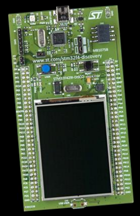
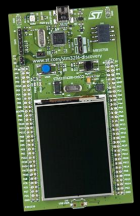
Microcontroller programming

02 – The basic toolset



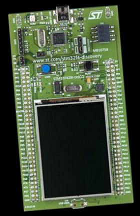
Reading tips

- The keyboard symbol means it's practice time
- Colored text usually carries a meaning :
  - Blue text highlights a new concept or an important lesson to take away
  - Red text highlights a tricky part or a risk of mistake
  - Green text highlights good practices and stuff that is now done
- At the end of each slide deck, you'll find a recap of technologies and concepts



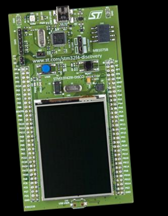
Agenda

- What's in STM32 Cube ?
- Blinking LED
- Hardware corner: GPIO
- The code behind a blinking LED
- Hardware corner: interrupt
- Configuring pins with STM32 CubeMX
- Software corner: C weak symbol



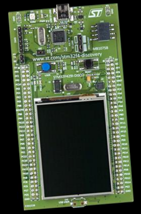
What's in STM32 Cube ?

Butterfly sold separately



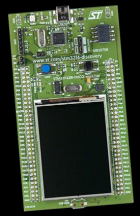
What's in STM32 Cube ?

- What is a **development environment for embedded** ?
- Slightly different than programming for a PC !
- Our needs:
  - Writing code
  - Compiling code to a program
  - Storing program on the target hardware
  - Debugging program from the target hardware



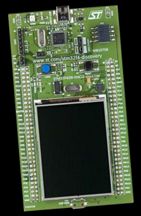
What's in STM32 Cube ?

- Our needs:
  - Writing code ➔ Text editor on console / GUI
  - Compiling code to a program ➔ Cross-compiler
  - Storing program on the target hardware ➔ Flasher (for “flashing”)
  - Debugging program from the target hardware ➔ Cross-debugger
- Some new terms for you !



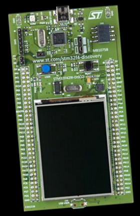
What's in STM32 Cube ?

- The **cross-compiler** runs on hardware architecture A, and produces code for hardware architecture B
- A → host
- B → target
  - x86-64 → ARM
  - PowerPC → aarch64 *[64-bits ARM]*
  - …
- “gcc” is actually a native compiler (A == B)



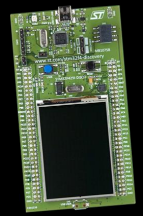
What's in STM32 Cube ?

- Native compilers are not practical for MCUs
- Compiling is very CPU intensive
  - You would wait forever
- Compilers are big
  - You can’t even store them on the board !
  - On Alpine Linux gcc binary is 1.7MB large (without dependencies)
  - STM32F429ZIT internal flash is 2MB large



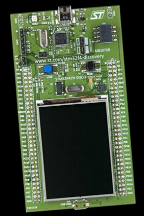
What's in STM32 Cube ?

- Compiler examples !
- **gcc**
  - Implicitly native for your arch (e.g. x86-64 → x86-64)
- **arm-none-eabi-gcc**
  - Host : your arch
  - Libc: none
  - ABI : Extended ABI
  - Target: ARM (32-bits)
- (The compiler’s full name is called a tuple)



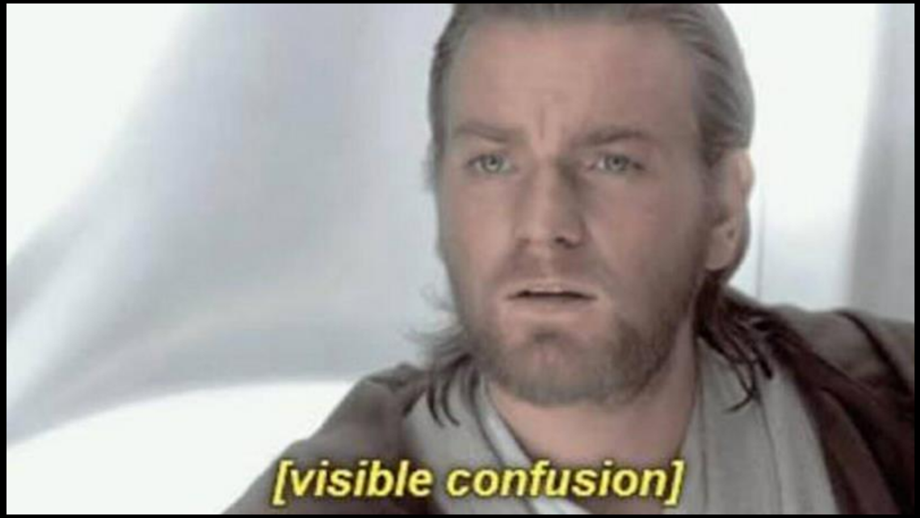
What's in STM32 Cube ?

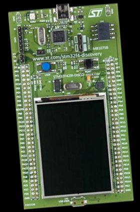
- **mips32-musl-eabi-gcc**
  - Host : your arch
  - Libc: musb libc (official website)
  - ABI : Extended ABI
  - Target: ARM (32-bits)
- **riscv64-glibc-gnueabi-gcc**
  - Host: your arch
  - Libc: GNU C library (the most common one)
  - ABI: GNU Extended ABI
  - Target: Risc-V 64-bits



What's in STM32 Cube ?

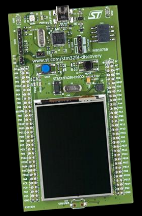
- This logic works with gcc but also clang, Keil, Microchip etc.
- You may be asking yourself:
  - *Why are there multiple C libraries ?*
  - *What is an ABI ?*
  - *How to choose a cross-compiler ?*
- We’ll answer those questions later ;-)





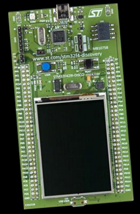
What's in STM32 Cube ?

- The **simplest toolset for the ARM course** could be:
  - Writing ➔ vim
  - Compiling ➔ arm-none-eabi-gcc
  - Flashing ➔ openocd
  - Debugging ➔ openocd
- All are command-line tools
- All are open-source are require no license



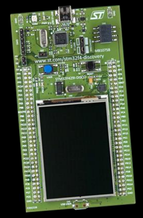
What's in STM32 Cube ?

- **For ARM course let's use the beginner-friendly STmicro IDE**
- The IDE allows not thinking about :
  - Where to get libraries, and which ones ? (they require configuration)
  - How to handle board-specific code ? (it would requires directly diving into the SMT32F429 reference manual)
  - How to boot my MCU ? (specific initialization code would again require precautious study of the STM32F429)
- *Let’s launch STM32 Cube IDE !*



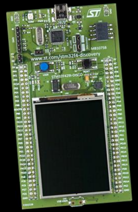
What's in STM32 Cube ?

- STM32 Cube IDE is an Eclipse-based IDE, and offers :
  - Text editor
  - C/C++ Compiler
  - Flasher
  - Debugger
  - Board-specific graphical configurator
  - Board-specific code generator
  - Hardware Abstraction Layer (think “library” for now)
  - Example programs



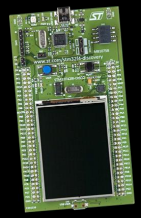
What's in STM32 Cube ?

- Today we'll be doing the "Hello World" of embedded systems...switching a LED when you press a button
- This simple application will require understanding :
  - How STM32 Cube generates code for us
  - What is the generated code's structure
  - Figuring out why the main loop looks weird



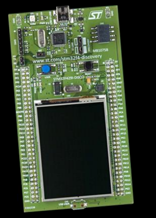
Blinking LED

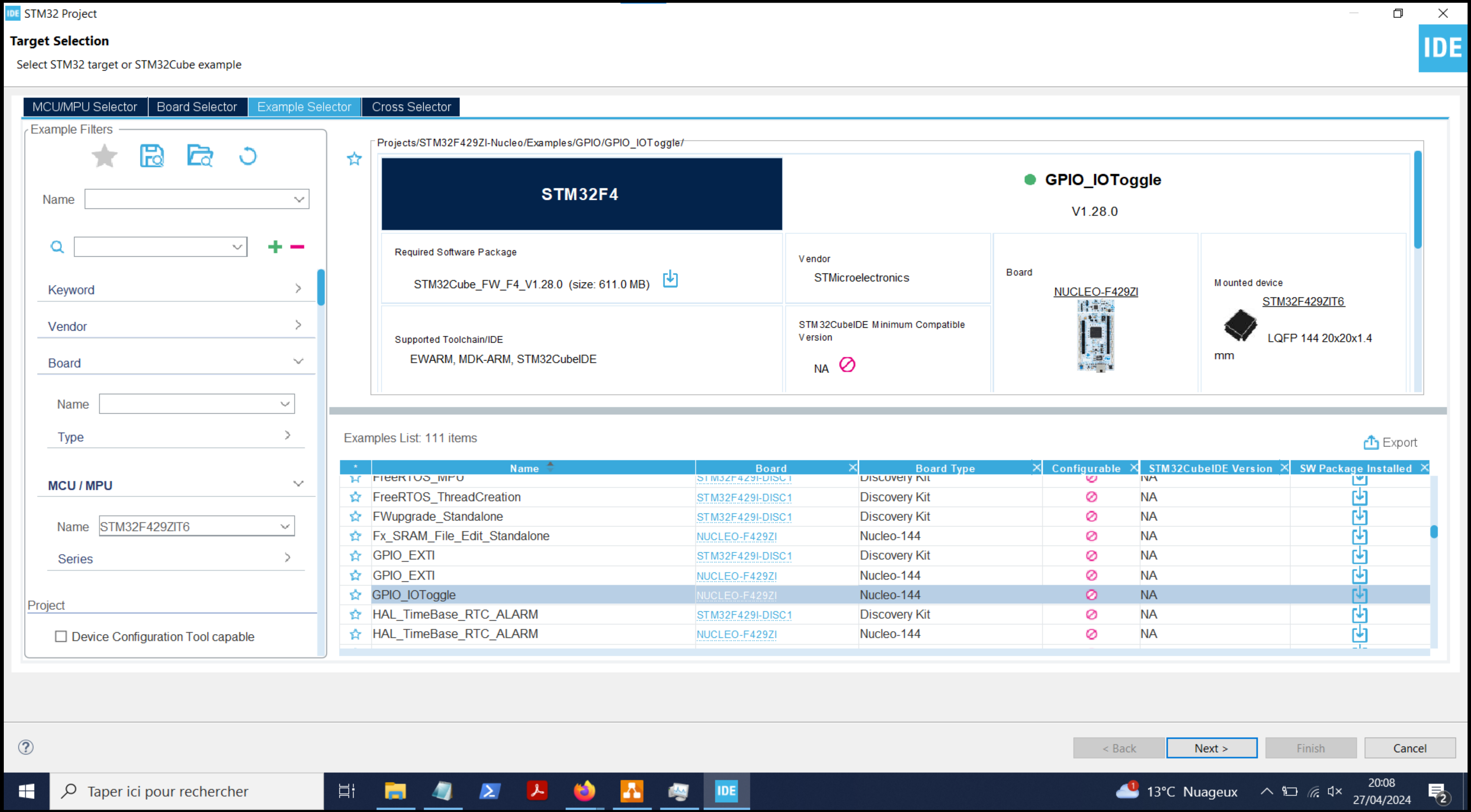
Gotta start somewhere



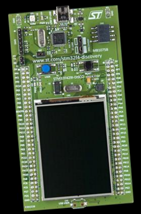
Blinking LED

- **Please open the GPIO_EXTI project**
  - You should already have downloaded it before the course
  - Open *gistre26-arm-setup.pdf* on Moodle if not !
- Please compile and run the program on the devkit
- Let’s take a moment to make sure everyone is up and running
- The following slides offer tips for debugging



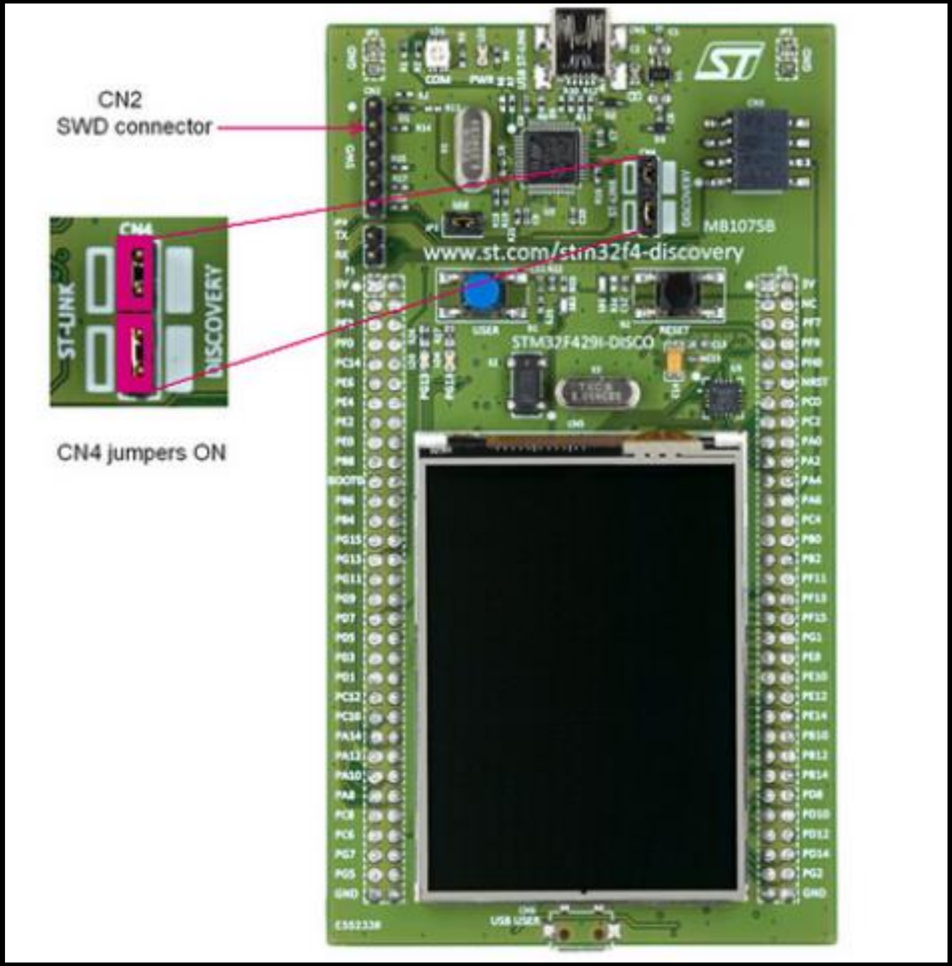


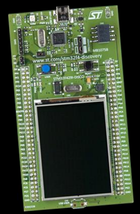
The STM32 Cube IDE example code selector



Blinking LED

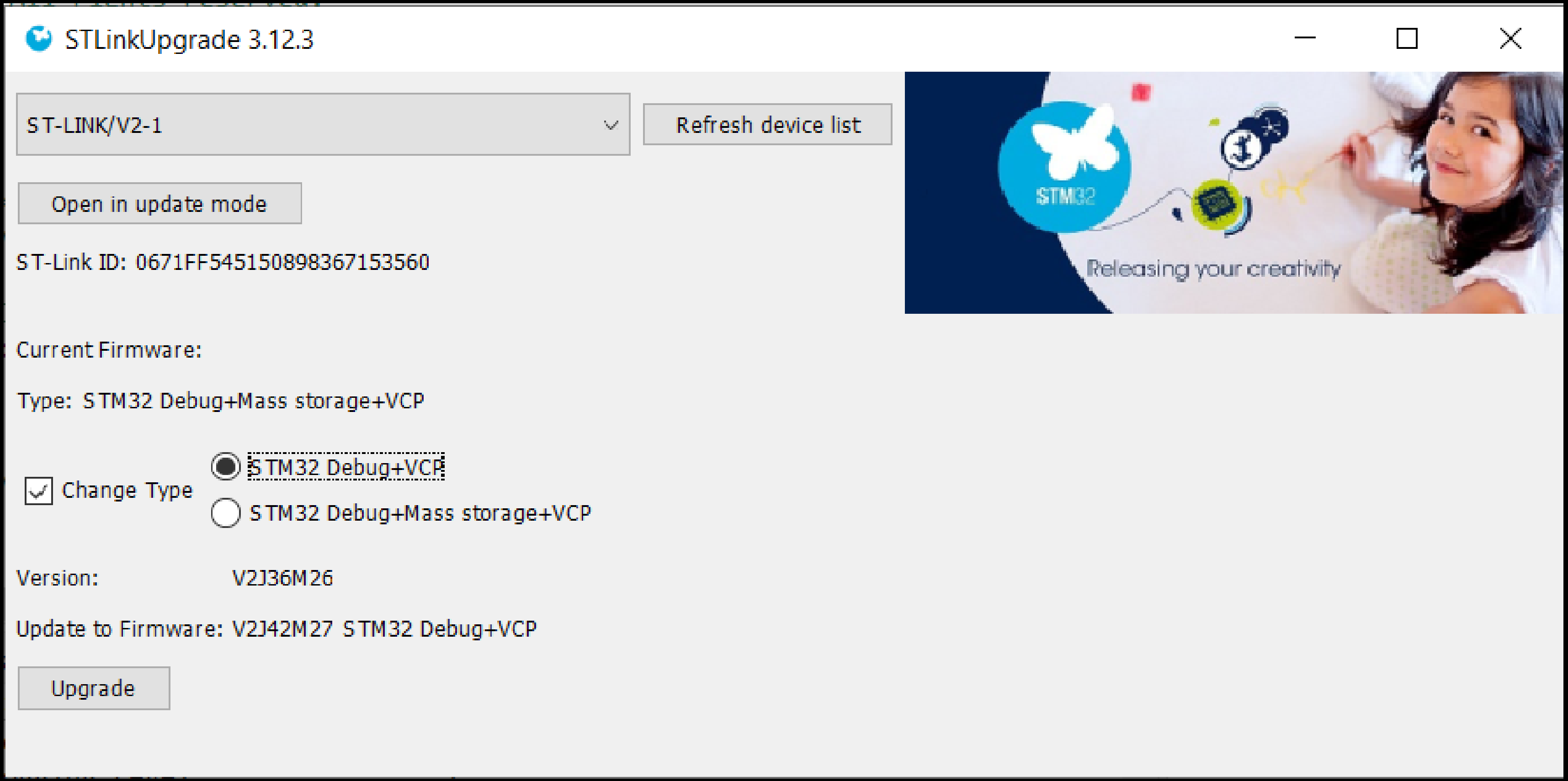
Make sure you've put on jumpers on *JP3* (1 jumper) and *CN4* (2 jumpers) in order to be able to connect to the board using USB

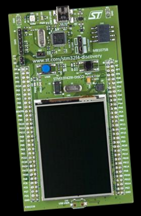




Blinking LED

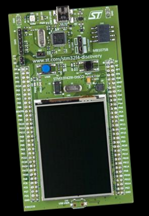
- Make sure to upgrade the ST link firmware if asked
- The prompt looks like this :





Hardware corner: GPIO

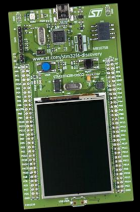
General Purpose Input/Output



Hardware corner: GPIO

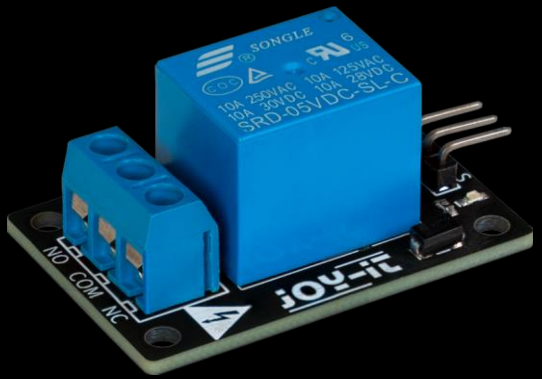
<u>New Hardware : GPIO</u>

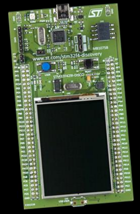
- **GPIOs are digital, 1-wire signals**
- 1 GPIO means 1 pin
- Can generally be in one of 3 **states**:
  - Input (reading)
  - Output (writing)
  - Floating (detached)



Hardware corner: GPIO

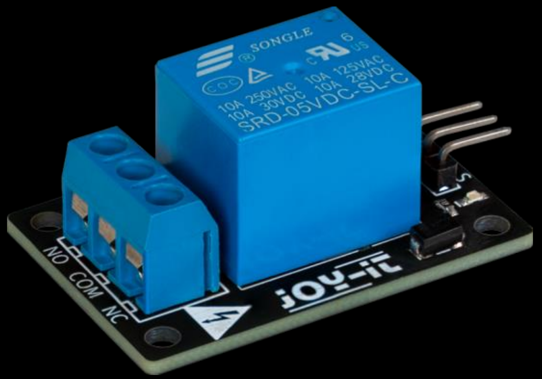
- GPIOs are used for controlling devices with binary logic
  - Buttons (pressed / not pressed)
  - Lights (on / off)
  - Relays (current flows / current does not flow)
- GPIOs can also be used for manual signal generation

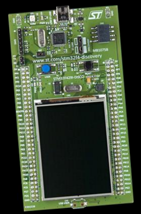




Hardware corner: GPIO

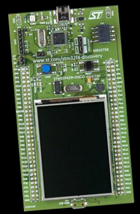
???





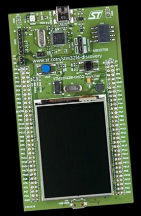
Hardware corner: GPIO

- Merci *Le Chat* (Mistral AI) ☹
- Ceci est un signal *analogique* qu'il est bien sûr impossible de générer avec une GPIO !



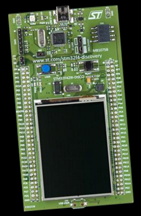
Hardware corner: GPIO

- Programming the GPIO is possible thanks to registers
  - Some register bank is associated with the GPIO
  - The register bank is linked to the CPU through the I/O bus
- As input...
  - Default value can be set (push/pull : pull-up == VREF, pull-down == GND)
  - Default value can also be left floating/tristate which can be required by the facing component's datasheet
  - CPU reads value from register
- As output...
  - CPU writes value to register



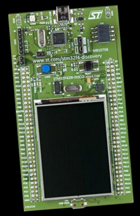
Hardware corner: GPIO

- Finally, GPIOs are usually organized in GPIO banks
- "Pin A-3" means GPIO bank A, pin number 3
  - Beware 0-based counting ;-)
- Banks are usually powered separately
  - This opens the way to power-efficient designs
- Each GPIO bank has got its register bank
  - Thus each GPIO bank is operated independently



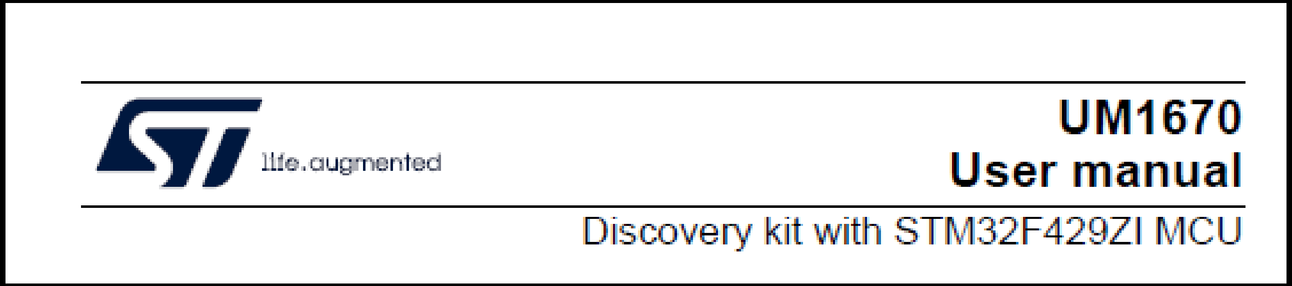
Hardware corner: GPIO

- Let us build an hardware architecture model for the STM32F429I-DISC1 development kit
- During the course, we shall enrich that model
- We begin our architecture study with the green LED
- You will now need to master the documentation needed to get correct information on a microcontroller system
- We begin with the development kit’s user manual !



Hardware corner: GPIO

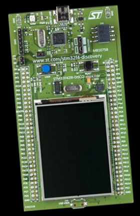
- Find the STM32F429I-DISC1’s user manual on st.com
  - Official name: UM1670
  - Target document revision: 5



life.augmented

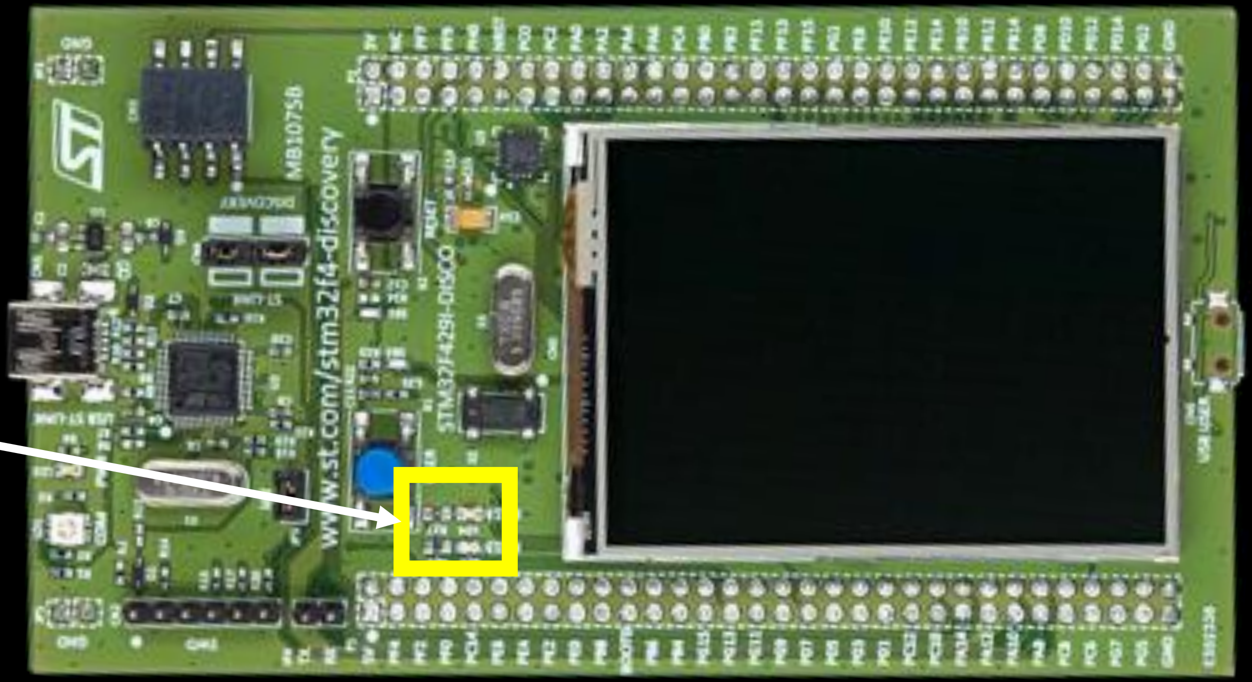
UM1670
User manual

Discovery kit with STM32F429ZI MCU



Hardware corner: GPIO

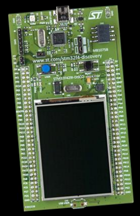
LD3



Find LD3 in the STM32F429I-DISC1 user manual.

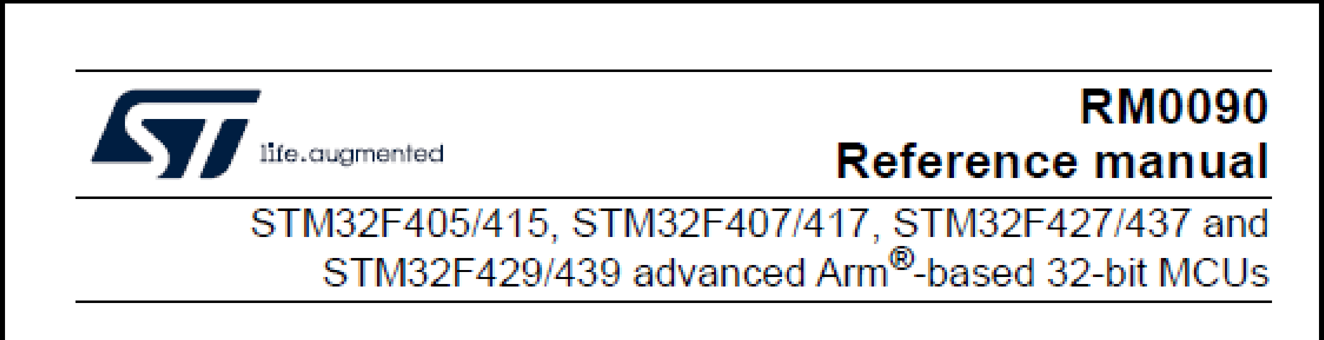
Hardware corner: GPIO

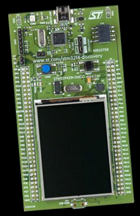
- The development kit's user manual describes hardware information specific to the board
  - LD3 is routed to some GPIO of the MCU
  - Documented by EE (Electronics Engineers) who built the devkit…
  - …who are not the EE who built the MCU !
- Information specific to the MCU will be found elsewhere
- Different levels of hardware → different documents
- Our low-level treasure trove: the MCU reference manual !



Hardware corner: GPIO

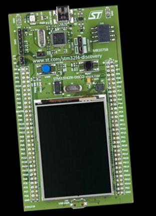
- Find the STM32F429 MCU reference manual on st.com
  - Official name: RM0090
  - Target document revision: 20



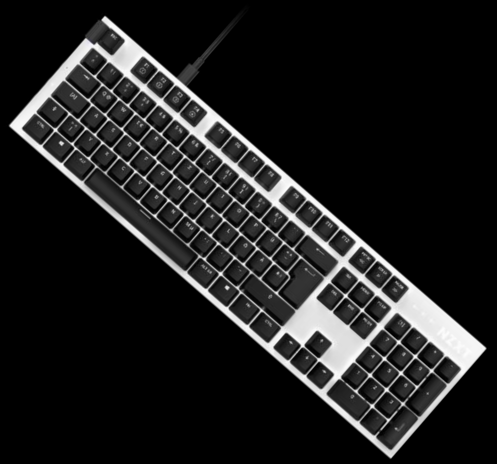


Hardware corner: GPIO

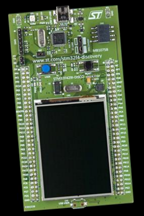
- Using the two documents in your hands:
  - Find which GPIO bank + pin number is routed to LD3
  - Find which the address in memory of the associated register bank, in the STM32F429 MCU memory system



Hardware corner: GPIO

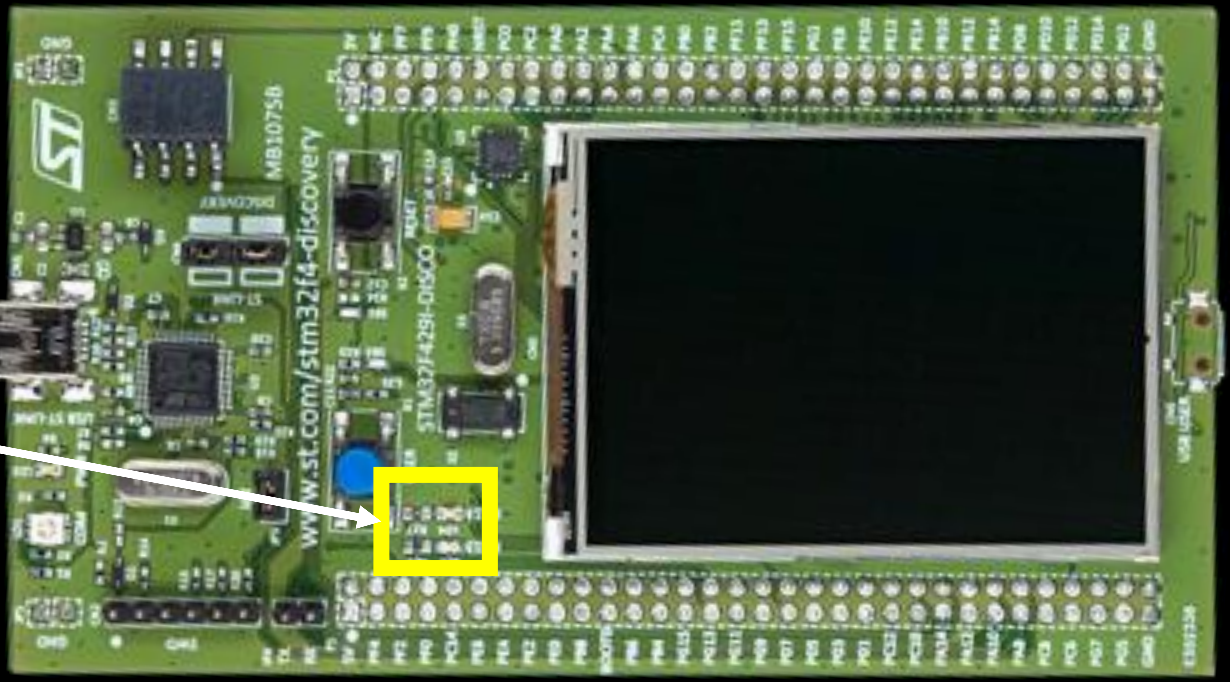


- Using the two documents in your hands:
  - Find which GPIO bank + pin number is routed to LD3
  - GPIO PG13 → bank G, pin 13 (UM1670 § 6.5)
  - Find which the address in memory of the associated register bank, in the STM32F429 MCU memory system
  - 0x4002_1800 (RM0090 table 1 “STM32F4xx register boundary addresses”)



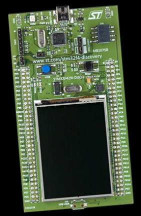
Hardware corner: GPIO

LD4



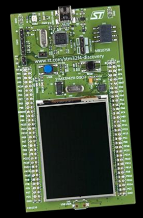
LD3 is actually named PG13 in the STM32F429 documentation

So GPIO bank G, pin number 13

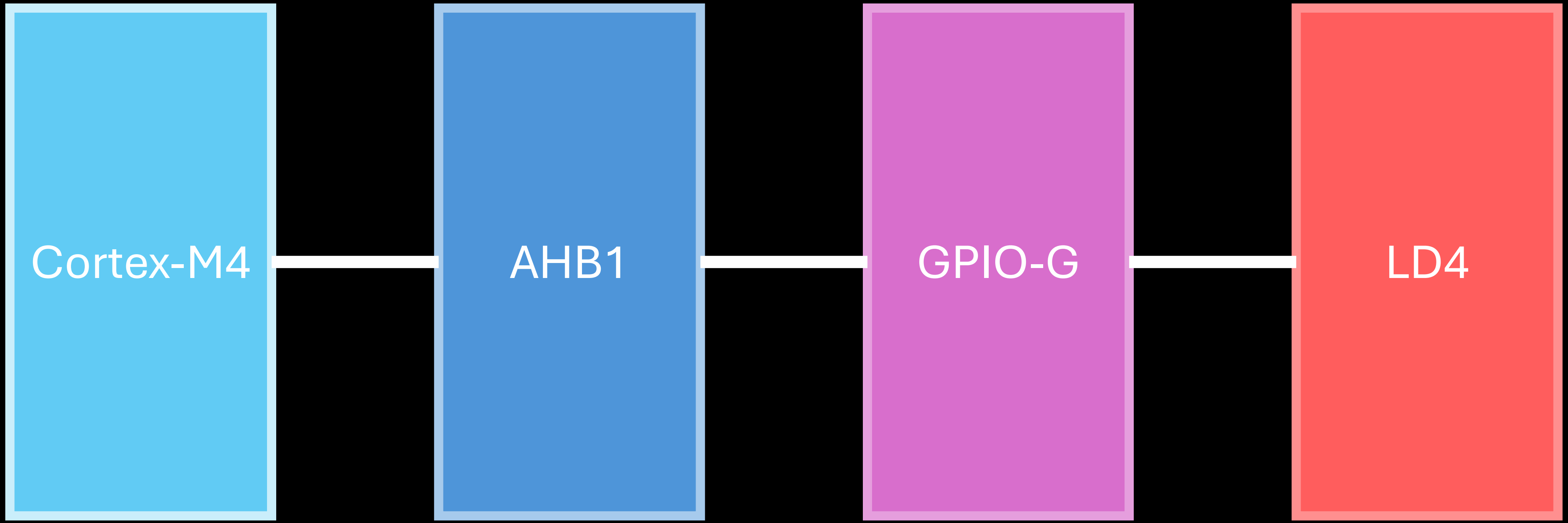


Hardware corner: GPIO

- Let us build an architecture model for the STM32F429I-DISC1 development kit
- During the course, we shall enrich that model
- We begin our architecture study with how CPU connects with LD4
- You will now discover the documentation needed to get correct information on a microcontroller system



Hardware corner: GPIO

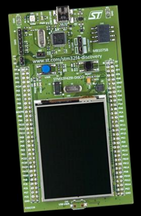


In this data flow diagram, the CPU (Cortex-M4) is connected to the high-speed AHB bus.

The AHB bus gives access to many peripherals, including GPIO banks.

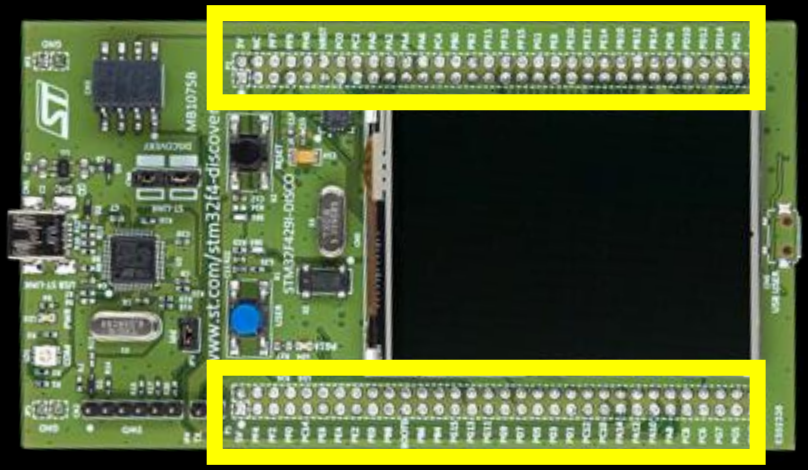
The GPIO bank G controls several pins.

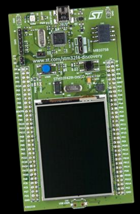
Pin 13 is physically soldered to LD4.



The code behind a blinking LED

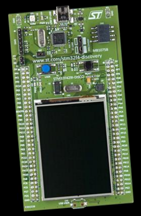
- The pins headers on your devkit are not necessarily GPIOs
- In fact, each pin of the MCU has a fixed set of functions it can be dynamically associated to (“GPIO” is one *function*)
- To know which pin can do what, you have to figure it the pin number in the general pin numbering scheme



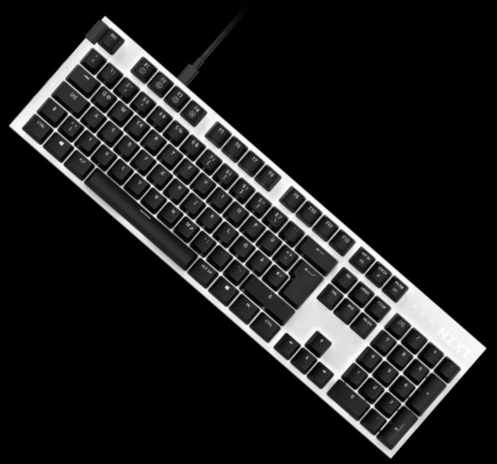


The code behind a blinking LED

- What document can explain MCU pin numbering ?
- What is the pin number of PG13 ?



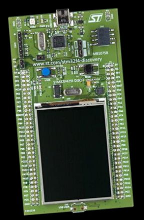
The code behind a blinking LED



- What document can explain MCU pin numbering ?
- What is the pin number of PG13 ?
- UM1670 table 7 (repeats pin # information)

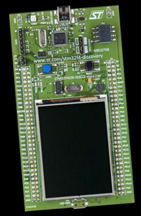
Table 7. STM32 pin description versus board functions (continued)

STM32 pin		Board functions																		
Main function	LQFP144	System	VCP	SDRAM	LCD-TFT	LCD-RGB	LCD-SPI	I3G4250D	USB	LED	Push-button	I^2C Ext	Touch panel	Free I/O	Power supply	CN2	CN3	CN6	P1	P2
PG13	128	-	-	-	-	-	-	-	-	Green	-	-	-	-	-	-	-	-	29	-



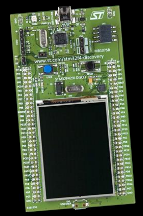
The code behind a blinking LED

Like a layered cake



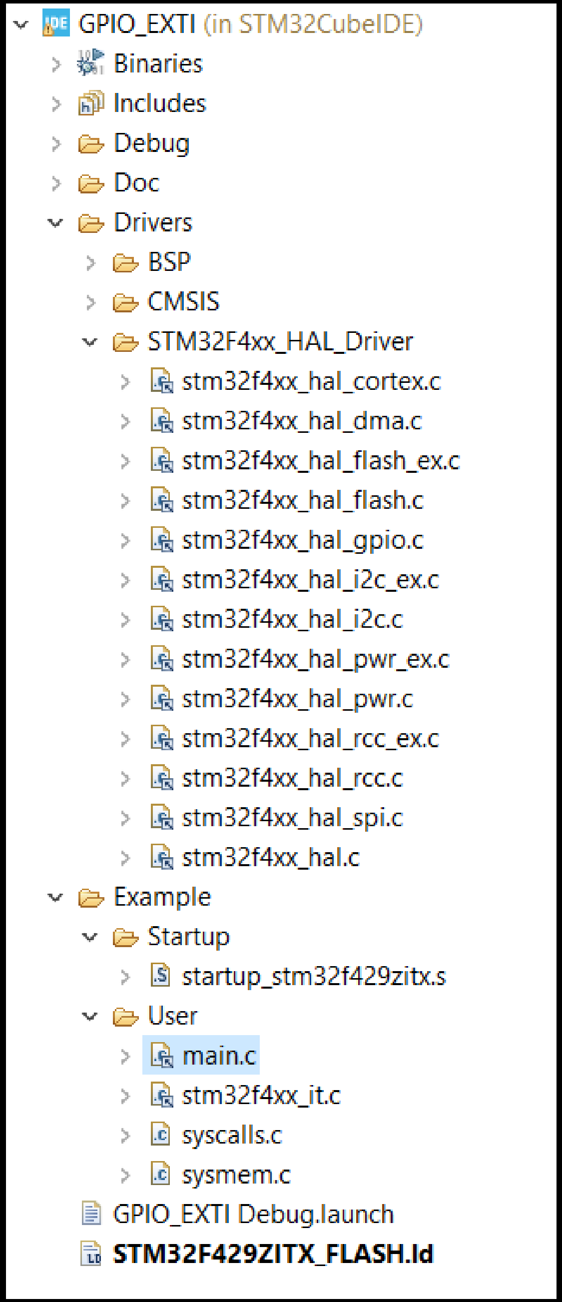
The code behind a blinking LED

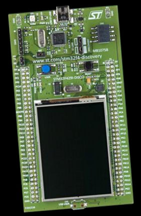
- As software developers, we should consider each piece of hardware as a new library to learn
- In fact, hardware manufacturers provide libraries to make our life easier → the Hardware Abstraction Layer
- The HAL is, by definition, specific to the target hardware
- In this course we’re studying STM32F429 HAL



The code behind a blinking LED

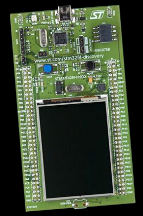
- Let's read the GPIO_EXTI project structure…
- Application code :
  - Main function in *Example/User/main.c* (feel free to modify !)
- MCU initialization :
  - Hardware initialization code in *Example/Startup/** (shouldn't touch)
- Libraries & drivers :
  - Hardware Abstraction Layer in *Drivers/STMF4xx_HAL_Driver/* (vendor API)
  - CMSIS layer in *Drivers/CMSIS/** (you can ignore)
  - STM32F429-Disco high-level layer in *Drivers/BSP/** (vendor API)





The code behind a blinking LED

- All this code has been generated for us...why ?
- This is a good occasion to build a software architecture model
- Here, we'll draw a **layer diagram** to focus on dependencies
- This will not be a . h include tree



The code behind a blinking LED

GPIO_EXTI app

STM32F429I Discovery BSP

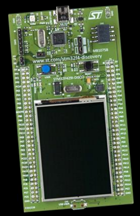
STM32F429 HAL GPIO

GPIO_EXTI software architecture, layered view. This simplified view focuses on GPIO control.

The app (the main() function) sits on a vendor “BSP” library.

The BSP sits on the STM32F429 HAL.

The HAL knows what registers to control, and their addresses.



The code behind a blinking LED

GPIO_EXTI app

```
    /* Toggle LED3 */
    BSP_LED_Toggle(LED3);
```

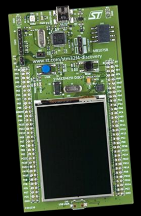
STM32F429I Discovery BSP

```
void BSP_LED_Toggle(Led_TypeDef Led)
{
  HAL_GPIO_TogglePin(GPIO_PORT[Led], GPIO_PIN[Led]);
}
```

STM32F429 HAL GPIO

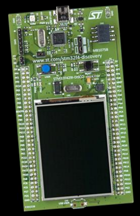
```
void HAL_GPIO_TogglePin(GPIO_TypeDef* GPIOx, uint16_t GPIO_Pin)
{
  uint32_t odr;

  /* Check the parameters */
  assert_param(IS_GPIO_PIN(GPIO_Pin));

  /* get current Output Data Register value */
  odr = GPIOx->ODR;

  /* Set selected pins that were at low level, and reset ones that were high */
  GPIOx->BSRR = ((odr & GPIO_Pin) << GPIO_NUMBER) | (~odr & GPIO_Pin);
}
```

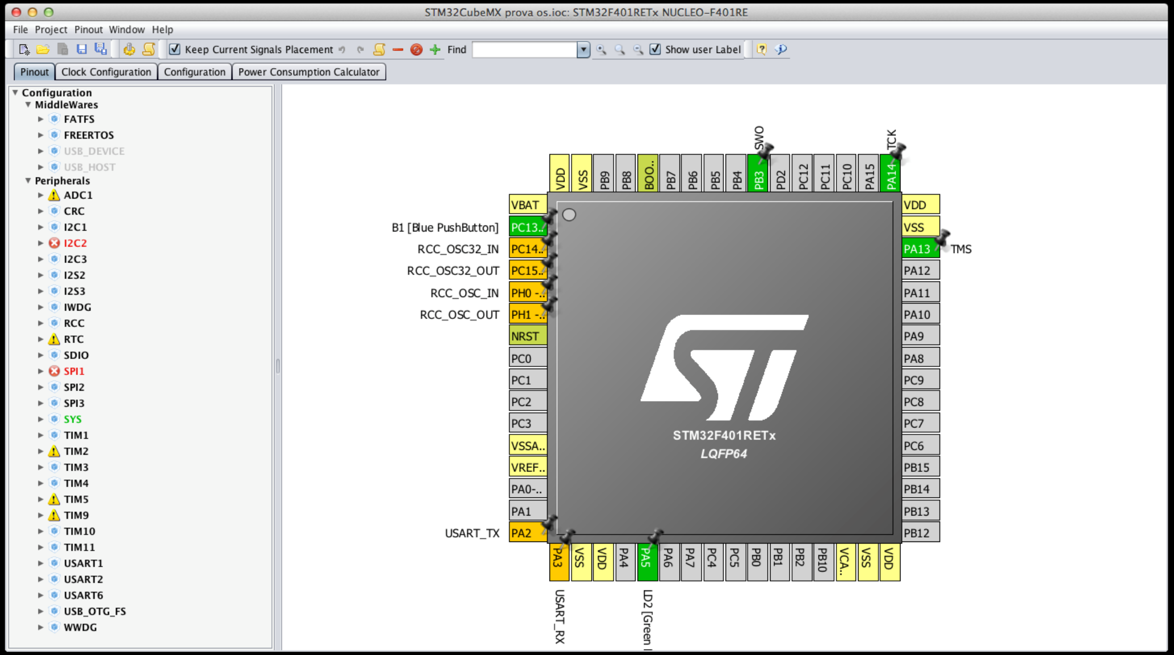
Only the HAL knows about registers (ODR, BSRR…)



The code behind a blinking LED

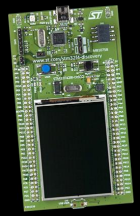
- Looks like the BSP layer just adds symbolic names
  - We should throw it away !
- The HAL is really useful
  - Practical software engineering for MCUs use the HAL
  - Developers build hardware-agnostic libraries on top of that
- Could we have controlled the GPIO by hand ?
- Let’s recode this app ourselves





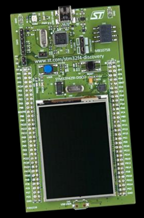
Configuring pins with STM32CubeMX

Graphical bonanza



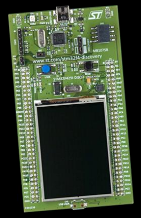
Configuring pins with STM32CubeMX

- We're going to do the same blinking code but ourselves, without premade code
- Let's create a new STM32 project again, but this time go to the **MCU Selector** and find our STM32F429 reference
- Don’t go to example projects



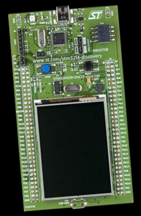
Configuring pins with STM32CubeMX

- You'll find the following variants :
  - STM32F429ZIT6
  - STM32F429ZIT6TR
  - STM32F429ZIT7
- We wanted "STM32F429ZIT6U"...
  - Can we still use one of these variants ?

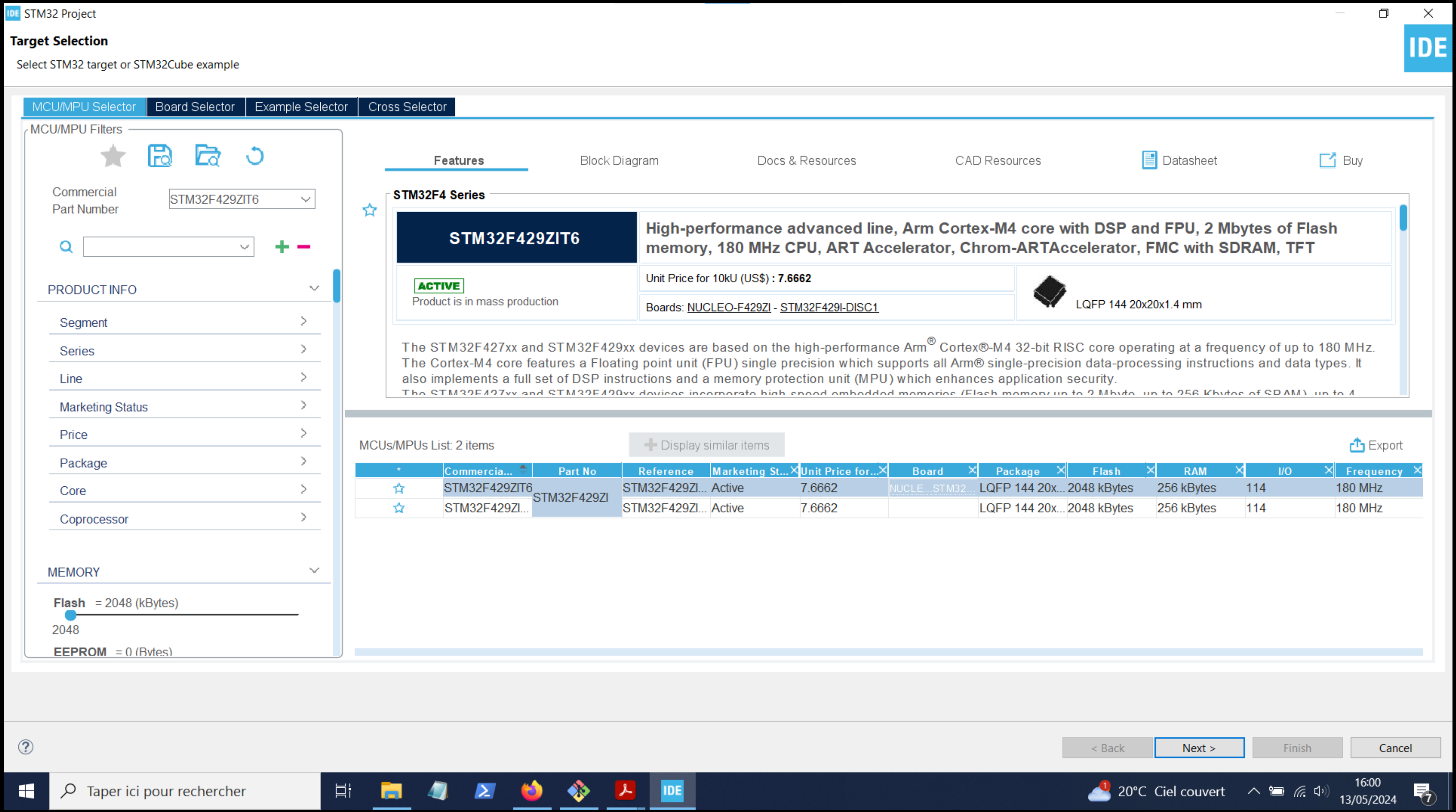


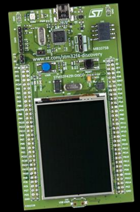
Configuring pins with STM32CubeMX

- You'll find the following variants :
  - STM32F429ZIT6
  - STM32F429ZIT6TR
  - STM32F429ZIT7
- Any one of these is fine !
  - Recall MCU datasheet § 8 "Part numbering" : 6 is chip temperature range, and "TR" indicate chip is packaged in tape and reel format
  - **Let's pick STM32F429ZIT6**



Configuring pins with STM32CubeMX



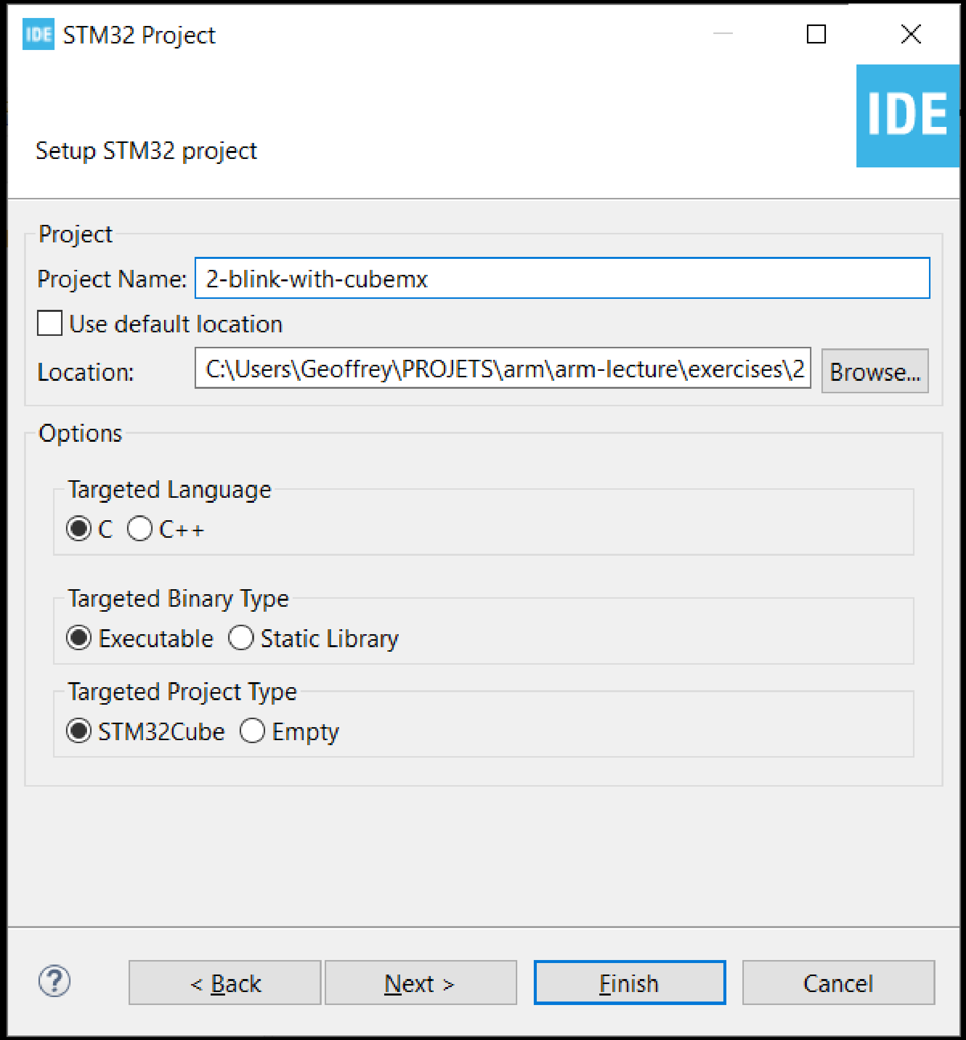


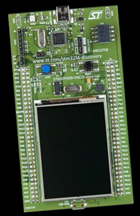
Picking the MCU

Configuring pins with STM32CubeMX

Create a new STM32 project.
Make sure to check "STM32Cube" as Target Project Type to get the CubeMX environment.

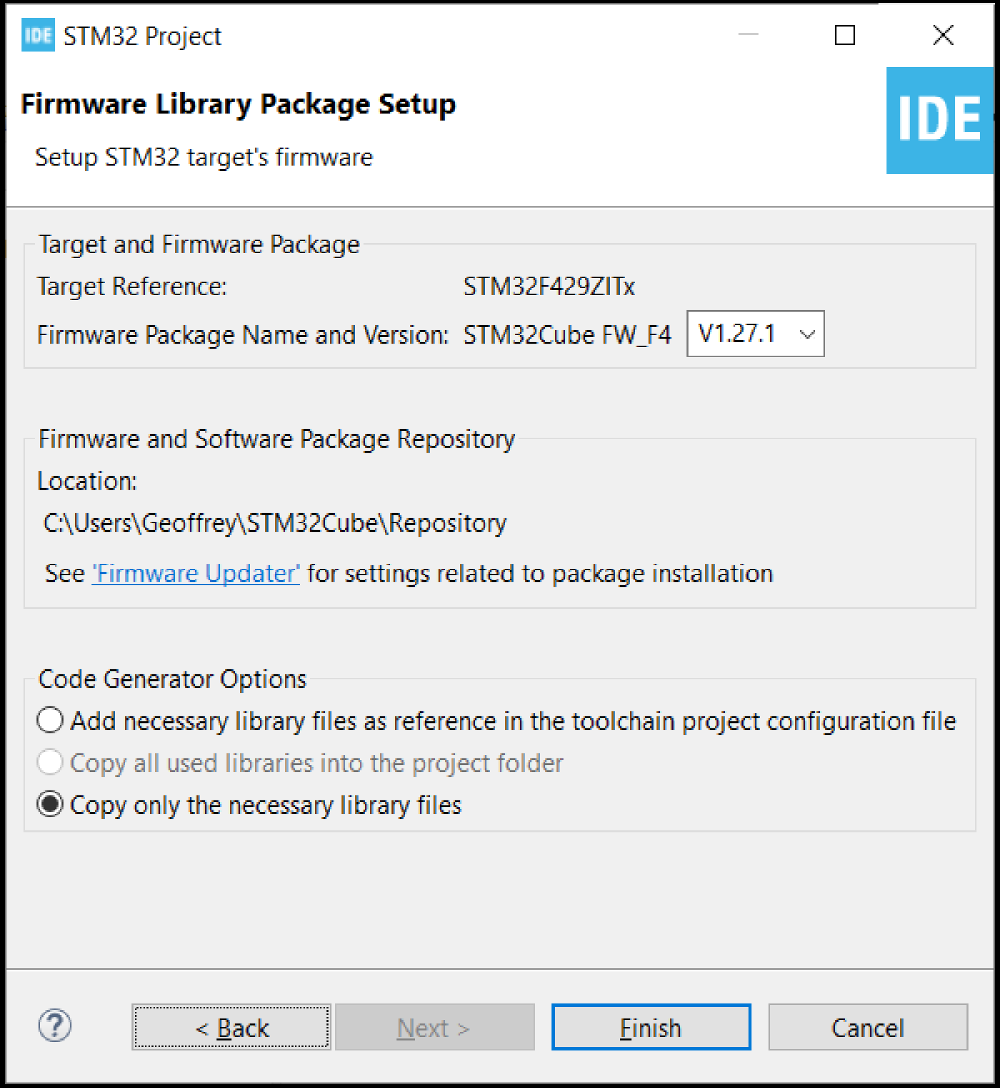
We'll use it to configure GPIOs using a GUI.

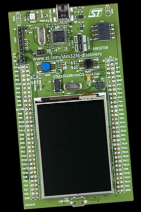




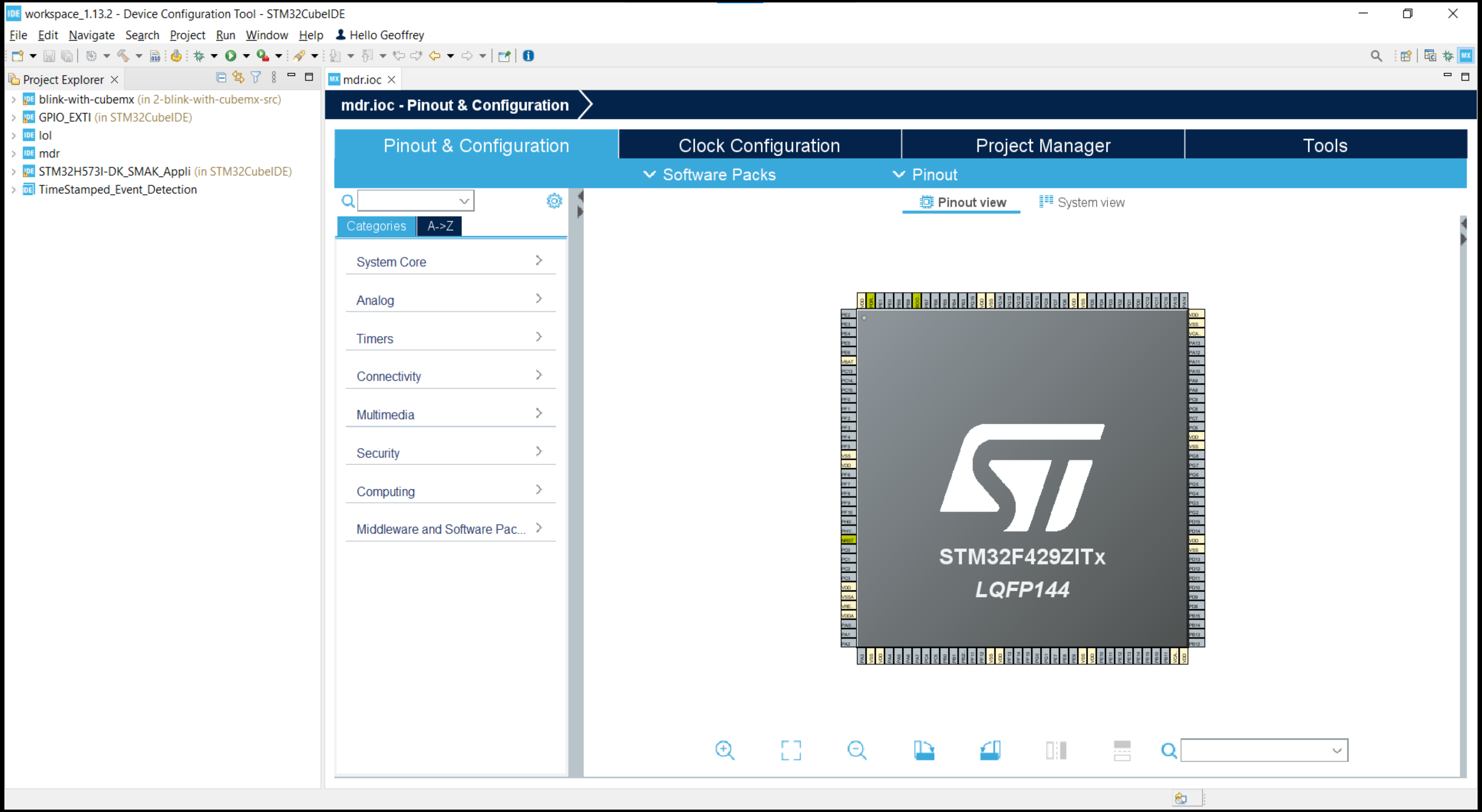
Configuring pins with STM32CubeMX

“Initialize peripherals to default ?”
==> Yes

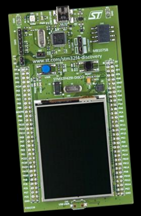




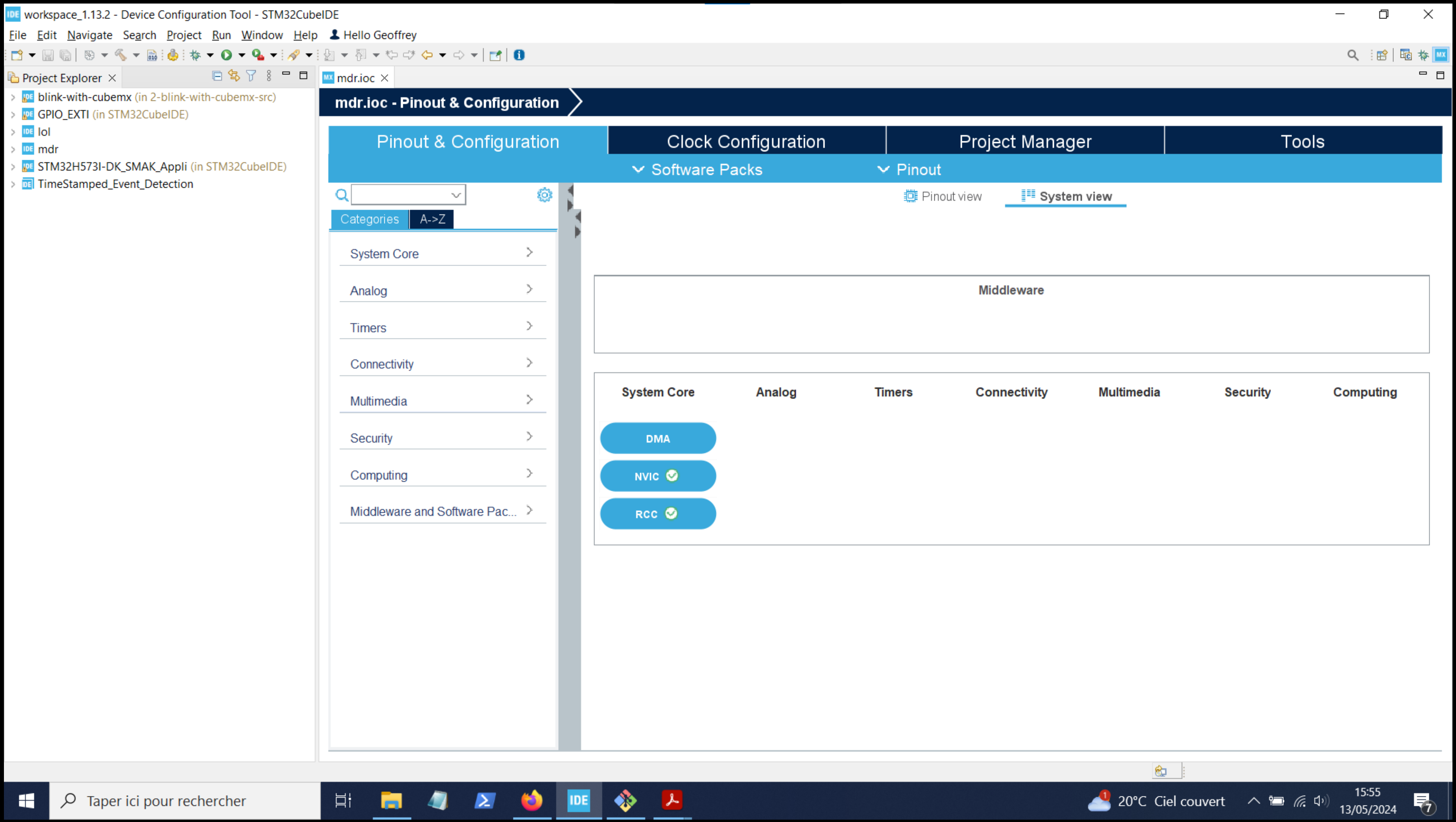
Configuring pins with STM32CubeMX



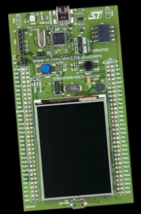
Our new project ! Meet CubeMX GUI.



Configuring pins with STM32CubeMX



The *System view* lists all enabled peripherals. For now we have the bare minimum.

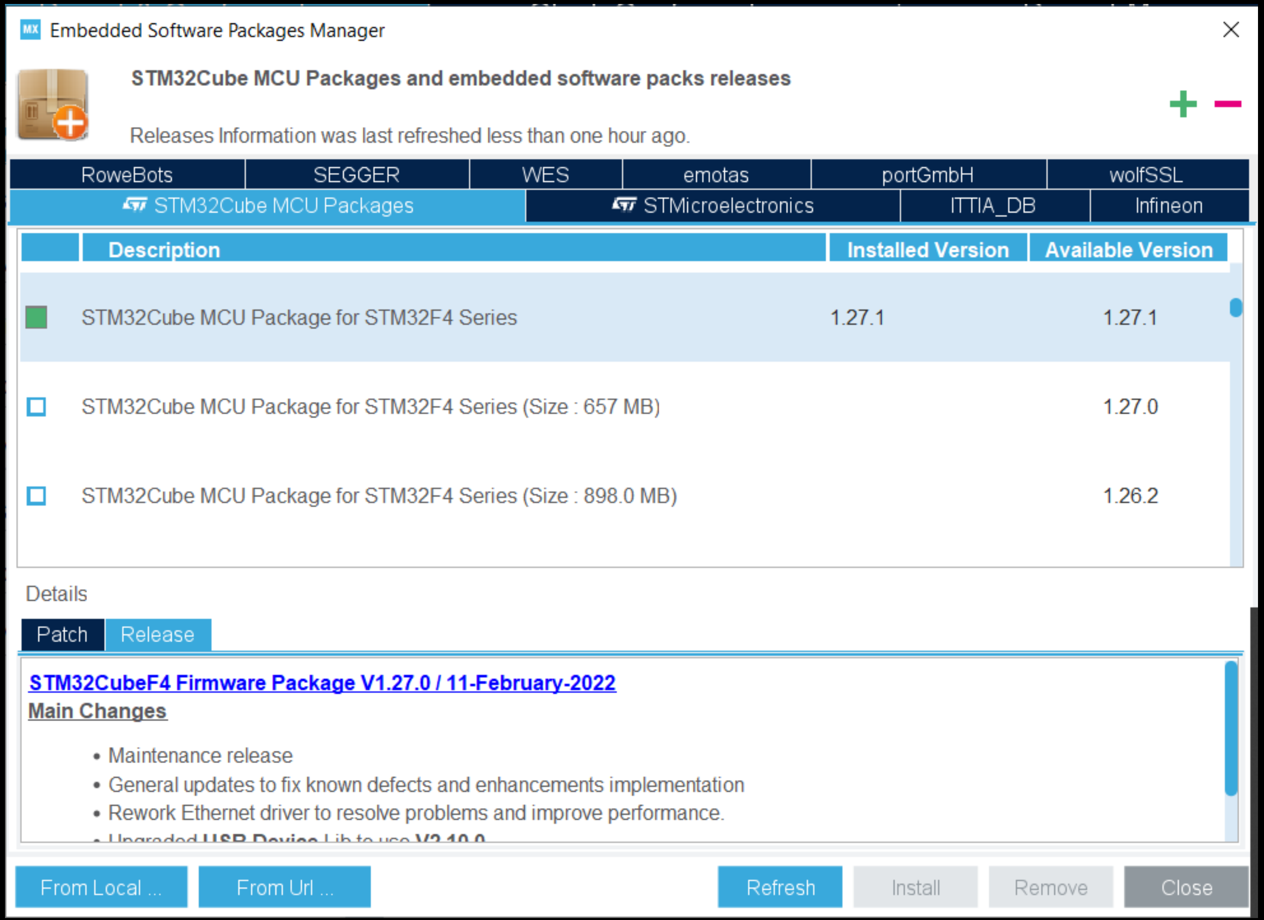


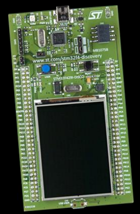
Configuring pins with STM32CubeMX

Clicking on « Software Packs » shows that we have installed STM32CubeF4 package.

It contains :

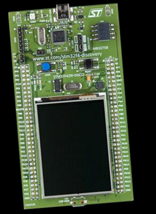
- HAL
- Code generator
- Some of the GUI's « backend »





Configuring pins with STM32CubeMX

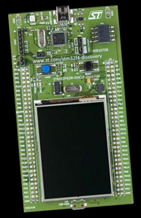
- Build and run default code
- LED does not react to button press : this project only initializes (prepare use of) peripherals but does not change their state
- Compare the code to the previous example
  - What has been added ? Removed ?
  - What missing logic do we need to code ?



Configuring pins with STM32CubeMX

- We have to code two things :
  1. Lighting on/off the LED (LED3)
  2. Reacting to button press (USER)

- You can get inspiration from previous code
- Don't forget the STM32F4 HAL reference manual for details

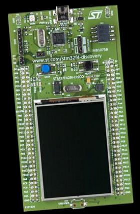


Configuring pins with STM32CubeMX

EPITA LED blinking app

STM32F429 HAL GPIO

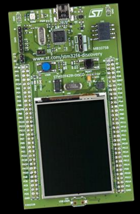
Manual LED blinking target software architecture



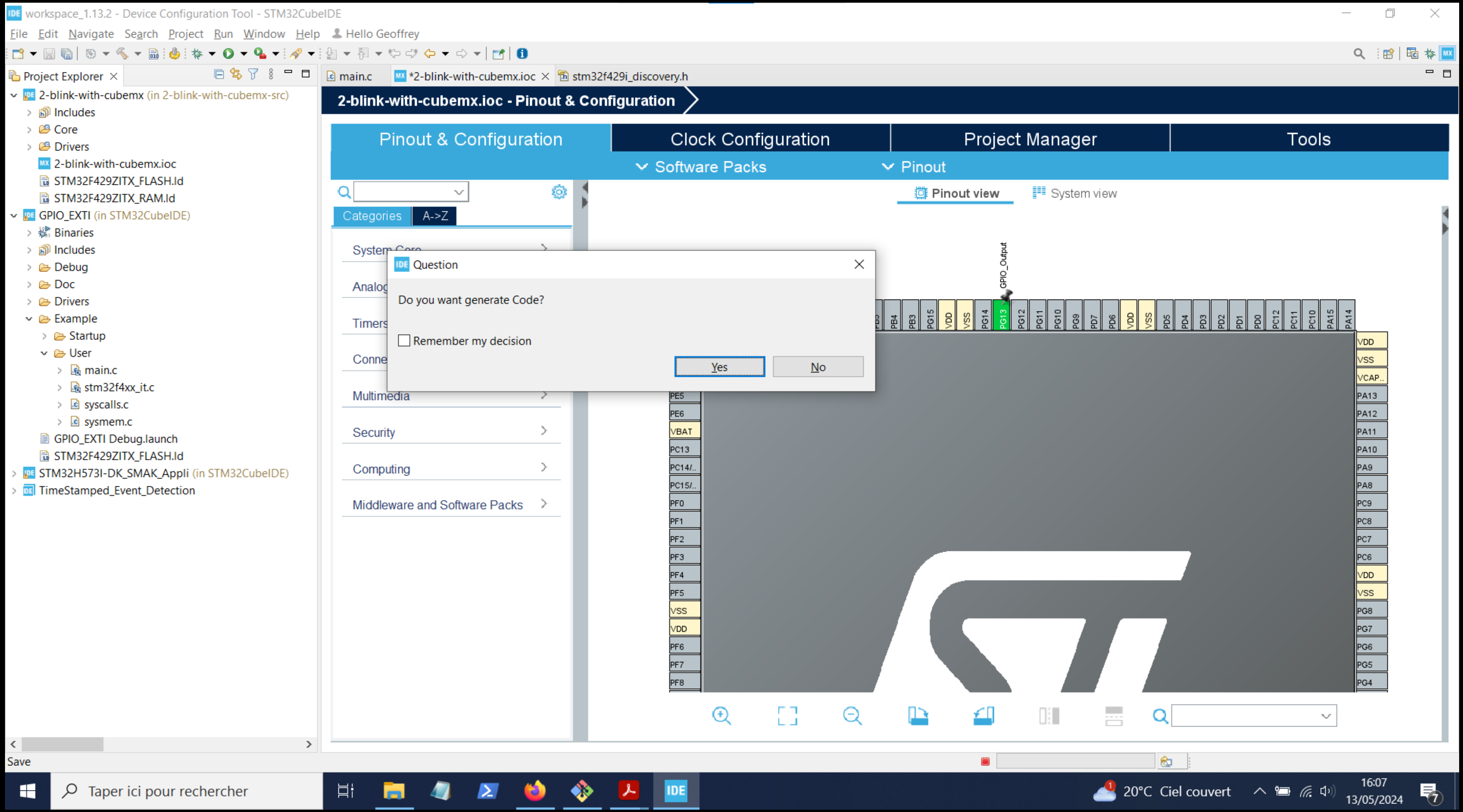
Configuring pins with STM32CubeMX

Let's start with the LED

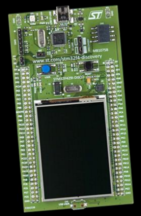
1. Go to "Pinout & Configuration" (if needed, reopen .ioc file) and configure the pin behind LED3 as a GPIO output
2. Regenerate code
3. Code *gistre_led_turnon()* and *gistre_led_turnoff()* functions
4. Turn on the LED at program startup



Configuring pins with STM32CubeMX

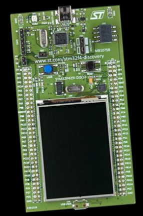


When you save changes in *.ioc*, code generator kicks in



Configuring pins with STM32CubeMX

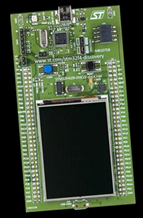
- Cool, we can light up a LED !
- And we got rid of ST’s BSP code…
- Find the exercise with commented code on Moodle
- Now we need to program the button
- *We’ll see that in the next chapter !*



In the next chapter

- New hardware feature: interrupts
- Input GPIO configuration using STM32 CubeIDE
- More about the STM32 HAL, and C weak symbols !

- Until then:
  - Read full code of GPIO_EXTI
  - Read § 2.1 / 2.2 / 2.3 of RM0090 (global system architecture)
  - Read § 8.1 / 8.2 / 8.4 of RM0090 (GPIO features + registers)



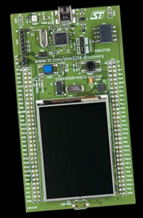
Quick recap

Technologies :

- arm-none-eabi-gcc
- openocd

Concepts :

- Cross-compiler
- Cross-debugger
- Flasher
- Hardware Abstraction Layer
- Host (when compiling)
- Native compiler
- Reference manual (for a MCU)
- Register bank



Quick recap

Concepts :

- Target (when compiling)
- Tuple (full compiler name)
- User manual (for a devkit)