Porting U-Boot Drivers to seL4

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INTRODUCTIONS

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- Capgemini Engineering, Bath, UK
- Small team working with seL4 since late 2021

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CONTEXT

WIDER PROJECT GOALS

- Make adopting seL4 easy, quick, and cheap

- Produced an open-source developer kit
  - Enables users to get started with seL4 very quickly
  - Provides a shopping list of required hardware
  - Provides pre-built binaries, tooling and a build environment
  - Provides clear and detailed setup instructions

- To be released imminently…

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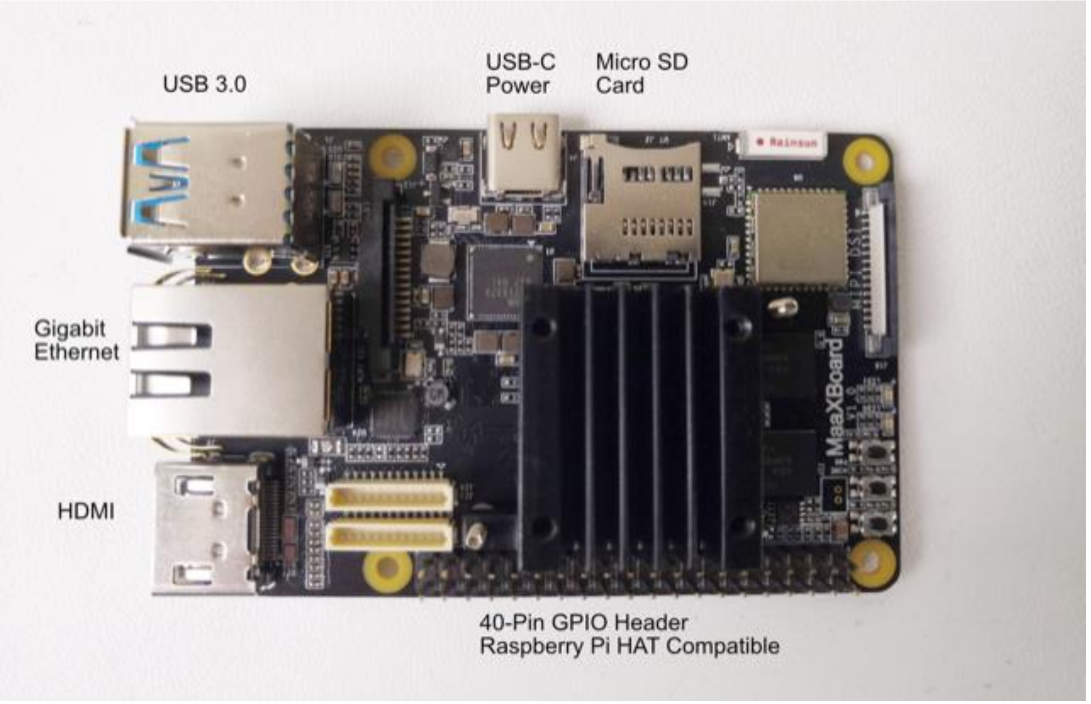
PLATFORM

- Selected a modern, low-cost board for development
  - Avnet MaaXBoard
  - i.MX 8M SoC (Quad ARM Cortex-A53)



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DEVICE DRIVERS

- Focus today is on device drivers

- Availability of device drivers can be a significant barrier to use of seL4

- Developer kit provides extensive driver support for the chosen platform

- … but also provides a route to providing extensive driver support for a wide range of platforms

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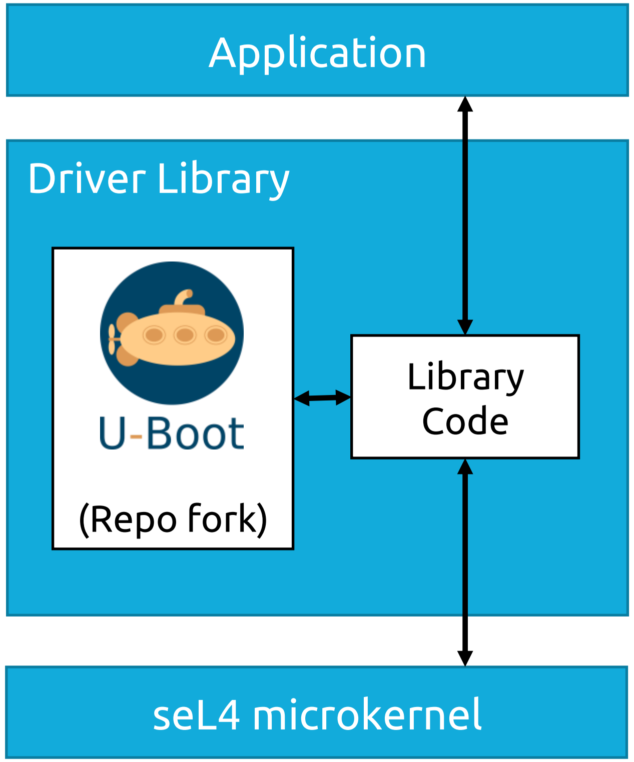
seL4 U-BOOT DRIVER LIBRARY

seL4 U-BOOT DRIVER LIBRARY

An extensible, native library allowing use of U-Boot device drivers

- Why build a driver library based upon U-Boot?
  - Individual drivers have previously been ported to seL4
    - Made to function independently of the U-Boot driver framework
    - Workable for simple devices, harder as device complexity increases (e.g. USB stack)
  - Wanted to make the U-Boot driver framework function within seL4
    - Provides a route for supporting any driver from U-Boot
- Primary design goal is ease of extension
  - Structured to allow new boards and devices to be easily supported
  - Allow device drivers to function with no, or minimal, code change



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CURRENT LIBRARY CAPABILITIES

- Extensive support for Avnet MaaXBoard
  - USB, Ethernet, SPI, I^{2}C, MMC / SD, GPIO, Pin multiplexing (IOMUX), Clock and LED
- Limited support for Odroid-C2
  - GPIO, Pin multiplexing (IOMUX) and LED
  - Proof of concept for support of multiple boards
- xHCI USB stack
  - USB mass storage and USB keyboard drivers
- Disk support
  - Partition table formats: ISO, GPT, DOS and MAC
  - Filesystem formats: FAT(16/32) and EXT(2/3/4)
- Capable of utilising an external TCP stack
  - Demo application provided using PicoTCP stack

CURRENT LIBRARY LIMITATIONS

- Performance
  - Library is optimised for ease of extension, not performance
  - U-Boot drivers typically do not use interrupts, they must be polled
- No support for WiFi
  - Not supported by U-Boot
- Unlikely to be amenable to formal proofs

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TECHNICAL CHALLENGES

REPLACING THE U-BOOT BUILD SYSTEM

- First obstacle is getting U-Boot code to build
- U-Boot uses a Kconfig / make build system whilst seL4 uses CMake / Ninja
- Created CMake script to replicate the U-Boot build system functionality
  - Defines which drivers to include based upon the platform
  - Control which source files to compile based upon required drivers
  - Set up the U-Boot pre-processor macros
  - Convert seL4 build options to equivalent U-Boot macros, e.g. logging level, architecture details

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LIBRARY INITIALISATION

- Map device address ranges into the virtual address space

- Create a device tree for U-Boot to query
  - Derived from the seL4 device tree
  - Contains the minimal set of devices the library needs to access
  - Replace bus addresses with the mapped virtual memory address

- Perform bespoke initialisation of U-Boot
  - Initialise required sub-systems
  - Setup "global data" with required status and data; second-stage bootloader after relocation to RAM
  - Initialise "linker lists"; arrays of optional components normally held in linker sections

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EXECUTING U-BOOT WITHIN VIRTUAL ADDRESS SPACE

- U-Boot is designed to execute within the physical address space
  - Drivers provide memory addresses to devices for DMA
  - Without modification, drivers will provide virtual memory addresses to devices
  - Devices cannot access a virtual memory address. Problem!

- Driver modification is required in limited cases
  - Only devices that utilise DMA are affected
  - Library provides seL4 specific DMA routines for allocation, address translation and cache flush / invalidate
  - Replace local memory allocation / deallocation with DMA equivalents
  - Drivers using the Linux “DMA Mapping” API work without modification; library provides a mapping onto seL4 routines

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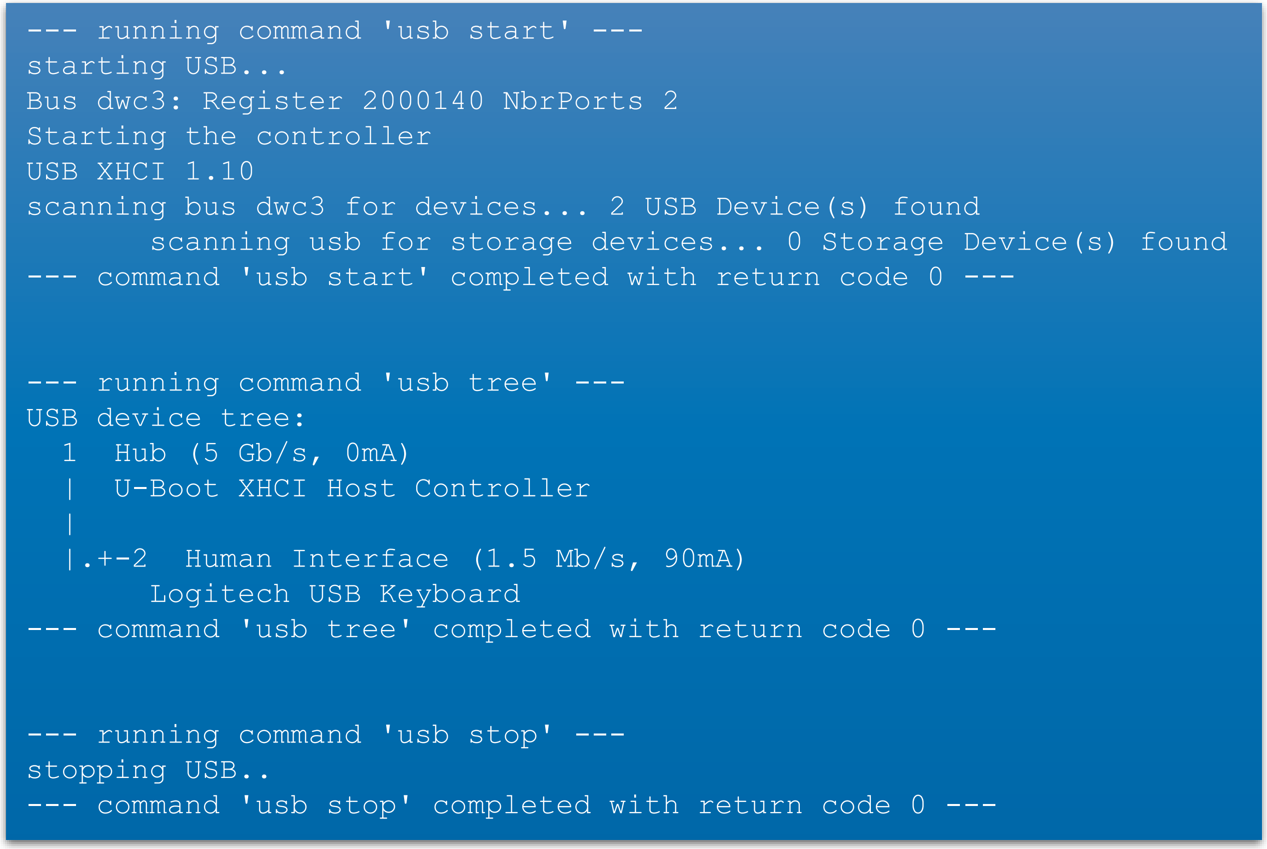
LIBRARY USAGE EXAMPLES

PUBLIC INTERFACE

- Primary interface is through textual commands
  - Same commands as input to the U-Boot CLI
  - Exposes full capability of U-Boot
- Easily extendable to provide programmatic interface for any command
- Interface to send / receive raw Ethernet frames
  - Allows library to be linked to an external TCP stack
- Interface to receive input from character devices
  - Receive input from USB keyboard

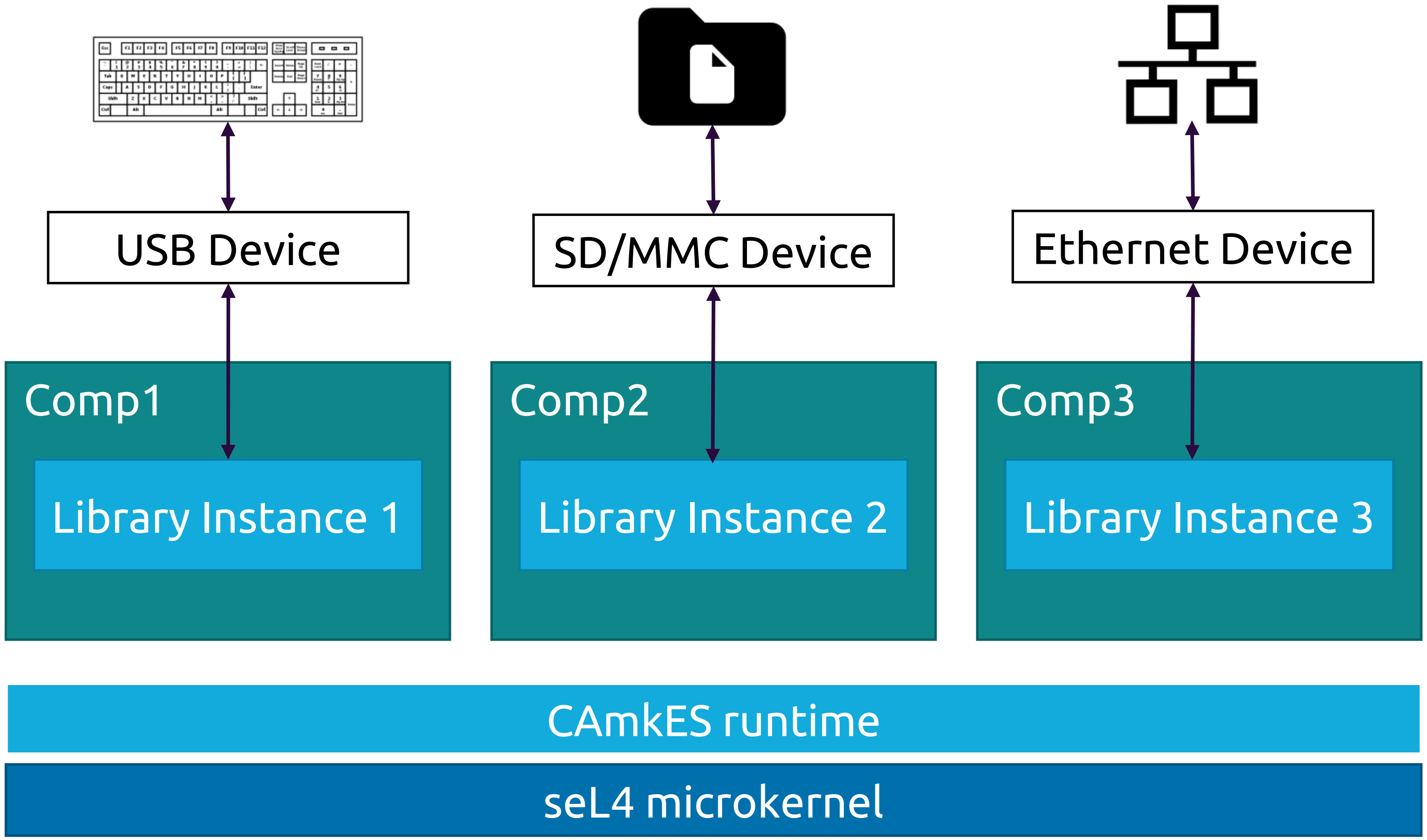


```
--- running command 'usb start' ---
starting USB...
Bus dwc3: Register 2000140 NbrPorts 2
Starting the controller
USB XHCI 1.10
scanning bus dwc3 for devices... 2 USB Device(s) found
       scanning usb for storage devices... 0 Storage Device(s) found
--- command 'usb start' completed with return code 0 ---


--- running command 'usb tree' ---
USB device tree:
  1  Hub (5 Gb/s, 0mA)
  |  U-Boot XHCI Host Controller
  |
  |.+-2  Human Interface (1.5 Mb/s, 90mA)
       Logitech USB Keyboard
--- command 'usb tree' completed with return code 0 ---


--- running command 'usb stop' ---
stopping USB..
--- command 'usb stop' completed with return code 0 ---
```

USAGE EXAMPLE



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EXTENDING THE LIBRARY

HOW TO EXTEND THE LIBRARY

- Adding a new platform or driver, what is required?
- Update the CMake build script
  - List which drivers are associated with the platform
  - Define the source files and macros for the driver
- Provide “linker lists” initialisation routine
- Provide a monotonic real-time clock
  - Required for drivers with timing requirements
- Perform DMA driver updates

```
if("${KernelPlatform}" STREQUAL "odroidc2")
   set(iomux_driver "meson-gxbb-pinctrl")
   set(gpio_driver "meson_gx_gpio_driver")
   set(led_driver "gpio_led")

...

if(iomux_driver MATCHES  "meson-gxbb-pinctrl")
   list(APPEND uboot_deps uboot/drivers/pinctrl/meson/pinctrl-meson-gxbb.c)
   list(APPEND uboot_deps uboot/drivers/pinctrl/meson/pinctrl-meson.c)
   list(APPEND uboot_deps uboot/drivers/pinctrl/meson/pinctrl-meson-gx-pmx.c)
```

```
void initialise_driver_data (void) {
   driver_data.uclass_driver_array[0] = _u_boot_uclass_driver__nop;
   driver_data.uclass_driver_array[1] = _u_boot_uclass_driver__root;
   driver_data.uclass_driver_array[2] = _u_boot_uclass_driver__simple_bus;
   driver_data.uclass_driver_array[3] = _u_boot_uclass_driver__phy;
   driver_data.uclass_driver_array[4] = _u_boot_uclass_driver__blk;
   driver_data.uclass_driver_array[5] = _u_boot_uclass_driver__pinconfig;
   driver_data.uclass_driver_array[6] = _u_boot_uclass_driver__pinctrl;
   driver_data.uclass_driver_array[7] = _u_boot_uclass_driver__gpio;
   driver_data.uclass_driver_array[8] = _u_boot_uclass_driver__led;

   driver_data.driver_array[0] = _u_boot_driver__root_driver;
   driver_data.driver_array[1] = _u_boot_driver__simple_bus;
   driver_data.driver_array[2] = _u_boot_driver__pinconfig_generic;
   driver_data.driver_array[3] = _u_boot_driver__meson_gxbb_pinctrl;
   driver_data.driver_array[4] = _u_boot_driver__meson_gx_gpio_driver;
   driver_data.driver_array[5] = _u_boot_driver__led_gpio_wrap;
   driver_data.driver_array[6] = _u_boot_driver__led_gpio;

   driver_data.cmd_array[0] = _u_boot_cmd__dm;
   driver_data.cmd_array[1] = _u_boot_cmd__env;
   driver_data.cmd_array[2] = _u_boot_cmd__setenv;
   driver_data.cmd_array[3] = _u_boot_cmd__pinmux;
   driver_data.cmd_array[4] = _u_boot_cmd__gpio;
   driver_data.cmd_array[5] = _u_boot_cmd__led;
}
```

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ANY QUESTIONS?

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