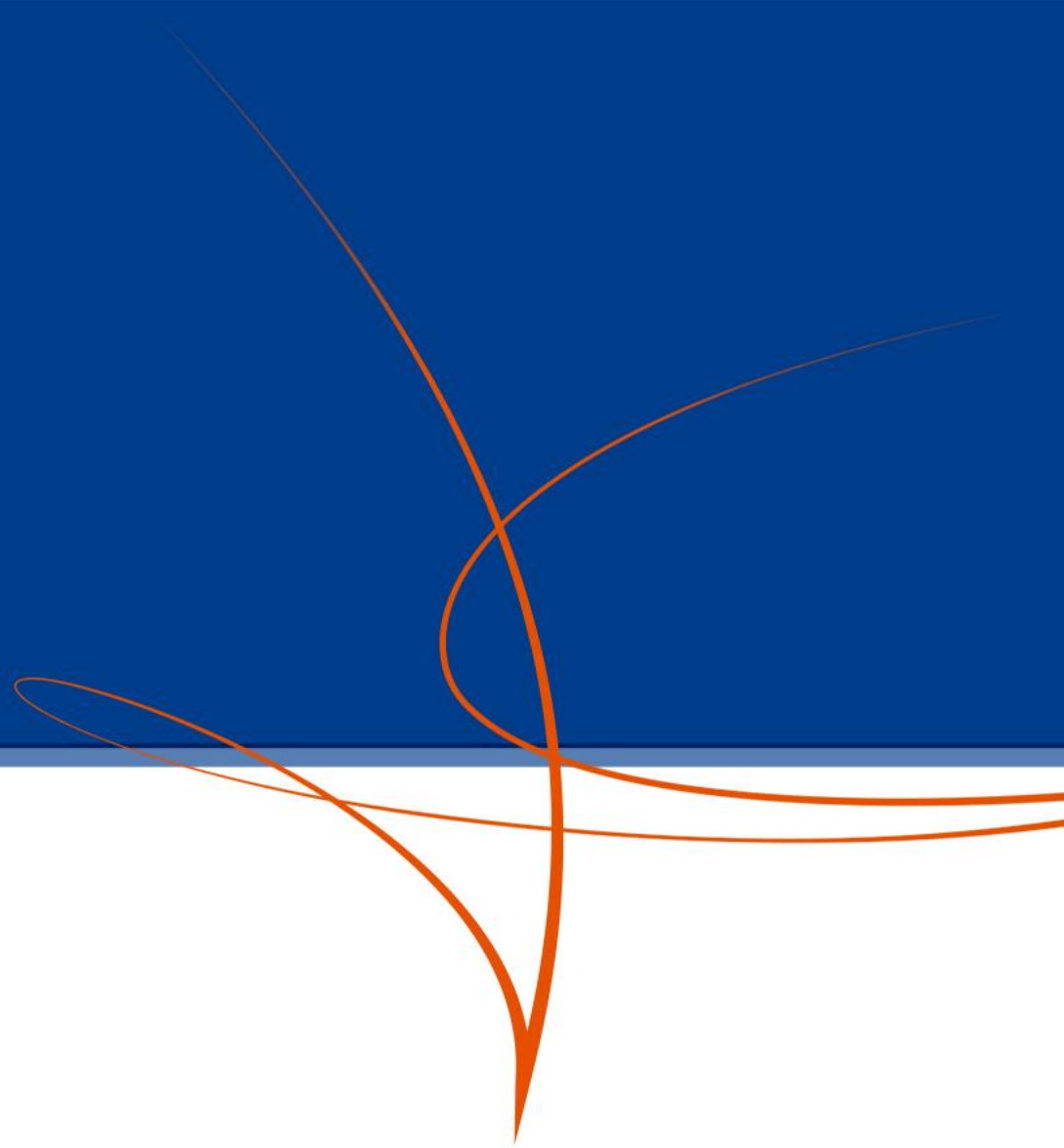

Unikernel entry point after boot

defined by Config.uk

Porting an External Library



How To Port an External Library

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- Write **`Makefile.uk`** and add the external library source files to it
  - The library's original Makefile can serve as a template
  - I'll show how to in a second

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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

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- Write **`Config.uk`** with library-specific options
  - Isn't strictly required
  - But at least a simple "library on/off" option for kbuild is a good idea
- Sometimes a bit of *glue* code is needed
  - E.g., in newlib to link POSIX thread creation to Unikraft's thread library
- In this early phase: implement core unikraft functionality that is required to support your library, for example:
  - File descriptors/sockets
  - Threading support

How To Port an External Library – Makefile.uk

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

How To Port an External Library – Makefile.uk

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← **Register library with unikraft build system**

How To Port an External Library – Makefile.uk

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##########################################################################
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$(eval $(call addlib_s,libaxtls,$(LIBAXTLS)))

##########################################################################
# Source Download
##########################################################################
# Nothing here: sources are small and included directly in the uk library repo
```

← **Register library with unikraft build system**

How To Port an External Library – Makefile.uk

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

##########################################################################
# Source Download
##########################################################################
$(eval $(call fetch,libaxtls,$(LIBAXTLS_URL)))
$(eval $(call patch,libaxtls,$(LIBAXTLS_PATCHDIR),newlib-$(LIBAXTLS_VERSION)))
```

← **Register library with unikraft build system**

← **Download and patch library code**

How To Port an External Library – Makefile.uk

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##############################################################################
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##############################################################################
# Library includes
##############################################################################
CINCLUDES-y +=    -I$(LIBAXTLS_BASE)/include \
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                  -I$(LIBAXTLS_BASE)/ssl
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← **Register library with unikraft build system**

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← **The library's original include directories**

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##########################################################################
# 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
```

← **Register library with unikraft build system**

← **Download and patch library code**

← **The library's original include directories**

← **The library's original source files**

How To Port an External Library: Outlook

- This can be a lot of busywork
- What about special cases?
  - Special build systems
  - Additional steps other than compiling/linking
  - Preprocessing/dependencies?

```
################################################################################
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How To Port an External Library: Outlook

- This can be a lot of busywork
- What about special cases?
  - Special build systems
  - Additional steps other than compiling/linking
  - Preprocessing/dependencies?
- Coming soon:
  Build passthrough mode
  - Currently under review
  - Vastly simplifies Makefile creation work
  - Especially for large or complicated libraries

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```

```
################################################################################
# build
################################################################################
UK_ARS-y += $(LIBAXTLS_ORIGIN)/$(LIBAXTLS_DIR)/build/libaxtls.o
LIBAXTILS/.prepared:
            $(call verbose_cmd,CONFIGURE,libaxtls: $@,\
            mkdir -p $(LIBAXTLS_ORIGIN)/$(LIBAXTLS_DIR) && \
            ./configure && make)
```

Unikraft 0.2 Titan

Current Status

Available Libraries

Core Libraries

- libfdt
  - Flat device tree parser
- libnolibc
  - A tiny libc replacement
- libukalloc
  - Memory allocator abstraction
- libukallocbbuddy
  - Binary buddy allocator
- libukargparse
  - Argument parser library
- libukboot
  - Unikraft bootstrapping
- libukdebug
  - Debug and kernel printing
  - Assertions, hexdump
- libuksched
  - Scheduler abstraction
- libukschedcoop
  - Cooperative scheduler
- libukbus
  - abstraction for device buses, e.g., PCI
- libuklock
  - mutexes and semaphores
- libukmpi
  - message-passing interface
- libuknetdev
  - network device support
- libukswrand
  - pseudo-RNG interface
- libuktimeconv
  - time calculation/conversion
- libvfscore
  - basic file descriptor management / mapping / handling

External Libraries

- libnewlib
  - libc originally aimed at embedded devices
- liblwip
  - lightweight TCP/IP stack

Architecture Libraries

- libarmmath
  - 64bit arithmetic on ARMv7
- libx86ctx
  - Extended register support for x86 ctx switch

Platform Libraries

- libxenplat
  - Xen (PV)
  - x86_64, ARMv7
- libkvmplat
  - QEMU/kvm
  - x86_64, ARM64, virtio-net support
- liblinuxu
  - Linux userspace
  - x86_64, ARMv7

Current work: coming soon (in the pipeline) or being ported

Core Libraries

- libukschedpreempt
  - Pre-emptive scheduler

External Libraries

- libclick
  - Click modular router (e.g., for NFV)
- libaxtls
  - TLS support aimed at embedded devices
- libstdc++
- libmicropython
  - Python implemented for microcontrollers

Architecture Libraries

- libarmctx
  - Extended register support for Arm ctx switch

Platform Libraries

- libxenplat
  - ARM64 support
  - netfront support
- liblinuxu
  - tap device based networking support

The road ahead

- First public alpha release (without much functionality) in December
- Released as a Xen incubator project
- Initially, mostly internal contributors from NEC Labs

- Currently external contributors from
  - Romania (netfront, scheduling; from University Politehnica Bucharest)
  - Israel (bare-metal support)
  - China (ARM64 support; from ARM)

- We welcome additional contributors!

- Resources:
  - Code: https://xenbits.xen.org/gitweb/?pf=unikraft (make sure you check out staging!)
  - On-line documentation: unikraft.org
  - IRC: #unikraft @ freenode
  - Mailing list: minios-devel@lists.xen.org

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