Zephyr Optimisations

Through the looking ~~glass~~ code

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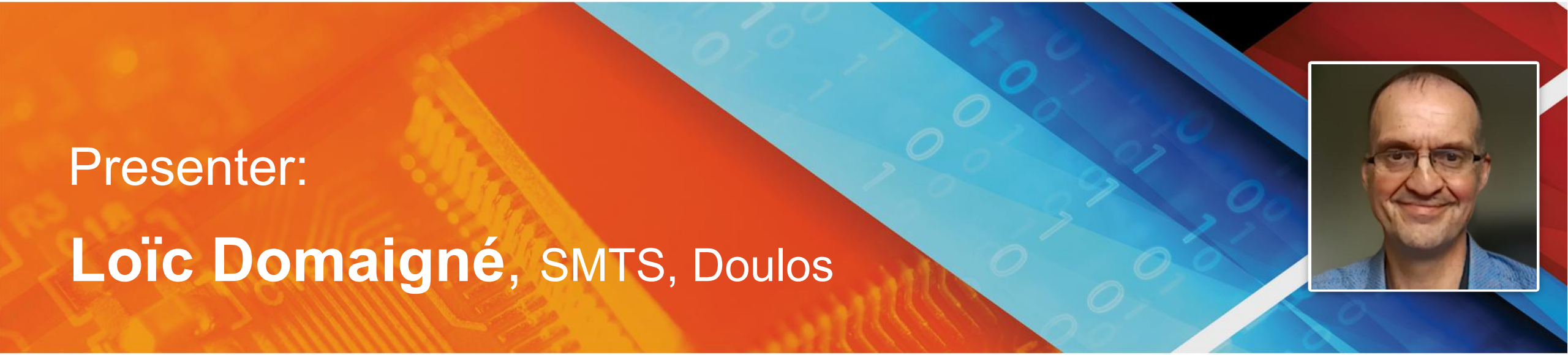

Presenter:

Loïc Domaigné, SMTS, Doulos

DOULOS

Zephyr Project Meetup: Winterthur, Switzerland

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» Embedded software

» Python, Edge AI and Deep Learning

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Agenda

1. Motivation
2. Kconfig, autoconf.h and conditional compilation
3. Size optimisations using SysV voodoo
4. DT macro, the good part
5. Driver API: abstraction and optimisations

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Blinky: from Bare Metal to Zephyr

- Classic Embedded Programming:
  - Use header file and #define macro
  - Configure the peripheral
  - Access the registers directly

Could be encapsulated
in a file or static library

→ **"driver"**

- Zephyr:
  - Configure project to enable GPIO
  - Query the devicetree
  - Use GPIO driver to blink LED

Zephyr:

- common APIs for GPIO
- API realized by SoC-specific drivers

- Zephyr feels very high level…
- Impact on code speed or size?

How does Zephyr handle this ?

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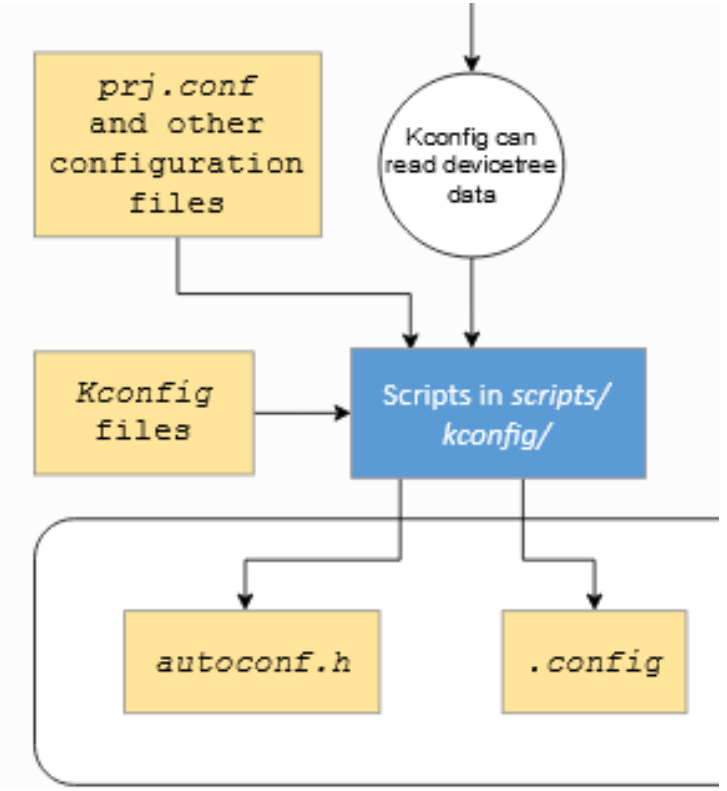
Kconfig

- Kconfig: text file using a DSL to describe
  - Configuration items in a hierarchical manner
  - For each config item:
    - Type (boolean, int, string, choice)
    - Evt. Valid range
    - direct / reverse dependencies to other config options

- Customize zephyr to match application/platform requirements:
  - Select what feature to enable/disable
  - CONFIG_xxx in prj.conf (or board overlay)



Zephyr Build and Configuration Phases

```
# prj.conf
CONFIG_GPIO=y
CONFIG_BLINKY=y
```

```
$ find -name "autoconf.h" -o -name ".config"
./build/zephyr/include/generated/zephyr/autoconf.h
./build/zephyr/.config
```

Compile Time Modularity

main.c

```
#if CONFIG_BLINKY
#include "blinky.h"
#define TEN_SECONDS_IN_MS 10000

int main()
{
    return blinky(TEN_SECONDS_IN_MS/CONFIG_BLINKY_SPEED);
}

#else /*BLINKY demo is not enabled*/
...
#endif
```

autoconf.h

```
#define CONFIG_SERIAL 1
...
#define CONFIG_BLINKY 1
#define CONFIG_BLINKY_SPEED 10
```

Automatically included

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.20.0)
find_package(Zephyr REQUIRED HINTS $ENV{ZEPHYR_BASE})
project(blinky)

target_sources(app PRIVATE src/main.c)
target_sources_ifdef(CONFIG_BLINKY app PRIVATE src/blinky.c)
```

Add source to project if set

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Everything is a Library

```
$ cd build; find . -name "*.a"
./modules/hal_nxp/hal_nxp/lib..__modules__hal__nxp.a
./zephyr/arch/arch/arm/core/…/libarch__arm__core__cortex_m__cmse.a
./zephyr/arch/arch/arm/core/…/libarch__arm__core__cortex_m.a
./zephyr/arch/arch/arm/core/mpu/libarch__arm__core__mpu.a
./zephyr/arch/arch/arm/core/libarch__arm__core.a
./zephyr/arch/common/libisr_tables.a
./zephyr/arch/common/libarch__common.a
./zephyr/lib/libc/picolibc/liblib__libc__picolibc.a
./zephyr/lib/libc/common/liblib__libc__common.a
./zephyr/libzephyr.a
./zephyr/drivers/mfd/libdrivers__mfd.a
./zephyr/drivers/clock_control/libdrivers__clock_control.a
./zephyr/drivers/gpio/libdrivers__gpio.a
./zephyr/drivers/console/libdrivers__console.a
./zephyr/drivers/serial/libdrivers__serial.a
./zephyr/drivers/pinctrl/libdrivers__pinctrl.a
./zephyr/drivers/timer/libdrivers__timer.a
./zephyr/kernel/libkernel.a
./zephyr/boards/nxp/frdm_mcxn947/libboards__nxp__frdm_mcxn947.a
./app/libapp.a
```

Vendor HAL

arch. specific

libc hooks

drivers

kernel

our app

Objects Size

```
$ find build/ -name "*.a" -exec du -bc {} +

414672  ./modules/hal_nxp/…/lib..__modules__hal__nxp.a
 22630  ./zephyr/arch/arch/arm/…/libarch__arm__core__cortex_m__cmse.a
139138  ./zephyr/arch/arch/arm/…/libarch__arm__core__cortex_m.a
 52084  ./zephyr/arch/arch/arm/core/mpu/libarch__arm__core__mpu.a
 27518  ./zephyr/arch/arch/arm/core/libarch__arm__core.a
 13072  ./zephyr/arch/common/libisr_tables.a
  3370  ./zephyr/arch/common/libarch__common.a
 27996  ./zephyr/lib/libc/picolibc/liblib__libc__picolibc.a
 23328  ./zephyr/lib/libc/common/liblib__libc__common.a
345430  ./zephyr/libzephyr.a
 18524  ./zephyr/drivers/mfd/libdrivers__mfd.a
 27402  ./zephyr/drivers/clock_control/libdrivers__clock_control.a
 40094  ./zephyr/drivers/gpio/libdrivers__gpio.a
 10544  ./zephyr/drivers/console/libdrivers__console.a
 50790  ./zephyr/drivers/serial/libdrivers__serial.a
 20130  ./zephyr/drivers/pinctrl/libdrivers__pinctrl.a
 35374  ./zephyr/drivers/timer/libdrivers__timer.a
739624  ./zephyr/kernel/libkernel.a
 50974  ./zephyr/boards/nxp/…/libboards__nxp__frdm_mcxn947.a
 19004  ./app/libapp.a

2081698 total
```

"Objects"	Size
Code	~2.0 Mb
Picolibc	~1.6 Mb
Total	~3.6 Mb

Image Size

```
$ find . -name "zephyr*" -type f -executable -exec du {} +
```

objcopy

Size Kb	Path (relative to build)	Comments
668	./zephyr/zephyr.elf	Binary using ELF format
24	./zephyr/zephyr.bin	Binary flash on target
664	./zephyr/zephyr_pre0.elf	Intermediary build file / internal use only

Image flashed on target is 24 Kb

sysV voodoo

Question? How do we go from 3.6 MB → 668 Kb → 24 Kb

Build post-processing

Ancient SysV Voodoo

- Archive is a collection of objfiles (compilation unit)

```
$ ar -t zephyr/kernel/libkernel.a
main_weak.c.obj
…
sem.c.obj
timer.c.obj
```

- Linker discards unreferenced .o files if no symbol is needed.

```
$ nm zephyr/kernel/libkernel.a
sem.c.obj:
00000000 b lock
00000000 T z_impl_k_sem_give
00000000 T z_impl_k_sem_init
00000000 T z_impl_k_sem_reset
00000000 T z_impl_k_sem_take
         U z_pend_curr
         U z_ready_thread
         U z_reschedule
         U z_unpend_first_thread
```

It's ancient SysV voodoo, basically

Andy Ross
Kernel dev.

Discarded in zephyr.elf when semaphore is not used

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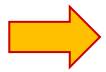

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Devicetree

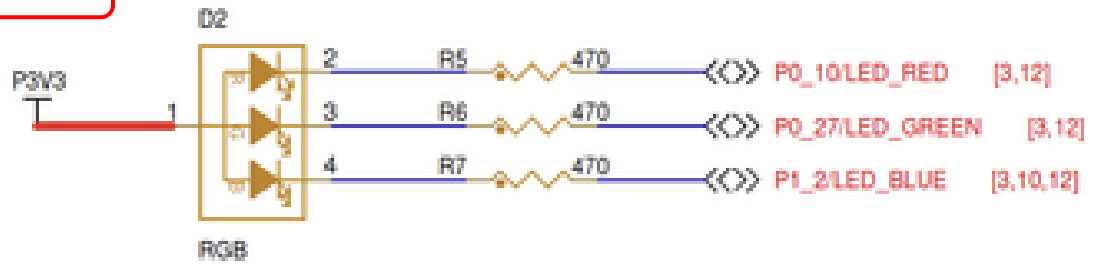
Devicetree: tree-like data structure using a DSL to describe:

- Hardware: SoC, CPUs, Memory, Buses, Peripherals,…
- Hardware Boot-time configuration

devicetree specification

GPIO0, PIN 10, ACTIVE_LOW

```
red_led: led_3 {
    gpios = < &gpio0 0xa 0x1 >;
    label = "Red LED";
    status = "okay";
};
```



The devicetree contains the information from the reference manual / schematic needed by the corresponding drivers!

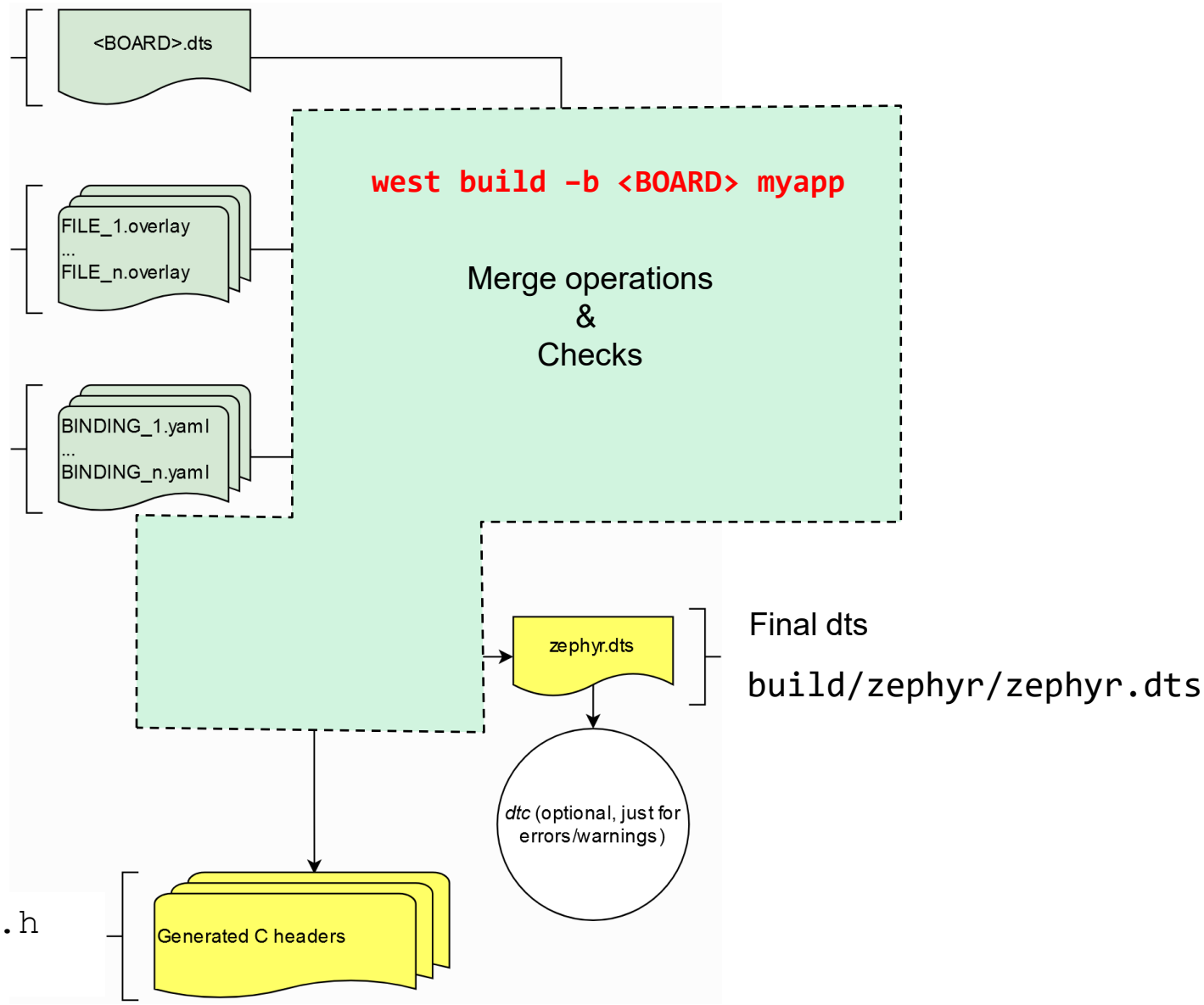
Devicetree Files

Board DT files

coming from Zephyr

```
myapp
├── board/
│   └── <BOARD>.overlay
├── CMakeLists.txt
...
```

Contains rules for devicetree contents



devicetree_generated.h

Use <devicetree.h>

DT macros – looking through the glass

```
11  /* The devicetree node identifier for the "led0" alias. */
12  #define LED0_NODE DT_ALIAS(led0)
13
14  /*
15   * A build error on this line means your board is unsupported.
16   * See the sample documentation for information on how to fix this.
17   */
18  static const struct gpio_dt_spec led = GPIO_DT_SPEC_GET(LED0_NODE, gpios);
19
```

```
aliases {
    led0 = &red_led;
    …
};                    zephyr.dts
```

```
red_led: led_3 {
    gpios = < &gpio0 0xa 0x1 >;
    label = "Red LED";
    status = "okay";
};                              zephyr.dts
```

```
gpio0: gpio@96000 {
     compatible = "nxp,kinetis-gpio";
     status = "okay";
     reg = < 0x96000 0x1000 >;
     gpio-controller;
…
};                              zephyr.dts
```

expands to:

```
{ .port = (&__device_dts_ord_11),
  .pin = 10,
  .dt_flags = 1,
}
```

Provided by:

```
/* GPIO SoC/board driver:
 *   zephyr/driver/gpio/gpio_mcux.c
 */
#define DT_DRV_COMPAT nxp_kinetis_gpio
...
DT_INST_FOREACH_STATUS_OKAY(GPIO_DEVICE_INIT_MCUX)
```

DT Macros – The Good Parts

- "DT APIs" are just C-macros
  - Expand to scalar value or struct/array initializer
- Devicetree is queried during build time
  - no runtime penalty (speed/size)
- When it works, relatively easy to use from an application point of view
  - like APIs
- Bad part: when it doesn't work
  - Example: typo in property name
  - Driver for device is not enabled: __device_ord_dts_XX symbol not found
- Ugly part: in the driver

since v4.3: dtdoctor

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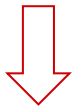
Toggle LED… How many Calls?

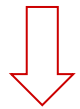
```
ret = gpio_pin_toggle_dt(&led);
```

```
static inline int gpio_pin_toggle_dt(const struct gpio_dt_spec *spec)
{
    return gpio_pin_toggle(spec->port, spec->pin);
}
```



```
static inline int gpio_pin_toggle(const struct device *port, gpio_pin_t pin)
{   ...   }
```

```
static inline int gpio_port_toggle_bits(const struct device * port, gpio_port_pins_t pins)
{   ...   }
```



```
static inline int z_impl_gpio_port_toggle_bits(const struct device *port, gpio_port_pins_t pins)
{   ...   }
```

```
static int gpio_mcux_port_toggle_bits(const struct device *dev, uint32_t mask)
{ ... gpio_base->PTOR = mask; ... }
```

GPIO driver

Toggle LED… looking through the asm glass

- 5 or 6 level of indirections… But the functions are:
  - declared **static inline**
  - in header file

Good candidates for compiler optimization

```
ret = gpio_pin_toggle_dt(&led);
```

```
=> 0x100012d8 <+68>:    ldr     r3, [r6, #8]
   0x100012da <+70>:    mov.w   r1, #1024       ; 0x400
   0x100012de <+74>:    mov     r0, r6
   0x100012e0 <+76>:    ldr     r3, [r3, #20]
   0x100012e2 <+78>:    blx     r3
```

```
static int gpio_mcux_port_toggle_bits(const struct device *dev, uint32_t mask)

Dump of assembler code for function gpio_mcux_port_toggle_bits:
   0x100044c2 <+0>:     ldr     r3, [r0, #4]
   0x100044c4 <+2>:     movs    r0, #0
   0x100044c6 <+4>:     ldr     r3, [r3, #4]
=> 0x100044c8 <+6>:     str     r1, [r3, #76]   ; 0x4c
   0x100044ca <+8>:     bx      lr
```

Production code

Conclusions

- Zephyr uses:
  - Kconfig and Devicetree
  - Good'old linker techniques to minimize the code size
  - Hints to compilers for optimizing indirections from abstractions

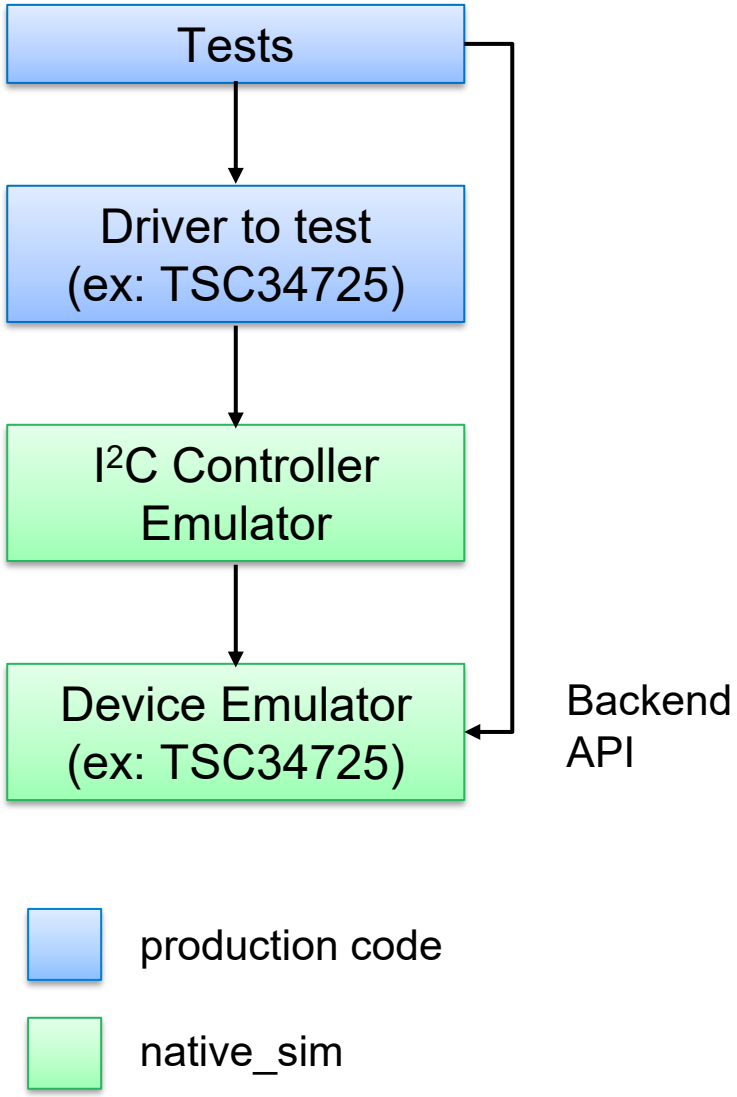
Zephyr removes the strong dependencies to hardware!

- Example:

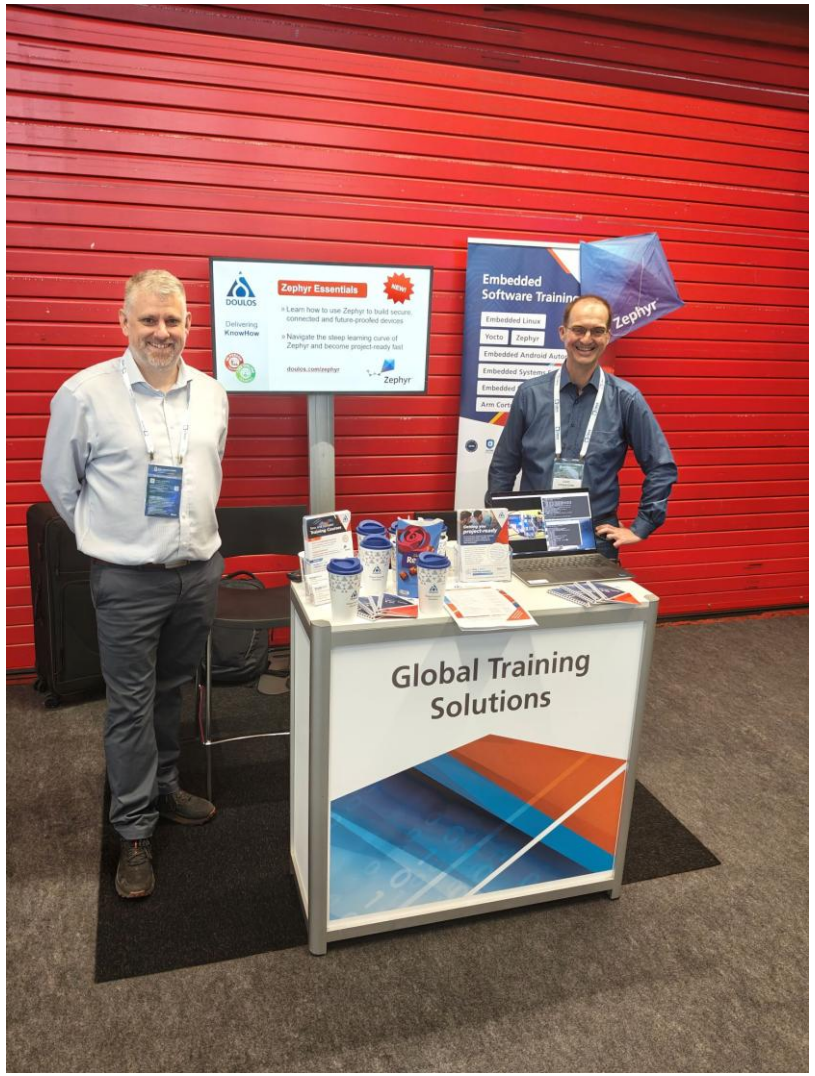
  native_sim can be used to develop and test without hardware

https://github.com/NXPHoverGames/Doom-MCX

https://zswatch.dev/



Q&A and looking forward!



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ljd42_63516

Q&A time (now or later)

THE END.

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