seL4 Developers Day

Beginner sel4 Development

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October 2015

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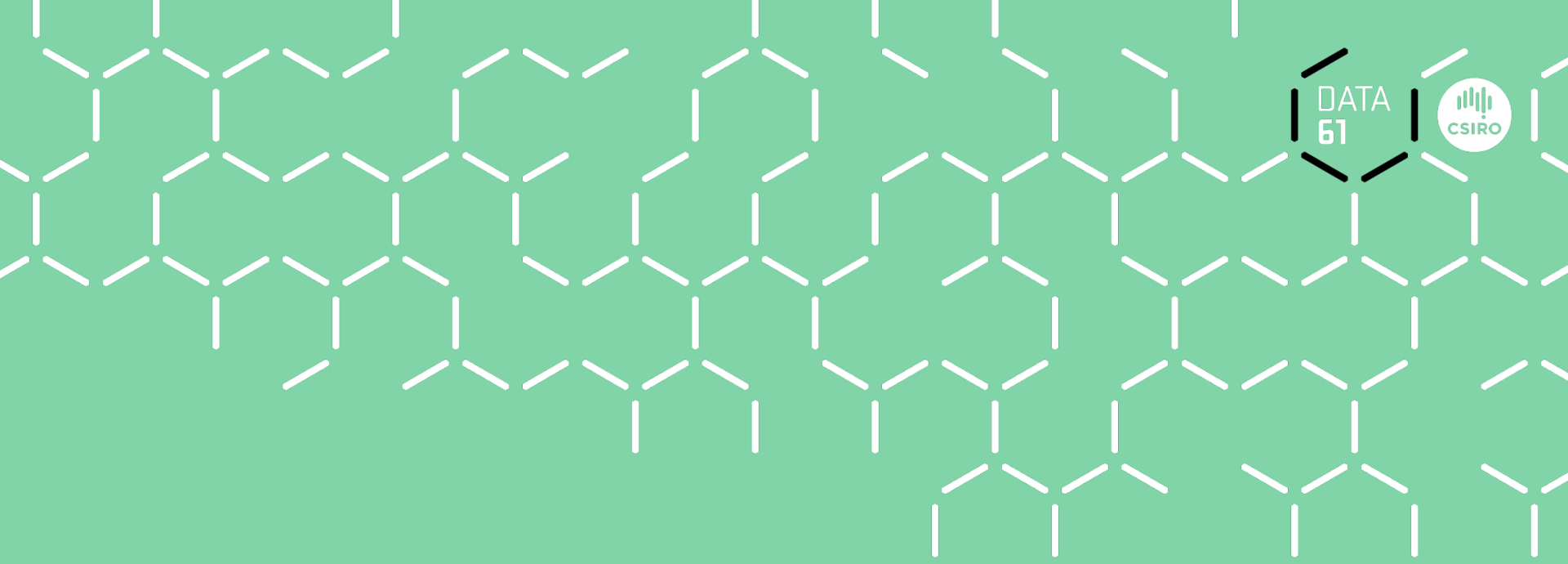
Agenda and Exercises

Agenda

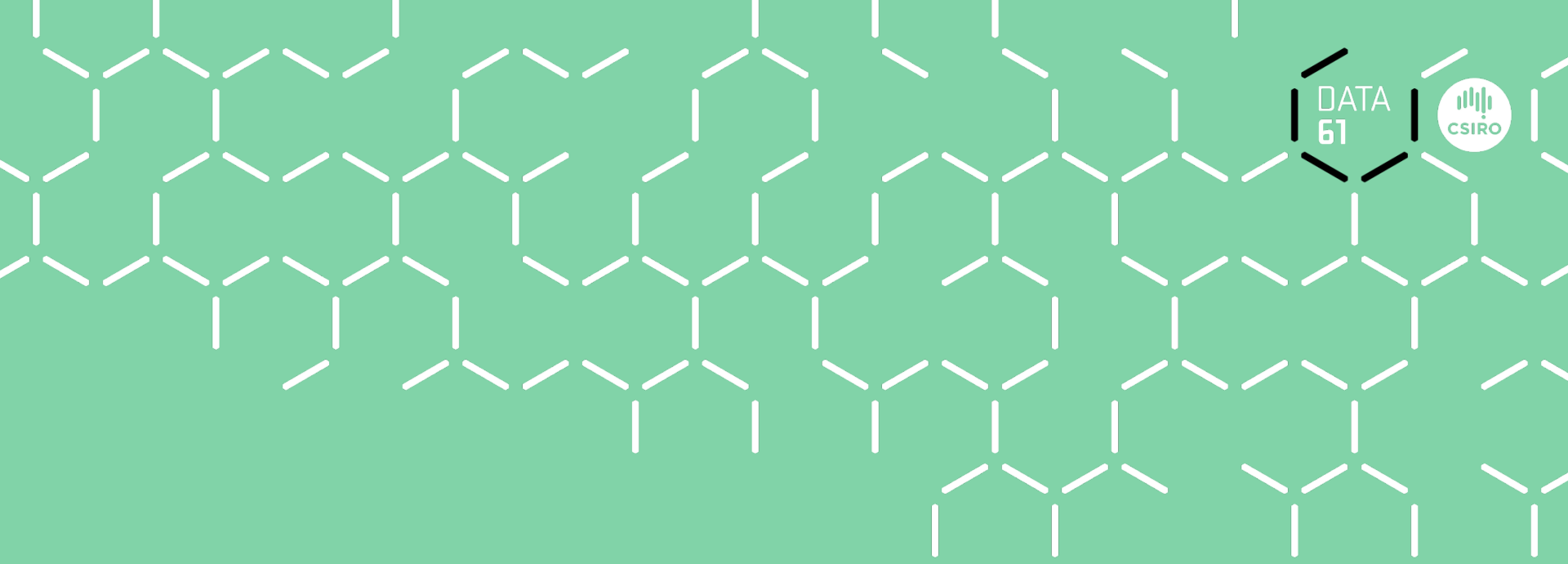
- seL4 overview
- Building and running
- Finding code and debugging
- System startup
  - Root task and bootinfo
- Untypeds and Allocators
- Threads and IPC
- CSpaces, VSpaces
- Processes
  - Vspace library
  - Sel4utils library

Exercises

- Hello-1:
  - simple hello world
- Hello-2:
  - start a new thread
- Hello-3:
  - IPC between threads
- Hello-4:
  - start a new process
  - IPC between processes
- Platform: ia32 (x86)
  - Bonus: make it work for ARM

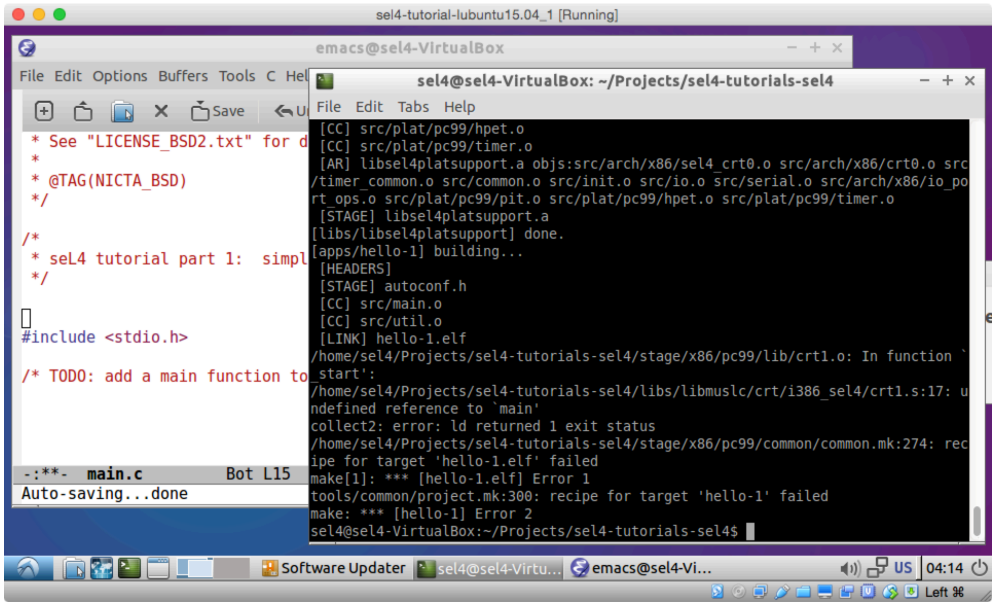


seL4 Overview



Building and running a basic seL4 program - Hello World

VirtualBox VM



- VirtualBox VM contents:
  - Linux: Lubuntu 15.04
    - login: sel4:sel4
  - Prerequisites installed
  - Tutorial code
    - In ~/Projects/
  - Tutorial slides & seL4 docs

Install and run

- Get Virtualbox (newest: 5.0.4)
- Install it
  - Also get and install the Extension Pack
- Get seL4 tutorial “appliance”
- Import it, Run it

Prerequisites

- Knowledge prereqs (what we expect)
  - Not required:
    - Previous seL4 experience
  - Required:
    - Be a quick learner!
    - C programming
    - Unix environment (editing files, running build tools, etc.)
- Technical prereqs (what you should have working already)
  - Linux (will work on BSD, MacOSX with some extra work, cygwin maybe?)
  - C compilers and build tools (gcc)
  - Python and packages
  - Haskell, cabal, and packages
  - Git and repo
  - qemu

Getting the code

- Using repo (and git)

```
mkdir sel4-tutorials
cd sel4-tutorials
repo init -u http://github.com/sel4-projects/sel4-tutorials-manifest
       -m sel4-tutorials.xml
repo sync
```

- ***Root directory***
  - The directory where you did `repo init`
- Exercises
  - In apps/hello-*
  - Contain program skeletons
    - Interesting bits replaced with “TODO” comments
    - Includes lots of hints
  - Goal is to add code for the TODOs to create complete programs

Working Directory

- What's there?
  - Config and build files: Kconfig, Kbuild, Makefile
  - kernel/ - from https://github.com/seL4/seL4
  - libs/ - from https://github.com/seL4/libs*
  - projects/
    - sel4-tutorials/ - from https://github.com/seL4-projects/sel4-tutorials
      - docs/, run-arm.sh, run-ia32.sh
  - apps/
    - hello-*/
      - src/*.c, Kbuild, Kconfig, Makefile
  - configs/
    - *_defconfig
  - tools/
  - - build system (.mk files) and build tools

Documentation

- seL4 manual
  - https://sel4.systems/Info/Docs/seL4-manual.pdf
- CAmkES manual
  - https://github.com/seL4/camkes-tool/blob/master/docs/index.md
- Code
  - seL4 API
    - https://github.com/seL4/seL4/tree/master/libsel4
    - kernel/libsel4
  - Libraries
    - https://github.com/seL4/lib*
    - libs/*
- These slides

Configuration

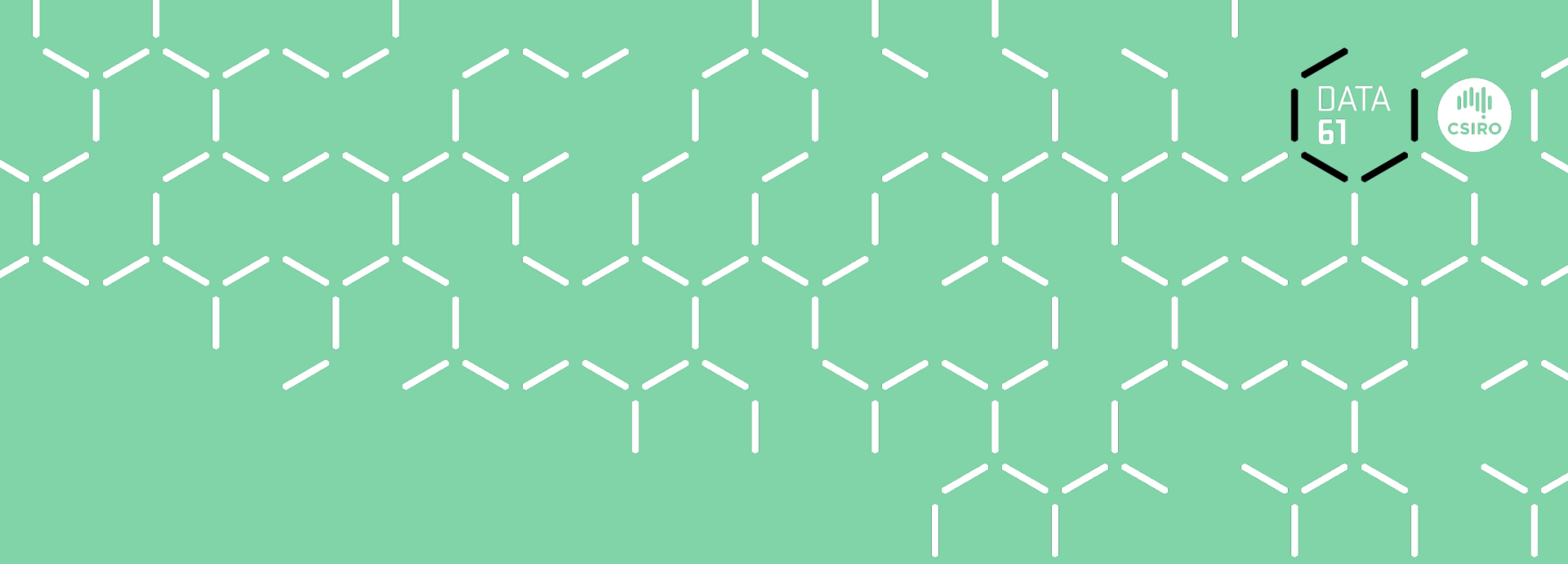
- Based on the Linux Kernel Build System: Kbuild
  - `Kconfig`: define config symbols and their attributes
  - `Kbuild`: defines dependencies between modules
  - `Makefile`: make rules (uses many .mk files from tools/common)
  - `.config`: stores each config symbol's selected value
- make menuconfig
  - Curses-based interface, set various config options
  - Writes a .config file
- configs/
  - Default configurations (copies of .config files for different configurations)
  - E.g.: ia32_hello-1_defconfig
- make …defconfig
  - E.g. make ia32_hello-1_defconfig
  - Copies configs/ia32_hello-1_defconfig to .config

Building and Running

- `make`
  - Builds required modules based on .config
  - Compilation occurs outside of source directory
    - `build/`: generated files and results of compilation
    - `stage/`: intermediate results, copies of header files, etc.
  - `images/`
    - Loadable system image files. Example:
      - Kernel: `kernel-ia32-pc99`
      - User: `hello-0-image-ia32-pc99`
- Run using qemu: system emulator
  - `qemu-system-i386 -nographic -m 512 -kernel <kernel> -initrd <user>`
- `make clean, make mrproper`
- Convenience scripts
  - `run-ia32.sh, run-arm.sh`

Hands-on: hello-1

- Goal: Get and build a simple seL4 system
- Get code (if you haven't already)
  - Hint: `mkdir …; cd …; repo init …; repo sync`
- `make ia32_hello-1_defconfig`
  - `make menuconfig`
- `make`
  - Compilation failure!
  - Find and fix TODO 1
- Run:
  - `qemu-system-i386 -nographic -m 512 -kernel images/kernel-ia32-pc99 -initrd images/hello-1-image-ia32-pc99`
  - Quit qemu with: C-A x
- Where's the solution?
  - `projects/sel4-tutorials/solutions/hello-1`



Finding code and Debugging

Looking up code

- Github
  - http://github.com/sel4
  - Lookup appropriate repo (sel4, lib*, etc.)
  - Search (github search isn't great)
- Cscope
  - Search C code
  - Run directly: `cscope -R`
    - <Tab> between fields
    - Choose file to view
    - Ctrl-D to exit
- Run cscope in browser
  - Vim:
    - http://cscope.sourceforge.net/cscope_vim_tutorial.html
    - :cscope f g <function>, C-t
    - C-\ g, C-<space> g
  - Emacs: xcscope.el
    - https://github.com/dkogan/xcscope.el
    - C-s s s

Hands-on: looking up code

- Find these functions:
  - simple_default_init_bootinfo()
  - allocman_make_vka()
  - vka_alloc_tcb()
  - seL4_TCB_Configure()
- Use:
  - Github
  - Cscope
- What about libsel4?
  - It is generated at build time!
  - libsel4/include/interfaces/sel4.xml
  - build/…/libsel4/include/interfaces/sel4_client.h

Build detail

- Build detail
  - Increase detail with V=
  - Example:
    - make V=0
    - make V=1
    - make V=2
    - make V=3
  - Useful to find out why a build step fails
    - What is being run
    - What are the arguments (e.g., include paths, or library paths)

Debugging

- VM fault

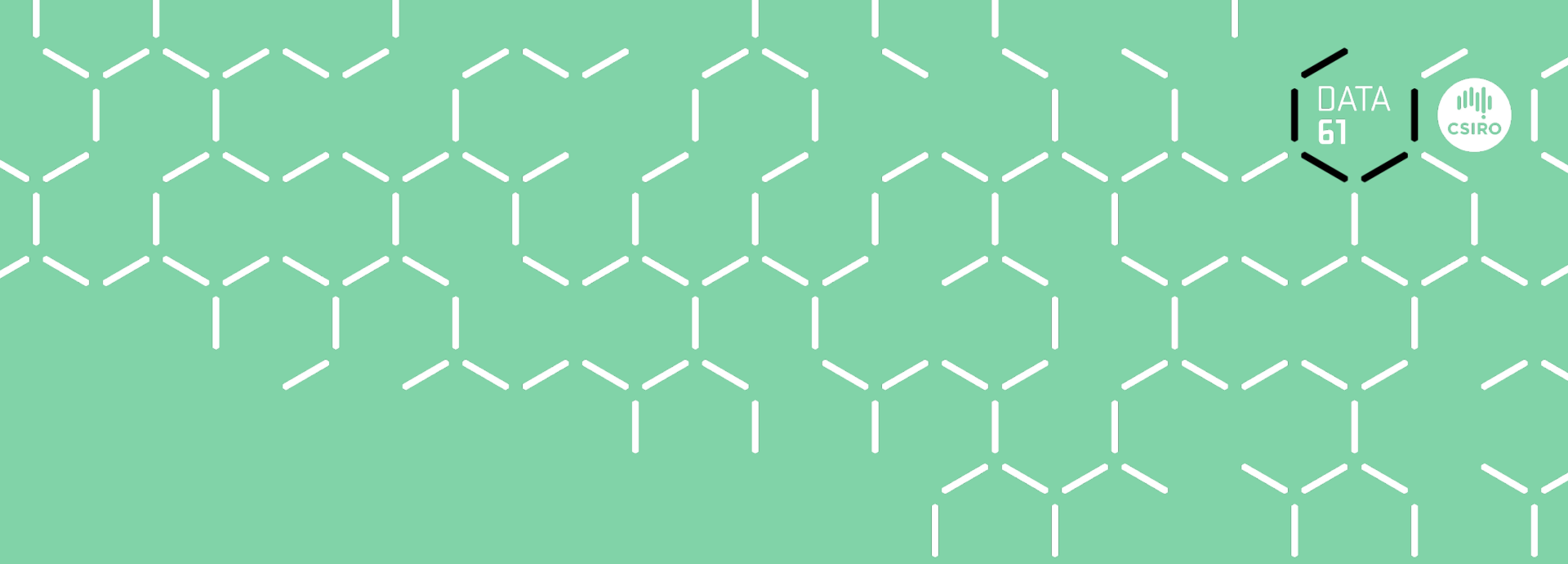
```
Caught cap fault in send phase at address 0x0
while trying to handle:
vm fault on data at address 0x0 with status 0x6
in thread 0xffaf9900 "rootserver" at address 0x80480db
```

- use objdump
  - `objdump -dS build/x86/pc99/hello-1/hello-1.bin | less`
  - look for instruction at address: 80480db

```
printf("hello world\n");
 80480d1:       68 40 c8 04 08    push   $0x804c840
 80480d6:       e8 c8 02 00 00    call   80483a3 <puts>
    *(char*)0x0 = 'a';
 80480db:       c6 05 00 00 00 00 00  movb $0x0,0x0
 80480e2:       0f 0b                 ud2
```

Hands-on: hello-1 with errors

- Goal: Introduce an error into hello-1
- Add a line in main():
  - `*(char*)0x0 = 'X';`
- Build and run it -> VM fault
- Find it
  - Use objdump to find it
- Fix it ☺



seL4 System Startup

- Root task and Bootinfo
- libsimple

seL4 system startup

- Image
  - Kernel image
  - User-space image
    - Root task & Cpio file containing elf files
- Boot loader
  - Loads kernel into memory
  - Loads user-space image into memory
  - Starts kernel running
- Kernel startup
  - Kernel creates object (untypeds, frames for device memory)
  - Kernel creates root task objects
  - Loads and runs root task
- Root Task
  - Responsible for setting up the rest of the system

BootInfo: Start-up Information

- Kernel creates:
  - root task CSpace, root task VSpace, Root task TCB
  - frames for device memory
  - untyped caps for RAM memory
- All startup objects are available to root task
  - kernel places caps to these objects in root task CSpace
  - kernel needs to tell root task
    - what caps it has
    - what the objects are
- Bootinfo
  - info about all the initial objects and the caps to them

Initial caps

- Some Initial Caps
  - seL4_CapNull = 0, /* null cap */
  - seL4_CapInitThreadTCB = 1, /* initial thread's TCB cap */
  - seL4_CapInitThreadCNode = 2, /* root CNode cap */
  - seL4_CapInitThreadVSpace = 3, /* VSpace cap */
  - seL4_CapBootInfoFrame = 9, /* bootinfo frame cap */
  - seL4_CapInitThreadIPCBuffer = 10, /* initial thread's IPC buffer frame cap */
- Some bootinfo fields
- seL4_SlotRegion untyped; /* untyped-object caps (untyped caps) */
- seL4_Word untypedPaddrList[…]; /* physical address of each untyped cap */
- seL4_Uint8 untypedSizeBitsList[…]; /* size (2^n) bytes of each untyped cap */
- seL4_Word numDeviceRegions; /* number of device regions */
- seL4_DeviceRegion deviceRegions[…]; /* device regions */

Intro to seL4 Libraries

- Goal:
  - Make seL4 programming less “user-unfriendly”
  - Do a bunch of the hard things for you
- Interfaces vs Implementations
  - *Interface*
    - key datastructs
    - function definitions
    - generic code to facilitate use of interface
  - *Implementation*
    - adds implementation-specific parts to datastructs
    - implements interface functions

Key interfaces and libraries

- Key Interfaces
  - **simple**: access to initial caps
  - **vka**: virtual kernel allocator
  - **vspace**: VSpace management
- Key Libraries
  - **libseL4**: seL4 kernel API
  - **allocman** (vka): allocator manager
  - **sel4utils** (vspace, io operations): higher level concepts
- Other Libraries
  - **muslc**: C library
  - **platsupport**, **sel4platsupport**: device access
  - **utils**, **debug**, **benchmark**: other useful functionality

Dependencies

- simple:
  - libsel4
- vka:
  - libsel4, utils
- allocman:
  - vka, libsel4, sel4utils, vspace, utils
- vspace:
  - vka, libsel4, utils
- sel4utils:
  - simple, vka, vspace, platsupport, sel4utils, utils, elf, cpio
- platsupport:
  - utils
- sel4platsupport:
  - simple, vka, vspace, platsupport, sel4utils, utils

Library: Simple

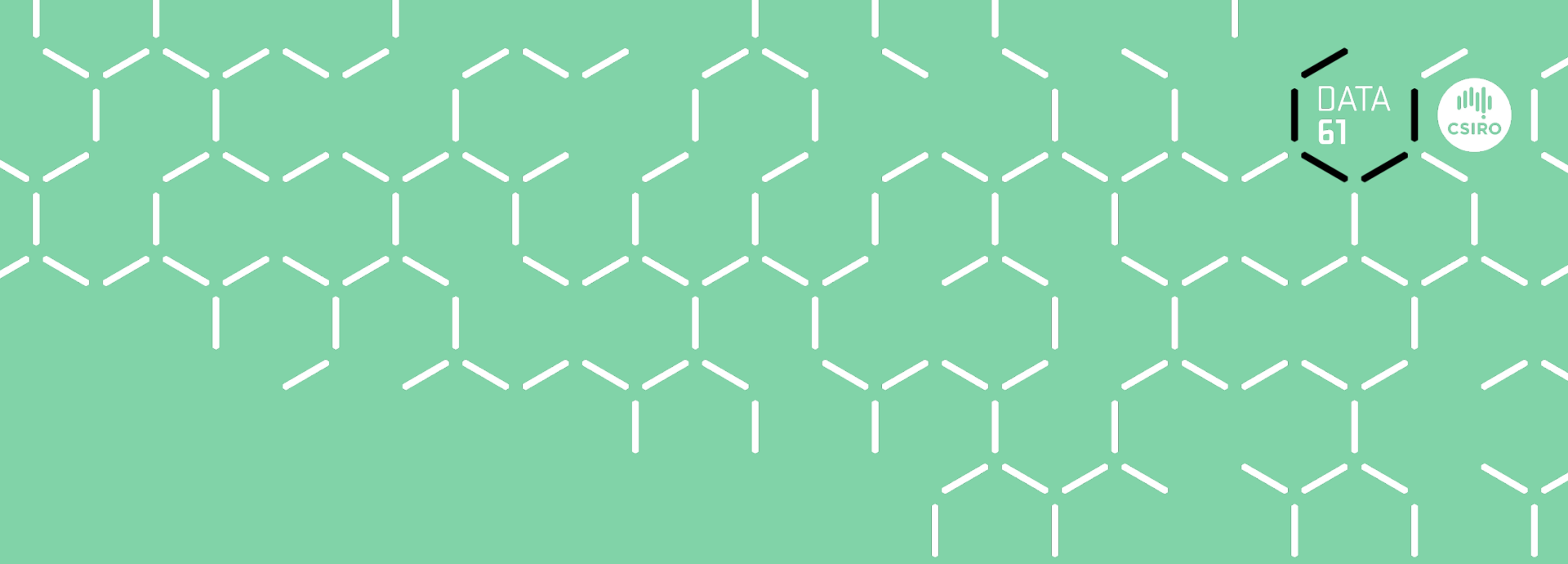
- Easy way to access initial caps
  - Includes: untypeds, device memory, initial CSpace, initial VSpace
- Abstracts over spec of initial caps
  - root task: uses bootinfo
  - user-level task: can use bootinfo or some other format
- Key concepts
  - location of resources, caps to resources
  - acquiring resource without cap
- Interfaces defined
  - `Simple`
- Implemented by
  - simple-default, simple-stable

Simple: API

- Files
  - libsel4simple, #include <simple/simple.h>
    - `libs/libsel4simple/include/simple/`
  - libse4simple-default, #include <simple-default/simple-default.h>
    - `libs/libsel4simple-default/include/simple-default/`
- Datastructs
  - `simple_t`
- Functions
  - `simple_default_init_bootinfo`
  - `simple_print`
  - `simple_get_*`: pd, tcb, cnode, node_size
  - `simple_get_nth_untyped`
  - `simple_get_frame_*`: cap, info, vaddr

Hands-on: hello-2 (part 1)

- Goal: Initialise a simple and look at bootinfo
- `make ia32_hello-2_defconfig`
- Edit `apps/hello-2/src/main.c`
- Fix TODOs
  - TODO 1: get bootinfo
  - TODO 2: init simple
  - TODO 3: print out bootinfo
- `make`
- run
  - Print out showing what's in bootinfo
  - See if it makes any sense…



seL4 API and libraries
- Starting a new thread

Untyped and retyping

- Untyped Memory Object
  - region of (RAM) memory
  - must be retyped to another object to use it
    - results in a nested tree from a root untyped to other objects:
- Retyping
  - kernel uses part of untyped's memory region to store a new kernel object
    - can only create an object if you have a cap to a big enough untyped object
  - retype provides user with cap to the new object
- seL4_Untyped_Retype
  - `seL4_Untyped_Retype(seL4_Untyped` **`service`**`, int` **`type`**`, int` **`size_bits`**`, seL4_CNode root, int node_index, int node_depth, int node_offset, int` **`num_objects`**`)`

Allocators

- Allocating objects requires
  - Pool of untypeds to retype into the new objects
  - CSpace slots to put the cap to the new object into
  - Memory for bookkeeping structures
  - Bookkeeping:
    - What untypeds are available, what sizes are they, where are their caps?
    - How much of the untyped has been used?
    - What CSpace slots are available?
    - Which objects have been created, and which untypeds where used and in which Cspace slots are their caps stored?
- Allocator
  - Manages the untyped pools, the CSpace slots
  - Takes care of bookkeeping
  - Maybe even allows objects to be freed!

Library: VKA

- VKA: Virtual Kernel Allocator
- Interface for allocating kernel objects
  - abstracts away
    - creation of objects through retyping untypeds
    - managing CSpace and book keeping
- Key concepts
  - ***vka***: allocator
  - ***Object****s*: represent kernel objects
  - ***CSpace slots***: slot in local cspace where caps can be found
  - ***cspace path***: fully qualified capability address
  - ***utspace***: pool of untyped memory, used to create objects
- Interfaces defined: `vka`
- Implemented by: allocman

VKA: API

- Files
  - libsel4vka, #include <vka/…> : vka.h, object.h
  - `libs/libsel4vka/include/vka/`
- Datastructs
  - `vka_t`: a VKA interface instance
  - `vka_object_t`: VKA representation of a kernel object
    - Contains: cptr, ut cookie, object type, size
- Functions
  - `vka_alloc_*`: pd, cnode, tcb, endpoint. returns vka_object_t
  - `vka_cspace_alloc`: allocate an empty slot in the CSpace
  - `vka_cspace_free`: doesn't delete object!
  - `vka_utspace_alloc`: given empty slot create an object and put the cap to it in the slot. returns ut cookie
  - `vka_utspace_free`: given ut cookie, free object

Library: Allocman

- Allocator Manager
  - implements vka interface
  - framework combining independent CSpace and utspace allocators
  - solves difficult recursion problems in allocation: Black Magic!
- Key concepts
  - resources: allocator needs underlying resources (e.g. untypeds)
  - memory pool: needs an initial pool for internal allocations
- Interfaces implemented
  - `vka`
  - `allocman`: to add resources after initialisation

Allocman: API

- Files:
  - libsel4allocman, #include <allocman/…>: allocman.h, vka.h, bootstrap.h
  - `libs/libsel4allocman/include/allocman`
- Datastructs
  - `allocman_t`
- Functions
  - Bootstrap: create new allocman
    - `bootstrap_use_current_simple`
      - use current CSpace and simple
    - `bootstrap_new_2level_simple`
      - create and switch to a new CSpace
  - `allocman_make_vka`
    - get VKA interface to allocman

Hands-on: hello-2 (part 2)

- Goal: Create an allocator
- Fix TODOs:
  - TODO 4: create an allocator
  - TODO 5: create a vka
- Build and run
  - No new visible output.

seL4 API: Overview

- Key Concepts
  - Kernel Object
    - in-kernel datastruct, only directly accessible by kernel
  - Capability
    - reference to a kernel object
    - allows holder to invoke functions on the objects
      - i.e. ask kernel to do something with the object
      - holder: thread invoking the cap
- Low-level interface for key activities
  - create kernel objects (retype untyped)
  - create and manage caps in a CSpace
  - create and manage VSpace
  - create and manage threads
  - communicate between threads (IPC)

seL4 API: key files

- Files:
  - Libsel4, #include <sel4/sel4.h>
    - Includes: types.h, bootinfo.h, arch/syscalls.h, interfaces/sel4_client.h
  - `libs/libsel4/`
    - `include/sel4`
    - `arch_include/x86/sel4/`
  - `build/x86/pc99/libsel4/include/interfaces/`
- Generated from
  - `libs/libsel4/include/interfaces/sel4.xml`
- Note:
  - libsel4 actually lives in the kernel
  - `libs/libsel4` is a symlink to `kernel/libsel4`

seL4 Capability

- Kernel-maintained
  - user-level cannot directly access or manipulate a capability
  - capability is stored in CSpace
  - pass CSpace address of cap in system calls
- Datatypes
  - `seL4_CPtr`
    - index into current thread's CSpace root (CNode)
    - this can be tricky….

seL4 API: TCB (Thread Control Block)

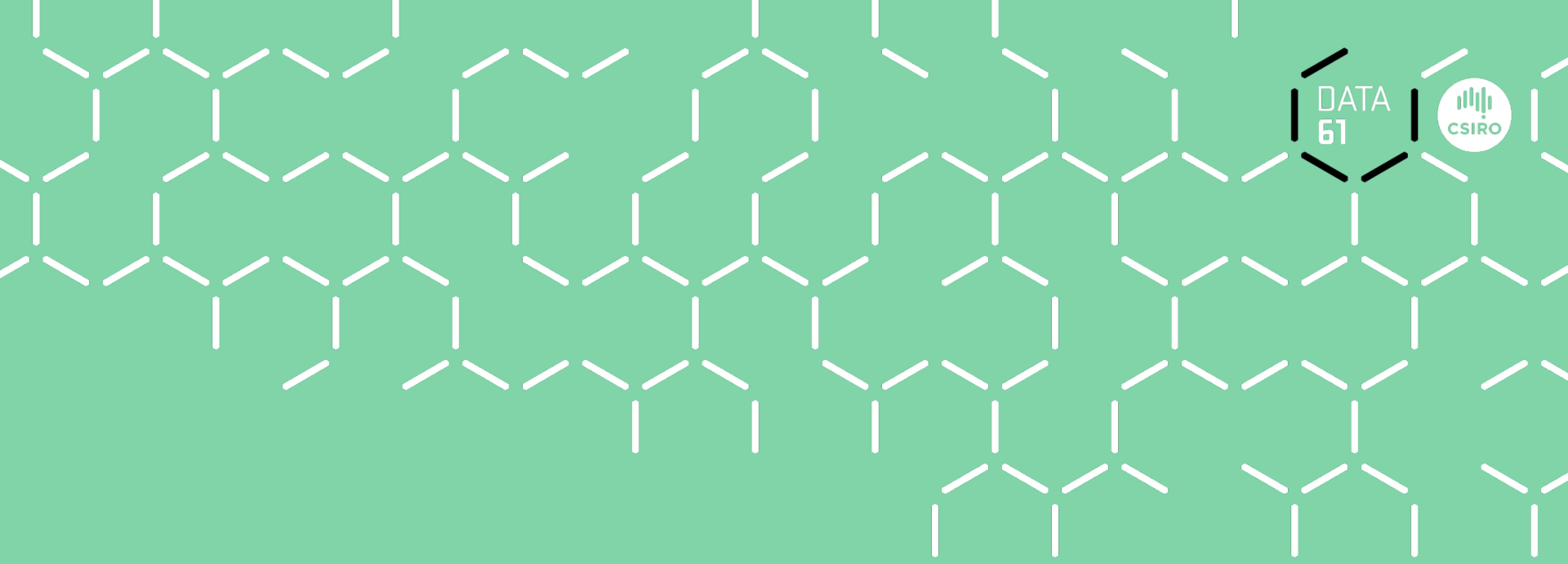
- TCB Object:
  - kernel's representation of a thread.
  - contains:
    - Caps: CSpace, VSpace, IPC Buffer Frame
    - Other: IP (instruction pointer), SP (stack pointer), IPC Buffer, Priority
- IPC Buffer
  - buffer used to pass data during IPC
    - 512 byte object, must be wholly in one frame
    - also used for all syscalls
  - passed to TCB as:
    - index to Frame cap in TCB's CSpace
    - address where it is mapped in TCB's VSpace

TCB: API

- Configure
  - `seL4_TCB_Configure`: set CSpace, VSpace, IPC buffer, priority
- Write Registers
  - `seL4_TCB_ReadRegisters`: retrieve current registers (ip, sp, etc.)
  - `seL4_TCB_WriteRegisters`: set the current registers (ip, sp, etc.)
  - Set of registers is arch-specific
  - Defined in arch-specific struct
- Resume
  - `seL4_TCB_Resume`: start thread running at it's current instruction pointer
- Suspend
  - `seL4_TCB_Suspend`: stop thread running

Hands-on: hello-2 (part 3)

- Goal: Create a thread
- TODO 6: get CSpace root Cnode
- TODO 7: get our VSpace root page directory
- TODO 8: create a new TCB
- TODO 9: initialise the new TCB
- TODO 10: give the new thread a name
- TODO 11: set instruction pointer
- TODO 12: set stack pointer
- TODO 13: actually write the TCB registers
- TODO 14: start the new thread running
- TODO 15: print something in new thread
- Wow – that's a lot of effort for a thread!



More seL4 API and libraries
- IPC

IPC in seL4 – Endpoints

- Endpoint Object
  - Formerly: synchronous endpoint object
  - enables synchronous (blocking) communication
  - communicating threads must hold caps to same endpoint
- Endpoint Caps
  - ***master cap*** (typically receiver): received when creating the endpoint object
  - ***derived caps*** (senders): minted from master (or other) caps
  - ***badge***: identifies specific sender cap
  - ***reply cap***: temporary cap allows receiver to reply to sender for two-way communication
- Message Registers
  - Data to be sent is stored in message registers (MR)
  - Stored in machine registers or in IPC buffer

IPC – Endpoints: API

- Sending and Receiving
  - `seL4_Send`: send message registers. Blocks if receiver not Waiting.
  - `seL4_Wait`: wait for a send on endpoint. Blocks if no send pending.
  - `seL4_Call`: send and wait in one syscall. Also sends a reply cap.
  - `seL4_Reply`: send a message using reply cap.
  - `seL4_ReplyWait`: send and wait in one syscall. Using reply cap to send.
- Message Registers
  - `seL4_GetMR`: retrieve a given message register from IPC buffer.
  - `seL4_SetMR`: set a given message register in IPC buffer.
  - `seL4_GetCap`: retrieve a cap sent in an IPC.
  - `seL4_SetCap`: prepare a cap to send in an IPC.
- Tag: `seL4_MessageInfo_t`
  - Label, message length, number of caps, caps unwrapped

seL4 IPC – Notification

- Notification Object
  - Formerly: asynchronous endpoint object
  - allows one thread to send a notification to another
  - notification: asynchronous (non-blocking) message
  - sends limited data (32-bit word)
    - sets (ORs) bits in receiver notification word, not queued
- Notification Object Caps
  - master cap (receiver), derived caps (senders)
- API
  - `seL4_Notify`: set (OR) notification's data word
    - Also ORs sender badge
  - `seL4_Wait`: retrieve (and clear) notification's data word.
    - Blocks if no new notification since last wait

seL4 API: CSpace

- CNode Object
  - consists of slots in which capabilities are stored
  - can also store CNode caps in slots, creates hierarchical CSpace structure
- API
  - insert cap:
    - indirectly: through `seL4_Untyped_Retype`
    - `seL4_CNode_Copy`: copy from one slot into another
    - `seL4_CNode_Mint`: copy but change some cap attributes
    - `seL4_CNode_Move`: remove from one slot and put in another
  - remove cap
    - `seL4_CNode_Delete`:remove cap from cslot, destroy object if last cap
    - `seL4_CNode_Revoke`: delete all child caps (e.g. through copy or retype)
    - `seL4_CNode_Recycle`: revoke and then reset object attributes

Cspace slots and addresses

- CSpace structure
  - Hierarchy of CNodes: 1-level, 2-level, 3-level, …
- CNode size (radix)
  - 2^{radix} slots
- CSpace Slot (CSlot) address
  - CPtr: 32-bit Word
  - CPtr is resolved based on CSpace structure (see examples)
  - CPtr resolution relative to a **root cnode**
  - **Depth:** how many bits of CPtr to resolve
- Use of CSlot addresses in syscalls:
  - Just CPtr (implicit root = TCB's CNode cap & implicit 32-bit depth)
  - Explicit root (is a 32-bit depth CPtr with implicit root) & CPtr (called index) & explicit depth

CSpace example and addressing

CNode 0: 2^{16}	
0	
1	A
2	U: cnode 1
3	V: cnode 0
4	
…	…

Cnode 1: 2^{16}	
0	
1	W: cnode 2
2	B
3	X: cnode 0
4	
…	…

Cnode 2: 2^{16}	
0	
1	
2	C
3	
4	Y: cnode 3
…	…

Cnode 3: 2^{16}	
0	
1	
2	D
3	Z: cnode 4
4	
…	…

Cnode 4	
0	
1	E
2	
3	
4	
…	…

- B: CPtr: 0x 0002 0002
- W: CPtr: 0x 0002 0001
- X: CPtr: 0x 0002 0003
- A: CPtr: 0x 0001 ????
  - CPtr: 0x 0003 0001
  - Or: Root: X index 0x 0003 depth: 16
- U: CPtr: 0x 0002 ????
  - CPtr: 0x 0003 0002
  - Or: Root: X index: 0x 0002 depth: 16

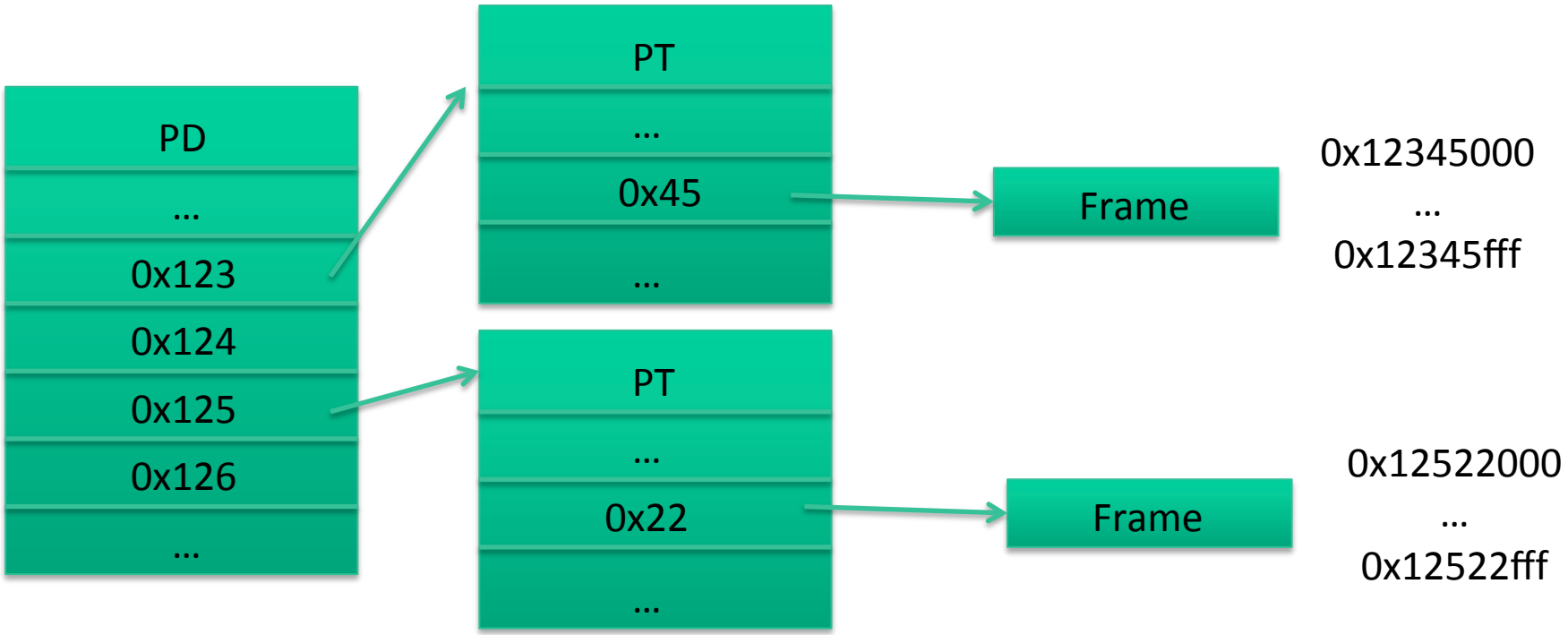
- C: CPtr: 0x 0002 0001 ~~0002~~
  - Root: W index: 0x 0002 depth: 16
- Y: CPtr: 0x 0002 0001 ~~0004~~
  - Root: W index: 0x 0004 depth 16
- D: root: W index: 0x 0004 0002 depth: 32
- Z: root: W index: 0x 0004 0003 depth: 32
- E: root: W index: 0x 0004 0003 ~~0001~~

CSpace and guards

- CNode caps can also have guards
  - Inspired by *guarded page tables*
  - Enables sparseness
- Guard
  - Fixed prefix of a CNode's address fragment
  - Example:
    - CNode: radix = 8, guard size = 8 bits value = 0x44
      - CNode's address fragment must be 0x44XX
    - CNode: radix = 12, guard size = 4 bits value = 0x8
      - CNode's address fragment must be 0x4XXX
    - 2-level CSpace: CNode 0: r: 8 g: 8,0x44 CNode 1: r: 12 g: 4,0x4
      - CPtrs must be 0x 44XX 4XXX

seL4 API: VSpace

- VSpace:
  - Objects: PageDir (PD), PageTable (PT), Frame
  - represents mapping: virtual address → physical address
    - i.e. abstraction of CPU page table
- Example (on ARM):



seL4 API: Vspace (contd.)

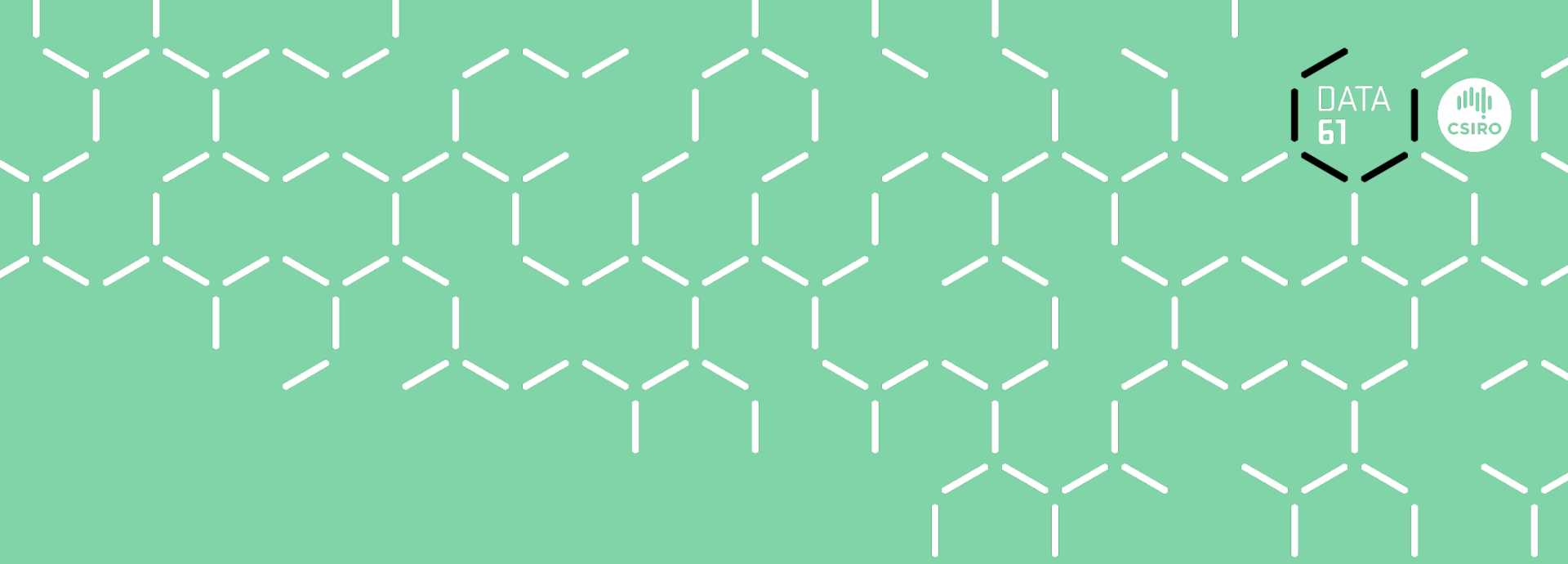
- VSpace-related objects are platform-specific
- Sizes (ARM)
  - PD: 16KiB, 4 byte slots
  - PT: 1KiB, 4 byte slots
  - Frame: 4KiB, 64KiB, 1MiB, 16MiB
- Size (x86)
  - PD: 4KiB, 4 byte slots
  - PT: 4KiB, 4 byte slots
  - Frame: 4KiB, 4MiB

seL4 VSpace: API

- PD
  - `seL4_<ARCH>_PageTable_Map`
  - `seL4_<ARCH>_PageTable_Unmap`
  - Can map in large frames directly:
    - `seL4_<ARCH>_Page_Map`
    - `seL4_<ARCH>_Page_Unmap`
- PT
  - `seL4_<ARCH>_Page_Map`
  - `seL4_<ARCH>_Page_Unmap`
- Note:
  - <ARCH> is either ARM or IA32
  - Libsel4utils provides architecture independent versions of calls
    - E.g.: `seL4_ARCH_Page_Map`

Hands-on: hello-3

- Extends code-base from hello-2 to do IPC between threads
- Prepare
  - `make ia32_hello-3_defconfig`
  - `make`
  - Edit `apps/hello-3/src/main.c`
- Root task main thread:
  - TODO 1: get a frame cap for the ipc buffer
  - TODO 2: try to map the frame the first time
  - TODO 3: create a page table
  - TODO 4: map the page table
  - TODO 5: then map the frame in
  - TODO 6: create an endpoint
  - TODO 7: make a badged copy of it
  - TODO 8: set the data to send
  - TODO 9: send & wait for reply
  - TODO 10: get reply message
- Second thread:
  - TODO 11: wait for a message
  - TODO 12-13: get & check message
  - TODO 14-15: send message back



More seL4 API and libraries
- Starting a new process

What's a seL4 process?

- seL4 doesn't have a concept of "process"
- Traditional process:
  - Each process has its own:
    - CSpace & VSpace & Threads
- Non-traditional process:
  - Different combinations of VSpace and CSpace sharing:
    - Shared CSpace, separate VSpaces
    - Separate CSpace, shared Vspace
    - Partially shared CSpace
    - Partially shared VSpace

Build system: non-root task apps

- Adding a non-root-task app, Steps:
  - Example: root task: hello-4, non root-task app: hello-4-app
  - Make a new app for it (e.g. hello-app-4), with config and src files
  - Add dependency information about the new app in root task app's Kbuild
    - `hello-4-components-y += hello-4-app`
    - `hello-4-components = $(addprefix $(STAGE_BASE)/bin/, $ (hello-4-components-y))`
    - `hello-4: export COMPONENTS=${hello-4-components}`
    - `hello-4: ${hello-4-components-y} kernel_elf $(hello-4-y)`
  - And in the root task app's Makefile to add it to the cpio archive
    - {COMPONENTS}: false
    - archive.o: ${COMPONENTS} $(Q)mkdir -p $(dir $@) ${COMMON_PATH}/ files_to_obj.sh $@ _cpio_archive $^

Library: vspace

- Interface for managing VSpaces
  - manage current VSpace
  - manage other VSpaces
    - note: create is not part of vspace API !
  - allocate frames and map them into a VSpace
- Key concepts
  - ***reservation***: portion of VSpace, that will not be given to others
  - ***mapping***: frame mapped into a VSpace at a virtual address
- Interfaces defined
  - `vspace`
- Implemented by
  - sel4utils

Vspace: API

- Files
  - libsel4vspace, #include <vspace/vspace.h>
- Datastructs
  - `vspace_t`
  - `reservation_t`: a reserved range of vspace addresses
- Functions
  - `vspace_reserve_range`, `vspace_free_reservation`
  - `vspace_new_pages`: create frames and map into VSpace
  - `vspace_map_pages`: map given frames into VSpace
  - `vspace_unmap_pages`: provides different ways to free frame object
  - `vspace_get_cap`: get frame cap for specific virtual address
  - `vspace_get_root`: get cap to PD of VSpace

Library: sel4utils

- Utility code to make life easier
  - create and manage threads and processes
  - create vspaces, implement vspace interface
  - load ELF code
- Key concepts
  - process: CSpace + VSpace + TCB
- Interfaces implemented
  - `vspace`
  - `sel4utils`: util functions provided by the library
    - Thread and process management
    - Logging and profiling
    - Architecture agnostic functions

seL4utils: API

- Files:
  - libseL4utils, #include <sel4utils/…>: vspace.h, process.h, mapping.h
  - `libs/libsel4utils/include/sel4utils`
- Datastructs
  - `process_t`
  - `thread_t`
- Functions
  - `sel4utils_bootstrap_vspace_with_bootinfo`
  - `sel4utils_get_vspace`: create new vspace
  - `sel4utils_configure_process`: create process
  - `sel4utils_spawn_process_v`: start process
  - `sel4utils_*_cap_to_process`: mint, copy
  - `seL4_ARCH_*`: architecture independent wrapper for seL4 syscalls

Hands-on: hello-4 (part 1)

- Create a new process
- Prepare
  - `make ia32_hello-4_defconfig`
  - `make`
- Edit `apps/hello-4/src/main.c`
  - TODO 1: create a vspace object
  - TODO 2-3: use sel4utils to make a new process
  - TODO 6: spawn the process
- Edit `apps/hello-4-app/src/main.c`
  - Fix it so that the asserts don't fail
- Build and Run
  - New process should print something

Hands-on: hello-4 (part 2)

- Add IPC between the root task and the new process
- Edit `apps/hello-4/src/main.c`
  - TODO 4: make a cspacepath for the new endpoint cap
  - TODO 5: copy the endpoint cap and add a badge to the new cap
  - TODO 7: wait for a message
  - TODO 8: send the modified message back
- Edit `apps/hello-4-app/src/main.c`
  - TODO 9: send and wait for a reply
- Build and run
  - See message sent back and forth!

What’s Next?

Advanced seL4

- In-depth VSpace and CSpace
  - See seL4 manual: http://sel4.systems/Info/Docs/seL4-manual.pdf
- Reimplement hello-2 (and 3 and 4) using only seL4 API
- CapDL: capability distribution language – static system setup
  - https://github.com/seL4/capDL-tool
  - https://github.com/seL4/capdl-loader-app
- Device drivers (in seL4; or with CAmkES)
  - Libplatsupport: https://github.com/seL4/libplatsupport
  - Libsel4platsupport: https://github.com/seL4/libsel4platsupport
- A whole operating system (e.g. UNSW Advanced Operating Systems Assignments)
  - http://www.cse.unsw.edu.au/~cs9242
  - https://bitbucket.org/kevinelp/unsw-advanced-operating-systems