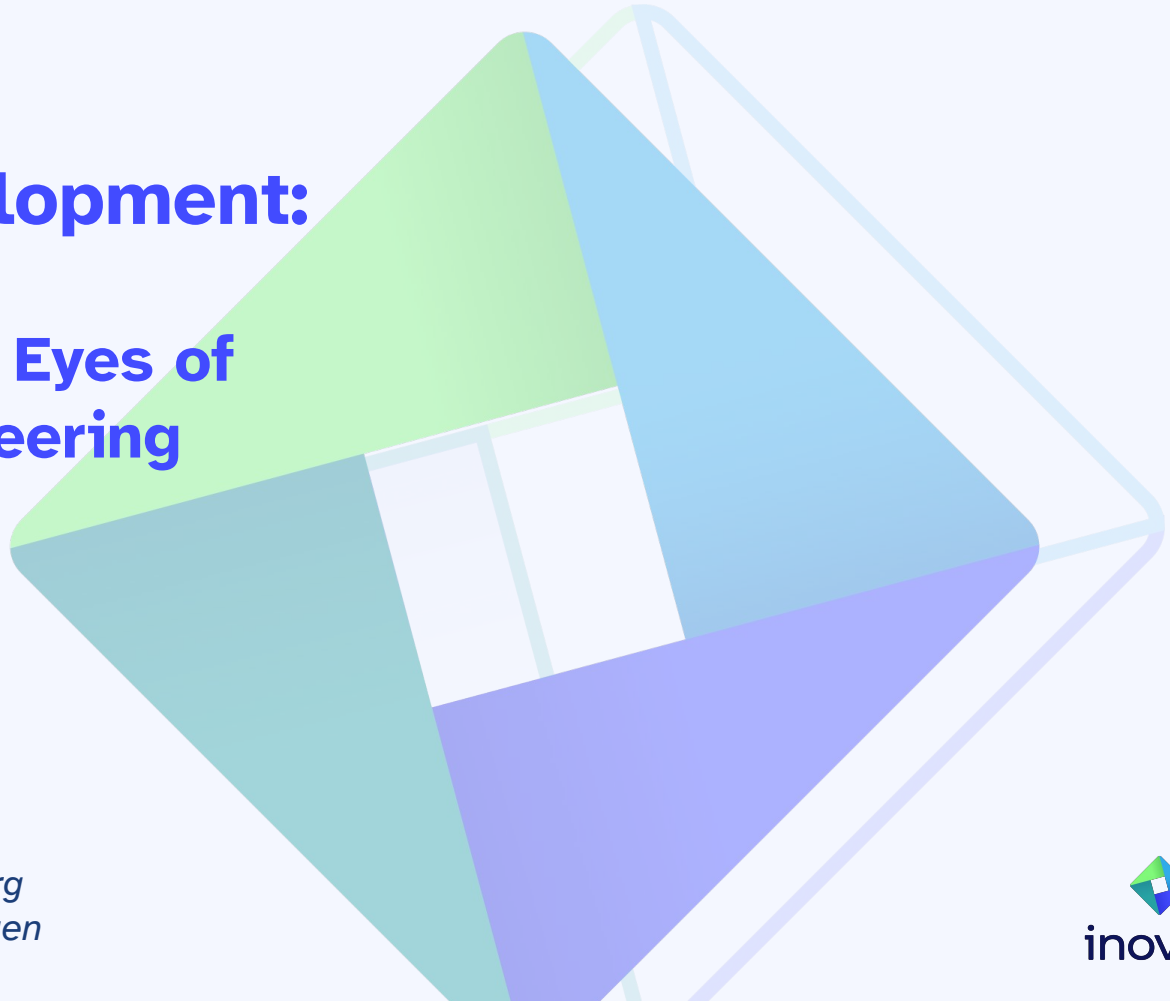
Rethinking Embedded Development:

Zephyr Through the Eyes of Model Driven Engineering



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#FOSS4MEDICAL

- PhD in Physics (long ago)
- SW/System Architect since 15 years
  - mainly Medical Devices
- Trainer & Technical Consultant
  - SW-Architecture, Zephyr, Yocto
- In Love w/ Zephyr since 2016
  - realised several prototype projects for life-science R&D
  - Maintainer of TiacSys-Bridle Project
  - Participant Zephyr Safety-WG & Zephyr TSC

- Inovex Zephyr Project Silver Member since Nov 2024

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Agenda for today

- A very short 101 on MDSD
- The many DSLs of Zephyr
- The power of models

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A very short 101 on MDSD

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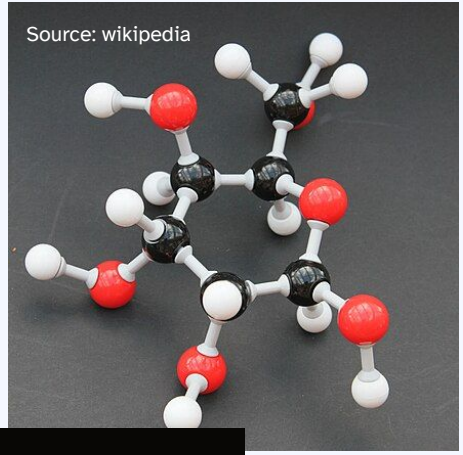
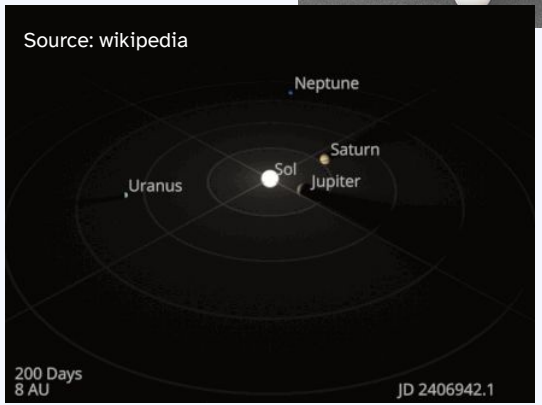
What is a model - and if, how many?



Models are sense-making devices to

- encode information about the world
- and reason about its properties
- **communicate** our understanding &
- make predictions



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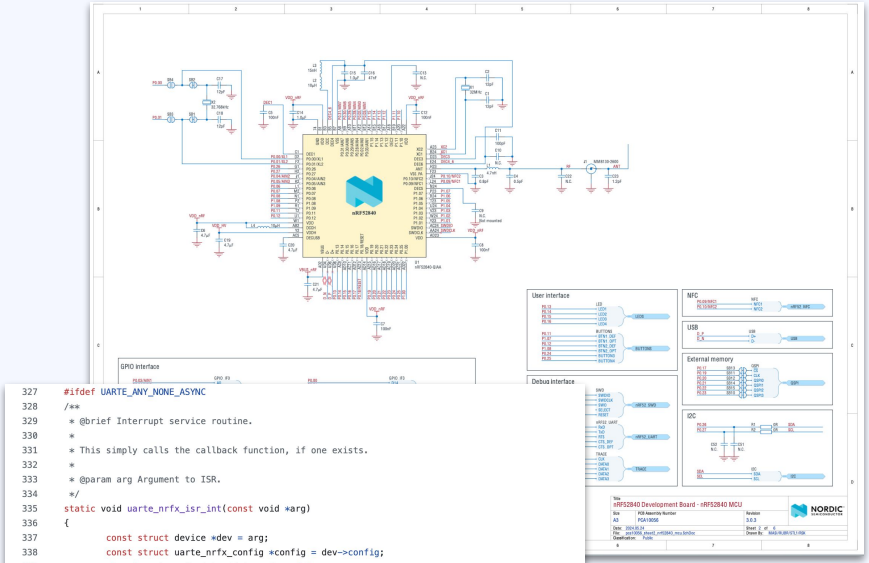
The many forms of models

Models are

- unavoidable
- abstractions
- domain-specific
- potentially disagree with each other



```
#ifdef UARTE_ANY_NONE_ASYNC
/**
 * @brief Interrupt service routine.
 *
 * This simply calls the callback function, if one exists.
 *
 * @param arg Argument to ISR.
 */
static void uarte_nrfx_isr_int(const void *arg)
{
        const struct device *dev = arg;
        const struct uarte_nrfx_config *config = dev->config;
        struct uarte_nrfx_data *data = dev->data;
        NRF_UARTE_Type *uarte = get_uarte_instance(dev);

        /* If interrupt driven and asynchronous APIs are disabled then UART
         * interrupt is still called to stop TX. Unless it is done using PPI.
         */
        if (!IS_ENABLED(UARTE_HAS_ENDTX_STOPTX_SHORT) &&
            nrf_uarte_int_enable_check(uarte, NRF_UARTE_INT_ENDTX_MASK) &&
                nrf_uarte_event_check(uarte, NRF_UARTE_EVENT_ENDTX)) {
                endtx_isr(dev);
        }

        bool txstopped = nrf_uarte_event_check(uarte, NRF_UARTE_EVENT_TXSTOPPED);

        if (txstopped && (IS_ENABLED(CONFIG_PM_DEVICE_RUNTIME) || LOW_POWER_ENABLED(config))) {
                unsigned int key = irq_lock();

                if (IS_ENABLED(CONFIG_PM_DEVICE_RUNTIME) &&
                    (data->flags & UARTE_FLAG_POLL_OUT)) {
                        data->flags &= ~UARTE_FLAG_POLL_OUT;
                        pm_device_runtime_put(dev);
                } else {
                        nrf_uarte_disable(uarte);
                }

#ifdef UARTE_INTERRUPT_DRIVEN
                if (!data->int_driven || data->int_driven->fifo_fill_lock == 0)
#endif
```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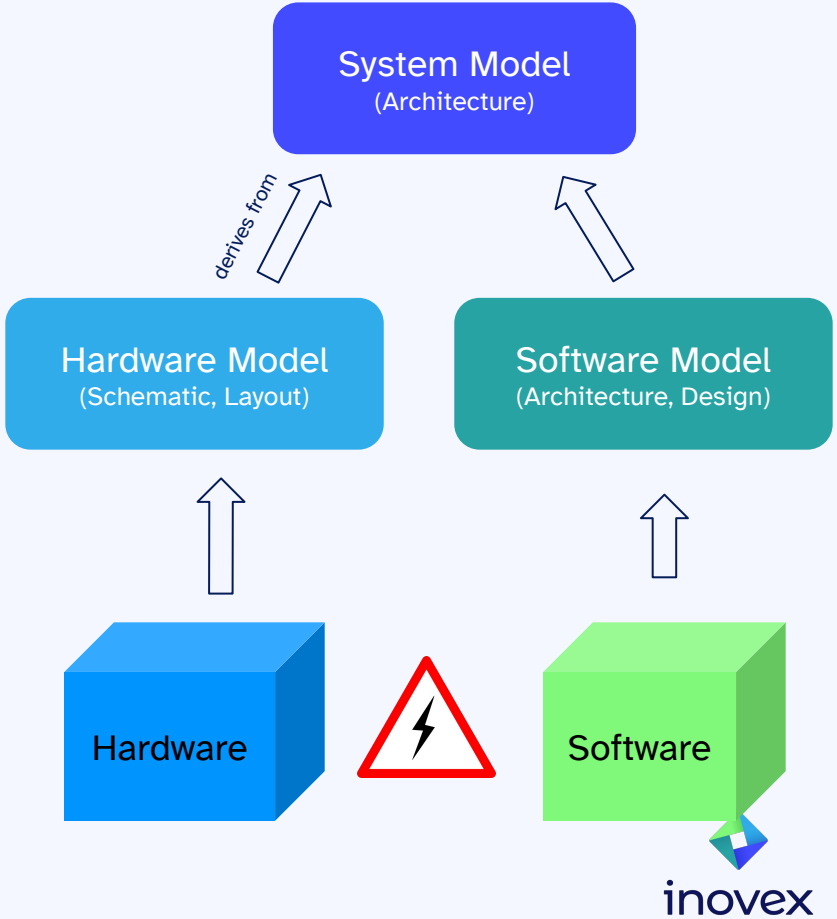
Models in Embedded

Embedded Development comprises of

- System Development Domain
- Hardware Development Domain
- Software Development Domain

Key Challenges of Embedded Development

- how to make sure **models do align**
- propagate **changes** consistently
- deal with **implicit** models



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Models in Embedded

System Model
(Architecture)

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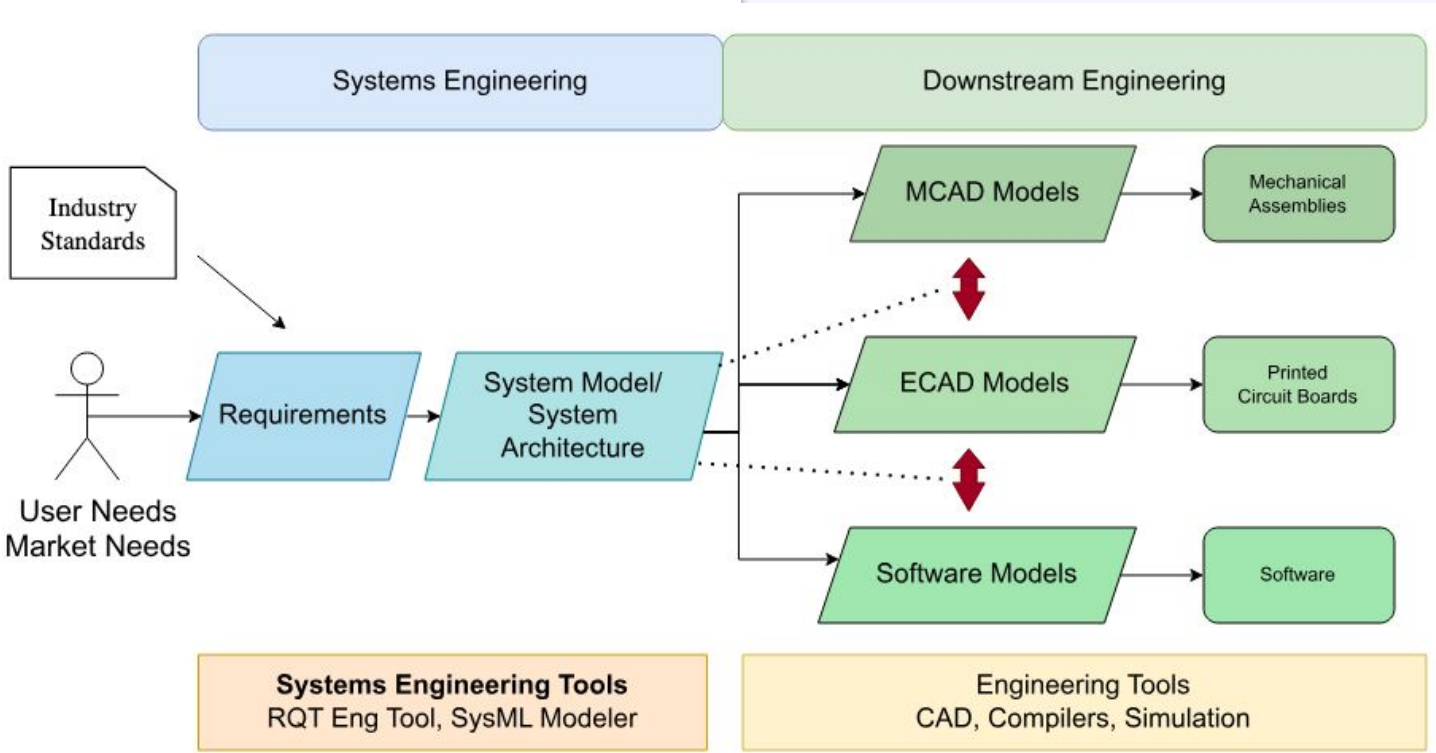
- Har
- Soft

Key Cha

- how
- prop
- dea



Model
Design)

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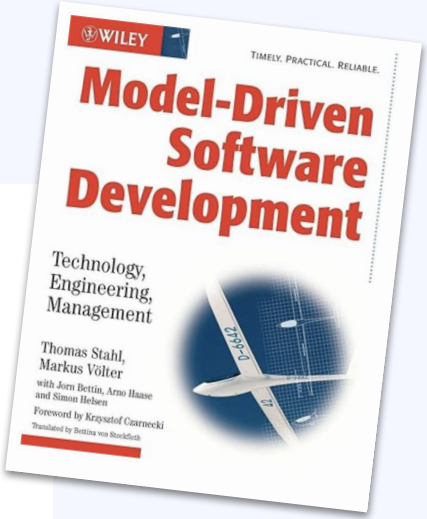
Model Driven Software Development



“ To successfully apply the ‘domain-specific model’ concept, ***three requirements*** *must be met:*

- ***Domain-specific languages*** *are required to allow the actual formulating of models.*
- *Languages that can express the necessary* ***model-to-code transformations*** *are needed.*
- ***Compilers, generators or transformers*** *are required that can run the transformations to*

generate code executable on available platforms.”

MDSD by Stahl and Voelker, 2006

https://voelter.de/data/books/mdsd-en.pdf

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The many DSLs of Zephyr

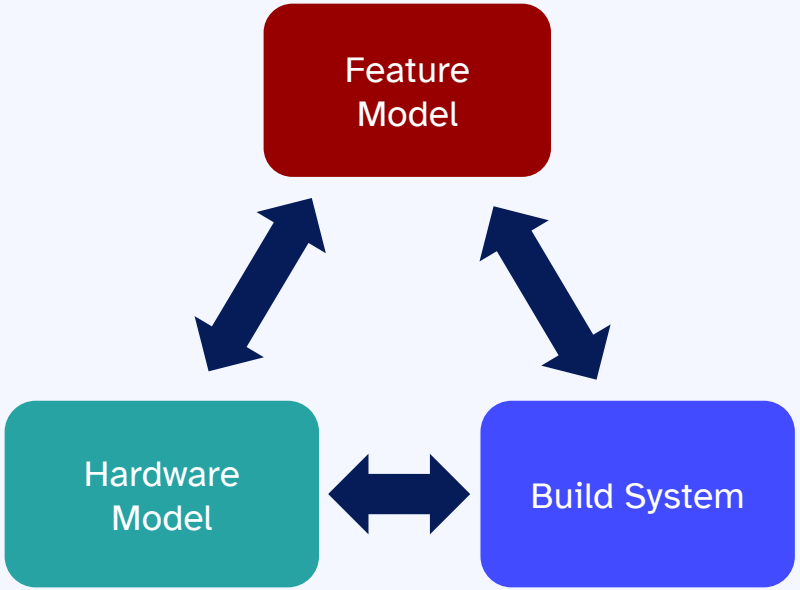
Models in Zephyr

3 domain-specific models at play

Feature Model: select desired functionality

Hardware Model: to describe hardware properties

Build System: to describe build process



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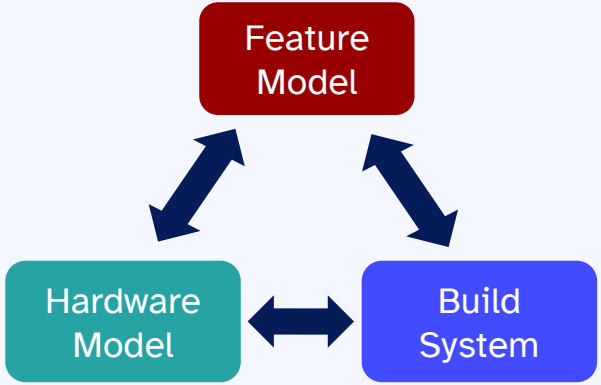
Models in Zephyr



3 domain-specific models at play

```
west build -b nucleo_g474re samples/hello_world
```

- `west build` — invoke CMake build system
- `-b nucleo_g474re` — select hardware & features (`<BOARD>.dts`, `<BOARD>_defconfig`)
- `samples/hello_world` — select application & features (`prj.conf`)

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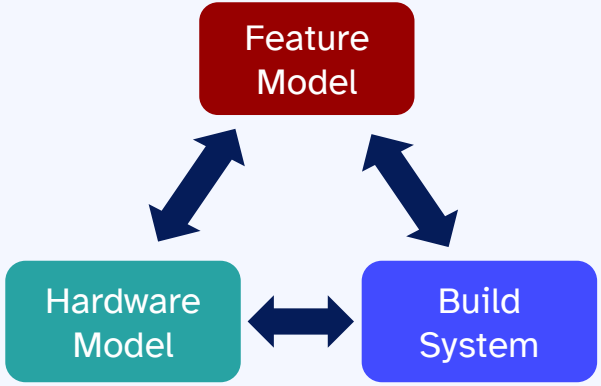
Models in Zephyr



3 domain-specific models at play

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- `samples/hello_world` — select application & features (`prj.conf`)

models are coupled and interact with each other !!!

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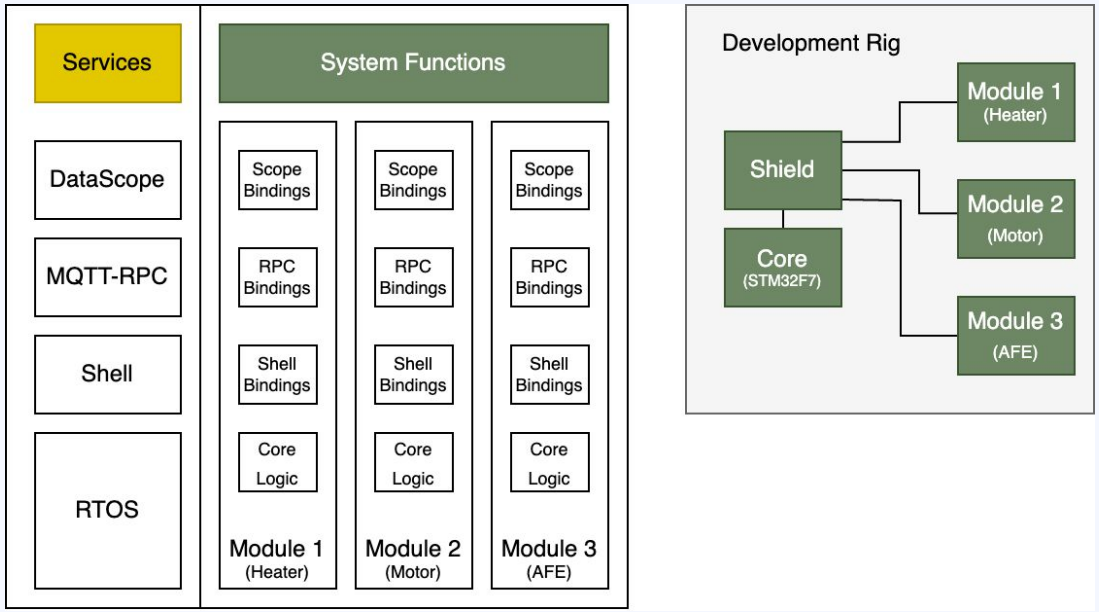
Introducing ACME-NG



A couple of years ago ...

Goals of ACME : develop new type of high-performance test to diagnose Covid-19

Iterative system design - basic system functions known but specific details dependent on reagent chemistry developed simultaneously

Time to Market - extremely time-sensitive due to ongoing pandemic

Supply-Chain-Risks - Availability of HW components worsened dramatically during project time

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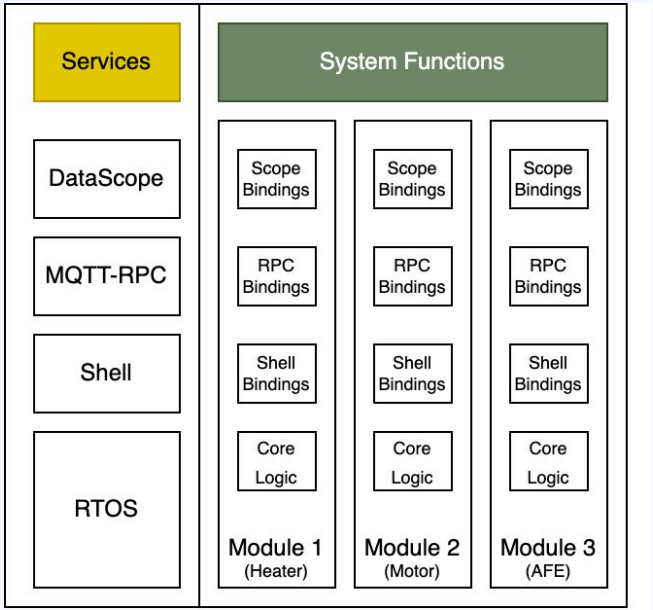
Modeling Software Features w/ Kconfig




```
1   menu "ACME Subsystems"
2
3    menu "Modules"
4     rsource "m_heater/Kconfig"
5     rsource "m_motor/Kconfig"
6     rsource "m_afe/Kconfig"
7    endmenu #Modules
8
9    menu "Core Services"
10    rsource "s_mqtt_rpc"
11    rsource "s_datascope"
12   endmenu #Core Services
13  endmenu #ACME Subsystems
```

System Model
(Architecture)

Software Model
(Architecture, Design)

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Modeling Software Features w/ Kconfig

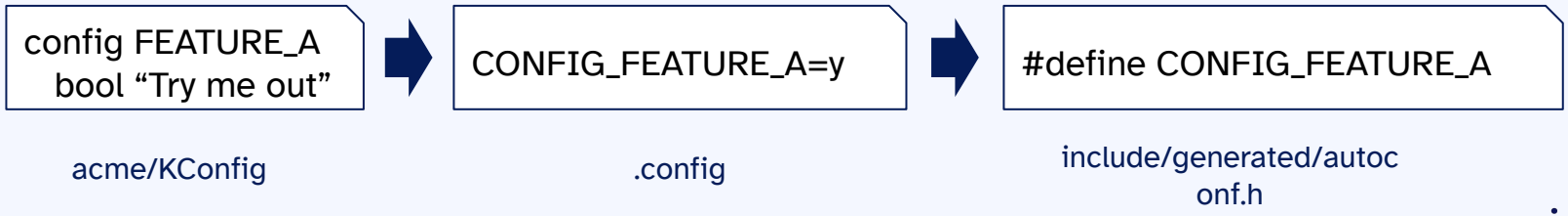
```
menu "ACME Subsystems"

 menu "Modules"
  rsource "m_heater/Kconfig"
  rsource "m_motor/Kconfig"
  rsource "m_afe/Kconfig"
 endmenu #Modules

 menu "Core Services"
  rsource "s_mqtt_rpc"
  rsource "s_datascope"
 endmenu #Core Services
endmenu #ACME Subsystems
```

```
menuconfig ACME_SUBSYS_HEATER # option to toggle the entire subsystem on/off
    bool "Heater subsystem"
    help
        The Heater subsystem is responsible for measuring and controlling
        the temperature.

if ACME_SUBSYS_HEATER

    config ACME_SUBSYS_HEATER_THREAD_STACK_SIZE
        int "Stack size of subsystem thread"
        default 2048

    config ACME_SUBSYS_HEATER_MQTT_RPC
        bool "Enable MQTT-RPC bindings for $(subsys-str) subsystem"
        depends on ACME_MQTT_RPC

    config ACME_SUBSYS_HEATER_SHELL
        bool "Enable shell bindings for $(subsys-str) subsystem"
        depends on SHELL

    config ACME_SUBSYS_HEATER_SCOPE
        bool "Enable data scope bindings for $(subsys-str) subsystem"
        depends on ACME_SCOPE #only selectable if datascope is enabled

endif
```

Modeling Software Features w/ Kconfig

Kconfig is a domain-specific language to describe software feature models

- features are typed & can relate to each other (**`select, depend, imply`**)
- models can be composed from smaller models (**`[or]source`**)
- models are transformed at build time into C language constructs



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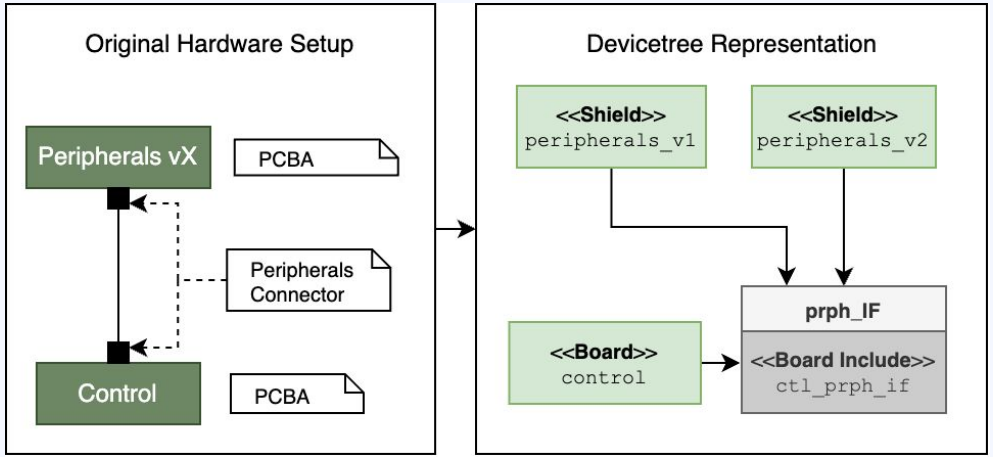
Modeling Hardware Features w/ Devicetree

Devicetree is a domain-specific language to describe **hardware properties** which are **software relevant**

If used correctly, HW setups can be mapped faithfully to devicetree models including hardware interface aka interconnects



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Modeling Hardware Features w/ Devicetree

```
/ {
        model = "Nordic nRF52840 DK NRF52811";
        compatible = "nordic,nrf52840-dk-nrf52811";

        aliases {
                led0 = &led0;

        leds {
                compatible = "gpio-leds";
                led0: led_0 {
                        gpios = <&gpio0 13 GPIO_ACTIVE_LOW>;
                        label = "Green LED 0";
                };

        gpio0: gpio@50000000 {
                gpio-controller;
                compatible = "nordic,nrf-gpio";
                reg = < 0x50000000 0x200 0x50000500 0x300 >
                #gpio-cells = < 0x2 >;
                status = "okay";
                …
                };
}
```

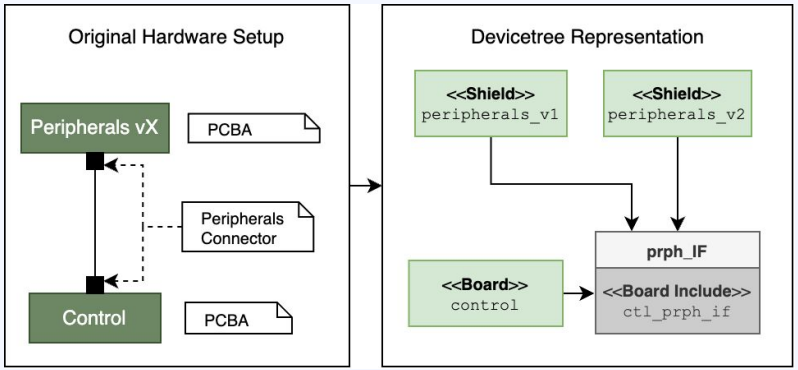
scripts/dts/gen_defines.py

```
#include <generated/devicetree_generated.h>
```

```
#include <zephyr/devicetree.h>

#define LED0_NODE DT_ALIAS( led0)

static const struct gpio_dt_spec  led = GPIO_DT_SPEC_GET(LED0_NODE,
gpios);

int main(void)
{
        int ret;
        bool led_state = true;

        if (!gpio_is_ready_dt(& led)) {
                return 0;
        }

        ret = gpio_pin_configure_dt(&led, GPIO_OUTPUT_ACTIVE);
…
```

The power of models

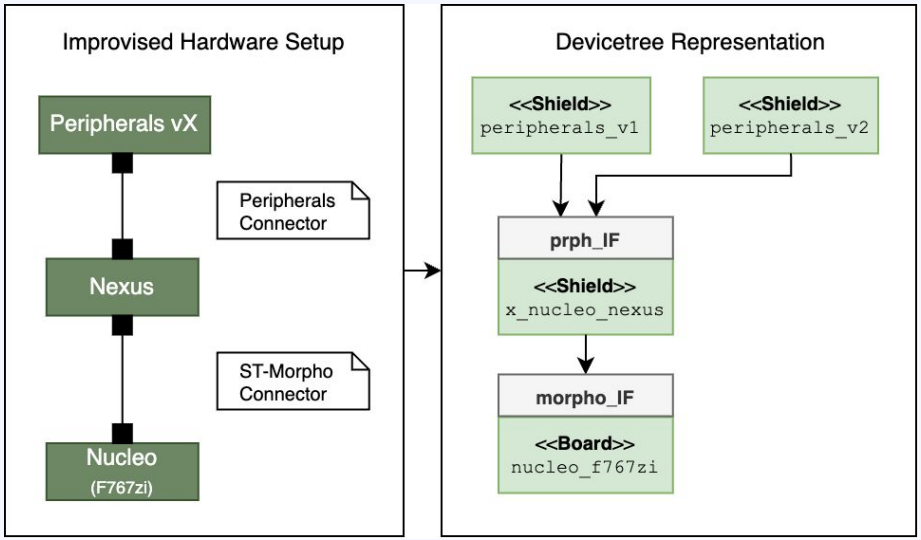
When supply chains fall apart ...



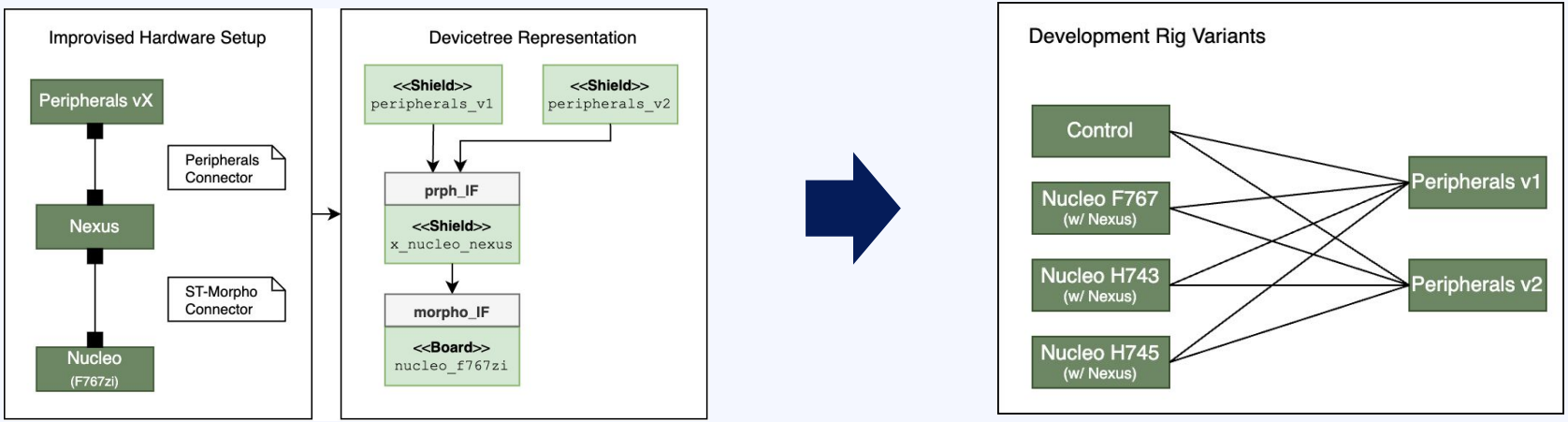
When ACME needed parts to make hardware the most, the parts had disappeared ...

... and all we could do, was to by existing devkit boards

devicetree models allowed us to **compensate for all HW changes** without touching a single line of source code

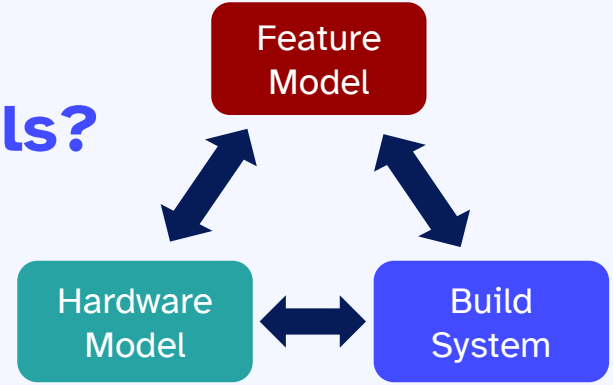


When supply chains fall apart ...




```
west build -b core -shield peripherals_v1 acme_app
west build -b core -shield peripherals_v2 acme_app


west build -b nucleo_f767zi -shield x_nucleo_nexus -shield peripherals_v1 acme_app
west build -b nucleo_h743zi -shield x_nucleo_nexus -shield peripherals_v1 acme_app
```

What makes us go that fast w/ models?



Appropriate: Devicetree, Kconfig and CMake established and mature

Textual DSL: easy to diff and version control, models as code

Automated: model transformations happen as part of software build process

Transparent: generated expressions consumable by standard C compiler

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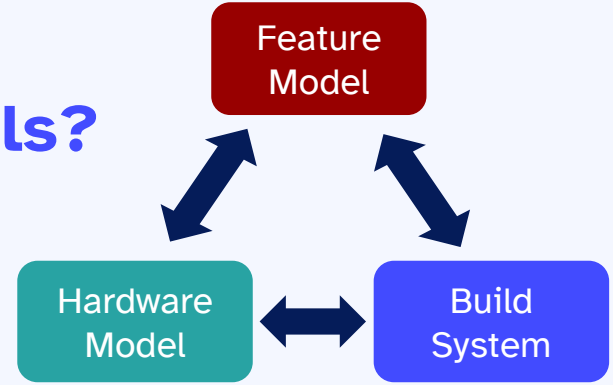
What makes us go that fast w/ models?



Integrable: Models can interact with each other to further increase usefulness

Extensible: Model languages can be extended with new constructs

Open: Underlying technologies open-source, no limitations to use or future development

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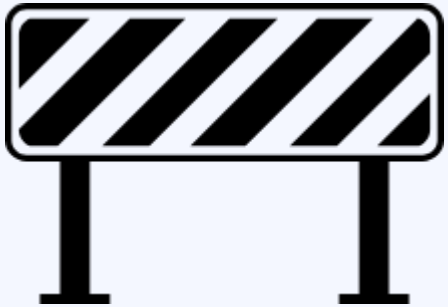
No model is perfect - never



Existing models as expressed by Kconfig, Devicetree and Zephyr CMake functions already extremely powerful ...

... however, not without limitations:

- missing abstractions: connectors (interface & multi-instance)
- missing concepts: multi-board setups (only via --shield ... --shield ...)
- missing composability: CS-lines of SPI devices

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Conclusion

- Zephyr showcases MDSD techniques, not through intent but by convergence
- Productivity gains partly explainable through this modeling approach
- Still plenty of space for improvements:
  - What other transformations could be looked at?
  - What other domains could be modeled?

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Thank You

Zephyr Hands-On Trainings
starting 2025: Jan 22/23, Apr 02/03, Jul 02/03

Find out more
https://www.inovex.de/de/training/zephyr-basic-training/

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